

A Buoyancy-Based Feasibility Framework for Amphibious Housing in Indian Riverine Floodplains: A First-Principles Design and Material-Sensitivity Analysis

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ABSTRACT

Riverine flooding is among the most frequent and damaging natural hazards in India, and conventional responses based on permanent elevation or post-flood reconstruction impose recurring costs on low-income households. Amphibious construction, in which a dwelling rests on the ground in dry conditions and floats on rising floodwater, offers an adaptive alternative, yet quantitative feasibility evidence calibrated to Indian design standards and affordable-housing norms remains scarce. This study develops a transparent, first-principles buoyancy framework for a representative single-storey amphibious dwelling sized to the Pradhan Mantri Awas Yojana minimum dwelling envelope (a 3.5 m by 6 m plan, 21 m²). Using material unit weights and imposed loads drawn from the relevant Indian Standards, a load take-down, an Archimedes buoyancy and freeboard analysis, an expanded-polystyrene reserve-buoyancy calculation, and a guide-pile hydrodynamic check were carried out for three superstructure options: reinforced concrete, fibre-cement panel, and bamboo or treated-timber walls. The analysis shows that a shallow 0.6 m pontoon is structurally inadequate in every case, producing negative freeboard and a factor of buoyancy below unity (0.31 to 0.55). Superstructure mass emerges as the dominant design lever: a reinforced-concrete superstructure requires a pontoon depth of about 2.69 m to achieve a 0.3 m freeboard, whereas lightweight bamboo or fibre-cement walls reduce this requirement to roughly 1.6 m and lower total weight by more than 40 per cent. Guide piles govern only at flood-current velocities above approximately 2.6 to 3.6 m/s, confirming that the concept is best suited to low-velocity overtopping floodplains rather than fast-flowing channels. The framework provides a reproducible pre-design envelope for practitioners and aligns with United Nations Sustainable Development Goals 9, 11 and 13. All computations are derived from secondary standards data; no laboratory experimentation is claimed.

Keywords- amphibious architecture; buoyant foundation; flood resilience; affordable housing; freeboard; sustainable construction; SDG 11.

I. INTRODUCTION

Flooding is the most pervasive natural hazard in India, recurring annually across a wide range of geographies from the Himalayan foothills to the deltaic plains of the east. Recent basin-scale assessments identify the Ganga and Brahmaputra systems as carrying the highest flood risk in the country, a consequence of their combined hazard probability, exposure and social vulnerability [1]. The same river systems support extremely dense rural and peri-urban populations, so the people most exposed to inundation are frequently those least able to absorb its financial consequences [5]. Climate projections for these basins indicate intensifying precipitation extremes and shifting flow regimes, which are expected to increase both the frequency and the severity of damaging floods over the coming decades [6,13]. The dominant engineering responses to this hazard fall into two broad categories. The first is permanent elevation, in which a dwelling is raised on stilts or a plinth above an estimated flood level; the second is resistance, in which barriers and drainage attempt to keep water away from the building. Both approaches are capital-intensive, and elevation in particular disrupts the everyday relationship between a household and the ground on which it lives. Where flood depths exceed the design elevation, the structure is inundated

regardless, and the household faces the familiar cycle of damage and reconstruction [2]. For economically weaker households, this cycle is a recurring shock rather than a one-time loss. Amphibious construction offers a third path. An amphibious building rests on the ground under normal conditions and floats on the surface of rising floodwater, returning to its original position as the water recedes [27]. The approach was pioneered for flood-prone communities in the Netherlands and subsequently adapted for low-income and heritage contexts in North America, the Caribbean and South Asia [2,3]. A buoyant foundation comprises three functional elements: buoyancy units that displace water and provide flotation, vertical guidance posts that constrain horizontal movement while permitting vertical rise, and a structural sub-frame that ties the assembly to the superstructure [27]. Because the building moves with the water rather than against it, freeboard is maintained automatically and the structure is not subjected to the hydrostatic loads that damage a fixed building during inundation.

Despite a growing international literature, the Indian context remains under-served. Most documented amphibious projects are situated in the Netherlands, the United States or Bangladesh, and the affordable LIFT House prototype in Dhaka remains one of the few South Asian examples developed in detail [28]. Crucially, the published evidence is largely descriptive: case studies and conceptual designs are common, but quantitative feasibility envelopes calibrated to a specific national code framework and affordable-housing standard are rare. A practitioner in India seeking to size an amphibious dwelling has little guidance on the pontoon depth, buoyancy reserve or guide-pile capacity that would be required for a dwelling built to the Pradhan Mantri Awas Yojana minimum standard [26]. This study addresses that gap. Its objective is to establish a transparent, reproducible buoyancy framework for a representative Indian amphibious dwelling, computed entirely from published material properties and the imposed-load provisions of the Indian Standards [14,15]. The framework is deliberately first-principles: every result follows from Archimedes' principle, a code-based load take-down and elementary hydrodynamics, so that a practitioner can reproduce and adapt each step. The novelty of the work lies not in a new structural concept but in the quantified, code-anchored design envelope it provides for the Indian floodplain context, and in its explicit treatment of superstructure material as the governing design variable. The analysis is framed honestly as a desk-based feasibility study using secondary data; no physical prototype is built or tested.

II. MATERIALS AND METHODS

2.1 Design unit and analysis pipeline

The representative dwelling is a single-storey unit with a rectangular plan of 6.0 m by 3.5 m, giving a footprint of 21 m². These dimensions correspond to the minimum dwelling envelope encouraged under the Pradhan Mantri Awas Yojana affordable-housing mission [26] and are consistent with the dimensions sketched in the originating design study on which this work builds. A clear storey height of 3.0 m is assumed. The buoyant base is modelled as a hollow reinforced-concrete pontoon spanning the full footprint, which doubles as the raft foundation and the flotation hull. Four 300 mm reinforced-concrete guide piles, one at each corner, provide vertical guidance and lateral restraint, following the standard three-element configuration of buoyant foundations [27]. The complete analysis pipeline is shown in Fig. 1.

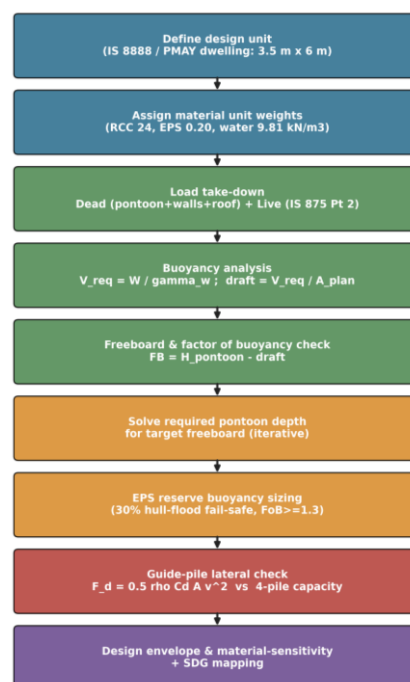


Fig. 1. Analysis pipeline.

The physical configuration analysed is shown in Fig. 2. The dwelling rests on a buoyant reinforced-concrete pontoon containing sealed air chambers, separated from the reinforced-concrete bottom slab by a water gap and a 0.65 m sandbox damping layer that provides seismic energy dissipation. Hydraulic suspension units and dampers connect the pontoon to the lightweight superstructure, and corner guide piles driven 13 to 15 m deep constrain horizontal movement while permitting vertical rise. This configuration follows the design concept developed in the originating study and embodies the three-element buoyant-foundation principle of buoyancy units, vertical guidance and a structural sub-frame [27].

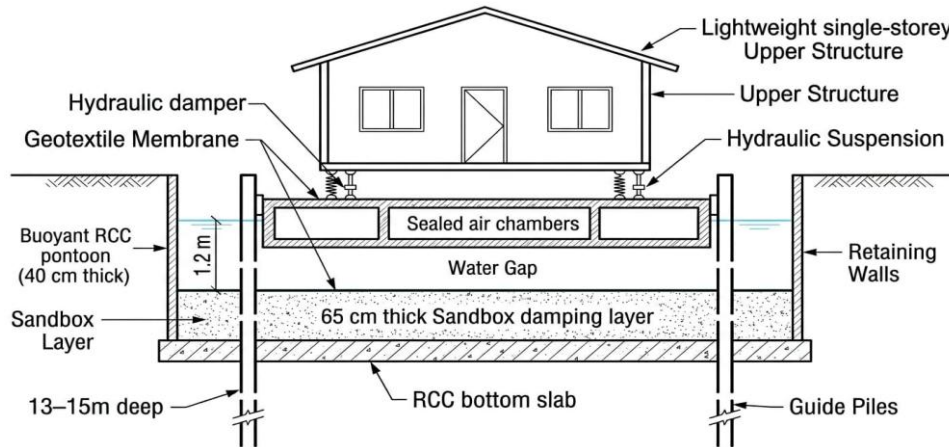


Fig. 2. Amphibious housing system (schematic section).

All material unit weights and imposed loads were taken from published standards and material specifications, summarised in Table 1. The unit weight of reinforced concrete was taken as 24.0 kN/m^3 in accordance with IS 875 Part 1 [14]. Expanded polystyrene, used as reserve-buoyancy fill, was assigned a unit weight of 0.20 kN/m^3 , corresponding to a density of about 20 kg/m^3 within the range specified by IS 4671 [19]. Fresh water was taken as 9.81 kN/m^3 , a conservative value given that silt-laden floodwater is slightly denser. Imposed floor and roof loads followed IS 875 Part 2 [15], which specifies a minimum uniformly distributed live load of 2.0 kN/m^2 for residential floors and 1.5 kN/m^2 for accessible flat roofs.

Table 1. Input parameters and sources.

Parameter	Symbol	Value	Source
Plan length	L	6.0 m	Design unit [26]
Plan breadth	B	3.5 m	Design unit [26]
Footprint area	A	21.0 m^2	Computed
Storey height	H	3.0 m	Assumed (residential)
RCC unit weight	γ_{rcc}	24.0 kN/m^3	IS 875 Pt 1 [14]
Water unit weight	γ_{w}	9.81 kN/m^3	Standard
EPS unit weight	γ_{eps}	0.20 kN/m^3	IS 4671 [19]
Floor live load	qf	2.0 kN/m^2	IS 875 Pt 2 [15]
Roof live load	qr	1.5 kN/m^2	IS 875 Pt 2 [15]
Drag coefficient	Cd	1.2	Bluff body (conservative)

2.2 Load take-down and buoyancy analysis

The total weight W of the floating unit is the sum of all dead loads and the imposed loads acting at the time of flotation. The pontoon self-weight comprises a 0.15 m base slab and 0.10 m perimeter walls of depth equal to the pontoon hull, giving a base contribution of about 103.0 kN (75.6 kN slab and 27.4 kN perimeter walls). The superstructure dead load depends on the wall material and is computed as the external wall area multiplied by the wall thickness and the material unit weight, with no deduction for openings so as to remain conservative. The roof dead load was taken as 0.75 kN/m^2 , representative of a light roofing system. Imposed loads were applied to both the floor and the roof in accordance with IS 875 Part 2 [15]. Three superstructure options were evaluated: reinforced concrete (0.15 m walls), fibre-cement panel (0.05 m walls) and bamboo or treated timber (a lightweight composite wall), bracketing the practical range from heavy to light construction. Flotation is governed by Archimedes' principle. The displaced water volume required for the unit to just float is $V_{\text{req}} = W / \gamma_{\text{w}}$. Assuming a prismatic pontoon of constant plan area, the draft d is V_{req} / A , and the available freeboard is the pontoon depth less the draft. The factor of buoyancy is defined as the maximum displacement available at full pontoon

immersion divided by the total weight; a value above unity is necessary for flotation, and a value of at least 1.3 is adopted here as a reserve target. Because the draft for a given unit is fixed by its weight, the minimum flood depth required to initiate flotation equals the draft, and the freeboard once floating is independent of further rise in water level. Where the hull alone provides insufficient displacement, expanded-polystyrene blocks supply reserve buoyancy. The net buoyancy per unit volume of EPS is $(\gamma_w - \gamma_{eps})$. The reserve volume was sized so that a target factor of buoyancy of 1.3 is retained even if 30 per cent of the hull is assumed flooded, providing a fail-safe against partial hull breach. Finally, the pontoon depth required to deliver a 0.3 m design freeboard was solved iteratively, because deepening the pontoon increases its self-weight and therefore the displacement it must provide.

2.3 Guide-pile lateral check

The lateral hydrodynamic force on the floating unit was estimated as $F_d = \frac{1}{2} \rho C_d A_{proj} v^2$, where ρ is the water density, C_d a drag coefficient of 1.2 representative of a flat-ended box, A_{proj} the submerged frontal area taken against the longer face for the worst case, and v the flood-current velocity. The force was distributed equally among the four guide piles and compared with a conservative allowable lateral capacity of 15 kN per 300 mm pile embedded in medium-dense sand. The current velocity at which the per-pile demand equals the allowable capacity defines the upper bound of the concept’s safe operating range. Velocities from 0.5 to 2.0 m/s were examined, spanning typical riverine overtopping conditions. All computations were implemented in Python; the resulting design dataset is provided as a supplementary CSV file.

III. RESULTS AND DISCUSSION

3.1 Load take-down and buoyancy

The computed load take-down is shown in Table 2 and Fig. 3. Total weight ranges from 224.1 kN for the bamboo or timber superstructure to 397.4 kN for the reinforced-concrete superstructure, a difference of 173.3 kN or 77 per cent. The pontoon self-weight (103.0 kN) and the imposed load (73.5 kN) are common to all three options; the entire spread arises from the superstructure walls, which contribute 205.2 kN in the reinforced-concrete case but only 31.9 kN in the bamboo case. This single result establishes the central finding of the study: for a floating dwelling, the choice of wall material is not a finishing decision but the dominant determinant of the buoyancy demand the foundation must satisfy.

Table 2. Load take-down by wall type.

Component	RCC walls	Fibre-cement	Bamboo/timber
Pontoon self-weight (kN)	103.0	103.0	103.0
Superstructure walls (kN)	205.2	42.8	31.9
Roof dead load (kN)	15.8	15.8	15.8
Dead load subtotal (kN)	323.9	161.5	150.6
Live load (kN)	73.5	73.5	73.5
Total weight W (kN)	397.4	235.0	224.1

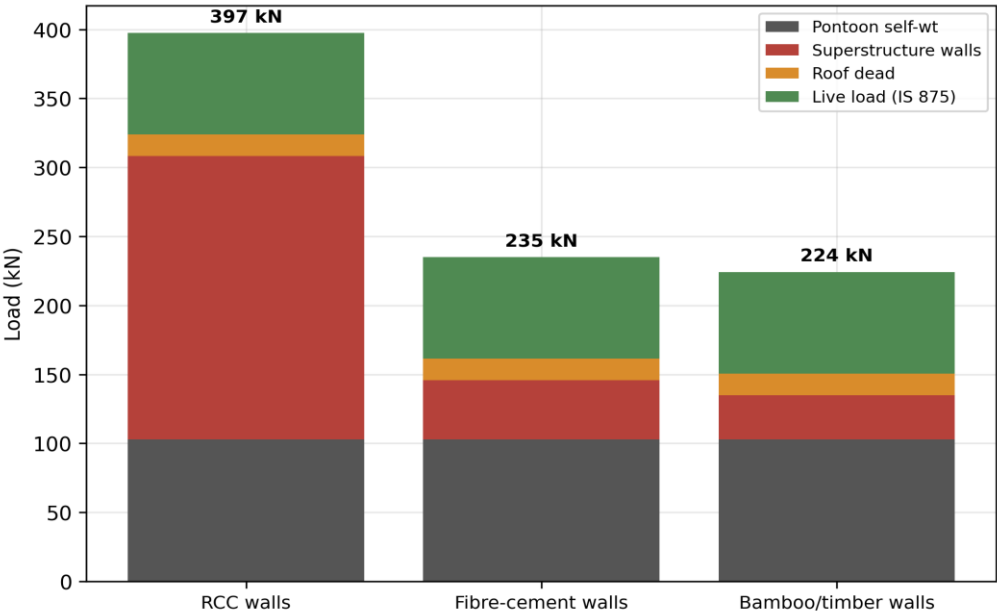


Fig. 3. Load take-down by wall type.

A naive design with a 0.6 m pontoon fails to float in every case. Table 3 and Fig. 4 report the required displaced volume and the resulting draft. For the reinforced-concrete option, the required displacement of 40.5 m³ implies a draft of 1.93 m, more than three times the 0.6 m hull depth, and a factor of buoyancy of only 0.31. Even the lightest bamboo option requires a 1.09 m draft against a 0.6 m hull, with a factor of buoyancy of 0.55. In physical terms, a 0.6 m pontoon would be fully submerged and continue to sink; it cannot displace enough water to support the dwelling. This is an important and easily overlooked result, because a 0.6 m base appears generous against the everyday intuition of a raft foundation, yet it is wholly inadequate for flotation.

Table 3. Buoyancy results, 0.6 m pontoon.

Quantity	RCC walls	Fibre-cement	Bamboo/timber
Total weight W (kN)	397.4	235.0	224.1
Required displacement (m ³)	40.5	23.9	22.9
Draft at 0.6 m pontoon (m)	1.93	1.14	1.09
Factor of buoyancy at 0.6 m	0.31	0.53	0.55
Floats at 0.6 m?	No	No	No

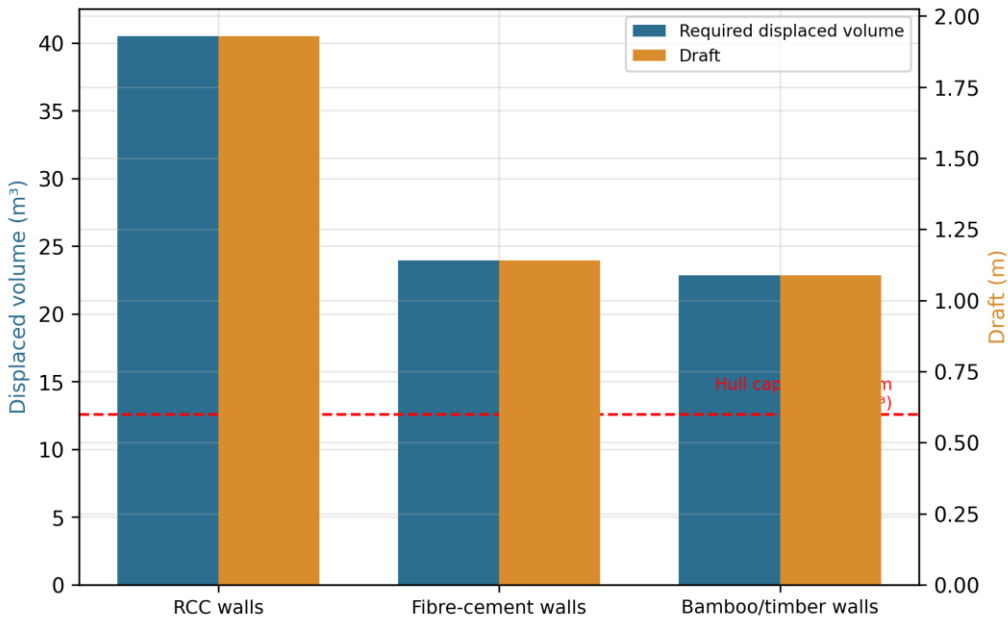


Fig. 4. Required volume and draft vs. wall type.

3.2 Pontoon depth, freeboard and reserve buoyancy

Sizing the pontoon for a 0.3 m design freeboard transforms the picture and quantifies the value of lightweight construction. Table 4 and Fig. 5 report the iterated solution. The reinforced-concrete dwelling requires a pontoon 2.69 m deep, an impractical and material-intensive hull that approaches the storey height of the dwelling itself. The fibre-cement and bamboo options require only 1.68 m and 1.61 m respectively, with factors of buoyancy of 1.22 and 1.23 comfortably above the flotation threshold. Reducing the superstructure mass therefore reduces the required pontoon depth by roughly 40 per cent, with direct consequences for material consumption, embodied carbon and constructability. The result reframes the design problem: rather than building an ever-larger hull to float a heavy house, the rational strategy is to lighten the house so that a modest, buildable hull suffices.

Table 4. Required pontoon depth for 0.3 m freeboard.

Quantity	RCC walls	Fibre-cement	Bamboo/timber
Required pontoon depth (m)	2.69	1.68	1.61
Draft at required depth (m)	2.39	1.38	1.31
Total weight at depth (kN)	492.8	284.2	270.3
Factor of buoyancy	1.13	1.22	1.23

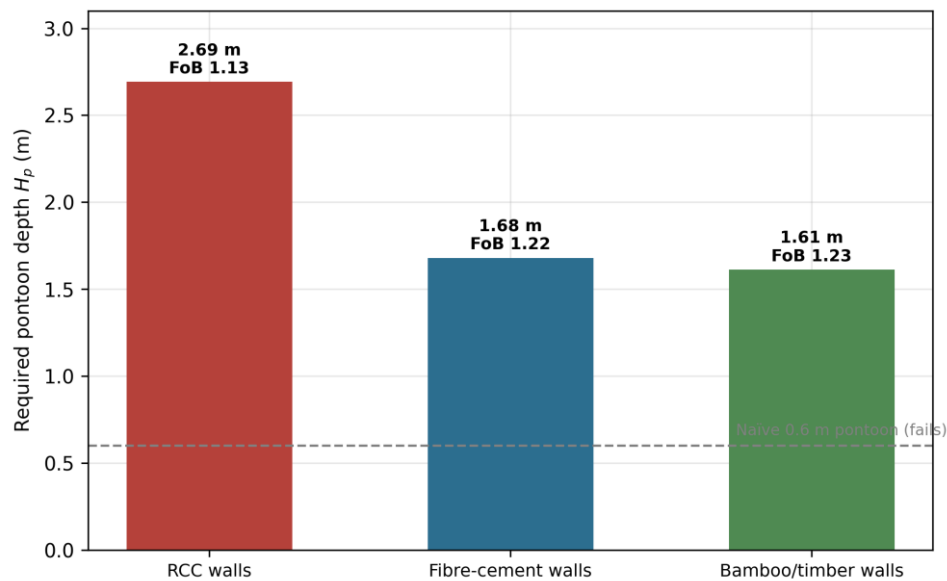


Fig. 5. Required pontoon depth for 0.3 m freeboard.

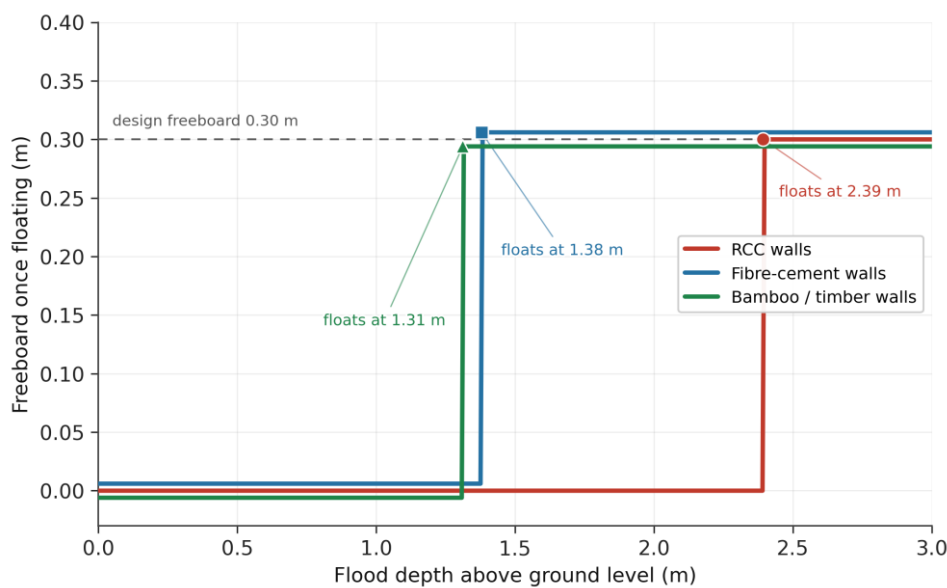


Fig. 6. Freeboard vs. flood depth.

Fig. 6 shows the flotation behaviour across flood depth for the depth-optimised designs. Each unit remains grounded until the floodwater reaches its draft, at which point it lifts and thereafter maintains a constant freeboard regardless of further rise. The lighter superstructures begin to float at a shallower flood depth (1.31 m for bamboo against 2.39 m for reinforced concrete), an operational advantage because the dwelling responds earlier in a flood event and is protected across a wider range of inundation.

Expanded-polystyrene reserve buoyancy provides a fail-safe against partial hull flooding. Fig. 7 reports the EPS volume required to retain a factor of buoyancy of 1.3 under an assumed 30 per cent hull flood. The lightweight options require 21.3 m³ (bamboo) and 22.8 m³ (fibre-cement), while the reinforced-concrete option requires 44.8 m³, again reflecting its much greater weight. Because EPS contributes negligible self-weight, it is an efficient redundancy measure, and its specification scales directly with the superstructure mass, reinforcing the case for lightweight walls.

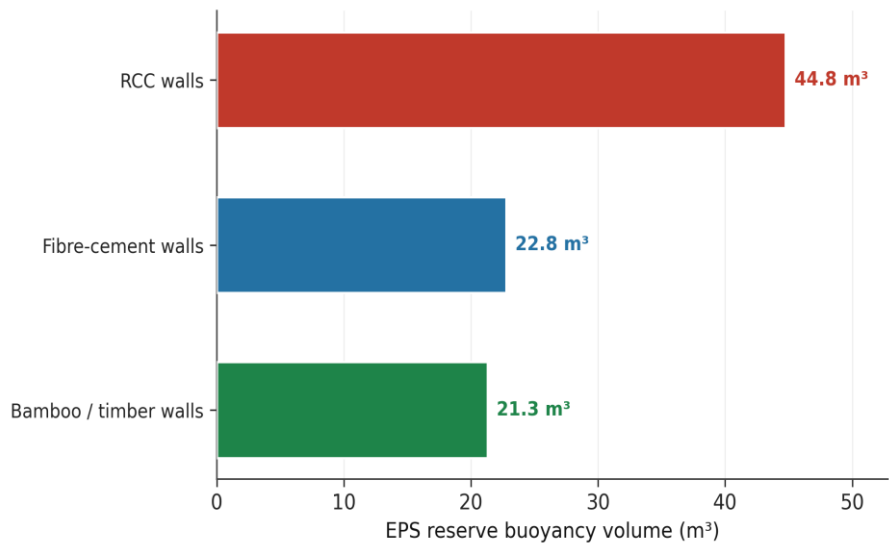


Fig. 7. EPS reserve buoyancy by wall type.

3.3 Guide-pile demand and sensitivity

The guide-pile check confirms that the concept is suited to low-velocity floodplains. Fig. 8 plots the per-pile lateral demand against flood-current velocity for the three designs, alongside the 15 kN allowable capacity. The per-pile demand grows with the square of velocity, and the demand reaches the allowable capacity at about 2.64 m/s for the reinforced-concrete unit and at higher velocities, around 3.5 m/s, for the lighter units with their smaller submerged frontal areas. These thresholds lie well above the velocities typical of overtopping floods on flat floodplains, which supports the established guidance that amphibious foundations are appropriate where water primarily rises rather than rushes [3]. They would not, however, be adequate for fast channel flows or storm-surge wave action without additional anchoring, a limitation that must be stated plainly.

To identify which inputs most strongly govern the design, the required pontoon depth for the bamboo case was recomputed under a plus-or-minus 20 per cent variation of each principal input. Fig. 9 presents the result as a tornado diagram. The water unit weight is the single most influential parameter, because it sets the buoyant force per unit volume and therefore enters the draft calculation directly; a denser flood medium reduces the required depth while a less dense one increases it. The concrete unit weight and the base-slab thickness, which together govern the pontoon self-weight, are the next most influential, followed by the floor live load and the storey height. The practical implication is twofold: site-specific flood-water density, which rises with suspended sediment, materially affects flotation and should be measured rather than assumed where possible; and among the controllable design variables, economising on pontoon concrete through thinner sections or lighter mixes yields the largest reduction in required hull depth.

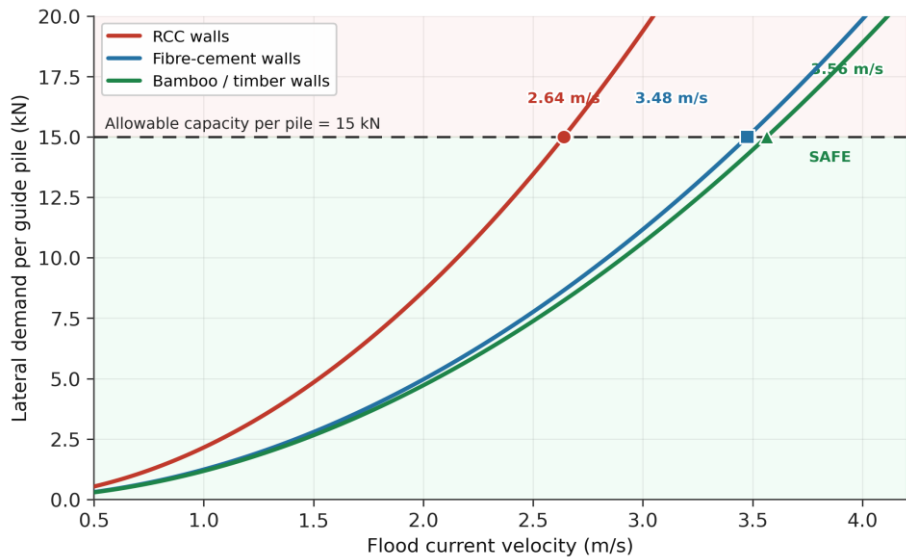


Fig. 8. Guide-pile demand vs. current velocity.

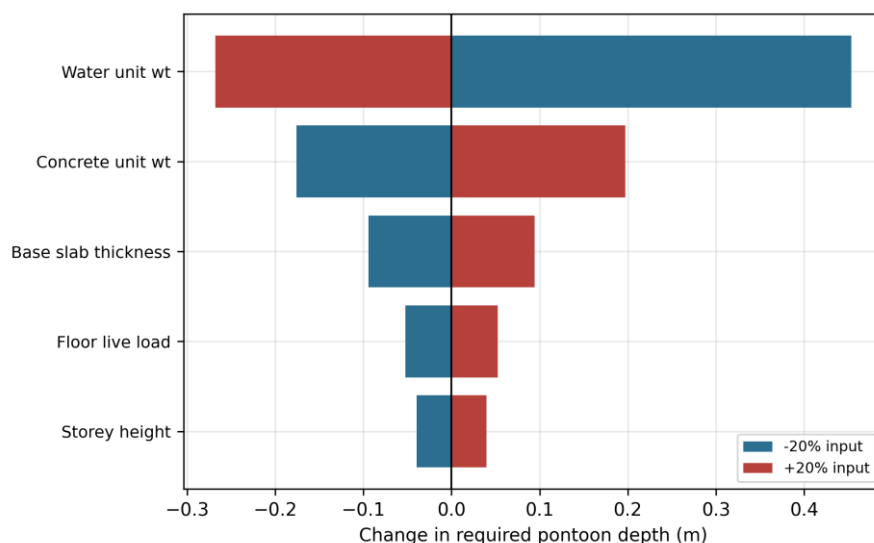


Fig. 9. Sensitivity of required pontoon depth ($\pm 20\%$).

3.4 Discussion: materials, novelty, limitations and SDGs

The finding that lightweight superstructures are decisively advantageous connects this work to the wider literature on sustainable construction materials. Where reinforced concrete is unavoidable, partial replacement of cement with supplementary cementitious materials such as fly ash and ground granulated blast-furnace slag reduces both embodied carbon and, to a degree, density, while maintaining adequate strength [7,8,9]. Life-cycle assessments confirm that such replacements lower the environmental burden of concrete elements without compromising structural performance [10,22]. For an amphibious dwelling, these materials are doubly attractive: they reduce the carbon cost of the pontoon and, by trimming its self-weight, ease the very buoyancy demand the pontoon exists to satisfy. The lightweight bamboo and fibre-cement options explored here extend the same logic to the superstructure, and align the design with circular-economy approaches that valorise industrial by-products in construction [20,21,23].

Against the existing literature, this study contributes a quantified, code-anchored feasibility envelope rather than a further case study. The international evidence base, dominated by projects in the Netherlands, North America and Bangladesh, demonstrates that amphibious construction works but offers little numerical guidance calibrated to Indian standards and affordable-housing norms [2,3,28,29]. By computing the load take-down, buoyancy, reserve and guide-pile demand from the Indian Standards and the Pradhan Mantri Awas Yojana envelope, the present framework gives practitioners a reproducible starting point for sizing an amphibious dwelling in the Indian floodplain context, and it isolates superstructure material as the governing design variable, a point not emphasised in the prior descriptive work.

The limitations are equally important to state. The analysis is a desk study based on secondary data; no prototype has been built or tested, and no laboratory measurements are claimed. The hydrodynamic check is a first-order estimate that does not capture wave action, debris impact, dynamic mooring forces or the soil-structure interaction of the guide piles in detail. The cost dimension, the utility connections and the long-term durability of EPS and timber in repeated wetting cycles all lie outside the present scope. These are precisely the questions that physical testing and detailed structural and geotechnical modelling should address in subsequent work, and the framework here is intended to define the design envelope within which such testing would be most usefully concentrated.

The framework supports several of the United Nations Sustainable Development Goals where the computed results genuinely bear on the claim [25]. It contributes to Goal 9 by offering resilient, adaptable infrastructure for hazard-prone regions; to Goal 11 by providing a route to safe and affordable housing for the populations most exposed to flooding, consistent with the Pradhan Mantri Awas Yojana mission [26]; and to Goal 13 by advancing a climate-adaptation strategy that accommodates intensifying flood regimes rather than resisting them [6,13]. The connection to Goal 12 is more limited and is claimed only insofar as the lightweight, supplementary-cementitious-material strategy reduces material consumption and embodied carbon [10]; the present analysis does not quantify resource flows in enough detail to assert a stronger responsible-production claim.

IV. CONCLUSIONS

This study developed a transparent, first-principles buoyancy framework for a representative single-storey amphibious dwelling sized to the Indian affordable-housing envelope, computing every result from published material properties and the imposed-load provisions of the Indian Standards. Four conclusions follow directly from the analysis. First,

a shallow 0.6 m pontoon is structurally inadequate for flotation in every superstructure case examined, producing negative freeboard and a factor of buoyancy between 0.31 and 0.55. Second, superstructure mass is the dominant design variable: a reinforced-concrete superstructure requires an impractical 2.69 m pontoon to achieve a 0.3 m freeboard, whereas lightweight bamboo or fibre-cement walls reduce the requirement to about 1.6 m and lower total weight by more than 40 per cent. Third, expanded-polystyrene reserve buoyancy is an efficient fail-safe, requiring 21 to 23 m³ for the lightweight options against 45 m³ for the reinforced-concrete option. Fourth, guide piles govern only above flood-current velocities of roughly 2.6 to 3.6 m/s, confirming that the concept suits low-velocity overtopping floodplains rather than fast channels.

Taken together, these results provide a reproducible pre-design envelope for amphibious housing in Indian riverine floodplains and identify lightweight, low-carbon construction as the rational design strategy. The framework is offered as a foundation for subsequent physical testing and detailed structural, geotechnical and cost analysis, which remain necessary before site implementation. The work is presented honestly as a secondary-data feasibility study, and its value lies in defining, quantitatively and reproducibly, the design space within which a buildable Indian amphibious dwelling can be realised.

LIST OF SYMBOLS

A plan footprint area of the dwelling (m²)
B plan breadth of the dwelling (m)
Cd hydrodynamic drag coefficient (dimensionless)
d draft of the floating pontoon (m)
Fd lateral hydrodynamic force on the floating unit (kN)
FoB factor of buoyancy (dimensionless)
H clear storey height (m)
Hp pontoon hull depth (m)
L plan length of the dwelling (m)
qf, qr floor and roof imposed (live) loads (kN/m²)
v flood-current velocity (m/s)
Vreq displaced water volume required for flotation (m³)
W total weight of the floating unit (kN)
γ_{rc}, γ_{eps}, γ_w unit weights of reinforced concrete, EPS and water (kN/m³)
ρ density of water (kg/m³)

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AUTHOR CONTRIBUTION STATEMENT

Goutham Kattakola: Conceptualisation, Methodology, Investigation, Writing – original draft. **Sphurty Raman:** Supervision, Conceptualisation, Methodology, Validation, Writing – review and editing, Project administration.

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