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AN EXPERIMENTAL STUDY ON BUBBLE DECK SLAB SYSTEM WITH ELLIPTICAL BALLS

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ABSTRACT

Bubble Deck is a revolutionary method of virtually eliminating concrete from the middle of conventional slab which does not perform any structural function, thereby dramatically reducing structural dead weight by linking air and steel directly. Bubble Deck slab uses hollow spherical or elliptical balls made by recycled plastic. A Bubble Deck slab has a two-dimensional arrangement of voids within the slabs to reduce self-weight. The behaviour of Bubble Deck slabs is influenced by the ratio of bubble diameter to slab thickness. This new prefabricated construction technology is recently applied in many industrial projects in the world. This shows the effectiveness and feasibility of the application of Bubble Deck in the construction. Voids in the middle of a flat slab eliminate 35% of a slab's self-weight removing constraints of high dead loads and short spans. Combination of recycled plastic bubbles permits 50% longer spans between columns without any beams. This provides a wide range of cost and construction benefits. Usually the Bubble Deck system combines the benefits of factory-manufactured elements in controlled conditions along with on-site completion with the final monolithic concrete, resulting in a completed floor slab. This paper presents a study on the properties and advantages of Bubble Deck slab system.

KEYWORDS: Bubble Deck Slab System, Filigree Element, Hollow Spherical Balls, Hollow Elliptical Balls, Deck, etc.

In building constructions, the slab is a very important structural member to make a space. And the slab is one of the largest member consuming concrete. Bubble Deck is the invention of Jorgen Bruenig in 1990's, who developed the first biaxial hollow slab (now known as Bubble Deck) in Denmark. This new prefabricated construction technology using Bubble Deck slab is recently applied in many industrial projects in the world. Bubble Deck slab uses hollow balls made by recycled plastic and therefore it is an innovatory method of virtually eliminating the concrete part in the middle of conventional slab which does not contribute to the structural performance. This hence reduces significantly the structural self-weight and also leads to 30 to 50% lighter slab which reduces the loads on the columns, walls and foundations, and of course of the entire building. Bubble Deck uses less concrete than traditional concrete floor systems; it offers a more sustainable construction option, contributes less CO_2 to the atmosphere in the manufacturing process and also meets sustainability goals through the use of recycled plastic spheres. 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. Therefore, the Bubble Deck has many advantages as compared to traditional concrete slab, such as: lower total cost, reduced material use, enhanced structural efficiency, decreased construction time, and is a green technology. The reinforcements are placed as two meshes one at the bottom part and one at the upper part that can be tied or welded. The distance between the bars are kept corresponding to the dimensions of the bubbles that are to be embodied and the quantity of the reinforcement from the longitudinal and the transversal ribs of the slab. The two-way concrete slab system was developed in Denmark and was first used in Holland. It became an integral part of the Millennium Tower which was built to celebrate the new millennium. Now, the Bubble Deck technology gains much of attention from engineers and researchers from the world [Amer M 2013].

MATERIALS AND PROPERTIES

The following materials are used in Bubble Deck slab construction:

Hollow bubbles

The bubbles (Fig.1) are made using high density polypropylene materials. These are usually made with nonporous material that does not react

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chemically with the concrete or reinforcement bars. The bubbles have enough strength and stiffness to support safely the applied loads in the phases before and during concrete pouring. Bubble diameter 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. The nominal diameter of the gaps may be of: 180, 225, 270, 315 or 360 mm. The bubbles may be of spherical or ellipsoidal in shape.

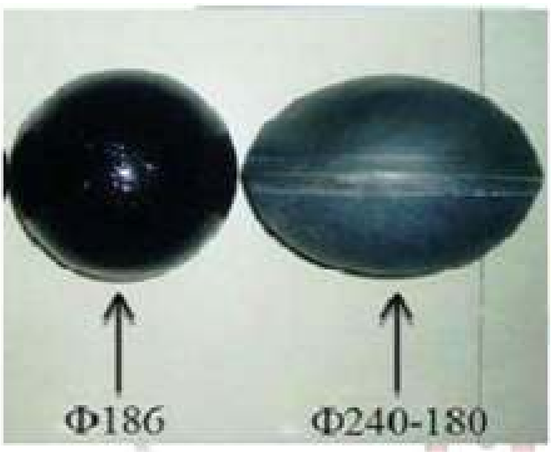


Fig.1 Hollow spheircal and elliptical bubbles

Concrete

The concrete used for joint filling in the Bubble Deck floor system must be above class 20/25. Usually self-compacting concrete is used, either for the casting of prefabricated filigree slab, or for the joint filling on the site. Self compacting concrete can be poured into forms, flow around congested areas of reinforcement and into tight sections, allow air to escape and resist segregation. The nominal maximum size of the aggregate is the function of thickness of the slab. The size should be less than15mm. M30 Grade and above should be 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 for lateral support and diagonal girders for vertical support of the bubbles. The distance between the bars are corresponding to the dimensions of the bubbles that are to be used and the quantity of reinforcement from transverse ribs of the slab.

THE EXPERIMENTAL PROGRAM

In order to investigate the behaviors of Bubble Deck using traditional spherical balls, the experimental program were carried out at Laboratory of Full-Scale Structural Testing.

Bubble Deck Samples

Advanced engineering of the Bubble Deck system comprises a hollow flat slab, into which recycled plastic ball 'void formers' are in incorporated to eliminate concrete that does not contribute to the structural performance of a slab. The plastic balls have dimensions and shapes as follows: hollow elliptical balls with diameter 240mm and height 180mm as shown in Figure 2. Front View and Side View.

Front view

Side view

Figure 2: Shape and Dimension of Plastic Balls

There are total 5 Bubble Deck samples named as A.BD.2, A.BD.3, A.BD.4, B.BD.2 and B.BD.3.

All samples have the same dimension of 1900x800x230 mm. The notations A and B denote for the concrete strength B25 and B35, respectively. Table 1 depicts the dimension and notation of Bubble Deck samples. It should be mentioned that only the sample A.BD4 has been provided the links and other samples do not have links. Figure 3 demonstrates the plan view and sections of modified Bubble Deck using hollow elliptical balls. There have total 18 elliptical balls for 1 Bubble Deck sample. The reinforcing rebar at the top and bottom layers is $24\phi8$ and the concrete cover is 25mm. Figure 4 shows the actual Bubble Deck samples in the laboratory[A.N Prakash 2011].

Table 1: Dimension and Notation of Bubble Deck Samples

Slab		Concrete strength	Dimension 1900x800x230 mm		
			BD Φ186 (no links)	BD Φ240-180 (no links)	BD Φ240-180 (have links)
Notation	A	B25	A.BD.2	A.BD.3	A.BD.4
	B	B35	B.BD.2	B.BD.3	

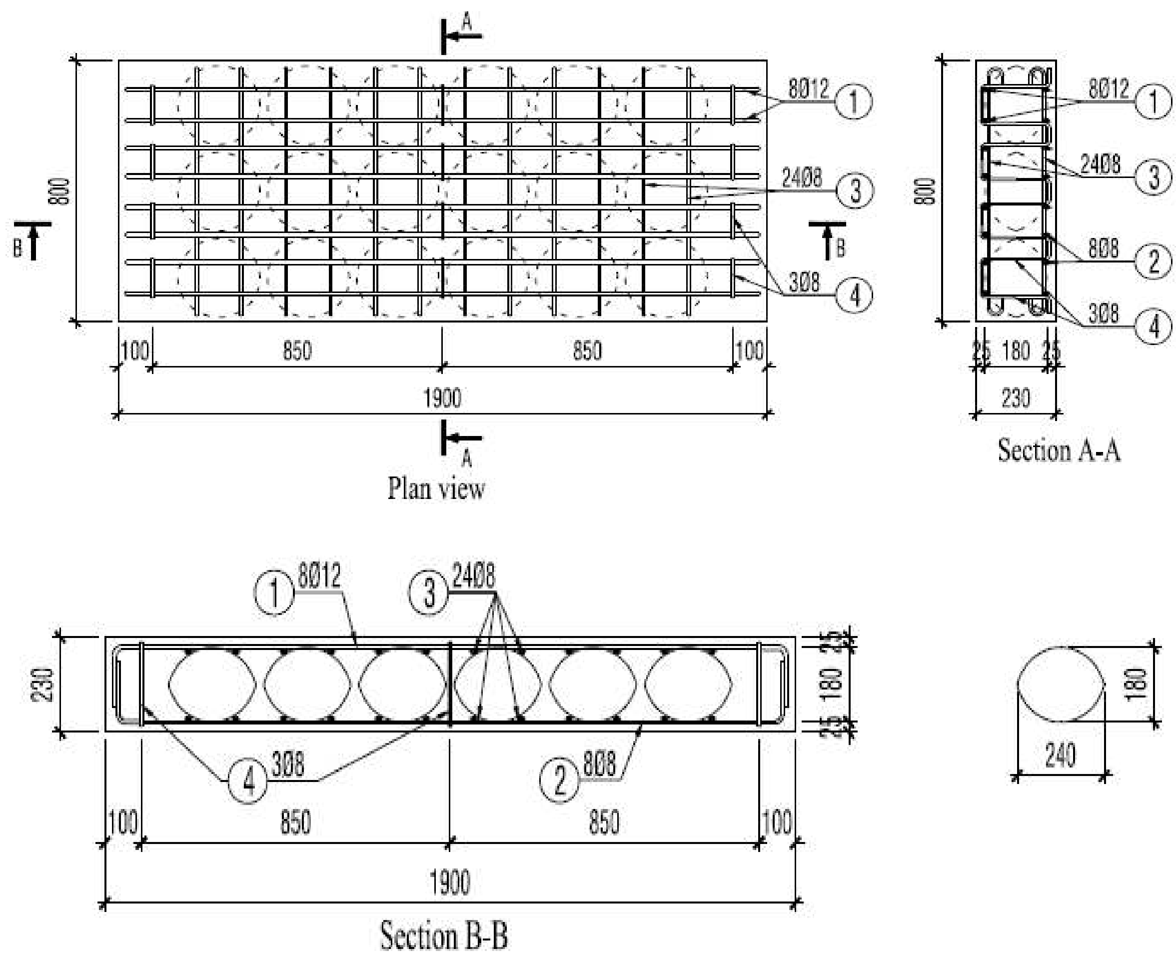


Figure 3: Modified Bubble Deck A.BD.3 v/s B.BD.3

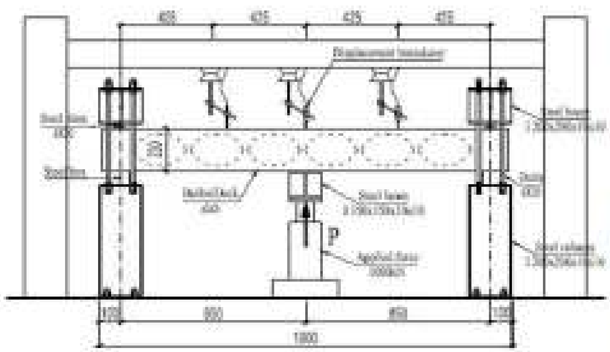
Hollow spherical balls

Hollow elliptical balls

Figure 4: Bubble Deck Samples

Experimental procedure

Figure 5 gives the modeling and actualization of experimental setup. The Bubble Deck samples are simply supported by two steel beams 1200x200x10x10 along the short span. The applied force at the center of slabs is produced by the hydraulic jack with the capacity of maximum loading 1000kN. Initially, the hydraulic jack is adjusted with the force same as the self weight of the slab. In this experiment, the applied force is provided from the bottom to the top of the slab, which is opposite to the direction of gravity. By applying this procedure, it is easier for us to record the strain and deformation of concrete and rebar from the top side of the slab. It should be noted that the strain and deformation of concrete and rebar are measured by using the wire strain gauge as shown in Figure 6. Next, the applied force will be increased step by step until the cracks are found in the slabs and the failure modes are appeared.



Modeling of experimental setup

Actualization of experimental setup

Figure 5: Experimental Setup

Figure 6: Wire Strain Gauge

Experimental results

Figure 7 shows the observed crack patterns at failure for the slab B.BD.2 and B.BD.3. It can be seen from this figure that failure modes of slabs B.BD.2 and B.BD.3 are shear and bending modes, respectively. In details, Table 2 demonstrates the ultimate loading, maximum deflection at the center and type of failure of all slabs. It should be noted that the Bubble Deck using hollow spherical balls A.BD.2 and B.BD.2 has the shear failure modes. On contrary, the Bubble Deck using modified elliptical balls A.BD.3, A.BD.4 and B.BD.3 has the bending failure modes. It can be concluded that with the same dimension and concrete grade, the Bubble Deck using modified elliptical balls has greater ultimate loading compared with using other plastic balls.

The shear failure of slab B.BD.2 **The bending failure of slab B.BD.3**

Figure 7: The Failure Modes of Bubble Deck

Figure 8 shows the relationship between ultimate loading P and the maximum deflection at the center of Bubble Deck. The figure is plotted for two types of concrete strength, e.g. M35 (type A) and M25 (type B), and for different types of Bubble Deck. It can be observed from this figure that the maximum deflection at the center of slabs is increased when the applied loading is increased More details, Table 3 depicts the results of ultimate loading and center deflection of all types of Bubble Deck. It can be seen from this table that the loading capacity of Bubble Deck using concrete grade M35 is higher from 3% to 8% as compare to that of Bubble Deck using concrete grade M25. The system shown good load carrying capacity and shearing capacity. The loading capacity is increased approximately 6% by using the links in Bubble Deck, e.g. the links has not much contribution to the capacity of the slabs.

Table 2: Experimental results

Slab	Ultimate loading P_u (kN)	Deflection Δ_u (mm)	Type of failure
A.BD.2	175	16.15	*Shear*
A.BD.3	185	21.06	*Bending*
A.BD.4	195	23.04	*Bending*
B.BD.2	180	15.18	*Shear*
B.BD.3	200	20.22	*Bending*

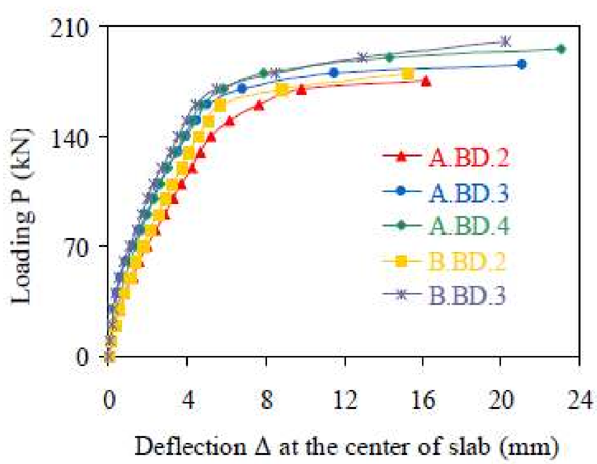


Figure 8: Load – Deflection of Bubble Deck

Table 3: Comparison of Ultimate Loading and Center Deflection of Bubble Deck

Slab	Ultimate loading P_u (kN)		Error (%)	Deflection Δ_u (mm)		Error (%)
A (B25)	A.BD.2	A.BD.3		A.BD.2	A.BD.3	
	175	185	5.7	16.15	21.06	30.4
B (B35)	B.BD.2	B.BD.3		B.BD.2	B.BD.3	
	180	200	11.1	15.18	20.22	33.2
BD Φ186	A.BD.2	B.BD.2		A.BD.2	B.BD.2	
	175	180	2.9	16.15	15.18	-6.0
BD Φ240-180	A.BD.3	B.BD.3		A.BD.3	B.BD.3	
	185	200	8.1	21.06	20.22	-4.0
BD Φ240-180	A.BD.3	A.BD.4		A.BD.3	A.BD.4	
(Links and no links)	185	195	5.4	21.06	23.04	9.4

CONCLUSIONS

1. The Bubble Deck configuration gives much improved flexural capacity, stiffness and shear capacity of at least 70% when the same amount of concrete and the same reinforcement is used as in the solid slab, realizing 30-50% concrete economy, in comparison with the solid slab.

2. Advantage of Bubble Deck system is the significant cost saving, because of the possibility of obtaining great spans with less support elements.

3. By using the hollow elliptical balls, the better load-bearing capacity in Bubble Deck can be achieved.

4. Concrete usage is reduced as 1 kg of recycled plastic replaces 100 kg of concrete. This avoids the cement production and allows reduction in global CO2 emissions. Hence this technology is environmentally green and sustainable.

5. Reducing material consumption made it possible to make the construction time faster, to reduce the overall costs. Besides that, it has led to reduce dead weight up to 50%, which allow creating foundation sizes smaller.

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