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Analysis of R.C Deep Beam by Finite Element Method

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ABSTRACT : *The analytical study of reinforced concrete simply supported deep beams subjected to two point loads was carried out using finite element method to study the behavior of deep beam by considering flexural stress, flexural strain, and shear stress variations at different sections for various effective lengths to depth ratio and compared with Euler-Bernoulli Theory. The effective span to depth ratios of the beams considered were 1.25, 1.375 and 1.5*

Keywords: *Finite Element Method (FEM), Reinforced Concrete (R.C) deep beam, Shear strength.*

I. INTRODUCTION

The use of Reinforced deep beam has become more prevalent in recent years. In IS-456 (2000) clause 29, a simply supported beam is classified as deep when the ratio of its effective span L to overall depth D is less than 2. Continuous beam are consider as deep when the ratio L/D is less than 2.5.The effective span is defined as the center to center distance between the supports or 1.15 times the clear span whichever is less.

Deep beam often appear in form of transfer girders in high-rise building as well as pile caps, foundation walls, water tanks, bins, folded plate roof structures, floor diaphragms, shear walls & brackets or corbels. They are characterized as being relatively short & deep, having thickness that is small relative to their span or depth and being primarily loaded in the plane of the member. They are "two dimensional" members in a state of plane stress in which shear is dominant feature. The internal stresses cannot be determined by ordinary beam theory & ordinary design procedures for determining strength do not apply.

The behavior of deep beams is significantly different from that of beams of more normal proportions, requiring special consideration in analysis, design and detailing of reinforcement. A deep beam is in fact a vertical plate subjected to loading in its own plane. The strain or stress distribution across the depth is no longer a straight line, and the variation is mainly dependent on the aspect ratio of the beam.

Stresses in deep beams can be studied using the methods of two dimensional elasticity or Finite Element analysis. Plane sections before bending remaining plane after bending does not hold good for deep beams. Significantly warping of the cross-sections occurs because of high shear stresses consequently flexural stresses are not linearly distributed, even in the elastic range, and the usual methods for calculating section properties and stresses cannot be applied. Shear strength of deep beams may be as much as 2 to 3 times greater than that predicated using conventional equations developed for members of normal proportions.

The stresses in isotropic homogeneous deep beams before cracking can be determined using finite element analysis or photo elastic model studies. It is found that the smaller the span/depth ratio (i.e., less than 2.5), the more pronounced the deviation of the stress pattern from that of Bernoulli and Navier.

II. OBJECTIVES OF STUDIE

a) To analyze the deep beam by using Finite Element Method. The finite element model consists of subdividing the Deep beam into small 2D rectangular elements. Each element has four nodded plane stress Element to study the behavior of deep beam through flexural stresses, flexural strains, and shear stresses variation with various L/D Ratio.
b) To compare the flexural steel requirement as per codal provisions with that calculated using the finite element method.

III. ANALYTICAL STUDY OF DEEP BEAMS

A deep beam having following data is analyzed for various L/D ratios. Beam is simply supported subjected to two points loading as shown in Figure 1.
Depth = 400 mm and Width of beam = 150 mm (constant for all cases);
L/D ratios is varied from 1.25, 1.375, 1.5 i.e. (Span = 500, 550, 600) mm

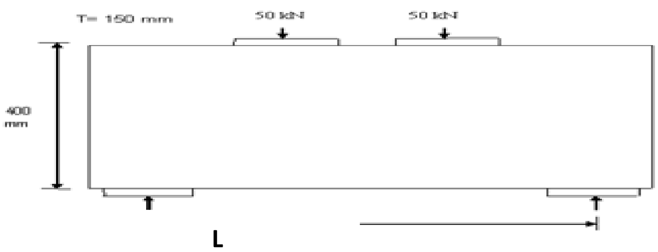

Fig. 1 Deep beam with two point loads

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Deep beam is an example of plane stress conditions. It is assumed that no stress component varies across the thickness. The state of stress is then specified by σ_x, σ_y and τ_{xy} only.

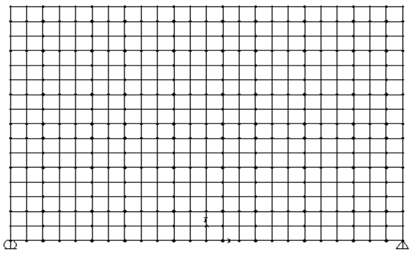

Fig.2a-Deep beam subdivided into rectangular element

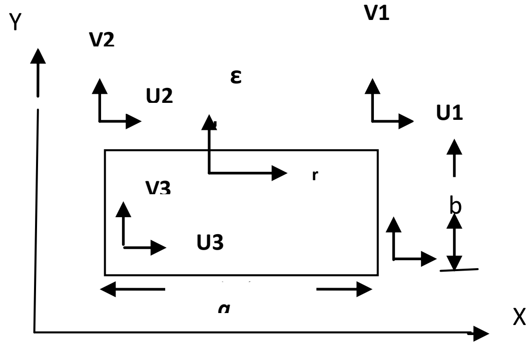

Fig.2b-Typical rectangular finite Element

Fig 2a shows Deep Beam which has been subdivided into small rectangular finite element for analysis purpose. The selection of mesh size for element depend on accuracy desired, the finer the mesh, the better the result but at the same time the larger the computation required. Rectangular elements are found to be very convenient due to simplicity in formulation,

The accuracy of FEM depends on the determination of stiffness matrix of Rectangular element. The two dimensional four noded Rectangular element is as shown in fig.2b. It has four nodes located at the corners and has two translational degrees of freedom at each node, displacement component in X and Y directions with constant σx, σy and τxy.

The analysis of Deep Beam is carried out with the Finite Element Method by using the SAP (Structural Analysis program me) software. The variation of flexural stresses, strains at mid span and shear stresses near support is valuated for all these cases.

- **(a) Variation of flexural strain**

Fig.3a to Fig. 3c show that the flexural strain at mid span of simply supported deep beam for different span –to-depth ratios. The beams have disturbed region in flexural strain distribution. Deep beams behave differently from shallow beams. In these members, the distribution of strain across the depth of the cross section is nonlinear and a significant amount of load is carried to the supports by a compression strut joining the load and the reaction. It is found that the smaller the span/depth ratio (i.e., less than2.0), the more pronounced the deviation of the strain pattern from that of Euler Bernoulli theory.

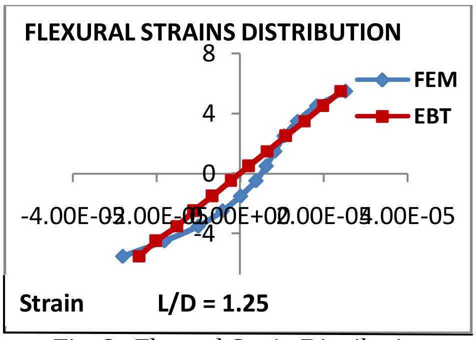

Fig. 3a Flexural Strain Distribution

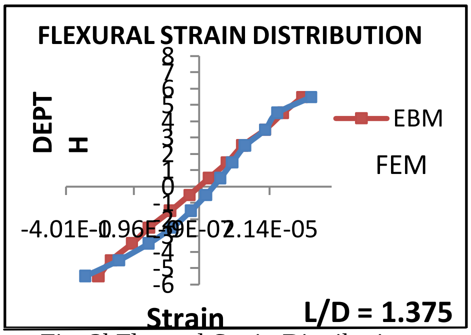

Fig. 3bFlexural Strain Distribution

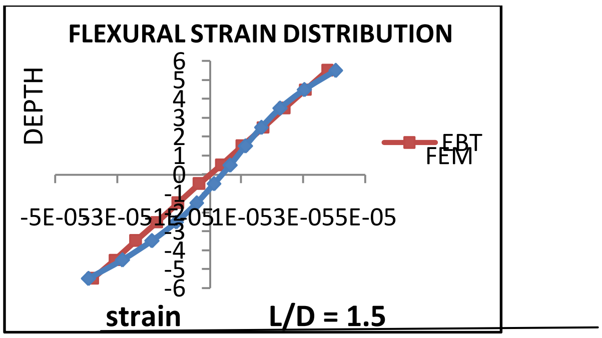

Fig.3c Flexural Strain Distribution

(b)Variation of flexural stress

Fig. 4a to Fig. 4c shows the flexural stress at mid span of simply supported deep beam for two different shear span–to-depth ratios. The compressive stresses increase rapidly at the top and neutral axis moves towards soffit of the beam. From the variation of flexural stress graphs the definition of simply supported deep beam as per IS 456:2000 i.e. when L/D ratio is less than or equal to 2.0 is reasonably accurate.

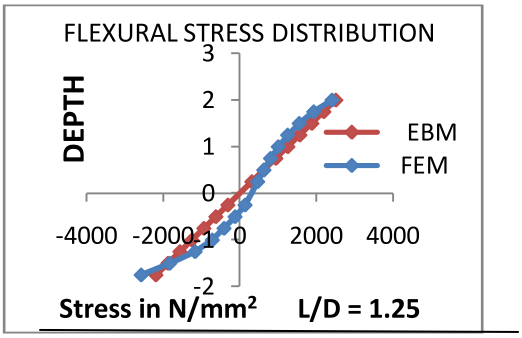

Fig.4a Flexural Stress Distribution

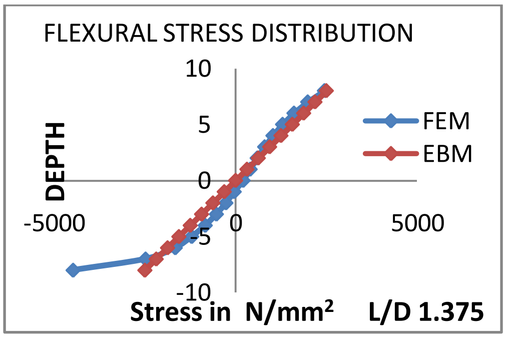

Fig.4b Flexural Stress Distribution

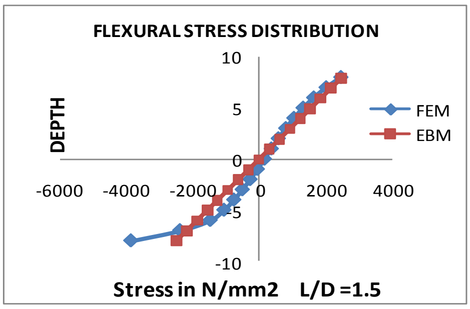

Fig.4c Flexural Stress Distribution

(c) Variation of shear stress

Fig.5a to Fig.5c shows the shear stress near support of simply supported deep beam for different shear span to depth ratios .The beams have drastic change in shear stress distribution. Deep beams behave differently from shallow beams. The shear stress patterns have also changed in case of deep beam. It is found that the smaller the span/depth ratio (i.e., less than2.0), the more pronounced the deviation of the shear stress distribution from that of Euler Bernoulli theory

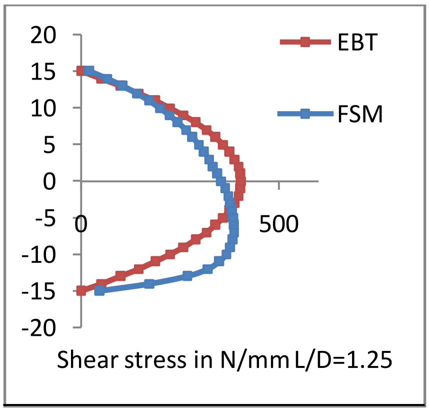

Fig.5a Shear Stress Distribution

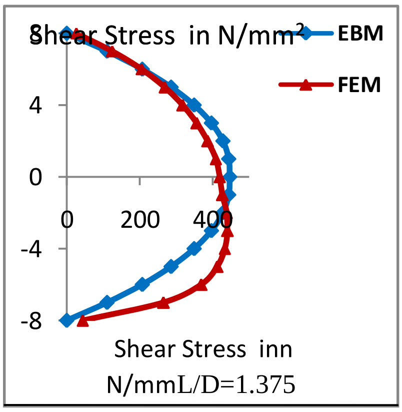

Fig.5b Shear Stress Distribution

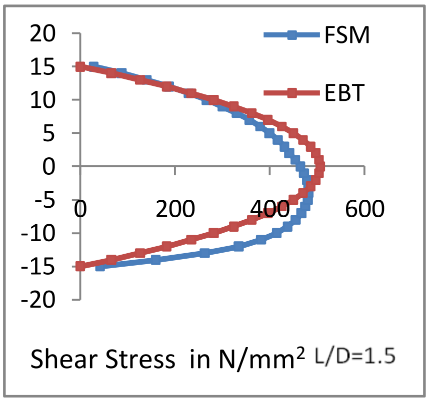

Fig. 5c Shear Stress Distribution

From the variation of shear stress graph it is clear that shear effect is predominant in beams having L/D ratio less than or equal to 2.0 which may lead to warping of the section.

The reinforcement required as per Finite Element Method based on flexural stress distribution graphs for various L/D ratios was presented in table1.

Table1. Reinforcement required as per FEM

Sr.No.	Depth from Center of Beam (mm)	Reinforcement required mm2		
	L / D Ratio ➡	1.50	1.375	1.25
	200	39.23	46.56	56.73

	175	23.57	25.79	26.70
	150	15.59	17.24	18.97
	125	11.65	12.56	12.05
	100	6.39	8.692	7.36
	75	3.923	5.493	4.2
	50	1.987	2.77	1.205
	25	0.123	0.398	1.5
Total		102.45	119.503	128.75

TABLE 2: AREA OF FLEXURAL STEEL REQUIRED

Case No.	**Case 1a**	**Case 1b**	**Case 2a**	**Case 2b**	**Case 3a**	**Case 3b**
Design Method	**I.S.456**	**ACI 318**	**I.S.456**	**ACI318**	**I.S.456**	**ACI318**
Span L (mm)	500	500	550	550	600	600
Span to depth (L/D) ratio Z (Lever Arm)	1.25 280	1. 25 333	1.375 270	1.375 333	1.50 260	1.50 333
Flexure steel Required in $mm^{2`}$	149.37	179.42	154.89	179.42	160.85	179.42
Flexural steel required in mm^2	102.45	102.45	119.5	119.5	128.72	128.72

IV. CONCLUSION

- Flexural stress and strain variation graphs indicate that the definition of simply supported deep beam as per IS 456:2000 i.e. when L/D ratio is less than or equal to 2.0 is reasonably accurate.
- With Finite element analysis, Flexural strain and stress of deep beams is not linear is confirmed.
- Shear effect is predominant in beams having L/D ratio less than or equal to 2.0 which may lead to warping of the section.
- The flexural steel requirements inversely proportionally to the Effective span to Depth Ratio of deep beam.
- The flexural steel required by finite element method is approximately 21 % less than I.S.456 and A.C.I.318.

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