Economical Design of Slab by using HDPE Balls with Comparison of Conventional and Hollow Core Slab

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Abstract

Concrete is a strong, durable material composed of cement, aggregate and water. Concrete has an overall load-bearing potential under compression, but it fails miserably under tension. That's why steel bars are inserted in the concrete for the structure to support tensile loads. The slab is a very significant building structural element, and the slab is one of the main concrete-consuming members. The load acting on the slab is the heavy or clear span between columns is more, the slab thickness is increasing. As a result, more material such as concrete and steel is consumed; the self-weight of the slab is increased. To overcome these disadvantages, various studies have been conducted, and researchers suggest a void flat plate slab system to reduce the weight of the slab by three. This technology is termed Bubble Deck technology.

The strength of any concrete slab is mainly dependent on the effective mass of concrete. Due to the introduction of High-density polyethylene balls (HDPE), the strength of a Bubble Deck slab is low compared to a solid slab. From the studies, it is known that the strength of the bubble deck slab increases by adding admixtures, i.e., 80% of a solid slab with the same thickness. If the strength of the buddle deck slab is less, more reinforcement must be required. Material weight reduction, construction and time saving, cost-saving, eco-friendly and high thermal resistance are the main advantages of buddle deck slab.

***Keywords**: - Bubble Deck Technology, Deck Slab, Eco-Friendly, High Density Polyethylene Balls (HDPE), Slab Strength.*

INTRODUCTION

In building constructions, the slab is one of the largest structural member consuming concrete and rests on beams and columns to provide shelter and carries vertical loads [18]. Practically, there are various types of slabs, including:

- Conventional RCC Slab [4]
- Bubble Deck Slab [8]
- Flat Slab [11]
- Composite Slab [5]
- Hollow Core Slab [3] etc.

Conventional RCC Slab

The conventional slab is supported with beams and columns, with the load transferred to those elements. It is a common structural element of the buildings. Horizontal slabs of steel-reinforced concrete, typically between 100 to 500 mm thick, are most often used to construct floors and ceilings. This type of slab is further classified as One Way and Two Way Slabs, respectively. For this study, Conventional RCC Slab was made with a thickness of 175mm [4], [19]. **Fig. 1** below presents the Conventional RCC Slab.

Fig. 1: Conventional RCC Slab

Bubble Deck Slab

Bubble deck slab is a biaxial hollow core slab invented in Denmark by Jorgen Bruenig in the 1990s. Bubble Deck, a unique light, biaxial concrete slab, is generally designed using the conventional design method by semi precast module or precasting or pre-stressing modules. Bubble deck slab is an efficient technique of effectively eliminating all the concrete from the center of a floor slab, which does not serve any structural role, thereby significantly reducing structural dead weight. The highly dense polyethylene hollow spheres bring the unsuccessful concrete back into the middle of the slab, thus reducing the dead weight and the floor capacity.

Bubble Deck can be designed exactly as a solid slab with very few differences as per fully documented tests and many completed projects. There are differences in terms of shear and deflection when a bubble deck slab is compared to a solid slab. There is less weight in a bubble deck slab than a solid slab, so deflection is less. The flexural stiffness is about 90 percent of an equivalent thickness solid slab, but this is largely offset by weight reduction in deflection terms. A cracking moment of 80 percent of a comparable thickness solid slab is suggested. Shear resistance of the solid zone (through the balls) is taken conservatively as 60 percent of a comparable solid thickness slab (67 percent or more is seen in tests). **Fig. 2** below presents the typical Bubble Deck Slab. [1], [10].

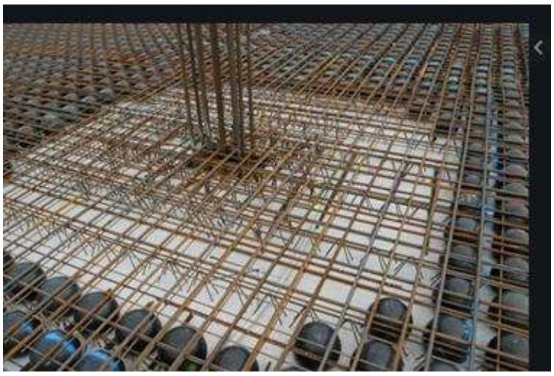


Fig. 2: Bubble Deck Slab

LITERATURE REVIEW

[6] N. Lakshmipriya, M. Karthikpandi (2018), have published a technical paper entitled, "*Study and model making of slab using Bubble Deck technology*" and have found the below:

They implemented a new technique of using high-density polyethylene hollow spheres in the construction field. It deals with the construction techniques and the innovation implemented considering the cost, efficiency and structural behavior of the concrete structure. The result identified that 1 m cube of concrete replaced by high-density polyethylene hollow sphere with 27% cost reduction in the total amount of concrete. Bubble Deck will distribute the forces in a better way than any other hollow floor structure. Because of the 3D structure and gentle graduated force flow, the hollow areas will have no negative influence and cause no loss of strength.

[7] Shreya Singh, Dr. (Prof.) Kailash Narayan (2018) have made a study on "*Analysis of bubble deck slab using different materials*" and have inferred the following results:

In this study, conventional slab as compared with bubble deck slab made up of various materials using finite element analysis on ANSYS workbench 14.0 Total deformation were obtained for fiber and epoxy were analyzed and compared. This study showed that different values of total deformation was obtained for bubble decks made up of materials like carbon-reinforced polymer fibers, glass-reinforced polymer fibers, epoxy and conventional reinforced concrete slab. Total deformation in bubble deck slab made of carbon-reinforced polymer fiber was 1.241% more as compared to a conventional concrete slab. Total deformation in bubble deck slab of glass-reinforced polymer fiber was 0.405% more as compared to conventional reinforced concrete slab. And for epoxy, it was 0.634% less as compared to a conventional reinforced concrete slab. Since there was not much difference between the total deformation of conventional reinforced concrete slab and bubble deck slab, hence conventional reinforced concrete could be replaced by bubble deck slab.

[8] Muhammad Shafiq Mushfiq, Shikhasaini and NishantRajoria, (2017), have presented the work, "*Review on Bubble Deck Slabs Technology and their Applications*," and found the below:

This research work focused on the use of bubble deck in construction.M30 Grade of concrete as used. Three slabs were cast two with spherical bubbles and the other without bubbles. The slab without bubbles was cast with 183.35kg of concrete. In the slabs with bubbles, one has spherical balls of size 90 mm in which 164 kg of concrete was used, and the other has spherical balls of size 120mm in which 151.54 kg of concrete was used.

Experimental test results indicate that the conventional slab carried a load of 424.95KN and cause 12.1mm deflection with crack occurring after a load of 164km. Bubble deck slab carried a load of 350KN and caused 12.64mm deflection, with crack occurring after a load of 198KN. The last bubble deck slab carried a load of 398.2KN and caused 13.3mm deflection, with crack occurring after a load of 300 km. A total of 10.55% of concrete was saved in the first bubble deck slab and 17% of concrete saved in the second one. This means that the bubble deck slabs have less load carrying capacity compared to the conventional slabs.

[9] Raj. R. Vakil, Dr.Mangulkar Madhuri Nilesh (2017), have made a study on "*Comparative Study of Bubble Deck Slab and Solid Deck Slab – A Review*" and stated the below:

The various tests and studies done on the Bubble deck slab. From their study, they concluded that Bubble Deck would distribute the forces in a better way (an absolute optimum) than any other hollow floor structures. Because of the three-dimensional structure and the gentle graduated force flow, the hollow areas will have no negative influence and cause no loss of strength. 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 presupposed, this indicates a positive influence of the balls. All tests, statements and engineering experience confirm the obvious fact that Bubble Deck in any way acts as a solid deck and consequently. It will follow the same rules/regulations as a solid deck (with reduced mass), and further, it leads to considerable savings.

OBJECTIVES

- To design and manufacture of Bubble Deck Slab as per EN 13369:2004 [12].
- To understand the features and properties of Bubble Deck Slab.
- To determine of Maximum Load Carrying Capacity, using Two Point Load on the Bubble Deck Slab and compare it with that of a Conventional RCC Slab.
- To determine of Maximum Deflection on the Bubble Deck Slab and compare it with that of a Conventional RCC Slab.
- To observe the Stress-Strain curve of both the slab specimens.
- To make a Cost Comparison between Bubble Deck Slab, Hollow Core Slab and Conventional Slab.

MATERIALS USED

Here is the list of materials that have been used for this study,

Cement

Cement is the basic construction material in today's construction industry. The most commonly used cement in the field of construction is the Ordinary Portland Cement (OPC). It is the basic ingredient for producing concrete, mortar, and non-specialty grouts. Ordinary Portland cement as a hydrated paste is the binder of concrete. The binder often called the cement gel, governs in large part most of the properties of the concrete. Ordinary Portland cement of Grade 53 is being used, whose specific Gravity is found to be 3.15 [16].

Fine Aggregate

Fine Aggregates acts as a filler material in mortar concrete. It also helps to absorb the Heat of Hydration produced from cement [20]. In the Fine Aggregates, the grain-size lies between 4.75 mm and 0.15 mm. In other words, these pass-through from a sieve with the size of 4.75 mm and are retained on a sieve of 0.15 size [17]. River Sand is the natural Fine Aggregate, which is the most widely available is used for this study. The Specific Gravity and Water Absorption found for this material are 3.05 and 0.46, respectively. **Fig. 3** below presents the River Sand.

Fig. 3: Fine Aggregate

Coarse Aggregate

Coarse Aggregate is a material that enhances the strength and provides stability for the Concrete [20]. Coarse aggregates are those that are retained on the sieve of size 4.75 mm [17]. Their upper size is usually around 7.5 mm. River bed gravels are the best coarse aggregates for making Traditional Concrete. As per mix design, coarse aggregate sizes provided in concrete between are 20mm and 10mm [14], [15]. The Specific Gravity and Water Absorption found for this material are 2.66 and 1.0, respectively. **Fig. 4** below presents the Coarse Aggregate used for this study.

Fig. 4: Coarse Aggregate

Water

Water is an extremely element when it comes to dealing with cement. The amount of water in concrete controls many fresh and hardened properties of concrete, including workability, compressive strength, permeability, water tightness, durability and weathering, drying shrinkage and potential for cracking [20]. Potable water was being used in this study for both mixing and curing.

Reinforcement Steel

Steel is an alloy, strong metal that is a mixture of iron and carbon, because of its high strength and low cost. High-grade steel of Fe 500 is used. Top and bottom steel reinforcement is used with the same grade of steel. Here 8mm diameter steel bar is used for main reinforcement, and an 8mm diameter steel bar is used for distributor reinforcement. Reinforcement is provided in both transverse and longitudinal directions in the form of mesh. The Reinforcement is used in the manufacture of the Conventional Slab of this study is presented in **Fig. 5** below.

Fig. 5: Reinforcement Steel

Recycled Balls

The hollow spheres are made of high-density, recycled polyethylene or HDPE. This ball doesn't react chemically with the concrete or the reinforcement. It has no porosity and has enough strength and rigidity to take more loading while pouring the concrete. The size of the HDPE ball is about 100mm in diameter with a wall thickness of 1.5mm. The mass density of HDPE ranges from 0.93 to 0.97g/cm^3. The balls are used in the manufacture of Bubble Deck Slabs in this slab are presented below in **Fig. 6**.

Fig. 6: Recycled HDPE Balls

Super Plasticizer

Superplasticizers prolong concrete to cure. Their application to concrete or mortar allows the water-to-cement ratio to be decreased without adversely affecting the mixture's workability and allows the development of self-consolidating concrete and high-performance concrete. For this study, Aurocast (M) is used as a Superplasticizer confining to [13].

METHODOLOGY

As this study aims to make a comparison among Conventional Slab and Hollow Cast slab in various parameters, the following process is adopted for this study:

Step 1: Collection of Materials and Specifications

- All the materials are initially collected in limited quantities for testing. They are subjected to various tests to attain their specifications. These specifications are used in designing the Concrete.

Step 2: Concrete Mix Design and Testing

- Initially, M40 Concrete is designed with respect to **IS: 456-2000** [14] and **IS: 10500-2012** [15]. Where the proportion for the concrete is found to be 1: 1.434: 2.315, with Water-

Cement Ratio as 0.32, without the addition of admixture.

- A total of 9 cubes are cast, as shown in **Fig. 7** below. After that, they are cured for 7, 14, 28 days, and their strengths are presented in **Table 1** below and proceeded for slab manufacturing.

Fig. 7: Casted Cube Specimens

Step 3: Conventional Slab Manufacture

- Initially, the drawings are prepared for the manufacture of this slab and are presented below in **Fig. 8.**

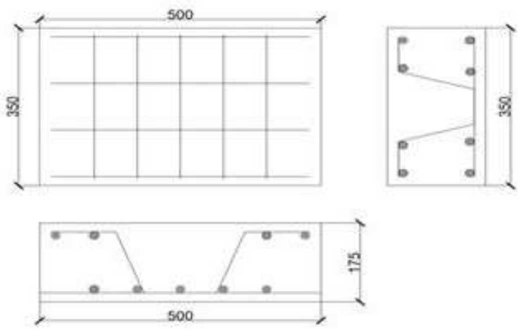


Fig. 8: Conventional Slab Steel Design

- A wooden frame of size 500*350*175(mm) is prepared. Cover blocks of 50mm size are placed to provide clear cover, as shown in **Fig. 9** below.

Fig. 9: Wooden Frame as Formwork for Slab

- A reinforcement cage as per drawings is prepared and introduced in this formwork. Then concrete is filled and is left to harden and proceeded for curing in a pond. After the curing period, the specimens are sent for testing.

Step 4: Bubble Deck Slab Manufacture

- Initially, the drawings are prepared for the manufacture of this slab and are presented below in **Fig. 10**.

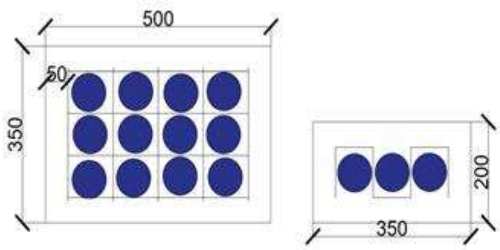


Fig. 10: Bubble Deck Slab Steel Design

- A wooden frame of size 500*350*175(mm) is prepared. Cover blocks of 50mm size are placed to provide clear cover, as shown in **Fig. 9** above.

- The reinforcement cage, along with HDPE Balls clamped, as per drawings, is prepared and introduced in this formwork. Then concrete is filled and is left to harden and proceeded for curing. After the curing period, the specimens are sent for testing.

Step 5: Testing of Slabs

- Basically, the concrete cube specimens are subjected to Compression Test to determine the Ultimate Strength of the Concrete, as shown in **Fig. 11**. The Test results are presented in **Table 1** below.

Fig. 11: Compression Testing of Cube

- Casted Slabs are subjected to the Two Point Load Test, as shown in **Fig. 12**, and the results for Conventional Slab are presented in **Table 2,** and for Bubble Deck Slab are presented in **Table 3**.

Fig. 12: Two Point Load Testing of Slab Specimen

Further, based on the items of work and quantities of materials required, a comparative analysis is made among both the slab specimens, and those results are presented in **Table 4** below.

RESULTS AND DISCUSSIONS

Compression Test Results for M40 Cube Specimen

Table 1: Compression Test Results for M40 Cube Specimen

Age of Concrete	Cross Sectional Area (A) in mm^2	Compressive Strength (P/A) in N/mm^2
7 Days	150* 150	32.19
14 Days	150* 150	38.73
28 Days	150* 150	47.78

From the above **Table 1**, the average compressive strength is found to be 47.78 N/mm^2 by the end of 28 days for the M40 cube specimen, which is really satisfactory and adaptable.

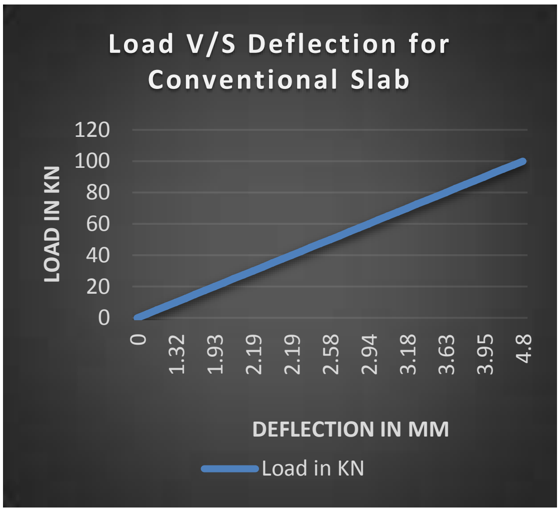
2) Two Point Load Results for Conventional Slab Specimen

Table 2: Two Point Load Results for Conventional Slab Specimen

S. No	LOAD (KN)	DEFLECTION		E=ΔL/L	A_0	$A_C=A_0/(1-E)$	STRESS L/A(N/mm^2)
		DIV	MM				
1	0	0	0	0	0	0	0
2	2.5	100	1	2X10^{-3}	175000	175.350x10^3	0.0142
3	5	110	1.1	2.2 X10^{-3}	175000	175.385x10^3	0.0285
4	7.5	123	1.23	2.46X10^{-3}	175000	175.431x10^3	0.0427
5	10	132	1.32	2.64X10^{-3}	175000	175.463x10^3	0.0569
6	12.5	150	1.50	3.6X10^{-3}	175000	175.632x10^3	0.0711
7	15	180	1.80	3.7X10^{-3}	175000	175.649x10^3	0.0853
8	17.5	185	1.85	3.6X10^{-3}	175000	175.649x10^3	0.0996
9	20	193	1.93	3.86X10^{-3}	175000	175.678x10^3	0.1138
10	22.5	215	2.15	4.3X10^{-3}	175000	175.755x10^3	0.1280
11	25	216	2.16	4.32X10^{-3}	175000	175.759x10^3	0.142
12	27.5	218	2.18	4.36X10^{-3}	175000	175.766x10^3	0.156
13	30	219	2.19	4.38X10^{-3}	175000	175.769x10^3	0.170
14	32.5	219	2.19	4.38X10^{-3}	175000	175.769X10^3	0.184
15	35	219	2.19	4.38X10^{-3}	175000	175.769X10^3	0.199
16	37.5	219	2.19	4.38X10^{-3}	175000	175.769X10^3	0.213
17	40	219	2.19	4.38X10^{-3}	175000	175.769X10^3	0.227
18	42.5	229	2.29	4.58X10^{-3}	175000	175.805X10^3	0.241
19	45	239	2.39	4.78X10^{-3}	175000	175.840X10^3	0.255
20	47.5	243	2.43	4.86X10^{-3}	175000	175.854X10^3	0.270
21	50	258	2.58	5.16X10^{-3}	175000	175.907X10^3	0.284
22	52.5	267	2.67	5.34X10^{-3}	175000	175.939X10^3	0.298
23	55	283	2.83	5.66X10^{-3}	175000	175.996X10^3	0.312
24	57.5	290	2.90	5.8X10^{-3}	175000	176.020X10^3	0.326
25	60	294	2.94	5.88X10^{-3}	175000	176.035X10^3	0.340
26	62.5	300	3.00	6.0X10^{-3}	175000	176.056X10^3	0.355
27	65	312	3.12	6.24X10^{-3}	175000	176.098X10^3	0.369
28	67.5	312	3.12	6.24X10^{-3}	175000	176.098X10^3	0.383
29	70	318	3.18	6.36 X10^{-3}	175000	176.120X10^3	0.397
30	72.5	319	3.19	6.38 X10^{-3}	175000	176.123X10^3	0.411
31	75	340	3.40	6.8 X10^{-3}	175000	176.198X10^3	0.425
32	77.5	354	3.54	7.08 X10^{-3}	175000	176.247X10^3	0.439
33	80	363	3.63	7.26 X10^{-3}	175000	176.279X10^3	0.453
34	82.5	380	3.80	7.6 X10^{-3}	175000	176.340X10^3	0.467
35	85	390	3.90	7.8 X10^{-3}	175000	176.357X10^3	0.481
36	87.5	392	3.92	7.84 X10^{-3}	175000	176.382X10^3	0.496

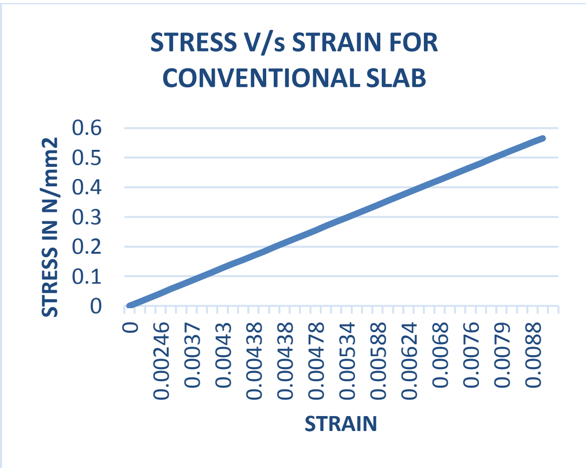
37	90	395	3.95	$7.9 X10^{-3}$	175000	$176.393X10^{3}$	0.510
38	92.5	397	3.97	$7.94 X10^{-3}$	175000	$176.400X10^{3}$	0.524
39	95	420	4.20	$8.4 X10^{-3}$	175000	$176.482X10^{3}$	0.538
40	97.5	440	4.40	$8.8 X10^{-3}$	175000	$176.55X10^{3}$	0.552
41	100	480	4.80	9.6 X10-3	175000	$176.696X10^{3}$	0.565

Based on the above **Table 2**, **Graph 1** below is developed between load and deflection and is analysed and presented below. From the same Table, The Stress-Strain Curve is plotted for the Specimen in **Graph 2**.



Graph 1: Load V/s Deflection for Conventional Slab

From the above **Graph 1**, it can be inferred that the Conventional Slab specimen is capable of withstanding a Maximum Load of 100KN; also the Maximum Deflection is observed as 4.8mm.



Graph 2: Stress V/s Strain for Conventional Slab

From the above **Graph 2**, it can be noticed that the Stress-Strain relationship for the Conventional Slab specimen is found to be linear.

Fig. 13 below shows the Crack formation on the Conventional Slab Specimen.

Fig. 13: Observed first crack on the conventional slab specimen at load 105 KN

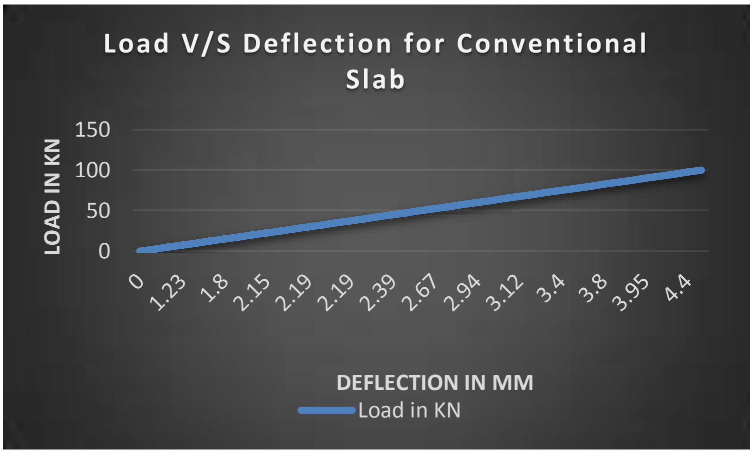
The first crack was formed at 105KN, and the failure is found to be Shear Failure.

3) Two Point Load Results for Hollow Core Slab made of HDPE Balls

Table 3: Two Point Load Results for Hollow Core Slab made of HDPE Balls

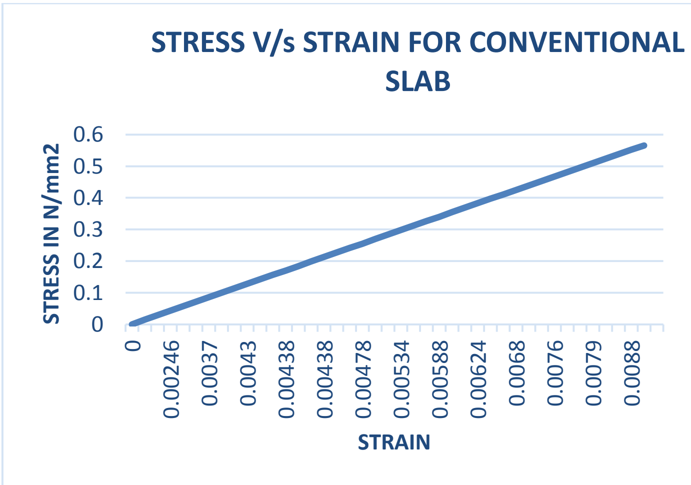
S.no	LOAD (KN)	DEFLECTION		E=ΔL/L	A_0	A_C=A0/(1-E)	STRESS L/A(N/mm^2)
		DIV	MM				
1	0	0	0	0	0	0	0
2	10	43	0.43	8.6x10^{-4}	175000	175.15x10^3	0.0142
3	20	50	0.5	1x10^{-3}	175000	175.385x10^3	0.0285
4	30	56	0.56	1.12X10^{-3}	175000	175.431x10^3	0.0427
5	40	62	0.62	1.24X10^{-3}	175000	175.463x10^3	0.0569
6	50	68	0.68	1.36X10^{-3}	175000	175.632x10^3	0.0711
7	60	72	0.72	1.44X10^{-3}	175000	175.649x10^3	0.0853
8	70	79	0.79	1.58X10^{-3}	175000	175.649x10^3	0.0996
9	80	82	0.82	1.64X10^{-3}	175000	175.678x10^3	0.1138
10	90	88	0.88	1.76X10^{-3}	175000	175.755x10^3	0.1280
11	100	90	0.90	1.8X10^{-3}	175000	175.759x10^3	0.142
12	110	95	0.95	1.9X10^{-3}	175000	175.766x10^3	0.156
13	120	100	0.10	2X10^{-4}	175000	175.769x10^3	0.170
14	130	101	1.01	2.02X10^{-3}	175000	175.769X10^3	0.184
15	140	108	1.08	2.16X10^{-3}	175000	175.769X10^3	0.199
16	150	110	1.10	2.2X10^{-3}	175000	175.769X10^3	0.213

Based on the above **Table 3**, **Graph 3** below is developed between load and deflection and is analysed and presented below.



Graph 3: Load V/s Deflection for Bubble Deck Slab

From the above **Graph 3**, it can be inferred that the Bubble Deck Slab specimen is capable of withstanding a Maximum Load of 150KN; also the Maximum Deflection is observed as 1.10mm.



Graph 4: Stress V/s Strain for Bubble Deck Slab

From the above **Graph 4**, it can be noticed that the Stress-Strain relationship for the Bubble Deck Slab specimen is found to be linear. **Fig. 14** below shows the Crack formation on the Bubble Deck Slab Specimen. The first crack was formed at 180KN, and the failure is found to be Shear Failure.

Fig. 14: Observed first crack on the Bubble Deck slab specimen at load 180 KN

Comparative Cost Analysis

Based on the quantities of materials involved and practical conditions, a comparative Cost Analysis is made per 1 unit of Slab of size 500x350x175(mm) among Conventional Slab and Bubble Deck Slab and is presented below in **Table: 4**.

Table 4: Comparative Cost Analysis among Conventional Slab and Bubble Deck Slab

S. No	Material	Cost of Material per 1 Unit of Slab	
		Conventional Slab	Bubble Deck Slab
1	**Cement**	₹. 98/-	₹.78.4/-
2	**Fine Aggregate**	₹.28.42/-	₹.22.71/-
3	**Coarse Aggregate**	₹.35/-	₹.28.14/-
4	**Water**	₹.10.80/-	₹.8.50/-
5	**Admixture**	₹.25.48/-	₹.20.38/-
6	**Steel**	₹.114.18/-	₹.163.93/-
7	**HDPE Balls**	-	₹.22.8/-
8	**Tools**	₹.50/-	₹.30/-
Total Cost		₹. 446.38/-	₹.374.86/-

Therefore, from the above **Table 4**, based on all the materials consumed for manufacture, it is evident that the Bubble Deck Slab is found to be lesser than the Conventional Slab and is highly economical and feasible.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of this project is to practically use high-density polyethylene balls in the reinforced concrete slab, which is called a bubble deck slab. Therefore, both the Slabs are manufactured and are tested. Numerical and experimental investigation of conventional and bubble deck slab is followed by the comparison of both. From the testing process, it was inferred that:

- The Maximum Load Carrying Capacity and Deflection of the Bubble Deck Slab are found to be really higher when compared to Conventional RCC Slab.
- From **Graphs 2 and 4,** it can be seen that the Stress-Strain behavior of both the specimens is found to be similar and linear.
- The Unit Weight of the Bubble Deck Slab is found to be 25% lesser than the Conventional Slab.
- Taking the Economy into consideration, Bubble Deck Slab could be manufactured at about 80% cost of RCC Slab.
- Bubble Deck Slab is a really feasible, simple component that could be easily manufactured and demands fewer resources compared to RCC.

Finally, it is concluded that the bubble Deck slab is far better than Conventional RCC Slab.

Recommendations and Scope for further Studies

- Further developments could be made on the Bubble Deck Slab by altering the Ball Diameters, by which the Slab thickness could be varied.
- The analysis for slabs could also be done using the Lower Grades of Concrete.
- This model could also be used in Roads Construction as a replacement for CC Roads by further analysis.
- These Slabs could be used in the construction of longer span halls like theatres and auditoriums.

It can also be used in parking areas as less number of columns are required and pedestrian bridge decks.

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