Carbon – Science and Technology

ISSN 0974 – 0546

http://www.applied-science-innovations.com

RESEARCH ARTICLE Received: 10/03/2016, Accepted:15/04/2016

A CAD model for energy efficient offshore structures for desalination and energy generation

R. Rahul Dev, R. Sharma [(*)], R. Sundaravadivelu

Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu – 600 036, India.

Abstract: This paper presents a 'Computer Aided Design (CAD)' model for energy efficient design of offshore structures. In the CAD model preliminary dimensions and geometric details of an offshore structure (i.e. semi-submersible) are optimized to achieve a favorable range of motion to reduce the energy consumed by the 'Dynamic Position System (DPS)'. The presented model allows the designer to select the configuration satisfying the user requirements and integration of Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD). The integration of CAD with CFD computes a hydrodynamically and energy efficient hull form. Our results show that the implementation of the present model results into an design that can serve the user specified requirements with less cost and energy consumption.

Keywords: Computer Aided Design, Semi-submersible, Computational Fluid Dynamics; Design optimization; Response analysis

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1 Introduction: The world energy consumption is reaching alarming levels with passing of each of the years and this quest for energy is forcing the researchers to explore and exploit new and novel resources of energy that are ecology and environment friendly. The energy requirements are related to survival and growth and in this regard, a developing nation like India has the most difficult choice, i.e. IT has to develop to lift its majority of the population that is below the poverty line and at the same time IT has to cater to the considerations of ecology and environment. And, that is not so easy. We firmly believe that the 'energy' scenario needs a holistic and integrated planning. We need to critically examine the energy from production to consumption and our focus needs to be on developing systems that are efficient, economic and reliable. This aim for developing an integrated design for the 'Efficiency, Economy and Reliability (EER)' has motivated this work. Our idea is that the focus needs to be on design and development of energy efficient systems that reduces the energy consumption per unit of production and allows us to look at the energy life cycle in a holistic manner.

In this work we focus on a CAD model for designing new energy efficient design configurations. Although, our presented model is general and applicable to the area of offshore structures, the application example is restricted to a semi-submersible that is planned for a desalination plant. The water is essential for human survival, agriculture, and industrial growth. The world's available fresh water reservoirs are limited and unevenly distributed. Of the quintillions of gallons in the sea and the polar ice caps less than 2 percent is available as fresh water. At present, a billion people worldwide lack clean drinking water. It has been estimated that more than a billion will be living in countries facing an absolute water shortage by 2025. On current estimates, the desalination provides about one quarter of 1 percent of human water needs. The desalination of sea water is becoming more and more viable and cost effective with advancements in science, technology, and engineering of the process of 'desalination' and supporting plant structures. Around, more than 2 billions of fresh water a day is produced in this day at around 3500 plants, mostly in the Middle East. Recently, there has been a shift towards floating desalination plants to reduce environmental issues and to supply water on-demand and on-time. Also, a floating desalination plant can improve upon its energy efficiency utilizing the 'ice from fire' concept that is available from **[1]**. Because of essential requirement of water, the floating platform is to operate 24×7×365 in all weather conditions. Hence, the structure must have low and favorable motion and good station keeping characteristics.

In this paper, we paper presents a 'Computer Aided Design (CAD)' model for energy efficient design of offshore structures. Our results show that the implementation of the present model results into a design that can serve the user specified requirements with less cost and energy consumption. The remaining of this paper is organized as follows: Section 2 describes the CAD methodology, Section 3 presents a brief description and application of the design concepts and model 'ice from fire' concept, Section 4 presents design example and discussion, and Section 5 concludes the paper with some identification about future scope of research.

2. CAD methodology: The definition of complete design process is shown in Figure 1. In the present work, our CAD model is structured in three modules: 1) Module 1 – stability, 2) Module 2 – Stability and motion, and 3) Module 3 – Motion. The idea is look for design solutions that minimize motion while satisfying the rules and requirements of stability. The hydrodynamic motion response is evaluated using a CFD software (Ansys-AQWA^{*TM}) and integrated with CAD definition model implemented in Matlab^{**TM}. The basic dimensions of semi-submersible are derived from [2], and the basic design configuration is shown in Figures 2 and 3. All the design configurations satisfy the safety and stability requirements and on a basic design three column design alternatives (i.e. square shaped, elliptical shaped and circular shaped) are studied for motion response analysis.

Module 1 Stability - Basic dimension of structure, materials, etc. → **Module 2** Stability and motion – Shape of structural components → **Module 3** Motion - Basic dimensions and shape of structure with weather data

Figure (1): Basic modular architecture of the design approach.

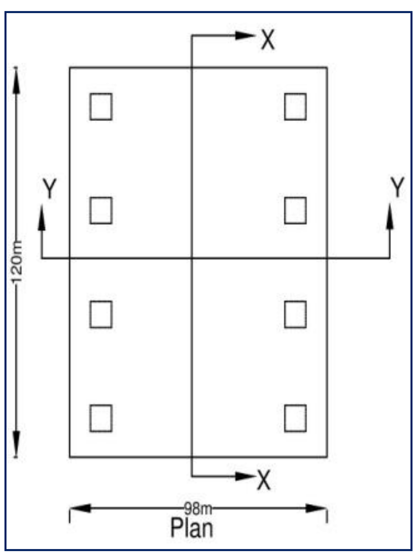

Figure (2): Basic schematic layout of semi-submersible in plan.

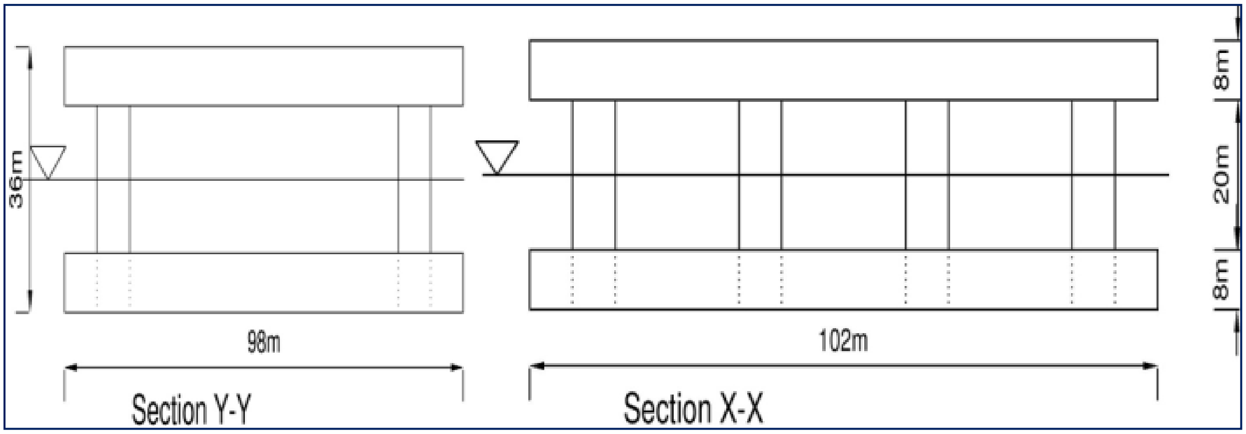

Figure (3): Basic schematic layout of semi-submersible in elevation.

3. Brief description and application of the design concepts and model: Three different models of semi-submersibles are considered: with square columns, circular columns, and elliptical columns; and details are listed in Table I. The basic design of semi-submersible consists of the rectangular pontoons in box structure and hence without any spacing. Our idea is to reduce the motion response and in addition to that it can be used to store desalinated drinking water. The basic design is arrived after modification to the conventional semi-submersible like truss-pontoon semi-submersible with heave plates, truss-pontoon semi-submersible telescopic keel tank, etc., for more details see **[2-13]**. The advantage of this rectangular pontoon is not only the reduction in the responses but also the additional space provided by the pontoon that can be used for storing purified water and other things. In each of the design alternatives, the design has eight columns that are used to increase the stability. The extra buoyancy provided by the rectangular pontoon leaves the center of buoyancy closely to the middle of the pontoon. So the pontoon is to be ballasted significantly to bring the center of gravity close to center of buoyancy. The numerical simulation for design alternatives is done for the water depth of 1000 m.

The numerical analysis is done with software ANSYS-AQWA*TM that is based upon the potential flow theory. For the computation in frequency domain, the waves are added in range of 0 m to 1800 m, with an increment of 450 m. The FDA is performed using diffraction theory to obtain the RAO, damping and added mass, etc. The size of the deck and pontoon are made equal and the only variation is in the plate thickness. The semi-submersible design configurations are designed for the sea state 9, with an air gap of 10 m for the operating condition. The payload acting on the pontoon and deck are 10, 000 tons each. In the square column semi-submersible, the columns pass through the pontoon which increases the strength and weld-ability of semi-submersible. The side length of the column is equal to the pontoon height for strength requirements and adequate side clearance along the breadth is implemented to prevent the failure of columns due to continuous wave action. The solid models of semi-submersible design alternatives are developed in SolidWorks***TM and shown in Figures 4,-6. The circular columns offer less stability when compared to square columns but from manufacturing point of view the circular columns are lucrative because they can be manufactured with primarily rolling and will need less amount of welding. The elliptical columns offer more stability compared to circular columns but less stability when compared to square columns.

This is due to the increase in cross sectional area compared to circular columns. In all the three cases of Figures 4-6, the cross sectional area is maintained almost constant to keep the water plane area constant. From our analysis, we conclude that the elliptical columns are not a favorable design choice because of the difficulty in manufacturing and high responses associated with them.

The ammonia-water absorption cooling is employed with large refrigeration loads and that has a cost advantage with increasing unit capacity. At present the commercially viable applications are in the range of below 100 kW of cooling capacity. The research and development of **[1]** that have motivated the application in this paper has resulted into an absorption cooling system with its world-wide unique selling proposition and cooling in the range up to 1 MW.

Table (1): Details of various column configurations.

Parameter Details (in SI units)	Design 1 (Square column)	Design 2 (Circular column)	Design 3 (Elliptical column)
Length of pontoon (m)	132	132	132
Breadth of pontoon (m)	105	105	105
Height of pontoon (m)	8	8	8
Column dimension (m)	Length/breadth 8	Diameter 8	9 (major axis) 8 (minor axis)
Centre of gravity from keel (m)	7.506	7.46	7.50
Centre of Buoyancy from keel (m)	4.397	4.31	4.35
Meta-centric height in x (GMr)(m)	4.154	2.60	2.97
Meta-centric height in y (GMy)(m)	4.064	2.53	2.87
Ixx (Kgm^2)	12×10^{10}	16×10^{10}	16×10^{10}
Iyy (Kgm^2)	18×10^{10}	22×10^{10}	22×10^{1}
Izz (Kgm^2)	28×10^{10}	31×10^{10}	32×10^{10}
Weight (tons)	118900	117773.77	118288.99

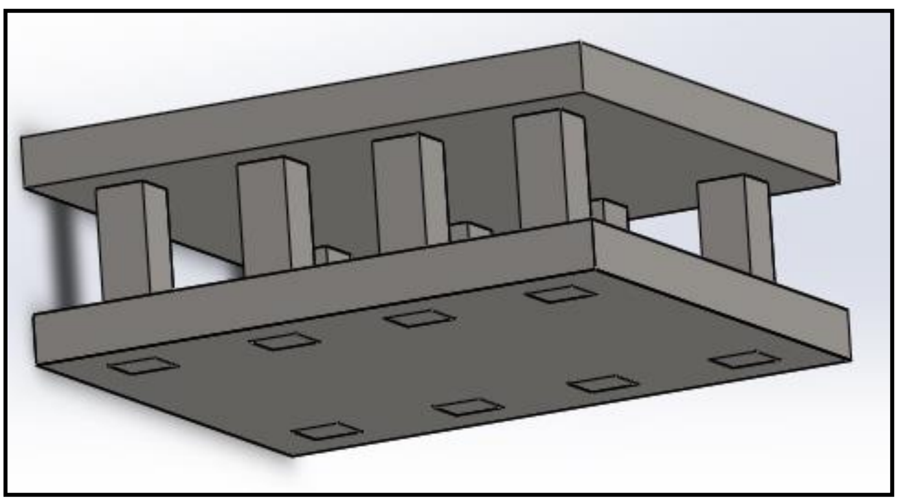

Figure (4): SolidWorks***TM model for square column semi-submersible.

The main feature is an optimized system-flow-scheme allowing driving heat temperatures below 100 ^{0}C and cooling temperatures down to -10 ^{0}C. The schematic of ‘ice from heat’ concept is shown in Figure 7. The application of compact heat exchangers reduces the physical dimensions up to an order of magnitude compared to conventional shell and tube heat exchangers. This idea is expected to rationalize the energy supply in decentralized energy systems especially by using waste heat in the offshore structures. The main components are: Desorber – here the thermal energy is supplied to the system and the refrigerant separates from the absorbent; Condenser – here the refrigerant liquefies by heat transfer to the heat output; Evaporator – here an evaporation process takes place that causes the cooling effect by heat transfer from the refrigeration load; and Absorber – here the ammonia is absorbed again by the water and the cycle can start anew. The refrigerant is ammonia and the absorbent is water.

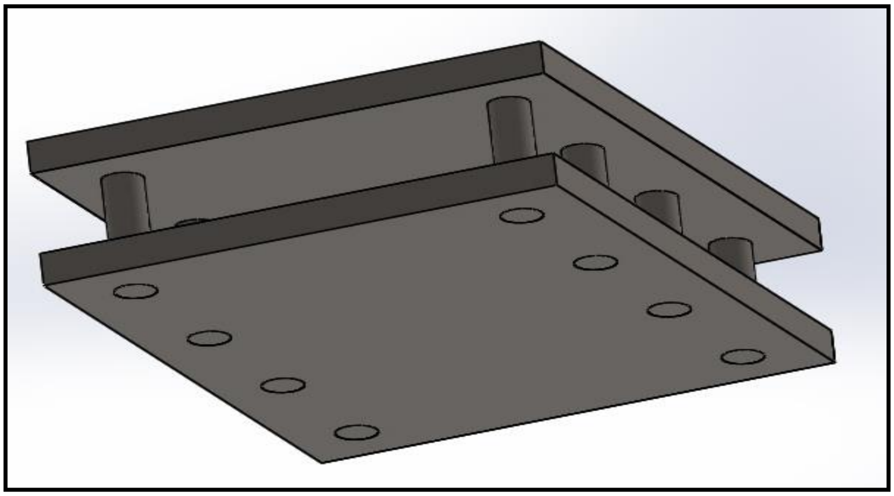

Figure (5): SolidWorks***TM model for circular column semi-submersible.

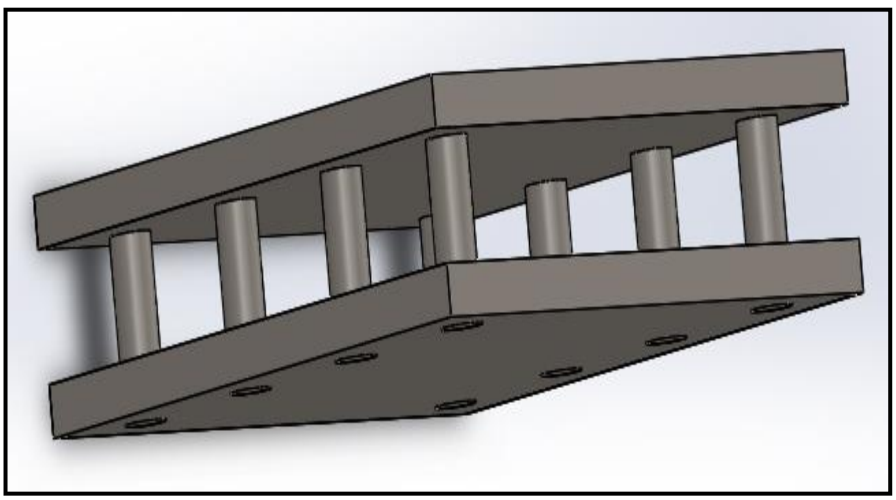

Figure (6): SolidWorks***TM model for elliptical column semi-submersible.

4. Design example and discussion: Our results from Table 1 show that the semi-submersible with square columns offers high stability as compared to the other two configurations. However, in the developed designs the center of buoyancy is close to middle of the pontoon, so the semi-submersible is to be ballasted a lot to bring the center of gravity close to center of buoyancy. Figures 8 and 9 show that the heave response for all design configurations does not change significantly and here the change in the column shape has minimum effect. Although, the responses are less in roll, we can clearly see that the response of square column is very less when compared to other two configurations, Figures 10-11. The roll and pitch motion curves for same sea state look similar, this is due to the fact that the semi-submersible is closer to square. The roll motion in head sea condition is same as the pitch motion in beam sea condition and same is the case with other motions. We conclude that the heave motion is predominant and other motions are very small, Figures 8-13. Hence this new innovative model of semi-semisubmersible is an important design to be investigated in-detail.

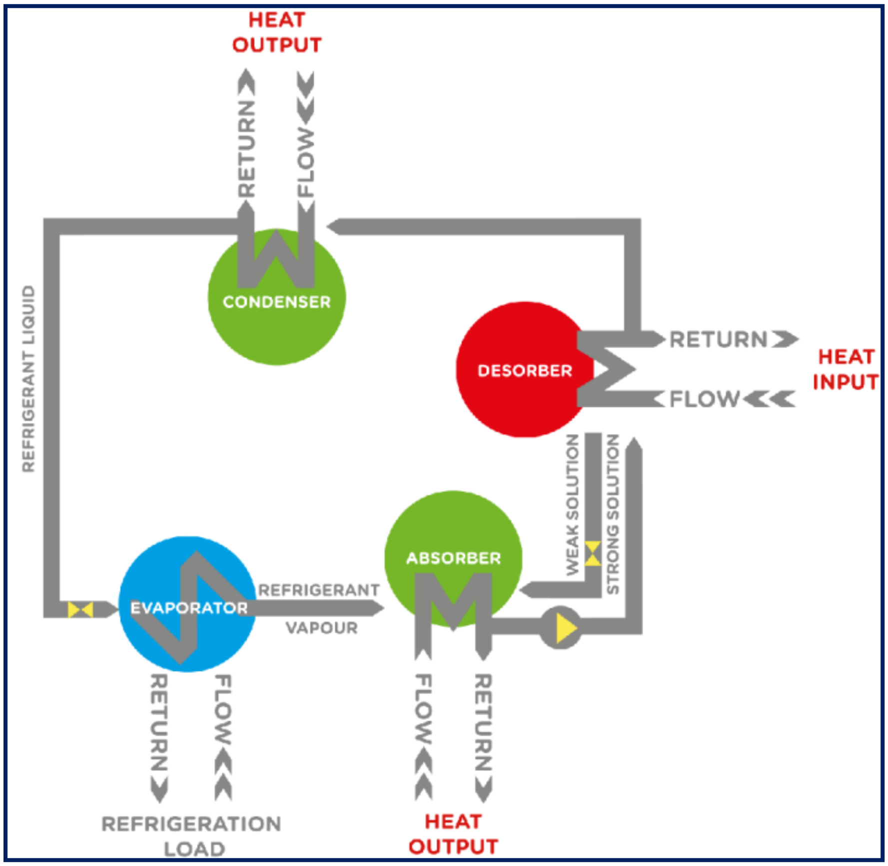

Figure (7): Schematic diagram of 'ice from heat' concept adapted from [1].

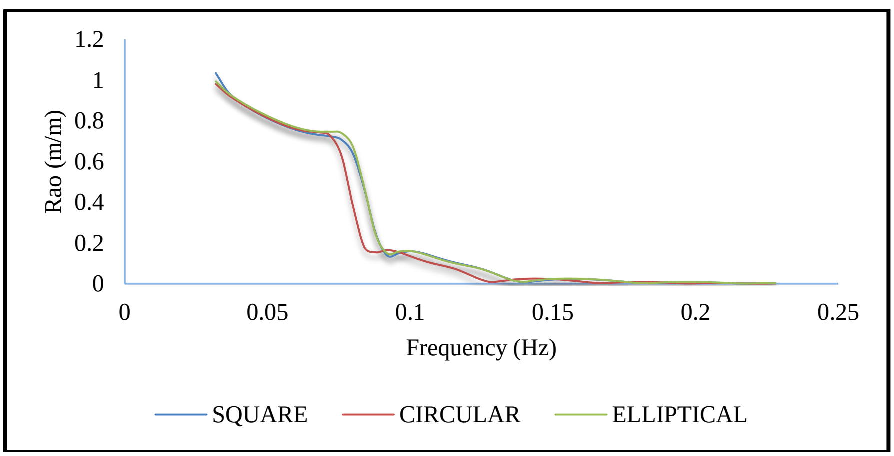

Figure (8): Comparison of heave RAOs for head sea condition.

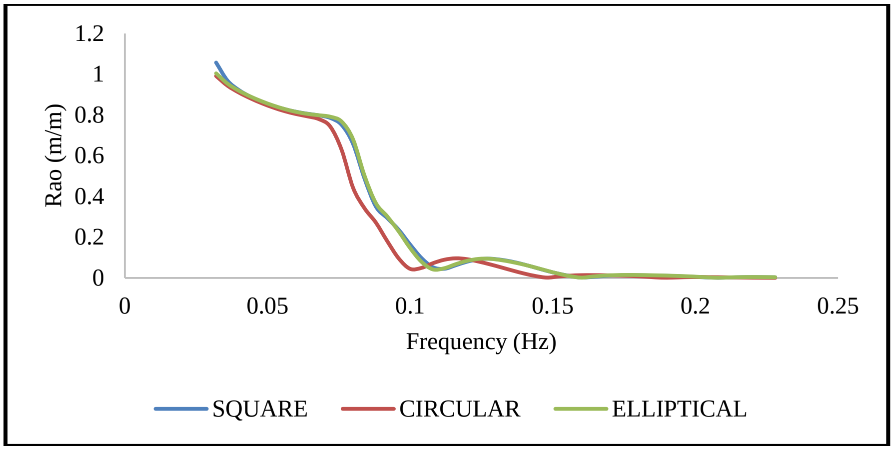

Figure (9): Comparison of heave RAOs for beam sea condition.

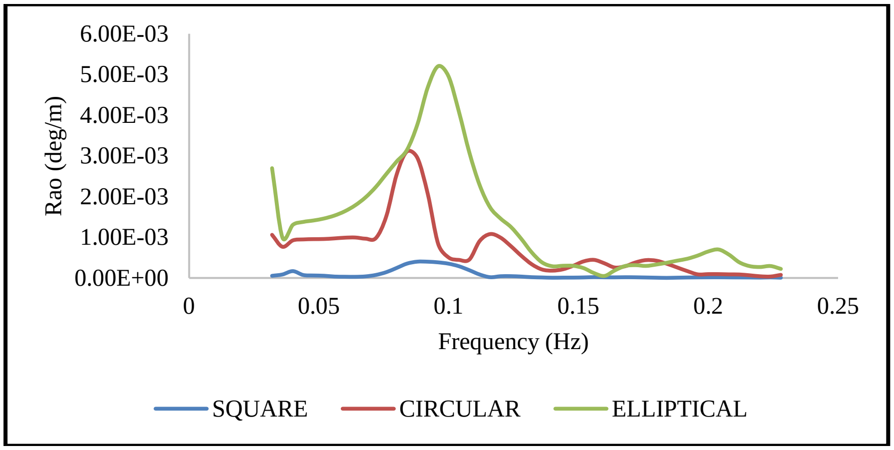

Figure (10): Comparison of roll RAOs for head sea condition.

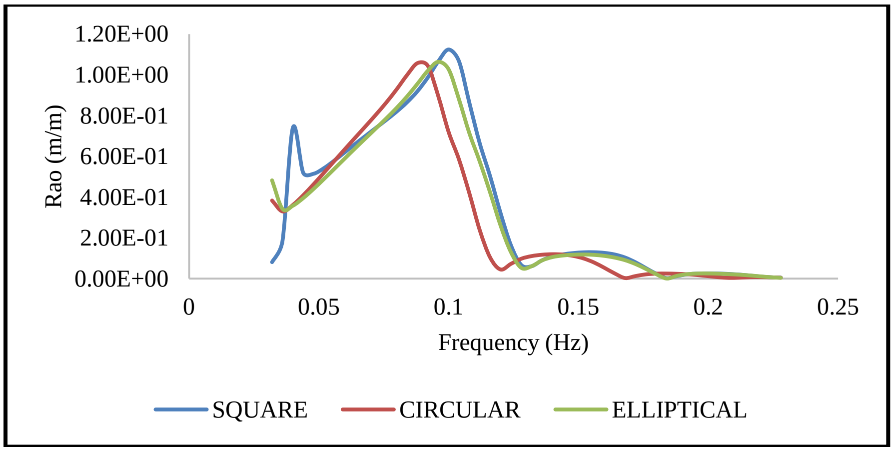

Figure (11): Comparison of roll RAOs for beam sea condition.

A brief comparison of the motions of the semi-submersible with rectangular pontoon/square columns and semi-submersible with two pontoons with spacing has been done and the results are shown in Figures 14-16. As only few references are available on semi-submersible used for desalination, here the comparison is done with a 10 mld desalination plant.

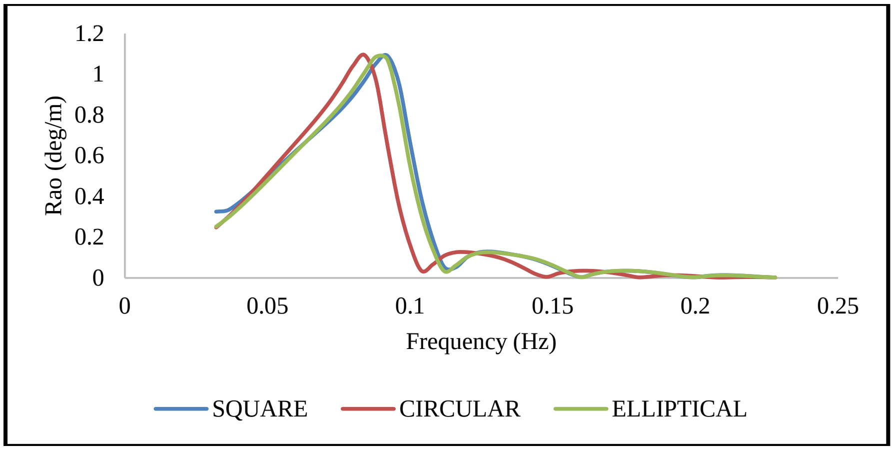

Figure (12): Comparison of pitch RAOs for head sea condition.

From Figure 14 we can observe that for normal semi- submersible the heave response is very high and the maximum response occurs at around 21 seconds which in the normal wave period hitting the platform on regular basis. However, for the rectangular semi-submersible the maximum occurs at beyond 30 seconds which is safe from normal waves and further the response is very less. This results in energy savings via reduction in requirements of the dynamic positioning system.

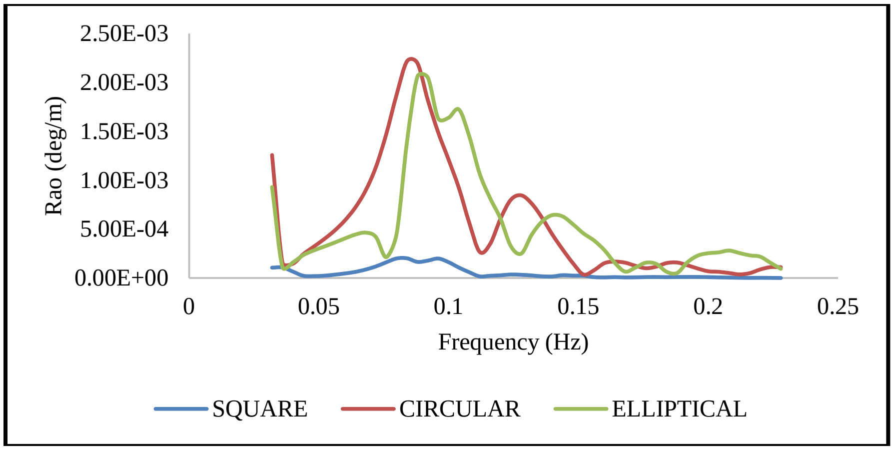

Figure (13): Comparison of pitch RAOs for beam sea condition.

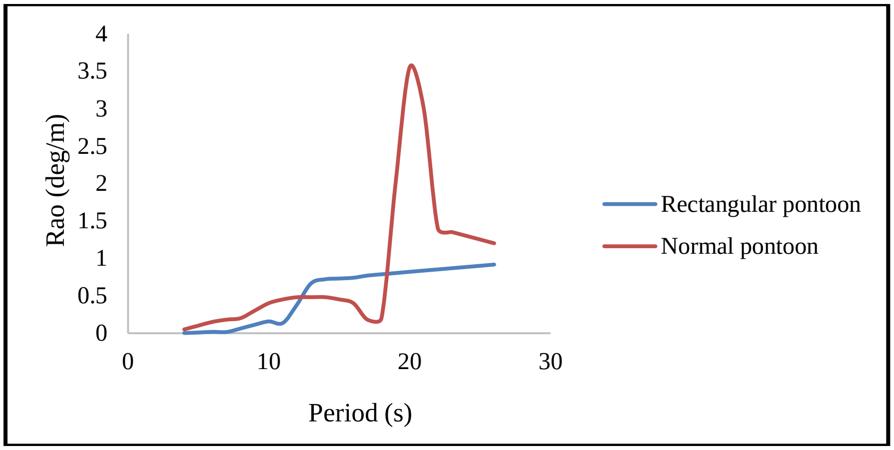

Figure (14): Comparison of heave RAOs of semi-submersible with rectangular and normal pontoons (twin pontoon with spacing).

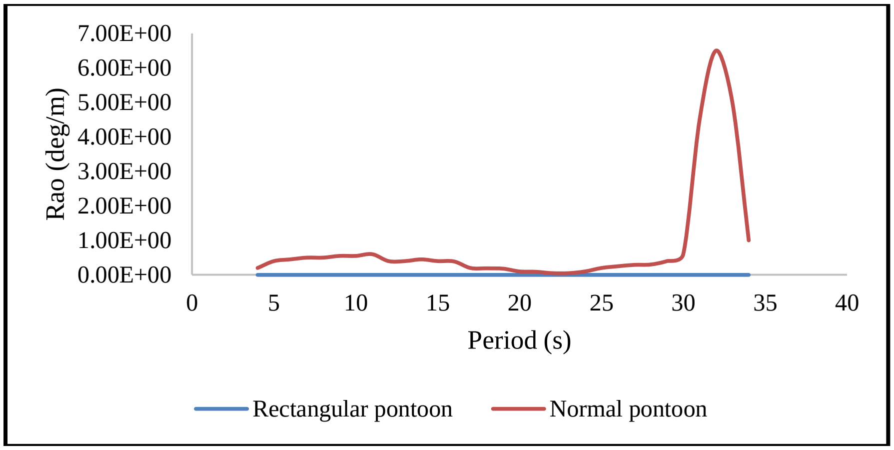

Figure (15): Comparison of roll RAOs of semi-submersible with rectangular and normal pontoons (twin pontoon with spacing).

Our primary computations show that the savings can be of the order of around 30 to 50 percent in the DPS operating costs. Also, from the roll comparison in Figure 15 we can see that the roll response of the innovative model is very less. Similarly, from Figure 15, we observe that the pitch response is also very less.

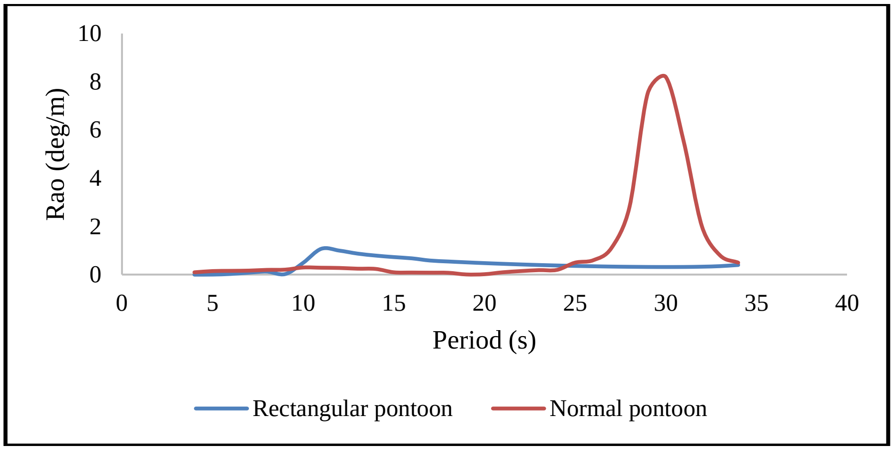

Figure (16): Comparison of heave RAOs of semi-submersible with rectangular and normal pontoons (twin pontoon with spacing).

5. Conclusions: This paper has presented a 'Computer Aided Design (CAD)' model for energy efficient design of offshore structures. In the CAD model preliminary dimensions and geometric details of an offshore structure (i.e. semi-submersible) have been optimized to achieve a favorable range of motion to reduce the energy consumed by the 'Dynamic Position System (DPS)'. The presented results allow the designer to select the configuration satisfying the user requirements and integration of Computer Aided Design (CAD) and Computational Fluid Dynamics (CFD). The integration of CAD with CFD computes a hydrodynamically and energy efficient hull form. Our results show that the implementation of the present model results into a design that can serve the user specified requirements with less cost and energy consumption.

However, the reported results in the present paper are at the 'conceptual stage' only and they need to be investigated in detail for see that they are meaningfully application in the design of new offshore structures. Our future works will go in these directions and currently they are under investigation.

Acknowledgements: This research was supported by the internal research grants of IIT Madras through research scheme: OE14M010.

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