REVIEW ON BUBBLE DECK WITH SPHERICAL HOLLOW BALLS

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ABSTRACT
The aim of this paper is to discuss about various significance of Bubble Deck Slab against Conventional Slab based on the various studies. Reinforced concrete slabs are one of the most common components in modern building construction consuming most of the concrete.

Due to the sheer amount of concrete required to produce these slabs, the dead weight of them tend to be very large. Heavier structures are less desirable than lighter structures in seismically active regions because a larger dead load for a building increases the magnitude of inertia forces which the structure must resist, as large dead load contributes to higher seismic weight. Bubble Deck is a revolutionary method which was developed in the 1990s in Europe and is gaining popularity and acceptance worldwide. This method virtually eliminates concrete from the middle of the conventional slab, thereby dramatically reducing structural dead weight. Bubble voided slabs are capable of reducing the amount of concrete necessary to construct a building by 30 percent or more. Voids in the middle of a flat slab eliminate up to 35% of a slab’s self-weight removing constraints of high dead loads and short spans. This provides a wide range of cost and construction benefits.

Key words: bubble deck, dead load, elliptical balls, recycled plastic, voids, HDPE, structural function, reinforcement mesh.


1. INTRODUCTION
A concrete slab is a common structural element of modern buildings. Horizontal slabs of steel reinforced concrete are most often used to construct floors and ceilings, exterior paving. A slab being the essential part of the Structure has to be effectively designed and utilized.
tends to use more concrete than requirement, hence has to be optimized. Bubble deck slab is the slab in which some amount of the concrete is replaced by the plastic hollow bubbles which are made by the waste plastic material, which reduces the self-weight of the structure. The main effect of the plastic sphere is to reduce the dead load of the deck by \( \frac{1}{3} \) in compare to solid slab having same thickness without effecting its deflection behavior & bending strength. The slab is cast with the same capabilities as a solid slab, but with considerably lesser weight due to elimination of excessive concrete. The spheres could be recycled even after the building is demolished or renovated in the future. The dead air space in the hollow spheres provides insulating value and can be introduced with foam for additional energy efficiency, this also increases fire resistance as well as sound insulation.

2. LITERATURE REVIEW

**Tina Lai** "Structural behavior of bubble deck slab and their applications to lightweight bridge decks", M.Tech thesis, MIT, 2009

This paper summarizes that that the BubbleDeck technology is more efficient than a traditional biaxial concrete slab in an office floor system, citing various advantages over conventional slabs. The finite element models of the office slabs created for this study in **SAP2000** verify the prior analysis and experiments. However, the performance of the voided slab is not as successful in a pedestrian bridge deck.


This study compares the Conventional slab against Bubble Deck Slab systems with continuous or alternative bubble arrangements in terms of their ultimate load carrying strength and deflections.

**Sergiu Călin, Roxana Gințu and Gabriela Dascălu, "Summary of tests and studies done abroad on the Bubble deck slab system", The Buletinul Institutului Politehnic din Iași, t. LV (LIX), f. 3, 2009.**

This study shows different tests carried out on conventional slabs and bubble decks including bending strength and deflection behavior, shear strength, punching shear, dynamic punching shear, anchoring, fire resistance, sound insulation and various other tests. This study says that the Bubble Deck behaves like a spatial structure – as the only known hollow concrete floor structure, the tests reveal that the shear strength is even higher than conventional slab system, this indicates a positive influence of the balls. All tests, statements and engineering experience confirm that Bubble Deck:

a) Bubble Decks act as a solid deck.
b) Follows the same regulations as that of a solid deck.
c) Leads to much considerable savings.

**Martina Schnellenbach-Held and Karsten Pfeffer,"Punching behavior of biaxial hollow slabs” Cement and Concrete Composites, Volume 24, Issue 6, Pages 551-556, December 2002.**

Because of bubble deck’s main field of application as a flat slab, the punching shear capacity is one of the most interesting properties of this slab. This paper investigates the influence of the cavities on the punching behavior, tests were carried out at the Institute for Concrete
Structures in Darmstadt. In addition to these tests nonlinear computations using the Finite Element Method were also performed.


This paper presents some experimental programs which refer to concrete slabs with spherical gaps, i.e. bubble deck slabs existing in similar execution and loading conditions as those from a real construction; this implies the realization of a slab element at a scale of 1:1, which was subjected to static gravitational loadings in order to determine the deflection, cracking and failing characteristics respectively.

Reshma Mathew, Binu.P “Punching Shear Strength Development of Bubble deck Slab Using GFRP StIRRups”, SNGCE kadayirippu, India, 2016

Punching shear capacity of bubble deck slab is a major problem because of its reduced weight due to the HDPE balls. GFRP strengthening system was used in this study. Strengthened slabs did have higher punching capacity compared with normal bubble deck slab. There was an increase in load carrying capacity up to 20 % due to strengthening of the bubble deck slab with GFRP. Although the strengthened bubble deck had low deflection when compared to an un-strengthened bubble deck slab.

2.1. Case Study

Bubble Deck Slab

The geometry of the Bubble Deck slab is defined by spheres of a certain size, which are placed in a modular grid for a particular overall deck thickness, depending upon the diameter of the balls used. Bubble deck produces floors 20% faster with less formwork and beams, reduces construction costs by 10% and agrees with the 35% reduction in concrete use.

Objectives

- The main objective of this is to study the practicality in using hollow spherical plastic balls in reinforced concrete slab, which is called as bubble deck slab.
- To present a procedure for comparison of all parameters between solid conventional slab & bubble deck slab.
- To study the bending (deflection) behavior of conventional slab & bubble deck slab.
- To study the behavior of conventional slab & bubble deck slab.
- The effects of using Hollow plastic ball (HDPE - High Density of polyethylene) in the reinforced concrete slab.

3. MATERIALS REQUIRED: [1]

The following materials are used to construct a Bubble Deck slab:

Hollow Balls/Bubbles [8 & 9]: The hollow balls are made using high density, polypropylene plastic which is a nonporous material that does not react chemically with the concrete or reinforcement bars. The bubbles have enough strength and stiffness to safely support the applied loads. Bubble diameter usually varies between 180mm to 450mm. Depending on this, the slab depth is 230mm to 600mm. The distance between bubbles must be greater than 1/9th of bubble diameter. They may be of spherical or ellipsoidal in shape.

Concrete: The concrete that is to be used for joint filling in the Bubble Deck floor system must be above class 20/25. Usually, self-compacting concrete is used.
Reinforcement bars: The reinforcement of the plates is made of two meshes, one at the bottom part and one at the upper part that can be tied or welded. The steel is fabricated in two forms- the meshed layers and diagonal girders for vertical support of the bubbles. The distance between the bars correspond to the diameter of the bubbles that are to be used and the quantity of reinforcement from transverse ribs of the slab.

4. PREPARATION OF REINFORCEMENT MESH [8 & 9]
The steel bars are provided in Bubble deck for tension zone and concrete is provided for compression zone.

![Figure 1](image_url)

4.1. Construction
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. Both methods use the same three basic components. In both methods, the main component is the plastic balls containing void. These voids are often spherical, hollow, and made of recycled plastic. 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. The next main component is the steel cage. 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. The voids are assembled in steel cages and then concrete is poured to a height part way up the voids. The filigree slab panels are then transported to the construction site and lifted in place by crane. Once in place, the top layer of concrete is placed, covering the voids and completing the slab. Wire trusses run between the precast and cast-in-place layers of concrete to ensure that the two layers bond properly.

5. CONTACT BETWEEN BUBBLES AND REINFORCEMENT
The potential for any contact is only theoretical because the balls do not perfectly fit between reinforcement bars and moves slightly during assembly and site concrete compaction so that some grout surrounds it. However, even if there were contact between the ball and the steel, the environment inside the void is very dry and protected - there is also no breach (apart from micro cracking) of the concrete to the outside air. It is a better situation than what exists with the inclusion of plastic rebar spacers within solid slabs that create a discontinuity within the concrete between the outside air and the rebar in solid slabs.
6. COMPARISON WITH CONVENTIONAL SLABS

6.1. Experimental Case Study

Types of slab casted
1. Conventional slab
2. Bubble deck (continuous arrangement of bubble)
3. Alternative bubble deck slab (type I)
4. Alternative bubble deck slab (type II)

- The conventional slab was prepared with M30 grade of concrete & the design of reinforcement according to the IS Code 456-2000 & IS 10262:200.
- In the Bubble deck slab, firstly the design of continuous bubble deck slab was prepared using DIN 1045 (1988) or DIN 1045 (2001) code (German code).
- After the preparation of continuous bubble deck slab, the design of alternative bubble deck slab was prepared using, DIN 1045 (1988) or DIN 1045 (2001) code, (German code) codes and analyses it.
- In the alternative bubble deck slab preparation there are different arrangements of the bubbles which is alternative bubble deck slab (type I) & (type II) accordingly.
- The conventional slab & bubble deck slab was casted with the hollow strong plastic balls i.e. HDPE (High density polyethylene balls).

Conventional slab
The conventional concrete i.e. M30 grade concrete was having mix design according to the IS 456:2000 & IS10262:2009.

Continuous Bubble deck
In this slab continuous arrangement of bubbles are placed.

Alternative bubble deck slab (type I & II)
- Reinforcement of alternative bubble deck slab is same as continuous bubble deck slab.
- In the alternative bubble deck slab we reducing the bubbles volume and increasing the volume of volume and analyzing the ultimate effect on it’s strength.
- In the alternative bubble deck slab (type II) the arrangement of bubbles are different from the alternative bubble deck slab (type I).

6.2. Experimental Procedure

Conventional slab
The conventional slab is prepared with M30 grade of concrete. It’s dimension is 1m x1m x 0.125m. Reinforcement used is 4 crank bar longitudinal, 4 crank bar lateral, and 4 distribution bar on four sides of slab. Diameter of that reinforcement bars used is 8mm @ 240mm c/c spacing. Total length of the bars are 960mm, straight portion of that bar is about 810mm in length and crank portion of bar length is about 150mm length and the Crank bar is bent at about an angle 45°.
Continuous Bubble deck
The reinforcement mesh is placed on both side of the bubbles and bubbles are arranged in continuous manner. Reinforcements are 6mm @ 62mm c/c spacing and 6mm @ 12mm c/c spacing, which are provided in alternatively. Total length of the bars are 960mm.

Alternative bubble deck slab (type I & 2)
The reinforcement mesh is placed both side of the bubble and bubbles are placed in alternative manner. Reinforcement is same as that of continuous bubble deck slab.

6.3. Testing Procedure
The tested slabs were simply supported and loaded with a single-point load. The slab specimens were placed on the testing machine and adjusted accordingly, the point load and dial gauge were placed in their correct locations. At the end of each load increment, observations were recorded for the mid-span deflection and crack development on the slab surface. The deflection of the specimens were measured at their mid span beneath the lower face. When the slab reached it’s advanced stage of loading, smaller increments on load were applied until it’s failure.
7. RESULTS OF THE EXPERIMENTS

Graph 1 shows the load carrying capacity on the slab

Graph 2 shows the Deflection behavior on the slab

<table>
<thead>
<tr>
<th>Type of slab</th>
<th>Load (KN)</th>
<th>Deflection (mm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Slab</td>
<td>260</td>
<td>8.70</td>
<td>321</td>
</tr>
<tr>
<td>Continuous Bubble deck</td>
<td>320</td>
<td>9.20</td>
<td>242</td>
</tr>
<tr>
<td>Alternative bubble deck</td>
<td>290</td>
<td>8.95</td>
<td>278</td>
</tr>
<tr>
<td>deck type I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative bubble</td>
<td>275</td>
<td>8.80</td>
<td>281</td>
</tr>
<tr>
<td>deck type II</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. INFERENCE

In the experiment we find that the bubble deck (continuous) with much reduced the volume of concrete has much lower self-weight. Simultaneously the load carrying capacity has also increased as compared to the conventional slab. But the arrangement of the bubbles does have an effect on the load carrying capacity of the slab, in the case of alternative arrangements of bubbles there is an increase in the load carrying capacity when compared with the conventional slab, but the load carrying capacity is lower than the continuous bubble deck slab.

Simultaneously, bubble deck slab also has improved elasticity property compared to the conventional slab which causes the conventional slab to deflect less than the bubble deck slab, the number of bubbles in the slab also has an effect on the this elasticity property.

Weight reduction is one of the most important factor here in case of the bubble deck slab. Weight of the conventional slab is much more than that of the bubble deck slab.

Similar tests run on conventional slabs and bubble deck slabs have shown us that bubble deck slabs are usually more susceptible to failure due to shear. In any flat slab, design shear resistance is usually critical near columns. The shear stresses from the columns lowers down quickly and outside the column zones. Near the columns, bubbles are usually left out so in these zones the Bubble deck slab is designed exactly the same as a conventional slab. Shear resistance of Bubble deck slab is 0.6 times the shear resistance of a solid slab of the same thickness [1 & 4]. The results are shown in table 2 when a bubble deck slab is compared with
a conventional slab. Punching shear [1 & 4] the average shear capacity is measured to 91 % compared to the calculated values of a solid deck.

Table 2 Comparison of shear capacity in girders with solid deck and bubble deck slab [3]

<table>
<thead>
<tr>
<th>Shear capacity (in % of solid deck)</th>
<th>a/d=2.15</th>
<th>a/d=3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid deck</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Bubble deck, secured girders</td>
<td>91</td>
<td>78 (81)*</td>
</tr>
<tr>
<td>Bubble deck, loose girders</td>
<td>77</td>
<td></td>
</tr>
</tbody>
</table>

*Corrected for test elements with longer time for hardening

Another comparison for sound insulation was made between Bubble Deck and conventional one way prefabricated hollow deck of similar height. The noise reduction with Bubble Deck was 1db higher than the one way prefabricated hollow deck [5 & 6].

9. CONCLUSIONS

- It enables reduced foundation sizes since the structural dead-weight is reduced.
- Concrete usage is significantly reduced; 1kg of recycled plastic replaces 100kg of concrete. It is, therefore, environmentally friendly. The overall result is a significant cost saving of between 2.5% to 10% of total construction costs.
- Makes the building soundproof comparatively.
- Helps to achieve much greater fireproof designs compared to using conventional slabs. [7]
- Time savings as on site construction time can be shortened since Bubble Deck slabs can be precast. Quicker casting time as there is much lesser concrete content in the slabs. [1]
- Green Design: According to Bubble Deck Company, 1 kg of recycled plastic replaces 100 kg of concrete. By using less concrete, designers can save up to 40% on embodied carbon in the slab. Additionally, the HDPE bubbles can be reused for other projects, or can be recycled. [1]
- 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
  - 278 tonnes of CO2 emissions (BubbleDeck-UK)
  - 1,798 tonnes of foundation load, or 19 less piles [1, 8 & 9]
- There is a marginal increase in cost of production due to assembly and manufacturing of HDPE spheres. [1]
- Punching shear capacity is low, which is a major problem due to the decreased weight of the Bubble Deck systems. [1,3 & 10]
- Finished depth of slabs increases in general when compared to conventional slabs.
- Difficulty in structural health monitoring.
- Skilled labor is required.
- Not applicable to slabs having limited Thickness.
10. FUTURE SCOPE

- One can test the Ball Deck Slab system by changing the thickness of the slab using different bubble diameter in the future.
- The results coming from lower grades of concrete can also be checked.
- One can test the results with the HDPE balls being filled with gases lighter than air, such as Helium or Nitrogen which in turn will produce inner thrust.

REFERENCES