DESIGN AND ANALYSIS OF FLOATING RESIDENCE

[1]Emilin Sara Varkey, [2]Fayiz Ameen M M, [3]Sonam G Bose, [4]Syamlal V, [5]Linda Lawrance

[1234]Graduate Student, Dept. of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India.

[5] Professor, Dept. of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

---

Abstract - *Climate change is redefining the rules by which we live and at a pace we never expected. Because of the rising sea level, several areas of the globe are in danger of vanishing from the map, disappearing under water. Society must adapt and maybe, one day, live in floating houses. Depending on their geographical situation, some countries are more advanced than others in their adjustment to the effects of global warming, and particularly the rising level of the seas. Architects and city planners across the world are starting to look beyond the traditional confines of the city, towards building on water as one of the answers to reducing inner-city population density and also developing flood-resilient designs. The objectives of our project were to design a floating residential building moored to soil bed and to analyze the structure using Ansys software.*

Key Words: Floating residential building, Pontoon, Buoyancy, Stability, Mooring lines, Metacentre

1. INTRODUCTION

Floating structures can be defined as those structures which are constructed on water in a way that the total load of the structure is less than or equal to the uplift force of the water which helps the structure to float on water. Floating structures offer several advantages over more permanent structures which might extend from the shore into open water:

- They do not damage the marine eco-systems
- They do not cause silt deposition in deep harbours
- They do not disrupt the ocean currents
- They are easy to construct, since much of the construction is completed onshore
- Installation is rapid
- They are immune to seismic shock

Mooring systems are incorporated which ensures that the structure is kept in position so that the facilities on the floating structure can be reliably operated as well as to prevent the structure from drifting away under critical sea conditions and storms. A freely drifting very large floating structure may lead not only damage to the surrounding facilities but also to the loss of human life if it collides with other floating structures or boats, ships etc. Mooring piles must be designed to adequately and safely resist all lateral loads resulting from the most adverse load combinations which are likely to act on the floatation system and superstructure of the floating building and any vessel attached to the floating building or mooring piles. Pontoon type floating structures are structures that float in the water like vessels and without any fixed attachment to the bed. Basically, just like ships constructed as large platforms. Pontoon type floating structures are most suitable for use in calm waters, often inside a cove or a lagoon and near the shoreline. All materials used in a floating building or any structure associated with a floating building must be suitable for the conditions to which they are exposed. All fastenings used in a floating building or any structure associated with a floating building, must be appropriate for the conditions to which they are exposed taking into account their ability to be maintained or replaced if necessary. The material should be corrosion resistant and should have adequate strength to withstand the loads.

1.1 RELEVANCE

For at least a century, the average global sea level has been rising mostly because global warming is driving thermal expansion of seawater and melting land-based ice sheets and glaciers. The trend is expected to accelerate during the 21st century. The analysis, design and construction of offshore structures is arguably one of the most demanding sets of tasks faced by the engineering profession. Due to the rising sea level, several areas of the globe are in danger of disappearing under water. Society must adapt and maybe, one day, live in floating houses.

1.2 OBJECTIVES

To design a floating residential building using pontoon principle and to analyze the structure using ANSYS software.

1.3 METHODOLOGY

Research on various techniques and materials available for the construction of floating structures.

1. Preparation of residential plan.
2. Calculation of design loads.
3. Design of floating base using pontoon principle with EPS (Expanded Polystyrene).
4. Design of mooring
5. Analysis of the structure using ANSYS software.

2. LITERATURE REVIEW

C.M. Wang and Z.Y. Tay in their paper discussed the applications, research and development of the very large floating structures. They also presented main emphasis on the hydro elastic response, structural integrity and steady drift forces. The technological developments on the mooring systems, anti-motion devices and connector designs of very large floating structures over the past decades were highlighted.
Pirooz Mohazzabi in his paper gives a general idea about the Archimedes principle which is the principle on which our structure floats on water. Basically, the principle states an object immersed in a fluid is buoyed up by a force equal to the weight of the fluid that it displaces.

3. TECHNIQUES ADOPTED

3.1 SUPERSTRUCTURE

We decided to use carbon fibre composite panels, also known as epoxy sandwich panels as the superstructure material, for walls. It is a material having lesser density compared to other building materials, but at the same time, has high strength. The basic advantage is the resistance of the separate panel components to full impact loads. The weight density of the material is 1600 kg per cubic mere.
For roof slab, the material selected was light weight aggregate concrete, with a weight density of 1440 kg per cubic metre. Light weight concrete was selected so that there is no risk for the wall panels to carry roof load.

3.2 FLOATING BASE

Out of the major floatation systems, we opted the technique of concrete EPS system. It consists of a thick core of Expansive Polystyrene (EPS), with a thin concrete layer on top and concrete side walls for stiffness and protection. Eps is a material having 90-95% air but has strength sufficient to carry a building. The weight density of concrete-EPS system is 60-640 kg per cubic metre.

3.2.1 DESIGN BASED PRINCIPLE

The design principle is Buoyancy. The principle of buoyancy can be described with Archimedes principle:
"Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object."
This upward force is called Archimedes force. This force is equal to the weight of the displaced water. This weight is equal to the density of water ρ (kg/m3), times the gravitational acceleration g (m/s2), times the volume of the displaced water V (m3). In formula this gives:

$$F_A = \rho.g.v$$

For a free-floating structure in equilibrium situation, the weight of the floating structure is equal to the Archimedes force.

$$F_A(\text{Archimedes force}) = F_g(\text{gravity force})$$

Stability of a floating Body:
The stability or instability will be determined by whether a righting or overturning moment is developed when the centre of gravity and centre of buoyancy move out of vertical alignment.

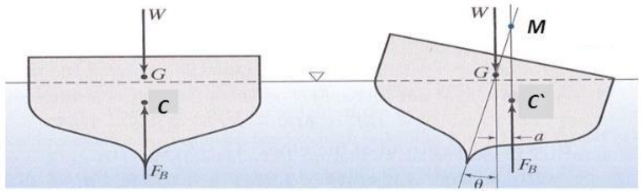


Fig-1: Stability condition

With reference to Fig-1,the vertical line through c` intersects the original centre line at point "M", this point is called Meta Centre. And the distance "MG" is called the Meta Centric Height which is the direct measure of stability.
When "M" is above "G" the floating body is stab

4. BUILDING PLAN

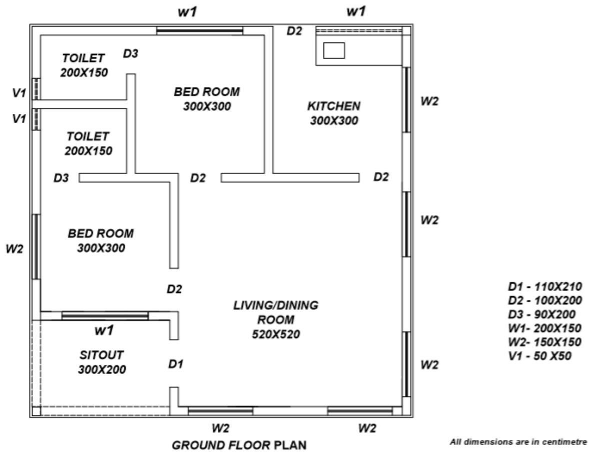


Fig.2: Plan of the building

5. LOAD CALCULATIONS

Table 1: Load Calculation

Sl.no	Item Particulars	Length (m)	Breadth (m)	Height (m)	Quantity (m^3)	Remarks
1.	Total Centre line quantity of the building	61	0.2	3	36.6	61x0.2x3 = 36.6m^3
2.	Roof Slab	9.3	9.1	0.15	12.7	9.3x9.1x0.15 = 12.7m^3

Wall load = 36.6x1600 = 585.6 kN
Self-weight of roof slab = 12.7x1440 = 182.88 kN
With reference to IS code 875(Part 2), 1987, Live load on floor is taken as 2kN/m^2
Therefore, Total live load on floor= 134.48 Kn
With reference to IS code 875(Part 3), 1987
Wind Load = 104.24 kN
Maximum wave load = 5.025 kN

5.1 LOADS DUE TO FLOATING BASE

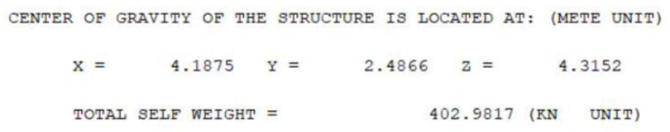
Floating base is constituted by EPS blocks of density 28 kg/m^3 separated using LWA concrete of density 1440 kg/m^3
Dimension of floating base = 12m x 12m
Assumed EPS blocks of size 4'x4'x36" = 1.36m^3
No. of blocks required = 81
Weight of Pontoon = 2223.29 kN
Weight of EPS blocks= 30.27 kN
Total weight of floating base = 2223.29+ 30.27= 2253.56 kN
Reinforcement load from roof slab = 8733.87 N = 8.73 kN
Total load transferred from the superstructure=3019.66kN

Dimensions of floating base:
Density of water = 997 kg/m3 = 9.77 kN/m^3
F = Density x Volume of water
3019.66 = 9.77 x V
V = 3019.66 ÷ 9.77 = 309.07 m^3
V = l x b x d ; d = 309.07 / (12x12) =2.2 m
Therefore, provide a draught of 2.2 m
The minimum free board requirement is 0.6m.Thus provide a free board of 0.6m.
Now the total depth = 2.8 m

6. STABIITY ANALYSIS

6.1 CENTRE OF GRAVITY

Centre of gravity of the super structure was obtained using the software STAAD pro V8i (the base was located on XZ plane).



```
CENTER OF GRAVITY OF THE STRUCTURE IS LOCATED AT: (METE UNIT)

     X =       4.1875   Y =       2.4866   Z =       4.3152

     TOTAL SELF WEIGHT =               402.9817  (KN    UNIT)
```

Fig-3: Output of STAAD

6.2 METACENTRIC HEIGHT

Minimum value of GM is 0.35m
Assuming the angle of disturbance is very small, i.e. less than 10^0

$$BM = {}^{I}/_{V} = \frac{\frac{12 \text{ x } 12\text{\^{}}3}{12}}{12 \text{ x}12 \text{ x } 2.2} = 5.45 \text{ m}$$

$$KG = \frac{(KG1 \text{ x } W1) + (KG2 \text{ x } W2)}{W1 + W2}$$

$$= \frac{(0.3134 \text{ x } 229799.12) + (3.3134 \text{ x } 307919.56)}{229799.12 + 307919.56} = 1.91 \text{ m}$$

$$GM = \frac{2.2}{2} + 5.45 - 1.91 = 4.64\text{m}$$

Metacentric height is obtained as 4.64m from the keel. Therefore the metacentre lies above the centre of gravity and thus the structure is stable.

7. ANALYSIS USING ANSYS

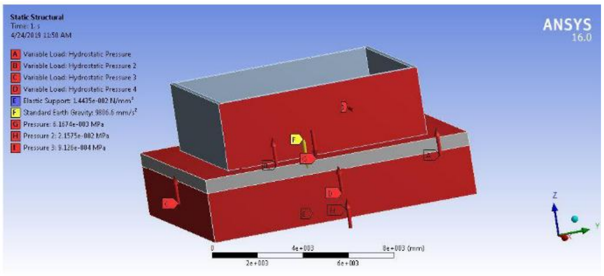


Fig.3: Support Conditions and Loads

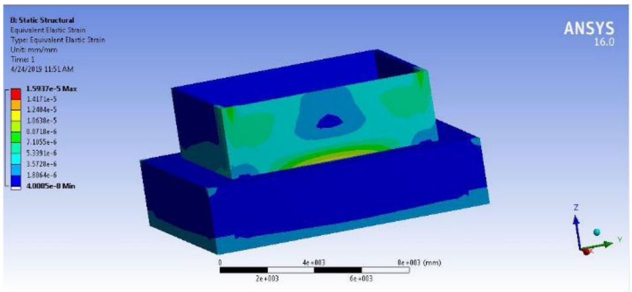


Fig-4: Equivalent Elastic Strain

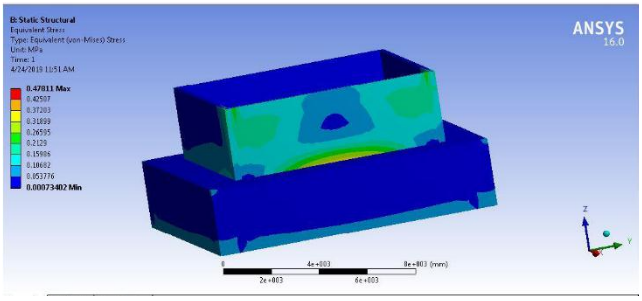


Fig-5: Stress Intensity

8. DESIGN OF MOORING SYSTEM

8.1 CATENARY LINE EQUTIONS

Loading Mechanism:
$F_{environmental} = F_{wave} + F_{wind} + F_{current}$
Suspended line length
$L_s = a \sinh(\frac{x}{a})$ (1)
Vertical Dimension (Depth)
$h = a \{\cosh(\frac{x}{a}) - 1\}$ (2)
Combining the above equations,
$L_s^2 = h^2 + 2ha$ (3)
Where $a = T_H / w$ (4)
Using line tension at the platform, tension at the top is
$T = W \frac{(L_s^2 + h^2)}{2h} = \sqrt{{T_H}^2 + T_z^2}$ (5)
$T_H = T \cos(\theta_w)$ (6)
Maximum tension

$$T_{max} = T_H + wh \quad (7)$$

Combining equations 8.3, 8.4, 8.7
We have the minimum length

$$L_{min} = h\sqrt{2\frac{T_{max}}{wh} - 1} \quad (8)$$

Requirement, $T_{max} \le T_{br}$ (9)
(T_{br} is the tension in mooring line)
Considering the horizontal distance x between the anchors point "A" and the point where the lines are connected to the vessel.

$$X = L - Ls + x \quad (10)$$

$$X = L - h\sqrt{(1 + \frac{2a}{h}} + a\cos^{-1}(1 + \frac{h}{a}\quad) \quad (11)$$

$$X = L - h\sqrt{(1 + \frac{2T_H}{wh})} + \frac{T_H}{w}\cosh^{-1}\left(1 + \frac{wh}{T_H}\right) \quad (12)$$

$$X = \cosh^{-1}(1 + \frac{h}{a}) \quad (13)$$

Ls = suspended line length
h = vertical dimension (depth)
T_H = Horizontal restoring force applied by the mooring lines
T_Z = Vertical component of tension
T_{max} = Maximum tension
T = Tension at the top
W = Weight per unit length of chain/cable in water
L_{min} = Minimum line length
a = Horizontal dimension
Sinh and Cosh are parabolic function
Length of Anchors Chain (L) = 25m
Number of Anchors used = 6 Anchors
Horizontal pretension T_H = 172KN
Weight of Anchor in water (W) = 10kN/m
Height of Water depth (h) = 10m
Length of Work Barge L_p = 12m
Breadth of Work Barge B_p = 12m
Height of Work Barge H_p = 2.2m

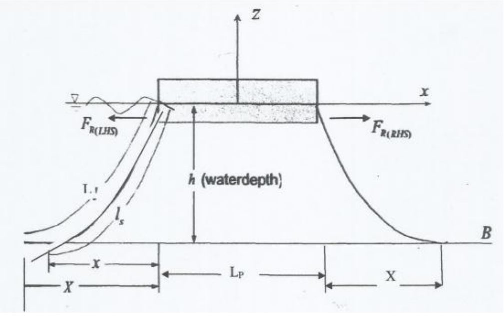


Fig.6 : Catenary Mooring System

Distance between anchor A and B from the geometry of the figure, the distance is ($2x + L_p$) m.
We know,

$$L_s^2 = h^2 + 2ha$$
$$\text{Where } a = T_H / w = 172/10 = 17.2 \text{ m}$$
$$\text{Hence } L_s^2 = 10^2 + (2x10x17.2) = 444$$
$$L_s = 21.07 \text{ m}$$

Calculating the value of x,

$$x = 17.2 \text{ x } \sinh^{-1}(\frac{21.07}{17.2}) = 17.74 \text{ m}$$

Substituting the value of x in the equation,

$$X = L - L_s + x = 25 - 21.07 + 17.74 = 21.13 \text{ m}$$

Therefore the distance between anchor A and B is :

$$2X + L_s = 2x21.13 + 21.07 = 57.26\text{m}$$

Tension at top = 271.98 kN
Maximum tension T_{max} =172 + (10x10) = 272 kN/m

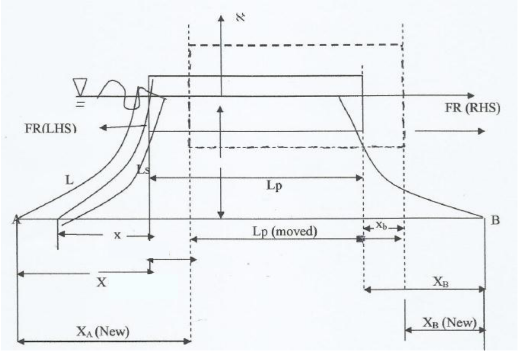


Fig.7: Mooring cable design

From the geometry of the figure below, X_A representing increase in X_A due to movement as a result of environmental RHS force. X_B; Decrease in X_B due to movement of platform in response to RHS environmental force to pull anchor A. The environmental force on the platform to move anchor A is a right hand side pulling force FR (RHS); movement of the platform stretches the touchdown point until the length of the anchor line is fully extended at anchor A.
New a = 26.25m, and new T_H = aW = 10 x 26.25 = 262.5 m

New Xa due to movement is,

$$x = a\sinh^{-1}\frac{L_s}{a}$$

$$x = 26.25 \text{ x } \sinh^{-1}\frac{25}{26.25} = 22.24\text{m}$$

Hence the platform is moved by a distance,

22.24 – 21.67 = 0.57m

This is also the movement of the fair lead point on the platform at anchor A.

At the initial pretension T_H of 262.5kN, X = 0.57m

This movement caused a reduction in X_B by

21.67 – 0.57 = 21.09m

After a number of trials, the exact THb is obtained,

T_{Hb} =115kN L_s =18.16m

x corresponding to 115 kN = 14.23m

The Environmental force on the platform to move anchor A = (262.5-115) kN = 147.5 kN

Hence the design is safe for carrying the force acting over the mooring system as well as floatation system.

9. CONCLUSION AND FUTURE SCOPE

By 2030, 60% of the world's population will be living in the cities. This is going to put a huge strain on the world's existing metropolises and they will have climate change to deal with too-about 90% of the largest cities are situated on the waterfront and are vulnerable to rising sea levels. To cope up with these changes engineers, researchers and technologists say we should reconsider how we build cities. It is time to do something totally different instead of building on land, let's make them float.

Taking all the aspects of feasibility and stability into concern we have come up with a simple residential structure using the most modern techniques in the floating building design. Thus floating residence can be considered as an effective alternative to the conventional houses.

10. ACKNOWLEDGEMENT

First and foremost, we sincerely thank the 'God Almighty' for his grace for the successful and timely completion of the project. We express our gratitude and thanks to Dr. Solly George, our Principal and Dr. Binoy Alias, Head of the Department, Civil Engineering, for providing facilities and all the encouragement and support. With great respect, we express our sincere thanks to our project guide Prof. Linda Lawrence and the staff in charge of the project, Prof. Alice Mathai the project coordinator for their valuable guidance, support and encouragement throughout this humble endeavour. We owe a debt of gratitude to all the staff of Civil Engineering Department, who has directly or indirectly helped our project team with the work. Finally, we would like to acknowledge the heartfelt efforts, comments, criticisms, cooperation and tremendous support given by our friends, seniors and family during the preparation and presentation of the project, without whose support this work would have been all the more difficult to accomplish.

11. REFERENCES

1. C.M. Wang and Z.Y. Tay / Procedia Engineering 14 (2011), 'Very Large Floating Structures: Applications, Research and Development'.

2. Appendix on 'Releasing a floating city'; by K.K.M. Ko.

3. Pirooz Mohazzabi / Department of Mathematics and Physics, University of Wisconsin-Parkside, Kenosha, WI, USA

4. Bureau of Indian Standards, "Code of Practice for Design Loads (other than earthquake) for buildings and structures, part 3: Wind loads", IS 875(Part 3), New Delhi, India, 1987

5. Bureau of Indian Standards, "Code of Practice for Design Loads (other than earthquake) for buildings and structures, part 2: Wind loads", IS 875(Part 2), New Delhi, India, 1987

6. Inegiyemiema M, Nitonye S, Dick I.F and Erekosima A (2014)'Design of Mooring System for offshore structures'

7. A.Ambica and K. Venkatraman, 'Design on Hydrophilic Floating House for Fluctuating Water Level'

8. Yuan Zhuang, Yang Li,Wei Su, (2016) 'Influence of anchoring on burial depth of submarine pipelines'

9. 'Ádvanced anchoring and mooring study', Oregon Wave Energy Trust(2009)