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Feasibility Study and Performance Analysis of a Sustainable Bubble Deck Slab System Utilizing Recycled HighDensity Polyethylene (HDPE) Bubbles

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***Abstract*—This study investigates the feasibility and structural performance of a sustainable Bubble Deck slab system incorporating recycled High-density Polyethylene (HDPE) spheres as void formers. Bubble Deck technology is an innovative slab construction method that reduces self-weight by replacing nonstructural concrete in the neutral zone with hollow plastic spheres, thereby enhancing material efficiency without significantly compromising structural integrity. In this research, recycled HDPE spheres are utilized to improve sustainability by reducing plastic waste and embodied carbon. The analysis includes loadbearing capacity, flexural strength, deflection behavior, and material savings compared to conventional solid reinforced concrete slabs. Analytical methods and numerical modeling are employed to evaluate structural performance under static loading conditions. Results indicate that the Bubble Deck slab achieves a reduction in self-weight of approximately 30–35%, leading to decreased dead load and foundation cost, while maintaining comparable flexural performance. Additionally, the use of recycled HDPE contributes to environmental sustainability by promoting circular material usage. The study concludes that the proposed system is a viable and ecofriendly alternative for modern construction, particularly in large span structures.**

***Index Terms*—Bubble Deck slab, HDPE, sustainable construction, lightweight structures, recycled materials, structural performance.**

I. INTRODUCTION

The construction industry is a major consumer of natural resources and a significant contributor to global carbon emissions, primarily due to the extensive use of reinforced concrete [1]. Conventional reinforced concrete slabs are inherently inefficient, as a considerable portion of concrete located near the neutral axis contributes minimally to structural performance while increasing self-weight [2]. This inefficiency has encouraged the development of innovative structural systems aimed at reducing material usage without compromising strength, durability, and serviceability. Biaxial voided slab systems, such as the Bubble Deck, have emerged as an effective solution by introducing hollow spheres within the concrete matrix to eliminate nonfunctional material [3]. These systems are designed based on fundamental bending theory, where stresses near the neutral axis are negligible, allowing concrete removal without significantly affecting flexural capacity [2]. As a result, bubble deck slabs can achieve a reduction in self-weight of approximately 30–35%, leading to lower dead loads and improved structural efficiency [4].

Extensive experimental research has been conducted to evaluate the structural performance of bubble deck slabs. Ibrahim et al. demonstrated that the flexural strength of voided slabs remains comparable to that of solid slabs when appropriate geometric parameters such as void size, spacing, and slab thickness are maintained [5]. Similarly, Schwellenbach Held and Prefer investigated the punching shear behavior of biaxial hollow slabs and emphasized the importance of reinforcement detailing near column regions to ensure adequate shear resistance [6]. Numerical studies using finite element methods further confirm that the stress distribution and deflection behavior of bubble deck slabs are similar to conventional slabs under service loading conditions [7].

Comparative studies highlight the structural and economic advantages of voided slab systems. Aziz and Chan reported that bubble deck slabs reduce concrete consumption and construction costs while enabling longer spans and improved ar chitectural flexibility [8]. Experimental investigations by Calin et al. further demonstrate that spherical void former provide optimal stress distribution and structural performance compared to other void shapes [9]. The selection of material for void former's plays a crucial role in the overall performance and sustainability of the system. High-density Polyethylene (HDPE) is widely used due to its lightweight nature, durability, and resistance to chemical and environmental degradation [10].

Recent studies on recycled HDPE indicate that its mechanical properties remain comparable to those of virgin material, making it suitable for structural applications [11]. Additionally, the utilization of recycled plastics in construction contributes to waste reduction and promotes sustainable material usage [12]. Sustainability has become a central focus in modern civil engineering practices. Cement production is a major source of CO_2 emissions, significantly impacting the environment [13]. The incorporation of recycled materials, such as HDPE, aligns with sustainable construction principles and circular economy strategies by reducing embodied energy and conserving natural resources [14]. These approaches are essential for minimizing the environmental footprint of infrastructure development. The design and analysis of bubble deck slabs must comply with established standards and guidelines to ensure safety and performance. International codes such as Euro-code 2 [15]and national standards like IS 456 [16] pro- vide design provisions for reinforced concrete structures, while load considerations are governed by IS 875 [17]. Additionally, the fib Model Code offers advanced recommendations for evaluating structural behavior and serviceability of innovative concrete systems [18]. Recent studies on voided reinforced concrete slabs have demonstrated reliable structural performance under both service and ultimate loading conditions [19]. Analytical modeling approaches have also been developed to predict the behavior of voided slab systems with improved accuracy, enabling optimized design and performance assessment [20]. Despite these advancements, challenges such as reduced shear capacity and long-term durability of recycled materials require further investigation.

This study aims to evaluate the feasibility and structural performance of a sustainable bubble deck slab system utilizing recycled HDPE spheres. The research focuses on key parameters including load-carrying capacity, deflection behavior, and material efficiency, while also assessing environmental benefits. By integrating structural optimization with sustainable material utilization, this study contributes to the development of efficient, eco-friendly, and innovative construction systems for future infrastructure.

II. METHODOLOGY

An experimental investigation was conducted to evaluate the structural efficiency and material optimization achieved using a Bubble Deck slab system incorporating recycled High-Density Polyethylene (HDPE) spheres. The study involved a comparative analysis between a conventional reinforced concrete slab and a Bubble Deck slab designed with identical geometric dimensions and reinforcement configurations to ensure uniformity in testing conditions. The primary objective was to reduce the self-weight and concrete consumption of the slab without significantly affecting its structural performance. Both slab specimens were designed with dimensions of 1 m × 1 m and a thickness of 150 mm. M20 grade concrete with a mix proportion of 1: 1.5: 3 was adopted in accordance with IS 456 recommendations. Reinforcement was provided using 10 mm diameter steel bars placed at a spacing of 120 mm center-to-center in both directions. The reinforcement arrangement was maintained identical for both slabs to ensure a fair comparison of structural behavior.

The material quantification for the conventional slab was determined from the total slab volume calculated as

$$V = 1 \times 1 \times 0.15 = 0.15\ \text{m}^3 \quad (1)$$

A dry volume factor of 1.54 was considered to account for material wastage and voids during concrete preparation.

$$V_d = 1.54 \times 0.15 = 0.231\ \text{m}^3 \quad (2)$$

Based on the adopted mix proportion of 1 : 1.5 : 3, the quantity of cement required was calculated as

$$V_c = \frac{1}{5.5} \times 0.231 = 0.042\ \text{m}^3 \quad (3)$$

The corresponding weight of cement was obtained using a density of 1440 kg/m^3:

$$W_c = 0.042 \times 1440 = 60.48\ \text{kg} \quad (4)$$

Similarly, the quantity of fine aggregate was determined as

$$V_s = \frac{1.5}{5.5} \times 0.231 = 0.063\ \text{m}^3 \quad (5)$$

while the quantity of coarse aggregate was calculated as

$$V_{ca} = \frac{3}{5.5} \times 0.231 = 0.126\ \text{m}^3 \quad (6)$$

The reinforcement quantity was estimated considering the spacing of steel bars in one direction:

$$N = \frac{1000}{120} \approx 8 \quad (7)$$

The total steel weight was obtained as

$$W_s = 8 \times 0.62 = 4.96\ \text{kg} \quad (8)$$

For the Bubble Deck slab, recycled HDPE spheres having a diameter of 60 mm were introduced within the central region of the slab to replace ineffective concrete. A total of 64 spheres were arranged uniformly between the reinforcement layers. The volume of a single sphere was calculated using

$$V_b = \frac{4}{3}\pi r^3 \quad (9)$$

Substituting $r = 0.03$ m,

$$V_b = \frac{4}{3}\pi\,(0.03)^3 = 0.000113\ \text{m}^3 \quad (10)$$

The total volume displaced by all HDPE spheres was determined as

$$V_{total} = 64 \times 0.000113 = 0.0072\ \text{m}^3 \quad (11)$$

Hence, the effective concrete volume required for the Bub-ble Deck slab became

$$V_{new} = 0.15 - 0.0072 = 0.1428\ \text{m}^3 \quad (12)$$

Accordingly, the revised material quantities for the Bubble Deck slab were approximately 57 kg of cement, 0.06 m3 of sand, and 0.12 m3 of coarse aggregate. The reinforcement ar-rangement was maintained identical to that of the conventional slab to ensure consistency in comparative evaluation.

The casting procedure for the Bubble Deck slab was carried out in a controlled three-stage process. Initially, a bottom layer of concrete was cast to provide a stable base for reinforcement placement. Subsequently, the HDPE spheres were positioned systematically between the reinforcement layers in a predefined grid arrangement. Finally, the remaining concrete was poured to fully encapsulate the reinforcement and spheres within the slab body. The conventional slab was cast using standard reinforced concrete procedures under identical environmental conditions. After casting, both slab specimens were subjected to curing using the ponding method for a duration ranging from 7 to 14 days to ensure proper hydra-tion and strength development. The slabs were then tested under identical loading conditions to evaluate their structural response. Parameters such as ultimate load carrying capacity, deflection behavior, and crack propagation characteristics were observed during testing. The comparative performance evaluation between the conventional slab and Bubble Deck slab was carried out based on reduction in concrete volume, reduction in self-weight, structural efficiency, and overall cost effectiveness. The obtained results were used to assess the practical feasibility of incorporating recycled HDPE spheres in sustainable slab construction systems

III. RESULTS AND DISCUSSION

The experimental investigation was conducted to evaluate the feasibility and material efficiency of the Bubble Deck slab system incorporating recycled HighDensity Polyethylene (HDPE) spheres. A comparative analysis was performed between a conventional reinforced concrete slab and a Bubble Deck slab having identical geometric dimensions, reinforcement arrangement, and material properties. The comparison was primarily focused on material consumption, reduction in concrete volume, selfweight reduction, and expected structural performance.

A. Material Comparison

The quantities of materials required for both slab systems were calculated and compared. Table I presents the detailed comparison of steel, cement, fine aggregate, coarse aggregate, and concrete volume for the conventional slab and Bubble Deck slab.

Material	Conventional Slab	Bubble Deck Slab
Steel (kg)	4.96	4.96
Cement (m^3)	60.48	57.00
Sand (m^3)	0.063	0.060
Coarse Aggregate (m^3)	0.126	0.120
Concrete Volume (m^3)	0.15	0.1428

Table I Material Comparison Between Conventional and Bubble Deck Slab

From Table I, it can be observed that the incorporation of HDPE spheres in the Bubble Deck slab reduced the quantity of concrete materials required for casting. The reduction in cement, fine aggregate, and coarse aggregate demonstrates the effectiveness of replacing structurally ineffective concrete within the neutral zone of the slab. However, the quantity of reinforcement steel remained unchanged in both slabs to maintain comparable structural performance and flexural resistance.

The reduction in concrete materials directly contributes to a decrease in the self-weight of the slab system. Since dead load is one of the major components affecting the design of beams, columns, and foundations, the Bubble Deck slab system offers improved structural efficiency by reducing the load transferred to supporting members. This reduction in dead load can further contribute to economical structural design and reduced construction cost in large-span applications.

B. Concrete Volume Reduction

The reduction in concrete volume achieved by the Bubble Deck slab was determined using the following expression:

$$\%\ Reduction = \frac{0.15 - 0.1428}{0.15} \times 100 = 4.8\% \qquad (13)$$

The obtained reduction in concrete volume for the experimental model was approximately 4.8%. The reduction is comparatively smaller because the present investigation was carried out on a small-scale slab model with dimensions of 1 m × 1 m using HDPE spheres of 60 mm diameter. In practical large-scale applications, Bubble Deck slabs can achieve concrete savings ranging from 30% to 35%, depending on slab thickness, bubble diameter, and reinforcement configuration.

The reduction in concrete consumption also contributes to environmental sustainability by reducing cement usage and promoting the utilization of recycled HDPE materials. Since cement manufacturing is one of the major sources of carbon dioxide emissions in the construction industry, minimizing concrete consumption can significantly reduce the environ-mental impact associated with slab construction

C. Graphical Representation

Figure 1 illustrates the comparative material consumption between the conventional slab and the Bubble Deck slab. The quantities are represented in their respective units, where cement is expressed in kilograms and aggregates are expressed in cubic meters.

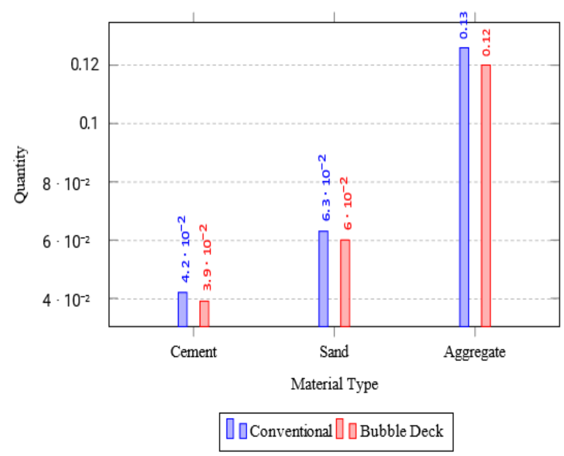

Fig. 1. Material usage comparison between conventional and Bubble Deck slabs

The graphical representation clearly indicates that the Bub-ble Deck slab requires lower quantities of cement and ag-gregates compared to the conventional slab. The reduction in material consumption demonstrates the effectiveness of incorporating HDPE hollow spheres as void formers within the slab system. Furthermore, the reduction in concrete volume contributes to lower structural dead load while maintaining the reinforcement arrangement and expected flexural behavior of the slab. These observations confirm that the Bubble Deck slab system utilizing recycled HDPE spheres is a sustainable and efficient alternative to conventional reinforced concrete slabs. The concrete present near the neutral axis of a slab con-tributes minimally to its structural performance. In Bubble Deck slab systems, this ineffective concrete is replaced with hollow HDPE balls, resulting in significant reduction in dead load and concrete consumption. This innovative technique enables longer spans, economical construction, and improved structural efficiency

D. Discussion

The results demonstrate that the Bubble Deck slab system effectively reduces concrete volume by introducing HDPE spheres in the neutral zone. Although the reduction observed in this study is approximately 4.8%, it is important to note that the model scale significantly influences the outcome. The structural performance of the Bubble Deck slab is expected to remain comparable to that of a conventional slab, as the reinforcement layout and load-carrying mechanism are not altered. The primary advantage lies in reduced self-weight, which can lead to lower loads on columns and foundations in large-scale structures.

Additionally, the use of recycled HDPE spheres contributes to sustainability by reducing plastic waste and minimizing the environmental impact of construction materials. This aligns with modern construction practices focused on resource effi-ciency and eco-friendly design. Overall, the Bubble Deck slab system proves to be a feasible and sustainable alternative to conventional slabs, particularly for large-span structures where weight reduction is critical.

IV. CONCLUSION

This study evaluated the feasibility and performance of a Bubble Deck slab system incorporating recycled HighDensity Polyethylene (HDPE) spheres through experimental analysis and material comparison with a conventional reinforced concrete slab.

The results indicate that the Bubble Deck slab reduces con-crete consumption by approximately 4.8% in the scaled model. Although the reduction is relatively small, it is primarily due to the limited size of the experimental slab (1 m × 1 m) and the use of smaller diameter HDPE spheres (60 mm). In practical large-scale applications, significantly higher material savings in the range of 30–35% can be achieved.

The structural behavior of the Bubble Deck slab is expected to remain comparable to that of a conventional slab, as the reinforcement configuration and load transfer mechanisms are preserved. The reduction in self-weight contributes to de-creased loads on supporting structural elements such as beams, columns, and foundations, thereby enhancing overall structural efficiency. Furthermore, the use of recycled HDPE spheres promotes sustainable construction practices by reducing plas-tic waste and lowering the environmental impact associated with concrete production. This approach aligns with modern engineering objectives focused on resource optimization and eco-friendly infrastructure development.

Overall, the Bubble Deck slab system demonstrates poten-tial as a feasible, economical, and sustainable alternative to conventional reinforced concrete slabs, particularly in large-span and load-sensitive structures.

V. FUTURE SCOPE

The present study demonstrates the feasibility of utilizing recycled HDPE spheres in Bubble Deck slab systems; however, further research is required for practical largescale implementation. Future work may include fullscale experimental testing to evaluate load carrying capacity, deflection behavior, and failure mechanisms under different loading conditions. Optimization of HDPE sphere size and spacing can also be carried out to achieve greater reduction in concrete volume while maintaining structural safety.

Further investigations using Finite Element Analysis (FEA) software such as ANSYS or ABAQUS may help in understanding stress distribution, crack propagation, and longterm structural performance. Studies on shear strength, punching behavior, and seismic performance are also necessary to improve the structural reliability of Bubble Deck slabs. In addition, future research can focus on the use of alternative sustainable materials, durability assessment under environmental exposure, and detailed costbenefit analysis for practical construction applications.

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