J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011
Vol. 21(S2), (2026) 72-78
DOI: https://doi.org/10.51220/jmr.v21-S2.9

Bubble Deck Slab Systems: Design Innovations and Structural Analysis

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Received: 8.9.2025; Revised:5.1.2026; Accepted: 5.1.2026

Abstract: The most crucial element of every structure is the concrete slab. When we provided the bubble deck slab, it also provided a high standard of living, increasing the amount of thermal comfort that individuals enjoyed. When creating floors and roofs, more concrete is used in the concrete slabs. Concrete is a heavy material, and more than 5% of CO_2 is produced during cement manufacture. When making bubble deck slabs, extra concrete that does not contribute to the interlocking of aggregates for shear strength can be removed, leaving behind the concrete that is needed as a compression block for flexural strength. Furthermore, this well-known technique enables lower design loads for columns and footings and longer spans without compromising the slab's flexural strength with little deflection. According to a literature analysis, bubble deck slabs are more cost-effective and effective in terms of structural integrity than traditional slabs. In this work, we investigated whether or not it is possible to create concrete slabs that are both lightweight and functional by reducing the slab uses hollow, high-density polyethylene spheres and concrete. The dead weight and effectiveness of the slab can be improved by removing a significant percentage of the concrete from the centre, which is not necessary for the slab's structural integrity. This technique produces a slab that is 30 to 50% lighter and can lessen the strain on foundations, walls, and columns. Cost and CO2 emissions can both be decreased. A thorough overview of the structural behavior of deck slabs is given in this study.

Key Words: Bubble deck • Carbon emission • Polyethylene hollow sphere • Voided biaxial slab

Introduction:

One of the most crucial structural components for the distribution of loads produced by the structure is the slab. There are typically two different kinds of slabs: unilaterally supported slabs are those that are supported on only one side and mostly deflect in one direction. Two-way slabs are those that are supported by columns that are typically organized in rows and allow the slabs to deflect in both directions. The recycled spherical hollow members are used in the structural system, each one performing a certain duty or function members are sandwiched between the steel reinforcement in the bubble deck slab design. Because of the voids this causes in the slab, less concrete is needed to build it. In comparison to a solid slab of the same size, using spheres to fill the spaces in the centre of a flat slab reduces its dead weight by 35%, thickness without affecting flexural strength and deflection behavior.

Literature review:

The rapid growth of urbanization and the increasing demand for sustainable, economical, and

structurally efficient construction systems have prompted extensive research into alternatives to conventional reinforced cement concrete (RCC) slabs. One of the most significant challenges associated with traditional solid slabs is their excessive self-weight, which increases material consumption, construction cost, foundation demand, and seismic vulnerability. In this context, Bubble Deck slab technology—characterized by the incorporation of hollow plastic spheres within the neutral axis of slabs—has emerged as a promising innovation aimed at eliminating non-structural concrete while maintaining

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structural integrity. A substantial body of literature over the last two decades has examined the structural behavior, sustainability potential, design considerations, and practical feasibility of Bubble Deck and other voided slab systems.

Early analytical and design-oriented research by Bindea et al. (2013) provided a theoretical foundation for the flexural and shear design of flat slabs with spherical voids. Their study established that flexural behavior of voided slabs could largely follow conventional solid slab principles, provided that the neutral axis remains above the voided zone. However, the authors emphasized that shear resistance—particularly punching shear near column supports—remains a governing concern due to the reduction of solid concrete volume. Consequently, they recommended eliminating voids in column zones to preserve shear capacity. While analytically robust, the study lacked experimental validation and did not address construction complexity, long-term performance, or environmental benefits, highlighting the need for empirical studies to complement theoretical models.

Subsequent analytical work by Taskin et al. (2014) further explored plastic voided slabs within the framework of Turkish design codes using SAP2000-based numerical modeling. Their comparative assessment with waffle, ribbed, and mushroom slabs demonstrated that voided slabs provide significant weight reduction, architectural flexibility, and economic advantages without compromising structural safety under static loading. Nevertheless, the study primarily relied on numerical simulations and did not investigate long-term serviceability, seismic performance, fire resistance, or on-site construction challenges. As such, it positioned voided slabs as a theoretically viable alternative but underscored the necessity for real-scale experimental and lifecycle studies.

Experimental investigations gained prominence with the work of Bhade and Barelikar (2016), who examined the behavior of two-way Bubble Deck slabs reinforced with spherical hollow balls. Their results indicated that substantial self-weight reduction could be achieved without compromising load-carrying capacity, deflection limits, or crack control. The study demonstrated delayed crack propagation and acceptable serviceability behavior, reinforcing the practical feasibility of the system. Importantly, this work linked structural efficiency with sustainability by highlighting reduced concrete usage and associated CO_2 emissions. However, it also implicitly identified unresolved issues related to punching shear, durability, and dynamic loading, which remain critical for real-world applications.

In the same year, Reshma Mathew et al. (2016) addressed one of the most critical limitations of Bubble Deck slabs—reduced punching shear capacity—by introducing Glass Fiber Reinforced Polymer (GFRP) strengthening. Using finite element analysis in ANSYS, they demonstrated that GFRP-reinforced voided slabs exhibited up to 20% higher punching shear capacity and reduced deflection compared to unstrengthened Bubble Deck slabs. This study made an important contribution by proposing a practical reinforcement strategy that enhances structural safety without negating the benefits of weight reduction and sustainability. Nonetheless, the reliance on numerical simulations highlighted the need for experimental validation and full-scale testing.

Parallel experimental studies by Mushfiq et al. (2017) examined Bubble Deck slabs with different bubble-to-depth (B/H) ratios using recycled HDPE spheres. Their results confirmed material savings ranging from 10.55% to 17%, accompanied by moderate reductions in ultimate load capacity and marginal increases in deflection. The stiffness reduction observed with increasing bubble size aligned with theoretical expectations,

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reinforcing the trade-off between material efficiency and serviceability. This study demonstrated that Bubble Deck slabs remain structurally viable under two-point loading but require careful optimization of void geometry to balance sustainability and performance.

Bhowmik et al. (2017) expanded the discussion by synthesizing earlier findings and emphasizing the environmental and functional advantages of Bubble Deck slabs. Their review highlighted dead weight reductions of 30–35%, comparable flexural strength to conventional slabs, and additional benefits such as improved fire resistance, acoustic insulation, and faster construction. Importantly, they did not overlook limitations, noting increased deflections and punching shear sensitivity near columns. The authors also discussed reinforcement strategies such as GFRP to enhance shear capacity, reinforcing the view that Bubble Deck slabs require informed detailing rather than direct substitution for solid slabs.

The sustainability-oriented perspective was further strengthened by Desai and Dhawale (2018), who emphasized the economic and environmental rationale of Bubble Deck slabs using recycled polypropylene balls. Their synthesis of prior studies indicated that slabs could retain up to 75% of load-carrying capacity while achieving significant weight reduction. Although the paper remained largely qualitative and lacked detailed structural analysis, it successfully bridged advanced research with practical relevance, positioning Bubble Deck technology as part of a broader sustainable construction philosophy.

A more comprehensive review was presented by Lakshmikanth and Poluraju (2019), who examined a wide spectrum of performance parameters including flexure, punching shear, cracking behavior, fire resistance, and long-term effects such as creep. Drawing on European case studies, they reported that Bubble Deck slabs retain nearly full flexural strength but exhibit approximately 13% reduction in stiffness compared to solid slabs. Their emphasis on avoiding voids near column supports and careful detailing provided practical guidance for designers. Additionally, their comparison of different void shapes and materials highlighted that Bubble Deck is not a uniform system, but one whose performance is highly sensitive to design choices.

Experimental contributions by Konuri and Varalakshmi (2019) reinforced the feasibility of Bubble Deck slabs through small-scale two-point loading tests. The study demonstrated reductions in material usage and embodied carbon, along with practical benefits such as reduced foundation demand. However, the experiments did not capture two-way action, punching shear, or large-span behavior, and the observed increase in deflection contradicted claims of improved flexural performance. These inconsistencies underscored the need for cautious interpretation and comprehensive evaluation before widespread adoption.

Waghule et al. (2019) presented a detailed review of design, construction, and performance aspects of Bubble Deck slabs. Their work highlighted advantages such as reduced dead load,
increased span efficiency, and sustainability benefits, while also emphasizing the need for continued research to address design limitations. Although primarily a review, the paper reinforced the consensus that Bubble Deck slabs represent an innovative construction technique with substantial potential if supported by rigorous design development.

A broader design-oriented synthesis was provided by Abdul Aziz and Chan Lek Heng (2021), who examined Bubble Deck slabs from architectural, structural, and sustainability perspectives. Their study detailed design considerations related to void size, spacing, and analytical approaches for predicting load capacity, deflection, and vibration behavior. The authors also

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highlighted thermal and energy efficiency benefits, reinforcing the system's relevance to green building practices. The review offered valuable insights for practitioners but relied heavily on secondary sources, pointing again to the need for standardized design guidelines and empirical validation.

More focused experimental research by Ali Sabah Mahdi and Mohammed (2021) investigated cracking behavior, ductility, and energy absorption of Bubble Deck slabs with varying void sizes. Their findings revealed that while Bubble Deck slabs exhibit reduced stiffness and earlier cracking, they demonstrate superior ductility and higher energy absorption at ultimate load compared to solid slabs. Deflections were found to be 12–39% higher, indicating a trade-off between stiffness and seismic performance. This study highlighted that Bubble Deck slabs may be particularly advantageous in earthquake-prone regions due to their enhanced ductility, provided serviceability limits are adequately controlled.

A comprehensive combined experimental and numerical investigation was presented by Kamble et al. (2022), who examined Bubble Deck slabs using AutoCAD modeling, ANSYS finite element analysis, and laboratory testing. Their results showed self-weight reductions of 25–35% while maintaining acceptable strength and serviceability. The study also emphasized sustainability benefits through reduced cement consumption and the use of recycled HDPE balls. However, critical aspects such as punching shear, long-term behavior, and realistic loading conditions were not extensively addressed, limiting the generalizability of their conclusions.

Across the literature, a consistent pattern emerges: Bubble Deck slabs offer substantial reductions in dead weight, material consumption, and environmental impact while maintaining comparable flexural strength to conventional slabs. At the same time, increased deflection, reduced stiffness, and vulnerability to punching shear near columns remain persistent challenges. Many studies rely on small-scale experiments or numerical simulations, with limited full-scale validation. Long-term performance aspects such as creep, shrinkage, fatigue, durability, and behavior under seismic and dynamic loads are inadequately explored. Moreover, cost analyses often focus solely on material savings, neglecting construction complexity, labor, formwork, and quality control.

In summary, the existing literature clearly establishes Bubble Deck slab technology as a structurally viable and environmentally sustainable alternative to conventional RCC slabs.

However, its successful implementation depends on careful optimization of void geometry, reinforcement detailing, and shear-critical regions. The technology should not be viewed as a direct replacement for solid slabs, but as a specialized system requiring informed design judgment. Future research must focus on full-scale experimental validation, long-term

Serviceability, seismic performance, life-cycle assessment, and the development of codified design guidelines to enable confident and widespread adoption in modern construction practice.

Observations and Discussion

Applications of BDS:

MPCC Building: The MPCC, which was finished in October 2016, is the country's first public building. It is located in the Perth, Western Australia neighborhood of Buckingham. The building's design and construction required 2.3 m2. The suspended ceilings were constructed using 132 BD semi-precast panels. With the low weight of the overall structure and BD cavities panels designed in two directions, the foundation loads are reduced, and flexibility in the design of the foundations is provided to lessen the various

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settlements of the building. Last but not least, the MPCC is predicted to use 20% less mass and 250 m3 less concrete than the Traditional Alternative. The MPCC won the category for environmental and sustainability excellence in construction, earning a six-star certification for design and construction.

Millennium Tower:

The first structure with slab bubble ceilings was developed at the Millennium Tower in Rotterdam, Netherlands. The project's original specifications called for using bubble deck hollow core slabs. However, it was decided to adopt the bubble deck slab design before building started, which caused an increase of 10 storey construction cycles over a duration of 4 days. Additionally, this resulted in a 50% decrease in the quantity of piers utilized during construction and a savings of 500 truck trips. Due to the fact that this technique does not need beams, the decrease of the right foot allowed for the addition of up to two levels. The 35 storey of the 130.8 m-tall Millennium Tower. It is the second-tallest skyscraper in the Netherlands and was created by WZMH Architects and AGS Architecten and it was finished in 2000.

Advantages:

The **Bubble Deck slab system** offers several advantages that make it both practical and innovative. From a **structural perspective**, the design is significantly lighter than traditional slabs, eliminating the need for heavy beams and reducing the number of supports required. This not only improves efficiency but also allows greater freedom in architectural design, making it well-suited for large-scale and complex projects.

On the **construction side**, the system is highly efficient as it reduces on-site activities and speeds up the overall building process. With less formwork and simpler assembly, projects can be completed faster while ensuring quality and safety.

The **economic benefits** are equally noteworthy. By cutting down material use by up to 50% and reducing concrete consumption by nearly 35%, the system ensures considerable cost savings. It also lowers transportation expenses and minimizes the need for intensive labor or carpentry, making construction more affordable and less dependent on skilled manpower.

Finally, from an **environmental standpoint**, the Bubble Deck system supports sustainable development. By reducing material use, energy demand, and carbon emissions, it contributes to greener construction practices and helps minimize the ecological footprint of modern buildings.

Conclusion:

In the current state of the construction industry, there is a growing need for conservative strategies that are easily adaptable and based on consensus. The introduction of the bubble deck slab is an innovative solution that promotes cost-effectiveness, ease of development, and improvement in local conditions. The bubble deck technology serves as a creative support system that eliminates the use of concrete in the central section of the slab, with additional structures like beams reinforcing the concrete columns.

The adoption of this technology results in a reduction in the consumption of steel and concrete. By implementing the bubble deck slab, the overall usage of materials is minimized, leading to cost savings. Furthermore, structures utilizing this technology require smaller foundations due to the reduced load transferred to the ground. It is worth noting that the execution of bubble deck technology requires a high level of expertise, although not necessarily from the end-user.

Moreover, the implementation of bubble deck technology in Brazil provides a valuable

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opportunity for civil engineering education. It allows for project supervision and involvement with the bubble deck technology, which is highly beneficial for the learning experiences of civil engineers.

In future research, it is recommended to conduct experimental tests to ensure the consistency and reliability of the data provided by the bubble deck plate manufacturers. Additionally, performing a comparative analysis of execution times is important to assess the efficiency of the bubble deck technology compared to traditional construction methods.

In summary, the bubble deck slab technology offers a promising approach to achieve cost reduction, efficient material utilization, and improved construction practices. Its implementation has the potential to bring significant benefits to the construction industry. Further research and development efforts are necessary to enhance its adoption and effectiveness.

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