Behavioral Analysis of Conventional Slab and Bubble Deck Slab under various Support and Loading Conditions using ANSYS Workbench 14.0: Review Paper

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Abstract— The objective of this study is to perform the behavioral analysis of conventional slab and bubble deck slab using ANSYS workbench 14.0. This comparative study includes the study of normal slab and slab with HDPE spherical ball at center to form voids. Normally the Bubble Deck framework consolidates the advantages of production line made components in controlled conditions alongside on location site with reduced quantity of concrete. High Density polyethylene (HDPE) empty sphere replaces the ineffective concrete at neutral axis of the slab section, in this way diminishing the dead weight. Simply supported End conditions are assumed for both slabs under Static (UDL) loads. The analysis result showed the total deflection, Von-mises Stress of both slab under uniformly distributed load for different end conditions. This paper moreover displays a review on the properties and preferences of Bubble Deck section over conventional slab.

Key words: Bubble Deck Slab, Finite Element Method, Voided Slab, Structural behaviour, HDPE Sphere Balls

I. INTRODUCTION

The finite element method is a numerical techniques ever devised for solving differential as well as integral equation of initial and different boundary value problems in a very geometrically complicated conditions .some factors that cannot be ignored when analysing an element by the finite element method. This data is to define the domain and the boundary and initial condition and also the physical properties of specimen. After knowing this data, if the analysis is done carefully, it will give the satisfactory result. It can also be said that the finite element analysis is very methodical and that it is why is so popular, because that makes it easier to apply. In finite element analysis problem is systematically divided into a set of logical steps that can be implemented on a digital computer and can be utilized to solve a wide range of problems by merely changing the data input to the software.

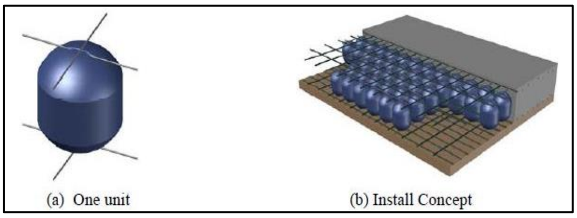

Fig. 1: Bubble deck concept

The finite element analysis is used for one, two and three-dimensional problems. Sometimes the easier problems are including one and two dimensions problems and can be solved without software if they are handled with care, an exact result can be achieved. But if the analysis requires three-dimensional tools, then it would be a lot more complicated, because it will involve a lot of equation that are very difficult to solve without having an errors.

Because of this software have developed that can perform these analyses by computer, making everything easier. This software can make analysis of one, two and three dimensional problems with a very good accuracy.

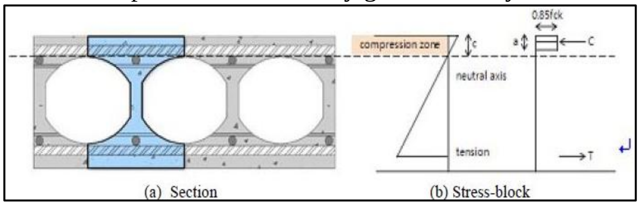

Fig. 2: Stress Block

A basic fundamental of finite element works is that it divides the whole element into a finite number of small elements. The domain of the problem is viewed as a collection of non-intersecting simple sub domains, called finite element. The subdivision of a domain into elements is termed finite element discretization. The collection of the elements is called the finite element mesh of the domain. The benefit of dividing a big element into small ones is that it allows that every small element has a simpler shape, which leads to a good approximation for the analysis. Another advantage is that at every node (the intersection of the boundaries) arises an interplant polynomial, which allows an accurate result at a specific point.

The invention of bubble deck slab was a breakthrough at the turn of 20th and 21st centuries. During the 1st decade there have been many studies on the feasibility of using the bubble deck technology.

In any structure, slabs are the essential individuals utilized for berthing reason and furthermore used to transmit the stacking and loading to other basic individual structural members. According to the reviews played out, the concrete at mid of the section is not completely used. The concrete that is set in tension zone is expected to convey no load and thus unused. The unused concrete may impart up to 80% of the total volume of concrete. This unused concrete can't be completely expelled as it decreases the Load carrying capacity at conveying limit and furthermore increases the deflection. So an incomplete volume of this unused concrete can be supplanted by conceivable method of providing void formers which merely create voids.

Slab is one of the biggest individuals devouring concrete. We know that increase in length of span increases the thickness of slab also. Increasing slab thickness makes slabs heavier and it ends in increased column and foundation size. Thus, it makes structure consume more concrete and steel.

Now, this innovative technology has been applied to only few residential or high rise buildings, and industrial floor slab due to limited understandings. For this investigation, the structural behaviour of Bubble Deck under various loading conditions will be analysed in order to gain understanding on this technique and to compare it to the current slab system.

II. SCHEMATIC DESIGN

Bubble deck slab is made over the prefabricated bubble-matrix` on conventional design of slab. In this slab system, the bottom of the slab is provided with a pre-cast concrete layer. Bubble Deck is intended to be a flat slab, two way spanning slab supported by columns. It consist of plastic spheres that is sandwich between top and bottom steel meshes. These structural unit then placed at site on formwork and then concreting is done.

It generally regulates to allow maximum deflection during service loading.

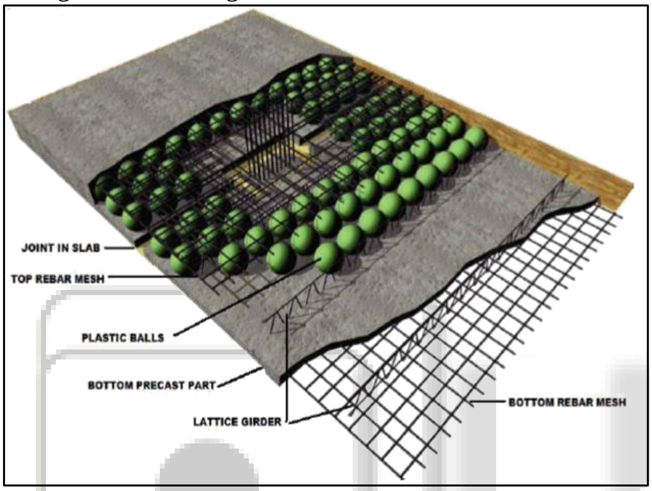

Fig. 3: Cut-through Section of Bubble Deck

III. TYPES OF BUBBLE DECK

All of the Bubble Deck versions come in three forms-Filigree elements, reinforcement modules, and finished planks.

For all types of Bubble Deck, the maximum element size for transportation reasons is 3 m. Once the sections are connected on site however, there is no difference in the capacity.

A. Type A- Filigree Elements

Bubble Deck Type A is a combination of constructed and unconstructed elements. A 60 mm thick concrete layer that acts as both the formwork and part of the finished depth is precast and brought on site with the bubbles and steel reinforcement unattached. The bubbles are then supported by temporary stands on top of the precast layer and held in place by a honeycomb of interconnected steel mesh. Additional steel may be inserted according to the reinforcement requirements of the design. The full depth of the slab is reached by common concreting techniques and finished as necessary. This type of Bubble Deck is optimal for new construction projects where the designer can determine the bubble positions and steel mesh layout.

B. Type B- Reinforcement Modules

Bubble Deck Type B is a reinforcement module that consists of a pre-assembled sandwich of steel mesh and plastic bubbles, or "bubble lattice". These components are brought to the site, laid on traditional formwork, connected with any additional reinforcement, and then concreted in place by traditional methods. This category of Bubble Deck is optimal for construction areas with tight spaces since these modules can be stacked on top of one another for storage until needed.

C. Type C- Finished Planks

Bubble Deck Type C is a shop-fabricated module that includes the plastic spheres, Reinforcement mesh and concrete in its finished form. The module is manufactured to the final depth in the form of a plank and is delivered on site. Unlike Type A and B, it is a one-way spanning design that requires the use of support beams or load bearing walls. This class of Bubble Deck is best for shorter spans and limited construction schedules.

IV. MATERIALS AND PROPERTIES

Bubble Deck is composed of three main materials-reinforcement steel, plastic spheres and concrete.

A. Reinforcement Steel

High grade steel of Fe 550 or Fe 500 is generally used. Top and bottom steel reinforcement used with same grade of steel. Here 10mm diameter steel bar is used for main reinforcement and 8mm diameter steel bar is used for distributor reinforcement. Reinforcement provided in both transverse and longitudinal direction in the form of mesh.

B. Recycled Balls

The hollow spheres are made from recycled high-density polyethylene or HDPE. This ball don'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 of the concrete. The size of the HDPE ball is about 80mm diameter with wall thickness 1.5mm.

C. Concrete

Standard Portland cement is commonly used. No plasticizer is used. On the basis of grade used, design mix procedure takes place. Common concrete or Self compacting concrete used for the precast layer. Minimum grade of concrete should not be less than M30. The depth of the slab is about 130mm.

Name of Material	**Parameter**	*Value*
Steel	Modulus of Elasticity (E)	200000 MPa
	Density	7850 Kg/m^3
	Poisson's Ratio	0.3
Concrete	Modulus of Elasticity (E)	25000 MPa
	Density	2460 Kg/m^3
	Poisson's Ratio	0.18
Plastic HDPE	Modulus of Elasticity (E)	1035 MPa
	Density	970 Kg/m^3
	Poisson's Ratio	0.4

Formulation Detail	Usual Chemical Designation	Polyethene (high density)
	Chemical formula	(-CH2-CH2-)n
	Genus	Polyolefin
	Hazardous additional substances	none
	CAS No.	9002-88-4
Physical & Chemical Properties (Polymer characteristics)	Physical condition	Solid (at+20°c)
	Colour	Chosen by manufacturer
	Odour	Weakly of parafin
	pH	Not applicable
	Relative density	940-965kg/m^3
	Melting point	127-137°c
	Softing point	123-124°c
	Solubility in water	insoluble
Safety characteristics	Decomposition temperature	>300°c
	Flashpoint	>355°c

Table 1: Properties of Materials

V. Advantages of Bubble Deck

A. Material and Weight Reduction

1) It uses 30-50% less concrete than normal solid slabs reducing the dead load of the structure.
2) Less structural steel since the need for reinforcement diminishes.
3) The building foundations can be designed for smaller dead loads as well.
4) Overall, due to the lighter floor slabs, the several downstream components can be engineered for lower loads and thus save additional material.

B. Structural Properties

1) In two-way spanning action, load-bearing walls become unnecessary.
2) When designed as a flat slab, which eliminates the need for support beams and girder members.
3) Construction And Time Savings
4) On site construction time can be shortened.
5) eliminate the need for onsite erection of formwork,
6) Bubble Deck can be fully shop fabricated and transported on site for installation as well.

C. Cost Savings

1) In relation to the savings in material and time, cost reductions are also typical with the Bubble Deck system.
2) The decreased weight and materials mean lower transportation costs, and would by more economical to lift the components.
3) With semi-precast modules, labor costs will decrease as well.
4) Money can be saved downstream in the design and construction of the building frame elements.

D. Green Design

1) A green alternative is growing exponentially.
2) Lowering the embodied carbon in new buildings.
3) 1kg of recycled plastic replaces 100 kg of concrete.
4) Carbon emissions from transportation and equipment usage will also decrease with the use of fewer materials.
5) HDPE bubbles can be reused for other projects, or can be recycled.

For every 5,000 m^2 of Bubble Deck floor slab, we can save:

- 1,000 m^2 of on-site concrete and 278 tonnes of CO_2 emission.
- 166 concrete truck trips.
- 1,798 tonnes of foundation load, or 19 less piles.
- 1,745 GJ of energy used in concrete production and transportation.

VI. Contact between Bubble & Reinforcement

The contact is only theoretical because the balls do not perfectly fit between reinforcement bars and moves slightly during concreting compaction. Provision of plastic rebar spacers within solid slabs creates a discontinuity within the concrete between the outside air and the rebar in solid slabs. Now this situation is better than existing with plastic rebar spacers. Balls with cut open has also been practiced many years and there has been no sign of significant corrosion.

VII. Effect of Bubble Voids upon Stiffness

In Voided slab construction concrete removes from locations of the slab that are less critical to resist the applied loads. Removing concrete from the slab core shows that section modulus and stiffness are roughly equivalent to a solid slab and hence the self-weight of the section is greatly reduced. This reduction has many benefits.

VIII. Behavior of the Slab

A. Shear Strength

The results and analysis from a number of practical tests confirm that the shear strength depends on the effective mass of concrete. The shear capacity is measured to be in the range of 80% of the shear capacity of a solid deck. For large safety margins, factor of 0.6 is used on the shear capacity for a solid deck of identical height. Due to use of plastic bubbles, the shear resistance of bubble deck greatly reduces in comparison of solid slabs. In any flat slab, design shear resistance is usually critical near columns. Hence bubbledeck slab is designed exactly the same way as the solid slab by left out the bubles near the columns.

The shear capacity is measured for a ratio of a/d (distance from imposed force to support divided by deck thickness) of a/d = 2.3

Shear capacity (in % of solid deck)	a/d = 2.3
Solid deck	100
Bubble Deck, no girders	76

Table 2: Shear Capacity

B. Bending Strength

Bubble Deck when compared to a solid deck, both practically and theoretically. Bending stresses in the Bubble Deck slab are found to be 10% lesser than that of solid slab. The ultimate load value obtaining bending tests were upto 90% greater than the ultimate load value. The bottom reinforcement steel and the top compressive portion of stress block contributes to flexural stiffness in the bending.

C. Deflection

Deflection of Bubble Deck is 5-10% more than solid slab as the stiffness is reduced due to the voided portion. Strengthened Bubble Deck has low deflection compare to un strengthened Bubble Deck slab. The Bubble Deck slab can withstand with 80% of stress as compared with conventional slab with slightly variation occurs in the deformation when compared to conventional slab.

D. Fire Resistance

The fire resistance of the slab is chiefly dependent upon the reinforcement to check sufficient strength during a fire. When it will be heated and lose significant strength as the temperature rises. In an long term, the ball would melt and eventually crack without significant or detectable effect. Fire resistance depends on concrete cover nearly 60-180 minutes. Smoke resistance is about 1.5 times the fire resistances.

E. Punching Shear

Due to the localized forces the failure at extreme condition is associated with the term of Punching Shear or Hogging Phenomenon. As highly concentrated reactions comes from the column onto the slab this become a common concern for flat plate floor systems. Approved research verified that the crack pattern was similar to that of a solid slab. The punching shear was 90% of the same solid slab and local punching failure did not occur within the given load cases.

IX. CONSTITUTIVE MODELS AND THEIR PROPERTIES

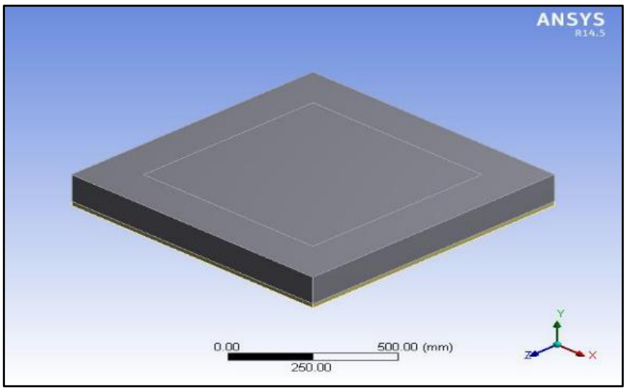

Fig. 4: Modelling of Conventional Slab

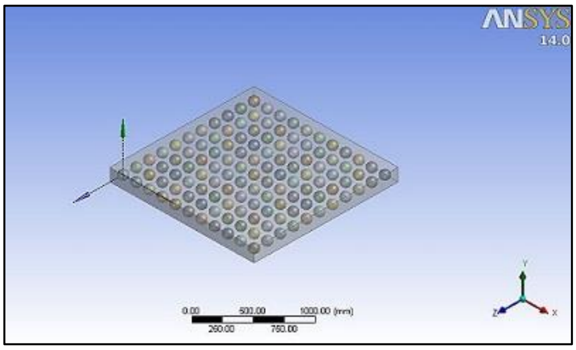

Fig. 5: Modelling of Bubble deck Slab

A. Specifications of Tested Slab Specimens

- The slab specimens are of dimensions 1000mm x1000mm x 130mm with simply supported boundary conditions.
- For simplification purpose, only a small portion of a slab is modelled and symmetric boundary conditions were applied to create conditions of full geometry.
- The clear spacing between the voids is of 40mm, 60mm, 80mm respectively.
- The bubble is of spherical shape is assumed to be made of High Density Poly ethylene (HDPE).
- 10mm diameter steel bar is used for main reinforcement and 8mm diameter steel bar is used for distribution reinforcement.
- Reinforcement provided in both transverse and longitudinal direction in the form of welded mesh.
- The effective cover of the specimen of the slab are assumed as 25 mm.

B. Loading Criteria

1) The Bubble deck slab and conventional slab are discretized using tetrahedral element type as 4 nodes.
2) On two adjacent faces at the bottom a slab is constrained against vertical movement. And on the other faces of the slab model is provided with symmetric boundary condition for a full section effect.
3) The end supporting conditions are provided as simply supporting end conditions.
4) The load applied is of area type and applied as pressure of 4.5kPa ($45x10^{-3}$ N/mm2), 9.3kPa, 12.0kPa, 19.5kPa, 27.0kPa in 5 steps respectively.

X. APPLICATION ASPECTS OF BUBBLE DECK SLAB

- Suitable for the majority of new-build projects, also suspended ground floor slabs and alteration/refurbishing projects.
- Comprises of prefabricated “bubble-lattice” hence sandwiched elements easily placed on traditional formwork with no time.
- Acts directly like a seamless ceiling
- As it is a biaxial deck technology it is very beneficial for biaxial slab designs.
- Proves worthy for limited areas such as balconies or staircases with Finished panels and complete precast slab elements.

XI. Future Scope

The prevailing beneficial of a Bubble Deck slab is that it uses 30-50% less concrete than normal solid slabs. By using less concrete, designers can save up to 40% on embodied carbon in the slab, resulting in significant savings downstream in the design of other structural members. Carbon emissions from transportation and equipment usage will also decrease with the use of fewer materials. Overall, due to the lighter floor slabs, the several downstream components can be engineered for lower loads and thus save additional material.

As clearly seen from current study, the design of Bubble Deck cannot economically accommodate high shear resistance hence the type of loading that bridge decks experiences is a major design requirement.

Punching shear is another significant concern for a bridge deck filled with HDPE bubbles.

Since the results from the test case Bubble Deck slab corresponded with the prior research, this concept can studied further for a variety of bridge layouts to fully determine the feasibility of bubble deck slab in a bridge deck (lightweight pedestrian bridge deck and vehicular bridge deck) because of the lower live loads and minimized shear forces.

XII. Conclusions

This paper presented a brief overall review on the conventional slab suitability and bubble deck slab suitability at different places as a different component (office slab, bridge deck slab etc.).Office slab test provides the results of prior research, proving that the Bubble Deck slab performed better than a traditional solid concrete, biaxial slab. The maximum stresses and internal forces in the voided deck about to 40% less than the solid slab due to the decreased dead load from the use of HDPE spheres in place of concrete.

The deflection of the Bubble Deck slab was slightly higher but the stiffness decreased due to the presence of the bubbles but this situation will be overcome by the reduced overall stress in the slab. This paper demonstrate that this type of biaxial deck will give better results under long-term and a more durable floor slab under a dominant gravity and uniform load.

This detailed investigation has proven that the Bubble Deck concept is more efficient than a conventional concrete slab in all aspects. The finite element analysis of models of the slabs also verified the prior analysis.

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