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A study on structural behaviour of bubble deck slab using spherical and elliptical balls

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Abstract - *Concrete plays a major role in the construction field. In building construction slab is one of the largest and important structural member consuming concrete. Concrete slab use more concrete than requirement, hence has to be optimized. So reduce the concrete in center of the slab by using hollow recycled plastic balls. High density polyethylene (HDPE) hollow balls replace the ineffective concrete in the center of the slab, thus decreasing the dead weight and increasing the efficiency of the floor. By introducing the gaps leads lighter slab which reduces the loads on the columns, walls, foundations and entire part of building. The advantages of the bubble deck slab are less energy consumption both in production, transport and less emission of exhaust gases, especially CO_2.Finite element analysis (FEA) was carried out by using the FEA software ANSYS to study the structural behavior of bubble deck slab with spherical and elliptical balls. The bubble deck slabs with spherical and elliptical balls were subjected to uniformly distributed load with proper boundary conditions. The analysis was done on bubble deck slab using both M25 and M30 grade of concrete. Total deformation, Directional deformation and Equivalent stress (Von Mises stress) were studied. Then the results of bubble deck slab with spherical balls and elliptical balls were compared.*

Key Words: *Bubble deck slab, Finite element analysis (FEA), High density polyethylene (HDPE), ANSYS, Hollow recycled plastic balls.*

1. INTRODUCTION

The invention of a new type of hollow core slabs was a breakthrough at the turn of 20th and 21st centuries. Bubble deck slab technology is an innovatory method of virtually eliminating all concrete from the middle of a floor slab, thereby reducing dead weight and increasing the efficiency of the floor by using recycled hollow plastic balls. Bubble deck is the invention of Jorgen Bruenig in 1990's, who developed the first biaxial hollow core slab (now known as bubble deck) in Denmark.

The main obstacle with concrete constructions in case of horizontal slabs is the high weight, which limits the span. So the major developments of reinforced concrete have focused on enhancing the span reducing the weight or overcoming concrete's natural weakness in tension. In a general way, the slab was designed only to resist vertical load. However, as people are getting more interest of residential environment recently, noise and vibration of slab are getting more important, as the span is increased, the deflection of the slab is also increased. Therefore, the slab thickness should be increase. Increasing the slab thickness makes the slabs heavier, and will increased column and foundations size. Thus, it makes buildings consuming more materials such as concrete and steel reinforcement. Increase the self-weight of the slab due to increase in thickness. So many studies were conducted for to reduce the disadvantages caused by self-weight of the concrete.

For past few decades, several attempts have been made to create biaxial slabs with hollow cavities in order to reduce the self-weight. But there have a chance of stress concentration in corner of hollow cavities. Stress concentration in hollow cavities leads to severe crack generation in slabs. Most attempts have consisted of laying blocks of a less heavy material like expanded polystyrene between the bottom and top reinforcement, while other types including waffle slabs or grid slabs. These types, only waffle slabs can be regarded to have a certain use in the market. But the use will always be very limited due to reduced resistances towards shear, local punching and fire.After this, many studies have been conducted in concrete slabs to reduce the self-weight. Though many materials have been selected for the study related to this, materials like polypropylene and polyethylene were found ideal because of reduced weight and act as good crack arrester. Then materials like polypropylene and polyethylene were used for creation of hollow plastic balls. These hollow plastic balls are introduced in the middle portion of the slab between top and bottom reinforcement, thereby reducing self-weight of the slab. To avoid the disadvantages which were caused by increasing self-weight of the slabs, the bubble deck slab technology was suggested.

Behaviour of bubble deck slab is influenced by the ratio of bubble diameter to slab thickness. The reinforcements are placed as two meshes one at the bottom part and one at the upper part that can be tided or welded. The distance between the bars are kept corresponding to the dimensions of the bubbles that are to be provided between the top and bottom meshes. In this technology it locks ellipsoids between the top and bottom reinforcement meshes, thereby creating a natural cell structure, acting like a solid slab. High Density Polyethylene (HDPE) hollow spheres replace the ineffective concrete in the center of the slab, thus decreasing the dead weight and increasing the efficiency of the floor.

2. MATERIALS DESCRIPTION PROPERTIES

2.1 Concrete

The Concrete is made of standard Portland cement with a maximum aggregate size of ¾ inch. No plasticizers are necessary. Concrete of M25, M30 and above grades are used for bubble deck slab construction.

2.2 Steel

The steel reinforcement is of grade Fe 415,Fe 500 strength or higher is generally used. The steel is fabricated in two forms. Meshed layer for lateral support and diagonal girder for vertical support of the bubble. The same grade of steel is used in both in top and bottom.

2.3 Hollow plastic Balls

Generally recycled plastic balls are used, because to reduce wastage of plastics instead of burning the plastics and also reduce the environmental pollution. Cost of plastic ball is very low. The plastic balls don't react chemically with concrete or reinforcement. Generally hollow plastic balls made from high density polyethylene.

2.4 Material properties

For concrete, steel and HDPE following material properties have been used.

Table -1: Material Properties

		M25	M30
Concrete	Modulus of Elasticity(E_c) in MPa	25000	$30x10^5$
	Compressive ultimate strength(fck) in MPa	25	30
	Poisson's ratio (μ)	0.2	0.2
Steel	Modulus of Elasticity(E_s) in MPa	200000	$2.18x10^{11}$
	Tensile yield stress(fy) in MPa	415	550
	Poisson's ratio (μ)	0.3	0.28
HDPE	Modulus of Elasticity in MPa	1030	1030
	Poisson's ratio (μ)	0.4	0.4

3. NUMERICAL INVESTIGATION

In this section, the structural behaviour of bubble deck slab with spherical and elliptical balls were investigated using finite element package ANSYS. The finite element method is extensively used to study the behaviour of the structure such as Total deformation,Directional deformation and Equivalent stress. The finite element method is the discretization of the structural member in to finite number of element by imaginary line or by surface. The interconnected element may have different size and shape and connected at finite number of points called nodes. The test parameters included diameters of ball, slab thickness, width of the slab are provided into ANSYS.

3.1 Numerical modeling

Three dimensional bubble deck slab with spherical balls were modelled in ANSYS with dimension of (1250x1250x230). The void is of spherical shape with a diameter of 150 mm and is assumed to be made of High Density Polyethylene (HDPE) spherical balls provided with center to center spacing of 200mm.Bubble deck slab with elliptical balls were modelled with the dimension of (1730x1350x230). The void is of elliptical shape with dimension of (180x240) mm and is assumed to be made of High Density Polyethylene (HDPE) elliptical balls. Reinforcements are provided in two forms. That is meshed layer and diagonal girder. The reinforcements are placed as two meshes one at the bottom part and one at the upper part that can be tided or welded. Meshed layer having diameter of 10mm and provided for lateral support. Reinforcement provided for vertical support is termed as vertical reinforcement (diagonal girder) having diameter of 12mm.

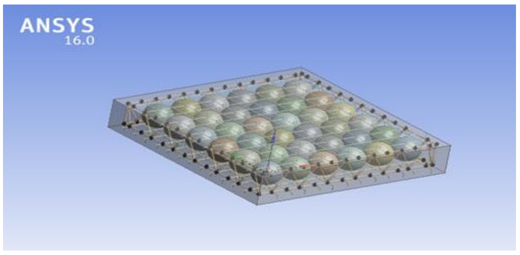

Fig -1: Bubble deck slab with spherical balls

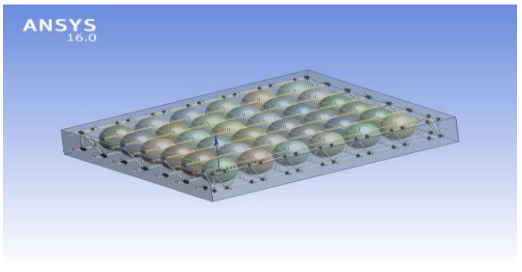

Fig -2: Bubble deck slab with elliptical balls

3.2 Meshing

Bubble deck slab with spherical and elliptical balls were modelled using tetra mesh, which is a four noded mesh. Tetra mesh is used in bubble deck slab due to irregular geometry of the slab.

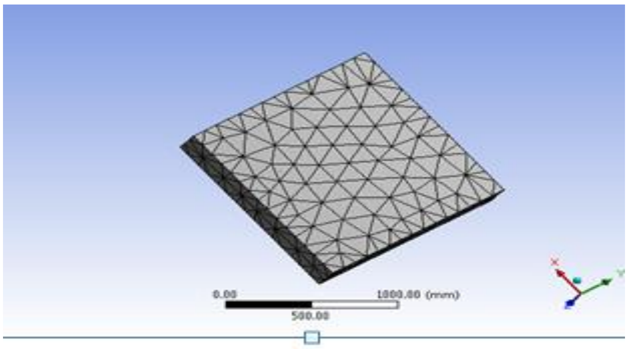

Fig -3: Meshed model of bubble deck slab with spherical balls

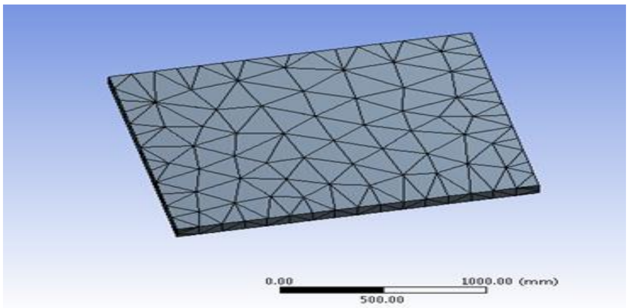

Fig -4: Meshed model of bubble deck slab with elliptical balls

3.3 Boundary conditions and loading

In Bubble deck slab with spherical and elliptical balls Provide hinged support at one end and roller support at another end. Load is applied over the top area as areal load (UDL). The load was applied on an incremental method and analysis is carried out.

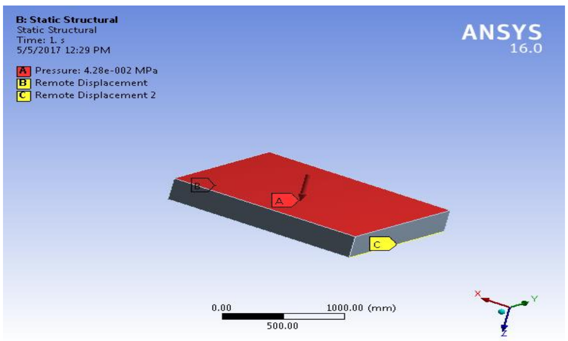

Fig -5: Boundary conditions and loading

4. RESULTS AND DISCUSSIONS

The finite element analysis is performed to analyze the bubble deck slab with spherical and elliptical balls of M25 and M30 grade concrete. Through this analysis structural behaviour of bubble deck slab with spherical and elliptical balls were studied. Results obtained from analysis are given below.

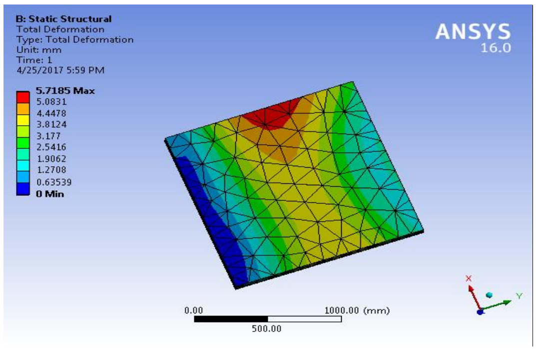

Fig -6: Total deformation of bubble deck slab with spherical balls of M25 grade concrete

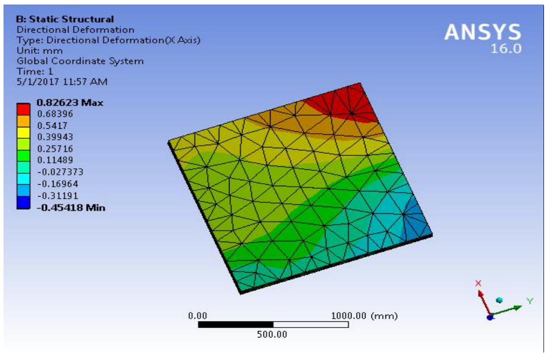

Fig -7: Directional deformation of bubble deck slab with spherical balls of M25 grade concrete

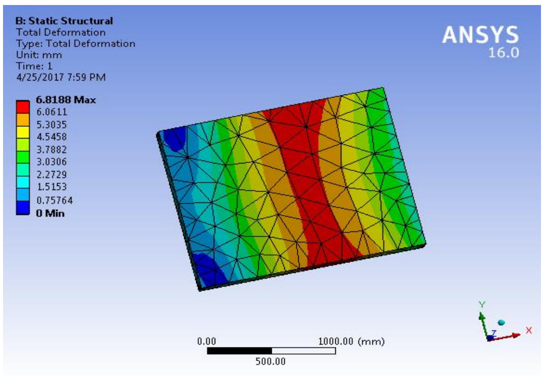

Fig -8: Total deformation of bubble deck slab with elliptical balls of M25 grade concrete

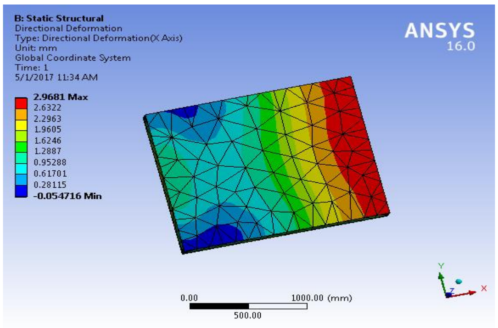

Fig -9: Directional deformation of bubble deck slab with elliptical balls of M25 grade concrete

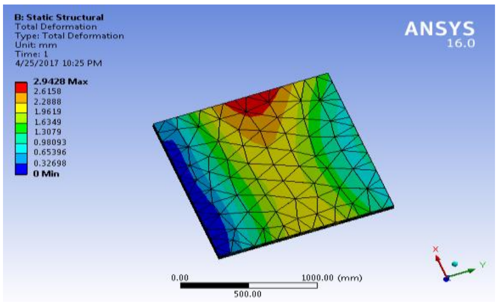

Fig -10: Total deformation of bubble deck slab with spherical balls of M30 grade concrete

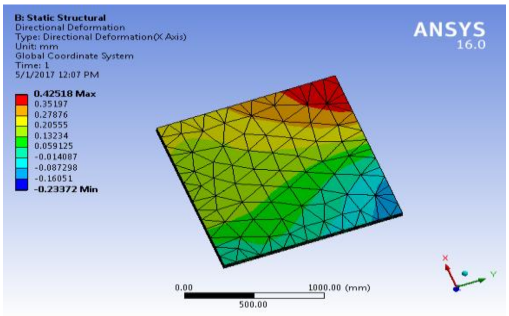

Fig -11: Directional deformation of bubble deck slab with spherical balls of M30 grade concrete

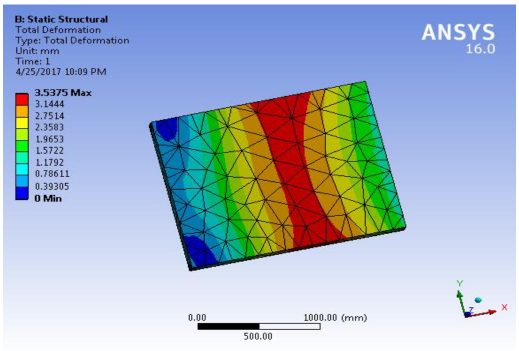

Fig -12: Total deformation of bubble deck slab with elliptical balls of M30 grade concrete

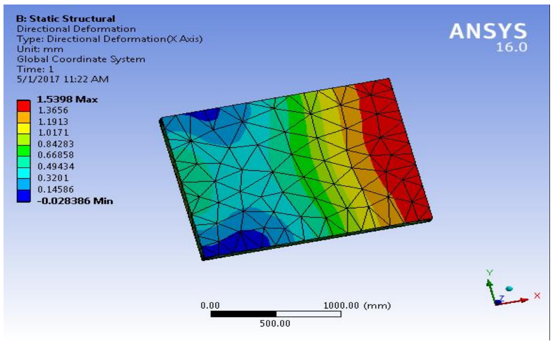

Fig -13: Directional deformation of bubble deck slab with elliptical balls of M30 grade concrete

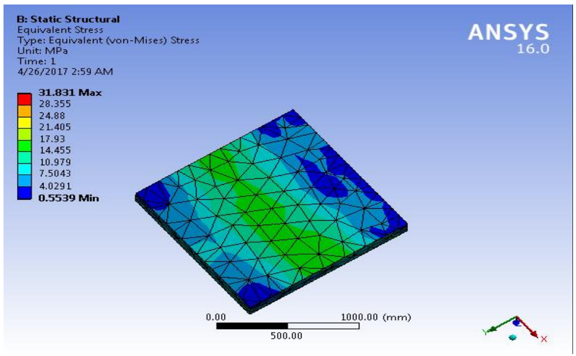

Fig -14: Equivalent stress of bubble deck slab with spherical balls of M30 grade concrete

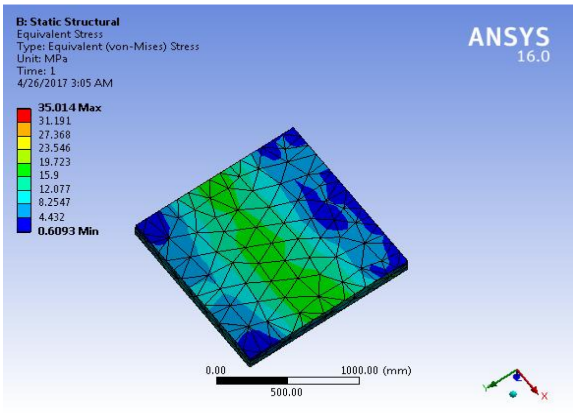

Fig -15: Equivalent stress of bubble deck slab with elliptical balls of M30 grade concrete

The analysis was done on bubble deck slab using both M25 and M30 grade of concrete. Total deformation, Directional deformation and Equivalent stress (Von Mises stress) were studied.

The load-deflection values for various bubble deck slab using M25 and M30 grade of concrete obtained are tabulated in table 2 .According to these deflection values load-deflection graph of bubble deck slab with spherical and elliptical balls were plotted. Finally compare the results obtained from graphs.

Table -2: Load deflection values of bubble deck slab

Load (kN)	Deflection values in mm			
	Bubble deck slab of M25 grade concrete		Bubble deck slab of M30 grade concrete	
	Spherical balls	Elliptical balls	Spherical balls	Elliptical balls
100	0.3855	0.7128	0.2056	0.5372
125	0.8224	1.3431	0.4626	0.9918
175	2.0420	3.4920	0.9638	1.3638
300	5.0118	6.3228	2.3131	2.6035
350	5.7474	6.8188	2.9428	3.5375

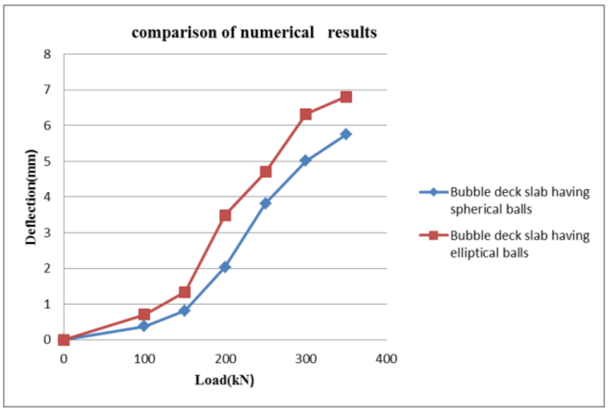

Chart -1: Load-deflection graph of bubble deck slab using M25 grade concrete

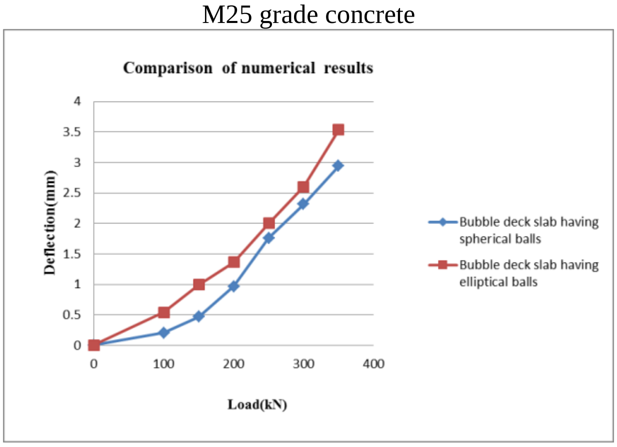

Chart -2: Load-deflection graph of bubble deck slab using M30 grade concrete

From the above load-deflection values, bubble deck slab with spherical and elliptical balls of M30 grade concrete shows better performance than bubble deck slab with spherical and elliptical balls of M25 grade concrete.

Bubble deck slab with spherical balls using M30grade concrete carried the stress of about 31.831MPa by applying the uniformly distributed load of about 350kN and causes the deflection of 2.9428mm.The bubble deck slab with elliptical balls using M30 concrete carried the stress of about 35.14MPa by applying the uniformly distributed load of about 350kN and causes the deflection of 3.5375mm. Bubble deck slab with elliptical balls have better load carrying capacity compared to Bubble deck slab with spherical balls.

5. WEIGHT REDUCTION OF BUBBLE DECK SLAB

5.1 Bubble deck slab with spherical bubble

Total thickness of slab = 230mm
Diameter of the hollow sphere = 180mm
Width of solid section around hollow sphere = 200mm
Volume of slab without void former (v_1) = 0.2 x 0.2 x 0.23
$= 9.2 \times 10^{-3} m^3$
Volume of 180mm diameter sphere (v_2) = $\frac{4}{3}\pi r^3$
$= 4/3 \times 3.14 \times 0.09^3$
$= 3.05 \times 10^{-3} m^3$
Weight of slab without void former (w_1) = $v_1 \times \rho_c$
$= 9.2 \times 10^{-3} \times 2400$
= 22.08kg
Weight of 180mm diameter concrete sphere (w_2) = v2 x ρ_c
= 7.32kg
Percentage of weight saving = $\frac{w2}{w1} \times 100$
= 33.152%

5.2 Bubble deck slab with elliptical bubble

Total thickness of slab = 230mm
Dimension of hollow elliptical ball = (240 x 180)
Width of solid section around the Elliptical ball = 260mm
Volume of slab without ball(v_1) = 0.26 x 0.26 x 0.23
$= 15.548 \times 10^{-3} m^3$
Volume of elliptical balls (v_2) = $\frac{4}{3}\pi a^2$ b
$= 4/3 \times 3.14 \times 120^2 \times 90$
$= 5.428 \times 10^{-3} m^3$
Weight of solid section without void former (w_1) = $v_1 \times \rho_c$
$= 15.548 \times 10^{-3} \times 2400$
= 37.315kg
Weight of concrete elliptical ball (w_2) = $v_2 \times \rho_c$
= 13.028kg
Percentage of weight saving = $\frac{w2}{w1} \times 100$
= 34.91%

6. CONCLUSIONS

Bubble deck slab technology is an innovatory method of virtually eliminating all concrete from the middle of a floor slab, thereby reducing dead weight and increasing the efficiency of the floor by using recycled hollow plastic balls. This new prefabricated construction technology using bubble deck slab is recently applied in many industrial projects in the world. This technology is widely used for the construction of multi-storeyed buildings. Bubble deck slab technology reduces the loads on the columns, walls, foundations and entire part of the building. Bubble deck uses less concrete than traditional concrete floor systems.

Analysis was performed on the bubble deck slab with spherical and elliptical balls of grade M25 and M30.The results have concluded that

- Bubble deck slab with elliptical balls have better load carrying capacity compared to that of bubble deck slab with spherical balls.
- Bubble deck slab with spherical and elliptical balls of M30 grade concrete shows better performance than bubble deck slab with spherical and elliptical balls of M25 grade concrete.
- Bubble deck slab save weight up to 33.15% around one spherical ball and 34.90% for one elliptical ball.

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