Finite element analysis on effect of different ball spacing in bubble deck lightweight concrete slab

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Abstract: Reinforcement Concrete (RC) is considered one of the heaviest construction materials hence many attempts have been done to reduce the self-weight of concrete and since the most mass focused in the slab element of structure, a new type of slab has been developed in 1990 called bubble deck slab and started recently used around the world, on the other hand using of Lightweight Concrete (LWC) will decreased the self-weight of concrete which has density less than (1850 kg/m3) compare with conventional concrete (2400-2500 kg/m3), this research conduct an analytical study of the bubble deck slab using lightweight concrete. Four types of bubble deck slabs are modelled in the Finite Element (FE) Software ABAQUS of uniform size 1400 mm x 1400 mm x 150mm. Analytical investigation is conducted to find the performance of four different types of bubble deck slabs which is varied based on arrangement of location of spherical balls and reinforcement. Finite Element Analysis (FEA) results show that all the slab models has less than 2.5% difference in load carrying capacity. Introduction of bubble deck concrete slab system in construction will reduces the consumption of concrete in construction which results in economy of the project.

Key Words: Bubble Deck Slab, Lightweight Concrete, Spherical Bubble, Finite Element (FE) Software ABAQUS, Finite Element Analysis (FEA)

1. INTRODUCTION

A slab considers as the essential part of the structure which it has to be effectively designed and utilized, RC slabs are most often used to construct floors and ceiling. Concrete is heavy material, therefore, various attempts have been made in the past to reduce the weight of concrete without reducing their flexural strength of slab. About 7% of total greenhouse emissions is due to the production of cement (Nagan and Mohana 2014) [1]. Utilization of alternative materials for aggregate in construction not only reduces the scarcity of aggregate and or reduces the dead weight of the structure in one form and also this will decrease the overall cost of the project (Vinod Kumar et al. 2019) [2]. Recently, waste materials from industries have been used as partial replacement of cement to protect the environment (Kockal 2013) [3]. The voided slab which consumes a less quantity of concrete would aid in green construction. Bubble deck slab [figure 1] is biaxial technology that increases span length and makes floors thinner by reducing the weight while maintaining the performance of reinforced concrete slabs in this type of slab some amount of the concrete is replaced by plastic polyethylene hollow bubbles which are made by waste plastic material in order to achieve concept of removing non-working concrete in slab, as per Jorgen Breuning 1990 (BubbleDeck-UK 2008) [4] this process will reduce the dead load of the deck around 30% while having almost same capacity compare to solid slab, bubble deck slab consist of three main elements:
• Concrete of any grade can be used, generally grade 20 or 30 MPa.
• Hollow plastic spheres (ball) made of recycled plastic waste (HDPE: High density polyethylene).
• Reinforcement mesh at top and bottom concrete layers and lattice girder for vertical support of the bubbles.

2. RELATED RESEARCH WORK

Amer Mohamed Ibrahim et al (2019) [5] conducted an experimental work to investigate the effect of ball shapes (spherical and elliptical) and its spacing in the slab. The experimental result shows that the bubbled slabs (containing spherical and elliptical balls) have about 96% to 90% of the ultimate load than the solid slab. The bubble deck slab having spherical balls are more efficient in bearing loads than slab containing elliptical balls. Sagadevan and Rao (2019) [6] studied the experimental and analytical performance of biaxial voided slab under one-way flexure test, the flexural stiffness of voided specimen is approximately 50% lesser in comparison with solid slab and the ultimate load carrying capacity of specimens with sphere is equal to that of the solid slab. Sattainathan Sharma et al (2019) [7] conducted laboratory test for conventional slab and two types bubble deck slab having ball diameter of 60 mm. Bubbles are arranged in zig-zag pattern and uniform pattern. Test results revealed that the load capacity of the bubble deck slab about 85% (zig-zag) and 73% (uniform) as compared to solid slab. Nagashree et al. (2017) [8] carried out experimental study to examine the stiffness and deflection on conventional slab and bubble deck slab of 60 mm and 70 mm. The bubble deck slab with 60mm voids has higher stiffness and lesser deflection than 70 mm voids slab. Subramanian et al. (2017) [9] identified and found that spherical-shaped void formers reduces maximum reduction of volume of concrete. So, in this analytical investigation, spherical-shaped void formers are used. Other shapes of void formers include doughnut, frustum of pyramid, rectangular blocks etc., (Churakov 2014) [10].

![Figure 1. Bubble Deck Slab](image)

3. RESEARCH SIGNIFICANCE:

Many researchers carried out the experimental and analytical of bubbled slab with spherical, elliptical and cupid voids to reduce the dead weight of the slab. Based on preceding attempts, spherical voided bubble deck slab performed better than the elliptical and cupid voids. It is realized that only few very analytical investigations have been carried out on bubble deck slab. Separate studies have been conducted on slab with different void spacing and Lightweight Concrete (LWC). Hence, in this analytical study, a new attempt has been made to investigate the performance of bubble deck slab with LWC under different arrangement of balls and reinforcement to find the unrivalled bubble deck slab.
without compromising in its performance.

4. METHODOLOGY

4.1. Material Properties
The solid slab design is carried out in accordance with IS-456: 2000 [11]. M25 and M18 grade of concrete is used for modelling of Conventional Concrete (CC) and Lightweight Concrete (LWC) bubble deck slab, whose elastic modulus is 28960 N/mm² and 26242 N/mm² respectively. Poisson’s ratio is considered as 0.2 for both the grade of concrete. 8 mm and 10 mm diameter steel reinforcement is used in both top and bottom of the slabs. The yield and ultimate stress of steel reinforcement is 250 and 500 MPa respectively. Hollow plastic spheres balls of 100 mm diameter are used in the slabs. Moment of inertia of solid slab section (Is) and moment of inertia of HDPE ball (Iv) is 393750000 mm⁴ and 4906250 mm⁴ respectively. The moment of inertia of voided slab is calculated based on the reference given by Muhammad Shafiq Mushfiq et al. (2017) [12].

4.2. Model Description
In this analytical investigation, different types of bubble deck slab are modelled as mentioned in the table 1 and all the specimens are uniform in size of 1400mm x 1400mm x 150mm. The arrangement position of balls and reinforcement is different in bubble deck slab as shown in figure 2 - figure 6. The number of balls, mass reduction of slab in Kilogram, percentage of weight reduction and stiffness reduction of different types of slab is mentioned in the table 2.

| Model ID | Category | Abbreviation |
|----------|----------|--------------|
| CS       | Conventional Concrete (CC) | Conventional concrete Slab |
| CBDS1    | Conventional Bubble Deck concrete Slab- Type 1 |
| CBDS2    | Conventional Bubble Deck concrete Slab- Type2 |
| CBDS3    | Conventional Bubble Deck concrete Slab- Type3 |
| CBDS4    | Conventional Bubble Deck concrete Slab- Type4 |
| LS       | Lightweight concrete Slab |
| LBDS1    | Lightweight Bubble Deck concrete Slab- Type 1 |
| LBDS2    | Lightweight Bubble Deck concrete Slab- Type2 |
| LBDS3    | Lightweight Bubble Deck concrete Slab- Type3 |
| LBDS4    | Lightweight Bubble Deck concrete Slab- Type4 |

Figure 2. Solid Slab (All dimensions are in millimetre)
Figure 3. Bubble Deck concrete Slab - Type 1

Figure 4. Bubble Deck concrete Slab - Type 2

Figure 5. Bubble Deck concrete Slab - Type 3

Figure 6. Bubble Deck concrete Slab - Type 4

Table 2. Number of Bubbles, Weight Reduction and Stiffness Reduction

| Model ID | No. Balls | Balls Spacing (mm) | Weight Reduction (kg) | Weight Reduction % | Stiffness Reduction % |
|----------|-----------|--------------------|-----------------------|--------------------|-----------------------|
| CS       | 0         | 0                  | 0                     | 0                  | 0                     |
| CBDS1    | 25        | 250                | 32.71                 | 4.45               | 6.23                  |
| CBDS2    | 15        | 250                | 19.63                 | 2.67               | 3.37                  |
| CBDS3    | 13        | 500                | 17.01                 | 2.31               | 3.37                  |
| CBDS4    | 21        | 250-500            | 27.48                 | 3.74               | 6.23                  |
| LS       | 0         | 0                  | 0                     | 0                  | 0                     |
| LBDS1    | 25        | 250                | 23.55                 | 4.45               | 6.23                  |
| LBDS2    | 15        | 250                | 14.13                 | 2.67               | 3.37                  |
| LBDS3    | 13        | 500                | 12.25                 | 2.31               | 3.37                  |
| LBDS4    | 21        | 250-500            | 19.78                 | 3.74               | 6.23                  |

*Stiffness reduction = [(Is - (Iv x number of balls for each type) *100)] %

4.3. Application of Load

Solid and bubble deck slabs were analyzed under four point bending as shown in figure 7-8
respectively. The slab supports consisting of a pin support and a roller support at the two ends. The specimen overall length is 1400 mm with a span length of 1200 mm and the load was applied at points dividing the length into three equal parts. The slab models were tested up to the ultimate load. Deflections and strains were measured in the center of slab for different loads.

**Figure 7.** Solid Slab under Four Point Bending (All dimensions are in millimetre)

**Figure 8.** Bubble Deck Slab under Four Point Bending (All dimensions are in millimetre)

### 5. ANALYTICAL INVESTIGATION

Solid and bubble deck slabs are modeled using Finite Element Analysis (FEA) software (ABAQUS). This FEA software is analyzing the plastic behaviour of slab model using concrete damage plasticity to get an accurate result. The stress - strain behaviour of concrete under compression and tension for CC and LWC as shown in figure 9 and figure 10 respectively.

**Figure 9.** Stress - Strain Behaviour of CC and LWC under Compression
The application of load in solid and bubble deck slab model is shown in figure 11. The arrangement position of balls is shown in figure 12 (a) – figure 12 (d). The meshing of solid and bubble deck slab model in ABAQUS is shown in Figure 13 and Figure 14 respectively to analysis the slab models.
6. RESULTS AND DISCUSSION

After analyzed all the slab models shown in Table 1, the results are compared in terms yield load, ultimate load, yield displacement and ultimate displacement and mentioned in the table 3.

| Model ID | Load in (kN) | Displacement in (mm) |
|----------|--------------|----------------------|
|          | Yield Load (Py) | Ultimate Load (Pu) | Yield Displacement (Dy) | Ultimate Displacement (Du) |
| CS       | 150          | 153.36               | 1.58                   | 2.47                     |
| CBDS1    | 147          | 150.66               | 2.07                   | 3.04                     |
| CBDS2    | 145.1        | 149.50               | 1.71                   | 2.77                     |
| CBDS3    | 147          | 152.11               | 1.73                   | 8.36                     |
| CBDS4    | 145          | 151.04               | 2.10                   | 2.93                     |
| LS       | 138.5        | 140.05               | 1.97                   | 3.65                     |
| LBDS1    | 136          | 138.74               | 1.83                   | 3.95                     |
| LBDS2    | 135          | 137.28               | 1.91                   | 2.48                     |
| LBDS3    | 137.5        | 138.92               | 3.20                   | 8.32                     |
| LBDS4    | 134          | 138.05               | 1.87                   | 3.13                     |

The ultimate load and displacement difference for different types of bubble deck slab with respect to conventional concrete slab and lightweight concrete slab is mentioned in the figure 15 and figure 16. From the figure 15, it is found that, all the types of slabs in CC and LWC has less than 2.5% difference in load carrying capacity.

The load carrying capacity of Conventional Bubble Deck Concrete Slab - Type3 (CBDS3) is slightly 0.8% Lesser than Conventional concrete Slab (CS) and also observed that the ultimate load of CBDS1, CBDS2 and CBDS4 is 1.7%, 2.5% and 1.5% is lesser than CS respectively. The difference between the ultimate load carrying capacity of Lightweight concrete Slab (LS) and different types of bubble deck slab in LWC (LBDS1, LBDS2, LBDS3 and LBDS4) is 0.9%, 1.9%, 0.8% and 1.4% respectively.

The ultimate load difference for different types of bubble deck slab with respect to conventional concrete slab and lightweight concrete slab is mentioned in the figure 15. From the same figure, it is found that, all the types of slabs in CC has less than 2.5% difference in load carrying capacity. The load carrying capacity of Conventional Bubble Deck Concrete Slab - Type3 (CBDS3) is slightly 0.8% only Lesser than Conventional concrete Slab (CS) and also observed that the ultimate load of CBDS1,
CBDS2 and CBDS4 is 1.7%, 2.5% and 1.5% lesser than CS respectively.

![Figure 15. Ultimate Load Comparison with respect to CS and LS](image)

![Figure 16. Ultimate Displacement with respect to CS and LS](image)

| Table 4. Comparison of Percentage Difference in Load Carrying Capacity and Weight of the Slab |
|---------------------------------------------------------------|
| **Model ID** | **Weight of the Slab (kg)** | **Load Carrying Capacity (kN)** | **% Increase in Load Carrying Capacity** | **% Reduction in Weight of the Slab** |
| LS | Control | 529.2 | 140.5 | 0 | 38.89 |
| CS | 735 | 153.36 | 9 | 0 |
| LBDS1 Type 1 | 469.2 | 138.74 | 0 | 38.89 |
| CBDS1 | 651.7 | 150.66 | 8 | 0 |
| LBDS2 Type 2 | 493.2 | 137.28 | 0 | 38.89 |
| CBDS2 | 685 | 149.50 | 8 | 0 |
| LBDS3 Type 3 | 498 | 138.92 | 0 | 38.89 |
| CBDS3 | 691.7 | 152.11 | 9 | 0 |
| LBDS4 Type 4 | 478.8 | 138.05 | 0 | 38.89 |
| CBDS4 | 665 | 151.04 | 9 | 0 |

Table 4 shows comparison of percentage difference in load carrying capacity and weight of the slab. The load carrying capacity of all slab models in CC increases 8-9% than the LWC slab models. But the slab models weight reduces nearly 39% in LWC than CC. This will reduce the consumption of concrete in construction which results in economy of the project. The ultimate displacement difference for CBDS1, CBDS2, CBDS3 and CBDS4 (different types of bubble deck slab in CC) is 23%, 12%, 238% and 18% Greater than the Conventional concrete Slab (CS) respectively. Likewise, LWC bubble deck slab models LBDS1 and LBDS3 is 127%, and 8% than Lightweight concrete Slab
(LS) respectively. Due to 6% stiffness reduction (refer table 1), the deformation of bubble deck slabs models (except LBDS2 and LBDS4) is greater than CS and LS. LBDS2 and LBDS4 is lesser by 32%, 14% in deformation than Lightweight concrete Slab (LS).

From the figure 15 - 16 and table 4, it is clear that Bubble Deck concrete Slab type 3 (CBDS3 and LBDS3) is performed better in terms of weight, ultimate load and displacement. The reason is Bubble Deck concrete Slab- Type 3 reduces only 2.31% by weight of concrete (as shown in table 2) whereas Bubble Deck concrete Slab- Type 1, Type 2 and Type 4 reduces 4.45%, 2.67% and 3.74% respectively than CS and LS.

Figure 17. (a) Max Displacement of CS
Figure 17. (b) Max Displacement of CBDS3
Figure 18. (a) Max Displacement of LS
Figure 18. (b) Max Displacement of LBDS3

Figure 17-18 shows the comparison of maximum displacement of Conventional concrete Slab (CS), Lightweight concrete Slab (LS) with Bubble Deck concrete Slab- Type 3 (CBDS3 and LBDS3) respectively. Figure 19-20 shows the plot of load versus displacement for CC and LWC. From the figure 19-20, it is identified that the load carrying capacity of all the slab models are almost same but the deformation characteristics of bubble deck slab models are less.

Figure 19. Load versus Displacement for CC
7. CONCLUSION

This study involves the analytical investigation of bubble deck system using ABAQUS finite elements program. The following conclusions are drawn based on the results obtained from the FEA software:

- All the slab models have almost the same load-carrying capacity (less than 2.5% difference).
- Load carrying capacity of all slab models in CC increases 8-9% than the LWC slab models.
- LWC slab models weight reduces nearly 39% than CC slab models.
- Due to 6% stiffness reduction, almost all the bubble deck slabs models is greater in the deformation. The ultimate displacement difference for CBDS1, CBDS2, CBDS3 and CBDS4 is 23%, 12%, 238% and 18% greater than CS. Likewise, LBDS1 and LBDS3 is 8% and 128% than LS, but LBDS2 and LBDS4 is lesser by 32% and 14% than LS.
- Bubble Deck concrete Slab type3 (CBDS3 and LBDS3) is performed better in terms of weight, ultimate load and displacement. The reason is Bubble Deck concrete Slab- Type3 reduces only 2.31% by weight of concrete whereas Bubble Deck concrete Slab- Type1, Type 2 and Type 4 reduces 4.45%, 2.67% and 3.74% than CS and LS.
- Introducing bubble deck concrete slab system in construction will reduces the consumption of concrete in construction which results in economy of the project.

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