Analysis And Design Of R.C. Deep Beams Using Finite Strip Method & I.S. 456 -2000 -A Comparative Study Supported By Experimental Investigation

Prof. S. K. Kulkarni
Assistant Professor,
W.I.T., Solapur

Prof. S. S. Patil
Professor
W.I.T., Solapur

Dr. S. A. Halkude
Principal &Professor
W.I.T., Solapur

Summary: *This paper describes analysis and design of beams subjected to two points loading with two different L/D ratios using Programme in FORTRAN 77 for analysis and I.S.456-2000 for design purpose , to plot the variation of flexural stress, strain and shear stress in deep beam. Only one parameter, Shear span of beam was varied during the analysis.*

Key words: Deep Beam, Finite Strip method, codal provisions, Design.

1.1. GENERAL INTRODUCTION

Beams with large depths in relation to spans are called deep beams. 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 beams are considered as deep when the ratio L/D is less than 2.5. The effective span is defined as the centre-to-centre distance between the supports or 1.15 times the clear span whichever is less.

1.2 OBJECTIVE OF STUDIES:

The main objective of this investigation is to conduct an experimental study on strength & behavior of deep beams. The detailed analysis has been carried out using the finite strip method. The study also aimed at testing validity & usefulness of IS 456:2000

The objectives of the experimental investigation can be listed as follows.

1. To observe & explain the deflection, cracking & failure modes of deep beams subjected to two point loads.
2. To compare the flexural steel requirement as per codal provisions with that calculated using the finite strip method.
3. To comment on suitability of finite strip method & codal provisions.

2. ANALYSIS OF DEEP BEAM

2.1. FINITE STRIP METHOD

The finite strip approach was first introduced by CHEUNG (1968). For a structure with constant cross section and end boundary conditions that do not change transversely, stress analysis can be performed using finite strips. It is recognized as best method of analysis for simply supported rectangular plate, deep beam and box structure in terms of accuracy and efficiency. Basically, the method is a hybrid procedure which retains advantages of both the orthotropic plate method and finite element concept.

2.2 THE COMPUTER PROGRAM

computer program has been prepared by Mr. Phadnis S.A.U.F.[2] under guidance of Prof.S.S.Patil and Dr.J.B.Dafedar for the analysis of Deep Beam having simple support. It is clear that a computer programme is necessary for the solution of Equation. It should be noted that the overall stiffness matrix is symmetrical and the non-zero element exist only in neighborhood of the leading diagonal forming narrow band. If a sub programme is written so that only half the band of matrix elements are required (in a rectangular array), considerable core storage and computing effort can be saved in the solution of equation. Computer programme is developed on the basis of direct stiffness method.

The essential steps in writing a programme are as follows.

1) Presenting input data to computer

2) Evaluation of stiffness matrix of individual strips.

3) Assembling of structure stiffness matrix

4) Forming the load vector

1) Solving the assembled equations for the displacements.
2) Computing the internal forces in the members and reactive forces at the support.
3) Presentation of the results.

Features of the Program

1. The programming language used is FORTRAN77.

2. The program can handle any number of joints and members depending upon memory allocations available with PC.

3. The program can handle yielding of the support in all three directions. Also it can handle symmetric structures in-plane, point load loads etc.

3. VARIATION OF FLEXURAL STRAIN:

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.

Figure 1 & Figure 2 show the flexural strain at mid span of simply supported deep beam for two different shear 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. These structural elements belong to D (disturbed) regions. Structural members can be broadly divided into two regions, namely, B (or Bernoulli) regions where the strain distributions are linear, and D (or Disturbed) regions where the strain distributions are non–linear. While well defined theories are available for designing B regions, thumb rule or empirical equations are still being used to design D regions, though B and D regions are equally important. Schlaich et al. (1987) identified deep beams as discontinuity regions where the strain distribution is significantly nonlinear and specific strut-and-tie models need to be developed, whereas shallow beams are characterized by linear strain distribution and most of the applied load is transferred through a fairly uniform diagonal compression field.

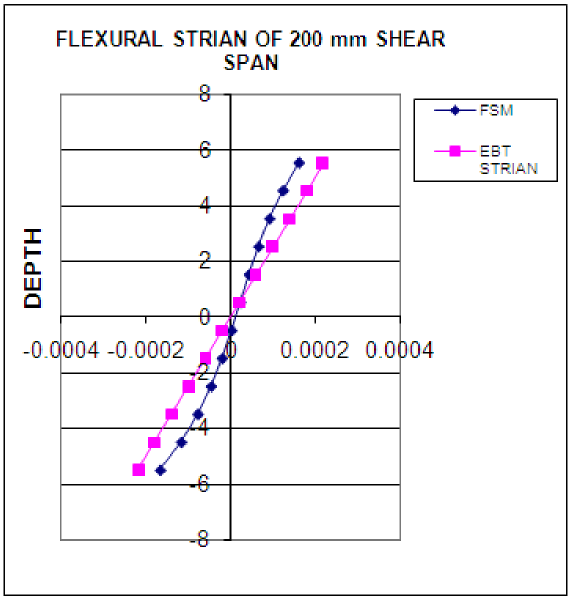

Figure 1: Flexural Strain Distribution shear span-to-depth ratio 0.57

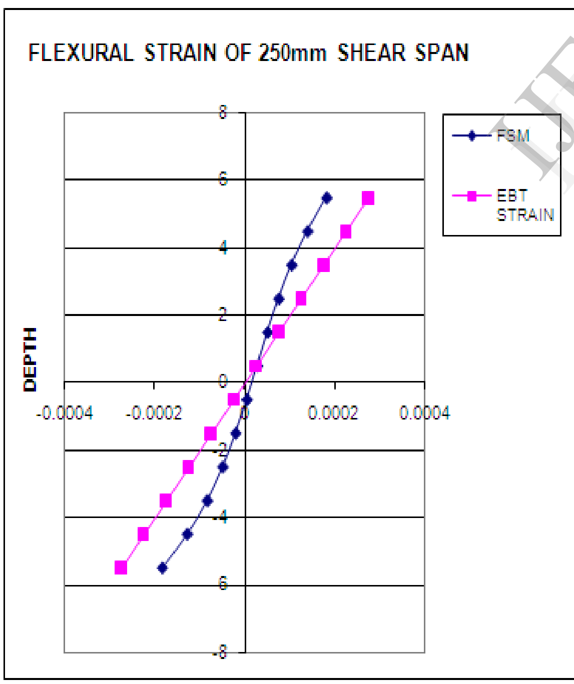

Figure2: Flexural Strain Distribution shear span-to-depth ratio 0.71

From the variation of flexural strain graphs the definition of simply supported deep beam as per IS 456:2000 i.e. L/D ratio is less than or equal to 2.0 is reasonably accurate.

4. VARIATION OF FLEXURAL STRESS:

The stresses in isotropic homogeneous deep beams can be determined using finite strip analysis. It is found that the smaller the span/depth ratio (i.e., less than2.0), the more pronounced the deviation of the stress pattern from that of Euler Bernoulli theory. Figure 3 & Figure 4 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.

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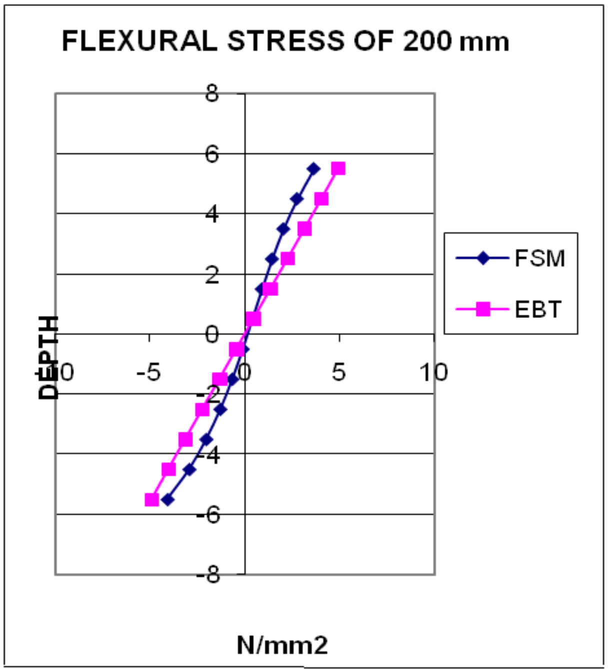

Figure 3: Flexural Stress Distribution shear span-to-depth ratio 0.57

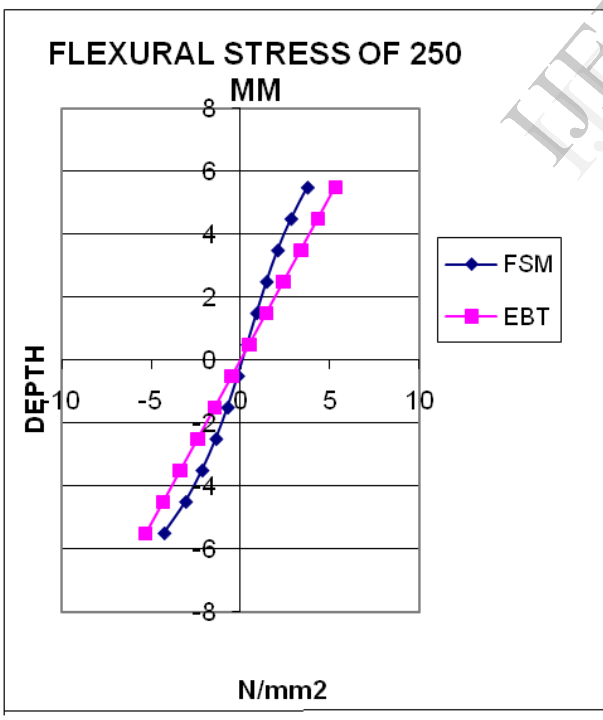

Figure 4: Flexural Stress Distribution shear span-to-depth ratio 0.71

From the variation of flexural stress graphs It is clear that beam behaves as deep beam when L/D ratio is less than or equal to 2.

5. VARIATION OF SHEAR STRESS:

Figure 5 & Figure 6 show the shear stress near support of simply supported deep beam for two 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.

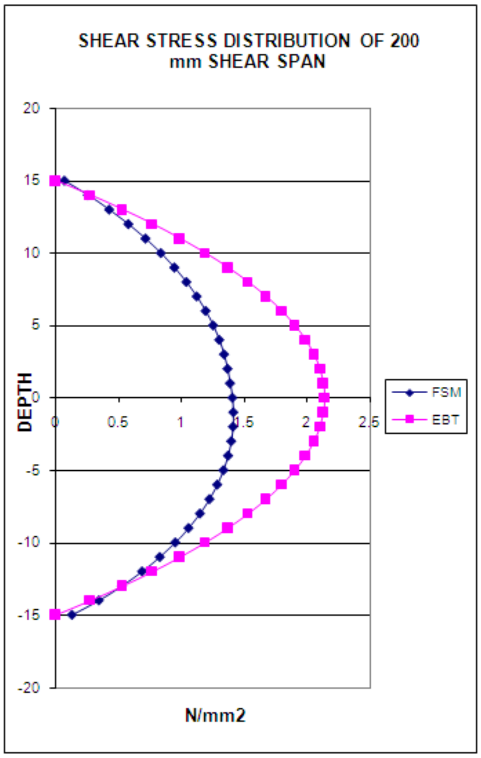

Figure 5: Shear Stress Distribution shear span-to-depth ratio 0.57

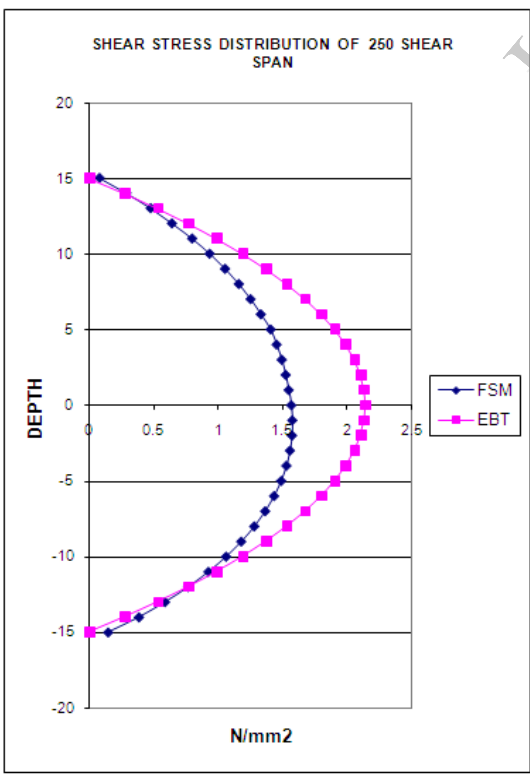

Figure 6: Shear Stress Distribution shear span-to-depth ratio 0.71

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.

6. TENSION REINFORCEMENT CALCULATIONS FROM GRAPH:

Tension Reinforcement required is calculated from the flexural stress graphs which are plotted by using Finite Strip program.

Reinforcement requirement for Shear span 200 mm:

Sample calculation of reinforcement for bottom most strip

Area of steel required

$$= \frac{\text{Flexural stress in strip x Area of strip}}{\text{Design stress in steel}}$$

$$= \frac{\sigma_y \text{ x } A_{strip}}{0.87\ f_y}$$

$$= \frac{4.10687 \text{ x } 31.819 \text{ x } 150}{0.87 \text{ x } 415}$$

$$= 54.29 \text{ mm}^2$$

Similarly calculations for all the strips are done and tabulated.

Table 1: Reinforcement required as per FSM for Shear span 200 mm:

Sr. No.	Strip No.	Reinforcement required mm^2
1.	1	0.86
2.	2	8.99
3.	3	17.3
4.	4	27.183
5.	5	38.973
6.	6	54.293
Total		**147.6 mm^2**

Reinforcement requirement for Shear span 250 mm:

Sample calculation of reinforcement for bottom most strip

Area of steel required

$$= \frac{\text{Flexural stress in strip x Area of strip}}{\text{Design stress in steel}}$$

$$= \frac{\sigma y \times A_{strip}}{0.87\ f_y}$$

$$= \frac{4.58062 \times 31.819 \times 150}{0.87 \times 415}$$

$$= 60.553\ mm^2$$

Similarly calculations for all the strips are done and tabulated.

Table 2: Reinforcement required as per FSM for Shear span 250 mm:

Sr. No.	Strip No.	Reinforcement required mm^2
1.	1	0.96
2.	2	10.032
3.	3	19.296
4.	4	30.32
5.	5	43.805
6.	6	60.55
Total		**164.97 mm^2**

7. EXPERIMENTAL WORK

7.1 Deep beams were designed, cast, & tested after 28 days of curing, for two point loads and for two shear spans viz. 200 mm and 250 mm. Point loads of 50 kN at each point was applied on deep beams. Dimensions of Deep beams were-

Length = 700 mm,

Depth = 350 mm,

Thickness = 150 mm

Total twelve beams were cast, tested and the average results are presented.

8. TESTING OF BEAMS

Testing of deep beams was carried out on UTM of capacity 40 Tonnes in Materials Testing Laboratory, W.I.T., Solapur.

Mode of failure[8] in almost all cases was found to be shear with diagonal tension, can be categorized as mode II- 3.

Photograph 1: Testing of deep beam

Referring to table nos. 1, 2 and 3, it is clear that flexural steel reinforcement requirement as found by FINITE STRIP METHOD is less than that specified by I.S.456.

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TABLE 3: TEST RESULTS

Loading: Two point loading, each point load of 50 kN (working load**)**

Beam dimensions:

Total Length = 700 mm, Effective Span = 600 mm,

Depth = 350 mm, Thickness = 150 mm, Average cube strength = 21 N/mm^2

Beam No.		**B1/1**	**B1/2**
Design Method		**I.S.456-2000**	**I.S.456-2000**
Shear span (mm)		200	250
Shear span to depth ratio		0.57	0.71
Reinforcement provided (No.of bars)	Flexure steel Required in mm^2`	160.74	199.845
	Flexure steel Provided i) 10 mm Φ ii) 08 mm Φ iii) mm^2	2 1 207.24	2 1 207.24
	Shear Required in mm^2` Vertical Horizontal	126 105	126 105
	6 mm dia. Vertical Horizontal	6 2	6 2
Load at first crack	Total	200 kN	190 kN
	Each Point load	100 kN	95 kN
Failure Load	Total	300 kN	280 kN
	Each Point load	150 kN	140 kN
Deflection at failure	Total	3.4 mm	3.8 mm
	Permissible deflection	2.4 mm	2.4 mm
	Deflection at 150 kN load	1.03 mm	1.37 mm
Observed mode of failure		Mode II 3	Mode II 3

Failure modes[8] of deep beam was as follows. (Salamy et al)

Mode II-3: Shear proper or compressive failure of struts, which is often observed in ratio (a/d < 1.5).In this case due to the small a/d ratio, the line of thrust will be so

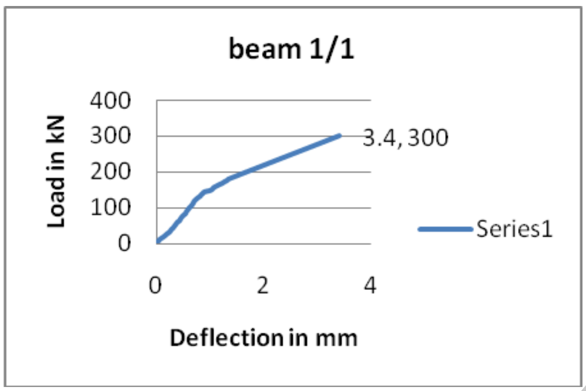

Fig. 7: Typical load vs. deflection graph

9. CONCLUSION

Following conclusions were drawn from above studies.

1. Failure of deep beams was mainly due to diagonal cracking and it was along the lines joining the loading points and supports.
2. The strength of beams with 250 mm shear span is about 5 % less than that of 200 mm shear span. It is clear from these results that the strength of deep beam is inversely proportional to the

steep and arch action not only reserve flexural capacity in most cases but also efficiently sustains required shear force.

Arch is clearly observed in those beams and finally beams fail due to either sudden tensile crack formation parallel to the strut axes or compressive crush in normal direction to the strut axes.

shear span for the constant depth of the beam.

3. No separate checking for shear is specified in I.S.456. It is assumed that the arching action of the main tension steel & the web steel together with concrete will carry the shear.
4. All the beams had low deflection at failure as there was no flexural failure.
5. The overall average load at first crack was found approximately half of the ultimate failure load. Therefore in design of deep beams, a load factor of 1.5 seems to be reasonable. As reported by F.K.Kong the shear strength of deep beams is 2 to 3 times greater than that given by usual equations which is true as in our case the strength is about 2 times greater than design loads.

6. The flexural steel requirement of by using IS456:2000 is more by a margin of 8.17 % than Finite Strip Method. Therefore it can be concluded that tensile reinforcement requirements of I.S . method is near to the FSM. The design was found conservative.
7. The flexural tensile force as per the FSM analysis is concentrated in lower 1/3 height for all the beams. Therefore in the deep beams loaded with two point loading, steel for the flexural tensile force may be provided mainly in this height. This is matching with the codal provisions.

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