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Engineering consideration for cage aquaculture

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Abstract: - Cage aquaculture has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressure from globalization and growing global demand for aquatic products. A cage represents a delineated volume in the body of water where the aquatic organism can be farmed. Designing and engineering are major components for cage aquaculture and it is essential to select ideal construction material, proper designing, suitable mooring and good management practices in bringing out commercial cage aquaculture which is quite simple and economically feasible. A range of cage systems is now potentially available for off-shore mariculture in world, though not all of these may prove to be effective in the intended environmental conditions and production regimes. The cost of installation and operation is also very critical. This paper provides an overview of the engineering components, and gives a brief description about various engineering materials.

***Key words: -** Cage aquaculture, engineering, construction material, proper designing, suitable mooring*

I. INTRODUCTION

Aquaculture is one of the fastest-growing industries in the world.Fish can be cultured in one of four culture systems—ponds, raceways, recirculating systems or cages. A cage or net pen is a system that confines the fish or shellfish in a mesh enclosure.A cage has a completely rigid frame (on all sides) and a net pen has a rigid frame only around the top.Cage culture uses existing water resources (ponds, rivers, estuaries, open ocean, etc.) but confines the fish inside some type of mesh enclosure.The mesh retains the fish, making it easier to feed, observe and harvest them. The mesh alsoallows the water to pass freely between the fish and surrounding water resource, thus maintaining goodwater quality and removing wastes (Masser 2008).Cage farming has been practiced at an artisanal level for hundreds of years, originally in freshwater and later in seawater (Beveridge, 1996). However, the development of modern cage systems has only taken place over the past 20-30 years, primarily in line with the development of the salmon farming industry. Such cages were originally designed for sheltered sites in inshore waters, and were constructed initially from wood/polystyrene, poles/buoys, and later from steel and plastic.

The design of open sea aquaculture system is a novel and unique engineering challenge that pushes the limits of structural integrity and economic viability and one of the most important things to design a fish cage system is to predict the wave forces acting on it. The engineering components can be technically simple but as a whole they are complex structures to dynamically represent. From an economically perspective, the commercial fish cage volume needs to be reasonably larger. As ocean currents induce both normal and tangential steady state drag forces onto the components, engineering methods foe cage culture need to be developed and perfected (Rao et al., 2013).

II. CAGE

A. Frame

The design of cage aquaculture system in open water bodies is novel and unique engineering system that pushes the limits of structural integrity and economic viability. The system components can be technically simple but as a whole they are complex structures to dynamically represent. From an economical perspective, the commercial fish cage volume need to be reasonably larger. The mooring system that keeps the cages on station must also be optimized considering both economic and structural integrity criteria. To achieve these long term goals, engineering method specific to inland open water bodies cage culture need to be developed and perfected.

One of the most important aspects to design a fish cage system is to accurately the wave force acting on it. A gravity fish cage system contains four components *viz* the float collar system, the cage net system, the sinker system and the mooring system. The float collar system provides buoyancy and the sinker system provides weight, maintaining stable shape of whole cage system. The collar frame work may have several function it help to support the cage safely in the water column, it helps to maintain the shape of net bag, and it helps in the buoyancy and may also serve as a working platform.

Three different methods may be used to construct the framework for a fish cage.

1. Stiff framework: This framework does not follow the wave movements. The construction is characterized by the large forces transferred to the framework.
2. Framework with movable joints: This framework to some extent follows the wave movements. Here joints are used to connect the single elements in the framework.
3. Flexible framework: This framework is quite flexible and follows wave movements well. These include frames made of plastics which are flexible to some degree (Lekang 2007).

B. Shape

Even though cages can be circular, rectangular or square shape, circular shape makes the most efficient use of materials and thus lowest cost per unit volume. Based on swimming behavior of fish, circular shapes are found to be better in terms of utilization of space (Rao et al., 2013). Circular cages have more favorable surface/perimeter ratio and for which the same volume can be obtained while saving on the materials used (more beneficial cost/volume ratio, while also considering that being lighter in weight, they require a simplified mooring and floating system). Another important feature of circular cages is that they are more resistant to dynamic stress which makes them better suited to less sheltered sites. It is best to use round frame because the forces are equal all around the circumference: polygonal or square frameworks will have large forces in the corners and eventually breakage in the construction will occur. Polygonal collars are better than square collar because there are more corners to share the total forces and the force in each corner is therefore reduced (Piccolotti and Lovatelli, 2013).

However square and rectangular cages have certain advantages that make them preferable in sheltered areas such as:

- Ease of construction
- Possibility of producing large modular structures and
- A higher water exchange rate within the net

C. Size

The resistance of a cage to dynamic stress caused by swell and currents is also determined by its dimension. The most of suitable size (just as that of volume) depends on the characteristic of the site. In sheltered sites, the cage size can be increased, while in exposed sites, small cages are more suitable.

The cost per cubic meter of cage volume is reduced as the size increases. Thus, a cage of $100m^3$ is less expensive than two cages of $50m^3$, while achieving the same production. Moreover larger unit have the advantage of having fewer cages with the same total farm volume (more or less same production), saving on the material used and on the cost of the management and maintenance. However, with large cages the losses are greater if the net is torn accidently. In addition, routine maintenance and certain management activities such as, net exchange or fish sorting can become more complicated (Piccolotti and Lovatelli, 2013).

D. Volume

The volume is determined by the dimension of the net which demarked the space in which the fish lives, influencing the potential production for a cage. In general by increasing the dimension 0f the cages, the cage per unit volume cost can be reduced.

The water exchange inside the cage is inversely proportional to the volume of the net and depends on the speed of the current and the distance between the opposite walls. The level of dissolved oxygen is strictly related to the water change by the current (the movement of the fish also have the influence on the flow of the water inside the cage). All condition being equal, small cages make it possible to increase the stocking density considerably (e.g. 200 Kg/m^3 of fish can be obtained in cage of $1m^3$, but only 25 Kg/m^3 in a cage of $100m^3$). On the other hand, small volume cages often induce a loss of feed, which is carried outside the cage by the current before the fish is able to consume to consume it and hence the feed conversion ratio is adversely affected (Piccolotti and Lovatelli, 2013).

Relationship between characteristics of a site and the most suitable cage model

Characteristics of site	Cage model		
	Shape	Size	Volume
Sheltered	Square/rectangular	Large Modular structures possible	Large
Exposed	Circular/hexagonal	Small	Small
Good quality (high level O_2)	All type suitable	Large	Large
Lower quality (low level O_2)	Square/rectangular	Small Modular structures possible	Small

(Piccolotti and Lovatelli, 2013)

E. Materials

Cages for fish culture can be constructed from a variety of material and practically in every shape and sizes. Most important things to remember while choosing materials for construction are

I. Cage should be steady

II. Material should be strong, durable and non-toxic.

The frame of the cage can be made from galvanized iron (GI), high density polyethylene (HDPE), poly vinyl chloride (PVC), aluminum, steel, timber and different plastic materials. The major criteria for selecting a material for cage fabrication are based on the characteristics like mechanical strength, resistance against corrosion and easy repairing and maintenance cost. Frame made from metals and wood should be coated with water resistance paint. The advantages of HDPE is that it is highly flexible, light weight, long lasting and are used most of the circular cages. Styrofoam or thermo coal filled HDPE pipe provides adequate floatation to the frame whereas, GI frames are coat effective lasting and easily available. Plastic and other material like wood can be used only for small scale operations and needs frequent replacement (Rao et al., 2013).

Relatively simple structure constructed from the local materials make it possible to use local labors (workers, blacksmiths, carpenters etc.) both for construction and maintenance, as sophisticated machines and techniques are not required for joining the various components. This provides the double advantage i.e. the smaller financial outlets and the creation of employment in the local communities (Piccolotti and Lovatelli, 2013).

III. FLOATATION SYSTEM

For floating cages, floats provide the required buoyancy and it also holds the system at a suitable level in the surface of water. The framework construction can be combined with buoyancy as in plastic cages (PE or PP pipes) or buoyancy can be independent of the cage collars seen in wooden or steel cages which are supported with floats of expanded polystyrene (PS) (Lekang 2007). The role of the float is to absorb swells of the water (to spread the surge strength). In addition they prevent the side of the cage exposed to the current from becoming submerged by the thrust of excessive current. Floats should have a smooth surface to inhibit accumulation of fouling which increases the weight of the frame and increases friction between flowing water and cages leading to increased forces on mooring system (Lekang 2007).

The floatation materials used include fiber glass coated metal or plastic drums, and HDPE pipes (Rao et al., 2013). Expanded polystyrene covered with PE is commonly used. PE reduces fouling and aging of PS due to sunlight. Sealed Styrofoam barrels can also be used. Float units are specified according to volume and shape, and to their resistance to deformation when submerged. Fiber glass drums can last for many years although the initial cost is comparatively high (Lekang 2007). The buoyant force varies depending on the size and materials used. If too much buoyancy is added, the cage collar will float high in water column and fully follow the wave motion, floating on top of the water column throughout. This may cause unnecessary large forces on cage bag and mooring system which will add to cost of buoyancy. Buoyancy elements ought to have an aerodynamic shape to reduce the transfer of forces from water current (Lekang 2007).

IV. NET

The net delimits the space where fish lives, and hence determines the stocking volumes. The volume depends on the dimensions of the net (surface x height), the height of the net being dependent on the height of the water column. It is advisable to leave a minimum of 2 meter between the bottom of the net and the bottom of the water body, so that the water current can remove the cage wastes while preventing the fish from being too close to bacterial fauna that colonize these wastes (Piccolotti and Lovatelli, 2013).

Main features of the net:

1. The net shape

The net always takes the shape of the cage on which it is mounted. The perimeter is slightly smaller to prevent the net rubbing against the frame which would inevitability create holes in the net. The height which determines the stocking volume is the more variable factor and depends primarily on the site, depth but also on the other technical factors (Piccolotti and Lovatelli, 2013).

2. Materials

Net can be from various synthetic fibers such as nylon, polyester, HDPE and polypropylene. Nylon, which is highly resistant, is the most widely used because of its superior breaking load and durability. However, it is more expensive and less resistance when exposed to ultra-violet rays.The following qualities of HDPE make it more suitable for the fabrication of cages.

1. Breaking strength of HDPE in water will be 110% as that of dry condition but that of nylon is 85-90% only.
2. Shrinkage in water is 5-8% only where as for nylon it is 10-12%.
3. HDPE will not absorb moisture but nylon absorbs.

4. It has same weight in water unlike nylon that weighs 12% more in water.
5. HDPE is easy for handling and cleaning.
6. Rigid nature makes the mesh opening perfect which enables free exchange of water (Philipose et al., 2012).

Synthetic materials are predominantly used for construction of net cages. As compare with vegetable fibers, they have better uniformity, continuity, higher breaking strength and are more resistance to biodegradation. Depending on the type of polymer, synthetic are classified into different groups and are known by different names in different countries. All together 7 groups have been developed, namely polyamide (PA), polyethylene (PE), polypropylene (PP), polyester (PES), polyvinyl dine chloride (PVD), poly vinyl chloride (PVC) and poly vinyl alcohol.

Another material recently introduced is ultra high molecular weight polyethylene (UHMWPE) available as Dyneema. It is very advantageous due low diameter, favorable weight/strength ratio, low elongation and nil shrinkage in water which helps the mesh size to remain stable during normal use of the netting (Rao et al., 2013).

The synthetic netting yarn used in Indian fisheries sectors includes polyamide, polyethylene and polypropylene. PA and PE are most commonly used fibers for netting while PP and PE are used for ropes. The material strength of net panels gets reduced when exposed to sunlight (UV), wind, rain, acid rain, etc. Even though all fibers are prone to weathering problem is in synthetic fibers. Major factors responsible are UV light. PVC is most resistant material for weathering followed by PE, PA and PP has the shortest lifetime. The lifetime can be increased by adding antioxidant. The resistant of netting materials to abrasion with hard substances such as frames, sea bottom and net haulers or abrasion between twines is important in determining the life of net. The following factors are to be considered for selection of suitable net material for construction of cages.

1. Cages net of synthetic fibers are convenient as they can be easily folded, installed, removed and are also light to handle.
2. The netting yarns should maintain its shape.
3. Material should be durable with high breaking strength and resistance to abrasion.
4. The material should not be very heavy as to make handling difficult.
5. With the exception of hapa net, cages are usually constructed with PE. It is preferred due to its high breaking strength, durability, high resistance to abrasion and cheaper cost compared to PA, PES, PP etc.
6. PA and PE are readily available locally. Knotless PA of 210D x 2 x 2 is popular for making cages. That are used for stocking fingerlings and prawns as the material has a smooth surface and there is minimal abrasion on the fish when the cage is lifted during net exchange. Even though PA is expensive, it has very high breaking strength and abrasion resistance. Its fibers deteriorate if exposed to direct sunlight and hence classified as medium durable. Materials being soft can also be damaged by crabs and fish with strong dentations resulting in fish escape from the cage.
7. PE netting is available in various specifications of Denier and ply and also in knotless and knotted form. However, it has to be stored in shade away from direct sunlight. When used at the farm, the portion of the cage above water lasts for 3 years, whereas the rest of the cage which is submerged in the water lasts for 5 or more years. PE netting is mainly used for making cages for nursery and growout (Klust 1973).

3. The twine number

The twine number is the size of the net twine; the higher twine number means a higher breaking load and higher weight, which is also reflected in the cost of the net (Piccolotti and Lovatelli, 2013).

4. Knotted or knotless

This two different types relates to the techniques used in the making the nets. Knotless is preferable in order to prevent the fish from becoming injured by rubbing themselves against the wall of the cage. Moreover, knotless provides better protection against colonization from fouling (Piccolotti and Lovatelli, 2013).

5. Design

Net size for a cage is determined based on stocking density and optimum carrying capacity of the cage. It is cylindrical in most of the cases. Non-toxic antifouling coating can be impregnate on net meshes to prevent bio-fouling. The upper side of cage bag above the surface is joined to the hangers in the brackets near the hand rail of the cage frame for lateral protection. Surrounding vertical and horizontal ropes which are used for joining the net to the rings reinforces the cage bag. The volume of the cylindrical bag is calculated suing the formula

$$V = \pi r^2 h$$

Where,

V is volume of the net

ris radius of the net bag
h is the height of the net bag

The rope which is used for the main and hanging lines of the hapa and nursery cages is PP/PE rope(6mm) diameter, while for grow out cages, PP/PE ropes of 10mm diameter is used (Rao et al., 2013).

Designing of net structures requires several forces to be considered; the main being static and dynamic load. Static load includes the weight of structure (net, support and other structural parts), and added loads due to maintenance and operation. Dynamic loads include forces generated by wind above the water surface, waves at the air water interface and currents in the water. Additional dynamic load may be encounter due to collection of floating debris collision with water craft or large predators etc. Effect of corrosion and fouling adds to it. Wave forces on net impoundment structures are based on the highest wave expected to occur in the design life of the structure. As fouling or surface debris drastically affect the coefficient of drag this factor must be considered. Fouled net creates twice the resistance to tidal current as the same net when clean (Milne 1970). The nets must be designed to withstand some of the forces, assuming that all the forces are at some moment acting on the same direction. If two nets are used loads on the supporting structured will be the sum of the loads imposed by each net. The aquaculture net enclosures should have good tidal flushing. Water flowing through the net will imposed load on it and supporting or mooring structures.

As net bags are subjects to damage by floating debris, large carnivorous animals and other agents, often a second larger mesh net is used outside the net to provide mechanical protection for the grow out net. The two nets must be placed in such a way that do not rub each other and cause abrasion (Rao et al., 2013).

6. The mesh shape and size

The shape may be square or hexagonal as this does not significantly affect either the cost or the behavior of the net in the water. However, the mesh size is very important. It depends on the size of the fish being reared and influences the water circulation in the cage and dynamic resistance to the water current. For the same volume, a closed meshed net is heavier and thus more expensive (Piccolotti and Lovatelli, 2013). Mesh size is selected based on the cultured species initial size of the seed and the culture method. If fingerlings of 6-8 inch are used the most suitable mesh size is ½ inch and nets with 1/8, 1/4 or 3/8 inch (0.5-1.0 mm) mesh size can be used for fry to fingerling rearing cages. For grow-out cages for finfish 16 mm to 40 mm mesh are used. Square mesh gives the maximum flow of water. Small mesh netting is rapidlyclogged with fouling organism especially in tropical seas (Chua, 1979).

Mesh size is a distance between the knots on a stretched mesh. In a hexagonal mesh, mesh size is the distance between two longest parallel bars. Hanging ratio (E) of the net also decides how the net panel is standing in water i.e. how the net is stretched in X and Y direction. Hanging ratio is the ratio between the length of the stretched panel (L_y) and the length of the line where the net is fixed (L_x) (Lekang 2007).

$$\mathbf{E = L_x/L_y}$$

Normally E for net bags for fish farming is in the range of 0.6-0.9.

Solidity is used to describe how tight the net is i.e. the ratio between total area covered by net and the area covered with threads including knots. This is important in calculating resistance offered by the net against water flow. Fouling increases solidity by increasing the area covered (Lekang 2007).

Factors to be considered for mesh size selection

- Mesh size should not be less than 10 mm to assure good water circulation through the cage while holding relatively small fingerlings (10-12.5 cm) at the start of the production cycle.
- The meshes of the cage should remain open completely in order to form diamond shape hole to allow proper water exchange.
- Mesh should not be large enough to gill the stocked fish.
- Mesh size should roughly equal to 25% of the body length of the fish (Rao et al., 2013).

V. CAGE MOORING

Mooring is required to hold cages against the forces generated by wind current and waves and allows the fish stocks, cages and the net the best chance of survival (Rao et al., 2013). The function of mooring is to keep the farm in position and to avoid transfer of excessive forces to the cages. Different methods are used depending on type of cage, whether and the requirement for position exactness (Lekang 2007). Mooring system design is site specific. It is necessary to quantify the incident forces that are likely to act on the cage under worst weather condition, and then to evaluate the proportion of energy transferred to mooring lines and anchors. The loadings transferred to mooring lines vary enormously depending on wave conditions and current, cage design and number of lines employed (Rao et al., 2013).

a) Designing

Mooring system must be powerful enough to resist the worst combination of static and dynamic forces expected at the site. It is designed based on the loads acting on the cage. The loads on the cage are of two types:

i. Static or vertical loads caused by action of gravity with reaction in buoyancy of the cage. These depend on the area and density of the netting, weight of rigging, weight of ballast, weight of the frame components and opposition in the floatation force.
ii. Dynamic loads are mainly horizontal and are caused by the currents, winds and wave reaction in the mooring and anchors of the cage. These depend on the materials used, panel shape, mesh size, current velocity and density of water (Rao et al., 2013).

The static loads are computed by calculating relation between weight of the cage with its components like ascendant and descendent forces. The weight is calculatedfor three conditions (Olivares, 2003; Ignatius, 2009; Shylaja, 2009):

1) Clean cage in air
2) Clean cage in water
3) Fouled cage in water

In order to compute weight of the cage, the density of material should be known. 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 forces acting on those components wholly or partially immersed in water and is equal to the weight of water displaced.

The buoyant force can be calculated by using the formula

$$F_B = VwQw - VmQm$$

Where FB = buoyant force (Kg)

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

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

Wind and current forces are proportional to square of the velocity. Wind forces act mainly on the cage superstructure comprising the hand rail, bracket and free board netting.

The general equation to calculate the current drag is

$Fx = ½ Cd.\rho Av^2$

Where Fx = current drag

Cd = coefficient of drag

ρ = density of water in T/m^3

A = area normal to flow in m^2

v = incident current velocity in ms^{-1}

Wave forces act mainly in the ring area of the cage. It can be derived from information on prevailing wave period, wave height and the water depth at the site

Wave force (Fw) = $K_d.\rho\mu^2 A$

Where $K_d$is the coefficient similar to Cd in the netting value of which depends on the material and shape of the collar.

ρ = density of water

μ = horizontal component of wave particle orbital velocity (for marine cage it is taken as $2ms^{-1}$)

A = area of the cage collar perpendicular to the wave train (Rao et al., 2013).

b) Mooring components

The key elements of mooring includes the anchor or mooring unit on the bed of water body, the rising lines which connect the anchor to the surface system, and the surface or subsurface mooring grid

1. Anchor

Various types of anchors used in mooring cages are:

Dead weight anchors: rely primarily on their weight which may vary from several kilograms to several tones. These are used because of their simplicity, stability to tension an all directions and their relative ease of positioning. However these are difficult to handle, reposition and load them on position and may also cause chafing of mooring lines e.g. concrete blocks, stones etc. these anchors need good friction between the anchor and bottom. Sand and clay have high friction coefficient while that of rock is lowmaking it unsuitable for rocky bottoms. To increase the friction coefficient, the bottom of anchor can be made rough by having iron barsemerging from the base, adding iron jacket around the bottom of block etc. Friction co-efficient of 0.5 for sand and 0.3 for clay may be used as a basis, for anchor choice if no measurements are done (Chang et al., 2005). The angle at which mooring line is attached to block is also important in inhibiting horizontal movement. To avoid tilting of block anchors, the width of block should be large in relation to height (>2:1) otherwise it may tilt and cause chaffing of lines.

Drag / ebbing anchor: these anchors can be dragged down into the ground like plough and becomes fixed e.g. stock anchor. Its efficiency depends on bottom condition and design. The angle for ebbing anchor used in sand is 30-35^0 and in clay is 30 - 50^0 (Beveridge 1996). Ebbing anchor tolerates a large horizontal force but tolerance of vertical forces is low. Heavy chain or small block weight on mooring line before anchor is used to improve tolerance to vertical forces.

Bolt: is used to fasten mooring lines to rocks, usually where mooring lines leadto land, but these can also be used under the surface of water. They are either eye type or T-type.

Piles: alternative in sand and clay bottoms. These can take only low forces if small in size and increasing size increases cost considerably (Lekang 2007).

2. Rising line component

Different materials and designs can be used for the mooring lines which are often made of synthetic ropes. When choosing rope, the breaking strength is most important factor along with weight, elasticity (length change with applied tension), dimensional wear and degradation, but price is also one of the major determinants (Lekang 2007).

Mooring line must withstand and transmit forces applied on to it from different sources. The loads imposed on a cage mooring system are principally dynamic. It is important that mooring line have a higher breaking strength and can absorb much of the kinetic energy of rapidly changing forces. Different materials are used for synthetic ropes such as PA (nylon), PE, PES and PP, all of which have advantages and disadvantages. PA tolerates the highest forces within a given diameter, while PP ropes have the lowest weight. PA (nylon) has high extensibility and thus energy absorbing properties, an important factor in designing cage moorings (Rao et al., 2013).

Ropes should not be directly attached to either shore or anchors, but instead should be collected by a section of chain. The chain serves to increase the effectiveness of mooring system, which directly as an efficient type of anchor and improves the holding power of existing anchor by both reducing the angle between the mooring line and anchor and by increasing energy absorbing properties of the mooring line. There are several types of chains available. Wrought iron is highly variable in quality but this has excellent corrosion resistance and mild steel chain with low carbon and manganese content has been widely recommended for cage anchorages. The total length of mooring line should be at least 3 times to the maximum depth of water at the site. Where the rope joins the chain, a galvanized heavy duty thimble should be spliced into the rope and a galvanized shackle of appropriate size should be used to connect the chain and the rope (Rao et al., 2013).

VI. CONCLUSION

Fish are raised commercially in one of four culture settings: open ponds, raceways, tanks, or cages. Cage culture of fish utilizes existing waterresources and fishes which are enclosed in a cage or basket allows water to pass freely between the fish and the pond. Modern cage culture began in the 1950s with the advent of synthetic materials for cage construction. Today cage culture is receiving more attention by both researchers and commercial producers. Factors such as increasing consumption of fish, some declining wild fish stocks, and a poor farm economy have produced a strong interest in fish production in cages. As the cage aquaculture is developing very fast there is need to develop stable cage design which can withstand ocean current while considering both economic criteria and structural integrity. Engineering components of a cage are the important factor which ultimately determines the cost along with stability of cage, so it is important to develop a feasible and economic viable cage while taking all the engineering components into consideration.

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