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Design of Steel Structure Offshore Fish Cage to Accommodate Ecotourism and Fish Farming in Open Ocean

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Key words: Offshore aquaculture, steel structure, mooring analysis, structural analysis

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Abstract: The prospect of aquaculture is likely to be more located far offshore, generating lesser conflict and higher nutrient assimilation capacity. Aquaculture structure also potentially available for ecotourism. This article presents the design of steel structure offshore fish cage, not only for fish farming but also for ecotourism. The design is proposed based on the oil and gas standard and code practice. To ensure the operational safety of both mariculture and ecotourism, the structural strength and mooring design needs to comply with the applicable standards. There are several sides of buoyancy frame. Each consists of K-Brace steel structure. These buoyancy frames form the floater shape. The shape is then equipped with adequate supporting structures on the topside to provide strength for aquaculture operation and ecotourism activities. The mooring system used is a rectangular array system and the study of fairlead position variation is performed. The initial design of the structural and mooring system of novel structure that able to accommodate offshore aquaculture farming as well as ecotourism is proposed. With these combined functions, the designed structure is adequate to withstand the loads exerted. Further works should be performed to check the fatigue performance of the structure.

INTRODUCTION

Seafood and fisheries products demand is increasing dramatically over the past few years[1]. However, the stocks of wild fish are dangerously decreasing[2]. Aquaculture is seemingly being the answer to this problem. However, the coastal aquaculture is an arduous effort to develop due to the conflict of usage, environmental problem and shipping traffic interference. Therefore, the prospect of aquaculture is likely to be more located far offshore, generating lesser conflict and higher nutrient assimilation capacity. Due to the nature of offshore aquaculture that goes farther from the shore, the vulnerability of higher currents and waves exposure is increasing.

Several offshore aquaculture models have been developed to answer the challenge. There are several products available in the market that are proven to be able to endure sea loads while providing service for fish farming. SINTEF Fisheries and Aquaculture, have produced types of floating offshore aquaculture, that have deployed in offshore Norway, Fig. 1 illustrates the

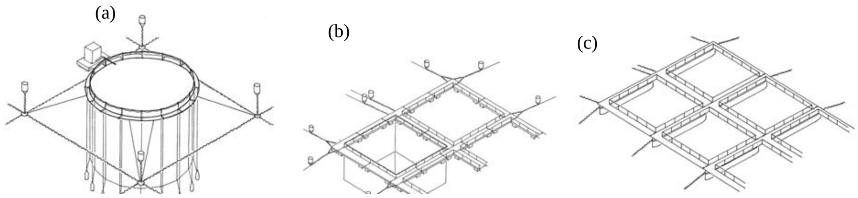

Fig. 1(a-c): SINTEF products of floating offshore aquaculture[3]

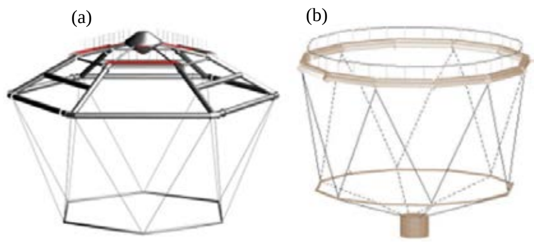

Fig. 2(a, b): SADCO products of floating offshore aquaculture, (a), SADCO-E and (b) SADCO-SG

SINTEF products namely (a) HDPE Collar Fish Farm, (b) Interconnected Hinged Steel Fish Farm, (c) Steel Catamaran Fish Farm[3].

SADCO offshore technology also managed to launch two types of products, the fully submerged steel structure offshore fish farm named SADCO-D and SADCO-E and HDPE floating fish farm named SADCO-SG (Fig. 2).

There are also gravity-type and semi-rigid central spar fish cage made of steel structure are proven examples of offshore aquaculture that able to withstand environmental loads at offshore New England, USA[4].

RCM (Research Center for Marine) from LPPM (Lembaga Penelitian dan Pengabdian Kepada Masyarakat) Institut Teknologi Sepuluh Nopember Surabaya developed the idea of holistic offshore aquaculture that not only able to harvest fish offshore but also develop the potential additional revenue by combining it with tourism and hospitality. This comprehensive approach is an ideal solution to maximize the potential of ecotourism, aquaculture and research station. The hybrid activities classified as ‘research ecotourism’ offers considerable potential and could well serve as a model for future developments, particularly in remote locations suited to the needs of this sector of the market[5].

Several locations have been assessed to be the potential offshore aquaculture site. This ambitious idea has to be strengthened with comprehensive numerical and physical simulations and assessment before the full-scale prototype deployed. Numerical simulation of steel structure floating fish cage configuration resulted in a promising result. The numerical research for mooring configuration has been carried out and it is discovered that rectangular array is the best mooring arrangement to be employed. Physical laboratory scale of structure and mooring configuration has been deployed and resulting in a satisfactory motion response[6].

Continuing the works that have been performed above, this paper elaborates and proposes an improved design of floating cage ‘hull’ and superstructure to accommodate the fish harvesting as well as tourism and hospitality.

MATERIALS AND METHODS

Design baseline and methodology: The design is proposed based on the oil and gas standard and code practice. To ensure the operational safety of both mariculture and ecotourism, the structural strength and mooring design needs to comply with the applicable standards[7].

Structural design: There are several sides of buoyancy frame. Each consists of K-Brace steel structure. These buoyancy frames form the floater shape. The shape is then equipped with adequate supporting structures on the topside to provide strength for aquaculture operation and ecotourism activities.

In order for the structure performs well in the open ocean, the steel framing configuration is introduced to interweave the individual hull structure and provide adequate strength to support the topside loads. There are numerous design example has been studied and adopted to the design, especially the ones that have been recommended by FAO (Food and Agricultural Organization of the United Nations). The modelled structural components are only the ones that have significant roles to the overall strength. Figure 3 gives an overview of the proposed structural design. The deck is composed of marine-grade woods supported with steel framing.

The hull is attached to the structural system by a marine-standard clamp to provide adequate strength against environmental loads. The hull structure made of HDPE (High-Density Polyethylene) material, injected with EPS (Expanded Polystyrene) foam that is light, robust and widely available in the market[8]. The hull is a steel frame with steel column as primary floatation force resources.

Fig. 3: Structural design modelling

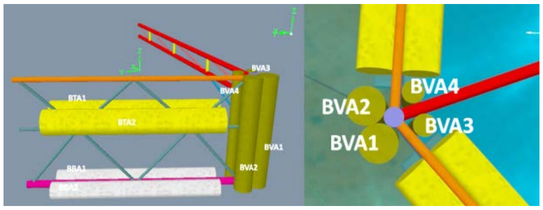

Fig. 4: Hull design

Practically, the hull adapts the principle of semi submersible platform, a floating unit with pontoon and column as floaters[9]. This concept is adapted with additional buoyancy from HDPE floater with lower density than seawater, to produce sufficient buoyant force without sacrificing the service life of the overall structure[10]. Steel hull and bracing system reinforced with HDPE floater in column and pontoon are designed to improve stability and buoyancy. Figure 4 shows the 1/8 part of the hull structure.

Full floater profile has been modelled in numerical hydrodynamic software, to analyze the motion performance of the system. Figure 5 explains the full profile arrangement.

The topside deck is designed to carry the load up to 10 MT (Metric-Ton) and designed as beam truss to accommodate the lightweight, reliable and preferably low-cost structure. The floating column that is attached is fastened to the structural column using a fastening connector. Buoyancy and frame addition columns to add buoyancy to force, another function of this component is to increase the stability of the structure.

Mooring design: The mooring system used is a rectangular array system, according to FAO recommendations[8]. He sensitivity study is carried out to obtain the optimum orientation direction of the grid system, as described in Fig. 6. In Grid A, the chain shackle is mounted at the edges of the hull system. While in Grid B, the shackle is installed at the center of the frame.

As in Fig. 6, the mooring system binds to the hull structure connected by Grid A1A2 ropes. The A1A2 grid is then connected to the Ring A. This ring is a place to connect the grid system to the mooring system. Just above Ring A, a chain is connected to the buoy as a stabilizer (Fig. 7).

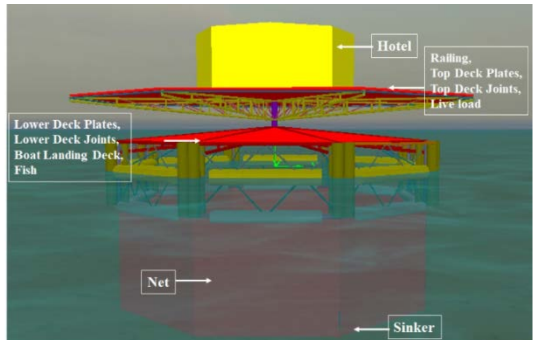

Fig. 5: Full hull floater assembly

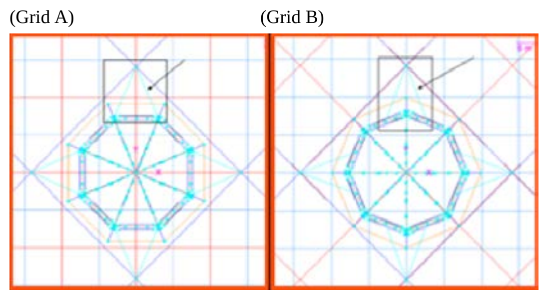

Fig. 6(a, b): Grid A and Grid B system configuration

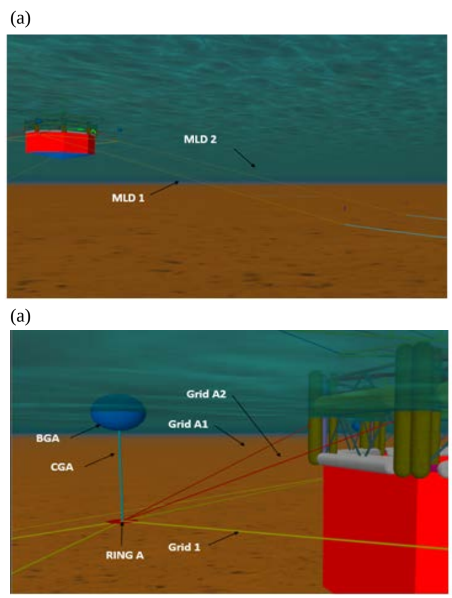

Fig. 7(a, b): Mooring design

From the ring, the force generated by the motion due to waves is distributed to the mooring system. It can be seen in Fig. 8, MLD 1 has two types of material, the line represented by yellow color is made of polyester (80 m) and the blue line is made of a chain (20 m). At the end of the chain, there is an anchor to tether the line to the seabed.

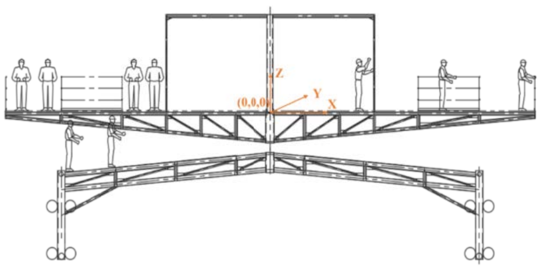

Fig. 8: CoG and CoB baseline

RESULTS AND DISCUSSION

Floatabilty and static stability analysis: Floatability defines whether the particular structure can sustain its floating conditions. Floatability is defined by the Center of Buoyancy (CoB) that lays below its Center of Gravity (CoG). The calculation of the location of the Center of Gravity (CoG) and Center of Buoyancy (CoB) is done by taking into account the details of each section on the deck and structural system. This CoG and CoB reference point is the center point of the Top Deck floor as described at Fig. 8. The CoG is calculated using following equation[9]:

$$a = \frac{\text{Moment a (kg.m)}}{\text{Mass (kg)}} \quad (1)$$

where, a = the center of gravity of the x, y and z axes. Table 1 shows the detailed results of the CoG calculation. Whereas the CoB is defined by following Eq. 2[9]:

$$b = \frac{\text{Inertial moment of displacement b(m}^4\text{)}}{\text{Volume displacement (m}^3\text{)}} \quad (2)$$

where, b = buoyancy point on the x, y and z axes. CoB calculation results are described at Table 2. The result showed that the CoB is below the CoG. The resulting calculations also yield the reserve buoyancy up to 8% of the total displacement. This result is an agreeable floatation ability for the structure to support the payload required from the topside.

Mooring design system: Table 3 shows the maximum offset of Grid A and B configuration as depicted in Fig. 8. The structure loaded by regular Airy wave ranging from 1-4 m. The result of maximum offset which is the maximum excursion from its initial position, represented by the percentage of change to its size.

From the result above, there is only slight difference between grid A and B. However, grid A is easier to install. The shackle positions at grid A is located at the edges of the octagon. The final selection of the mooring system is defined in Fig. 9.

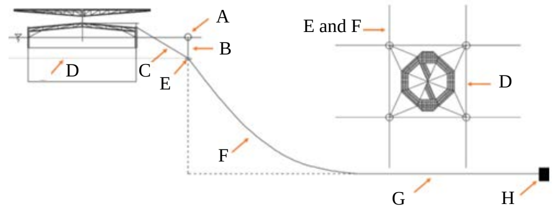

Fig. 9: Final mooring system selected

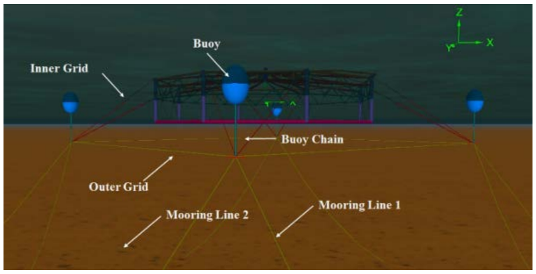

Fig. 10: Final configuration of mooring line (3D modelling)

Table 4 informs the mooring configuration selected and its specification. Code A is the aquaculture standard buoy used to stabilize the motion with the volume of 1130 L and maximum buoyancy force 1.035 metric-ton. There are several chain configurations installed, namely chain B for attaching the buoy to the grid. Chain C and D are the polyester ropes to form the mooring grid. Main mooring line F comprises of 48 mm wire rope and mooring line G consists of 40 mm Studlink chain. Plate ring E connects the grid system to the main mooring line. Figure 10 shows the final mooring arrangement in 3D view.

Structural design system: The structural performance is analyzed using 3D finite element analysis software. Due to its nature as a floating body, the boundary condition should accommodate the hydrostatic stiffness behaviour of a floating structure. Hydrostatic stiffness as displacement boundary condition is introduced in this study. The pitching, rolling and heaving stiffness of hydrostatic motion is transferred into the displacement boundary condition as spring constraints.

The topside loads and buoyancy forces are derived from Table 4 and Fig. 10 whereas the environmental loads are the maximum storm wave height, maximum wind and maximum current velocity on the installed location (Fig. 11).

The stress from static environmental loading analysis is presented at Table 5. The stress occurred at each members are compared with the applicable standard[11]. The comparation ratio is presented at Table 5 as Unity Check (UC) ratio. The structure is categorized as acceptable if UC<1. It is shown that the maximum UC is

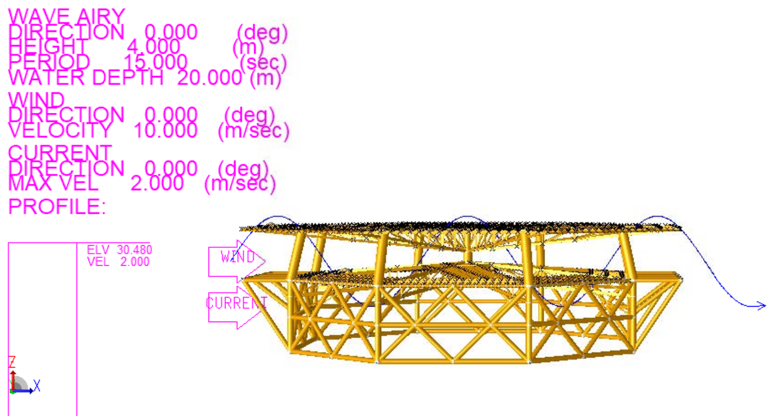

Fig. 11: Environmental loading scenario

Table 1: Centre of gravity calculation

Part name	Mass (ton)	Moment X (ton.m)	Moment Y (ton.m)	Moment Z (ton.m)	X	Y	Z
Top Deck	6.12	0.00	0.00	-0.55	0.00	0.00	-0.09
Connector	0.35	0.00	0.00	-0.41	0.00	0.00	-1.18
Railing	1.54	0.00	0.00	0.92	0.00	0.00	0.60
Lower Deck	4.46	0.00	0.00	-8.97	0.00	0.00	-2.01
Boatlanding	0.50	0.00	0.00	-1.25	0.00	0.00	-2.52
Buoyancy Frame	3.94	0.00	0.00	-15.05	0.00	0.00	-3.82
Floater	5.35	0.00	0.00	-20.73	0.00	0.00	-3.88
Hotel Furnitures	2.58	2.75	-0.10	2.54	1.06	-0.04	0.98
Fish Cage Net	0.83	0.00	0.00	-6.07	0.00	0.00	-7.31
Hotel Appurtenances	0.42	0.00	0.00	1.34	0.00	0.00	3.20
Plate Joint	5.00	0.00	0.00	0.00	0.00	0.00	0.00
			CoG coordinate		0.03	0.00	-0.52

Table 2: Center of buoyancy calculation

Part name	Mass (ton)	Moment X (ton.m)	Moment Y (ton.m)	Moment Z (ton.m)	X	Y	Z
Floater	30.20	0.00	0.00	123.89	0.00	0.00	-0.09
Buoyancy frame	2.81	0.00	0.00	-11.43	0.00	0.00	-1.18
Total displacement	33.01	0.00	0.00	112.46			
				CoB coordinate	0.00	0.00	-0.04

Table 3: Maximum offset of Grid A and B

		X Offset (m)		Y Offset (m)		Z Offset (m)	
Hs (m)	Wave attack angle (°)	A (%)	B (%)	A (%)	B (%)	A (%)	B (%)
1	180	12	13	0	0	2	2
	135	9	9	9	9	2	2
2	180	16	16	0	0	2	2
	135	11	11	11	11	2	2
3	180	18	18	0	0	2	2
	135	13	13	13	13	2	2
4	180	15	17	0	0	3	3
	135	12	12	12	12	3	3

Table 4: Mooring configuration details

Code	Part name	Specification
A	Buoy	Buoy 1130 L
B	Buoy chain	Chain Studlink 16 mm
C	Inner grid	Polyester Rope 36 mm
D	Outer grid	Polyester Rope 48 mm
E	Plate ring	Plate Ring D:25 mm
F	Mooring line 1	Wire Rope 48 mm
G	Mooring line 2	Chain Studlink 40 mm
H	Anchor	Anchor Block 5 tonne

Table 5: Mooring configuration details

Member	Max UC	Axial stress	Bending stress strong axis	Bending stress weak axis	Shear stress strong axis	Shear stress week axis
Topside Beam 8	0.498	-23.38	2.11	-26.78	0.96	-1.39
Topside Beam 27	0.495	-8.89	-24.7	1.09	0.07	-1.17
Hull Bracing 9	0.493	-23.2	2.21	26.47	0.94	1.49
Topside Beam 12	0.488	-22.39	2.25	27.84	0.91	3.14
Hull Bracing 6	0.488	-30.81	3.97	7.77	0.28	0.33
Topside Beam 34	0.473	-30.17	3.92	-6.97	0.25	-0.61
Topside Beam 12	0.447	-9.88	-10.03	-5.92	-0.12	-0.68
Hull Bracing 12	0.439	-3.59	-12.89	-78.7	22.29	11.73
Hull Bracing 3	0.418	-28.79	2.56	-2.14	0.25	-0.1
Topside Beam 66	0.417	-28.6	-0.1	3.58	0.23	0.17
Topside Beam 74	0.414	-27.89	1.37	4.28	0.16	0.8
Hull Bracing 4	0.412	-22.07	3.03	16.8	0.66	3.66
Hull Bracing 5	0.403	-27.77	0.11	-3.22	0.23	0

0.498 and occurred at topside beam 8. It can be stated that the structural design system is safe based on the static capacity of the structure.

Simple summary: Seafood and fisheries product demand is increasing dramatically over the past few years. Nevertheless, the stocks of wild fish are dangerously decreasing. Aquaculture is seemingly being the answer to this problem. However, coastal aquaculture is an arduous effort to develop due to the conflict of usage, environmental problem and shipping traffic interference. Therefore, the prospect of aquaculture is likely to be more located far offshore, generating lesser conflict and higher nutrient assimilation capacity. Due to the nature of offshore aquaculture that goes farther from the shore, the vulnerability of higher currents and wave exposure is increasing. The idea of holistic offshore aquaculture that not only able to harvest fish offshore but also develop the potential additional revenue by combining it with tourism and hospitality. This comprehensive approach is an ideal solution to maximize the potential of ecotourism, aquaculture and research station. The design of the hull, mooring, the structural and anchoring system is presented in this article. Based on the proposed design, it can be concluded that the proposed design can adequately support the open ocean aquaculture and ecotourism activities. However, further analysis should be performed in order for the structure to survive in a more extended period of operation.

CONCLUSION

This study emphasizes on the design proposal of the structural and mooring system of novel structure that able to accommodate offshore aquaculture farming as well as ecotourism. With these combined functions, the designed structure should be adequate to withstand the loads exerted. The structure should also be able to perform very minimal excursion to accommodate ecotourism activities. Based on the performed analysis and design, it has been proposed the structural and mooring configurations for the intended purpose.

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