

Analytical study on Flexural behaviour of RCC slabs with concealed beams using ANSYS

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Abstract - When the beam depth is equal to the thickness of slab that beam is known as concealed beam. Concealed beams are favoured structural elements because of their many inherent features that characterize them; they save on floor height clearance, formwork material cost and shuttering time. Moreover, they form an acceptable aesthetic appearance. The present study deals with the finite element modelling of RC slabs with concealed beam & with drop beams using ANSYS, which is based on Finite Element (FE) method. The flexural behaviour of slabs with the influence of concealed beams is investigated. The results of the slabs from the analytical solution are compared with the available experimental results. Comparison between load deflection curve, Crack pattern & load carrying capacity were carried.

Key Words: Concealed beam, drop beam, Load-deflection, Load carrying capacity, crack pattern, Finite Element, ANSYS.

1. INTRODUCTION

Slabs are constructed to provide flat surfaces, usually horizontal, in building floors, roofs, bridges, and other types of structures. In many situations, the architect may want to have a flat soffit of slab, without beams projecting out of the slab. In such situations, the structural engineer has to resort to concealed beams. Modern buildings have many structural constraints. The web of a T beam or inverted T beam may pose problems. In such situations, Concealed beams may be provided. This performs the function of a conventional beam to a great extent. Concealed beams in particular are required in drop free slabs. The beams of same depth as slab are placed as usual with exception of formwork of side or bottom. Nowadays, for nonlinear analysis of RC members, finite element (FE) analysis has become an important analytical tool. The FE method allows complex analysis of nonlinear response of RC structures to be carried out in understanding its behaviour under different loading conditions.

The present study deals with the finite element modelling of RC slabs with concealed beam & with drop beams using ANSYS. The validation of FE analysis has been verified using the experimental results. The aim of the study is to understand the structural performance of the slabs built in with concealed beams and drop beams.

2. RESEARCH SIGNIFICANCE

Execute a 3D Finite Element Model in order to investigate the influence of concealed beam in slabs replacing the conventional structural system of drop beam. Analysis of simply supported slabs with two grades of concrete M25 & M30 to study the importance of grade of concrete on flexural behaviour of slabs. Lastly to check the validity and accuracy of the finite element analysis used in this study to predict the flexural behaviour of the slabs.

3. METHODOLOGY FOR FINITE ELEMENT MODELLING AND ANALYSIS USING ANSYS

The experimental method of analyzing the RC slabs provides the actual behaviour of the structure. But it is time consuming and expensive. Hence Finite element analysis is used to analyze these structural components. Finite Element Analysis (FEA) is a method used for the evaluation of structures, providing an accurate prediction of the component's response subjected to various loads. The use of FEA has been the preferred method to study the behaviour of structural component as it is much faster than the experimental method and is cost effective. The finite element method is an approximate technique. The number of elements used in a model can greatly affect the accuracy of the solution.

The details & results of experimental work conducted by Sharanbasappa kembhavi (2016) [6] has been utilised in the present study. The experimental work was conducted on 12 specimens, 3 specimens each with different beam and concrete grade configuration. The average result of the three specimens was recorded. The same data has been used in the present analytical study as reference.

Table-1 Details of specimens

Specimen designation	Type of slab (with)	Dimensions (mm)		Grade of concrete	Grade of Steel
		Slab	Beam		
Type-A	concealed beam	1000x1800x75	200x75	M25	Fe 500
Type-B	concealed beam	1000x1800x75	200x75	M30	Fe 500
Type-C	drop beam	1000x1800x75	200x150	M25	Fe 500
Type-D	drop beam	1000x1800x75	200x150	M30	Fe 500

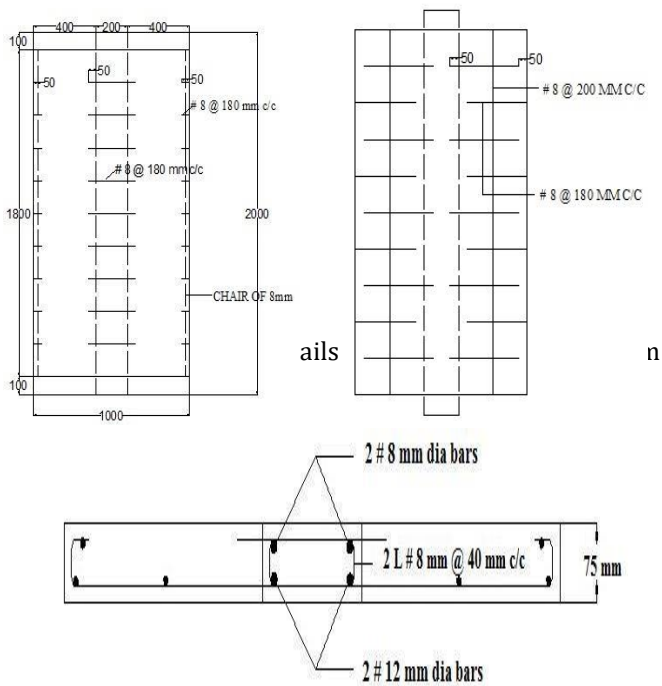


Fig-2: C/S Reinforcement details of type A & B slabs

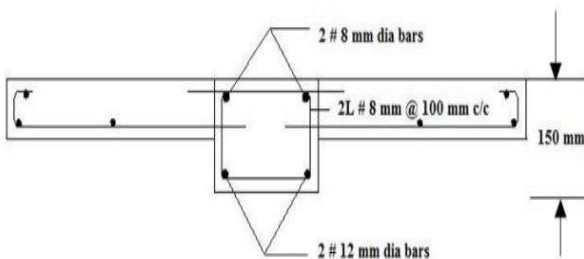


Fig-3: C/S Reinforcement details of type C & D slabs

A) Structural Material modelling

The following elements have been adopted for material idealization,

a) Concrete idealization:

The SOLID65 element is used for studying response of reinforced concrete. The Shape of the element is hexahedral. It has 3 translational degrees of freedom in x, y, z directions. The behaviour of the concrete material is based on a constitutive model for the triaxial behaviour of concrete. SOLID65 is capable of plastic deformation, cracking in three orthogonal directions at each integration point. The cracking is modelled through the material properties by changing the element stiffness matrices. If the concrete at an integration point fails in uniaxial, biaxial, or triaxial compression, the concrete is assumed crushed at that specific point.

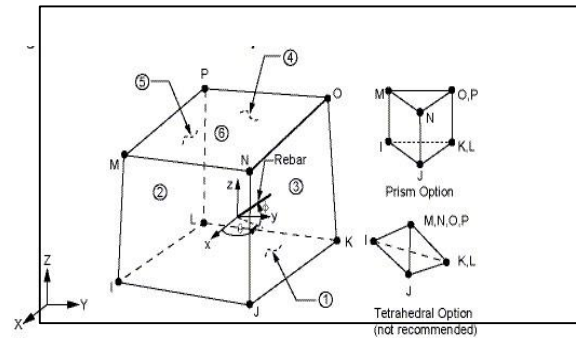


Fig-4: Geometry of SOLID65 element

Modelling an element for the behaviour of concrete is a challenging task. Typical shear transfer coefficient range from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). The uniaxial crushing stress in the models was inputted as -1 to turn off the crushing capability of the concrete element. The modulus of elasticity of concrete & uniaxial tensile cracking stress is obtained using IS 456:2000. The multi linear isotropic properties of concrete (stress strain behaviour), are inputted. Poisson's ratio is assumed to be 0.2. The shear transfer coefficient for open crack and closed crack are 0.3 and 0.9 respectively.

b) Steel reinforcement idealization:

LINK180 element has been adopted to model the steel reinforcement. It is a spar used in a variety of engineering applications. This element is, etc. The 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. Plasticity, creep, swelling, stress stiffening and large deflection capabilities are included. The element is not capable of carrying bending loads. The stress is assumed to be uniform over the entire element. Steel reinforcement in RC beam is Fe500. Elastic modulus of $2.1 \times 10^5 \text{ N/mm}^2$ and Poisson's ratio of 0.3 has been assumed for all the reinforcing bars. Tangent modulus of 20 N/mm^2 is used for reinforcement to avoid loss of stability upon yielding.

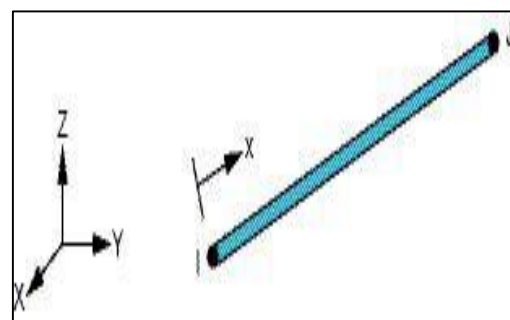


Fig-5: Geometry of LINK180 element

Table-2 Material properties of concrete

Material Model		Material Properties		
CONCRETE M25 Material ID 25 Element Type SOLID65	Linear Isotropic			
	Young's modulus(MPa)	24834.83		
	Poisson's ratio			0.2
	Multi-linear Isotropic			
		Strain	Stress (MPa)	
	Point 1	0.000333	8.27	
	Point 2	0.0004	9.62	
	Point 3	0.0008	17.58	
	Point 4	0.0012	23.06	
	Point 5	0.0016	26.15	
	Point 6	0.002	27.42	
	Point 7	0.00222	27.56	
	Point 8	0.003	27.56	
	Open shear transfer coeff	0.3		
	Closed shear transfer coef	.9		
Uniaxial cracking stress(MPa)	3.26			
Uniaxial crushing stress	-1			
CONCRETE 30 Material ID 30 Element Type SOLID65	Linear Isotropic			
	Young's modulus(MPa)	24000		
	Poisson's ratio			0.2
	Multi-linear Isotropic			
		Strain	Stress (MPa)	
	Point 1	0.00032	9	
	Point 2	0.0006	15.28	
	Point 3	0.0009	21.08	
	Point 4	0.0012	25.27	
	Point 5	0.0015	27.96	
	Point 6	0.0018	29.42	
	Point 7	0.0021	29.96	
	Point 8	0.00219	30	
	Open shear transfer coeff	0.3		
	Closed shear transfer coef	.9		
Uniaxial cracking stress(MPa)	3.30			

provides an accurate and true representation of the field reality. Hence, the discrete modelling is adopted in the present study & results of the same have been reported.

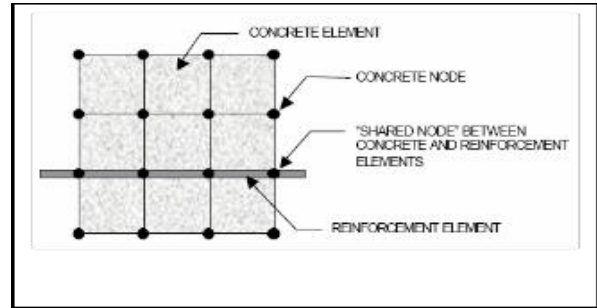


Fig-7: Discrete Reinforcement modelling for reinforced concrete

B) Model convergence study (patch test):

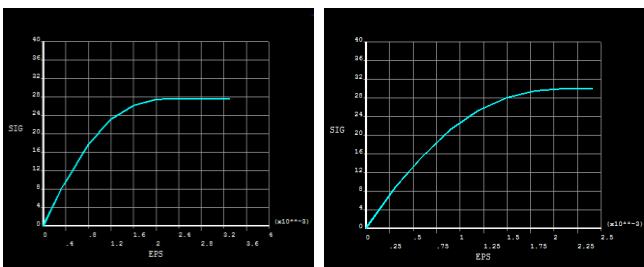
A complete model of RCC slab with concealed beam & drop beam is considered for the study with steel reinforcement to determine the appropriate mesh density.

A static linear Elastic Analysis on two different slab models with increasing number of elements as shown in Table 3 is carried out for the convergence study.

Table-3 Number of elements considered for convergence study

Case	Number of Elements	
	Slabs with concealed beam	Slabs with drop beam
(a)	5617	12360
(b)	9196	19280
(c)	12078	23630
(d)	19220	28808
(e)	22829	26390
(f)	27784	-

The discretized models are shown in figure 8 (a) to (f) and figure 10 (a) to (e) for slabs with concealed beam and drop beam respectively. Figure 9 & figure 11 shows the convergence plot for slab with concealed beam & drop beam respectively and it is observed that the deflection remains nearly constant from case (d) to (f) elements and from case (c) to (e) for slabs with concealed beam and drop beam respectively. The deflection is constant irrespective of the increase in the number of elements. The observed deflection is 1.0652 mm & 0.761mm in slabs with concealed beam and drop beam respectively. So the finite element model consisting 22829 & 26390 numbers of elements is adopted for slabs with concealed beam & drop beam respectively. Element aspect ratio which is defined as the ratio between the largest and smallest dimensions of two or three-dimensional element, is maintained between 1 & 2 for all the elements.



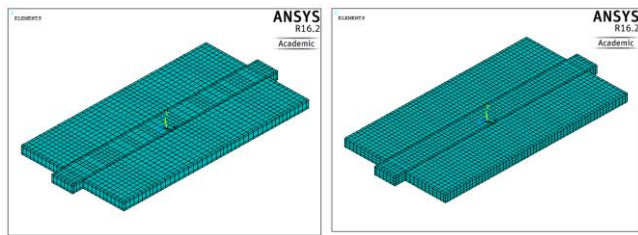
a) M25 b) M30

Fig-6: Stress strain curves for concrete plotted in ANSYS

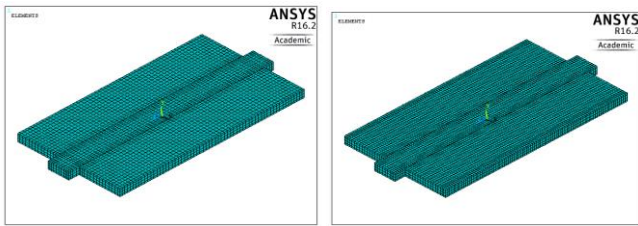
c) Idealization of reinforcement in concrete:

The steel reinforcement is incorporated in concrete using either discrete model, embedded model or smeared model depending on the geometry of the system. In the work presented in this paper, discrete modelling technique is used for modelling the reinforcement. In the *discrete model* as shown in Figure 7, spar or beam elements with geometrical properties similar to the original reinforcing elements are connected to concrete mesh nodes and hence the concrete and the reinforcement mesh share the same nodes and concrete occupies the same regions occupied by the reinforcement.

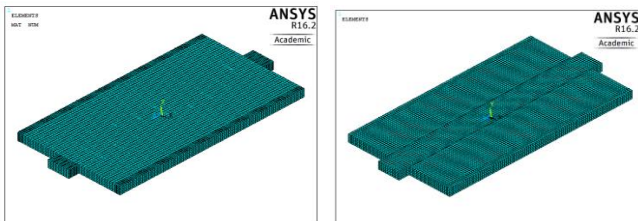
For the modelling of RC slabs with well-defined geometry and reinforcement details, the discrete modelling approach



a) 5617 Elements b) 9196 Elements



c) 12078 Elements d) 19220 Elements



e) 22829 Elements f) 27784 Elements

Fig-8: (a) to (f) slabs with concealed beam models with varying mesh density.

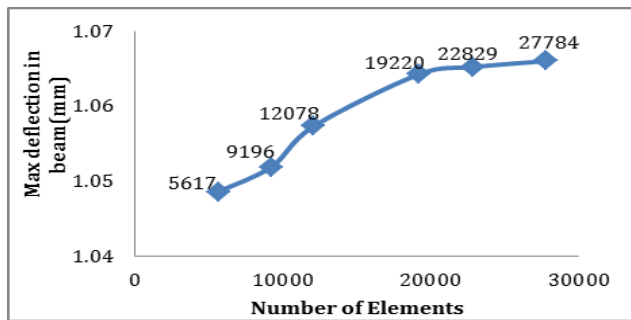
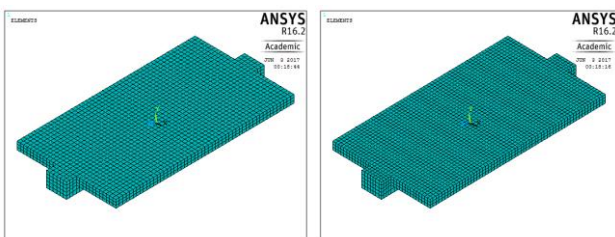
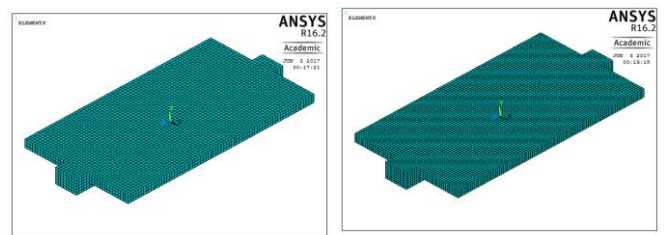


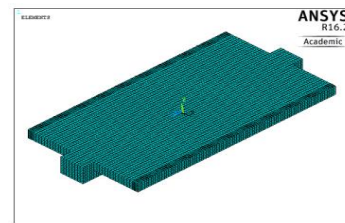
Fig-9: Results of the Convergence study with respect to deflection in slabs with concealed beam



a) 12360 Elements b) 19280 Elements



c) 23630 Elements d) 28808 Elements



e) 26390 Elements

Fig-10: (a) to (e) slabs with drop beam models with varying mesh density.

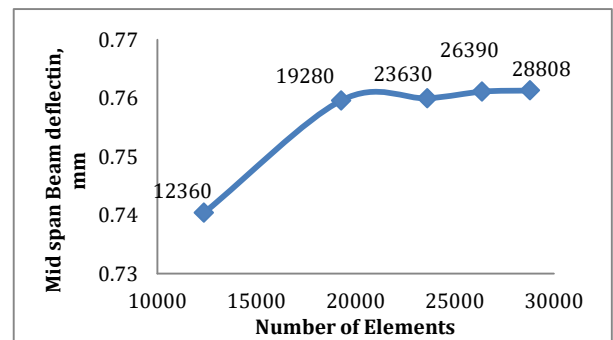
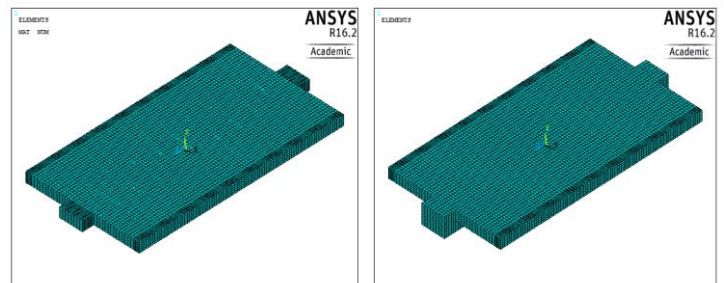


Fig-11: Results of the Convergence study with respect to deflection in slabs with drop beam

The FE models for concrete and reinforcement for both types of slab are shown below,



a) b)

Fig-12: FE concrete model for slabs with a) Concealed beam, b) drop beam

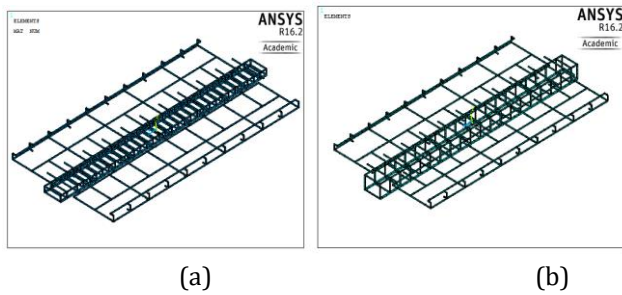


Fig-13: FE reinforcement model for slabs with a) Concealed beam, b) drop beam

Loading: To simulate the model behaviour in same way as experimental, boundary conditions have been applied at points where the supports and loadings exist. The boundary conditions that have applied experimentally are shown in Figure 14. The same has been simulated in ANSYS with displacement restrained in the UY, and UZ directions for nodes in the area 50mm x 1800mm at the continuous slab support (As the supporting steel plate in the experimental setup is 50 mm wide and along full length of 1800mm of slab) and for nodes in the area 200mm x 100mm at the projected portion of the beam (As a steel plate provided at 200x100mm portion of beam extension). By doing this, the specimen will be allowed to rotate at the support. In the experiment slab load of 2 kN/m² is applied using sand bags & UDL applied on beam portion using hydraulic jack with incremental loading. The same has been simulated in ANSYS with a live load of 2 kN/m² applied in the form of pressure load on the areas of slab portion. In order to simulate the wall load on the beam portion of the specimen, the UDL that was applied in experimental work is converted into an area load. That area load is applied as pressure load on the beam portion only. The boundary conditions simulated in ANSYS are shown in Figure 15 & 16.

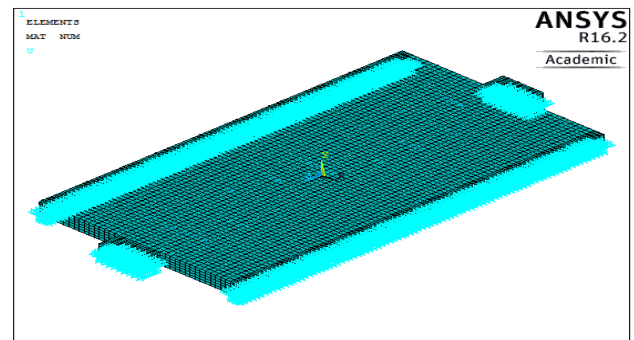


Fig-15: FE model with applied displacement constraints

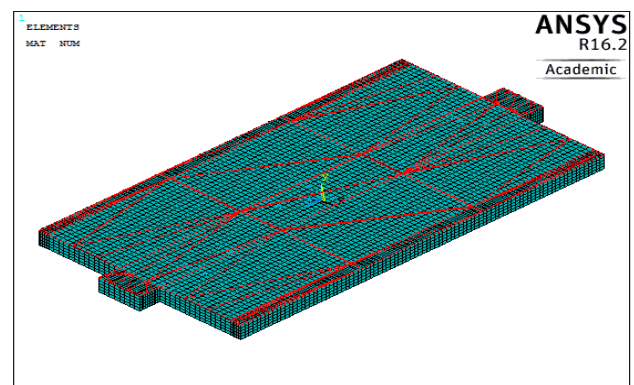


Fig-16: FE model with applied pressure load

The dial gauge positions for measuring deflection in slab & beam are shown in Fig 17

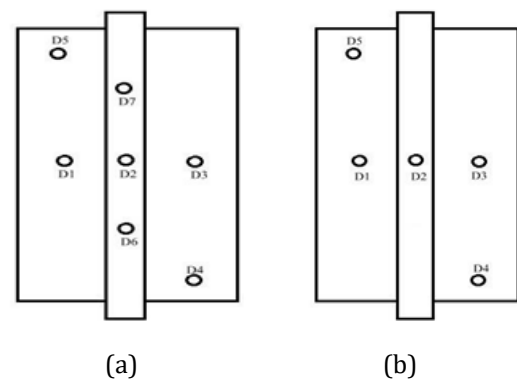


Fig-17: Dial gauge positions for slabs with a) concealed beam, b) drop beam

A static nonlinear analysis is considered for the study under transverse incremental loading to study the flexural behaviour (Load deflection behaviour, load carrying capacity and crack patterns) of slabs, by simulating the experimental work analytically. ANSYS employs "Newton-Raphson" method to solve nonlinear problems, which is a method that involves iterative process to solve a nonlinear or complex problem.

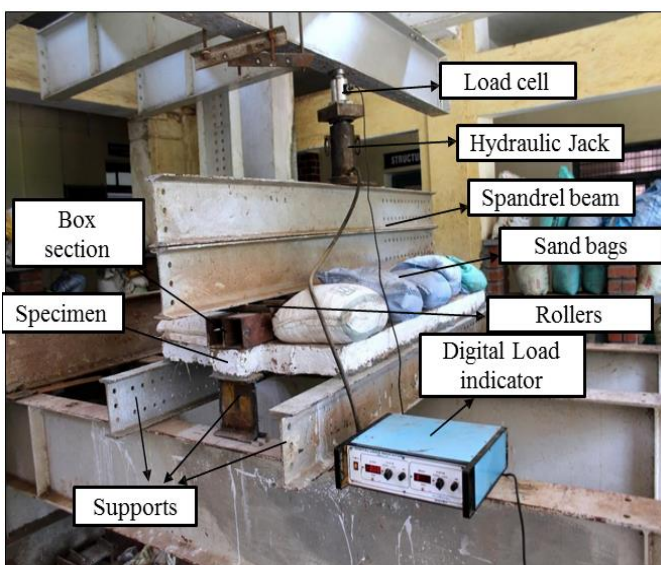


Fig-14: Experimental setup

4. RESULTS & DISCUSSIONS

The analytical results are obtained for Slabs with concealed beam & drop beam for both M25 & M30 grades of concrete. The deflection corresponding to the incremental load is obtained at the center of slab & at the center of beam. Load at initial crack, Ultimate load & the crack patterns are obtained, they are discussed as follows:

A) Comparison of Load- deflection behaviour between FE analysis & Experimental Results. The experimental values on deflection of specimens are compared with the analytical values of deflection under same loading condition within the elastic limit.

Table 4 comparison of deflection values for Type A specimen

Specimen ID		Type A			
Sl No.	Total Load (kN/m ²)	Deflection at mid span(mm)			
		Analytical		Experimental	
		Slab	Beam	Slab	Beam
1	27.625	0	0	0	0
2	52.625	0.287	0.431	0.265	0.243
3	77.625	0.453	0.682	0.38	0.537
4	102.625	0.722	1.093	0.615	0.817
5	127.625	0.885	1.322	0.865	1.183
6	152.625	0.971	1.753	1.147	1.623

Table 5 comparison of deflection values for Type B specimen

Specimen ID		Type B			
Sl No.	Total Load (kN/m ²)	Deflection at mid span(mm)			
		Analytical		Experimental	
		Slab	Beam	Slab	Beam
1	27.625	0	0	0	0
2	52.625	0.11	0.185	0.047	0.083
3	77.625	0.182	0.342	0.13	0.25
4	102.625	0.264	0.422	0.217	0.407
5	127.625	0.311	0.596	0.302	0.537
6	152.625	0.356	0.732	0.387	0.67

Table 6 comparison of deflection values for Type C specimen

Specimen ID		Type C			
Sl N o.	Total Load (kN/m ²)	Deflection at mid span(mm)			
		Analytical		Experimental	
		Slab	Beam	Slab	Beam
1	27.625	0	0	0	0
2	52.625	0.05	0.121	0.2	0.11
3	77.625	0.109	0.197	0.35	0.44
4	102.625	0.219	0.395	0.49	0.79
5	127.625	0.385	0.693	0.68	1.1
6	152.625	0.633	1.14	0.985	1.48

7	177.625	1.007	1.813	1.125	1.9
8	202.625	1.104	1.988	1.615	2.42

Table 7 comparison of deflection values for type D specimen

Specimen ID		Type D			
Sl No.	Total Load (kN/m ²)	Deflection at mid span(mm)			
		Analytical		Experimental	
		Slab	Beam	Slab	Beam
1	27.625	0	0	0	0
2	52.625	0.023	0.048	0.07	0.01
3	77.625	0.047	0.085	0.115	0.04
4	102.625	0.095	0.171	0.195	0.13
5	127.625	0.166	0.3	0.285	0.36
6	152.625	0.273	0.493	0.35	0.56
7	177.625	0.434	0.782	0.455	0.75
8	202.625	0.476	0.857	0.6	1.02

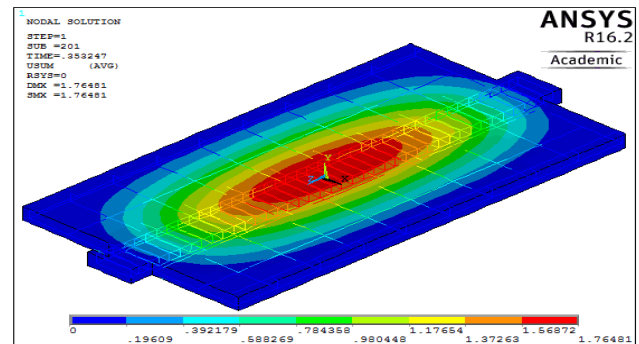


Fig-18: Deflection pattern in the slab

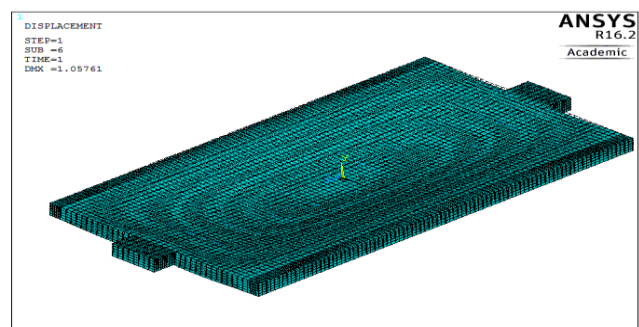


Fig-19: Deflected shape of slab

B) Load at first crack & Ultimate Load:

In FE analysis the load at first crack is obtained by reading the load step at which the first crack patterns are seen. The final load in the FE model is the last applied load step before the solution diverges due to numerous cracks and large deflections. The cracking load of all the specimens obtained from FE analysis are shown in Table 7

Table 7 Comparison of Analytical loads with experimental Loads

Sl No.	Specimen ID	EXPERIMENTAL		ANALYTICAL	
		First crack load (kN/m)	Ultimate load (kN/m)	First crack load (kN/m)	Ultimate load (kN/m)
1	Type A	29.167	80.525	32.54	83.409
2	Type B	34.692	88.025	35.17	94.976
3	Type C	40.525	110.525	41.32	113.685
4	Type D	48.025	120.525	50.21	124.259

C) Crack pattern:

In FE analysis concrete crack patterns were created at different load steps to examine the different types of cracking that occurred within the concrete. The ANSYS program records a crack pattern at each applied load step. Figure 20 and 21 shows the crack patterns observed in the analytical model of the Specimens. It is observed that, the crack patterns obtained from the analytical study are similar to that of crack patterns observed during experimental study. The cracks appear at the junction between the slab and the beam, further it propagates all along the length of the beam.

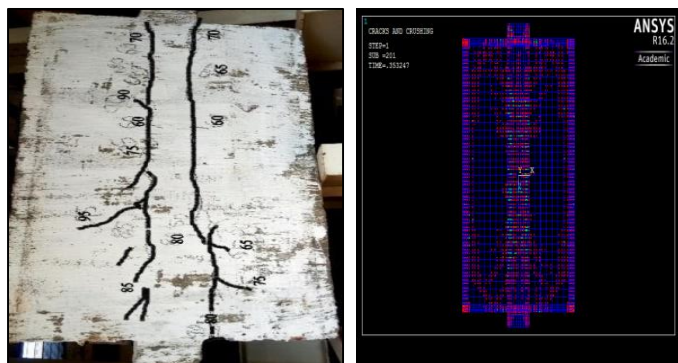


Fig-20: Comparison of crack pattern in slab with concealed beam



Fig-21: Comparison of crack pattern in slab with drop beam

5. CONCLUSIONS

The conclusions drawn from the analytical investigation are listed below,

1. The behaviour of RC slabs represented by load deflection curves in ANSYS show close agreement with experimental results, within the linear part before first cracking.
2. The deflection of slabs with concealed beam is more compared to that of drop beams. This is due to the reduction in cross section area & thus reducing the stiffness.
3. As the grade of concrete increases the deflection in the slab reduces, hence grade of concrete plays important role in reducing the deflection.
4. Analytically, the load carrying capacity of slab with drop beam increases by 26.63% as compared to that of slab with concealed beam & experimentally it was increased by 27.2%. The FE analysis results were in good agreement.
5. The ultimate loads from the FE analysis are slightly greater than the ultimate loads from the experimental results, due to the presence of initial micro cracks in the experimental models, instability issues of load mechanism adopted in the experimental setup
6. The experimental deflection is 21.2% more than that of analytical deflection in slab with concealed beam, due to the increased stiffness of the FE model.
7. The experimental deflection is 17.8% more than that of analytical deflection in slab with drop beam.
8. Analytically, the maximum deflection of slab with drop beam has decreased by 32% as compared to the slab with concealed beam. This is due to the increased stiffness & increased moment of inertia of slab with drop beam.

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