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Analysis and Design of R.C. Deep Beam by Finite Element Method

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Abstract: *R.C simply supported Deep beam subjected to two point loading, with varying l/D ratio is designed by using IS-456(2000) and ACI-318-08 (Strut and tie method). In order to investigate stress distribution along the depth of deep beam at mid section, Hypermesh11 (for pre-processing) and Radioss (for solving) is used. Quantity of main steel obtained by IS-456(2000) and by Strut and tie method is compared with the results obtained from finite element method.*

Keywords: *Finite element method, R.C. Deep beam, Hypermesh11-Radioss, Strut and tie method.*

1. Introduction

The followings are the major differences of deep beam and beam with normal proportion based on the design assumption, as follows:

1) Two-Dimensional action i.e. deep beam is act as a plate subjected to heavy loads in its own plane.
2) Plane Section Do Not Remain Plane, this assumption of plane section remain plane, cannot be used in the design of deep beam. Thus strain distribution is no longer linear.
3) The shear deformation cannot be neglected as in the ordinary beam. The stress distribution is not linear even in the elastic stage. At the ultimate limit state, the shape of concrete compressive stress block is not parabolic shape.

As per IS-456(2000) beam is deemed to be Deep beam when ratio of effective span to depth ratio is less than 2 for simply supported and 2.5 for continuous beam.

Strut and tie model method is introduced in ACI-318-08. This method is useful for the design of D-region, which occurs due to geometrical or loading discontinuity. For D-region (disturbed region) flexural theory does not hold true, and on the contrary for B-region (Bernoulli region) strain distribution is linear and flexural theory hold true. This method is based on load path. Finding the dimensions of strut means designing (taking checks) for dimensions (width and depth) of deep beam, and finding force in tie is to design main reinforcement required.

2. Design of Deep Beam

Problem Statement –

Simply Supported R.C Deep beam of clear span 700 mm subjected to two point loading of magnitude 160kN each at a shear span of 250 mm. Concrete grade M25 and steel grade Fe-415. Size of steel plate at loading and support is 100 X 230 mm2. Deep beams are designed varying depth, such as 400, 450 and 500 mm. So that having effective span to depth ratio as 2, 1.77 and 1.6.

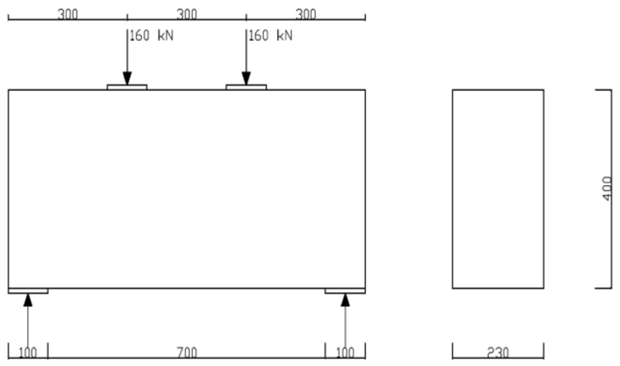


Figure 1. *Elevation and section of Deep beam.*

2.1 The Modelling of Deep Beam

2.1.1 Element Type

For doing finite element analysis of deep beam, firstly the study of different types of elements is necessary. For modeling of deep beam by using software Hypermesh11-Radioss, 2D-shell element and 3D-solid hexahedral element is used.

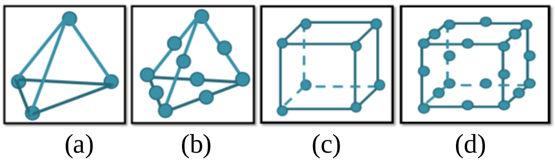


Figure 2. *Types of elements. a) First order tetrahedral element, b) Second order tetrahedral element, c) First order hexahedral element, d) Second order hexahedral element.*

Amongst these elements, results obtained by using second order tetrahedral element and first order hexahedral element are nearly same. Hence for modelling of deep beam any one of these two elements can be used. Degree of freedom per node is 3, i.e. translation in 3 directions. Second order tetrahedral element has 10 nodes, and that of first order hexahedral element has 8 nodes.

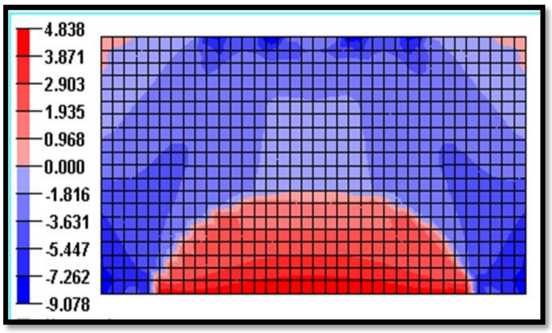
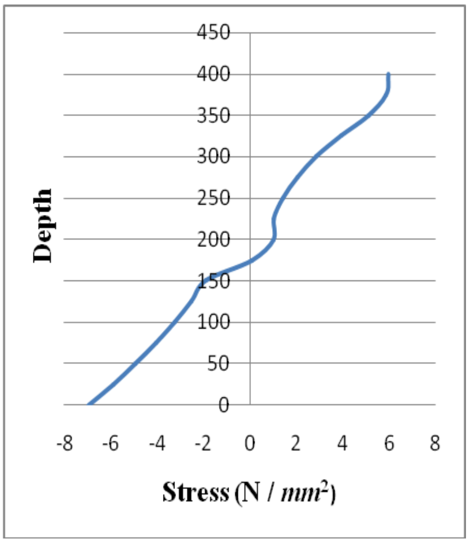


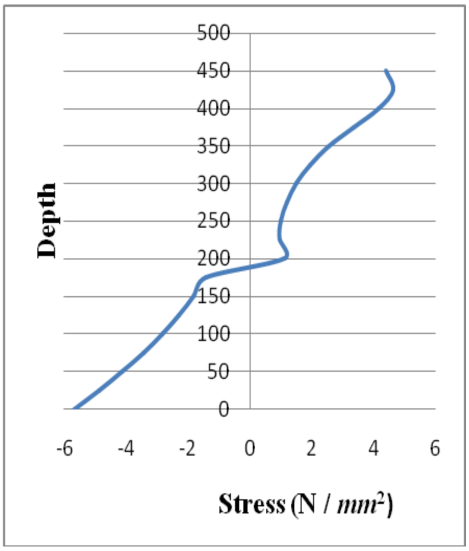
Figure 3. *Deep beam model (Stress contour)*

2.1.2 Flexural Stress Variation

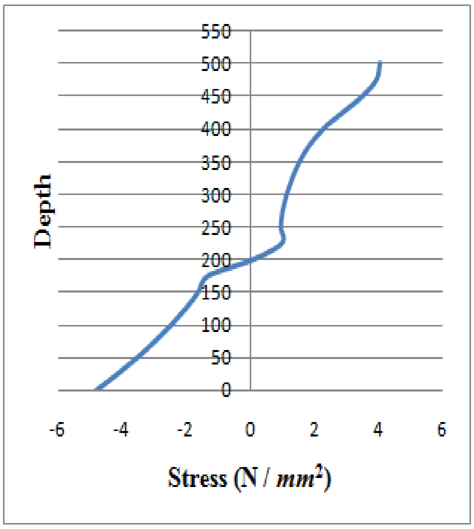
After modelling of deep beam and obtaining stress contour (Fig.2), flexural stress variation along depth, at the mid-section of deep beam is obtained. As discussed earlier, stress distribution of deep beam is not linear. From fig.3 it is clear that as the depth of beam increases neutral axis shifts towards bottom of the beam. The bottom portion of graph is in tension, thus the flexural tensile force is concentrated in lower 1/3rd depth. Hence tension zone defined by IS-456(2000) and that of Strut and tie model method is matching with tension zone marked by finite element method.



(*a*) *L* / D = 2



(a) *L* / D = 1.77



(a) *L* / D = 1.6

Figure 4. *Flexural stress variation.*

2.1.3 Calculation of Main Steel from Graph

Table 1. *Main reinforcement required as per FEM.*

Depth from bottom to neutral axis. (Tension zone) (*mm*)	Reinforcement required (mm^2)		
	L / D ratio		
	2	1.77	1.6
0	110.7902	90.6451	76.6948
25	94.03713	77.74585	66.23208
50	78.70135	65.84988	56.51783
75	64.68735	54.98903	47.56798
100	51.94735	45.17923	39.50993
125	40.43358	36.4364	32.37553
150	30.20973	28.82425	26.26033
175	-	22.4861	21.2758
Total	470.807	422.156	366.434

2.1.4 Comparison of main steel

Table 2. *Results of main reinforcement required.*

	L / D ratio		
	2	1.77	1.6
IS-456(2000)	522	491	464
Strut and Tie (ACI-318-08)	626	530	459
Finite element method	470.807	422.156	366.434

3. CONCLUSION

1. From flexural stress variation graph it is clear that as the *L / D* ratio increases neutral axis shifts towards bottom of the beam.
2. The flexural steel required by finite element method is 15% and 25-30% lesser than quantity of steel obtained by IS-456(2000) and Strut and tie method (ACI-318-08) respectively.
3. Flexural stress variation is non linear. Hence Flexural theory is not applicable to deep beam
4. As depth increases difference between steel required by FEM and IS-456-(2000) increases and on the contrary difference between FEM and Strut-tie method decreases.
5. Deep beams are useful where self weight is negligible compared to heavy load applied.
6. No separate check for shear is mentioned in IS-456(2000).
7. In Strut-tie method flexural reinforcement is provided along tie, which is provided throughout the length without curtailment, this codal provision is also made in IS-456(2000)
8. Tensile force as per FEM is at lower 1 / 3rd depth of beam. So the main steel is provided within this zone, and which is matching with the codal provision.

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