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Suitability and Performance of Bubble Deck Slab: A Review

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Abstract - **Slabs are of extreme importance in any structural construction, as they are primary members. However, about 80% of the concrete in the middle of conventional solid slab are of little structural importance. Bubble deck slab (also known as voided slab) is a phenomenon that removes the structurally-inefficient concrete in the middle of slab by replacing it with high-density spherical plastic balls. This solution will solve the problems of high cost, shorter span, longer construction duration, and environmental pollution associated with the use of traditional slab. This review study investigates how bubble deck slab compares with traditional solid slab in everyday use, under loading condition, and consequently making informed recommendations to minimize the inadequacies of the bubble deck slab system.**

Keywords- **Bubble deck, solid slab, plastics, punching shear, voids.**

I. INTRODUCTION

In the construction world, slabs are a very integral part of any structural system and one of the largest concrete-consuming member. Traditional solid slabs have high dead weight, resulting in low free-span and high construction cost. The concrete in the middle of solid slabs (about 80%) perform no structural function and is structurally ineffective. It is to this end that a Danish Engineer, Jorgen Breuning, in the 1980s suggested a slab filled with plastic balls, the 'Bubble Deck Slab'.Bubble Deck Slab also known as voided slab is a hollow, bi-axial slab in which the structurally ineffective concrete in the middle part of the slab has been replaced with spherical plastic balls to create a grid of void forms inside the slab. The plastic balls are usually made of recycled high-density polyethylene (HDPE).

Bubble Deck Slab is usually prefabricated and mainly consisting of three materials: spherical plastic balls, concrete, and steel reinforcements. As a result of its low-weight peculiarity, the dead weight is reduced, thereby leading to small column and foundation sections and longer spans between supports. Bubble deck slab can be of advantage in terms of cost reduction, reduced material use, shorter construction time, sustainability, and green environment. Use of bubble deck slab can lead to a about 35-50% reduction of construction cost. The purpose of this study is to investigate the suitability of bubble deck slab in everyday construction and report its performance in comparison with the conventional solid slab system under loading conditions.

Fig.1 Bubble Deck Slab.

II. LITERATURE REVIEW

Reich, Lima, & Strelets [1] stated that the search for new methods, materials and processes that improve the quality of construction and reduce construction redundancies is a never ending voyage. About 80% of the concrete in the middle region of conventional slabs is redundant, hence the bubble deck slab solution. 1 kg of plastic balls used in bubble deck system replaces 100 kg of concrete. Also, about 40kg of potential CO2 emission associated with cement production is saved per 1m3 of concrete production [2].

Maske & Kadao [3] highlighted that the various kinds of bubble deck installation includes Filigree Element, Reinforcement Modules and Finished Planks.
Filigree Element (Type A) installation is a system in which about 60mm thick precast concrete layer acts as

both the formwork and a part of the total concrete depth, with the plastic balls and steel reinforcement unattached, temporarily supported by stands on top of the precast layer, then the installation and final construction is done on site [4].

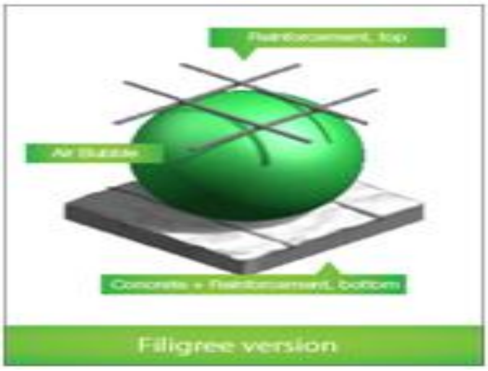

Fig.2 Filigree Element.

The Reinforcement Modules (Type B) installation is a system in which the balls and the steel reinforcement mesh have been prepared, i.e. a pre-assembled sandwich of steel mesh and plastic bubbles or bubble lattice. These components are brought to the site, laid on traditional formwork, connected with any additional shear or edge reinforcement, and then concreted in 2 stages to the full slab depth by traditional methods [5].

Fig.3 Reinforcement Module.

The Finished Plank (Type C) installation involves a shop fabricated module in which the concrete (in its total depth), the plastic balls and the reinforcements is in its finished form and delivered to the site for installation [6].

Fig.4. Finished Plank.

The precast bubble deck slab is made up of:

- **Steel reinforcement-** This is fabricated as a horizontal top and bottom rebar mesh and vertical lattice girder for tensional reinforcement of the concrete and support the bubbles.
- **Plastic balls-** Usually made of recycled high-density polyethylene or polypropylene (thermoplastic). The ball diameter usually varies from 180mm to 360mm depending on slab requirements.
- **Concrete-** Concrete is usually made of any kind of cement based on the mix design and requirement. The maximum aggregate size used for in bubble deck slab is usually 3/4in or 20mm [5].

Bubble Deck UK [7] reiterated that bubble-deck slab is designed as a flat, two-way spanning slab supported only by columns without the need for beams. The design of this system is generally governed by the maximum allowable deflection during service loading. The dimension criterion is controlled by the span/effective depth ratio (L/d) as postulated in BS8110 or EC2. This criterion be modified for bubble deck slab by applying a factor of 1.5 that takes care of the dead weight reduction. The author suggests that:
$L/d \leq 30$ – Simple supported panel, single span
$L/d \leq 41$ – Continuous panel, multiple spans
$L/d \leq 10.5$ – Cantilever panel.
According to Bubble Deck UK [7], there are five standard thicknesses for Bubble Deck slab, which vary from 230mm to 450mm, and up to 510mm and 600 mm for specific designs pending KOMO certification as documented by Lai [4]. This is shown in Table 1.

Version	Bubble Diameter (mm)	Minimum Slab Thickness (mm)	Minimum Center-to-Center-Spacing
BD230	180	230	200
BD280	225	280	250
BD340	270	340	300
BD390	315	390	350
BD450	360	450	400
BD510	405	510	450
BD600	450	600	500

Generally, for every 5,000 m2 of Bubble Deck floor slab, the owner can save:

- 1,000 m2 of on-site concrete
- 166 concrete truck trips
- 1,798 tons of foundation load, or 19 less piles
- 1,745 GJ of energy used in concrete production and transportation
- 278 tons of CO_2 emissions.[8].

III. MATERIALS AND METHODS

- **Materials**

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Fine and Coarse Aggregate: Aggregate has to meet the requirements of the mix design. The maximum aggregate size allowed for bubble deck slab is 20mm.

1. **Water:** The rule of thumb is that clean, potable water should be used for concrete production, and curing. Also taking into account the permissible limits of chloride content in water.
2. **Cement:** The cement should satisfy the mix design requirement. Usually Ordinary Portland Cement of grade 53 is used.
3. **Plastic Bubbles:** The plastic balls are made of high-density, non-porous, and non-reactive rubber material. The bubbles also must be of sufficient stiffness and strength to support the applied loading. The bubble diameter usually varies from 18cm-360cm.
4. **Steel Reinforcement:** The steel arrangement consist of horizontal (transverse and longitudinal) top and bottom steel to form a mesh, and vertical steel, resulting in a lattice-like arrangement. High yield steel is usually used. The distance between the bars corresponds to the diameter of the bubbles that are to be used [9].

- **Methods**

Banerjee [6] explained that depending on the manufacturer, plastic voided slab systems are constructed by two primary methods: a filigree method in which part of the system is precast off-site, and a method in which the entire system is constructed on-site. In both methods, the main component is the plastic balls containing void. These voids are often spherical, hollow, and made of recycled plastic. Maske & Kadao [10] explained that the voids allow the slabs to be lighter than traditional concrete slabs since the voids are nearly weightless and replace concrete in the center of the slab. Steel reinforcement is added to resist flexure for the slab, but a cage of thin steel is also used to hold the voids in place, keeping them in the center of the slab. The third main component is the concrete, which surrounds the voids and forms the slab. The concrete ultimately determines slab strength. Though both methods use each of these components, the two methods use different approaches [8].

- Manju & Mol [11] explains that, generally, The most common bubble deck deployment technique employed is the Finished Plank method in which the whole bubble deck slab module has been prefabricated at a shop and only brought to site for installation. The prefabrication process involves: Mold preparation, cleaning, and oiling; bottom steel mesh placement; plastic balls placement on bottom steel mesh; top steel mesh placement; diagonal girders steel placement for vertical support of the bubbles; and concrete pouring into the mold.

IV. RESULTS AND DISCUSSIONS

- **Stiffness and Deflection**

According to Manju & Mol [12], Table 2 compares the stiffness between bubble deck and traditional slab, under conditions of same strength, bending stiffness, and concrete volume. Also, Surendar & Ranjitham [13] in their numerical and experimental study on bubble deck slab plots the load-deflection curve for instances of bubble deck slab and conventional slab, and presented here as Figure 5.

Table 2: Strength, Stiffness, and Volume comparison

(in % of solid deck)	Same Strength	Same Bending Stiffness	Same Concrete Volume
Strength	100	105	150*
Bending Stiffness	87	100	300
Volume of Concrete	66	69	100
*On the condition of same amount of steel. The concrete itself has 220% greater effect.			

The table shows that under the same strength, bubble deck slab has 87% of the solid slab's bending stiffness, but using only 66% concrete. This implies that the resulting deflection will be higher in bubble deck slab than in solid slab, under the same loading condition, as presented graphically in Figure 5. However, the low bending stiffness is compensated by the reduced concrete use.

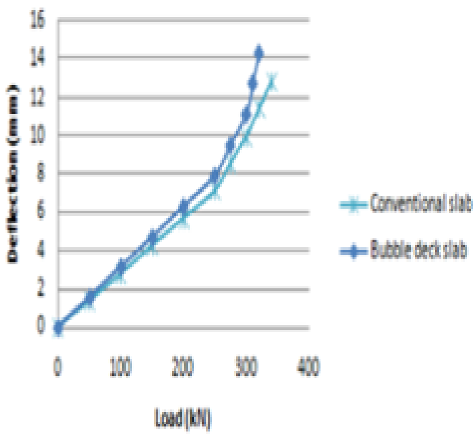

Fig.5. Load-deflection curve.

- **Bending Strength**

Bubble Deck when compared to a solid deck, both practically and theoretically. Bending stresses in the Bubble Deck slab are found to be 10% lesser than that of solid slab. The ultimate load value obtaining bending tests were up to 90% greater than the ultimate load value. The bottom reinforcement steel and the top compressive portion of stress block contributes to flexural stiffness in the bending [14].

- **Shear Strength**

Surendar & Ranjitham [14] and Lakshmikanth & Poluraju [12] from their separate investigations reported that the shear strength of the bubble deck slab stands between 60-80% of the shear strength of a corresponding solid slab. The results of the experimental investigation conducted by Tiwari & Zafar [15], and reported here as Table 3 results in a bubble deck slab shear capacity of 75% of the corresponding solid slab shear capacity. The authors therefore adopts a conservative safety factor of 0.6 for the determination of shear strength in bubble deck slab. In critical regions where shear capacity is less than the applied shear stress, shear reinforcements is provided.

Table 1: Shear strength comparison

Shear Capacity (in % solid slab)	a/d = 2.23
Solid Slab	100
Bubble Deck Slab	75

- **Punching Shear**

Lakshmikanth & Poluraju [12] reported a paper that investigated the validity of German design code, DIN 1045, for the structural behavior of bubble deck slab and concluded that the failure mode of both bubble deck slab and solid slab are similar, and modification was made for the available design rules.

Bubble Deck Slab is a flat slab system, hence it has to be carefully designed against punching shear failure. In flat slab, the critical areas are localized areas of influence around the supporting columns. Investigations carried out by [16] shows that the punching shear is 90% of corresponding solid slab, and local punching failure did not occur within the given load cases. When the applied shear is greater than the punching shear, provide drop panels or flared column heads, or increasing the slab depth [17].

- **Fire Resistance**

Varshney, Jauhari, & Bhatt [18] in their paper "A Review Study on Bubble Deck Slab" stated that Fire resistance of bubble deck slab is a somewhat complex phenomenon. The report affirmed that Bubble deck slab is similar to solid slab in terms of fire resistance. It is mostly dependent on the steel reinforcement's ability to withstand a fire event, how rapidly it loses strength during fire. This is because steel, when heated, loses significant strength as temperature increases. In the long term, the plastic ball will melt under fire condition, and eventually char without significant or detectable effect [7]. Balls simply carbonize, no toxic gases released. An important experimental investigation was conducted in order to determine the influence of concrete cover and steel stress on fire resistance in the laboratory "Material Research and Test Office for Construction Leipzig", as documented by Terec & Terec [5], and presented here as Table 4.

Table 4: Fire resistances of bubble deck slab

Steel Stress	**Fire Resistance (minutes)**				
	30	60	90	120	180
≤190	17 mm	17 mm	17 mm	17 mm	-
≤286	17 mm	29 mm	35 mm	42 mm	55 mm

The ability of the slab to withstand fire is directly dependent on the concrete cover. Ali & Kumar [16] reported that fire resistance of bubble deck slab is within 60-180 minutes, while smoke resistance is about one and half times the fire resistances.

V. CONCLUSION

Bubble desk slab is a viable replacement for conventional solid slabs, it has been deployed in more than twenty countries worldwide. The deployment of bubble deck slab system will reduce the quantity of CO2 emissions in our ecosystem, reduce construction cost, increase construction efficiency, and reduce project duration. However, there are some inadequacies associated with bubble deck slab system, such as the increased susceptibility to punching shear failure and deflection. This study has highlighted that a properly designed bubble deck system will curb these inadequacies. Using a safety factor of 0.6 for the determination of the shear strength; provision of the complete concrete thickness in the critical areas; provision of column head or capital; and provision of shear reinforcements are some of the highlighted solutions to the inadequacies associated with bubble deck system. Also, the fire resistance of bubble deck slab compares well with corresponding solid slab; the fire resistance can be increased by providing adequate concrete cover. Conclusively, the bubble deck slab is a worthy replacement of the conventional solid slab.

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Author's Profile

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