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Finite Element Analysis of Voided Slab with High Density Polypropylene Void Formers

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Abstract: Slabs being the essential part of the structure has to be effectively designed and utilised. Concrete slabs tend to use more concrete than requirement, hence has to be optimised. The solution is using void formers, in this case spherical shaped. Finite element analysis is performed using ANSYS software on 6 specimens in which 3 are solid and others voided. The slab specimens were of dimensions 1500 × 1500 × 100 mm with symmetric boundary conditions. The void diameter is taken as 70 mm, with a wall thickness of 1 mm and is assumed to be made up of HDPP. The clear spacing between the voids are varied between 30, 50 and 70 mm. The voids with a spacing of 30 mm proves to be more efficient because even though removes 20% of concrete, the deflection shown by the specimen is near to that of solid slabs. The results from finite element analysis is compared with that of plate theory which is used to compute reference values of deflection for corresponding load. The maximum deflection observed for V30 slab was 19.52 mm by numerical methods.
Keywords: Finite element analysis, concrete slab, voided slab, High Density Poly Propylene (HDPP).

Introduction

In any structure, slabs are the primary members used for berthing purpose and also used to transmit the loading to other structural members. As per the studies performed, the concrete in the slab is not fully utilised. The concrete that is placed in tension zone is assumed to carry no load and hence unused. The unused concrete may sum up to 80% of the total volume of concrete. This concrete cannot be fully removed as it reduces the load carrying capacity and also increases deflection etc. So a partial volume of this unused concrete can be replaced by any means possible. Using void formers which merely create voids. The void formers can be of any shape or material. Using recycled plastic in the void formers will reduce the impact on the environment due to them.

Performance of the slabs whether solid or voided can be predicted using analytical or numerical methods. These methods are time consuming but can be performed for any number of time and any boundary condition possible. But any experimental work cannot directly implicate the performance of the slab and it has to be validated either analytically or numerically.

Finite element analysis performed using software like ANSYS, ABAQUS etc. have been found to give results which are in coherence with the results obtained from experimental work [1-15]. The solid or voided slab can be optimised to perform at a higher quality. Voided slabs which are also pre-stressed can be optimised for cost using empirical equations that can be formed using many parameters[1]and such equations proved to be working with great elegance.

Finite element analysis can be performed on any member by applying the corresponding behaviour of the material to obtain the deflection, stresses, strains, cracking pattern etc.[1-15]. Tension stiffening effect and the shear behaviour of the concrete can also be modelled into the package to obtain the resulting behaviour which is nearly impossible in case of experimental work[2-5]. The crack pattern of the analysed slab can also be obtained along with integration points[5]. Layering of the model can lead to simplification of the numerical problem but sometimes the cracking behaviour varies according to the model under observation[5, 6].

Finite elements can be formed according to the problem in hand because different model can produce different successful results[7]. It can be modelled either as a layered element[7] or a shell element[8]of smaller thickness. The concrete properties such as stress vs. strain relationship, young's modulus can be arrived using empirical relations, if the value of the compressive strength is known[1-15].

Voided bubble deck slabs have been analysed with five point loading system tend to behave like a normal solid slab but with a little elevated deflection values and the initial cracks were formed at earlier loads when compared with solid slabs[13]. The crack pattern obtained is also similar to that of a solid slab which forms yield line pattern[13]. The slab itself can be modelled differently depending upon the requirement. The voided slab can also be used in a flat-slab system[14, 15]. The voids can be modelled as in the shape of the void former itself. Although it provides a more accurate answer takes longer solution running time, but modelling in the different formats as either a combination of beams or with cubical voids tends to have shorter running time but cannot produce the required result with required accuracy[15].

In the present work, solid and voided slabs with different reinforcement arrangement and void spacing are analysed using ANSYS program. The slabs are analysed for simply supported condition with area loading and were of dimensions 1500 × 1500 × 100 mm with symmetric conditions provided along x and z axis for simplification of the modelling work. The void is of spherical shape with a diameter of 70 mm and is assumed to be made of High Density PolyPropylene (HDPP). The void spacing was kept as 30, 50 and 70 mm for the analysis purpose and the reinforcement spacing is kept as 100, 120 and 140 mm in all the specimens.

Numerical Work

General

Finite element analysis will provide in-depth knowledge about the behaviour of the member, if performed with proper boundary conditions and material properties. The drawback of performing FEA is it being time – consuming and obtaining material properties for cracking pattern is a tedious process.

Slabs which consumes most of the concrete in any structure, actually requires only a lesser volume of concrete to carry all the loads applied on them. Hence the unused concrete, which is in general at the tension zone, has to be removed in order to optimise the slab in-terms of material consumption. As the material used is reduced, the self-weight of the slab and the whole structure will be reduced up to 35 %. Studies have shown that the reduction in the materials will not reduce the capacity of the slab. The voided slabs performed as a regular solid slab whether used in a regular frame type structure or in flat-slab type structure.

Till date experimental and analysis of any type, have been done only in doubly reinforced sections of slab with thickness starting from 180 mm. The performance of slabs having only reinforcement at the bottom and thickness of 100 mm have not been analysed in anyway. The finite element analysis is done using ANSYS software and the specimens of the slab used were of dimensions 3000 × 3000 × 100 mm. But for simplification purpose, only a quarter of the slab is modelled and symmetric boundary conditions were applied to create conditions of full geometry. The end supporting conditions were provided to mimic simply supporting end conditions. The load applied is of area type and applied as pressure.

Specimen Modelling

Element Type

The specimen has to be modelled for two materials namely concrete and steel. Concrete, by its virtue, is a brittle material and hence undergoes crushing and cracking. The steel on the other hand undergoes a large amount of plastic strain after yielding and before failure. The material limit for steel is considered as its yielding stress.

To bring out the crushing and cracking behaviour of concrete, SOLID65 is used to model the concrete part of the specimen.The void former with a wall thickness of 1 mm is modelled using SOLSH190. For steel, LINK180 is used to model the yielding behaviour of the reinforcement. The diameter of the reinforcement is assumed as 6 mm. The effective cover of all the specimens of the slabs are assumed as 25 mm.

Non-linear analysis is also performed by including the non-linear properties of the materials. The non-linear properties of concrete and steel is incorporated into the program.

Material Properties

For concrete and steel the following material properties have been used as given in table 1.

Table 1: Material Properties

Concrete	Young's modulus = 22222.22 N/mm^2
	Poisons ratio = 0.2
	Open shear coefficient = 0.3
	Closed shear coefficient = 0.9
	Uniaxial cracking stress = 3.13 N/mm^2
	Uniaxial crushing stress = 20 N/mm^2
Steel	Young's modulus = 2e5 N/mm^2
	Poisons ratio = 0.3
	Yield stress = 413.69 N/mm^2
	Rupture modulus = 19.99 N/mm^2
HDPP	Tensile strength = 31.03 N/mm^2
	Density = 0.85 tonnes/mm^3

The non-linear stress-strain relation of concrete is computed using the following formulas which are empirical.

$$f_c = \varepsilon E_c \quad (1)$$
$$f_c = \varepsilon E_c/(1+(\varepsilon/\varepsilon_o)^2) \quad (2)$$
$$\varepsilon_o = 2f_c'/E_c \quad (3)$$

The stress-strain values obtained using the above equations is tabulated in table 2.

Table 2: Stress-strain relation for concrete

Stress in N/mm^2	Strain in mm/mm
0.00027	6.000
0.00060	12.075
0.00100	17.080
0.00140	19.507
0.00180	20.1246

Meshing

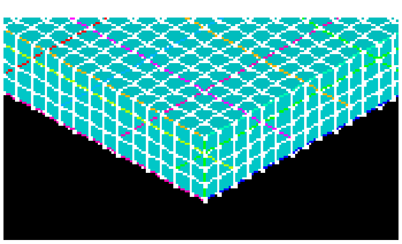

Fig 1. Hexa meshing of solid slab

The solid slab is modelled using a hexa mesh which is a 6-node mesh. The hexa mesh creates more symmetrical elements due to the solid geometry. But the voided slabs can only be modelled using tetra mesh which is a 4-node mesh. The tetra-mesh is used in voided slab due to the irregular geometry of the slab. Solid slab was also meshed in tetra mesh to check for voided slab.

The element size of the mesh was provided as 25 mm. The steel reinforcement or the link members are meshed for similar element size of 25 mm.

Solid slab with hexa-mesh and voided slab with tetra mesh is shown in figures 1 & 2 respectively.

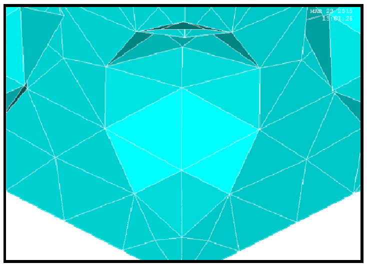

Fig 2. Tetra meshing of voided slab V30.

Loading

The slab is constrained on two adjacent faces at the bottom, against vertical movement. While the other two faces on the whole is provided with symmetric condition to approximate a full section effect. The loading is provided on the top area, as pressure in 45e-3 N/mm^2.

Load is applied in 10 steps and the corresponding values of deflection, for each load step. Figure 3 shows the slab with all the boundary condition.

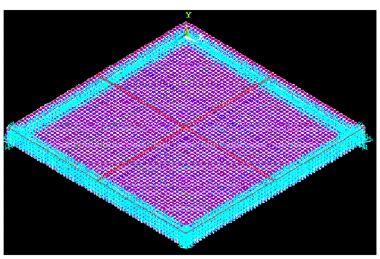

Fig 3. Slab with all boundary conditions

Results and Discussions

General

The finite element analysis is performed to analyse the load-deflection behaviour and the cracking behaviour of both solid and voided slab. The three specimens of solid slab with various reinforcement spacing does not produce a variation in the deflection. The software assumes the solid section to be stiffer and as the reinforcement dia. is small no considerable variation is seen.

Load vs. Deflection Behaviour

The voided slabs behaved similar to that of the solid slab but with a little increase in the deflection values. The reason is the reduction in the stiffness of the member due to removal of concrete. Lesser the concrete removed, similar is the performance of the slab to solid slab. Hence we can find the optimum spacing of the void formers or the amount of concrete removed from load-deflection behaviour of the specimens. The load vs. deflection values for various specimens are tabulated in table 3.

Table 3: Load vs. Deflection by FEA

Loadin $\times 10^{-3}$ N/mm^2	Deflection by Finite Element Analysis in mm			
	SolidSlab	VoidSlab 1	VoidSlab 2	VoidSlab 3
4.5	0.82	0.99	0.86	0.82
9.0	1.64	2.00	1.74	1.65
13.5	2.91	3.57	3.08	2.93
18.0	5.04	5.37	5.34	5.05
22.5	8.22	7.95	7.60	8.21
27.0	10.05	10.43	9.86	10.05
31.5	12.10	12.99	12.12	12.12
36.0	14.0	15.02	14.38	14.05
40.5	15.93	17.38	16.64	16.01
45.0	17.87	19.52	18.90	17.96

The final deflection of specimens are given in Fig.4-7.

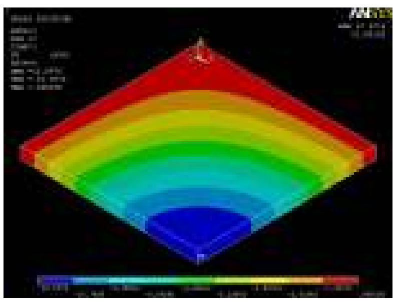

Fig 4. Deflection of solid slab

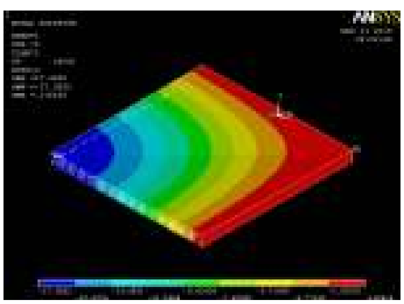

Fig 5. Deflection of voided slab V30

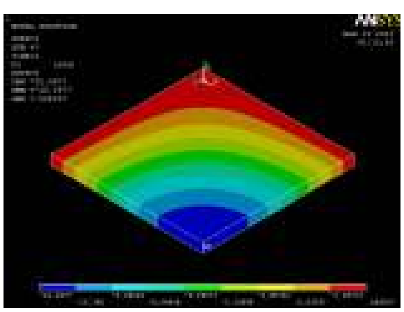

Fig 6. Deflection of voided slab V50

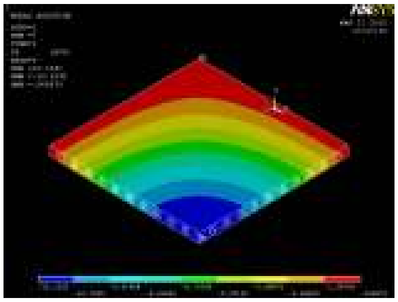

Fig 7. Deflection of voided slab V70

Crack Pattern

The solid slab specimen have shown crushing and cracks were concentrated at the centre of the slab. The crack patterns of all the specimens are shown in fig 8-11.

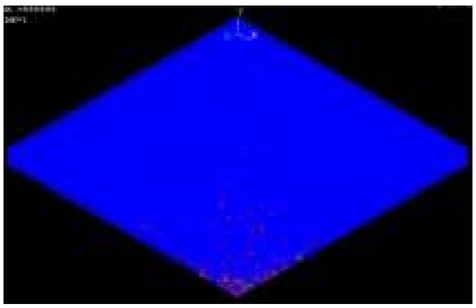

Fig 8. Crack pattern of solid slab

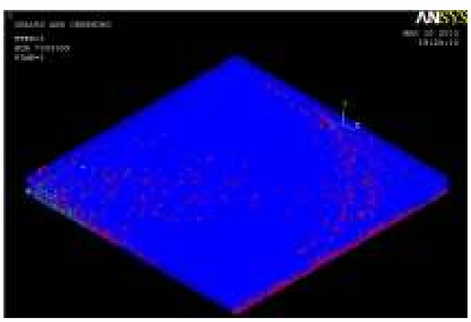

Fig 9. Crack pattern of voided slab V30

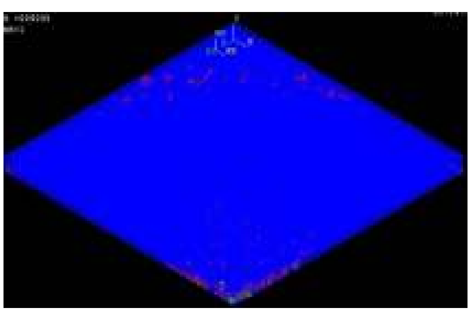

Fig 10. Crack pattern of voided slab V50

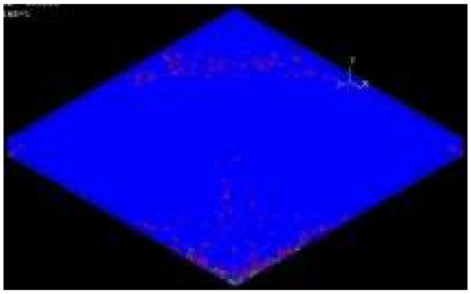

Fig 11. Crack pattern of voided slab V70

The voided slab V30 have undergone more cracks, even near the supports. Voided slabs V50 and V70 have shown similar crack patterns like that of the solid slab.The deflection values of all specimens are compared and charted as given in fig 12. The deflection values of solid slab specimen and voided slab V70 overlapped.

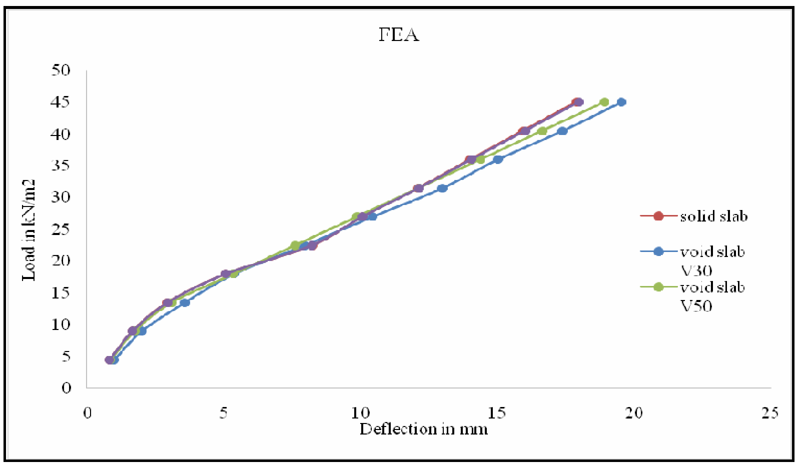

Fig 12. Load vs. deflection for all specimens

Conclusion

The above finite element study was performed on the voided slab of thickness 100 mm and varied spacing of void formers. The results have concluded that voided slabs performed similar to that of solid slab, either by plate theory or finite element analysis.

The voided slab can be provided with reinforcement only at the tension face of the slab if the slab is simply supported. The reason is the slab is not subjected to higher shear forces at a point as the load is uniformly distributed. The finding is that, voids should not be provided at the corners of the slabs to carry the shear force.

The voided slab V30 even though removed nearly 20% of the concrete undergoes similar deflection and crack pattern but with a little increase in the values. As the spacing of the slab is increased they tend to behave exactly like solid slab. The cracks tend to decrease with lowest being with solid slab and increase accordingly for V70, V50 & V30 resp.

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