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## COMPREHENSIVE REVIEW OF BUBBLE DECK SLAB TECHNOLOGY: STRUCTURAL PERFORMANCE, SUSTAINABILITY, AND EMERGING ALTERNATIVES

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### ABSTRACT

Bubble Deck slab technology is an innovative voided slab system developed to reduce self-weight and material consumption in reinforced concrete floor systems without compromising structural performance. By replacing non-structural concrete in the neutral axis with hollow plastic spheres, Bubble Deck slabs achieve significant reductions in dead load, enabling longer spans, improved seismic performance, and enhanced sustainability. This review paper synthesizes existing literature on the structural behavior, serviceability, construction methods, durability, and environmental impact of Bubble Deck slabs. Key limitations related to punching shear resistance, code provisions, and dependence on plastic void formers are critically discussed. Furthermore, emerging research on alternative void materials is reviewed, highlighting the need for eco-friendly and locally available solutions. The paper identifies current research gaps and emphasizes future directions for sustainable voided slab systems in structural engineering practice.

**KEYWORDS:** Bubble Deck slab, voided slabs, lightweight concrete, punching shear, sustainability, structural efficiency

### 1. INTRODUCTION

Conventional reinforced concrete slabs are typically designed as solid sections, although a substantial portion of concrete in the central region contributes minimally to flexural performance. This excess concrete increases dead load, material consumption, and

construction costs while imposing higher demands on supporting structural elements. To address these inefficiencies, voided slab systems have been developed, among which Bubble Deck slab technology has gained significant attention.

Bubble Deck slabs replace non-load-bearing concrete in the neutral axis with hollow spheres, commonly made of high-density polyethylene (HDPE). This configuration reduces slab self-weight while maintaining structural integrity in the compression and tension zones. Since its introduction in Europe in the 1990s, Bubble Deck technology has been applied in residential, commercial, and institutional buildings worldwide, offering both structural and environmental benefits.

## 2. Literature Review

Bubble Deck slabs are an innovative structural system designed to reduce slab self-weight by replacing non-structural concrete in the neutral axis with hollow spheres. Studies have shown that this approach reduces concrete usage by approximately 30%–50%, allowing for longer spans and smaller column dimensions compared to conventional reinforced concrete slabs (Lai & Veneziano, 2010). The reduction in dead load improves overall structural efficiency and decreases demands on supporting elements.

Research on structural performance indicates that Bubble Deck slabs maintain flexural strength comparable to solid slabs, as tensile and compressive stresses are primarily resisted by the outer concrete layers (Phalke et al., 2019). Experimental studies have reported that slabs with void volumes of 20%–30% retain more than 90% of the flexural capacity of conventional slabs (Nor Ashikin et al., 2020). Although punching shear resistance is reduced due to voids near column supports, this limitation can be addressed through appropriate reinforcement detailing and localized solid zones (Pulke, 2019).

From a sustainability perspective, Bubble Deck technology offers substantial environmental benefits. Varshney (2017) reported that replacing 100 kg of concrete with 1 kg of plastic void material significantly reduces material consumption and carbon emissions. The flat soffit configuration also facilitates efficient installation of building services. However, reliance on HDPE spheres raises concerns related to plastic usage, recyclability, and regional code compliance, particularly in the Indian construction context (Francis, 2019).

To address these limitations, the present study explores the **Coco-Deck slab**, a sustainable

alternative that replaces HDPE spheres with treated coconut shell voids. Coconut shells are an abundant agricultural waste material in tropical regions and offer potential advantages in terms of cost reduction, environmental impact, and local material utilization. Despite extensive research on coconut shells as aggregate replacements, their application as void-forming elements in slab systems remains unexplored, representing a clear research gap addressed in this work.

### **3. Principle and Construction of Bubble Deck Slabs**

Bubble Deck slabs consist of two layers of reinforcement separated by hollow spherical void formers positioned in the neutral axis. The lower reinforcement layer resists tensile stresses, while the upper layer carries compressive and shear stresses. The voids are held in position using steel meshes or prefabricated reinforcement cages, ensuring uniform spacing and effective load transfer.

Various construction methods have been adopted, including the filigree system, semi-prefabricated reinforcement modules, and fully precast finished planks. These methods improve construction speed, quality control, and labor efficiency, making Bubble Deck slabs suitable for medium- to long-span applications.

### **4. Structural Performance of Bubble Deck Slabs**

#### **4.1 Flexural Behavior**

Numerous experimental and numerical studies indicate that Bubble Deck slabs exhibit flexural strength comparable to conventional solid slabs. The presence of voids in the neutral axis does not significantly affect bending capacity, as the outer concrete layers primarily resist tensile and compressive stresses. Experimental results show that slabs with 20–30% void volume can retain over 90% of the flexural capacity of solid slabs. Proper sizing and positioning of voids are critical to preventing premature flexural failure.

#### **4.2 Punching Shear Behavior**

Punching shear resistance is one of the most critical design considerations for Bubble Deck slabs. The reduction in concrete near column–slab connections decreases the available shear-resisting area, leading to a marginal reduction in punching shear capacity. However, research demonstrates that this limitation can be effectively mitigated through localized solid zones, increased slab thickness near columns, reinforced concrete strips, or additional shear reinforcement. With appropriate detailing, punching shear performance can meet design

requirements.

### **4.3 Serviceability Performance**

Serviceability criteria, including deflection and crack control, play a vital role in slab design. Studies report that Bubble Deck slabs experience slightly higher deflections than solid slabs; however, these values remain within permissible limits prescribed by design codes. Crack patterns under service loads are similar to those observed in conventional slabs, indicating satisfactory performance under normal loading conditions.

### **4.4. Durability, Dynamic, and Seismic Performance**

Long-term performance of Bubble Deck slabs has been assessed in terms of creep, shrinkage, and durability. Research indicates that the reduction in concrete volume has only a minor influence on creep behavior, as load transfer occurs primarily through the compression and tension zones. HDPE spheres have been found to remain stable over time, ensuring void integrity and long-term load-carrying capacity.

The reduced mass of Bubble Deck slabs contributes to improved dynamic and seismic performance. Lower self-weight results in reduced base shear and inter-storey drift, making the system particularly advantageous in seismic regions. Studies suggest that voided slabs provide better performance in long-span seismic structures compared to conventional solid slabs.

### **4.5. Sustainability and Environmental Impact**

Bubble Deck technology offers significant environmental benefits by reducing concrete and cement consumption. It has been reported that approximately 100 kg of concrete can be replaced by 1 kg of plastic void material, leading to substantial reductions in embodied energy and CO<sub>2</sub> emissions. The flat soffit configuration also facilitates efficient installation of electrical and mechanical services without additional ceiling treatments.

Despite these advantages, the reliance on HDPE spheres raises concerns regarding plastic production, recyclability, and long-term environmental impact. Additionally, limitations in national design codes, particularly in countries such as India, restrict widespread adoption of the technology.

#### **4.6. Comparison with Conventional Solid Slabs**

Compared to conventional reinforced concrete slabs, Bubble Deck slabs offer reduced dead load (typically 25–35%), improved material efficiency, longer spans, and lower environmental impact. Flexural performance remains comparable, while punching shear resistance requires careful design consideration. Economically, Bubble Deck slabs become more advantageous for larger spans and multi-storey buildings, whereas conventional slabs may remain preferable for small-scale applications.

#### **5. LIMITATIONS AND RESEARCH GAPS**

Although Bubble Deck slabs have demonstrated proven performance, several limitations remain. Dependence on imported HDPE void formers, higher initial costs, lack of standardized design provisions, and environmental concerns related to plastic usage restrict broader implementation. Attempts to use bio-based void materials such as palm seeds and biodegradable spheres have shown promise but are limited by durability and moisture-related issues.

Furthermore, while coconut shells have been widely studied as aggregate replacements in lightweight concrete, their application as void-forming elements in slab systems has not been explored. This represents a significant research gap and highlights the need for sustainable, locally available alternatives to plastic void formers.

#### **6. CONCLUSIONS AND FUTURE SCOPE**

This review highlights that Bubble Deck slab technology is a structurally efficient and sustainable alternative to conventional solid slabs. The system provides comparable flexural performance, acceptable serviceability behavior, and improved seismic response while significantly reducing material usage and environmental impact. However, challenges related to punching shear resistance, code limitations, and plastic dependency must be addressed.

Future research should focus on developing eco-friendly void formers, improving design guidelines, and validating alternative materials through experimental and numerical studies. Advancements in this direction can enhance the applicability of voided slab systems and promote sustainable construction practices in modern structural engineering.