Non-Linear Finite Element Analysis of Deep Beam

Mr. V. D. Sabale [1]
[1]PG student Applied mechanics department
Govt. college of Engineering, Saidapur,
Karad-India

Miss. M. D. Borgave [2]
[2]PG student Applied mechanics department Padmabhooshan
Vasantraodada Patil Institute of Technology,
Budhgaon-India

Prof. P. K Joshi.[3]
Professor Applied mechanics department Padmabhooshan
Vasantraodada Patil Institute of Technology,
Budhgaon-India

***Abstract*— There are several analytical tools available for analyzing deep beams. Among all the available analytical methods, finite element analysis (FEA) offers a better option. In this paper the attempt has been made to study, the behavior of deep beam of various span to depth ratio by ANSYS 13.0 under two point loading of 50KN. The detailed analysis has been carried out by using non-linear finite element method and design of deep beam by using I.S 456-2000. The objectives of this study are to observe deflection, cracking of deep beams subjected to two point loading of 50KN. To study non- linear finite element analysis of deep beam by using ANSYS having different L/D ratio (1.5, 1.6, 1.71) and To study stress distribution of deep beam.**

***Keywords*— deep beam, non-linear finite elemnt, ANSYS13.0, deflection.**

I. Introduction

Reinforced concrete deep beam are very useful members widely used in buildings, bridges and infrastructures. Deep beams are the beam with a depth comparable with their span length. To consider a beam as a deep beam, depth to span length should be less than a certain value. This ratio is the most frequently used parameter by researchers and engineers. Generally, the simply supported beam with span to depth ratio less than 2 is classified as deep beam and beam with span to depth ratio exceeding 2 as shallow beams.

Reinforced concrete deep beams, in particular, show much complicated response to any sort of loads subjected to such members than conventional beams. It is well-known that deep beams behave very differently from shallow beams as arch action rather than flexure dominates the behavior, after diagonal cracking has occurred. However, causes of size effect in deep beams remain unresolved. This is mainly because experimental data are relatively scarce on deep beams with geometrically-varied beam sizes. A common practice in experimental investigation of size effect of deep beams is to keep the beam width constant while increasing the beam height. It was implicitly assumed by researchers that the beam width has a negligible effect on the structural behavior of deep beams. However, this conclusion is largely drawn from test results of beams having small height-to-thickness ratios. Size effect in shallow reinforced concrete beams is represented by reduction in ultimate shear strength due to an increase in beam size.

Beams with comparable large depths in relation to spans are called deep beams. According to I.S: 456-2000, a simply supported beam is classified as deep beam when the ratio of its effective span L to overall depth D is less than 2.0 and continuous beams are considered as deep beam 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. The bending stress distribution across any transverse section in deep beams deviates appreciably from the straight line distribution assumed in the elementary beam theory. Consequently section which is plane before bending does not remain plain after bending.

II. Objective of Study

The main objective of study is to analysis a deep beam of various Length to span ratio by ANSYS 13.0 under two point loading. The detailed analysis has been carried out using non-linear finite element method & design using I.S 456-2000.
The objective of the investigation are listed below

1. To observe deflection, cracking of deep beams subjected to two point loading.
2. To study non- linear finite element analysis of deep beam by using ANSYS of beam having different L/D ratio (1.5, 1.6, 1.71)
3. To study stress distribution (flexural, shear) of deep beam.

III. Finite Element Method

The FEM is a numerical method for analyzing structures and continua. Usually the problem addressed is too complicated tobe solved satisfactorily by classical analytical methods. The problem may concern stress analysis, heat conduction, or any of several other areas. The finite element procedure produces many simultaneous algebraic equations which are generated and solved on digital computer. Results are rarely exact. However, errors are decreased by processing more equations, and results accurate enough for engineering purposes are obtainable at reasonable cost.

The finite element analysis typically involves the following steps.

1. Divide the structure or continuum intofinite elements. Mesh generations programs called preprocessor, help the user in doing this work.
2. Formulate the properties of each element. In stress analysis, this means determining nodal loads associated with all elements deformation states are allowed.
3. Assemble elements to obtain the finite element model of the structure.
4. Apply the known loads; nodal forces, and/or moment in stress analysis.
5. In stress analysis, specify how the structure is supported .this step involves setting several nodal displacements into known values.
6. Solve the simultaneous linear algebraic equations to determine nodal dof.
7. In stress analysis, calculate the element strains from the nodal d.o.f. and the elelment displacement field interpolation, and finally stress from strains.

IV. PARAMETRIC INVESTIGATION

A. Data For Design Of Deep Beam:

Following are the data chosen for design purpose: Length L =700 mm, Effective depth d = 320mm, Depth D =350 mm, Width B = 150 mm, two point loading of 50 KN shear span = 200 mm, Clear Cover = 30 mm.
Use M20 and Fe 415.

B. Design Procedure Of Deep Beam:I.S. 456-2000

Following are the procedure of design of deep beam:

Step 1: Calculation of effective span

This shall be taken as lesser of

1) Center to center distance between supports = 600 mm
2) 1.15 times the clear distance between supports = 1.15 x 540 =621 mm …………….cl.29.2,IS 456-2000,pn 51

Hence effective span l =600 mm.
Step 2: Check for deep beam action

l/ D = 600/ 350
= 1.71< 2.00, hence beam behaves as a deep beam. …..cl.29.1,IS 456-2000,pn 51

Step 3: Calculation of lever arm
z = 0.2 (l + 2D) - l/D is between 1 to 2. cl.29.2,IS 456- 2000

= 0.2 (600 + 2 x 350)
z = 260 mm.

Step 4: Thickness of beam

1. It is controlled by two conditions to avoid buckling failure
   i) D/T ratio should be less than 25.
   ii) L/T ratio should be less than 50.
2. Thickness of beam =150mm.
   D/T= 350/150= < 25 hence ok
   L/T = 700/150 < 50 hence ok
   Adopt T= 150 mm.

Step 5: check for bearing stresses
Per. bearing stress= 0.45 fck…. cl.34.4,IS 456-2000 pn 66
= 0.45 x 20
= 9 N/mm2
Bearing stress at supports and at loading point
$\sigma_{b=} v_{u/}$ st
Where
v_u= factored S.F.
S= width of support 60 mm
t = thickness of beam.
= 8.33 N/ mm2 < 0.45 fck..hence safe
Provide bearing plate of 60 x 150 mm at support as well as loading point.

Step 6: Calculation of bending moment

a)Load due to self weight = 1.5 (b x D x 25)
= 1.5 (0.150 x 0.35 x 25)
. = 1.968 KN/m
b)Maximum Factored B.M. due to self weight = $wl^2/ 8$
= 1.968 x $0.6^2/ 8$
= 0.0885 KNm.
C) Maximum Factored B.M. due to two point loads
= 50 x 0.20 x 1.5
= 15 KNm
Total Factored B.M.(Mu) = 15 + 0.0085
= 15.00885 KNm

Step 7: Calculation of flexural reinforcement
A_{st} = Mu / (0.87 x fyx z)
= 15.00885 x 10^6/ (0.87 x 415 x 260)
A_{st} = 133.408 mm^2
Minimum reinforcement
A_{st} min = (0.85x b x d) / fy
A_{st} min = (0.85 x 100 x 864) / 415
A_{st} min = 176.96 mm^2 > $A_{s\ reqd.}$
Hence provide A_{st} min Provide 2-10 mm Φ at bottom after a clear cover of 30 mm
Zone (depth) of placement = 0.25D–0.05L
= 0.25 x 350 – 0.05 x 600
= 57.5 mm
Tension steel can be placed in the zone of 57.5 mm above cover.

Step 8: Calculation of development length
For flexural steel
For 10 mm bar,

$$L_d = \frac{\phi\ \sigma_s}{4\tau_{bd}}$$

= (10 x 0.87 x 230) / (4 x 1.2x 1.6)
= 566.40 mm
0.8 = 0.8 x 566.40
= 453.125 mm
Provide development length of 450 mm for 10 mm Φ bar.

Step 7: Check for shear:
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. A deep beam complying with the requirements of Cl.29.2 and Cl.29.3 shall be deemed to satisfy the provisions for shear.

Step 8: Side Face reinforcement:

As per Clause 32.5 of I. S. 456: 2000, Page 62 and 63, all specifications require minimum amount of vertical steel & horizontal steel in the form of U bars to be placed on both faces of deep beams. They not only overcome the effects of shrinkage & temperature but also act as shear reinforcement. These specifications are-

1. Vertical steel shall be 0.15 % for Fe 250 & 0.12 % for Fe 415. The bars shall not be more than 14 mm diameter & spaced not more than 3 times the thickness of the beams 450 mm.
2. diameter & spaced not more than 3 times the thickness of the beams or 450 mm.

1.Vertical Steel Av = (0.12 / 100) x 150 x 350
= $63mm^2$
i.e. $63mm^2$ on each face.

Hence provide 9 two legged vertical stirrups of 6 mm diameter bar at 150 mm c/c spacing.

2.Horizontal Steel Ah = (0.20 / 100) x 150 x 350
= $105\ mm^2$
i.e.$105\ mm^2$ on each face.

Provide 2- 8 mm dia. horizontal stirrups at 200mm c/c. on each face of the beam.

TABLEI. REINFORCEMENT OF BEAM DEPTH 350MM &375MM

Sr. No	*Type of reinforcement*	*Details of reinforcement*
1.	Main Steel	2-10 mm Φ (fe 415)
2	Side face reinforcement I. Vertical Steel II. Horizontal Steel	Two legged 8 mm dia. stirrups @ 190 mm c/c spacing (8 stirrups) 2-8 mm dia. @ 200 mm c/c spacing.

TABLE II. REINFORCEMENT OF BEAM DEPTH 400MM

Sr. No	*Type of reinforcement*	*Details of reinforcement*
1.	Main Steel	2-10 mm Φ (fe 415)
2	Side face reinforcement I. Vertical Steel II. Horizontal Steel	Two legged 8 mm dia. stirrups @ 190 mm c/c spacing (8 stirrups) 3-8 mm dia. @ 200 mm c/c spacing.

IV NON LINEAR FINITE ELEMENT ANALYSIS.

A. Element type

TABLE III. ELEMENT TYPE FOR MODEL

Sr. No	*Material type element*	*ANSYS13.0*
1.	Concrete	Solid65
2	Steel Reinforcement	Link180

A Solid65 element was used to model the concrete. This element has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions.. A schematic of the element was shown in Fig.1.

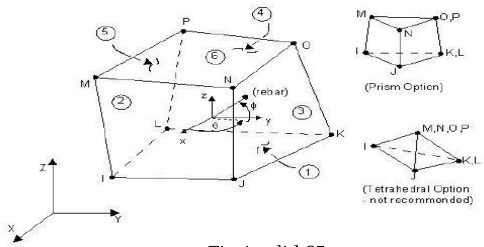

Fig.1 solid 65

A Link180 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.

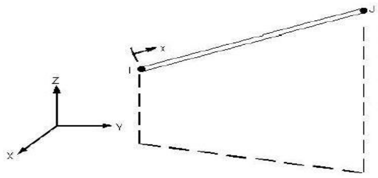

Fig.2 link 180

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 (m2) Initial strain	78.5e-6 0	- 0	- 0
3	LINK 8	Area (m2) Initial strain	50.24e-6 0	- 0	- 0

C.REAL CONSTANT

TABLE IV REAL CONSTANTS

D. Material properties

The material properties defined in the model are given in Table 4. For the reinforcing bars, the yield stress was obtained from the experimental test as fy = 432 MPa and the tangent modulus as 847 MPa. The concrete cube compressive strength fck determined from the experimental result is 44.22 MPa, 80% of which is used as the cylinder strength.The multilinear isotropic material uses the Von Mises failure criterion along with the Willam and Warnke (1974) model to define the failure of the concrete. Ec is the modulus of elasticity of the concrete, and ν is the Poisson's ratio. The characteristic strength of the concrete considered was 25 N/mm2 and the Poisson's ratio was 0.3.

$$E_c = 5000\sqrt{f}_{ck} = 2.5\ X\ 10^{10}\ \frac{N}{m^2}$$

The multilinear isotropic stressstrain curve for the concrete under compressive uniaxial loadingwas obtained using equation (Macgregor 1992).

$f = E_C\,\mathcal{E}/1+(\mathcal{E}/\mathcal{E}_0)^2$…………………

where,

f = stress at any strain ε,

ε = strain at stress f,

ε0 = strain at the ultimate compressive strength

D. Material properties

Material model no	***Element type***	***Material Properties***		
1	**Solid 65**	Multi linear Isotropic		
		Reference point	Strain	Stress
		Point 1	0.00036	9.802 e6 N/mm^2
		Point 2	0.00060	15.396 e6 N/mm^2
		Point 3	0.00130	27.517 e6 N/mm^2
		Point 4	0.00190	32.103 e6 N/mm^2
		Point 5	0.00243	33.096 e6 N/mm^2
		Concrete		
		Shear transfer coefficients for open crack		0.2
		Shear transfer coefficients for closed crack		0.9
		Uniaxial Tensile cracking Stress		3.78 e6 N/m^2
		Uniaxial crushing Stress		40 e6 N/m^2
		Biaxial crushing Stress		0
		Biaxial crushing Stress		0
		Ambient Hydrostatic stress state		0
		Biaxial crushing stress under ambient hydrostatic stress state		0
		uniaxial crushing stress under ambient hydrostatic stress state		0
		Stiffness multiplier for cracked tensile condition		0
2.	**Link8**	Steel		
		Linear Isotropic		
		E_X	$2.1X10^{11}$ N/m^2	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield Stress	$415X10^6$N/m^2	
		Tang Modulus	$20X10^6$ N/m^2	

E.Modelling

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 V. DIMENSIONS FOR CONCRETE

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

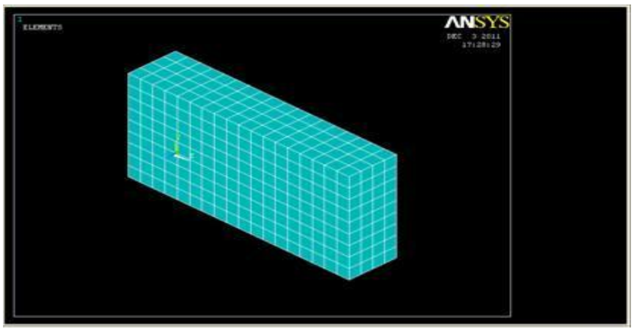

fig3.Finite element model & meshing

F.Meshing

To obtain good results from the Solid65 element, the use of a rectangular mesh was recommended. 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.

G. Loading and Boundary Conditions

Displacement boundary conditions were needed to constraint the model to get a unique solution. 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

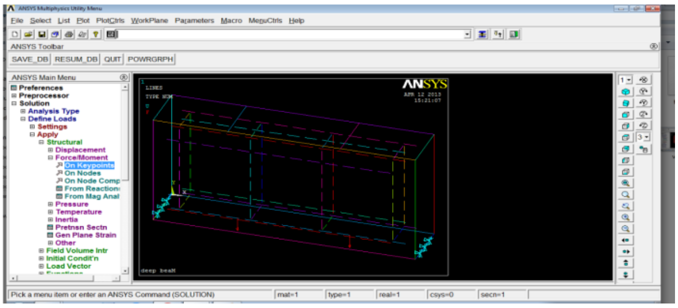

Fig.5.Loading and Boundary conditions

H. Cracking Patterns

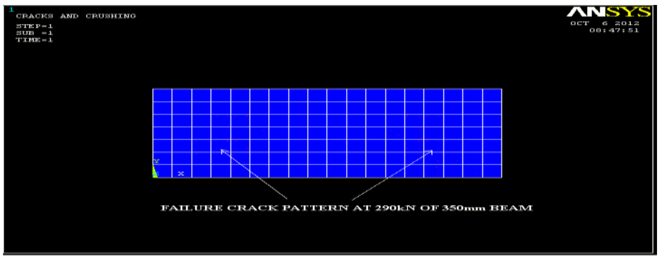

fig.6 Cracking

I. Deformed Shape

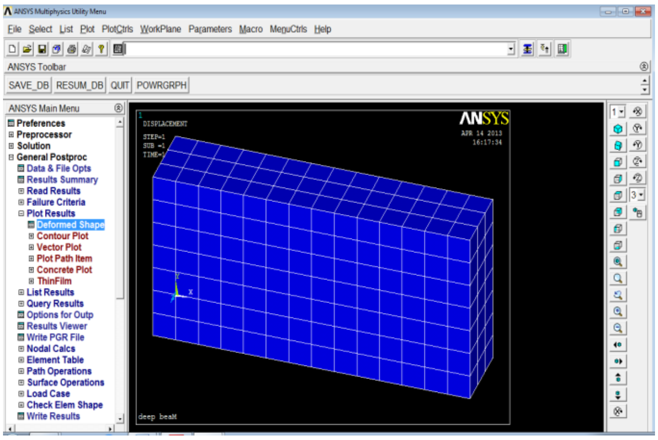

Fig.7.Deformed Shape

V.RESULTS & DISSCUSION

Design of deep beams by using IS 456-2000 for different Span to depth ratio the flexural steel required has nearly Same for beams. The deflection cracking and stress Distribution obtained after analysis is as below.

TABLE VI. RESULTS

Depth	400mm	375mm	350mm
Span to depth ratio	1.5	1.6	1.71
Flexural steel required in	85.06	95.862	102.689
Flexural steel provided in	157 2-10	157 2-10	157 2-10
Load at first crack	172	164	153
Load at failure	303	289	267
Deflection at first crack,mm	0.557	0.538	0.434
Deflection at failure,mm	1.269	1.186	1.230

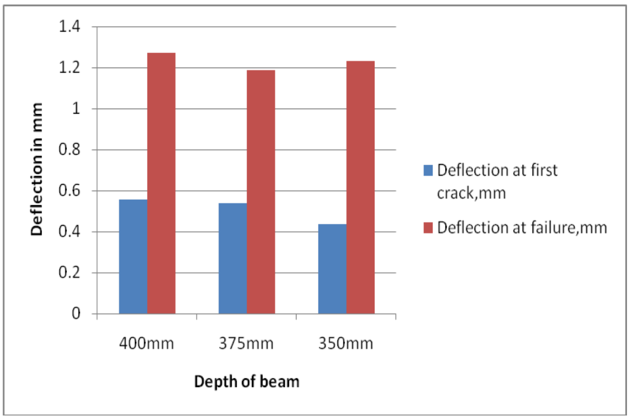

Fig.7 deflection of deep beam

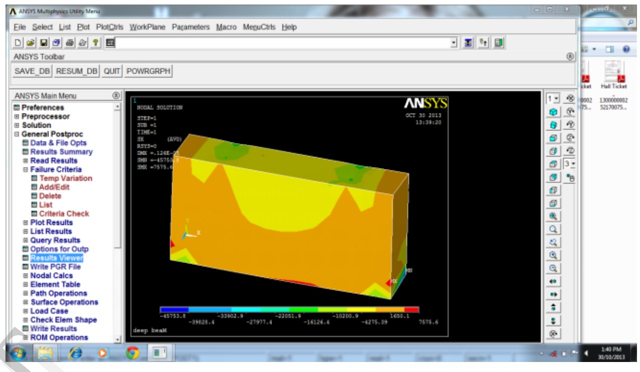

Fig.8 Stress distribution of deep beam

VI.CONCLUSION

It is well recognized that the exact analysis of concrete deep beams is a complex problem. This ease can be attributed to the use of computer programmes. In principle ANSYS has the capacity of idealizing any continuum into finer mesh which in turn enhances the results obtained, and with a high speed of operation. Starting from the literature survey regarding analysis of deep beams the different parameters that affect properties of deep beam were studied.After doing non linear finite element analysis of deep beam using ANSYS 13.0 following points to be concluded.

1. Deflection of beams increases as span to depth ratio decreases.
2. As span to depth ratio goes on decreasing the load at failure goes decreasing.

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