Anbar Journal of Engineering Science (AJES) **Vol. 16 , No. 2 (2025) , pp. 1 ~ 15**
P-ISSN: 1997-9428 ; E-ISSN: 2705-7440 DOI: http://doi.org/10.37649/AJES-25-009

University of Anbar

Anbar Journal of Engineering Science

journal homepage: https://ajes.uoanbar.edu.iq/

Bubble Deck Slabs: An Innovative Structural System for Sustainable Construction – A Review

Ahmed A. Mohammed Ali [a], Suhaib Y. Al-Darzi [b]
[a] *Department of Civil Engineering, College of Engineering, University of Mosul, Mosul, Iraq*
Email: a.aldubony@uomosul.edu.iq; ORCID: https://orcid.org/ 0000-0003-0172-0416
[b] *Department of Civil Engineering, College of Engineering, University of Mosul, Mosul, Iraq*
Email: suhaib.qasim@uomosul.edu.iq; ORCID: https://orcid.org/ 0000-0001-5346-8836

PAPER INFO

Paper history
Received: 03/03/2025
Revised: 26/06/2025
Accepted: 12/08/2025

Keywords:
Bubble deck slabs
Concrete slabs
Punching shear
Sustainability
Void geometry

ABSTRACT

The Bubble Deck slab is an innovative construction technique that incorporates spherical plastic voids inside concrete slabs to diminish self-weight while preserving structural integrity. This technology reduces the amount of material used by a significant amount by carefully replacing non-structural concrete with voids, which results in cost savings and improved sustainability. The production of bubble deck slabs, their design principles, benefits, drawbacks, and new developments in their use are all covered in this review study. Particular emphasis is placed on their role in modern construction, highlighting their environmental benefits, ease of installation, and structural performance compared to conventional solid slabs. Additionally, the study also highlights critical research areas, including the interaction between voids and reinforcement, the slab's behavior under static and dynamic loading conditions, and its contribution to sustainable building practices. Bubble Deck slabs help make concrete production more sustainable by minimizing the total carbon impact, improving load distribution, and decreasing construction waste. Even with these limitations, recent progress in material science and computational modeling has strengthened their potential as a sustainable and efficient substitute for standard reinforced concrete slabs. The use of Bubble Deck technology is an important advancement in the direction of structural systems that are more efficient in their use of resources and that perform better, as construction practices continue to develop toward more environmentally friendly solutions.

1. Introduction

Bubble deck slabs are a creative structural technique that reduces self-weight while maintaining enough load-bearing capacity by introducing spherical voids into a concrete slab. This concept, first introduced in the early 1990s, offers significant material savings and improved structural efficiency compared to traditional solid slabs [1]-[5]. As the construction industry increasingly prioritizes sustainability and reducing carbon footprints, interest in using state-of-the-art composite materials to enhance bubble

* Corresponding author: Ahmed A. Mohammed Ali; a.aldubony@uomosul.edu.iq

deck slab performance has increased [6]-[10].
The bubble deck slab is a fascinating invention with many possible benefits, such as increased spans between supports, less weight, and lower prices. The bubble deck slab floor. The bubble deck system is used for ground floor slabs, roof floors, and story floors.
The findings of this review research should enhance knowledge of the uses of composite materials in civil engineering, especially sustainable construction practices. Optimizing bubble deck slabs can increase structural efficiency, improve durability, and decrease environmental impact, which aligns with the global trend towards greener construction technologies [11]-[16].
In contrast to all these advantages and benefits of the bubble deck slab system, there are some disadvantge [17] such as:
1. Shear Capacity: The bubble deck slab exhibits approximately 40% lower shear resistance compared to a solid slab of identical thickness.
2. Bending Stresses: Flexural stresses in the bubble deck are 6.43% lower than those in an equivalent solid slab, attributed to reduced self-weight.
3. Deflection Behavior: The bubble deck shows 5.88% greater deflection than its solid counterpart due to diminished stiffness from the voided geometry.
That stand as an obstacle to the spread of this type of slab to this day, and this research will participate in reducing these limitations and finding solutions for them.
Although the Bubble Deck slab system has been extensively explored for its ability to reduce self-weight and improve material efficiency, notable gaps remain in key areas. This review examines the performance of Bubble Deck slabs compared to conventional solid slabs under identical loading conditions, and offers solutions to address the bubble deck system's limitations.

2. Bubble Slab's History

To promote environmental sustainability and reduce the ecological impact of construction, buildings should minimize cement usage. The bubble deck slab is an innovative solution that hasn't been fully adopted yet, despite its successful use in major construction projects across Europe and the United States. This approach enables the direct incorporation of air spaces inside the concrete, therefore declining the self-weight of slab while preserving its durability and strength standards. The gaps formed in the central area of a slab by the incorporation of plastic spheres diminish the slab's weight by over 30%, allowing for greater spans between supports in slabs with bubble deck voids compared to concrete slabs with conventional systems, thereby decreasing the necessity for columns or additional support constructions in a building. The slab's versatile configuration may readily handle irregular and curved plan combinations, as seen in figures (1) and (2), which demonstrate the philosophy of this approach. The aforementioned technology facilitates extended spans, expedited and cost-effective installation, and the removal of down-stand beams [18],[19].

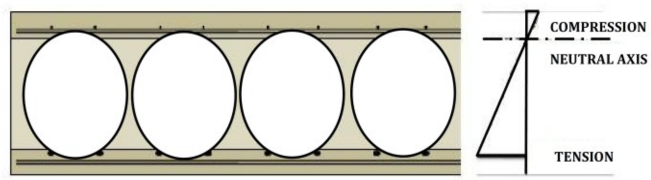

Fig. 1. Bubble deck slab stress diagram [19]

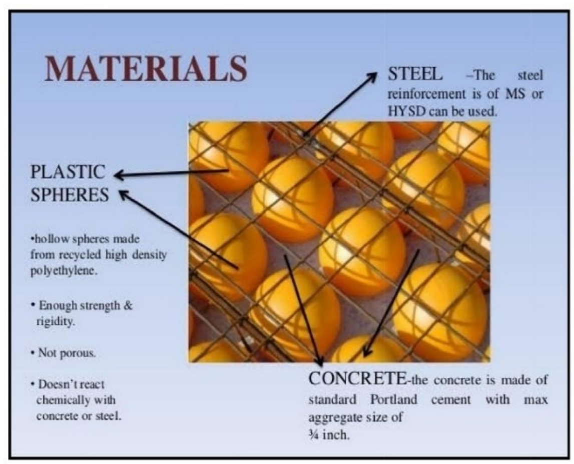

Fig. 2. Various components of bubble deck slab: [19]

Ibrahim et al. [20] conducted a study on the flexural strength of reinforced two-way bubble deck slabs. These slabs incorporate a two-dimensional void arrangement to reduce self-weight. The effectiveness of bubble deck slabs depends on the ratio of bubble diameter to slab thickness.
For their tests, the researchers supported the slab on all four edges with special steel beams. These beams had hinged tops to prevent unwanted stress concentrations during loading. Using custom equipment (shown in Figure 3), To evaluate

flexural performance—including ultimate load capacity, deflection, concrete compressive strain, and crack patterns—two-dimensional flexural tests were performed using a specialized loading system. As shown in Figure 4, mid-span deflection was measured along the bottom surface of the slabs, while compressive strain was recorded at nine locations using DEMEC strain gauges. The results revealed that both crack patterns and flexural behavior are influenced by the void diameter-to-thickness ratio. Notably, bubble deck slabs with a ratio between 0.51 and 0.64 exhibited ultimate load capacities comparable to solid slabs, with only a 10% reduction in strength.

Fig. 3. Test configuration of two-way Bubble deck slab. [20]

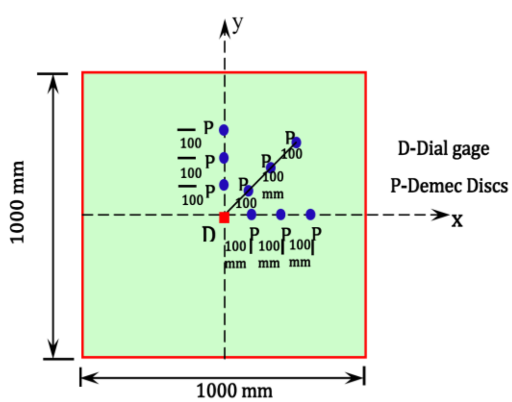

Fig. 4. Locations of dial gages and DEMEC. [20]

Hai et al. [21] conducted an experimental and computational study on bubble Deck Slabs, aiming to minimize the concrete volume in the slab's center by using recycled spherical balls. Plastic hollow balls were used to substitute the ineffective concrete in the slab's core, therefore diminishing the dead load and improving the floor's efficacy, as well as improving the performance of the bubble deck slab in places with Seismic sensitivity ranges from mild to severe. The structural behavior of the slab was analyzed using ANSYS program (Finite element analysis program). the Conventional and the bubble deck slabs are exposed to an equally distributed load. Analytical measurements were made of the ultimate load, stress, and deformation.
The primary characteristic of a bubble deck slab is the incorporation of voided plastic spheres, and anchored inside a prefabricated reinforcing structure. Thus, this reinforcement concrete structure serves as the top and bottom reinforcement for the concrete slab. The diameter of spherical balls ratio to the slab thickness may result in over a 30% reduction in concrete material use compared to a concrete slab of equivalent depth. The environmental effect is a crucial consideration in building projects using bubble deck slabs. Utilizing bubble deck system as slabs may decrease the overall quantity of concrete required for a project, hence reducing the emissions of carbon dioxide. Bubble deck panels contribute to reducing the need for heating and cooling, as a result of reducing the overall weight of the building, which in turn reduces energy consumption. Lighter structures use less energy for temperature regulation, leading to considerable long-term energy savings. The use of bubble deck slabs necessitates less resources, hence decreasing the quantity of trash produced during construction. This may mitigate the environmental effect of construction projects and foster more sustainable practices within the building sector. Moreover, using bubble deck slabs to lower the dead weight of structure is highly beneficial in areas vulnerable to earthquakes and other seismic disturbances, enhancing the seismic safety of the edifice [22].
By utilizing less concrete, bubble deck slabs may also significantly decrease construction time and cost. Additionally, because of their lighter weight, the slabs may be simpler to handle and install on site, which might result in shorter construction periods and cheaper labor costs [23].

Mahdi and Mohammed [24] performed research on the bubble deck slabs structural behavior subjected to static distributed loads. The experimental program included the assessment of five fixed-end supported two-way solid and bubble deck slabs, each slab measuring (length=2500, width=2500, and depth=200) mm, as seen in figure (5).

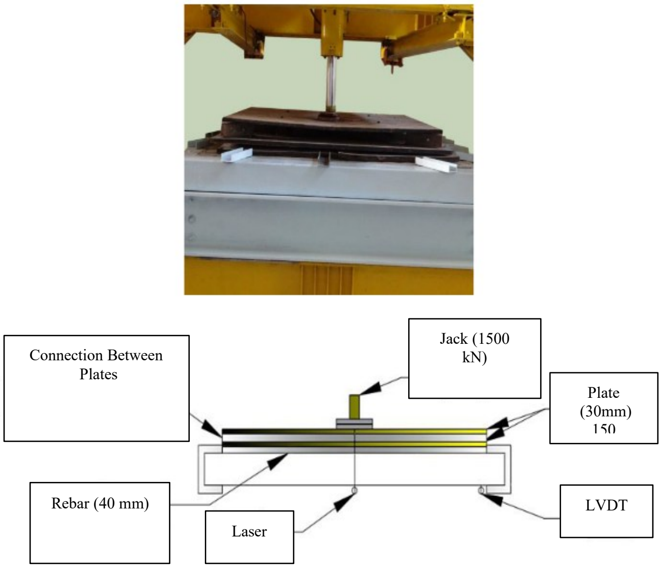

Fig.5. Test set up. [24]

The bubble diameters of 100 mm and 120 mm, together with concrete material reductions of (15% and 18%), were among the characteristics considered. Figures (6) and (7) illustrate that the remaining parameters,

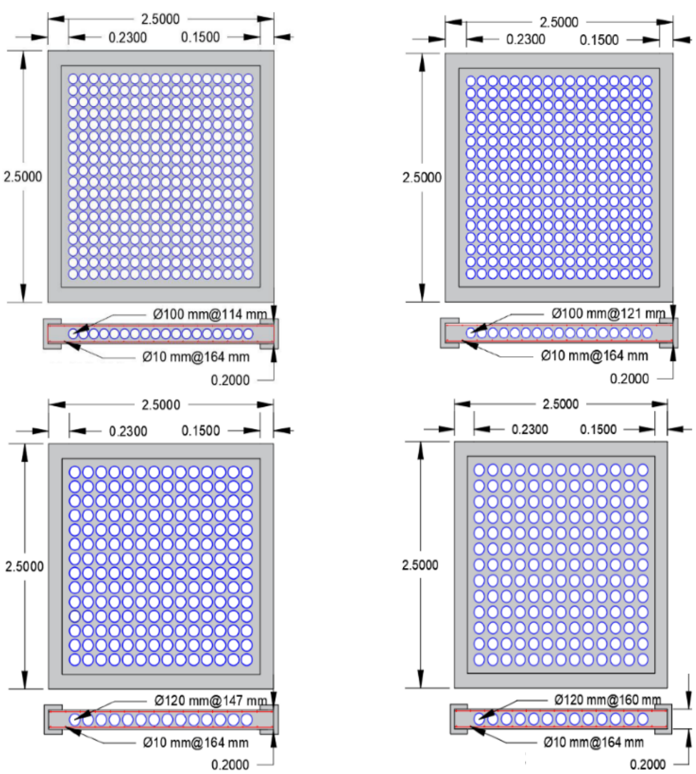

Fig. 6. Geometric layout and reinforcement details for the specimens. [24]

Fig. 7. (a) Bubble with Ø4 reinforcing steel (b) Bubble deck slab [24]

steel reinforcement configuration and compressive strength of concrete, were consistent throughout all examined specimens: (24 MPa for compressive strength of concrete and (Ø10 @164 mm) for steel reinforcement). The specimens were fabricated in accordance with ACI 318M [25]; they had suitable dimensions to ensure the bubbles were positioned within the permissible spacing (2/3D bubble) as recommended by (Technical Manual & Documents) [26]. the samples were divided into two categories: one was a solid slab, and the others were bubble deck slabs; they were classified into two categories to examine the impact of reduced concrete volume and bubble size on structural performance. Two bubble diameters (diameter (D1) = 100 millimeters and diameter (D2) = 120 millimeter) and two separate sets of inter-bubble spacings [(114 and 121) and (147 and 160)] were employed, as seen in figure (6). A compromise was achieved between the chosen diameters and the distance between each of the bubbles to provide comparative analysis of different concrete volume reduction percentages. The findings indicated that a reduction of 18% and 15% in concrete volume corresponded to a reduced in the maximum load strength of a bubble deck slab by 15.9% and 11.5%, respectively, relative to the solid slab. In contrast, an enhanced behavior was achieved, resulting in increases in the ductility factor, absorbed energy, and final deflection of 39%, 5.3%, and 14.94%, respectively.

The bubble deck slabs behavior under dynamic loading is of special interest for applications in construction subjected to vibrations or repeated loads, such as flooring used for industry as well as bridges. Mota et al. [27] investigated the response of bubble deck slabs under dynamic loading and found that the natural frequency of the bubble deck slabs was a little higher than that of solid slabs. However, Bubble deck slabs can function effectively under dynamic loading situations, nevertheless, as evidenced by the comparable damping qualities that were discovered. In addition, the study discoverd that bubble deck slabs showed excellent fatigue resistance, with no discernible degradation in performance after repeated loading cycles.

Shear strength is an essential feature of the design of bubble deck slabs, since the existence of bubbles may reduce the slab's resistance to shear f actions. According to Oukaili and Merie [28], the shear capacity of bubble deck slabs is slightly lower than that of conventional solid slabs, specially when the the slab is subjected to concentrated loads close to the supports. The study suggested the increasing the thickness of bubble deck slab or using additional shear reinforcement in high shear forces region where are predictable. Additionally, the study found that both bubble deck and conventional slabs exhibited similar failure mechanisms, with shear failure rather than flexural failure being the most common kind of failure.

Abdulkhaliq and Al-Ahmed [11] Examined the efficacy of plastic-bubbled deck slab structures. Six samples of one-way concrete slabs with dimensions (length=2600, width=600, and depth=150) mm were tested and supported at two points for bending study. The tested samples embedded with polymer spherical voids and included I-shaped steel beams as well as strengthened with Glass Fiber Polymer (GFRP) bars. The reference solid slab without polymers spheres was compared to five aerated slabs, a single one which was unreinforced. A 15.48% decrease in self-weight for slab incorporated with 90 mm diameter polymer sphere voids. Two designs of steel I-beams, consisting of two and four steel I-sections, were employed to improve many parameters, including specimen type and internal reinforcement. Ø10 mm bent-up steel bars and channel shear connections were employed to augment shear resistance. The 4I-section arrangement has a cross-sectional area comparable to that of the 2I-section configuration. Compared to the solid slab, the bubble slab showed a border variety of deformations during the same loading time, with the ultimate load capacity dropping by 30% and deflection occurs at a greater ratio of 18% to 85%. Furthermore, the specimen's performance was enhanced with the integration of embedded steel I-beams compared to bubble and solid slabs. This was accomplished by eliminating cracks, increasing by 85% and 30% of ultimate load capacity, reducing the deflection under service load by 60% and 49%, and boosting flexural stiffness by 102% and 71% at stage of ultimate load, respectively. The ultimate load rose by 13% to 22%, and deflection decreased by 8% to 15% when channel shear connections were utilized, in comparison to specimens lacking these connectors.

Mtashar and Al-Azzawi [29] performed research to evaluate six slab specimens (1000 mm × 1000 mm dimensions) as two-way simply supported slabs, with three subjected to monotonic loading and three to repetitive loading. The examined specimens consist of one solid slab and two voided slabs, differing in slab type (solid and voided), steel fiber content (0% and 1%), and the inclusion of GFRP layers. This study reports the results of the slab tests and recommends the 3D-Nonlinear finite element software (ABAQUS) to validate the slab tests under repetitive and monotonic loading conditions. The researchers determined that the ultimate load and energy absorption for models subjected to repeated loads is reduced by around 15-20% compared to those evaluated under monotonic loading, attributable to the cycles of loading and unloading. The finite element models used in this work are effective for modeling two-way voided slabs, as they correlate well with the experimental data, hence rendering the parametric analysis trustworthy and valid. The ABAQUS study shown that replacing cubic voids with cylindrical spaces in the voided slabs had a little effect, not surpassing 3% in both ultimate load and final deflection, while enhancing energy absorption by 17%. Moreover, the ultimate deflection decreased by 23%, and the energy absorption increased by 21.6% when a (Ø12 mm) bar was used as reinforcement instead of a (Ø10 mm) bar. Reinforcing the lower surface of the voided slab with four strips of GFRP sheets in both orientations is more efficacious in reducing deflection by 25% compared to complete reinforcement with GFRP sheets. Furthermore, supporting the solid slab on fixed edges rather than simple supports resulted in an increase in ultimate load and energy absorption by 15% and 12%, respectively.

Al-Gasham et al. [30] presented a study on the structural behavior of reinforced concrete one-way slabs with polystyrene balls as voids, loaded statically. They used four slab specimens, one solid control and three with different void diameters (60 mm, 70 mm, and 90 mm), representing different percentages of the slab depth. It was found that the slabs with a 50% slab depth-web depth voided (60 mm diameter) balls showed no significant decrease in strength, slight decrease in stiffness, ductility and toughness, thereby indicating that this void size is found to be structurally efficient. Upon increasing the void size to 90 mm (75% of slab depth), on the other hand, increasing the void diameter to 90 mm (75% of slab depth) led to significant reductions in all key performance indicators, including a 21.3% decrease in strength and a 67% reduction in ductility, alongside a notable shift in failure mode from flexural to shear. This highlighted the sensitivity of voided slab performance to void size and placement, emphasizing the need for optimization to avoid premature failure. In a complementary study, another research team Jabir et al. [31] examined the performance of both conventional (solid) and bubbled (voided) slab strips subjected to limited repeated loading using a four-point bending test. Each specimen was subjected to ten load cycles at 70% of the estimated ultimate load prior to failure testing. The study included variations in shear span-to-depth (a/d) ratios (2, 3.5, and 5), allowing an assessment of how geometry influenced behavior under repeated loads. The voided slabs consistently showed a rather sudden shear failure irrespective of a/d ratio whether the slab was solid or voided. As the a/d ratio increased, the slabs also exhibited lower strength, stiffness, and toughness, and tended to become more ductile. While the voided slabs showed decrease in their mechanical performance, the research emphasized their environmental benefits with around 14% less emissions of CO_2 and about 10% less embodied energy than the solid slabs.

Referring back to the results obtained by Al-Gasham et al. [30], the bubble slab that was tested under monolithic loading till failure experienced ductile flexural failure as opposed to the same specimen examined by Jabir et al. [31], which failed suddenly in shear.

This observation means that the failure modes on the bubble slabs tested under a repeated loading were different, although the loading was small. Moreover, in the al-Gasham et al. [30] slab reduced to around 17.7% of the strength in relation to the control solid sample as compared to 21.9% in Jabir et al. [31] for the same specimen. This statement also demonstrates that repeated loads reduce slab strength by positioning balls more significantly than monolithic loads.

Regarding design standards and the design process for the bubble deck slab, Researchers and engineers mainly depending on DIN 1045-1 [32] or Eurocode 2 (EN 1992-1-1) [33] as design codes. These standards establish important guidelines for material properties, structural analysis, and safety considerations applicable to conventional and innovative concrete slab systems [34],[35],[36].
The standards provide specifications for the stiffness and load bearing capabilities of reinforced concrete slabs. Bubble Deck slabs, due to their voids, possess unique stiffness as well as altered load distribution when compared to solid slabs. Both codes encompass specialized services that aid in the determination of bending moments, shear resistance, and deflection limits which impact serviceability and safety. In the case of shear and punching shear resistance, the voids also play major roles in the shear behavior of Bubble Deck slabs, especially in the column support regions. The two codes greatly assist in the establishment of shear reinforcement regulations that help counteract the negative impacts of diminished shear strength.

These codes greatly determine, define, and manage the precision of crucial information which aids in the construction of Bubble Deck slabs. However, additional experimental validation or case-specific approvals may be necessary to account for the system's innovative design. However, additional experimental validation or case-specific approvals may be necessary to account for the system's innovative design.

Table 1 below presents another main studies on bubble deck slabs together with the key results of the researchers.

Lee et al. [37] investigated the load-bearing capacity and deformation characteristics of bubble deck slabs. Concluded that spherical voids reduce the slab weight significantly without compromising structural performance for typical loads.
Markovic et al. [38] used finite element method to evaluate stress distribution and deflection. Concluded that bubble deck slabs exhibit similar flexural behavior to solid slabs but with reduced self-weight and material cost.
Jaya et al. [39] performed punching shear tests. Concluded that the slab's punching shear capacity decreases slightly with voids but remains within acceptable limits for design purposes.

Table .1 Summary of previous researches.

Author	Year	Methodology	Size of Spherical Voids (mm)	Thickness of Slab (mm)	Model Dimension (m)
Lee et al. [37]	2010	Experimental and Numerical Analysis	180	230	4 × 4
Markovic et al. [38]	2013	Finite Elementz Method	200	250	5 × 5
Jaya et al. [39]	2015	Experimental Study	150	200	3 × 3
Patel et al. [40]	2018	Analytical and Laboratory Testing	200	260	6 × 6
Alhassan et al. [41]	2020	Experimental Analysis with GFRP Reinforcement	190	300	4 × 6
Kumar et al. [42]	2022	Experimental Investigation of Punching Shear	180	280	5 × 5

Patel et al. [40] performed a comparative examination of bubble deck and traditional slabs. Discovered that bubble deck slabs achieve a 25% decrease in weight while preserving comparable load-bearing capability.
Alhassan et al. [41] investigated the incorporation of GFRP bars in bubble deck slabs. Determined that GFRP reinforcement improves durability and mitigates corrosion problems, making it appropriate for harsh settings.
Kumar et al. [42] investigated the punching shear resistance of bubble deck slabs. Determined that optimal void location and slab thickness are essential for preserving structural integrity under substantial loads.

3. Structural Efficiency

3.1. Design Principles of Bubble Deck Slabs

Spherical voids, a top and bottom reinforcing mesh, and the concrete around the bubble deck slab are its three primary constituents. All of these parts work together to produce a lightweight slab that is as heavy-duty as feasible. This design eliminates concrete since it has a minor effect on structural performance in the neutral axis region. Due to the replacement of superfluous concrete with spherical voids, the slab is about 30 to 50% lower than a solid slab of the same size. Standard design standards like Eurocode 2 [33] provide guidance for bubble deck slab research and design by accounting for their distinct structural characteristics.

3.2. *Design Parameters*

3.2.1 **Void Geometry:**

- The arrangement and morphology of air voids substantially affect the load-bearing capacity and self-weight of the slabs. An optimally planned void geometry can decrease the slab's weight by 30% to 50%. [43],[44],[45].
- Height and distribution of voids are critical; they directly affect the flexural stiffness and overall performance of the slab [44].

3.2.2 **Reinforcement Considerations:**

The type and quantity of reinforcement exert a minimal influence on stiffness; nonetheless, the overall shape of the slab is essential for enhancing performance. [44].

3.2.3 **Design Optimization:**

- Employing numerical homogenization and optimization methods can reduce material consumption while adhering to serviceability constraints. This method may result in a 23% decrease in concrete weight [46].
- The optimization process needs to take special structural requirements and environmental conditions, including seismic activity, to improve performance [43],[47].

Although these criteria are crucial for optimizing bubble deck slabs, it is also vital to acknowledge the potential trade-offs, including heightened design complexity and the necessity for specialist expertise in void configuration and material characteristics. Balancing these elements can result in successful and efficient construction solutions.

4. Advantages and disadvantage of Bubble Deck Slabs

Using bubble deck slabs as a structure in building offers many benefits and limitation that are essential for evaluating their suitability. These slabs, including hollow plastic bubbles to minimize concrete usage, provide considerable advantages in weight reduction and cost efficiency. Nonetheless, they present problems that must be resolved for effective application.

4.1 Advantages of Bubble Deck Slabs

4.1.1 **Material Reduction:** Bubble deck slabs use hollow spaces to remove non-structural concrete, resulting in decreased total material usage [48],[49].

4.1.2 **Weight Reduction:** The bubble deck slab system can reduce the weight of concrete structures by **30–50%**, which is particularly beneficial for high-rise buildings. This significant weight reduction lowers dead loads and enhances seismic performance [43],[50].

4.1.3 **Material Efficiency:** The design reduces concrete use, allowing a more sustainable building methodology. One kilogram of recycled plastic may substitute one hundred kilograms of concrete [50].

4.1.4 **Cost-Effectiveness:** Using less material results in reduced building costs overall, which includes cheaper labor and transportation expenses [43],[50]. researches show that using High Density Polyethylene (HDPE) spheres lowers material expenditures by about 14.4% when compared to traditional approaches [51].

4.1.5 **Augmented Structural Performance:** These slabs may extend greater lengths without supplementary support, hence enhancing the architectural versatility of high-rise designs Khairussaleh et al., 2022 [52],[53].

4.1.6 **Lightweight building:** The decreased dead weight enables smaller foundations and columns, hence reducing material needs and building expenses [54],[55],[56].

4.1.7 **Sustainability:** During production and transit, these slabs help reduce energy consumption and CO2 emissions [43],[51].

4.1.8 **Structural Integrity:** Despite the reduced use of concrete, bubble deck slabs maintain the integrity of the infrastructure, making them a suitable alternative to traditional slabs [48].

4.1.9 **Design Flexibility:** Bubble deck slabs are suitable for a broad range of structural and architectural applications since they can be produced to fit a variety of forms and sizes.

4.2 Restrictions of Bubble Deck Slabs

4.2.1 **Design Complexity:** The general application of bubble slabs may be limited due to the particular knowledge and expertise required for their design and manufacturing [44]. Compared to conventional approaches, the use of bubble technology necessitates sophisticated design processes and could lead to more complicated building procedures [53]. Bubble slabs provide innovative solutions for modern architecture, but their application needs to be carefully considered in light of any performance restrictions and design challenges. The solution of this disadvantage is publishing design manuals and create pre-engineered designs for common spans (Standardized Templates)

4.2.2 **Market Familiarity:** The adoption of the bubble slabs technology is hindered by the actual use of traditional technologies, as the engineers are more familiar with them [51]. campaigns for education, focus on architects and contractors, this could be a solution to this challenge.

4.2.3 **Performance Concerns:** The reduction of concrete is likely going to impact the flexural and shear capacity of the slabs, which demands a design approach to ensure load responsiveness without compromising performance [52]. It is possible to overcome this drawback by enhanced testing by conduct long-term load/durability tests. As well as, combine bubbles with fiber reinforcement (hybrid systems)

4.2.4 **Material Availability:** In some areas, however, acquisition and logistics for the production HDPE spheres can be challenging [49]. In contrast, despite bubble deck slabs offering novel solutions on new construction designs, standard reinforced concrete slabs still dominate due to its established methods and ease of use. A further underlying highlight is that research and development are ongoing to advance the applicability of the bubble deck system in different building and construction circumstances. Additionally, it could manufacture alternative materials or recycled plastic bubbles regionally.

4.2.5 **Higher Initial Costs:** Although considerable concrete material savings are carried out; the preliminary expenses of bubble deck slab can be excessive due to the manufacturing and transportation of voids. By using lifecycle cost analysis, this lake can be resolved: Emphasize long-term savings (maintenance, energy).

4.2.6 **Reduced Fire Resistance:** Voids in the slab can decrease the fire resistance of slab element. Although the slab's fire resistance [57] is a complicated issue, it mostly depends on the steel's capacity to maintain enough strength during a fire when it will be burned and lose a substantial amount of strength as the temperature rises. If the standard bubble material is used (HDPE), the products of combustion are relatively benign, certainly compared to other materials that would also be burning in the vicinity. The fire resistance of the slab is directly impacted by the concrete cover. The bubble deck slab's fire resistance ranges from 60 to 180 minutes, and its smoke resistance is around 1.5 times that of the fire resistance, according to Ali & Kumar [58].

4.2.7 **Applicability to Specific Projects:** Some specialized types of buildings, especially those with concentrated high loads, might not be suited for bubble deck slabs [59],[60].

5. Consideration of Durability

5.1 *Decreased weight*: By adding hollow plastic spheres, the dead weight of the slab is reduced by 30% to 50%, which might eventually result in less stress [61].

5.2 *Material Efficiency*: this design preserves structural integrity while requiring smaller volume of concrete mixture that may contribute to stability [48].

5.3 *Flexural Strength*: Studies show that bubble deck slabs can maintain or exceed higher flexural strength than conventional slabs resulting in a durable structure [62].

5.4 *Maintenance Considerations*:

5.4.1 **Cracking and Deflection:** The distinctive structure may result in inconsistent flexural stiffness, requiring routine examinations to detect cracks and deflections [46],[63],[64].

5.4.2 **Thermal Performance:** Various insulation materials may have been utilized, but the hollow spheres' temperature variation impacts are still expected to be long lasting [61].

Conversely, even though bubble deck slabs offer novel techniques to minimizing material consumption and enhancing strength performance, their sturdiness can be stricken by variables which includes environmental conditions and load-bearing demands, probably requiring greater normal maintenance than conventional slabs.

When choosing the ideal material for bubble deck slab construction, numerous critical elements must be evaluated to guarantee structural integrity, weight reduction, and cost efficiency. The criteria encompass the geometry of voids, concrete classification, type of reinforcement, and comprehensive design optimization [65].

6. Performance under Types of Loads

6.1 Performance under Static Loads

Studies indicate that bubble deck slabs have equivalent or marginally reduced load-bearing capability relative to solid slabs of same diameters. The reinforcement and concrete collaborate to offset the eliminated concrete in the voided area [24],[66].

6.2 Performance under Dynamic Loads

The dynamic performance of bubble deck slabs is affected by the interaction between the voids and the reinforcement. Research showed that these slabs can endure dynamic and repeated stresses, making them appropriate for bridges, parking structures, and industrial slab [27],[67].

6.3 Resistance to Punching Shear

A primary focus of study is the punching shear resistance of bubble deck slabs, particularly around columns. Experimental studies demonstrate that the existence of voids somewhat reduces punching shear strength; however, this impact may be mitigated by careful design and reinforcement specifications [28],[68].

7 Discussions of Results

7.1 Load Capacity

Both experimental and theoretical analyses reveal differences between Bubble Deck and conventional solid slabs. Studies indicate that the ultimate load capacity of Bubble Deck slabs is approximately 11% lower than that of solid slabs [69]. This finding is corroborated by experimental data showing maximum load capacities of 398.2 kN for Bubble Deck slabs versus 424 kN for conventional slabs under identical loading conditions [70]. As evidenced by the experimental data in Table 2, the Bubble Deck slab exhibits reduced load-carrying capacity compared to conventional solid slabs. This decrease in performance is primarily attributed to diminished sectional stiffness resulting from the incorporation of hollow plastic spheres within the slab's cross-section. However, the system maintains significant flexural resistance through the composite action of its tensile steel reinforcement at the bottom and the concrete compression zone at the top, which collectively enhance bending stiffness [58].

Table .2 Load Capacity conventional slab versus Bubble Deck slab (KN) [70]

conventional slab	Bubble Deck slab
0	0
50	42.8
100	58.92
157	100
214.2	133.92
324.9	192.85
371.4	235.7
424.9	317.14
378.5	399
373.2	389.28
300	355.35

7.2 Deflection

from figure 8 solid slab carried more load compare to that of bubble deck slab and causes less deflection to bubble deck slab. Results of study [70] show bubble deck slab carried a load of 398.2KN and causes a deflection of 13.3mm while conventional solid slab carried 424KN and causes deflection of 12.26. These findings confirm that under identical loading conditions, Bubble Deck slabs show approximately 8.5% greater deflection than their conventional counterparts, as graphically represented in Figure 8. This implies that the resulting deflection will be higher in bubble deck slab than in solid slab, under the same loading condition.

This increased deflection behavior stems primarily from the reduced stiffness inherent to the Bubble Deck slab, resulting from the introduction of bubble void. However, this structural drawback is mostly mitigated by the significant material efficiency. achieved through concrete volume reduction (approximately 33% less concrete usage compared to solid slabs).

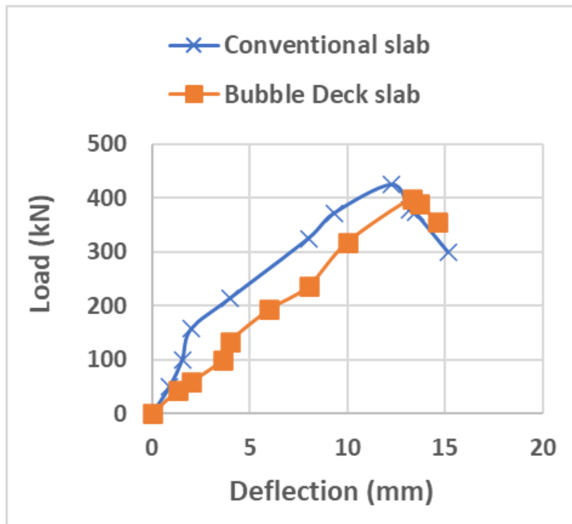

Figure 8 Load vs Deflection curve for comparison [70]

7.3 Shear Strength

According to Lakshmikanth and Poluraju [71], the shear strength of the bubble deck slab ranges from 60 to 80% of that of an equivalent solid slab. The experimental analysis done by Tiwari and Zafar [58] yielded a bubble deck slab shear capacity that was 75% of the corresponding solid slab shear capacity.

Based on the consistent data from several research, the current analysis uses a conservative safety factor of 0.6 for shear strength calculations in Bubble Deck design. When calculated shear demands exceed this reduced capacity, structural elements require additional shear reinforcement.

Critical locations requiring such reinforcement usually include: (Support areas near columns or walls, areas with concentrated burdens and locations for abrupt section changes).

This design technique ensures acceptable safety margins while preserving the system's material efficiency advantages. The 25% capacity loss is a suitable trade-off given the 33% concrete savings and lower dead loads associated with Bubble Deck construction.

8. Applications of Bubble Deck Slabs

Bubble Deck slabs have been effectively used in several construction projects, including high-rise structures where weight reduction is essential.

- Structures with extended spans, including bridges and auditoriums.
- Parking structures and industrial surfaces necessitating substantial load-bearing capability.
- Eco-friendly buildings designed to reduce environmental effect.

9. Conclusion

Bubble Deck slabs have come forth as an advanced approach in the domain of structural engineering. This system uses voided plastic spheres which helps to remove concrete in the middle of the deck where it is not needed from a structural point of view. As a result, it reduces the weight of the deck slab and also the quantity of concrete needed to a great extent. As a result, it reduced the load transferred to beams, columns, and foundations, which in turn can reduce construction costs and allow for more efficient foundation designs.

The Bubble Deck system has one of the most important pros of potentially reducing the amount of materials used and the time it takes to construct the building. Aside from cost efficiency, these advantages along with the sustainable construction process adhere to the rising eco-friendly concerns within the construction industry.

Of course, like any system, the Bubble Deck tiles do not come without their drawbacks. Concerns such as punch strength and fire resistance were raised, but studies showed that these problems could be effectively addressed with appropriate design strategies. For example, the use of a safety factor of 0.6 for the shear strength, the retention of full concrete thickness in critical areas and the inclusion of appropriate reinforcement of the shear may all contribute to addressing these deficiencies. Regarding fire safety, it has been demonstrated that increasing the concrete thickness increases the performance and often brings it into line with that of solid concrete.

In summary, when designed and implemented correctly, Bubble Deck slabs offer a compelling alternative to traditional solid slab construction. They bring together structural efficiency, environmental benefits, and cost-effectiveness—making them a smart and forward-looking choice for modern building projects.

Future study Directions are needed in order to improve sustainability while preserving structural performance; more study is required to investigate alternative lightweight fillers (such as recycled or bio-based materials) in relation to material optimization. Additionally, few studies on the long-term resilience of bubble deck slabs to cyclic loads and harsh environmental factors (such as corrosion and freeze-thaw cycles).

Funding

No funding was received for this work

Acknowledgements

The authors are very grateful to the University of Mosul/ College of Engineering/ Civil Engineering department for their provided facilities, which helped to improve the quality of this work.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Z. Abdul Aziz and C. L. Heng, "Bubble deck slab system: A review on the design and performance," Int. J. Innov. Educ. Res., vol. 9, no. 9, pp. 575–588, 2021.

[2] N. K. Oukaili and L. F. Hussein, “Experimental and analytical study on punching shear strength of bubble decks,” ACI Struct J, vol. 117, no. 2, pp. 17–31, 2020.

[3] S. Ali, S. A. Babu, " A Structural Study on Bubble Deck Slab and Its Properties," International Journal of Research & Review, vol. 6, no. 10, pp. 352–357, 2019.

[4] M. Ranjitham, N.V. Manjunath and S. Dhivyabharathi, “Numerical and Experimental study on Bubble Deck Slab with

M-SAND," Construction Materials and Management, pp. 228–239, 2019.
[5] B.M Sonia. and Y. M. Kumar S, "A Review on Bubble Deck Slab Technology," International Journal of Multidisciplinary Educational Research, vol. 10, no. 4(1), pp. 65–67, 2021.
[6] V. O. Francis, "Suitability and Performance of Bubble Deck Slab: A Review," International Journal of Scientific Research & Engineering Trends, vol. 5, no. 5, pp. 1538–1542, 2019.
[7] A. A. M. Ali, R. S. Zidan, and B. J. M. Al-Eliwi, "Evaluation of mechanical properties of high-strength concrete with sustainable materials," in IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, 2020.
[8] A. M. Humad, J. L. Provis and A. Cwirzen, "Alkali activation of high mgo bfs with sodium carbonate added dry vs. wet," Proceedings of the International Conference on Sustainable Materials, Systems and Structures (SMSS2019), 2023.
[9] S. Y. K. AL-Darzi, K. A. Ibrahim, and O. A. Salih, "The Impact Load Behavior of Reinforced Concrete Slab Samples Containing Waste Plastic Aggregate," Tikrit Journal of Engineering Sciences, vol. 31, no. 4, pp. 202–221, 2024.
[10] M. Kamal Askar, "Rehabilitation of Pre-Damaged RC Beam Containing Recycled Plastic Waste Using CFRP," Vol. 30, No. 1, pp. 164-174, 2025.
[11] M. Abdulkhaliq and A. Al-Ahmed, "The flexural behavior of one-way concrete bubbled slabs reinforced by GFRP-bars with embedded steel I-sections," Eng., Technol. Appl. Sci. Res., vol. 14, no. 4, pp. 15860–15870, 2024.
[12] P. P. Teja, P. V. Kumar, S. Anusha, C. Mounika, and P. Saha, "Structural behavior of bubble deck slab," in Proc. IEEE Int. Conf. Adv. Eng. Sci. Manag. (ICAESM), pp. 383–388, 2012.
[13] K. Taskin and K. Peker, "Design Factors and the Economical Application of Spherical Type Voids in Rc Slabs," International Scientific Conference People, Buildings and Environment 2014 (PBE2014), pp. 448–458, 2014.
[14] T. Gajewski, N. Staszak, and T. Garbowski, "Optimal Design of Bubble Deck Concrete Slabs: Serviceability Limit State," Materials, vol. 16, no. 14, Jul. 2023.
[15] Y. Nassif Sabr, H. Khalaf Jarallah, and H. Issa AbdulKareem, "Assessment the Shear Behavior of Sustainable Thick Hollow Core Slab Using Experimental and Nonlinear Finite Element Modelling," Anbar Journal of Engineering Science, vol. 8, pp. 35–43, 2019.
[16] H. S. H. Sany et al., "Experimental and Theoretical Design of Reinforced Bubble Deck Concrete (RBDC) Slab: A Review," Journal of Advanced Research in Applied Mechanics, vol. 117, no. 1, pp. 35–50, 2024.
[17] A. Jathar, S. Pharate, K. Warhate, P. Nandre, M. Tanpure, and B. E. Student, "Structural Behaviour of Bubble Deck Slab," International Journal of Advanced Research in Arts, Science, Engineering & Management (IJARASEM), , vol. 8, no. 3, pp. 1022–1024, 2021.
[18] T. Lai, "Structural behavior of bubble deck slab and their applications to lightweight bridge decks," M.S. thesis, MIT, Cambridge, MA, USA, 2009.
[19] M. M. Haque and M. M. Haque, "Finite element analysis of bubble deck slab with various thickness of HDPE bubble," Mater. Today: Proc., vol. 65, no. 6, pp. 1976–1981, 2022.
[20] A. M. Ibrahim, N. K. Ali, and W. D. Salman, "Flexural capacities of reinforced concrete two-way bubble deck slabs of plastic spherical voids," Diyala J. Eng. Sci., vol. 6, no. 2, pp. 1–12, 2013.
[21] L. Hai, T. Thi, and P. Nguyen, "The experimental analysis of Bubble-Deck slab using modified elliptical balls," Hokkaido Univ. Collect. Schol. Acad. Papers, pp. 1–9, 2013.
[22] E. V. Reich, M. Lima, and K. I. Strelets, "Efficiency of applying sustainable technology of bubble deck technology in concrete in Russia," Constr. Unique Build. Struct., vol. 15, no. 11, pp. 83–92, 2017.
[23] R. Sagadevan and B. N. Rao, "Numerical study on flexural capacity of biaxial hollow slab,"

in Recent Adv. Struct. Eng., vol. 1, Singapore: Springer, pp. 97–105, 2019.

[24] A. S. Mahdi and S. D. Mohammed, "Structural behavior of BubbleDeck slab under uniformly distributed load," Civ. Eng. J., vol. 7, no. 2, pp. 304–319, 2021.

[25] ACI 318-19: Building Code Requirements for Structural Concrete, Amer. Concrete Inst., 2019.

[26] BubbleDeck Voided Flat Slab Solutions: Technical Manual and Documents, BubbleDeck Int., 2008.

[27] T. Mota, M. Oliveira, and G. Doz, "Dynamic analysis in a bi-axial hollow slab submitted to human actions," IBRACON Struct. Mater. J., vol. 17, no. 6, pp. 1–13, 2024.

[28] N. Oukaili and H. Merie, "CFRP strengthening efficiency on enhancement punching shear resistance of RC bubbled slabs with openings," Case Stud. Constr. Mater., vol. 15, pp. 1–18, 2021.

[29] S. H. Mtashar and A. A. Al-Azzawi, "Finite element analysis of voided reinforced concrete slabs enhanced by GFRP sheets under monotonic and repeated loads," J. Eng., vol. 30, no. 10, pp. 46–68, 2024.

[30] T. S. Al-Gasham, A. N. Hilo, and M. A. Alawsi, "Structural behavior of reinforced concrete one-way slabs voided by polystyrene balls," Case Studies in Construction Materials, vol. 11, 2019.

[31] H. A. Jabir, J. M. Mhalhal, and T. S. Al-Gasham, "Conventional and bubbled slab strips under limited repeated loads: A comparative experimental study," Case Studies in Construction Materials, vol. 14, 2021.

[32] DIN 1045-1: Structural Use of Concrete – Part 1: Design and Construction, Deutsches Institut für Normung, 2008.

[33] EN 1992-1-1: Eurocode 2: Design of Concrete Structures – Part 1-1: General Rules and Rules for Buildings, Eur. Committee Standardization, 2004.

[34] L. Lakshmikanth and P. Poluraju, "Performance of structural behaviour of bubble deck slab: A review," Int. J. Recent Technol. Eng., vol. 7, no. 6, pp. 865–870, 2019.

[35] V. C. Nagma Fatma, "To study Comparison between Conventional Slab and Bubble Deck Slab," International Advanced Research Journal in Science, Engineering and Technology, vol. 5, no. 1, pp. 70–76, Jan. 2018.

[36] J. Corey, "Plastic voided slab systems: Applications and design," M.S. thesis, Kansas State Univ., Manhattan, KS, USA, 2013.

[37] J. L. Park, Y. Kim, and S. Kim, "Analysis of load-bearing capacity in bubble deck slabs using experimental and numerical methods," J. Struct. Eng., vol. 136, no. 5, pp. 123–130, 2010.

[38] D. Markovic, M. Kostic, and S. Zivaljevic, "Finite element analysis of bubble deck slabs for stress distribution and deflection," Int. J. Struct. Eng., vol. 41, no. 3, pp. 45–55, 2013.

[39] R. Jaya, A. Ramachandran, and K. Singh, "Experimental study on punching shear behavior of bubble deck slabs," J. Adv. Concrete Technol., vol. 13, no. 2, pp. 88–96, 2015.

[40] R. Patel, P. Shah, and K. Mehta, Comparative study of bubble deck slabs and conventional slabs using analytical and laboratory methods," J. Adv. Concrete Struct., vol. 25, no. 4, pp. 345–354, 2018.

[41] A. Alhassan, S. Mohammed, and H. Rahman, "Performance of bubble deck slabs reinforced with GFRP bars under cyclic loading," J. Compos. Struct., vol. 232, pp. 111–122, 2020.

[42] V. Kumar, P. Sharma, and R. Gupta, "Punching shear resistance of bubble deck slabs: Experimental insights," J. Struct. Integr., vol. 48, no. 2, pp. 203–214, 2022.

[43] A. Kamble, R. Patel, and M. Shah, "Optimization of void geometry in bubble deck slabs," Int. J. Struct. Eng., vol. 48, no. 3, pp. 45–56, 2022.

[44] P. Staszak, M. Kowalski, and K. Nowak, "Advanced design and flexural behavior of bubble deck slabs," J. Adv. Concrete Technol., vol. 17, no. 2, pp. 112–123, 2023.

[45] N. Oukaili, H. Merie, A. Allawi, and G. Wardeh, "Reduced Volume Approach to Evaluate Biaxial Bubbled Slabs' Resistance to Punching Shear," Buildings, vol. 14, no. 3, 2024.

[46] S. Gajewski, M. Jankowski, and P. Lesniak, "Numerical homogenization for bubble deck slabs: A sustainable approach," J. Sustain. Struct., vol. 14, no. 1, pp. 56–67, 2023.

[47] N. Staszak, T. Garbowski, and B. Ksit, "Optimal Design of Bubble Deck Concrete Slabs: Sensitivity Analysis and Numerical Homogenization," Materials, vol. 16, no. 6, Mar. 2023.

[48] R. Sany, A. Krishnan, and B. Dutta, "Material efficiency and sustainability in bubble deck slabs," J. Civ. Eng. Constr. Technol., vol. 20, no. 1, pp. 45–52, 2024.

[49] C. Cayanan, J. Santos, and G. De Guzman, "Investigating material properties of bubble deck slabs," Int. J. Eng. Appl. Sci., vol. 18, no. 3, pp. 77–86, 2023.

[50] A. Adenan, M. Rosli, and K. A. Yusof, "Sustainability and weight reduction in high-rise structures using bubble deck slabs," J. Green Build. Technol., vol. 12, no. 4, pp. 245–256, 2020.

[51] B. Kurnia, T. Widodo, and L. Arief, "Economic and structural advantages of high-density polyethylene in bubble deck slabs," J. Innov. Constr. Mater., vol. 19, no. 2, pp. 134–144, 2022.

[52] M. Khairussaleh, S. Abu Hassan, and H. Awang, "Flexural and seismic performance of lightweight concrete slabs," J. Struct. Dyn. Stab., vol. 25, no. 5, pp. 345–354, 2022.

[53] A. Aziz and P. Chan, "Innovative design of lightweight bubble deck slabs for architectural versatility," Int. J. Mod. Struct. Des., vol. 11, no. 3, pp. 112–123, 2021.

[54] R. John and J. Varghese, "A study on behavior of bubble deck slab using ANSYS," International Journal of Innovative Science, Engineering & Technology, Vol. 2, no.11, pp. 560-563, 2015.

[55] A. A. D. S. Quraisyah, K. Kartini, M. S. Hamidah, and K. Daiana, "Bubble Deck Slab as an Innovative Biaxial Hollow Slab-A Review," Journal of Physics: Conference Series, IOP Publishing Ltd, Dec. 2020.

[56] R. Bhowmik, S. Mukherjee, A. Das, "Review on Bubble Deck with Spherical Hollow Balls." International Journal of Civil Engineering and Technology (IJCIET), Vol.8, no.8, pp. 979–987, 2017.

[57] H. Varshney, "A Review Study on Bubble Deck Slab," Int J Res Appl Sci Eng Technol, vol. 5, no. X, pp. 2136–2139, 2017.

[58] S. Ali and M. Kumar, "Behavioral analysis of conventional slab and bubble deck slab under various support loading conditions using ANSYS Workbench 14.0: Review paper," Int. J. Sci. Res. Dev., vol. 5, no. 3, pp. 1357-1362, 2017.

[59] S. Ali, "Bubble Deck Systems with Spherical Hollow Balls: Types, Innovations, Structural Benefits, and Economic Implications.", Journal of Civil Engineering and Technology Sciences, 2025.

[60] S. Calin, C. As, and ˘ Asavoaie, "METHOD FOR BUBBLEDECK CONCRETE SLAB WITH GAPS," Bulletin of The Polytechnic Institute of Iaşi, Volume LV (LIX), Fasc. 2, 2009.

[61] A. Amruta and R. Bhusare, "Durability assessment of bubble deck slabs in modern construction," Int. J. Constr. Eng. Mater., vol. 16, no. 1, pp. 56–63, 2018.

[62] P. Dadzie and S. Kaliluthin, "Investigating flexural durability of bubble deck slabs under repeated loading," Int. J. Struct. Integr., vol. 9, no. 2, pp. 45–52, 2023.

[63] Sagadevan R, "Studies on Structural Behaviour of Biaxial Voided Slab Under Flexure and Punching Shear," A thesis Doctor of Philosophy in Structural Engineering Laboratory, Department of Civil Engineering, Indian institute of technology madras, 2020.

[64] A. Churakov, "Biaxial hollow slab with innovative types of voids", Construction of Unique Buildings and Structures, vol. 21, no. 6, pp. 70–80, 2014

[65] R. Ingeli, M. Čekon, and L. Paulovičová, "Enhancement of the thermal performance of voided concrete slabs filled with expanded polystyrene," Case Studies in Construction Materials, vol. 22, 2025.

[66] N. Oukaili and H. H. Yasseen, "Experimental Investigations on the Strength and Serviceability of Biaxial Hollow Concrete

Slabs," Journal of Engineering, vol. 22, no. 11, pp. 36–54, 2016.

[67] F. R. Aditama, C. Irawan, and P. Suprobo, "Biaxial Hollow Slab Under Seismic Load," J. Electrical Systems, Vol. 20, pp. 860-867, 2024.

[68] M. Schnellenbach-Held and K. Pfeffer, "Punching behavior of biaxial hollow slabs." Cement & Concrete Composites, Vol.24, pp. 551–556, 2002.

[69] S. K. Sabale, S. R. Sule, P. D. Utkhede, O. S. Phalke, N. K. Gupta, and B. E. Student, "Experimental Study on Bubble Deck Flat Slab." Vol. 8, No.6, 2019.

[70] M. Shafiq Mushfiq, P. Student, A. Shikha Saini, and A. Nishant Rajoria, "Experimental Study on Bubble Deck Slab," International Research Journal of Engineering and Technology, 2017.

[71] K. S. Srikanth, "Structural Behaviour of Bubble Deck Slab: Performance and Its Review," Journal of Emerging Technologies and Innovative Research (JETIR), vol. 6, no. 1, pp. 168–174, 2019.