Development of Submersible Fish Housing Operating with Submarine Principle.

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ABSTRACT

This design combines the principles of fluid mechanics, strength of material, material selection, and other engineering principles**.** Using easily available and affordable materials, we developed a submersible (submarine-like) fish cage/housing for fish farming. This design also incorporates solutions to high tide and waves in bad weather, presents an easier means of harvest, and integrates an improved security system and feeding method. It can be assembled and dissembled on site which makes transportation easy. It was tested in Nigeria's biggest river (River Niger) to ascertain its submergibility.

The result was pleasing; with its ability to resist corrosion and warpage, its low cost of construction, and good mechanical and physical properties. It has Flotation force of cage with air inside the pipe 3638.53 N, nominal flotation force of the cage 3792.74N, effective flotation force for clean cage 3302.93N, effective flotation force for fouled cage 1055.75N, emergency flotation force of the cage 154.24N, emergency effective flotation force for clean cage -335.6N, emergency effective flotation force for fouled cage -2582.78N, weight of outer cage netting in air 24 kg, weight of outer cage netting in water 21 kg, weight of inner cage netting in air 6kg, weight of inner cage netting in water 5 kg, approximate weight of cage in air 68kg, approximate weight of cage in water 50 kg, and current load on net panel 1855kg.

(Keywords: submarine, fish housing design, Clarias, fish farming)

INTRODUCTION

Fish farming in Nigeria has gained so much significance in the last decade and various methods are being employed to actualize results.

Fish are one of the major sources of protein which is being sought after by both the rich and the poor thereby creating a continuous market for its demand. The increasing demand for fish cannot be met by captured fisheries, hence the need to employ modern technology to increase productivity and improve efficiency cannot be over emphasized. Aquaculture which is a method of rearing fish in a confined and controlled environment is increasing and nowadays cage culture has gained an important role in the quest to increase fish production. Aquaculture in Nigeria has undergone stages of development from one geographical location to another and various methods are being engaged as follows:

Free Range

This is the oldest method generally used by local fishermen and is still in use. It involves catching fish in the wild. This method is not properly monitored by the designated authorities because it is mostly practiced in lakes, rivers, dams and reservoirs all over the country and extreme practices of using inappropriate nets for capturing fingerlings are carried out by many fishermen.

As a result of these practices, most of the indigenous fish species have suffered depletion and many others are being over exploited. This has led to the poor result obtained from this method and hence other methods were sought after to meet the increasing protein demand of the nation.

Earthen Pond

This method involves the excavation of the soil (mostly swampy or clay soil) to retain water and the fish are kept therein. This method has been fully utilized by the south-west part of the country because of geographical location and high rainfall. It requires less capital to establish and to maintain, but it has the challenges of not having absolute control over the fish, cannibalism loss, loss through flood, and uncontrollable environmental pollution. Fish are fed both naturally and by supplemented feeds in the enclosure which contributes to 70% of the running costs.

Concrete Pond

This method has gained much ground in the metropolis area due to space management and the ease of monitoring and controlling the activities of the fish. This involves the construction of surface reservoirs to retain water and the fish are kept there and fed. Its initial cost is high but provides more efficiency and minimal running costs. The fish are only dependent on the supplemental feed provided by the farmer, which accounts for approximately 80% of the running cost.

Cage Aquaculture

This method is one of the most recent methods to be used to commercial scale in Nigeria. It involves abhorring the fish in a cage which comes in different designs and size and the fishes are supplied with supplement feed. This method has proved to be more efficient over the others. It provide fish for harvest within a period of 3 months for species like Clarias (catfish) and has the capacity to produce fish in large tonnage.

The first three methods are well in use in Nigeria but cage aquaculture has not gained much ground because only a few individuals are able to afford it and most importantly its application knowledge has not been well published. We believe to a great extent that the engineering principle behind its operation which has not been given much attention, has been a major obstacle to its success in Nigeria.

Looking at cage aquaculture globally, so much progress has been done in China, Norway, Britain, the United States and other member countries of FAO (Food and Agriculture Organization), but the major problem encountered has been the issue of design defects, escape of farmed fishes to the large water body, damage by aquatic animals, vandalism by humans, adverse effects of climatic conditions and other marine activities on the health of farmed fishes.
However, considering the Nigerian ambient conditions, cage aquaculture can be utilized in our dams, rivers, lakes, lagoons and valleys with the design of the cage varying from one location to another.

The success of cage aquaculture has always been dependent on the design of the cage and secondarily on available facilities, construction materials, type and source of water, the area and depth of the water body, etc. Based on indigenous technology, the following were the early design of cages constructed and tested:

Stationary Bamboo Cage Design

The first material used for the construction of this cage was bamboo. The cage has a dimension (length 4m, width 1.8m, height 1.7m) and a capacity of two tons. (i.e., 2000 stocks).

Other materials used are fasteners (nails, binding wire), fishing nets, tension ropes, etc. This particular design was constructed in September 2006 costing approximately N 55,000 and was tested and used at Tunga Kawo Dam in Wushishi local government area of Niger State.

Some of the challenges encountered in this design include:

- Destruction of the cage by Upper Niger River Basin Development Authority on the claim that permission to carry out the project on the site was not passed through the appropriate channel.
- The tension ropes used to hold the cage in its position could not withstand the weight of the cage and began to fail after a period.
- The structure was not rigid enough to withstand high tide in raining condition and that increased mortality of the fish.
- Its inability to float calls for adjustment manually when the water level in the dam varies which is very tedious and stressful.
- The design did not accommodate any security measure thereby making it susceptible to vandalism.

However, the eminent advantage of this design was reduced cage weight because of the material used and it is less expensive.

Iron Wood Cage Design with Floaters

This design is an improvement over the bamboo cage design because it was specialized on solving the much problems encountered in the first design. The choice of material used was based on the desire to increase the cage strength and rigidity to be able to withstand tides and waves, floaters was incorporated to eliminate the challenge of manual cage adjustment in the case of water level variation, improve material workability during construction and ability to resist corrosion and warping.

The cage has a dimension (length 3.4m, width 3.4m, height 1.7m) and a capacity of five tons i.e. (5000 stock) to maturity within the period of three months. It was constructed in March 2007 costing approximately N 150,000 and was tested and used at Tunga Kawo Dam in Wushishi local government area of Niger State, Nigeria.

Among the materials used are iron wood as members, robber coated iron net, fasteners, planks and fishing nets. The challenges encountered in this design include:

- The cage was always tossed by the tide and wave since it is floating and not anchored to the dam bed.
- The iron wood became “stubborn” after bringing it out of the water which make repair very hard and drilling operation have to be engaged.
- The cage became very heavy after soaking water and carrying out of the water became a challenge during harvest.

The comparative advantage of this design is its durability, enhanced security measures, ability to float and mobility from one location on water to another.

Submersible Iron Cage Design

This design is an improvement over the two design earlier discussed. It is an engineering master piece because it combined the principle of fluid mechanics, strength of material and material selection and other engineering principle in its design.

Some of the features which this design has are as follow:

- Physical properties: This includes hardness, density and elasticity.
- Chemical properties: Ability to resist corrosion and warpage.
- Mechanical properties: This includes yield strength, fatigue, creep strength etc.
- Economics properties: This includes availability and cost of material and labor.

This design also incorporate solution to high tide and wave in bad weather, easier means of harvest, improved security system and feeding method. It can be assembled and dissembled on site which makes its transportation easy.

MATERIALS AND METHODS

Design Analysis

The most important relationship for construction in this project is between the gross weight of the cage when loaded i.e. (with stocks at harvest) and the floatation/buoyancy that support it. The buoyancy/floatation of the cage is what determines the magnitude of the load the cage will carry under certain environmental condition considering stability of the cage alongside and at the same time maintain the stock in a healthy condition.

Material Used

The materials used for this experiment are:

- Four (0.1016 m) diameter end caps
- Two (0.01016 m) diameter pipes
- Aluminum frame
- Loads (kg)
- Pool of water
- 50kg Scale
- Tack nails, and
- Tangit gum

Procedure

Two 0.1016 m diameter pipes having an equal length were sealed at both ends by 0.01016 m diameter end caps using the tangit gum to ensure that they were water proved and air tight. After drying, an aluminum frame was used to keep the pipes in place and they were placed on the scale to measure their weight.

The end caps of the two pipes and aluminum frame were also calibrated to know the depth of the pipe submerged when loaded and also to determine the position of the load on the aluminum structure.

The setup was then carefully and gradually loaded at the center to maintain stability and the weight and depth were recorded. The total volume of trapped air in the cylindrical pipes was also calculated.

The following parameters were used in the experiment:

i. Total length of PA Pipe: 1.825 m
ii. Radius of PA Pipe: 0.0508 m
iii. Volume of polyamide pipe: 0.014959 m^3
iv. Total weight of setup: 1.84 kg
v. Total weight (with upthrust force): 14 kg
vi. Total weight (without upthrust force): 7 kg
vii. Weight of PVC Pipes: 1.35 kg

Frame Dimension:
i. Length of Frame = 1.88 m
ii. Breadth of Frame = 0.24m
iii. Height of Frame = 0.125m
iv. Weight of Frame = 0.49 kg

Pipe Dimension:
Total Length of polyamide (PA) Pipe = 1.825 m
Radius of PA Pipe = 0.0508 m
Total Volume of PA Pipe = $\pi r^2 L$ = 3.142(5.08/100). (182.5/100) = 0.014959 m^3
Weight of PA Pipes = 1.35 kg
Weight of Aluminum Frame and PA Pipe =0.49kg

RESULTS OF THE EXPERIMENT

Table 1: Table of Result for Floatation Experiment.

S/N	Volume of Air in Pipe (m^3)	Load (kg)	Depth (mm)
1	0.014959	1.5	5.0
2	‘’	3.0	6.5
3	‘’	4.5	7.5
4	‘’	6.0	8.5
5	‘’	7.5	10.5

Diagrams

Figure 1: Under Construction.

Figure 2: Completed Housing.

Figure 3: Side View of the Housing.

Figure 4: Pipes for Flotation.

Figure 5: Transporting the Cage to the Dam.

Figure 6: Testing the Cage in Tunga Kawo Dam in Wushishi.

Observation of Experiment

It was observed that weight was directly proportional to the depth of the setup. The same volume of air was used throughout the experiment and the cylindrical pipes assumed the most suitable stability at horizontal position on water.

Conclusion of Experiment

In conclusion, with the floatation pipes in horizontal position, 0.014959 m^3 of air in the pipe would support a total weight of 14kg. This would be one of the parameters that will be used for determining the design and material selection for this project

DESIGN EQUATIONS

Mesh and Size

The smaller the mesh, the greater the projected area which cause increased fouling. Since the size of the fish to be stocked is at either fingerling/juvenile stage, it is important to specify the species of fish to be reared since juvenile/fingerling of different species varies in size.

However, in this case the catfish (Clarias) is adapted to this cage. The formula of Fridman for gill net was applied to know the approximately the size of the mesh to trap this species and with this data to reduce the mesh size.

Mesh Size

The mesh size gotten using (Fridman, 1986):

$$OM = L_f.K^{-1} \quad \textbf{(1)}$$

Where:
OM = Mesh Opening (mm);
L_f = Average Length of fish to be trapped (mm);
K = Coefficient according to the specie;
K = 2.5 for very thick, wide or high shaped fish.

Net Panel

The area of the net panel was calculated using the length (L) and height (H) of the cage. The primary and secondary hanging ratio (E_1 and E_2) is 0.707.

$$N_{sm} = L.\ OM^{-1} \text{ (for the length)} \quad \textbf{(2)}$$

$$N_{sm} = H.OM^{-1} \text{ (for the height)} \quad \textbf{(3)}$$

$$N_{rm} = N_{sm}.E_1^{-1} \text{ (for the length)} \quad \textbf{(4)}$$

$$N_{rm} = N_{sm}.E_2^{-1} \text{ (for the height)} \quad \textbf{(5)}$$

(Prado, 1990)

Where:
N_{sm}: The number of stretched meshes;
N_{rm}: The number of rigged meshes;
L: Total length of cage meshes (m);
H: Heights of cage mesh (m);
E_1: Primary hanging ratio;
E_2: secondary hanging ratio.

Netting Surface Area

The netting surface area was calculated using: (Prado, 1990)

$$S = E_1\sqrt{(1- E_1^2)}.L.H.OM^2 \quad \textbf{(6)}$$

Where:
S = Surface covered by netting (m^2).

WEIGHTS OF THE CAGE COMPONENT

Weight of Outer Cage Nettng in Air

The weight of the outer cage netting in air was calculated using (Prado, 1990):

$$W_{na} = [\, H_b.L_{sn}.\, (R_{tex}/1000).K\,]/1000 \qquad \textbf{(7)}$$

Where:
W_{na} = Weight of outer cage netting in air (kg);
H_b = Number of bars in the height of the netting (2×number of meshes);
L_{sn} = Stretched length of netting (m);
R_{tex} = size of twine in the netting (mkg^{-1});
K= Knot correction factor to take in account weight of the knots.

Table 2: Knot Correction Factor (k) for Different Panels (Prado, 1990).

Stretched mesh size (mm)	Twine diameter (Ø) mm							
	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00
20	1.20	1.40	1.60	1.80	-	-	-	-
30	1.13	1.27	1.40	1.53	1.80	2.07	-	-
40	1.10	1.20	1.30	1.40	1.60	1.80	-	-
50	1.08	1.16	1.24	1.32	1.48	1.64	1.96	-
60	1.07	1.13	1.20	1.27	1.40	1.53	1.80	2.07
80	1.05	1.10	1.15	1.20	1.30	1.40	1.60	1.80
100	1.04	1.08	1.12	1.16	1.24	1.32	1.48	1.64
120	1.03	1.07	1.10	1.13	1.20	1.27	1.40	1.53
140	1.03	1.06	1.09	1.11	1.17	1.23	1.34	1.46
160	1.02	1.05	1.07	1.10	1.15	1.20	1.30	1.40
200	1.02	1.04	1.06	1.08	1.12	1.16	1.24	1.32
400	-	1.02	1.03	1.04	1.06	1.08	1.12	1.16
800	-	-	-	1.02	1.03	1.04	1.06	1.08
1 600	-	-	-	-	-	1.02	1.03	1.04

Weight of Outer Cage Netting in Water

The weight of the outer cage netting in the water was calculated using (Fridman, 1986):

$$W_{nw} = W_{na}\, .\, (1- \gamma_w/\gamma_m) \qquad \textbf{(8)}$$

$$W_{nw} = W_{na}.E\gamma \qquad \textbf{(9)}$$

Where:
γ_w = Density of water (kgm^{-3}); fresh water 1000, sea water 1026;
γ_m = Density of material (kgm^{-3}); in this case iron (Fe) 7860;
$E\gamma$ = Coefficient of buoyancy or sinking force; for iron in water: 0.87278

Weight of Inner Cage Netting in the Air

The weight of the inner cage netting in the air was calculated using:

$$W_{ra} = L_r.W_r \qquad \textbf{(10)}$$

Where:
W_{ra} = Weight of inner cage netting in air (kg);
L_r = Total length of netting (m);
W_r = Weight of material: (kgm^{-1}); in this case iron (Fe) and polypropylene (PP).

Weight of Inner Cage Netting in the Water

The weight of the inner cage netting was calculated using (Fridman, 1986):

$$W_{rw} = W_{ra}\, .\, (1- \gamma_w/\gamma_m) \qquad \textbf{(11)}$$

$$W_{rw} = W_{ra}.E\gamma \qquad \textbf{(12)}$$

Where:
W_{rw} = Weight of inner cage netting in water
γ_m = Density of material (kgm^{-3}); in this case polypropylene (PP) and iron (Fe) 4380 kgm^{-3};
$E\gamma$ = Coefficient of buoyancy; for polypropylene (PP) and iron (Fe) in water: 0.7717.

Weight of Flotation Pipe in the Air

The weight of the pipe for flotation in air was calculated using:

$$V_{epf} = \pi.\, (D^2/4).L_p \qquad \textbf{(13)}$$

$$V_{ipf} = \pi.\, (d^2/4).L_p \qquad \textbf{(14)}$$

$$V_{cpf} = V_{epf} - V_{ipf} \qquad \textbf{(15)}$$

$$W_{pfa} = V_{cpf}.\gamma_m \qquad \textbf{(16)}$$

Where:
V_{epf} = Volume considering the exterior diameter of the pipe for flotation (m^3);
D = Exterior diameter of the pipe (m);
L_p = Total length of pipe (m);
V_{ipf} = Volume considering the interior diameter of the pipe for flotation (m^3);
d = Interior diameter of the pipe (m);

V_{cpf} = Cylinder volume of pipe (m^3);
γ_m = Density of pipe material (kgm^{-3}); in this case polyamide (PA) 1140;
W_{pfa} = Weight Of Flotation Pipe In Air (kg).

Weight of Flotation Pipe in Water

The weight of flotation pipe in water was calculated using (Prado, 1990):

$$W_{pfw} = W_{pfa}.E\gamma \qquad \textbf{(17)}$$

Where:
$E\gamma$ = Coefficient of buoyancy or floating force; for polyamide (PA): 0.12281
W_{pfw} = Weight of flotation pipe in water (kg)

Weight of Structural Members in Air

The weight of the structural members in air was calculated using:

$$W_{sma} = L_{sm}.\ W_{sm} \qquad \textbf{(18)}$$

Where:
W_{sma} = Weight of structural members in the air (kg);
L_{sm} = Total length of structural members in air (m);
W_{sm} = Weight of structural members in air (kgm^{-1}).

Weight of Structural Members in Water

The weight of the structural members in water was calculated using:

$$W_{smw} = W_{sma}\ .\ (1- \gamma_w/\gamma_m) \qquad \textbf{(19)}$$

$$W_{smw} = W_{sma}.E\gamma \qquad \textbf{(20)}$$

Where:
W_{smw} = Weight of structural members in water;
γ_m = Density of structural member (kgm^{-3}); in this case iron: 7860 kgm^3
γ_w = Density of water (kgm^{-3}); fresh water 1000, sea water 1026;
$E\gamma$ = Coefficient of buoyancy or sinking force (kgm^{-3}); in this case iron: 0.8728

Approximate Weight of the Cage in Air

The approximate weight of the cage in the air was calculated using:

$$W_{aca} = W_{na} + W_{ra} + W_{pfa} + W_{sma} \qquad \textbf{(21)}$$

Where:
W_{aca} = Approximate weight of the cage in air (kg);
W_{na} = Weight of outer cage netting in air (kg);
W_{ra} = Weight of inner cage netting in air (kg);
W_{pfa} = Weight of flotation pipe in air (kg);
W_{sma} = Weight of structural members in air (kg).

Approximate Weight of the Cage in Water

The approximate weight of the cage in water was calculated using:

$$W_{acw} = W_{nw} + W_{rw} + W_{pfw} + W_{smw} \qquad \textbf{(22)}$$

Where:
W_{na} = Weight of outer cage netting in water (kg);
W_{ra} = Weight of inner cage netting in air (kg);
W_{smw} = Weight of structural members in water (kg).

Approximate Weight of the Fouled Cage in Water

(a) For net panel, it was assumed that growth was 3 fold due to fouling which vary from different environments; the net weight was increased by 5.5 (Chua and Tech, 2002; Huguenin, 1997; Beveridge, 1996):

$$W_{fnwo} = 5.5.\ W_{nw} \qquad \textbf{(23)}$$

Where:
W_{fnwo} = Weight of fouled outer cage netting in water (kg).

(b) For the inner cage netting the same factor was applicable (Beveridge, 1996; Huguenin, 1997):

$$W_{fnwi} = 5.5.\ W_{rw} \qquad \textbf{(24)}$$

Where:
W_{fnwi} = Weight of fouled inner cage netting in water (kg).

(c) For the flotation pipes; in this case polyamide: (E_γ =0.12281), hence its weight in air was taken as its fouling weight.

$W_{pfa} = V_{cpf} . \gamma_m$ **(25)**

(d) For the structural member; it was assumed that the growth of fouling was increased by 5.5 (Beveridge, 1996; Huguenin, 1997):

$W_{fsmw} = 5.5\ W_{smw}$ **(26)**

Where:
W_{fsmw} = Weight of fouled structural member in water (kg).

(e) The approximated weight of the fouled cage in the water was calculated using:

$W_{afw} = W_{fnwo} + W_{fnwi} + W_{pfa} + W_{fsmw}$ **(27)**

Where:
W_{afw}: Approximated weight of fouled cage in water.

FLOTATION FORCES OF THE CAGE

Flotation Force on the Cage with Air Inside the Pipe

Flotation force of the cage with only air inside the pipe was calculated using:

$F_{pi} = V_{ipf} . \gamma_w$ **(28)**

$F_{po} = V_{opf} . \gamma_w$ **(29)**

$F_p = F_{pi} + F_{po}$ **(30)**

Where:
F_p= Flotation force of the cage with only air inside the pipe (kg);
F_{pi} = Flotation force of the inner pipes (kg);
F_{po}= Flotation force of the outer pipes (kg);
V_{ipf} = Volume considering the interior diameter of the pipe for flotation (m^3);
γ_w = Density of water (kgm^{-3}):1000

Emergency Flotation Force of the Cage

Emergency flotation force to prevent the sinking of the cage in case of damage to the pipes was formed by expanding polystyrene inside the flotation pipes. The stuffed of polystyrene expanded inside the pipe was about 80% of V_{ipf} for each pipe.

However, for the cage model, the emergency flotation pipes were located at the top of the cage side and no polystyrene was used for simplicity of design.

$F_e = W_{ef} .E\gamma$ **(31)**

$W_{ef} = V_{ef}. \gamma_m$ **(32)**

$V_{ef} = 0.80 .V_{ipf}$ (for each pipe) **(33)**

Where:
F_e = Emergency flotation force;
W_{ef} = Weight in air of material for emergency flotation (kg);
$E\gamma$ = Coefficient of buoyancy force; for polyamide in water: 0.12281;
V_{ef} = Volume of flotation pipes (kgm^{-3});
γ_m = Density of material (kgm^{-3}), in this case polyamide:;
V_{ipf} = Volume considering the interior diameter of the pipe for flotation (m^{-3}).

Nominal Flotation Force of the Cage

Nominal flotation force of the age with 20% air and 80% of polystyrene expanded inside of the pipe was determined using:

$F_n = F_e + 0.2F_p$ **(34)**

Where:
F_n= Nominal flotation force (kg)

Effective Floatation Forces on the Cage

Effective flotation force on the cage was calculated using:

$F_c = F_n - W_{acw}$ **(35)**

$F_f = F_n - W_{afw}$ **(36)**

Where:
F_c = Effective flotation force of clean cage (kg);
F_f = Effective flotation force for fouled cage (kg).

Emergency Effective Flotation Force

Emergency effective flotation force of the cage was calculated using:

$F_{ec} = F_{em} - W_{acw}$ **(37)**

$F_{ef} = F_e$ – **(38)**

Where:
F_{ec} = Emergency effective flotation force of clean cage (kg);
F_{ef} = Emergency effective flotation force of fouled cage (kg).

CURRENT FORCES APLLIED TO THE CAGE COMPONENTS

To calculate the loads of currents to the net panel (L_n: kg), the cage net area in front of the current perpendicular to the current force was taken into consideration. This represents the worst possible situation and maximum load.

Actual Working Area

The actual working area (A_a: m^2) was calculated as (Fridman, 1986):

$A_a = L.H$ **(39)**

Where:
L = Length of the netting facing the current (m);
H = Height of the netting or the mounted length of the side hanging line, facing the current (m);
A_a = Working area (m^2).

Fictitious Area of the Net Panel

The fictitious area of the net panel was calculated using:

$A_f = A_a / E_1.E_2$ **(40)**

(Fridman, 1986)
Where:
E_1 and E_2 = Primary and Secondary hanging ratios, previously determined.

Projected Area

The projected area facing the current was calculated using (Fridman, 1986):

$A_p = 2.A_f. (d/2.a).(1 + K_k. d/2.a)$ **(41)**

Where:
A_p= Projected area (m^2);
d = diameter of the mesh twine (mm);
a = Length of the mesh bar (m);
K_k = Coefficient of the knot-area, typically 10.1 for square-knot, 9.7 for single-knot and 14.8 for double-weavers-knot netting.

Current Load on Net Panel

The current load in the net panel was calculated using:

$L_n = C_d.\rho.V^2(A_p/2)$ **(42)**

Knotted materials:

$C_d = 1+3.77(d/a) + 9.37(d/a)$ **(43)**

Knotless materials:
$C_d = 1+2.77(d/a) + 3.12 (d/a)^2$ **(44)**

Where:
C_d = Coefficient of drag of the material; in this case circular net (dimensionless): 1.1
P = Mass density of water (kgs^2m^{-4}); fresh water = 100 and seawater = 105;
L_n = Current load in the net panel (kg).

The current force in clean netting, C_d was calculated using the original measurements of the mesh; for calculating loads in fouled netting ($L_{nf:}$ $_{kg}$) the twine thickness was increased 3 times.

For the calculation, the velocity was: $0.75ms^{-1}$(1.5 knots) and, for security, an extreme velocity of $1.0ms^{-1}$(2 knots); this was done for all the components of the cage affected by the current.

Current Load on Fouled Net Panel

$L_{nf} = C_d.\rho.V^2.(A_{pf}/2)$ **(45)**

Knotted materials:
$C_d = 1+3.77(3d/a) + 9.37 (3d/a)^2$ **(46)**

Knotless materials:
$C_d = 1+2.77(3d/a) + 3.12 (3d/a)^2$ **(47)**

$A_{pf} = 2.A_f. (3d/2.a).(1 + K_k. 3d/2.a)$ **(48)**

Where:
L_{nf} = Current load in the fouled net panel (kg);
A_{pf} = Projected fouled area

Current Load on the Flotation Pipes

The current load on the flotation pipes was calculated using (Fridman, 1987):

$L_{cp} = A_{pb}.q.C_b$ **(48)**

$A_{pb} = L_p.D_p$ **(49)**

$q = \rho.V^2/2$ **(50)**

Where:
L_{cp} = Current load on the flotation pipes (kg);
A_{pb} = Projected reference area for the resistance of the cage components (m^2);
L_p = Length of the pipe in front of the current (m);
D_p = Diameter of the pipe in front of the current (m);
Q = Hydrodynamic stagnation pressure (kgm^{-2});
C_b = Drag coefficient of the body; in this case circular cylinder: 1.2;
P = Mass density of water (kgs^2m^{-4}), previously determined;
V = Current velocity ($1ms^{-1}$), previously determined.

Table 3: Drag Coefficient (C_b) for Certain Body Shape (Fridman, 1986).

Body shape	C_b	Flow direction (V)	Reference area (A)
Circular or square plate	1.1	Normal to face	Surface of one side
Sphere	0.5		Diametric plane
Ellipsoid	0.06	Parallel to major axis	Maximum circular section
Ellipsoid	0.6	Normal to major axis	Maximum elliptical section
Circular cylinder	1.2	Normal to axis	Length x diameter
Circular cylinder	0.1	Parallel to axis	Cross-section area
Rectangular cylinder or prism	2.0	Normal to axis	Frontal (length x width)
Hemispherical cup	0.38	Axial, onto outside	Frontal ($\pi \cdot r^2$)
Hemispherical cup	1.35	Axial, into inside	Frontal ($\pi \cdot r^2$)
60° cone	0.52	Axial onto apex	Base
30° cone	0.34	Axial onto apex	Base

To calculate the current loads for fouled pipes (L_{pf}: kg), the drag, the coefficient of drag is unknown. In this case, it was considered a growth of 20% in the area exposed in front of the current force.

Current Load on Fouled Flotation Pipes

The current load on the flotation pipes was calculated using:

$L_{pf} = 1.2.A_{pb}.q.C_b$ **(51)**

Where:
L_{pf} = Current load on fouled pipe (kg)

Current Load on Structural Members

The current load on the structural members was calculated using (Fridman, 1987):

$L_{cs} = A_{pb}.q.C_b$ **(52)**

$A_{pb} = L_s.H_s$ **(53)**

Where:
L_{cs} = Current load on structural members (kg);
L_s = Length of structural member in front of the current (m);
H_s = Height of structural member in front of the current (m);
C_b = Drag coefficient of the body; in this case square plate: 1.1;
Other parameters remain as stated in Equations 48 and 49.

Current Load on Fouled Structural Members

The current load on fouled structural members was calculated using:

$L_{sf} = 1.2.A_{pb}.q.C_b$ **(54)**

Where:
L_{sf} = Current load on fouled structural member (kg)

Current Load on Inner Cage Netting

The current load on the inner cage netting was calculated using:

$L_{nr} = A_{pb}.q.C_b$ **(55)**

Where:
L_{nr} = Current load on inner cage netting (kg);
C_b = Drag coefficient of the body; in this circular shape: 1.1.

Current Load on Fouled Inner Cage Netting

The current load on fouled inner cage netting was calculated using:

$$L_{nrf} = A_{pb} .q.C_b \quad \textbf{(56)}$$

Where:
L_{nrf} = Current load on fouled inner cage netting (kg);
C_b = Drag coefficient of the body; in this circular shape: 1.4;

Table 4: Weight of the Cage for Different Conditions.

S/N	Cage Component	Clean Cage in Air (kg)	Clean Cage in Water (kg)	Fouled Cage in Water (kg)
1	Outer Cage Netting	24	20.95	115.23
2	Inner Cage Netting	6.06	4.67	25.69
3	Flotation Pipes	13.57	1.67	13.57
4	Structural Members	23.98	22.66	124.52
5	Approximate Weight of Cage	67.61	49.93	279

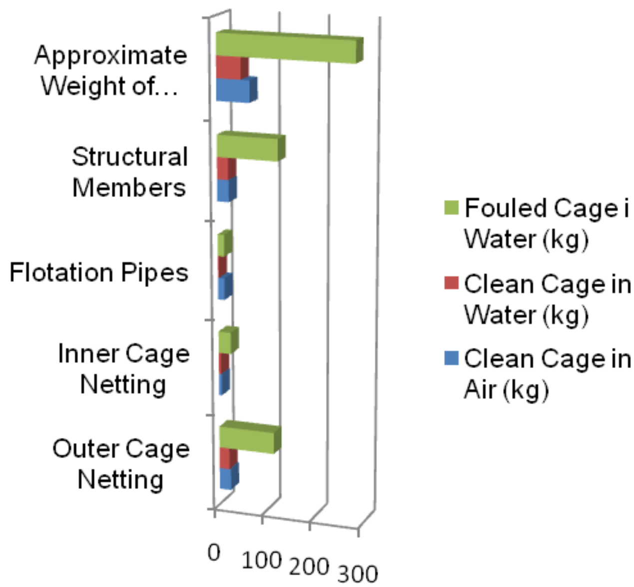

Figure 7: Nominal and Effective Flotation Force of the Cage.

Table 5: Current Forces Applied to the Cage under Different Conditions. V= 1ms^{-1}

S/N	Cage Component	Clean Cage (kg)	Fouled Cage(kg)
1	Net Panel	185.15	158.29
2	Flotation Pipes	11.15	11.38
3	Structural Members	153.29	183.95
4	Inner Cage Netting	120.17	152.94

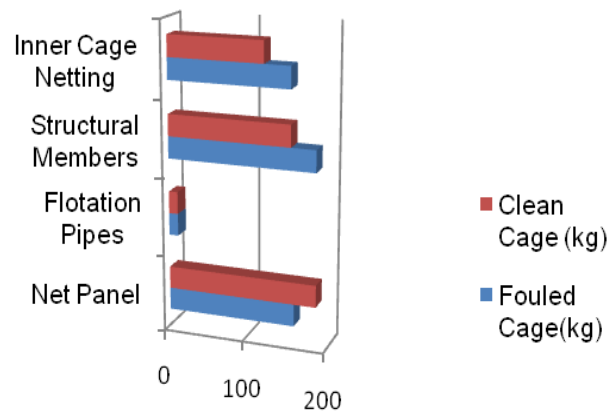

Figure 8: Current Forces Applied to the Cage under Different Conditions.

CONCLUSION

Cage aquaculture remains the only method to harness large water body for the purpose of fish farming, It has proven to be more effective in productivity than other methods of inland fish farming like; concrete ponds, earthen ponds, plastic ponds etc., with a record of raising catfish (Clarias) from fingerlings stage to standard table size (at least 1kg) within a period of three months.

This project has exploited the use of materials that are readily available in the market, hence made it easy for construction and could be adapted by rural fishermen to replace their old method of fishing in the wild without assurance of sufficient catch.

The projected challenges which the cage could encounter in the practical situation which includes the effect of fouling and water current among others were properly considered and solved in the design analysis.

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SUGGESTED CITATION

Ukoba, O.K., J.A. Olowonubi, and S.A. Fatokunbo. 2011. “Development of Submersible Fish Housing Operating with Submarine Principle”. *Pacific Journal of Science and Technology*. 12(2):130-142.

Pacific Journal of Science and Technology