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Bubble Deck Slab Technology: An Initial Investigation on Material Efficiency and Structural Integrity

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***Abstract*— This project explores the potential of BubbleDeck slab technology as a novel solution to reduce the amount of concrete used while maintaining a robust structure. The paper begins with a comprehensive literature review to highlight the areas that are currently unknown, as well as the gaps in the existing literature regarding the field. With the results, the BubbleDeck and traditional slabs have been sized with regard to the realistically achievable size and the experience of the past studies. The weights and the volumes of both slabs were computed to establish the percentage of reduction in the material consumption and dead load of the BubbleDeck system. These cuts prove the fact of the possible advantages of the technology, such as resource utilization and structural optimization. Finite Element Analysis (FEA) was performed by pure 3D modelling of both types of slabs using ANSYS software, and SolidWorks was used to create the 3D models. Some of the important parameters that have been analyzed are Total deformation, Maximum Deflection, Stress, Strain, Normal Stress, Shear Stress, Equivalent Elastic Stress, and Equivalent Elastic Strain. The outcomes are meant to confirm the benefits of BubbleDeck slabs and their applicability to the contemporary construction activities that place emphasis on sustainability and efficiency. The analysis results indicate that the BubbleDeck slab provides a 97.4 percent decrease in overall deformation and a significant decrease in strain energy, which is associated with excellent stiffness and load distribution. The tensile and compressive stress is decreased by 96.9 and 95.7 percent, respectively, which greatly minimizes the potential risk of cracks and fatigue of the material. The range of stress decreases by 96.3, which implies enhanced homogeneity in the distribution of stress. Furthermore, the shear stress is reduced by about 77 per cent, and the slab is also reduced by 2.74 per cent in the volume of concrete and 1.65 per cent in self-weight. These advancements affirm the efficiency of the structure, material savings and the performance of the BubbleDeck slab system.**

***Index Terms*— BubbleDeck slab, Voided slab system, Material efficiency, Structural integrity, Finite Element Analysis (FEA), ANSYS simulation, Total deformation, Stress distribution.**

I. INTRODUCTION

The self-weight of concrete slabs is huge, and the middle of a slab (not in tension/ compression areas) has minimal impact on strength. To eliminate this non-structural volume, voided-slab systems where hollow polymer shapes take the place of inefficient concrete were created to improve dead load and decrease embodied carbon with no loss in load capacity.

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A notable commercial implementation of this concept is the BubbleDeck system, in which arrays of HDPE recycled spheres are embedded into the mid-depth of the slab such that the structural behaviour of the slab resembles a solid deck, but significantly less concrete is required [1]. In early experimental and numerical models, a claim of significant material and weight conservation (usually 30 to 50 per cent); therefore, BubbleDeck may be utilized in sustainable building and long-span structures [2]. Meanwhile, the penetration of voids alters local stress paths and poses significant questions of serviceability and ultimate behaviour - e.g. deflection behaviour, crack propagation and punching shear about column supports. The geometry of voids, the arrangement of spacing and reinforcement, have therefore been studied in connection with flexural capacity and ductility. Both laboratory bending experiments and FEM modelling generally demonstrate that, at service loads, bubbled slabs will behave flexurally similarly to solid slabs, assuming good top/bottom reinforcement arrangement and void placement [3]. The second strategy has been explored in other literature to enhance punching resistance through the use of strengthening mechanisms (e.g., CFRP or localised steel inserts) to repair or enhance heavily loaded regions [4]. The current paper provides a preliminary study of BubbleDeck slabs with a short review of the recent experimental and numerical results and comparative analysis of material efficiency and structural integrity. It aims at summarizing the existing knowledge, determining the most important design variables (void size/arrangement, slab thickness, reinforcement), and pinpointing the gaps to be closed by the way of additional experimental investigation or long-term analysis [5].

II. Review of Literature

Staszak, N. (2023) conducts a numerical homogenization and sensitivity analysis to determine the geometric and material parameters with the strongest influence on serviceability and material use in BubbleDeck slabs. The paper introduces an optimisation process, which minimizes the volume of concrete and does not affect deflection and crack-width constraints, and shows that void diameter, spacing and effective slab thickness are the strongest design factors. Their study offers a strict computing framework to minimize the material consumption under the condition of serviceability [6].

Gajewski, T., Staszak, N., and Garbowski, T. (2023). Gajewski and colleagues build up on the theme of optimal design by co-locating limit-state/serviceability checks with automated layout optimization; they show that serviceability (deflection, crack control) usually governs design more than ultimate capacity in long-span bubbled slabs. The article underlines homogenized designs to attain efficient design cycles, and measures projected savings of concrete expected in several realistic slab spans and load cases [7].

Haque, M. M. (2022). Haque presents a complex of FEMs to investigate the effects of the thickness (shell) and configuration of HDPE voids on stiffness and load paths. Findings indicate that adding more void shells thickness or lessening void diameter enhances stiffness and ultimate load, and at the expense of less material savings- this clearly shows there is a trade-off between efficiency and structural performance, which the designers need to deal with. Simplified homogenization as opposed to complete 3D models is also proven to be correct in the paper [8].

Dheepan, K. R., Saranya, S., and Aswini, S. (2017). This laboratory experiment prepares some bubbled and reference solid slabs and subjects them to two-point bending. Dheepan et al. report 3040 per cent weight loss with similar load carrying behaviour on service loads with reinforcement arranged accordingly, and record crack behaviour and recommend void spacing diameter combinations to achieve balance in strength and economy with small-scale slab prototypes [9].

Nisar, A., Khan, Y. H., and Wani, T. A. (2024). Nisar et al. examine the effect of the use of fly ash and bubbled geometry in combination. Their experimental and comparative findings show that the bubbled fly-ash mixes can realize significant CO 2 embodied and cement reduction and acceptable flexural behaviour under service loads. The work brings out the mix-design implications (workability, bond around voids), and indicates slight layer-off ultimate flexural strength relative to standard slabs - indicating that, as a reinforcement, there will be a need to carefully detail [10].

Pawar, A. J. (2024). The study conducted by Pawar is a combined approach of an experiment with FE analysis to investigate the impact of biaxial layout of voids on the stiffness, ultimate load and ductility. Findings show that larger voids can substantially lower the initial stiffness and alter crack propagation behaviour, although with reinforcing that is optimized, the final capacity can be maintained near that of solid slabs in many load conditions. The article gives helpful parametric charts to designers (void size vs. stiffness loss) and demonstrates the significance of top reinforcement continuity [11].

Al-Gasham, T. S. (2019) tests the punching shear around columns in bubbled/voided slabs and finds that punching capacity can be significantly decreased by the existence of voids in the vicinity of column regions, unless something is done to mitigate it. The research measures the effectiveness of strengthening methods (local reinforcement, inserts, CFRP) and design suggestions on preventing punching failure - a serious practical issue with respect to the application of BubbleDeck in column-supported floor systems [12].

III. Methodology

The approach used in the given work is composed of three key phases, namely, 2D drafting, 3D modelling, and Finite Element Analysis (FEA). This systematic strategy of developing the slab models and comparison of the Conventional and BubbleDeck slab systems was accurate.

A. 2D Drafting Using AutoCAD

The preparation stage entailed elaborate 2D drawing of the two types of slabs in AutoCAD. This step was aimed at determining correct geometric parameters before 3D modelling and simulation. The dimensions such as slab size, reinforcement spacing, concrete cover and bubble arrangement were all drawn based on the provisions and literature-based requirements of IS 456:2000.

Each type of slab was generated in terms of plan (top view) and sectional (side view) drawings.

- In the Conventional slab, the illustrations were that of a complete solid section consisting of two layers of steel reinforcement.
- The drawings of BubbleDeck slab were made hiding the drawing of the hollow spheres of 60 mm diameter on a uniform grid in between the reinforcement layers.

These drawings formed the basis of geometrical validation, reinforcement detailing and subsequent steps on 3D modelling so that dimensions were always consistent, and that ambiguities in the design would be removed.

Fig. 1 and Fig. 2 shows the drafting of BubbleDeck Slab and Conventional Slab in AutoCAD, respectively.

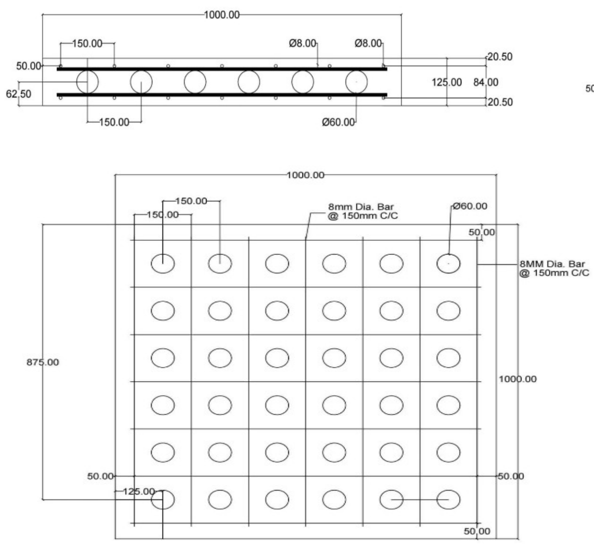


Figure 1 Section & Top View of BubbleDeck Slab

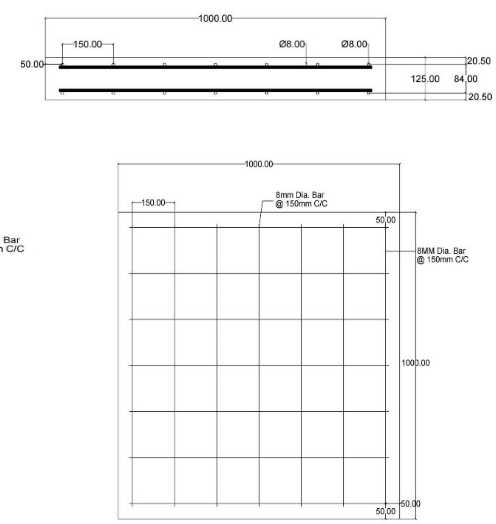


Figure 2 Section & Top View of Conventional Slab

B. 3D Modelling Using SolidWorks

Once the 2D drafting had been done, the models were modeled in SolidWorks using a parametric approach model. Individual part files were made on:

- Concrete block
- Hollow and solid bubbles spheres.

In the case of the BubbleDeck slab, the solid spheres were placed and cut out of the concrete block in a binary operation to create internal voids. In Conventional slab, the concrete block was not hardened. The assembly of all the models was done with proper reinforcement layout, cover, bubble distance and slab geometry. The finished models were exported using IGIS format in order to be compatible with ANSYS Workbench.

C. Finite Element Analysis (FEA) Using ANSYS Workbench

The last step involved the work of the analysis of the static structure with the help of ANSYS Workbench. The imported 3D models followed the following steps:

- Material Assignment: The concrete, steel reinforcement, and plastic bubble material properties were assigned in accordance with the standard mechanical characteristics. SOLID65 was used to model concrete, LINK180 to reinforce it and SOLID185 to model loading plates.
- Meshing: The models were meshed in the form of finite elements, but the meshing was done in high stress concentration areas, particularly around the voids in the BubbleDeck slab. The mesh provided good convergence and a correct distribution of stress.
- Boundary Conditions and loading: The four edges of the slabs were all fixed to represent the real support cases.
- Solution & Post-Processing: The analysis was run to obtain key performance parameters such as:
  - Total deformation
  - Strain energy
  - von Mises stress
  - Equivalent strain
  - Shear stress
  - Bending stress

The results were obtained in both slab systems and compared graphically to identify the structural efficiency gains that were realized by the BubbleDeck system.

D. Weight reduction

An experimental Model was made using AutoCAD and SolidWorks of Length 1 meter, Breadth 1 meter and Depth 150 mm for practical and experimental feasibility. Table I indicates Weight Reduction between Conventional Slab and BubbleDeck Slab calculated using the volume of material and density of material.

TABLE I. WEIGHT REDUCTION COMPARISON

Slab Type	Material	Calculation Volume (m^3) x Density (kg/m^3)	Weight (Kg)
Conventional Slab	Concrete	0.148723 × 2500	371.81
	Steel	0.001277 × 7850	10.02
	Total Weight	371.81 + 10.02	381.83
BubbleDeck Slab	Concrete	0.144651 × 2500	361.63
	Steel	0.001277 × 7850	10.02
	HDPE Balls		3.868
	Total Weight	361.63 + 10.02 + 3.868	375.52

E. Volume Reduction

Table II indicates Volume Reduction between Conventional Slab and BubbleDeck Slab

TABLE II. VOLUME REDUCTION COMPARISON

Parameter	Conventional Slab	BubbleDeck Slab
Plan Area	1 m × 1 m = 1 m^2	1 m × 1 m = 1 m^2
Slab Thickness	150 mm = 0.15 m	150 mm = 0.15 m
Total Slab Volume (m^3)	0.15	0.15
Bar Diameter	8 mm (0.008 m)	8 mm (0.008 m)
Length of Each Bar (m)	0.908	0.908
Number of Bars	28	28
Volume of One Bar (m^3)	4.561×10^{-5}	4.561×10^{-5}
Total Steel Volume (m^3)	0.001277	0.001277
Ball Diameter	—	60 mm (0.06 m)
Number of Balls	—	36 (6 × 6)
Volume of One Ball (m^3)	—	1.131×10^{-4}
Total Ball Volume (m^3)	—	0.004072
Concrete Volume (m^3)	0.148723	0.144651

F. Cost Reduction

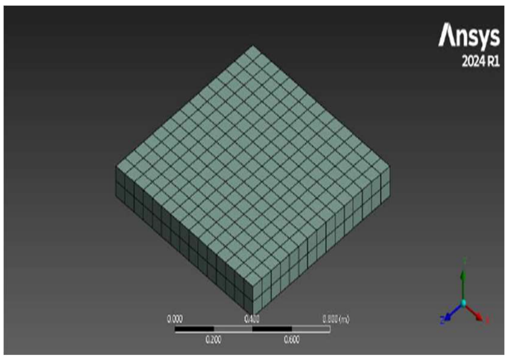
Table III indicates Cost Reduction between Conventional Slab and BubbleDeck Slab

TABLE III. COST REDUCTION COMPARISON

Parameter	Conventional Slab	BubbleDeck Slab
Concrete Volume (m³)	0.148723	0.144651
Cost of Concrete (₹/m³)	8,200	8,200
Total Cost of Concrete (₹)	1,221.31	1,185.13

IV. RESULT

These are the results obtained after Analysis Fig. 3, Fig. 4 shows Meshing, Boundary and Loading Conditions for both Conventional and BubbleDeck Slabs, respectively. Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10, shows Total Deformation, Strain Energy, Normal Stress, Shear Stress, Equivalent Elastic Strain, Equivalent Elastic Stress of Conventional Slab, respectively. Similarly, Fig. 11, Fig. 12, Fig. 13, Fig. 14, Fig. 15, Fig. 16 shows the same of BubbleDeck Slab, respectively. Table IV gives the summary of the results.



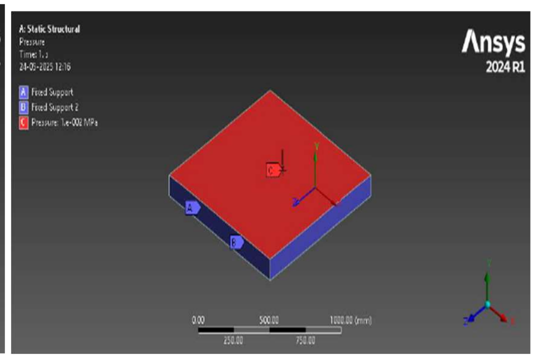
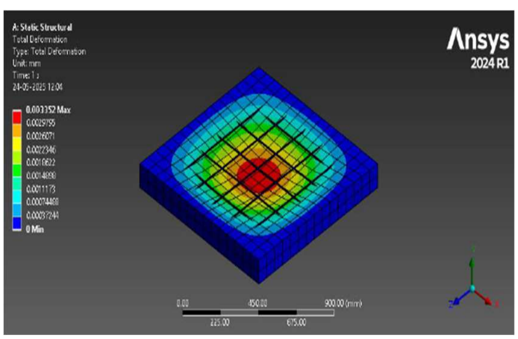


Figure 3. Meshing [Conventional & BubbleDeck]

Figure 4. Boundary Condition and Load Condition

A. Result for Conventional Slab



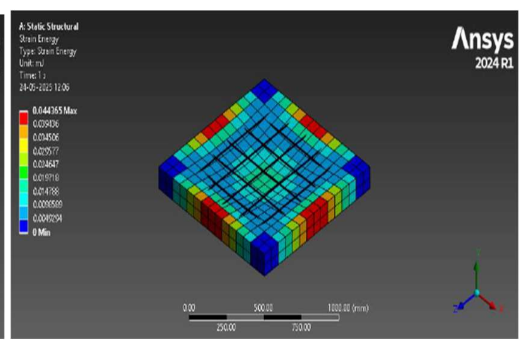
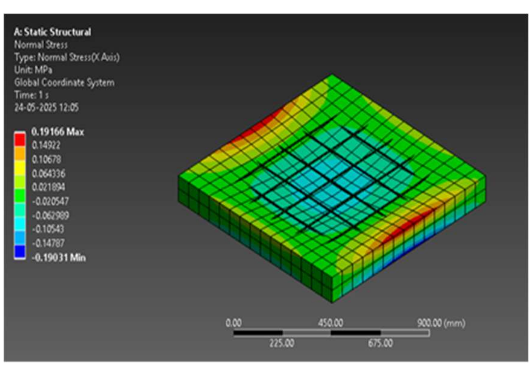


Figure 5. Total Deformation

Figure 6. Strain Energy



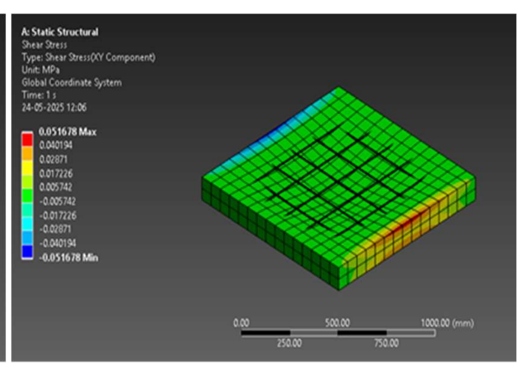


Figure 7. Normal Stress

Figure 8. Shear Stress

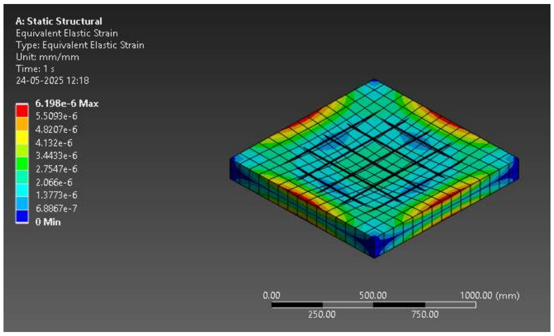


Figure 9. Equivalent Elastic Strain

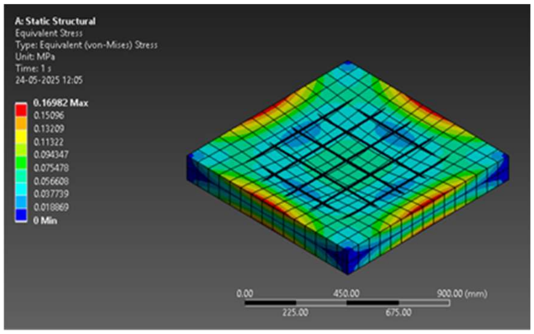


Figure 10. Equivalent Elastic Stress

B. Result for Bubbledeck SLAB

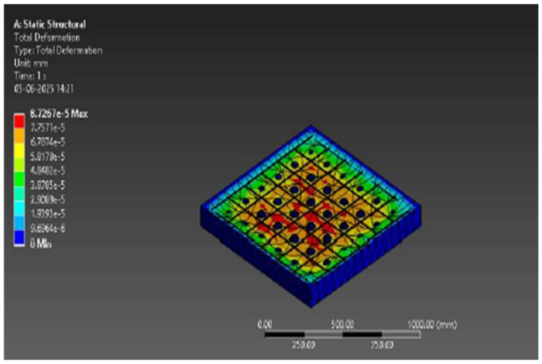


Figure 11. Total Deformation

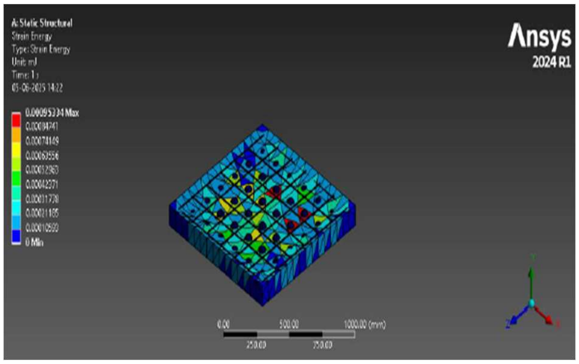


Figure 12. Strain Energy

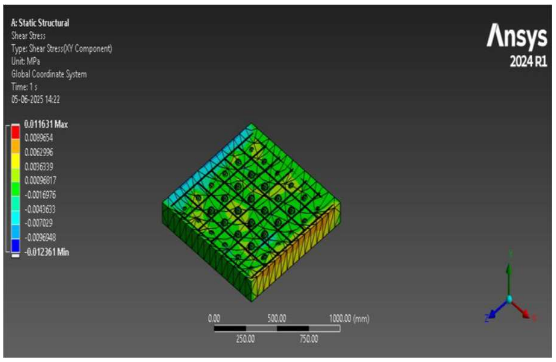


Figure 13. Normal Stress

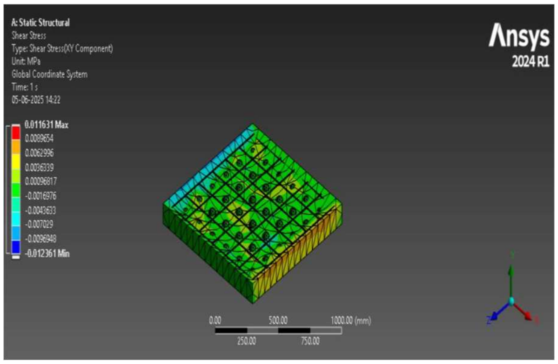


Figure 14. Shear Stress

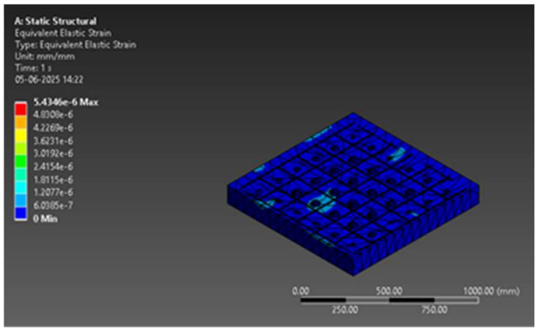


Figure 15. Equivalent Elastic Strain

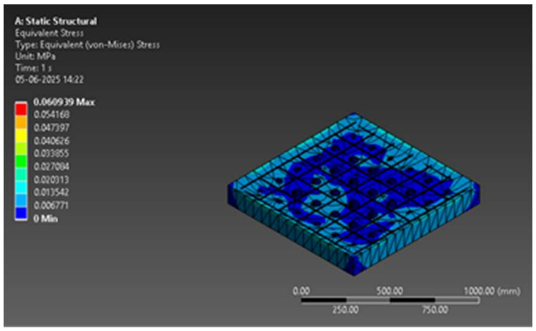


Figure 16. Equivalent Elastic Stress

TABLE IV: RESULTS

Total Deformation (mm)	0.003352	0.000087267
Strain Energy (mJ)	0.044365	0.00095334
Normal Stress (MPa)	0.19166	0.0059358
Shear Stress (MPa)	0.051678	0.011631
Equivalent Stress (MPa)	0.16982	0.060939
Equivalent Strain (mm/mm)	0.000006198	0.0000054346

V. DISCUSSION

- As per Fig. 5 and Fig. 11 suggests, the deformation (0.003352 mm to 8.7267e-5 mm) of the BubbleDeck slab reduced drastically. This refers to the fact that the internal voids add so much of rigidity and distribution of loads, but the weight taken by the self is minimized.
- As Fig. 6 and Fig. 12, The strain energy measure of work by the structure that was loaded reduced in the BubbleDeck slab between 0.044365 mJ and 0.00095334 mJ. The conclusion is based on the fact that the BubbleDeck is a more efficient energy absorber with a lower structural stress.
- According to Fig. 7 and Fig. 13, There was a normal stress of less than 0.19166 to 0.0059358 MPa. This demonstrates that BubbleDeck system has enhanced resistance to the direct stresses in the form of axial loading which again is in favor of the structural stability.
- The BubbleDeck slab exhibits a spectacular decrease in shear stress, demonstrating that the hollow-core structure does not have an impact on shear capacity, which can even be enhanced by redistribution of internal forces.
- According to Fig. 9 and Fig. 15, The highest equivalent strain decreased from 6.198e-6 mm/mm to 5.434e-6 mm/mm. This reduced strain implies that the BubbleDeck slab has less internal degradation when under stress and thus is more favorable to last longer.
- According to Fig. 10 and Fig. 16, The stress levels were lower than 0.16982 MPa in the conventional slab and 0.060939 MPa in the BubbleDeck slab. This shows that the bubble structure does not just provide structural integrity, but also increases stress management in uniform loading.
- From Table II, according to the BubbleDeck slab, there has been a reduction in volume of the concrete and the volume of the conventional slab, i.e. 0.148723 m3 is lower by a factor of 0.144651 m3. This is minimized through the inclusion of hollow plastic balls in the slab that not only displaces concrete at the neutral zone, but the structural integrity is not weakened.
- From Table I, the weight of the BubbleDeck slab was determined as 371.81kg, whereas the weight of the solid slab was 381.83kg. This reduction in dead load makes the slab suitable for long-span structures and high-rise buildings, and all this leads to the efficiency of the structure and cost-saving.

VI. CONCLUSION

Results of this research have clearly shown that the BubbleDeck slab system has significant structural and material benefits as compared to other solid slabs. The deformation decreased proving a drastic reduction in deformation and, consequently, higher stiffness and better load distribution, despite the reduced self-weight. A significant reduction in strain energy was observed indicating that the system effectively limits external forces and develops minimal internal stresses. The normal stress reduced substantially demonstrating improved resistance to stress in the BubbleDeck slab.

The total stress levels also decreased showing better performance under combined axial and bending stresses compared to a conventional slab. The notable decrease in shear stress and peak equivalent strain confirms that the introduction of voids does not compromise structural safety but instead redistributes forces more uniformly within the structure, leading to improved durability and performance. From a material efficiency perspective, the BubbleDeck slab showed a reduction in concrete volume compared to the conventional slab, without any loss in structural performance. The resulting reduction in self-weight highlights the potential of BubbleDeck slabs as a sustainable and economical system for long-span and high-rise structures. This study concludes that BubbleDeck technology can effectively enhance structural integrity while simultaneously reducing material consumption and dead load. The overall improvements in rigidity, stress distribution, deformation control, and material efficiency establish BubbleDeck slabs as a superior alternative to traditional solid slabs. Future research may extend these findings by investigating long-term performance, seismic behaviour, and optimisation of void geometry under different loading conditions.

FUTURE SCOPE

- Long-Term Performance Assessment: Long-term monitoring of the BubbleDeck slabs should be introduced into future research to check their durability under operating conditions such as creep, shrinkage, fatigue loading and environmental exposure.
- Variable Geometry and Positioning: More parametric studies can be done to optimize the size, spacing and distribution of the bubbles to bring about the optimal balance between stiffness, weight reduction and material savings.
- Combination with Sustainable Materials: Future research can consider the addition of BubbleDeck to other eco-friendly materials, including geopolymer concrete, recycled aggregates, or high-volume fly ash mixes, to make the material even more environmentally friendly.
- Cost-Benefit and Life-Cycle Analysis: An in-depth economic analysis, involving the construction time savings, transportation benefits, labour savings, and lifecycle costs, would help to understand the real feasibility of a broad implementation.

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