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Voided Slab: As a Sustainable Construction Technique

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Abstract : In Structural engineering, it can be challenging to incorporate a sustainable design without compromising structural integrity and strength. Voided slab which is used in Europe and other countries are becoming increasingly popular. However, flat plate voided slab can be an interesting alternative to standard flat plate concrete slab. By incorporating flat plate voided slab there will be reduction in concrete which will then be replaced by recycled plastic void formers. Our project is necessary because an increasing use of voided slab in concrete structure will be able to fight climate change by reducing the Co2 emission from cement production. Our design of voided slab follows the Indian Standard Code for strength and serviceability. Our project aims in achieving benefits which include reduced weight, which results in smaller seismic forces; economical longer spans, increase in accelerated construction schedule. Plastic voided material in a variety of shapes replaces the ineffective concrete from the center of the slab and decreases the dead load. The advantages are less energy consumption, less emission of exhaust gases from production and transportation, by reducing the material requirements.

Keywords - Voided Flat Slab; CO2 emissions; energy consumption; solid slab.

I. Introduction

Usage of concrete increases day by day with rapid growth of construction industries. Generally, in any structure, the slab represent the most important member that make a space. Besides, the weight of the slab is approximately 90% of the total weight of the structure. That's mean the slab is the largest member that consuming concrete. So an attempt has been made to reduce the weight of slab by providing plastic spherical voids in two way reinforced concrete slab without compromising with strength and safety, this system is called Voided Slab system. The use of Plastic Voids has a green effect on environment due to the use of reduced amount of concrete. This research presents theoretical and structural study of Voided Slab and their Sustainable advantages. It was concluded that the Voided slab has a saving on the concrete consumption. That's mean a considerable amount of raw martials (cement, sand and gravel) can be saved. So, the amount of CO2 emission and energy consumption reduced. Besides, when the diameter of the bubble increased, the amount of concrete reduced and as a result CO2 emission and energy consumption reduced. While by using high strength concrete, the percentage of cement increased and that's lead to increase CO2 emission.

II. Literature Review

Bhagyashri G. Bhade and S.M Barelikar (2016) -

An experimental study on two way bubble deck slab with spherical hollow balls.Weight reduction is 25% compared to solid slab. The Bubble Deck is green technology and sustainable avoiding the cement production allows reducing global CO2 emissions. In comparative of conventional slab the volume of concrete in bubble deck are less required, that is 25% approximately. The Volume of concrete is reduced, so that the weight of slab is decrease, comparative to Conventional slab. Cost and time saving by using bubbles in the slab like weight of slab, concrete volume indirectly load on the beam and walls also decrease less so that building foundations can be designed for smaller dead loads.

III. Materials And Methods

3.1Materials-Recycled Plastic-

Other than the conventional materials used in a Slab, distinct material used here is Recycled Plastic to make the Voiding Material in the shape of Cuboids.

3.2 Methods-Design Concepts And Requirement

3.2.1 Meeting the Building Codes

Reinforced concrete slabs constructed with the modern voided slab systems meet many of the prescriptive requirements and intents of the International Building Code (IBC) model building code (IBC 2012). Concrete slabs containing sacrificial void formers designed for the strength and serviceability provisions of ACI 318 will meet or exceed building code requirements. The leave-in void formers in use today behave much the same way as hollow-clay tiles or other insert materials (e.g., polystyrene) that have been successfully used for a century in the construction of voided concrete floor slabs. Furthermore, air-filled cavities are present in other concrete systems, including but not limited to precast hollow core planks and the box-shaped cross sections of bridge girders. As with any unique system, design, detailing, and construction of voided slab systems have system-specific requirements.

3.3 Defining the computational model and parameters.

Upon selection of the computational tool, initial design assumptions should be made to determine the input similar to the design of a solid flat slab floor system. This should include: • Geometry of slab (thickness, horizontal contours with supports and openings).2 • Load conditions. • Material parameters for reinforcing and concrete (unit weights, modulus of elasticity, strength, concrete cover over the reinforcing, long-term deflection modifiers). • Design criteria (deflections, stress or force limits).

A. Establish adjustment factors specific to the voided slab system.

The following design parameters are typically adjusted as straightforward scalar multipliers that compare the voided system to the characteristics of solid slabs:

Stiffness correction factor (for practical reasons, in lieu of altering the moment of inertia, E, the modulus of elasticity, is modified).

Dead load reduction.

Shear capacity.

B. Creation of negative dead load pattern.

The weight of voided slab systems is reduced compared to a solid slab in those areas where the void formers will be present. An initial estimate of average dead load reduction (typically on the order of 25-30%) is adopted and assumed to act uniformly (“smeared”) throughout the entire floor plate. To facilitate the computations, it is practical to represent this reduced self-weight as an additional load pattern applied over the entire area as negative surface load (acting upward). Where the designer can define more precisely the floor regions where voiding is planned, the reduced selfweight can be represented in the same manner in those areas only. In this case, the reduced slab weight can be more closely approximated.

C. Perform initial analysis.

Analysis should be conducted considering various code requirements for load patterns and combinations incorporating the above listed negative dead load. Most often, the slab design is governed by deflection criteria, including long term deformations, which the software tools may or may not directly account for. The design slab thickness might be repeatedly revised to meet the deflection limits, or strength that can be provided with reasonable reinforcement. Similarly to conventional slabs, analytical methods should be used to predict the extent of cracking of the slabs due to shrinkage and temperature volume changes.

D. Shear analysis to establish solid zones.

Upon establishing the slab thickness that satisfies the deflection and flexural criteria, the entire floor area is examined for shear induced by gravity forces. This step is to identify contours within which the reduced shear capacity of the voided system would not meet the shear demand. These shear-critical zones should be designed without void formers. In addition, there might be some other considerations that may preclude some areas as host to the voids, such as in-plane force transfer issues for diaphragms, etc. As with conventional slabs, the option to augment the shear capacity of the solid slab zones of the voided slab, for example, at supports with special shear reinforcement or drop panels is available to the designers. F. Refinement iterations. The previous steps provide sufficient accuracy for preliminary or schematic design. Final design, often accomplished with a FEM analysis program, necessitates a more accurate representation, as it influences the design of the slab as well as that of the supporting columns and foundations. At this stage of the design process, the dead load pattern is adjusted to depict the actual layout of the void formers. This is accomplished by determining the void type, size, and the corresponding concrete volume reduction at specific areas. With these refinements, the designer can determine the dead load reduction in areas designed with voids. G. Flexural design. Upon satisfying the shear and deflection criteria, flexural considerations should be addressed. Based on the moment distribution obtained from the analysis, steel reinforcement is designed to resist flexure and satisfy other strength requirements.

3.4 Parameters Used in Structural Analysis and Design

1. Stiffness Modification

The flexural and shear rigidities of the voided slab system are only slightly reduced compared to those of the solid flat slabs as the result of void formers placed at mid-height. The presence of localized and repeated cavities in the solid continuum is typically accounted for by using an effective moment of inertia reflecting the specific three-dimensional arrangement of voids. These include the thickness of the slab, the size, shape and spacing of the void formers, and their vertical position within the slab. Manufacturer guidelines may provide related data based on testing and/or computational models. However, as the geometrical variation of spacing and vertical positioning is in the hands of the designer, considering the variety of shapes and distributions, it is not possible to provide a generalized formula for changes in stiffness. Furthermore, even within the same single floor plate there could be a great variation of any of the above parameters depending on the floor layout, supports, load conditions, etc. For many common voided slab applications, the flexural stiffness modifiers, expressed as the ratio of effective inertia to gross inertia of the uncracked solid slab, were reported in the neighborhood of 90-92%.

2. Flexural Strength

Typical voided slab systems can be designed for flexure using the same principles as customary for conventional solid slabs. The usual geometry of the cross section and loading result in flexural strains and stresses that utilize only a thin top segment of compressed concrete. The neutral axis is commonly located above the void formers, making the behavior the same as a solid slab. Should the neutral axis fall below the contour of the void formers, it is likely to represent only a negligible calculation inaccuracy of the position of the resisting internal compressions force considering the rounded shape of the interspaced cavities. Also note, that in multispan configurations, maximum moments typically occur in the vicinity of the supports where void formers are omitted for punching shear considerations. These common features often allow engineers to omit the presence of the void formers placed at about mid-height of the slab in the flexural calculations. Thus, for customary design scenarios, the moment resistance can be determined based on usual methods with the rare exceptions associated with unusual forces or column layouts. Where unique conditions of high demand (e.g., presence of in-plane loads) occur within a small area of the floor plate, design is simplified by omitting the void formers in those zones. Linear elastic finite element models may yield to singularities under certain conditions, such as concave corners and at point loads. These conditions should be judiciously analyzed by the designer.

3. Shear Capacity

The flow of stress trajectories in voided slabs is significantly impacted by the presence of voids. The combined effect of the loss of materials compared to solid slabs and the disturbances in the flow of stresses markedly reduces the shear capacity of the voided slabs. However, the smooth rounded shape of the cavities allows for redistribution of stresses and the avoidance of singularities. This ultimately results in a reduced shear capacity that is usually taken on the order of 50-65% of the solid slab. This is a conservative estimate based on numerous laboratory tests that have shown shear capacities well above 65% of that of the solid slab with the same thickness. Some voided slab contractors suggest an approach, accepted by the German Institute of Building Technology, to substantiate the assumed shear capacities. This concept is based on the assumption that shear strength is developed as the sum of capacities attributed to:

• Resistance of the uncracked compression zone.

• Aggregate interlock along the cracked surface in reinforced sections.

• Resistance provided by the tension reinforcement. The presence of void formers at mid-depth of the cross section.

4. Serviceability Checks

Deflections –

Uncracked voided slabs typically have a slightly less (about 87-90%) flexural stiffness than solid slabs with the same thickness. Given the close to linear relationship between the slab deflection and the flexural stiffness, these code tables with an adjustment for the reduced voided slab stiffness may serve as a good predictor of deflection performance. The presence of the relatively large voids does influence crack formation and crack patterns and may impact stiffness values when determining the initial deflections. The cracking moment at the location of void formers is expected to be smaller and in proportion of the reduction of the cross sectional moment of inertia, typically on the order of 80% of the full solid cross section. As indicated in ACI 9.5.3.4, "Deflections shall be computed taking into account size and shape of the panel, conditions of support, and nature of restraints at the panel edges." Deflection analysis is often performed with two-dimensional finite element programs, some with the ability to do a more detailed analysis of reinforced concrete behavior.

IV. RESULTS AND DISCUSSION

The deformations developed in the solid slab are comparatively less than the bubble deck slab the variations are shown in fig 5 whereas the stresses developed in the solid slab are comparatively higher in case of solid slab the variations are shown in fig 6. The moments developed in xx direction (M11), in yy direction (M22), in xy direction (M12), the shear forces developed in xz direction (V13), in yz direction (V23), the maximum stresses that are developed in the slab (SMAX), and the deflections (U3) are shown in table 6.

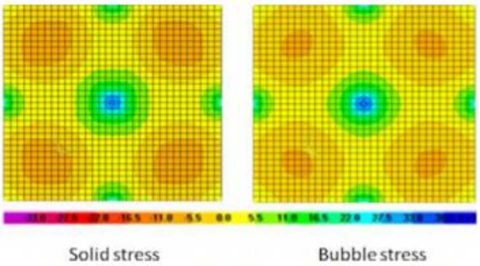

Fig 6: stresses in Solid slab Vs Bubble deck slab

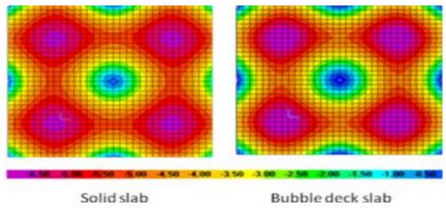

Fig 5: Deformation of Solid slab Vs Bubble deck slab

V. CONCLUSION

A. Bending stresses in the bubble deck slab are found to be 6.43% lesser than that of a solid slab.

B. Deflection of Bubble deck is 5.88% more than the solid slab as the stiffness is reduced due to the hollow portion.

C. Cement used in Voided Slab is 20% less as compared to Conventional Slab.

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