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Comparative Study of and Voided Slab System and Conventional RCC Slab

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Abstract: *This paper presents the flexural capacities of R.C.two-way hollow flat slabs with plastic voids. Recently, various types of slab systems which can reduce the self-weight of slabs have been studied as the height and span of building structures rapidly increase. To verify the flexural behaviour of this voided slab such as flexural stiffness, ultimate load, deflection, stresses and concrete compressive strain were studied.FEM model was created in ANSYS workbench 2022 for both conventional solid flat slab and voided slab. U-Boot beton from "daliform group building innovation Italy" was used as void former in this study. The dimensions of U-boot is 520×520mm and with 180mm and 160mm height. Dimension of FEM slab model is 8500×8500 mm with 500×500 column support at all four corners. Three different slab of 280mm, 300mm and 320mm was created. In addition, manual analysis of solid slab and voided slab was carried out using direct design method as per IS-456(2000). And further, design is checked to verify that it satisfies all design and serviceability criteria given as per IS-456(2000).Results obtain via theoretical calculation and FEM model simulation for both solid and voided slab were compared. The aim of this paper is to discuss and compare flexure behaviour of solid slab and voided slab and to study changes in inertia, stiffness and reduction in weight, of the slab by void formation.*

Keywords: Voided slab, ANSYS, U-Boot, Flat slab, flexure capacity, stiffness.

I. INTRODUCTION

Flat plate slabs are commonly used in multistorey buildings, as it provides various architectural freedom and it reduces overall height of building. When designing flat plate slab primary design limitation is span of the slab between column. Designing large spans between columns often requires the use of support beams and/or very thick slabs, thereby increasing the weight of the structure by requiring the use of large amounts of concrete. Heavier structures are less desirable than lighter structures in seismically active regions because a larger dead load for a building increases the magnitude of inertia forces the structure must resist as large dead load contributes to higher seismic weight. Incorporating support beams can also contribute to larger floor-to-floor heights which consequently increases costs for finish materials and cladding. Voided slab system is revolutionary method of eliminating non working excess concrete from slab, without significant changes in structural performance of slab. Voided slab reduces slab weight up to 35% of deadload, allowing engineers to design large span slabs.

The geometry of void formers varies depending on the manufacturers. Void formers are typically hollow plastic shapes created as either a single unit or as matched shapes that can be combined to form the designed void. The most common shapes are spheres, cuboid or flattened spheres, but a variety of shapes can be achieved. The ultimate load-carrying capacity of specimens with sphere- and cuboid-shaped voids was equal to that of the solid slab. The theoretical load-carrying capacity of voided and solid slabs using the yield line theory was the same. The presence of void formers did not influence the reinforcement behavior in longitudinal and transverse directions. (Effect of void former shapes on one-way flexural behaviour of biaxial hollow slabs R. Sagadevan1; B. N. Rao – 19 June 2019). Manufacturers and suppliers of the systems provide tabulated geometrical details in their catalogues.

Manufacturing of reinforced concrete emits massive CO2 in environment, ton of concrete emits 500 kg of CO2 in environment thus reducing concrete use can significantly cut down energy and raw material input thus reducing environmental pollutants. (Fiala, Hajek 2007; Abramski et al. 2010).

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The present study focuses on studying structural performance, flexural capacity, shear resistance of voided flat slab. Cuboid shaped (called U-Boot) void former Made from polypropylene is used. Different height of uboot is available from its manufacturer daliform group building innovation. And software is also available to determine flexural capacity of slab of chosen dimensions and chosen U-boot height.

Finite element model is created using ANSYS workbench 2022. And its results are studied. In actual design practice relatively, easier software are used for voided slab design, like SAFE2000.

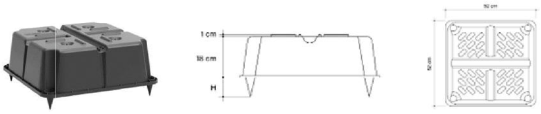
II. MATERIALS AND SPECIMEN

Concrete:

For modelling in FEM M25 and Fe415 was used.

Details of void former:

Void former used is cuboid shape U-boot from daliform manufacture. Height of uboot is 180mm and dimensions are 520mm by 520mm.piece volume = 0.0396m³



Specimen geometry:

Dimension of flat slab is taken as 8.5 by 8.5 meter. Thickness is 300mm. Fixed support conditions of 500*500 at all four corner was provided. the elevator feet height 60 mm was provided to ubootat bottom face and cover to reinforcement provided is 25mm.

III. METHODS

Stiffness modifications

Second moment of inertia is key variables in structural analysis of slab. The uncracked moment of inertia of solid section is given by I=bt³/12 where t is slab thickness. As we provide void the uncracked moment of inertia of section changes. By providing this U-boot void we create I shaped cross section is slab. By using CAD software, the uncracked moment of inertia for both solid rectangular and this I section as shown in figure is found out.

For solid rectangular section (300*670)

Isolid = 152.75*107 mm4

For I section created because of void

Ivoided= 126.7*107 mm4

It is 84% that of solid section

So, inertia loss = 16% (for given geometry)

from various manufacturer testing it is seen that I for cracked section is around 87 to 90% to that of solid slab.

I_{solid}(cracked) =0.9 I_{voided} (cracked)

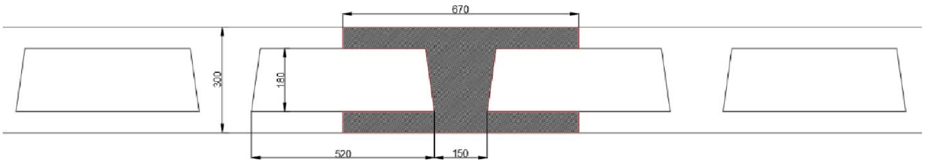


Fig. 3. I section created due to U-boot

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Moment analysis and Bending strength

After obtaining cracked and uncracked moment of inertia further analysis can be performed. Cracking moment is the flexural limit at which crack first develop in section. After cracking steel reinforcement resist tension and contribute to moment capacity.

Cracking moment for solid section:

$M_{cracked} = (f_{cr} * I_{gr}) / Y_t$(as per IS:456-2000 C-2.1)

Cracking moment for voided slab is 0.8 times of solid slab:

$M_{cracked} = 0.8 (f_{cr} * I_{gr}) / Y_t$

Manufacturer's testing on plastic voided slab sections has shown that, in most cases, the compression block for slab sections in bending is confined to the solid slab portion at the top of the section. In high loading conditions, the stress block has been shown to partially enter the void zone, but tests indicate that the effect of this is insignificant in all but the mostextreme circumstances. The ratio of total amount of moment resisted by the void region to the total amount of moment resisted by the whole section is represented by the variable μ_{ms}.

And if this ratiois less than 0.2 then moment stresses are within top portion of voids, means within concrete only. And then we can design slab as ordinary design methods.

$$\mu_{ms} = M_u \, 1.9D/(f_{ck} h^3)$$

And depth of neutral axis can be found from Equation given below.

X= depth of neutral axis (d N-A)

$\mu_{ms} = [(X - C_{void}) \, Z_{void}]/(X - Z)$

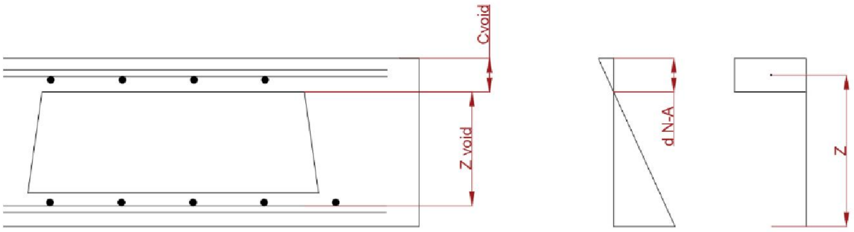

Fig. 4. Voided slab stress distribution

Punching shear strength

The shear force must be calculated from the structural analysis using service load. The areas with high punching shear, such as areas around columns or with high concentrated loads; the solid slab is designed instead of voided slab. The suggestion is often made to leave out the void former around columns to make that portion of voided slab as solid. The perimeter of the solid portion should be calculated from the face of column without shear reinforcement. Punching shear for voided slab should be limited by the following equations:

$V_{ED} < V_{RD}(\max)$

$V_{ED} = V_{max} / (u_{col} \text{ x } d_{om})$

$V_{RD}(\max) = 0.5 \text{ V x } F_{cd}$

Where,

u_{col} = perimeter of the column

d_{om} =mean effective depth of slab

IV. ANALYSIS AND DESIGN

A finite element Analysis carried out in Ansys workbench for 3 different thickness of slab 280, 300, 320mm voided and solid. Placement of U-boot in the panel created is shown here. At column where there is high punching shear present

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voids are not provided. Fixed support at corner is provided as shown. And then analysis was carried out with Live load value of 5 kN/m² on whole panel. The result obtain is discussed below.

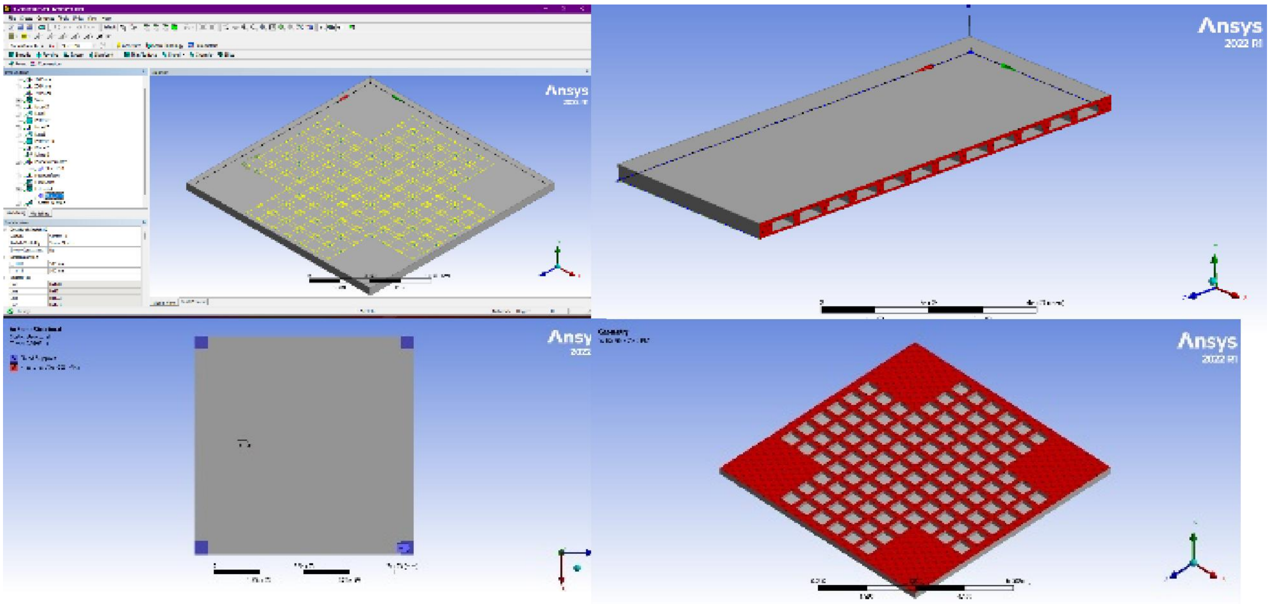


Fig. 5 Voided slab 300 mm modeling

Finite element result obtain from the ANSYS workbench is shown below. Deflection, shear stress, Normal stress and punching shear stress variation can be observed in it.

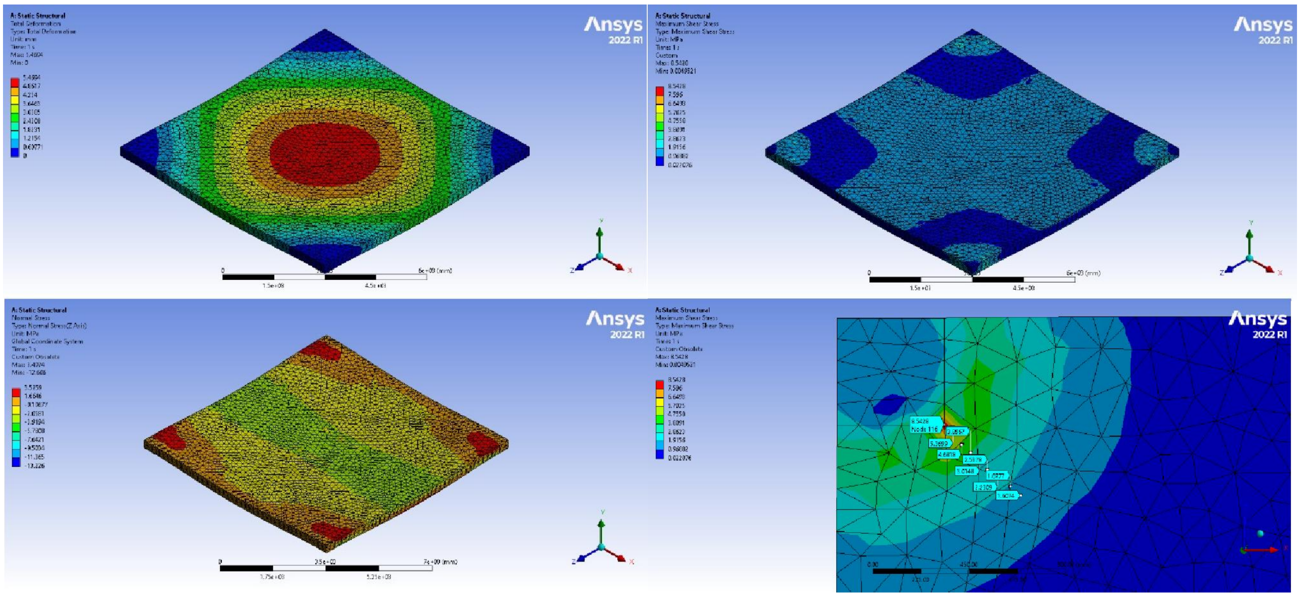


Fig. 6FEM Analysis results

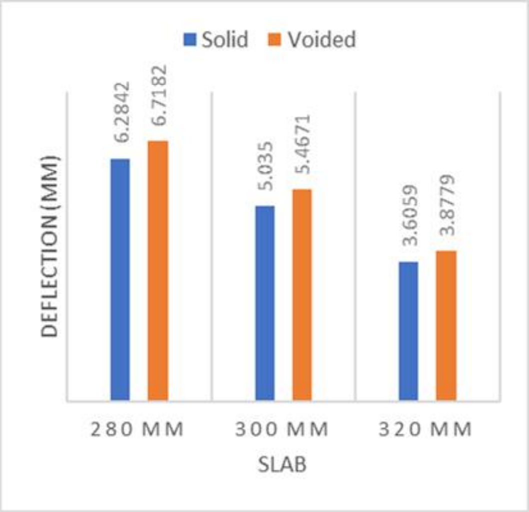
V. RESULTS AND DISCUSSIONS

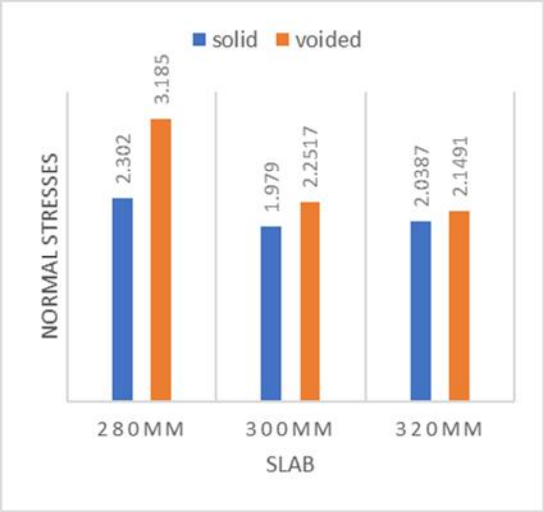
Maximum deflection Observed on voided slab was slightly higher than that of solid slab. As we increase slab thickness the deflection is reduced.

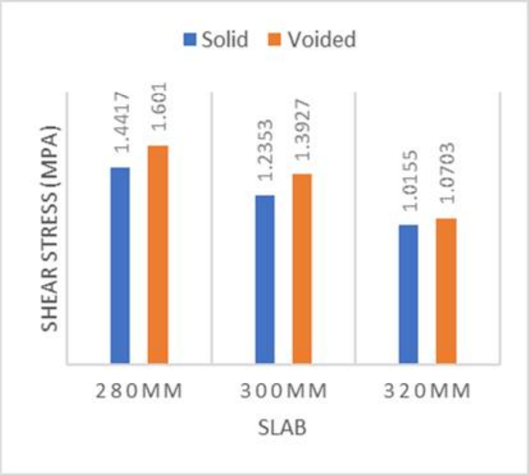
Shear stresses generated in voided slabs may be slightly higher compared to solid slabs, the material is utilized effectively to withstand these stresses. Additionally, normal stresses are slightly higher for voided slabs due to their lower stiffness relative to solid slabs. However, both shear and normal stresses remain within permissible limits, ensuring structural safety. It is important to note that voided slabs make optimal use of materials compared to solid slabs.

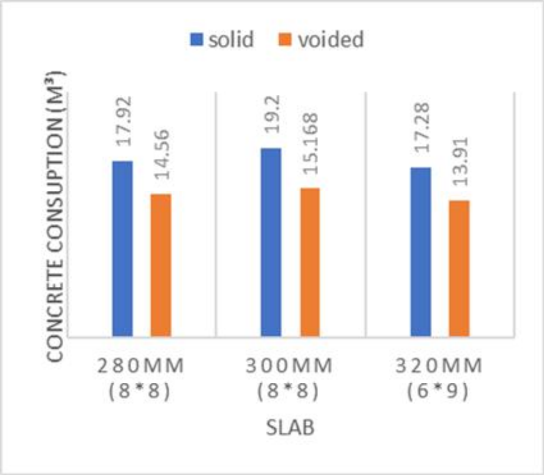
The maximum normal stresses observed in voided slab on top fibre of the slab is higher the solid slab. It shows that voided slab utilizes the concrete much efficiently compared to solid slab. With less concrete use. As we increase depth of slab it reduces because slab with more depth deflect less and experiences less normal stresses.

The results obtained from the comparison of concrete consumption between solid slabs and voided slabs reveal notable advantages in favour of the voided slab system. The data collected for three different thicknesses of the slabs demonstrated a consistent reduction in concrete consumption when utilizing voided slabs. For the solid slabs, the concrete consumption was recorded as 17.92, 19.2, and 17.28 cubic meters respectively. In contrast, the voided slabs exhibited significantly lower concrete consumption values, measuring 14.56, 15.17, and 13.91 cubic meters for the respective thicknesses.









VI. CONCLUSION

- From result it can be seen that by providing voids self-weight of slab is reduced significantly and so moment generated is less compared to solid slab and allowing us to use larger span.
- Deflection at mid span is quite similar in both solid and voided slab and are within permissible limits.
- Moment resisting capacity of voided slab found to be higher than that of equivalent solid slab.
- Slab weight is reduced by up to 30% and Overall weight of structure is reduced by 15%.

- Punching Shear produce at column is also reduced by 12 to 15% due to reduced slab weight.
- The advantages of employing plastic voided slabs instead of solid slabs are particularly significant for larger spans. Smaller spans do not necessitate excessively thick slabs, allowing for the utilization of only small voids and resulting in minimal savings. On the other hand, larger spans can accommodate larger voids, leading to substantial reductions in slab weight while satisfying the load capacity requirements. •
- By reducing the overall weight of the building, we simultaneously diminish the seismic weight, subsequently lowering the base shear generated. This reduction in seismic force requirements enables a decrease in the necessary reinforcement for design purposes. Furthermore, the moment is reduced by 10% due to the decreased weight of the voided slab.
- The presence of voids within the slab does not affect its flexural performance. Therefore, design modifications and calculations can be applied to solid slabs and effectively executed using tools such as csiSAFE, yielding results that closely align with those obtained through direct design methods.
- Under normal loading conditions, the depth of the neutral axis remains within the top concrete zone, ensuring structural integrity. Although the construction process for plastic voided slabs may involve additional steps compared to solid slabs, it is not significantly more complex. In fact, for bays of the same size, plastic voided slabs generally require less reinforcement.
- Additionally, the utilization of plastic voided slabs leads to a reduction of approximately 18% to 20% in concrete consumption without significantly compromising the performance of the slab. This reduction in concrete usage contributes to a corresponding decrease in the reinforcement requirement, resulting in cost savings of approximately 10% to 12%.

VII. ACKNOWLEDGEMENTS

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