International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.1, Jan-Feb. 2013 pp-45-52 ISSN: 2249-6645

Experimental and Analytical Study on Reinforced Concrete Deep Beam

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ABSTRACT: *Several reinforced concrete deep beams with different L/D ratios (1.5, 1.6, 1.71) were cast and tested in order to investigate the strain distribution pattern at mid-section of the beam. This paper describes analysis of deep beams subjected to two point loading with three different L/D ratios (1.5, 1.6, 1.71) using Non-linear Finite element method (ANSYS 9.0 software). In ANSYS 9.0 software, SOLID 65 and LINK 8 element represent concrete and reinforcing steel bars.*

Non-linear material properties were defined for both elements. Using ANSYS software Flexural Strains and deflections were determined at mid-section of the beam. The failure crack-patterns were obtained. Variations of flexural strains were plotted at mid-section of the beam. The beams were designed by I.S.456-2000 (Indian Standard Code of Practice for Plain and Reinforced Concrete). Flexural strains were measured experimentally at mid-section of the beam using Demountable mechanical strain gauge. The failure crack-patterns of the beam for different L/D ratios were also observed.

The comparison between ANSYS results and experimental test results were made in terms of strength, flexural strain and deflection of concrete beams. The analytical and experimental flexural strains were compared at mid-section of the beam for different L/D ratios.

It was found that the smaller the span/depth ratio, the more pronounced was the deviation of strain pattern at mid-section of the beam. As the depth of the beam increases the variation in strength, flexural steel and deflection were found to be more experimentally than the non-linear finite element analysis.

Keywords: *Deep Beam, Non-Linear Finite element method, ANSYS 9.0. L/D (Span to depth), Demountable Mechanical Strain Gauge.*

I. INTRODUCTION

Beams with large depths in relation to spans are called deep beams [4]. 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.

II. NON LINEAR FINITE ELEMENT ANALYSIS

The finite element analysis calibration study included modeling a concrete beam with the dimensions and properties [1]. To create the finite element model in ANSYS 9.0 there are multiple tasks that have to be completed for the model to run properly. Models can be created using command prompt line input or the Graphical User Interface. For this model, the graphical user interface was utilized to create the model. This section describes the different tasks and entries to be used to create the finite element calibration model.

2.1. Element Types

The element type for this model is shown in Table 1.

Table1. Element Types for Working Model

Material Type Element	ANSYS
Concrete	Solid65
Steel Reinforcement	Link8

A Solid65 element was used to model the concrete [2]. This element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. A schematic of the element was shown in Fig.1.

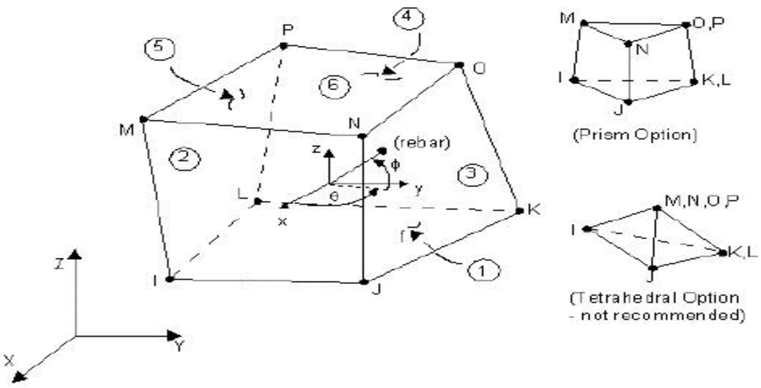

Figure1. Solid 65 element

A Link8 element was used to model steel reinforcement [2]. This element is a 3D spar element and it has two nodes with three degrees of freedom translations in the nodal x, y, and z directions. This element is capable of plastic deformation and element was shown in the Fig.2.

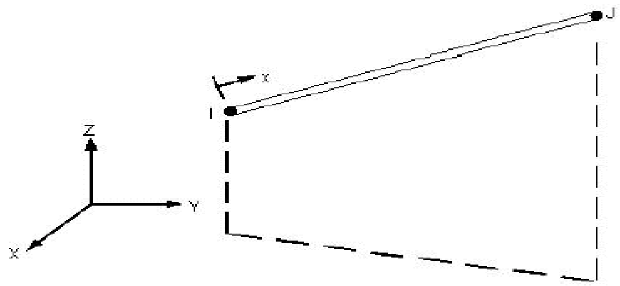

Figure 2. Link 8 element

2.2. Real Constants

Real Constant Set 1 was used for the Solid65 element [2]. It requires real constants for rebar assuming a smeared model. Values can be entered for Material Number, Volume Ratio, and Orientation Angles. The material number refers to the type of material for the reinforcement. The volume ratio refers to the ratio of steel to concrete in the element. The reinforcement has uniaxial stiffness and the directional orientations were defined by the user. In the present study the beam was modeled using discrete reinforcement. Therefore, a value of zero was entered for all real constants, which turned the smeared reinforcement capability of the Solid65 element of Real Constant Sets 2 and 3 were defined for the Link8 element.

Values for cross-sectional area and initial strain were entered. Cross-sectional area in set 2 refers to the reinforcement of two numbers of 10mm diameter bars. Cross-sectional area in set 3 refers to the 8 mm diameter two legged stirrups. A value of zero was entered for the initial strain because there is no initial stress in the reinforcement. The real constants were given in Table 2.

Table 2. Real Constants

Real Constants Set	Element Type		Real constants for Rebar 1	Real constants for Rebar 2	Real constants for Rebar 3
1	Solid 65	Material no. V.R	0	0	0
2	LINK 8	Area (mm2) Initial strain	78.5 0	- 0	- 0
3	LINK 8	Area (mm2) Initial strain	50.24 0	- 0	- 0

2.3. Modeling

The beam was modeled as volume [2]. The model was 700 mm long with a cross section of 150 mm X 350 mm. The Finite Element beam model was shown in Fig.3. The dimensions for the concrete volume were shown in Table.3.

Table 3. Dimensions for Concrete

ANSYS	Concrete(mm)
X1,X2,X-coordinates	0, 700
Y1,Y2,Y-coordinates	0, 350
Z1,Z2,Z-coordinates	0, 150

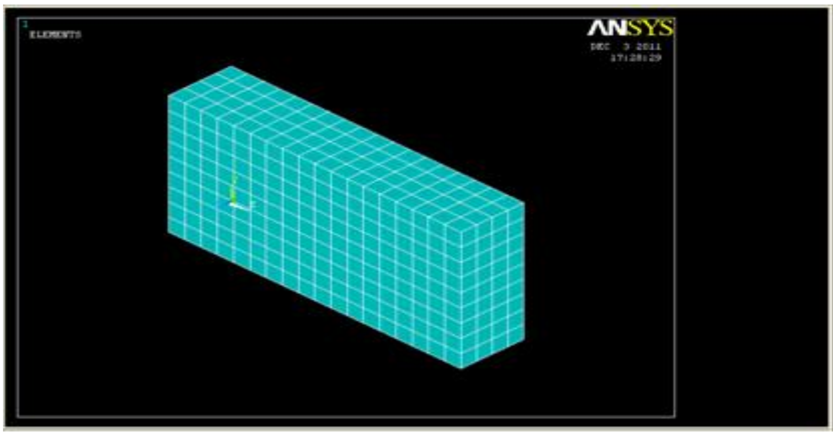

Figure 3. Finite element model & mesh of beam

2.4. Meshing

To obtain good results from the Solid65 element, the use of a rectangular mesh was recommended [2]. Therefore, the mesh was set up such that square or rectangular elements were created. The meshing of the reinforcement was a special case compared to the volumes. No mesh of the reinforcement was needed because individual elements were created in the modeling through the nodes created by the mesh of the concrete volume. The meshing and reinforcement configuration of the beam were shown in Fig.3 and Fig.4.

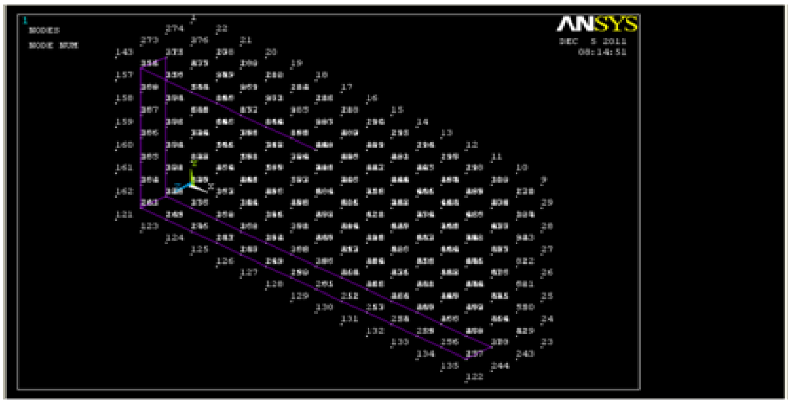

Figure 4. Reinforcement Configuration

2.5. Loads and Boundary Conditions

Displacement boundary conditions were needed to constraint the model to get a unique solution [2]. To ensure that the model acts the same way as the experimental beam boundary conditions need to be applied at points of symmetry, and where the supports and loading exist. The support was modeled as a hinged support at both ends. Nodes on the plate were given constraint in all directions, applied as constant values of zero. The loading and boundary conditions of the beam were shown in Fig.5.

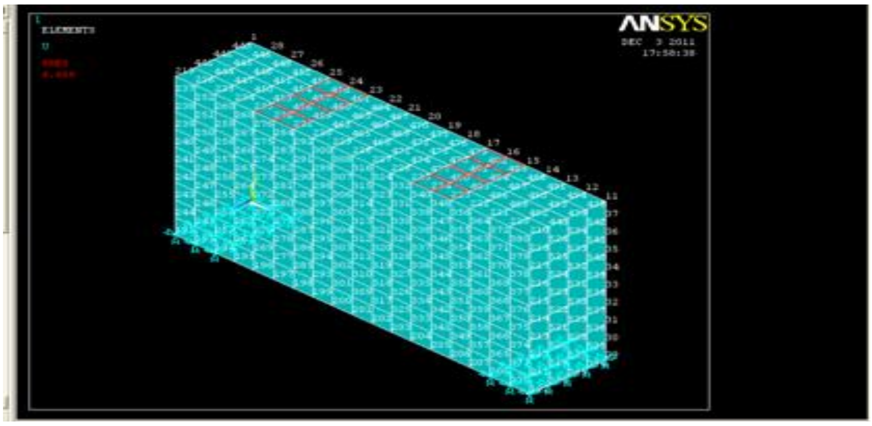

Figure 5. Loading and boundary conditions

1.6 Crack Patterns

The crack patterns of different beams using ANSYS 9.0 Software were shown in Fig.6 (a) to Fig.6(c).

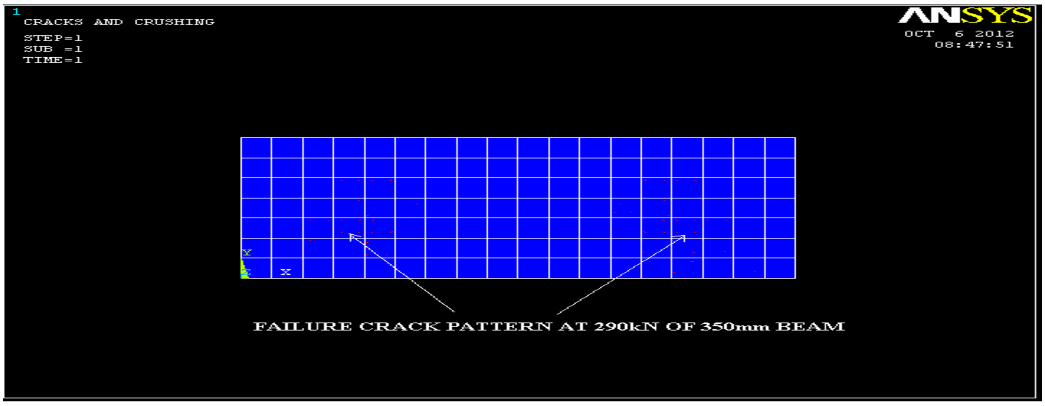

Figure 6(a). Failure crack pattern of 350mm Beam

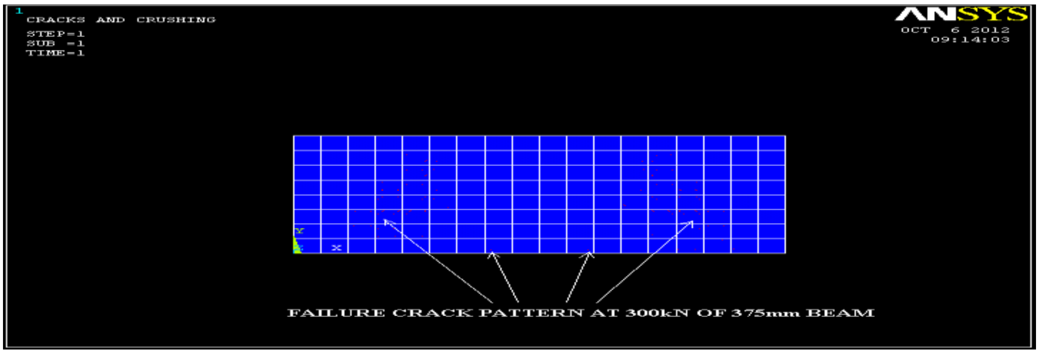

Figure 6(b). Failure crack pattern of 375mm Beam

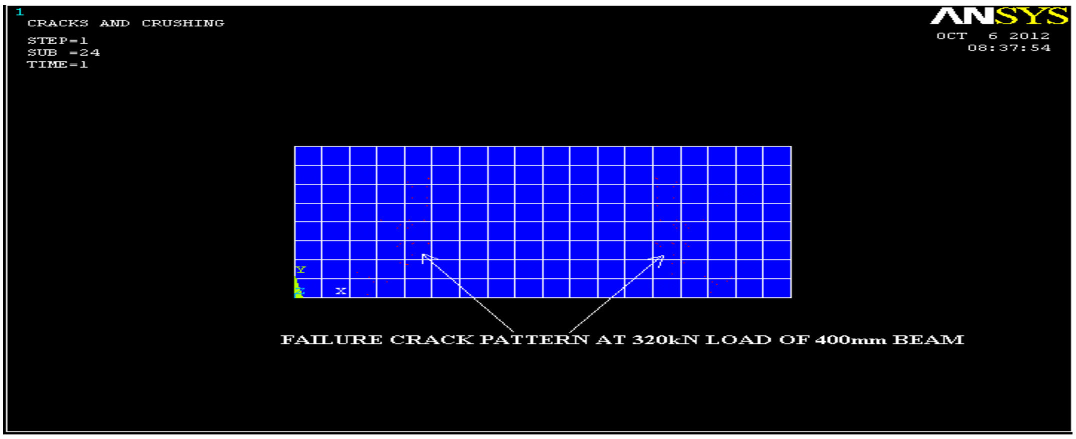

Figure 6(c). Failure crack pattern of 400mm Beam

III. EXPERIMENTAL WORK

3.1 Specimen Details

This experimental programme consists of casting and testing of several beams of 0.7 m length reinforced concrete deep beams. All the beams were tested over a simply supported span of 0.6 m. The beams were designed as under reinforced section to sustain a minimum two point loads of 50 kN.

3.2 Test Set Up

Tests were carried out at room temperature and as per the Indian standards in Heavy Structures Laboratory. The testing arrangement was shown in Image 1. Two point loads were applied on reinforced concrete deep beams of span 0.6 m through hydraulic jack of capacity 1000 kN. The specimens were placed on a simply supported arrangement of 100 kN Loading frame. The beams were suitably instrumented for measuring of middle strain by using Demountable Mechanical Strain Gauge including the mid span deflection with dial gauges.

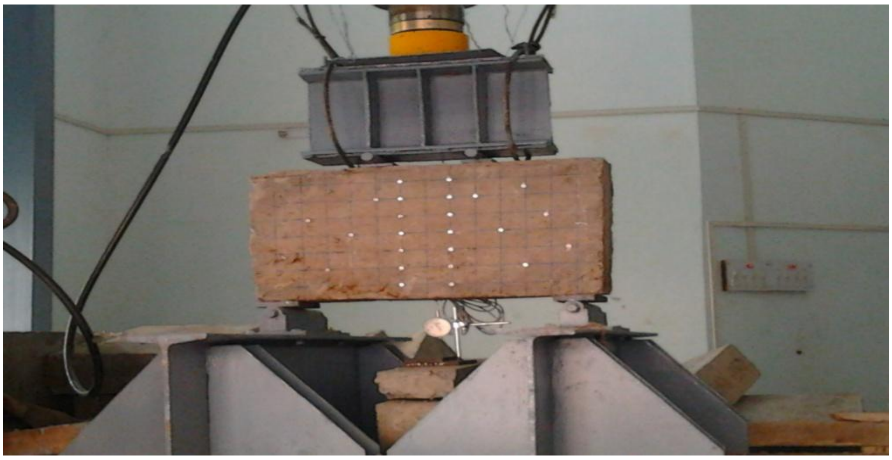

Image 1. Experimental Set Up

Image 2. Demountable Mechanical Strain Gauge

IV. RESULTS AND DISCUSSION

Beams of different L/D ratios were tested and experimental strains were measured at mid section of the beam by using demountable mechanical strain gauge. The beams were designed by using I.S. 456-2000 code and for 200 mm shear span. Shear span to depth ratio considered for the beams were 0.57, 0.53, 0.5 respectively. The beams were designed for two point loading of 50 kN each at 1/3 of span. At a load increment of 50 kN, strain at midsection and deflections were measured. The average initial cracking load for the beams was found to be 175 kN, 170 kN, 225 kN respectively. At these loads it was observed that minor cracks were developed in shear span region in the direction of the line joining the loading point and support. Also minor flexural cracks at mid span were observed. Loading was continued beyond this point. The failure loads observed were 290 kN, 300 kN, 350 kN respectively.

Table 4. Experimental Test Results

Beam Number	B1	B2	B3	B4	B5	B6	B7	B8	B9
Depth (D)	400mm	400mm	400mm	375mm	375mm	375mm	350mm	350mm	350mm
Effective Span to depth ratio (L/D)	1.5	1.5	1.5	1.6	1.6	1.6	1.71	1.71	1.71
Design Method	IS 456	IS 456	IS 456	IS 456	IS 456	IS 456	IS 456	IS 456	IS 456
Lever arm, (Z)	280mm	280mm	280mm	270mm	270mm	270mm	260mm	260mm	260mm
Flexural steel required in mm^2	120.64	120.64	120.64	124.93	124.93	124.93	129.52	129.52	129.52
Flexural steel provided in mm^2	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ	157 2-10Φ
Minimum Shear required ,mm^2 a) Vertical b) Horizontal	72 120	72 120	72 120	67.5 112.5	67.5 112.5	67.5 112.5	63 105	63 105	63 105
Vertical steel required,mm^2	251.48	251.48	251.48	274.86	274.86	274.86	304.86	304.86	304.86
8mm diameter a)Vertical b)Horizontal	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars	4 bars 2 bars
Load at first crack,kN(Total)	225	190	225	200	180	170	175	150	180
Load at failure kN (Total)	350	335	350	335	310	300	290	285	325
Deflection at first crack,mm	0.76	0.64	0.82	0.64	0.59	0.52	0.55	0.49	0.62
Maximum. total Deflection,mm	1.75	1.63	1.55	1.55	1.32	1.45	1.52	1.41	1.45
Permissible Deflection,mm	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Crack width at failure,mm	0.317	0.323	0.311	0.315	0.304	0.312	0.303	0.314	0.313
Permissible crack width,mm	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table 5. Analytical Test Results

Depth	400mm	375mm	350mm
Span to depth ratio	1.5	1.6	1.71
Flexural steel required in mm^2	85.06	95.862	102.689
Flexural steel provided in mm^2	157 2-10Φ	157 2-10Φ	157 2-10Φ
Load at first crack (Total)	190	185	170
Load at failure (Total)	320	300	290
Deflection at first crack, mm	0.591	0.588	0.458
Total Deflection at failure, mm	1.364	1.286	1.140

4.1 Variation of Flexural Strains

The analytical and experimental strains were recorded and variation of strain at midsection of beam for different L/D ratios plotted by considering analytical and experimental results.After plotting the experimental and analytical strains, the graph obtained experimentally was varying more than graph obtained analytically.

a) For the beam of L/D ratio 1.5, the experimental strains were 20% more than the analytical strains at mid-depth of the beam.

b) For the beam of L/D ratio 1.6, the experimental strains were 17% more than the analytical strains at mid-depth of the beam.

c) For the beam of L/D ratio 1.71, the experimental strains were 16% more than the analytical strains at mid-depth of the beam.

The variations of flexural strain were plotted at mid span of the beam for different L/D ratios. It was found that behaviour of flexural strain variation was non-linear. Also it was found that as the L/D ratio decreases the more pronounced was the deviation of strain pattern at mid-section of the beam. Fig.7 to Fig.9 were shown the variation of flexural strain at mid span for different L/D ratios.

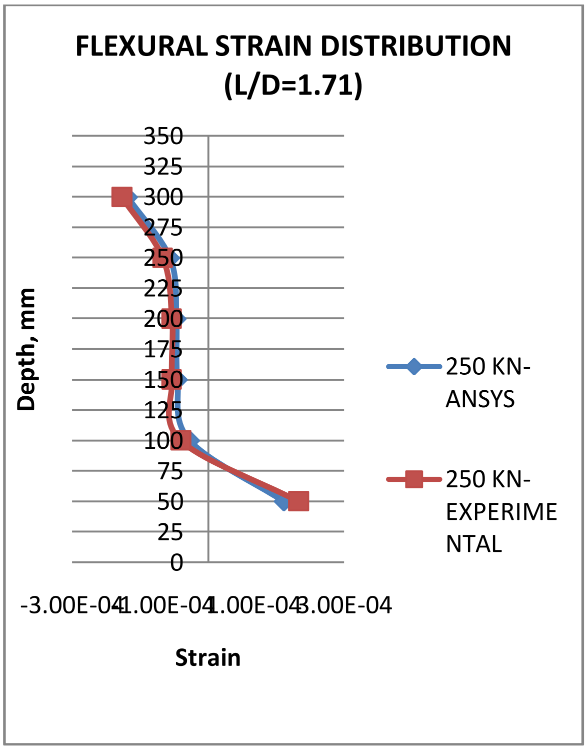

Figure 7. Flexural Strain Distribution (L/D=1.71)

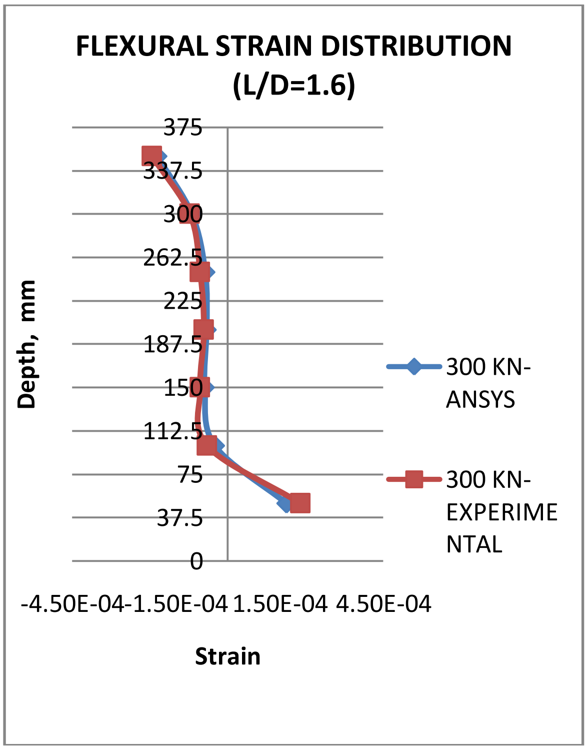

Figure 8. Flexural Strain Distribution (L/D=1.6)

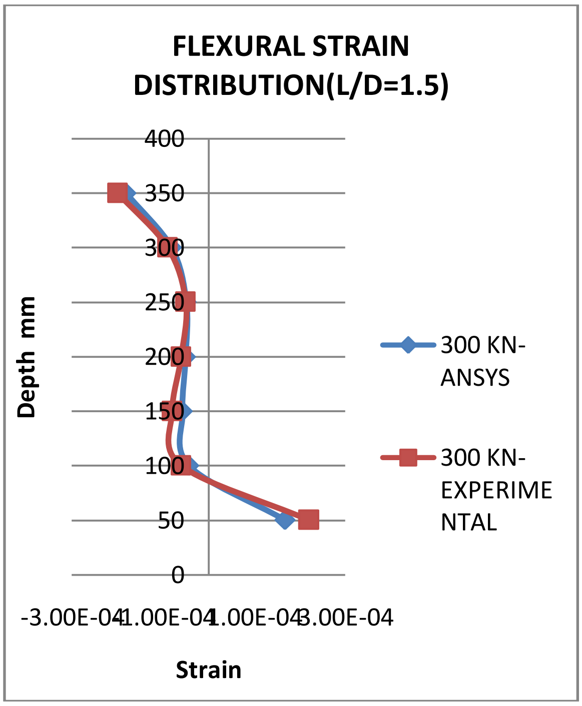

Figure 9. Flexural Strain Distribution (L/D=1.5)

V. Conclusions

Deep beams having different L/D ratios were analyzed by using non-linear finite element method (by ANSYS 9.0) and tested under two point loading. Some prominent conclusions were summarized here.

1. From the flexural strain graphs it was observed that smaller the span/depth ratio (i.e. less than or equal to 2.0), the more pronounced is the deviation of the stress-strain pattern i.e. the variation is not linear as in case of shallow beams.
2. Flexural 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.
3. From the flexural strain graphs it was observed that as L/D ratio of the beam decreases the neutral axis shifted towards soffit of the beam.
4. Failure of deep beams was mainly due to diagonal cracking.

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