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Comparative Study of Voided Flat Plate Slab and Solid Flat Plate Slab

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Abstract:
The slab is very important structure member in building and slab is one of the largest member consuming concrete. When the load acting on the slab is large or clear span between columns is more, the slab thickness is on increasing. It leads to consume more material such as concrete and steel, due to that self-weight of slab is increase. To avoid these disadvantages various studies carried out and researchers suggest voided flat plate slab system to reduce the self-weight of the slab.A voided flat slab system is known as one of the effective slab system, which can reduce self-weight of slab. A voided flat slab has hollow void former made from recycled plastic placed within slab in order to reduce self-weight of slab. The voided flat slab and solid slab are consider with interior span ranging from 6m x 6m to 14m x 14m having thickness from 280mm to 600mm having spherical balls into the slabs from 180mm to 450mm. Self-weight reduction, stiffness reduction factor and solid area for punching shear is derived for different cases of voided flat plate slab.

Key words: *voided flat plate slab, solid flat plate slab, moment of inertia, shear capacity, self-weight*

1. Introduction

The flat plate floor systems are commonly used in multi-storey buildings, because flat plate floor system present advantages from technical and functional point of view. The self-weight of slab can reduce by replacing the middle height of the cross section of slab with void former. Actually, the concept of removing non-working concrete from slab cross section is quite old. The voided slab used in construction field more than 50 years. By introducing void former into the slab, self-weight of the slab can be reduce and this lead to reduction in overall cost of the slab. The overall weight of slab is decreasing as much as 35% compared to solid slab of same capacity. The main idea behind voided flat plate slab is to removing the unused concrete from the middle of the slab. The spherical balls, which are inserted in the middle of the flat plate slabs, are manufactured from recycled plastic, which do not react chemically with concrete or steel.

2. Stiffness Modification Factor and Weight Reduction

The second moment of inertia is a key variable when performing structural analysis of slab. The untracked moment of inertia is dependent on the thickness and width of the flat plate slab and the contribution made by steel can be ignored since steel is not taking part prior to cracking. In addition, the values in Cobiax Technology Handbook are taken by calculating second moment of inertia in State-1 (uncracked) and in State-2 (cracked). The results have revealed that the stiffness reduction factor in state-1 is the determining factor. The stiffness reduction factor can be derived from the calculation of second moment of inertia of voided slab and solid slab. With the help of this reduction factor and taking into account the reduced self-weight of voided slab deflection of voided slab can be calculated.

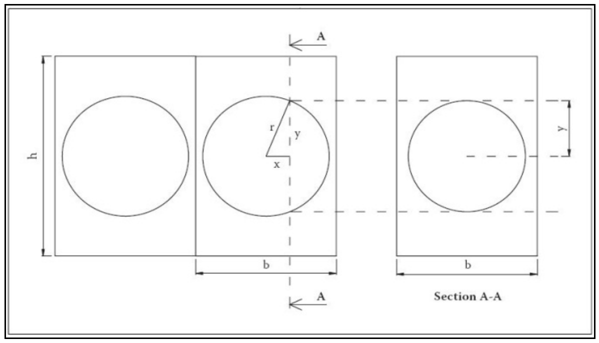


Figure 1: Voided slab stiffness calculation method

To find out stiffness reduction factor first find out second moment of inertia of solid slab without void former. And this can be calculated with:

$I_s = bh^3/12$ —— (1)

Where,

b = Width of solid section surrounding a single sphere.

h = Total thickness of the slab

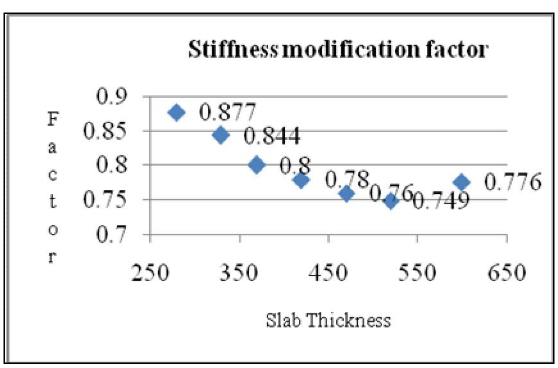
Second moment of inertia of circle can find out with following equation by considering average void area with radius y.

$I_c = \pi y^4/4$ —— (2)

To derive the stiffness reduction factor I_c can be subtracted from I_s and the answer can then be divided by I_s. Here in this study for moment of inertia and weight saving, slab thickness taken from 280mm to 600mm with respective ball diameter from 180mm to 450mm. detail dimensions and value of stiffness reduction factor are shown in table 1. For this study calculation of weight reduction is carried out by the same section that of used for stiffness reduction factor.

Slab thickness (h) mm	Ball Diameter (d) mm	Moment of inertia of solid section I_s	Moment of inertia of voided section I_v	Stiffness reduction factor	% Weight saving
280	180	420746666.7	369308426.7	0.88	20.62
330	225	808582500	683000859.4	0.85	26.77
370	270	1308535833	1048129743	0.8	28.98
420	315	2222640000	1740205569	0.78	30.07
470	360	3460766667	26377554827	0.76	32.48
520	405	5272800000	3954494160	0.75	33.03
600	450	9000000000	69906693750	0.78	31.81

Table 1: stiffness reduction factor and weight saving



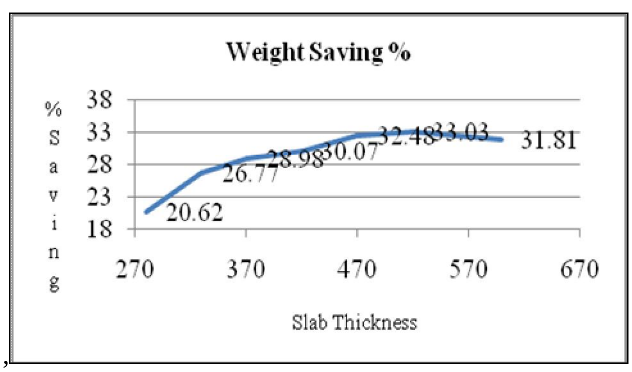


Figure 2: Slab Thickness Vs Stiffness modification factor

Figure 3: Slab Thickness Vs % Weight Saving

3. Bending Strength

The ratio of the moment resisted by the void region to the total moment resisted by the whole cross section (M_{void} / M_u) is denoted by the variable μ_{ms}. When the value of μ_{ms} is less than 0.2, the moment stress are allowed to redistribute within the section of the slab and the voided slab can be designed by using conventional design principles. The ratio μ_{ms} is calculated as follows:

$\mu_{ms} = M_u\ 1.96D/ (f'_c h^3) \leq 0.20$—— (3)

Where;
D = Void diameter
h = overall depth of the slab
M_u = design moment on the slab, which can be derived from structural analysis
In this paper, the design moment is derive by considering span of voided slab 8m x 8m interior panel, while load applied on the voided flat plate slabs are 4 KN/m^2 Live load and 1 KN/m^2 floor finish load and self-weight of the slab also apply. The grade of concrete considers 25 N/mm^2. The analyses are carried out on more number of voided flat plate slabs with dimensions ranges from 6x6m slab to 14x14m slab. The result shows that for all case value of μ_{ms} is less than 0.2 so the voided slab can be design as solid flat plate slab. The results have shown in table -2.

Slab Thickness (mm)	**Ball Diameter (mm)**	**Factored Load (KN/m^2)**	**Design Moment (M_u) (KN.m/m)**	**μ_{ms}**
280	180	15.29	122.31	0.08
330	225	16.53	132.25	0.06
370	270	17.12	136.97	0.06
420	315	18.18	145.44	0.05
470	360	19.27	154.16	0.05
520	405	20.67	165.36	0.04
600	450	22.45	170.6	0.03

Table 2: Test Results of μ_{ms}

4. 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:

$V_{Ed} < V_{Rd,max}$ —— (4)
$V_{Ed} = V_{max} / u_{col}\, d_{om}$ —— (5)
$V_{Rd,max} = 0.5\, V\, f_{cd}$ —— (6)

Where:
u_{col} = perimeter of the column
d_{om} = mean effective depth of the slab

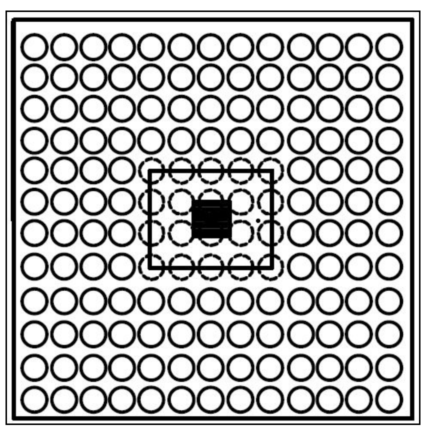


Figure 4: Punching shear

Fig -4 shows that the spherical balls are omitted around the column and make it solid. The spherical balls, which are removed from the voided flat plate slab, are presented by dotted ball in fig 4. The perimeter of the solid portion is calculated for the span ranging from 6m x 6m to 14m x 14m having thickness of the voided flat plate slab 280mm to 600mm with spherical ball diameter 180mm to 450mm. However, in this paper results are shown only for the voided flat plate slab having span 8m x 8m. The perimeter of solid slab is derived by trial and error method until the shear capacity of voided flat slab would be greater than the applied shear. The results of punching shear and distance of solid portion from the face of the column on each side is present in table – 3.

Slab Thickness (mm)	Ball Diameter (mm)	Solid portion each side of column (m)	Shear force of Voided slab (KN)	V_{ed} (N/mm^2)	$V_{rd,max}$ (N/mm^2)
280	180	1.385	861.2	1.18	5.5
330	225	1.562	888.41	1.04	5.5
370	270	1.74	896.54	0.93	5.5
420	315	1.7	975.6	0.89	5.5
470	360	1.74	999.00	0.82	5.5
520	405	1.92	1017.3	0.75	5.5
600	450	1.6	1206.9	0.77	5.5

Table 3: Method of punching strength calculation

5. Conclusion

From the results, it may be conclude that the voided flat plate slabs have lower stiffness than that of solid flat plate slabs. The values of stiffness reduction factor is lies in between 0.8 to 0.9, this means that the reduction of stiffness due to spherical balls are near about 10% to 20%. The stiffness of the voided flat plate slabs is decrease as the thickness of the slab is increase. Once the stiffness reduction factor has been calculated, structural analysis of voided flat plate slabs can be performed same as traditional solid flat plate slabs. By introducing spherical voids into flat plate slabs, the self-weight of the slabs can be reduced up to 32%. Results shows that, the stiffness of the voided flat slabs decrease up to 520mm slab thickness, beyond that stiffness of the voided flat plate slab increased and this would be equal to the stiffness of the voided flat plat slab of thickness 420mm. But, percentage of weight saving is decreasing. In addition, the thickness of the flat slab increase, the percentage saving in weight is also increase. Since the value of μ_{ms} for all cases falls below 0.2, the strength calculation of voided flat slabs can be done same as traditional solid flat plate slabs with the substitution of modified moment of inertia. From the results of punching shear calculation it may be conclude that, the calculated perimeter of solid portion around the column is adequate to take applied shear stress as $V_{ed} < V_{rd,max}$.

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