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Innovative Floating Foundation System Using EPS-based Low-density Concrete Pontoons for Amphibious Infrastructure: A Construction Management Approach

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Abstract

Background: *The growing demand for amphibious infrastructure has led to the need for lightweight, cost-effective, and sustainable construction solutions. This study proposes an innovative floating foundation system that utilises low-density concrete pontoons made from Expanded Polystyrene (EPS). The research focuses on various aspects of construction management, including modular construction, cost optimisation, scheduling efficiency, and sustainability. The proposed system significantly reduces structural weight while preserving load-bearing capacity. Its modular design enhances constructability and shortens project duration. The findings suggest that this system is a viable alternative for large-scale marine infrastructure, such as floating airports. The growth of offshore and amphibious infrastructure has led to a greater need for structurally efficient and buoyant foundation systems. Traditional floating platforms made from dense reinforced concrete or steel tend to be heavy, which reduces buoyancy efficiency and raises construction costs.* ***Aim:*** *This study introduces a new floating foundation system that utilises low-density concrete pontoon modules, which include hollow reinforced concrete units filled with Expanded Polystyrene (EPS). The goal of this concept is to reduce the overall density while maintaining the structural strength necessary to support heavy infrastructure loads, such as airport runways and terminal facilities.* ***Method:*** *The proposed system utilises modular cube-shaped pontoons with EPS cores to enhance buoyancy and improve resilience against water ingress. Stability is achieved through a controlled anchoring mechanism connected to the seabed, allowing vertical adaptability to tidal variations.* ***Findings:*** *The findings indicate that the integration of EPS within hollow concrete modules significantly enhances buoyancy without compromising load-bearing capacity. The system demonstrates potential as a sustainable and scalable solution for floating infrastructure applications. Conclusion: This study introduces an innovative method for designing floating foundations using low-density concrete pontoons filled with EPS hollow modules.*

Keywords: *Amphibious Infrastructure, Buoyant Structures, Floating Foundation, Low-density Concrete, Marine Engineering, Pontoon System, Expanded Polystyrene (EPS)*

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1.0 Introduction

The growing scarcity of land in coastal and urban areas has prompted the exploration of alternative construction methods in marine environments. As a result, floating infrastructure has emerged as a viable solution to address issues related to land shortages, environmental constraints, and urban expansion[1].

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Amphibious structures, such as floating airports, require foundation systems that can support significant loads while maintaining stability under varying environmental conditions. Traditional pontoon systems, while effective, are often criticised for their high material consumption, increased weight, and concerns about long-term durability in harsh marine environments[2,3].

To overcome these challenges, this study presents an innovative concept involving low-density concrete pontoons constructed from EPS-filled hollow modules. The aim is to develop a lightweight yet structurally sound system that enhances buoyancy and improves adaptability to dynamic water conditions.

2. Literature Review

Research on floating infrastructure has mainly concentrated on steel-based pontoons and solid concrete caisson structures. Large-scale experimental projects have proven the feasibility of floating runways and marine platforms under various environmental loading conditions.

At the same time, advancements in lightweight concrete technology have facilitated the creation of materials with reduced density, achieved through the incorporation of voids, lightweight aggregates, and polymer-based fillers. Expanded Polystyrene (EPS) has been extensively studied due to its low density, resistance to water absorption, and durability in construction applications.

However, the integration of EPS within structural concrete modules designed for heavy-load floating applications remains relatively unexplored. This study aims to address this gap by combining material innovation with structural design to develop an efficient floating foundation system.

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3. Materials and Methods

The research follows a conceptual and analytical approach comprising the following stages.

3.1 Modular Construction Strategy

(i) Prefabricated pontoon modules

(ii) Reduced on-site construction time

(iii) Improved quality control

3.2 Material Innovation (EPS Integration)

(i) Reduction in density

(ii) Improved buoyancy

(iii) Enhanced durability

3.3 Project Planning and Scheduling

(i) Parallel construction activities

(ii) Reduced critical path duration

(iii) Faster project delivery

3.4 Cost Optimisation

(i) Reduced material consumption

(ii) Lower transportation costs

(iii) Efficient resource utilisation

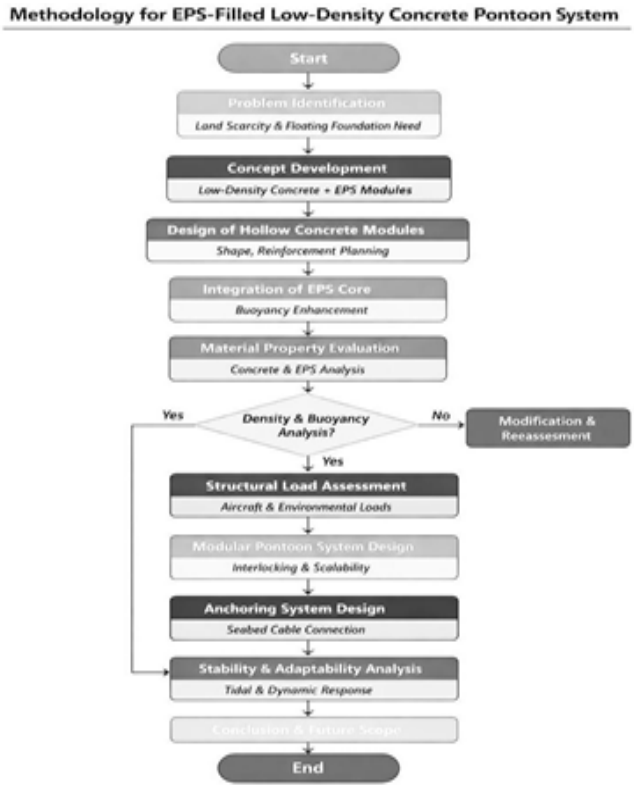


Figure 1. Methodology for EPS filed low density concerate pantoon system.

Source: A custom-created conceptual flowchart, made using the tools of Microsoft PowerPoint.

4. Structural Configuration of Pontoon Modules

4.1 Hollow Concrete Module Design

The proposed floating foundation system is based on the design of modular hollow concrete cubes that function as primary buoyant units. These modules are engineered to achieve an optimal balance between structural strength and reduced self-weight, which is critical for floating infrastructure applications. Each module consists of a reinforced concrete outer shell, which acts as the main load-bearing component. This outer shell is designed to withstand various structural loads, including dead loads from the superstructure, live loads such as aircraft movement, and environmental forces like wave action and wind pressure. The use of reinforced concrete ensures durability, structural integrity, and resistance to harsh marine conditions[2,3]. Inside the module, an internal hollow cavity is incorporated to significantly reduce the overall density of the unit. This cavity plays a crucial role in enhancing buoyancy by lowering the weight-to-volume ratio of the structure. In addition, the cavity can be partially or fully filled with lightweight materials such as Expanded Polystyrene (EPS), which further improves flotation stability and provides redundancy against water ingress.

Furthermore, the modules are designed with interlocking edges, enabling efficient modular assembly. This interlocking mechanism ensures proper alignment, load distribution, and structural continuity between adjacent units. It also facilitates ease of construction, transportation, and scalability, allowing the floating platform to be expanded or reconfigured based on project requirements. Overall, the hollow concrete module design contributes to improved constructability, enhanced buoyancy performance, and structural reliability, making it a suitable solution for large-scale amphibious infrastructure such as a floating airport.

4.2 Integration of EPS Core

Expanded Polystyrene (EPS) is incorporated within the hollow cavity of the concrete module to significantly reduce its effective density. The inclusion of EPS plays a crucial role in enhancing the buoyancy characteristics of the floating structure. By lowering the overall unit weight, EPS allows the module to displace more water relative to its mass, thereby improving flotation efficiency. Additionally, EPS is highly resistant to water absorption, which makes it suitable for long-term marine applications. This property ensures that the internal structure remains stable and does not degrade due to moisture ingress.

Another important advantage of EPS is its ability to enhance safety by preventing sudden loss of buoyancy. Even if the outer concrete shell develops cracks or minor leakage, the EPS core continues to provide flotation support. This redundancy improves the reliability and resilience of the floating system under extreme conditions. Furthermore, EPS contributes to impact resistance by absorbing energy from external forces such as wave action. The interaction between the rigid concrete shell and the lightweight EPS core creates a composite system with improved performance characteristics. Overall, this composite action enhances the structural efficiency, durability, and serviceability of the floating module under operational conditions.

4.3 Buoyancy Performance

The floating behaviour of the pontoon module is primarily determined by its average density in comparison to the density of water. For a structure to float, its overall density must be lower than that of water, allowing it to displace a sufficient volume of water to support its weight. The incorporation of Expanded Polystyrene (EPS) within the hollow concrete module significantly reduces the effective density of the system, thereby ensuring positive buoyancy and stable flotation.

In addition, the design is developed to maintain adequate reserve buoyancy, which refers to the extra buoyant capacity available beyond the minimum required to support the structural and operational loads. This reserve buoyancy ensures that the system remains stable even under high loading conditions such as aircraft loads, equipment weight, and environmental forces. Consequently, it enhances the reliability, safety, and operational performance of the floating infrastructure.

4.4 Integration of EPS Core

Expanded Polystyrene (EPS) enhances buoyancy and reduces structural weight. Its resistance to water absorption improves durability in marine conditions.

4.5 Buoyancy Performance

The floating behaviour of the pontoon module is governed by Archimedes' principle and material density relationships. Reserve buoyancy ensures stability under operational loads such as aircraft and environmental forces.

5. Anchoring and Adaptive Stability Mechanism

The stability of the floating platform is ensured through a seabed anchoring system consisting of high-strength cables or tendons.

Key Functional Aspects:

(i) Anchors provide resistance against lateral displacement.

(ii) Flexible cables allow controlled vertical movement.

(iii) The platform adapts to tidal fluctuations without structural distress.

This adaptive mechanism is essential for maintaining operational stability in amphibious applications. The stability of the floating platform is maintained through a seabed anchoring system using high-strength cables or tendons. These anchors provide resistance against lateral movements caused by waves, currents, and wind forces, thereby ensuring positional stability. At the same time, the flexible cable system allows controlled vertical movement, enabling the platform to rise and fall with tidal variations.

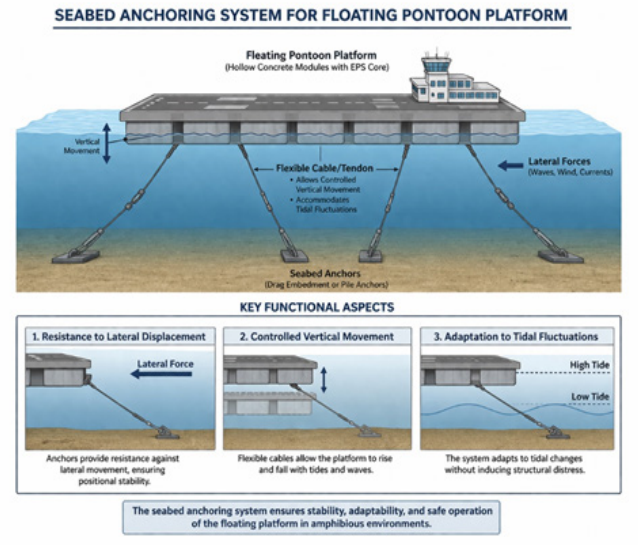


Figure 2. Seabed anchoring system for floating pontoon platform.

Source: Conceptual diagram developed by the scholar.

This adaptability prevents the development of excessive stress within the structure. As a result, the anchoring mechanism ensures continuous operational stability.

6. Load Transfer and Structural Performance

The proposed pontoon system is designed to support significant structural loads, including:

(i) Aircraft loads and runway stresses

(ii) Building loads from terminal infrastructure

(iii) Dynamic environmental forces such as waves and wind

Load transfer is achieved through:

(i) Reinforced concrete shell action

(ii) Distribution across interconnected modules

(iii) Redundancy provided by modular configuration

This system ensures adequate structural performance while maintaining reduced self-weight.

The proposed pontoon system is engineered to efficiently support and transfer significant structural loads associated with floating infrastructure. These include heavy aircraft loads and runway stresses, structural loads from terminal buildings, and dynamic environmental forces such as waves and wind. The load transfer mechanism primarily relies on the reinforced concrete outer shell, which provides the necessary strength and rigidity to resist these forces.

Additionally, loads are effectively distributed across interconnected modular units, ensuring uniform stress distribution and preventing localised failure. The modular configuration also introduces redundancy, allowing the system to maintain structural integrity even if individual units experience damage or overload. This integrated load transfer approach enhances the overall stability, safety, and performance of the floating structure under operational conditions.

7. Advantages of the Proposed System

7.1 Structural Efficiency

(i) Enhanced buoyancy due to reduced density.

(ii) High-strength-to-weight ratio.

(iii) Modular and scalable configuration.

The proposed floating pontoon system demonstrates high structural efficiency due to its optimised material composition and design configuration. The incorporation of lightweight materials such as Expanded Polystyrene (EPS) reduces the overall density of the modules, thereby enhancing buoyancy and enabling the structure to support greater loads while remaining afloat. This reduction in self-weight directly improves the flotation performance and operational stability of the system.

Additionally, the design achieves a high strength-to-weight ratio, as the reinforced concrete outer shell provides the necessary structural strength while the internal lightweight core minimises mass. This balance ensures that the system can withstand significant structural and environmental loads without unnecessary material usage.

Furthermore, the modular nature of the system allows for a scalable configuration, where individual pontoon units can be interconnected to form larger platforms based on project requirements. This modularity not only simplifies construction and transportation but also enhances flexibility in design, enabling phased development and easy expansion of the floating infrastructure. Overall, these factors collectively contribute to improved efficiency, adaptability, and performance of the proposed system. Reduced material usage and modular construction lower overall project cost. Efficient logistics and prefabrication reduce construction time and expenses[5,6].

7.2 Economic Feasibility

(i) Reduced material usage.

(ii) Lower transportation and installation costs.

(iii) Simplified construction methodology.

The proposed floating pontoon system is economically feasible due to its efficient use of materials and streamlined construction approach. The integration of lightweight components such as EPS significantly reduces the quantity of conventional concrete required, leading to lower material costs. Additionally, the reduced weight of the modules minimises transportation and handling expenses, as lighter units are easier to move and install. The modular design further simplifies the construction methodology by enabling prefabrication and quick

assembly on-site, which reduces labour requirements and project duration. Overall, these factors contribute to cost savings and improved financial viability of the system.

7.3 Environmental Sustainability

(i) Elimination of land reclamation

(ii) Reduced ecological disturbance

(iii) Lower carbon footprint compared to conventional systems.

The proposed floating pontoon system promotes environmental sustainability by minimising the need for traditional land-based construction methods. By eliminating land reclamation, it avoids significant alterations to coastal and marine ecosystems. The modular floating design reduces ecological disturbance, as it requires less excavation and preserves natural habitats. Additionally, the use of lightweight materials and efficient construction processes contributes to a lower carbon footprint compared to conventional infrastructure systems. Overall, the system supports sustainable development while reducing environmental impact. Floating infrastructure reduces the need for land reclamation and environmental disruption. Sustainable construction practices contribute to lower carbon emissions[7].

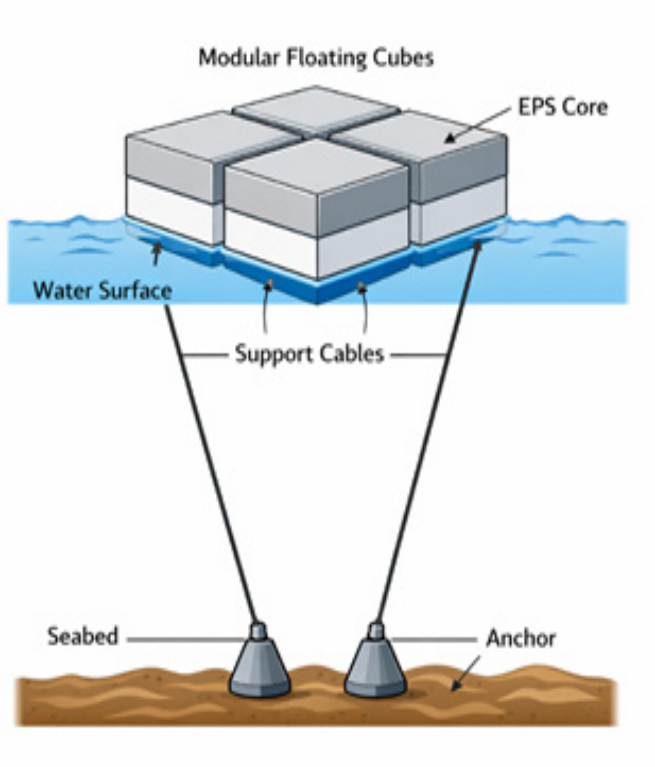


Figure 3. Conceptual floating pontoon system.
Source: Author Creation.

8. Result and Discussion

The proposed concept demonstrates a significant improvement over traditional floating systems in terms of buoyancy efficiency and adaptability. The inclusion of EPS within hollow concrete modules provides an effective solution for reducing density while maintaining structural integrity.

The modular nature of the system enhances flexibility in design and construction, allowing phased development and easy maintenance. Additionally, the anchoring mechanism ensures stability under varying environmental conditions, making the system suitable for large-scale marine infrastructure[7].

Table 1. Comparison of the conventional vs the proposed system

Parameter	Conventional System	EPS-Based System
Structural Weight	High	Low
Construction Time	Long	Reduced
Cost	High	Moderate
Sustainability	Low	High
Flexibility	Limited	High

Source: Author self-creation through analysis.

Although the concept shows strong potential, further experimental validation and numerical modelling are required to assess long-term performance and durability.

9. Conclusion

This study introduces an innovative approach to the design of floating foundations using low-density concrete pontoons combined with EPS-filled hollow modules. This system effectively overcomes the limitations of traditional floating structures by enhancing buoyancy, reducing overall weight, and preserving structural integrity.

By integrating modular construction with adaptive anchoring mechanisms, this design significantly improves the feasibility of the system for use in amphibious infrastructure applications. The proposed concept represents a promising direction for developing sustainable and resilient floating construction technologies.

10. Future Scope

Future research should concentrate on the following areas:

(i) Testing and validating prototypes

(ii) Conducting lifecycle cost analysis

(iii) Developing risk assessment models

(iv) Integrating Building Information Modelling (BIM) for project management

(v) Experimentally testing prototype modules

(vi) Analysing hydrodynamic interactions and wave behaviour

(vii) Assessing long-term durability in marine environments[8]

(viii) Optimising the bonding behaviour between EPS and concrete

(ix) Implementing findings in real-world pilot projects

Future research should concentrate on validating the proposed floating pontoon system by developing prototypes and conducting experimental tests to ensure its practical feasibility. A detailed lifecycle cost analysis is necessary to assess the long-term economic benefits and operational efficiency. Furthermore, creating risk assessment models will assist in identifying and mitigating the structural and environmental uncertainties linked to marine infrastructure.

Integrating Building Information Modelling (BIM) can significantly improve project planning, coordination, and management efficiency. Advanced research into hydrodynamic behaviour and wave interactions is essential for understanding how the system responds under actual sea conditions. Additionally, conducting long-term durability assessments in aggressive marine environments is necessary to ensure the structural reliability of the system. Furthermore, optimising the bonding behaviour between expanded polystyrene (EPS) and concrete will enhance the performance of the composite. Finally, implementing this system through real-world pilot projects will provide practical insights and facilitate the large-scale adoption of the proposed approach[9].

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