Journal of Materials and Construction
ISSN 2734-9438
Website: www. jomc.vn

Design guide for ferrocement floating pontoons for flood-adapted housing in the Mekong Delta

Do Thi My Dung[1], Vu Hoang Hung[2], Lam Thanh Quang Khai[1,*], Cao Quoc Khanh[1], Tran Xuan Hai[1], Ngo Van Thuyet[2]

[1]Faculty of Civil Engineering, Mien Tay Construction University

[2]Faculty of Civil Engineering, Thuyloi University

KEYWORDS

Ferrocement
Floating pontoon
ACI-based design
Climate change
Sea-level rise
Mekong Delta

ABSTRACT

Climate change, sea-level rise, and increasingly severe floods have intensified the demand for flood-adapted housing solutions in the Mekong Delta. Ferrocement floating pontoons are a promising option because they can be locally fabricated, provide adequate structural performance for thin-walled water-retaining tanks, and enable multifunctional use (e.g., flotation during floods and water storage in dry seasons). This study develops a practical calculation and design guide for ferrocement floating pontoons serving as buoyant foundations for floating/amphibious houses. The guide defines representative pontoon cross-sections (rectangular and U-shaped) and preliminary buoyancy sizing based on floor-area loading, equilibrium flotation, and freeboard requirements; formulates actions and load combinations consistent with pontoon working stages, including: pontoons resting on the ground subjected to external hydrostatic pressure and ground reaction, initial flotation under buoyancy, lateral water pressure and wave effects, and special accidental conditions including impact; and provides structural checks for strength and serviceability, emphasizing crack-width control for durability in non-aggressive and aggressive/water-retaining environments. For house systems guided by four corner posts or restrained by four flexible mooring lines, the guide highlights controlled vertical movement and connection detailing to prevent pontoon separation. The proposed workflow supports safer, more consistent engineering design and local deployment of ferrocement pontoons for flood resilience in the Mekong Delta.

1. Introduction

The Vietnamese Mekong Delta (VMD) is a highly dynamic lowland where housing safety is increasingly governed by compound water-level drivers - upstream flood waves, local rainfall, tidal backwater, wind setup and storm surges - superimposed on long-term relative sea-level rise. In recent regional planning work, flood and inundation are treated as a top constraint because of their direct impacts on socio-economic activities and life safety. In parallel, the built environment in the VMD is also pressured by seasonal extremes - flood seasons requiring safe shelter and continuity of daily life, and dry seasons challenged by water shortage and salinity intrusion - making multi-season, multi-hazard housing an urgent adaptation need.

At the global scale, the Intergovernmental Panel on Climate Change (IPCC) indicates that global mean sea level is projected to keep rising throughout the 21st century, with likely ranges by 2050 and 2100 differing across emissions pathways; for example, relative to 1995–2014, likely global mean sea-level rise by 2050 spans roughly 0.15–0.23 m (very low emissions) to 0.20–0.29 m (very high emissions), while by 2100 it spans about 0.28–0.55 m to 0.63–1.01 m, respectively [1]. Vietnam's official Climate Change Scenario (updated 2020) - issued by the Ministry of Natural Resources and Environment (MONRE) - provides a national basis for impact assessment and adaptation planning, including sea-level rise considerations and inundation risk mapping that leverages updated national datasets and downscaled modeling products [2].

The VMD is particularly sensitive to these drivers because it is not only low-lying but also experiencing subsidence, which can dominate relative sea-level rise locally. A detailed elevation assessment has shown that the delta is much lower than previously assumed, affecting sea-level-rise impact estimates [3]. In addition, groundwater extraction has been identified as a major mechanism behind subsidence in the Mekong Delta, compounding flood risk when combined with sea-level rise [4]. Together, these processes imply that design for flood-adapted housing in the VMD should not rely on a single "static" flood level; rather, it should account for scenario-based water levels that reflect both climate-driven sea-level rise and local/regional boundary conditions. For instance, hydrodynamic simulations have explored relative sea-level-rise scenarios (e.g., 30 cm and 100 cm by mid- and late-century) and reported large potential increases in flooded area, even when considering protective infrastructure [5].

Conventional flood-protection housing strategies in the VMD often rely on embankments or fixed pile-supported elevation so that the floor remains above flood water. However, this approach can be non-adaptive once flood levels exceed the assumed design elevation; it

---

*Corresponding author: Lamkhai@mtu.edu.vn

Received 01/02/2026, revised 18/02/2026, accepted 06/02/2026
Link DOI: https://doi.org/10.54772/jomc.v16i01.1178

may also adversely affect residents' daily living conditions for long portions of the year (e.g., access, usability, and thermal comfort), and it does not inherently provide benefits in the dry season. In contrast, floating or amphibious housing can provide a passive response - rising with water levels during flooding - while remaining usable on ground in normal periods. Beyond flood safety, adaptation in the VMD must also consider seasonal drought and water storage needs. The multi-functional floating-house concept proposed in the project underlying this paper explicitly targets both seasons: during floods, the house provides safe shelter, and during dry periods the pontoon tanks can be used for domestic water storage (and potentially agricultural storage functions), improving year-round utility rather than serving as a "single-season" disaster solution. This dual-season logic is aligned with the reality that climate change can intensify extremes and variability, requiring housing systems that remain beneficial under multiple seasonal stressors rather than optimizing only for peak floods.

Internationally, amphibious construction has been discussed as a flood-risk mitigation pathway in which a building can float when inundated while being restrained by guidance/mooring systems, limiting drift and ensuring re-centering after floodwaters recede. Systematic reviews of amphibious housing emphasize that performance depends not only on architectural planning but also on foundation buoyancy, stability, and constraints/guidance mechanisms that control motion during flood events [6].

From a structural-engineering standpoint, a key challenge is that a flood-adapted floating foundation experiences distinct mechanical stages as water rises: (i) the pontoon is supported by the ground (with possible external water pressure), (ii) the pontoon begins to float (with buoyancy developing and hydrodynamic pressures acting), and (iii) the pontoon is fully floating (subject to waves, currents, wind actions transferred from the superstructure, and potential impact from debris or floating objects). This stage-wise behavior is central to safe design because both load paths and boundary conditions change during transition, and the controlling limit state may differ by stage. This study focuses on floating pontoons made of ferrocement, a thin cementitious composite reinforced by multiple layers of wire mesh. Ferrocement is identified as suitable for VMD floating pontoon tanks due to its relatively low self-weight and favorable tensile/crack-resisting behavior for thin shells, while still being feasible for prefabrication and local deployment. Internationally, the American Concrete Institute provides a dedicated Design Guide for Ferrocement (ACI 549.1R-18) that consolidates practice-oriented design information for ferrocement structural applications [7-8].

For floating pontoons, serviceability and durability are as critical as ultimate strength because pontoons act as water-retaining elements. The draft guidance used in this work explicitly highlights tight crack-width control limits (e.g., approximately 0.10 mm in non-corrosive environments and 0.05 mm in corrosive or water-retaining conditions) to maintain watertightness and long-term performance. However, despite the availability of international guidance for ferrocement materials, this paper emphasize that Vietnam currently lacks a dedicated design standard for ferrocement floating pontoons for Mekong Delta housing, motivating the development of a practical, locally contextualized design guide.

2. Materials and Methods

2.1. Research framework and design context

This study develops a design guide for ferrocement floating pontoons used as buoyant foundations for flood-adapted (amphibious/floating) housing in the Mekong Delta. The research scope follows the project objective of preparing technical guidance for ferrocement pontoons for the Mekong Delta under climate change and sea-level rise, including application to housing systems that slide along four corner posts or are restrained by four flexible mooring lines. To ensure practical relevance, the workflow combines: (i) data collection on flood-depth zoning under climate-change and sea-level-rise scenarios, (ii) field surveys of existing housing and applied flood solutions, (iii) synthesis of existing practices, (iv) theoretical research on design methods and standards, and (v) expert consultation across materials, hydraulics, disaster prevention, and building engineering [9-10].

2.2. Design basis and stage-wise philosophy

Vietnamese Standards (TCVN) do not currently provide a dedicated design code for ferrocement structures. In this study, the guide framework is therefore formulated using an ACI-based approach: ACI 549.1R-18, ACI 318-19(22), concepts for load and resistance factor design and strength-reduction factors, together with ferrocement-specific recommendations [7,11]. To enhance local applicability, the adopted assumptions and action modeling are cross-checked against Vietnamese provisions for reinforced concrete and for loads and actions (e.g., TCVN 5574:2018 and TCVN 2737:2023) where relevant [12-13].

A central premise is that ferrocement pontoons supporting amphibious/floating houses experience distinct boundary conditions and dominant actions across water-level stages: (1) resting on the ground (soil reaction with possible external hydrostatic pressure), (2) transition to flotation (buoyancy develops while lateral water pressure and wave effects act), and (3) full flotation including accidental actions (e.g., debris impact). Because the governing limit state may differ by stage, the design workflow explicitly evaluates load combinations and critical sections for each stage rather than relying on a single floating-only scenario.

2.3. Buoyancy sizing and freeboard requirement

For preliminary sizing, the design vertical load per unit floor area is taken as (equation 1):

$$q = g + p \text{ (kN/m}^2\text{)} \quad (1)$$

where g is the sum of permanent loads from the superstructure, floor system, and utilities; and p is the imposed/live load due to occupancy and use. The total sinking force (downward resultant) is computed as (equation 2):

$$F = G_{pontoon} + q \times B \times L \text{ (kN)} \quad (2)$$

where $G_{pontoon}$ is the pontoon self-weight and B × L is the pontoon plan area. The buoyant force is computed by equilibrium flotation (equation 3):

$$W = h \times B \times L \times \gamma_w \text{ (kN)} \quad (3)$$

where h is the draft (submerged height) and γ_w is the unit weight of water (approximately 10 kN/m^3 for preliminary calculations). The flotation requirement W > F yields the minimum draft (equation 4):

$$h > (G_{pontoon} + q \times B \times L) / (B \times L \times \gamma_w) \quad (4)$$

To prevent overtopping and to accommodate water-level variations and wave runup, the pontoon height should satisfy (equation 5):

$$H \geq h + \Delta H \text{ (m)} \quad (5)$$

where ΔH is the design freeboard allowance. A practical range of ΔH = 0.3-0.5 m is commonly adopted depending on exposure (fetch), expected wave effects, and operational needs. An important implication of Eq. (4) is that draft increases approximately linearly with floor loading: for $\gamma_w \approx 10$ kN/m^3, every 1 kN/m^2 increase in q increases draft by about 0.10 m ($\Delta h \approx \Delta q/\gamma_w$).

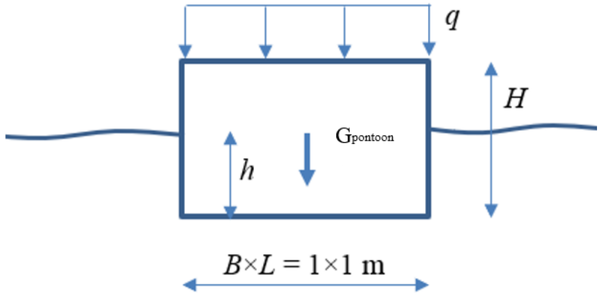

Figure 1. Buoyancy height calculation diagram.

2.4. Hydrostatic pressure and simplified wall actions

External hydrostatic pressure on pontoon sidewalls is modeled as a linear function of depth y below the water surface (equation 6):

$$p(y) = n \times \gamma_w \times y \text{ (kN/m}^2\text{)} \quad (6)$$

where n is an overload factor (n = 1.2). For a vertical wall with submerged height H_w, the lateral resultant per unit wall length is (equation 7):

$$P = 0.5 \times n \times \gamma_w \times H_w^2 \text{ (per unit length)} \quad (7)$$

acting at $H_w/3$ above the wall base. Accordingly, the base bending moment per unit length is (equation 8):

$$M_{base} = (1/6) \times n \times \gamma_w \times H_w^3 \text{ (per unit length)} \quad (8)$$

Equations (7)-(8) highlight a key design sensitivity: lateral bending demand increases with the cube of water depth. Therefore, modest increases in flood depth or freeboard height can significantly raise required wall thickness, stiffener spacing, or reinforcement content, especially for rectangular pontoons where walls behave similarly to cantilever plates.

2.5. Strength design check and reinforcement parameters

Ultimate limit state (strength) is checked using the standard inequality (equation 9):

$$U \leq \varphi N \quad (9)$$

where U is the factored action effect (from governing load combinations), N is the nominal resistance, and φ is the strength reduction factor. Section analysis follows classical strain compatibility assumptions used for reinforced concrete: linear strain distribution, perfect bond between mesh and mortar, and neglect of mortar tensile strength in strength calculations.

For wire-mesh reinforcement, the reinforcement content is conveniently represented by the volume fraction V_f. For square/rectangular welded mesh, V_f can be estimated as (equation 10):

$$V_f = [N \times \pi \times d_b^2 / (4 \times h)]\,(1/D_l + 1/D_t) \quad (10)$$

where N is the number of mesh layers, d_b is wire diameter, h is ferrocement thickness, and D_l and D_t are longitudinal and transverse wire spacings. To account for mesh orientation and anchorage effectiveness, an efficiency factor η is used to obtain an effective steel area for each mesh layer (equation 11):

$$A_{si} = \eta \times V_{fi} \times A_c \quad (11)$$

where A_c is the composite cross-sectional area and V_{fi} is the volume fraction contributed by the *i-th* layer. For a cracked section under pure axial tension, the nominal tensile resistance can be approximated by reinforcement capacity (equation 12):

$$N_n = A_s \times f_y, \quad A_s = \Sigma A_{si} \quad (12)$$

where f_y is the mesh yield strength. For bending-dominated components (walls and bottom slab), a practical design-aid expression may be used for quick estimates of nominal moment capacity of thin ferrocement plates (equation 13):

$$M_n/(f'_c b h^2) = 0.005 + 0.422\,\Psi - 0.0772\,\Psi^2, \quad \Psi = (\eta \times V_f\, f_y)/f'_c \quad (13)$$

Equation (13) indicates diminishing returns at higher reinforcement index Ψ due to the quadratic term; thus, beyond a certain reinforcement level, increasing thickness, improving detailing, or adding stiffeners can be more efficient than simply adding additional mesh layers.

2.6. Serviceability and durability checks

Because pontoons also act as water-retaining tanks (at least seasonally), serviceability is treated as a primary design driver. Crack-width limits under service actions are recommended as $w_{max} < 0.10$ mm for non-corrosive environments and $w_{max} < 0.05$ mm for corrosive environments and/or water-retaining conditions. In addition, allowable mesh tensile stress under normal service can be taken as $\sigma_{s,allow} = 0.60 f_y$; for liquid-retaining and sanitary structures, a conservative upper limit of about 207 MPa is recommended unless model tests justify higher stress without unacceptable cracking.

For repeated wave-induced actions, fatigue performance may govern. A practical recommendation is to limit the mesh stress range to approximately 207 MPa for at least two million cycles. These serviceability constraints directly influence selection of thickness h, stiffener spacing, and reinforcement layout, and they are particularly important for long-term durability under saline intrusion in parts of the Mekong Delta.

2.7. Numerical verification option

For routine design, simplified plate and beam idealizations can be used to estimate internal forces under hydrostatic pressure, buoyancy, and soil reaction (Eqs. 6-8). For complex pontoons (multi-cell pontoons, irregular stiffener layouts, or detailed connection zones), finite element (FE) modeling using shell or solid elements can be used to verify stress distribution, deformation, and crack-prone regions, and to calibrate stiffener spacing and local detailing under the stage-wise load combinations.

3. Results and discussions

3.1. Interpretation of governing equations and design sensitivity

The governing equations introduced in Section 2 provide transparent engineering interpretation and quick design sensitivity checks before detailed numerical analysis. Key implications for flood-adapted housing pontoons in the Mekong Delta are discussed below.

Buoyancy sensitivity (Eqs. 1-5). For a given plan area $B \times L$, Eq. (4) shows that draft h increases linearly with both floor loading q and pontoon self-weight $G_{pontoon}$. This creates a clear trade-off: increasing wall thickness, adding stiffeners, or increasing reinforcement content improves structural capacity but simultaneously increases $G_{pontoon}$ and therefore increases h, potentially reducing freeboard. In practice, an iterative sizing loop is recommended: update $G_{pontoon}$ after each structural sizing revision, recompute h from Eq. (4), and check the freeboard requirement in Eq. (5) for the governing water-level scenario.

Hydrostatic lateral demand (Eqs. 6-8). The triangular pressure distribution implies that sidewall demand is highly sensitive to submerged water depth H_w; the base bending moment scales with H_w^3. Consequently, the onset of flotation (transition stage) can govern local wall and corner design even when global buoyancy is satisfied. From a detailing perspective, wall-to-bottom junctions and corner regions should be treated as critical crack-prone zones requiring adequate mesh continuity, overlap, and local thickening or stiffeners where needed.

Reinforcement efficiency and diminishing returns (Eqs. 10-13). Equations (10)-(12) indicate that tensile resistance of a cracked ferrocement section is approximately proportional to effective steel area A_s, which depends not only on the amount of mesh (V_f) but also on orientation and anchorage effectiveness (η). Therefore, improving mesh arrangement (orientation, overlap length, and anchorage detailing) can be as influential as adding more layers. The design-aid relationship in Eq. (13) further indicates diminishing returns at high reinforcement index Ψ; beyond a certain point, adding thickness or adding internal diaphragms/partitions to reduce plate spans may be more effective than increasing V_f alone.

3.2. Stage-wise governing limit states and detailing priorities

The stage-wise philosophy implies that different actions and limit states may govern at different points during a flood. When the pontoon is grounded, external hydrostatic pressure can produce unfavorable bending at wall bases and corners in combination with soil reaction. During transition to flotation, buoyancy develops while lateral water pressure and wave effects act, and local stress concentration can occur near stiffeners and connection zones. In full flotation, accidental actions such as debris impact and repeated wave-induced cycles can govern local detailing and serviceability.

For amphibious houses restrained by four corner posts or four flexible mooring lines, the structural design focus shifts to controlled vertical movement and connection integrity rather than free-drift stability. Module-to-module connections must prevent separation while accommodating repeated vertical motion, and local bearing and cracking at connection points should be checked under the governing stage-wise combinations. Practical detailing measures include: (i) local mesh densification and U-wraps at corners and junctions, (ii) continuous mesh across wall-to-bottom joints, (iii) corrosion protection and strict crack control where the pontoon is used as a water-retaining tank.

3.3. Limitations and implementation notes

The equations and checks presented are intended for practical engineering design within a first-edition guideline context. Site-specific hydrodynamic effects (current, wave spectrum, boat wakes), debris-impact scenarios, and guidance-post foundation design may require supplemental analysis. For sites with large fetch, strong currents, or high debris hazards, numerical verification and, where possible, model or field testing are recommended to confirm stress distribution, crack control performance, and connection behavior.

4. Conclusions

This paper presents a practical, ACI-informed calculation and design guide for ferrocement floating pontoons used as buoyant foundations for flood-adapted housing in the Vietnamese Mekong Delta.

The proposed framework (i) links house loading, pontoon geometry, draft, and freeboard through transparent buoyancy equations; (ii) models stage-wise actions and highlights the strong sensitivity of lateral wall demand to flood depth; and (iii) integrates ferrocement strength and serviceability checks with explicit emphasis on crack-width control for durability and water-tight performance. The guide is intended to support safer and more consistent local deployment, and it can be refined further through site-specific hydrodynamic assessment, numerical verification, and field validation in representative flood and saline environments.

Acknowledgments

This study was carried out under the Ministerial-level Science and Technology Task of the Ministry of Construction (Vietnam), project code: RD 33-24. The authors gratefully acknowledge the support of Mien Tay Construction University and the contributions of experts and local stakeholders who provided technical feedback and field information during the development of the design guideline.

References

[1]. Intergovernmental Panel on Climate Change (2024), *IPCC AR6 Synthesis Report LR Figure 3.4 (a): Sea level rise: observations and projections 2020-2100, 2150, 2300 (relative to 1900)*, NASA Socioeconomic Data and Applications Center (SEDAC), IPCC DDC, DOI: 10.7927/adkr-bn17

[2]. Ministry of Natural Resources and Environment (2020), *Climate Change Scenario (updated 2020)*, Viet Nam Publishing House Of Natural Resources Environment And Cartography.

[3]. Minderhoud, P.S.J., Coumou, L., Erkens, G. et al. (2019). *Mekong delta much lower than previously assumed in sea-level rise impact assessments*. Nat Commun 10, 3847. DOI: 10.1038/s41467-019-11602-1

[4]. Erban, L. E., S. M. Gorelick, and H. A. Zebker (2014), *Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam*. Environmental Research Letters, 9(8), 084010. DOI: 10.1088/1748-9326/9/8/084010

[5]. Le, H.-A., Nguyen, T., Gratiot, N., Deleersnijder, E., & Soares-Frazão, S. (2023). *The Multi-Channel System of the Vietnamese Mekong Delta: Impacts on the Flow Dynamics under Relative Sea-Level Rise Scenarios*. Water, 15(20), 3597. DOI: 10.3390/w15203597

[6]. Varkey M.V., Philbin M Philip (2022), *Flood risk mitigation through self-floating amphibious houses - Modelling, analysis, and design*. Materials Today: Proceedings, 65(2), 442-447. DOI: 10.1016/j.matpr.2022.02.547

[7]. ACI 549.1R-18: Design Guide for Ferrocement

[8]. L.T.Q. Khai, V.H. Hung, D.T.M. Dung, L.N. Qui, D.H. Hoang, N.T. Nga, L.P. Thuan (2025). *Using Ferrocement In Design Of Floating For Houses In The Mekong Delta*, Journal of Materials and Construction, 15(1), 55-62. DOI: 10.54772/jomc.01.2025.819

[9]. Southern Institute for Water Resources Planning (2021). *Hydraulic Report for the Mekong Delta Region: Natural Disaster Prevention and Irrigation Planning for the 2021–2030 Period, with a Vision to 2050*.

[10]. L.T.Q. Khai et al. (2025). *Research on developing a technical guideline for the structural analysis and design of ferrocement floating pontoons for houses in the Mekong Delta to adapt to climate change and sea-level rise*. Ministerial-level Science and Technology Task (Ministry of Construction), project code: RD 33-24

[11]. ACI CODE-318-19(22): Building Code Requirements for Structural Concrete and Commentary (Reapproved 2022)

[12]. TCVN 5574:2018, Design of concrete and reinforced concrete structures

[13]. TCVN 2737:2023, Loads and actions