Study of Elastic Property of RC Beam under Static Load

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Abstract- *In structure analysis, especially in indeterminate structures, it becomes essential to know material and geometrical properties of members. The codal provisions recommend elastic properties of concrete and steel and are fairly accurate enough. As per the current I.S 456- 2000 codal provisions, modulus of elasticity of concrete is expressed as a function of grade of concrete. Also while performing analysis by any software for high rise building; cross area of plain concrete is taken into consideration whereas effects of reinforcement bars and concrete confined by stirrups are neglected. But, modulus of elasticity of concrete depends upon the percentage of reinforcement, and the spacing of stirrups, Depth of beam, Deflection at end of beam. The aim of this study is to determine Modulus of Elasticity of Reinforced Concrete by non-linear Finite Element Analysis (model size 300 x 500 x 6000 mm) with different grades of concrete (M20, M25, M30) with change percent of compression reinforced using ANSYS.*

Keywords- Reinforced Concrete Beam, Modulus of Elasticity, Finite Element analysis, ANSYS 14.0.

I. INTRODUCTION

Reinforced concrete is one of the most important building materials and is widely used in many types of structures. The economy, the efficiency, the strength and the stiffness of reinforced concrete make it an attractive material for a wide range of structural applications. The ultimate objective of the designer is to create a structure that is safe and economical. The safety and serviceability assessment of the structures necessitate the development of accurate and reliable methods and models for their analysis. The rise in cost of materials used in structures and labour costs encourage engineers to seek more economical alternative designs often resorting to innovative construction methods but without lowering the safety of the structure. In addition, the extent and impact of disaster in terms of human and economical loss in the event of structural failure promote designers to check the design thoroughly. The development of numerical models for the analysis of the response of RC structures is complicated due to following reasons.

a) Reinforced concrete is a composite material made up of concrete and steel, two materials with very different physical and mechanical behavior;
b) Concrete exhibits nonlinear behavior even under low level loading due to nonlinear material behavior, environmental effects, cracking, biaxial stiffening and strain softening;
c) Reinforcing steel and concrete interact in a complex way through bond-slip and aggregate interlock.

These complex phenomena have led engineers in the past to really heavily on empirical formulas for the design of concrete structures, which were derived from numerous experiments. With the advent of digital computers and powerful methods of analysis, much effort to develop analytical solutions which would obviate the need for experiments have been under taken by investigators.

II. METHODOLOGY

For the purpose of study the following specification is made for Doubly Reinforced section.

(A) Beam Size – the width and depth of the beam is 300mm and 500mm respectively.
(B) Span Length – 6000mm
(C) Grade of Concrete – M20, M25, M30.
(D) Grade of Steel – Fe 415 for all group specimen
(E) Percentage of Steel–0.34%, 0.47%, 0.54%, 0.60% and 0.743% are taken.
(F) Shear Reinforcement – 2 legged 8mm dia. bar
(G) Spacing of Stirrups – 250mm

2.1 Finite Element Modelling of Reinforced Concrete Beam:

Finite Element Analysis (FEA) represents a numerical method, which provides solution to problems that would otherwise be difficult to obtain. It is an effective method of determining the static performance of structures for three reasons which are saving in design time, cost effective in construction and increase the safety of the structure. The analysis of a structure with ANSYS is performed in three stages:

a) Pre-processing P – defining the finite element model and environmental factors to be applied to it.
b) Analysis solver – solution of finite element model.
c) Post-processing of results like deformations contours for displacement, etc., using visualization tools.

2.2 Element type used in Finite Element Model

(a) Reinforced concrete - The solid 65 element was used to model the concrete. This element has 8 nodes with 3degree of freedom at each node – translations in the nodal x, y, and z-directions. This element is capable of plastic deformation, cracking in three orthogonal direction, and crushing.

(b) Steel reinforcement – To model concrete reinforcing, one of two methods is following followed. In the first method, the reinforcing is simulated as spar element with geometric properties similar to the original reinforcing. These elements can directly be generated from the nodes in the model. This method of discretization is useful in simple concrete models. The second method of steel reinforcing is the smeared concrete element method. Cracks can also be analysed into either the discrete type or smeared type. Link 180 element is used to model steel reinforcement in this paper. This element is a 3D spar element. It has three nodes with two degrees of freedom – translations in the nodal x, y, and z-directions being also capable of plastic deformation.

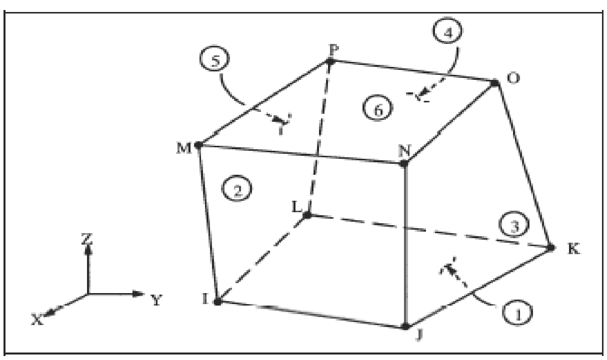

Fig.1 Solid 65 - 3D reinforced concrete solid element

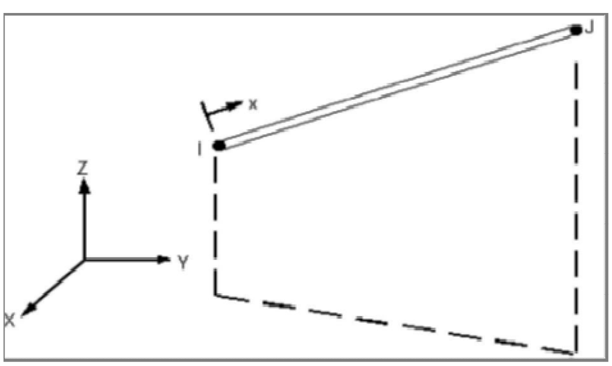

Fig.2 Link 180 element

2.3 Real Constants

Individual element contains different real constants. Real constant set 1 is used to for the solid 65element. Real constant sets 2, 3, 4, 5 are defined for the Link 180 element. Values of cross sectional area and initial strain are entered. A value of zero is entered for the initial strain because there is no initial strain in the reinforcement.

2.4 Modelling of the Beam– The beam can be modelled using solid 65 and link 180.

(a) Material Properties– Two material models are given: material 1 for concrete and material 2 for steel. Solid65 element requires linear and multi-linear isotropic material properties to properly model concrete.

For material model 1

Table 1 Linear Isotropic Properties

f_{ck} (N/mm^2)	Modulus of Elasticity EX (N/mm^2)	Poisson's Ratio (PRXY)
20	21967	0.2
25	24741	0.2
30	27117	0.2

Multi-linear isotropic properties- In the present numerical analysis, the uniaxial behaviour of concrete was modelled by the numerical expression proposed by Desayi and Krishnan [1965] incorporating the modification proposed by Gere and Timoshenko [1997].

Table 2 Stress-strain input data for different grade of concrete

M 20		M 25		M30	
Strain	Stress	Strain	Stress	Strain	Stress
0.000183	4.02	0.000203	5.03	0.00022	6.02
0.000275	6.01	0.000275	8.49	0.000275	7.42
0.0005	10.37	0.0005	11.77	0.0005	13.02
0.001	17.04	0.001	20.00	0.001	22.66
0.0012	18.51	0.0012	22.06	0.0012	25.28
0.0014	19.42	0.0014	23.49	0.0014	27.22
0.0016	19.89	0.0016	24.39	0.0016	28.57
0.0018	20.00	0.0018	24.86	0.0018	29.42
0.002	20.00	0.002	25.00	0.002	30.00
0..035	20.00	0.0035	25.00	0.0035	30.00

Open shear transfer co-efficient = 0.3
Closed shear transfer co-efficient = 1
Uniaxial cracking strength = 3.13 N/mm^2
Uniaxial crushing strength = 20 N/mm^2

For material model 2

Linear isotropic properties

Modulus of elasticity EX – 200000 N/mm^2
Poisson"s ratio PRXY – 0.3

Bilinear isotropic

Yield stress – 415 N/mm^2
Tangent modulus- 20 N/mm^2

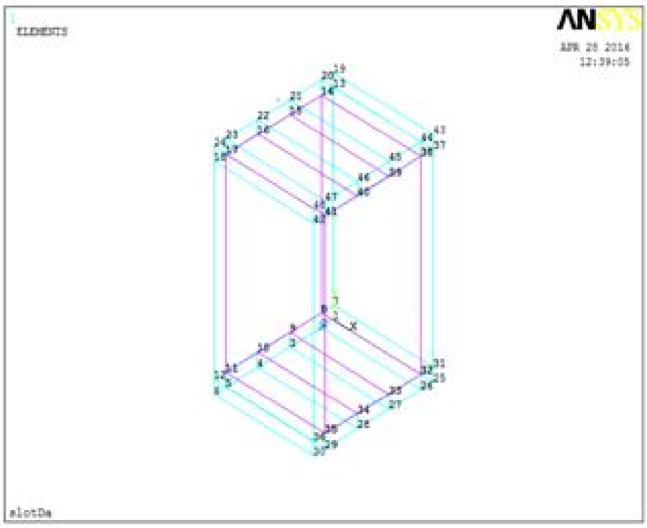

Fig.3 Element connectivity in FE model

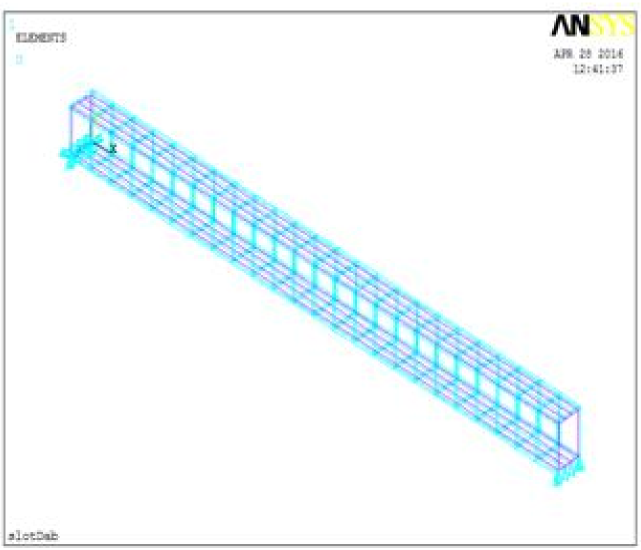

Fig. 4 FE model for beam specimen

2.5 Loading and Boundary Condition:

Horizontal and vertical restraints, representing a simply supported at both end of the beam. The load is applied at the center of the span.

2.6 Finite Element Discretization

The model is divided into a no. of small elements, and after loading stress and strain is calculated at integration points of these small elements.

2.7 Nonlinear Solution

In nonlinear solution, the total load applied to a finite element model is divided into a series of load increment called load steps. The ANSYS program uses Newton-Raphson equilibrium iterations for updating the model stiffness. In this study, for the reinforced concrete solid elements, convergence criteria is based on force and displacement, and the convergence tolerance limits is initially selected by the ANSYS program. It is found that convergence of solutions for the models is difficult to achieve due to the nonlinear behaviour of reinforced concrete. Therefore, the convergence tolerance limits is increased to a maximum of 5 times the default tolerance limits(0.5 % for force checking and 5% for displacement checking) in order to obtain convergence of the solutions.

2.8 Load Stepping and Failure Definition for FE Models

For the nonlinear analysis, automatic time stepping in the ANSYS program predicts and controls load step sizes. Based on the previous solution history and the physics of the models, if the convergence behaviour is smooth, automatic time stepping will increase the load increment up to a selected maximum load step size. If the convergence behaviour is abrupt, automatic time stepping bisect the load increment until it is equal to a selected minimum load step size. The maximum and minimum load step sizes are required for the automatic time stepping.

III. FINITE ELEMENT ANALYSIS

For the analysis of the RC beam, six combinations of different diameter of bars are used in tension reinforcement. The five models of M20, M25 and M30 grade of concrete with percentage of reinforcement varying from 0.34 to 0.74% are presented.

Table 3 Combination of Reinforcement for Midpoint Test

Model No.		Diameter of Bars (mm)	No. of Bars	Area of Compression steel (mm^2)	% of Steel (p_c)
M20	A_1	4#12ϕ	4	452.38	0.34
	A_2	2#20 ϕ	2	628.31	0.47
	A_3	2#16+1#20 ϕ	3	716.8	0.54
	A_4	4#16 ϕ	4	804.6	0.60
	A_5	2#25 ϕ	2	981.74	0.74
M25	B_1	4#12ϕ	4	452.38	0.34
	B_2	2#20 ϕ	2	628.31	0.47
	B_3	2#16+1#20 ϕ	3	716.8	0.54
	B_4	4#16 ϕ	4	804.6	0.60
	B_5	2#25 ϕ	2	981.74	0.74
M30	C_1	4#12ϕ	4	452.38	0.34
	C_2	2#20 ϕ	2	628.31	0.47
	C_3	2#16+1#20 ϕ	3	716.8	0.54
	C_4	4#16 ϕ	4	804.6	0.60
	C_5	2#25 ϕ	2	981.74	0.74

Table 4Combination of Reinforcement for two point test

Model No.		Diameter of Bars (mm)	No. of Bars	Area of Compression steel (mm^2)	% of Steel (p_c)
M20	D_1	4#12ϕ	4	452.38	0.34
	D_2	2#20 ϕ	2	628.31	0.47
	D_3	2#16+1#20 ϕ	3	716.8	0.54
	D_4	4#16 ϕ	4	804.6	0.60
	D_5	2#25 ϕ	2	981.74	0.74
M25	E_1	4#12ϕ	4	452.38	0.34
	E_2	2#20 ϕ	2	628.31	0.47
	E_3	2#16+1#20 ϕ	3	716.8	0.54
	E_4	4#16 ϕ	4	804.6	0.60
	E_5	2#25 ϕ	2	981.74	0.74
M30	F_1	4#12ϕ	4	452.38	0.34
	F_2	2#20 ϕ	2	628.31	0.47
	F_3	2#16+1#20 ϕ	3	716.8	0.54
	F_4	4#16 ϕ	4	804.6	0.60
	F_5	2#25 ϕ	2	981.74	0.74

IV. ANALYSIS OF THE MODELS

In the nonlinear region of the response, subsequent cracking occurs as more loads are applied to the beam. Cracking increases in the constant moment region, and the beam starts cracking outwards the support. Figures show in below represent the first crack, deformation, elastic strain for RCC beam.

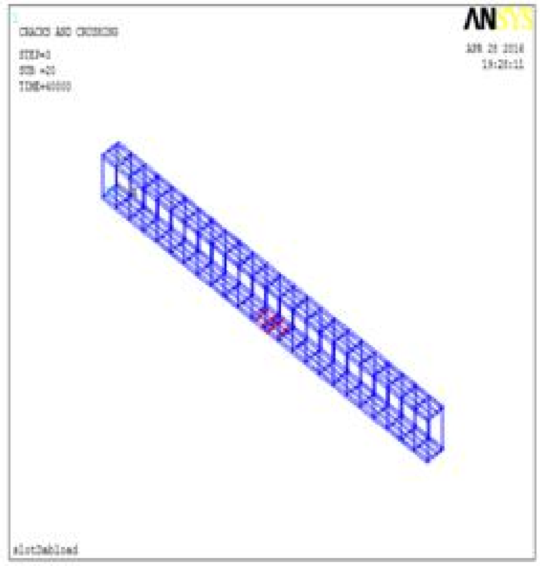

Fig.5 First crack in beam specimen

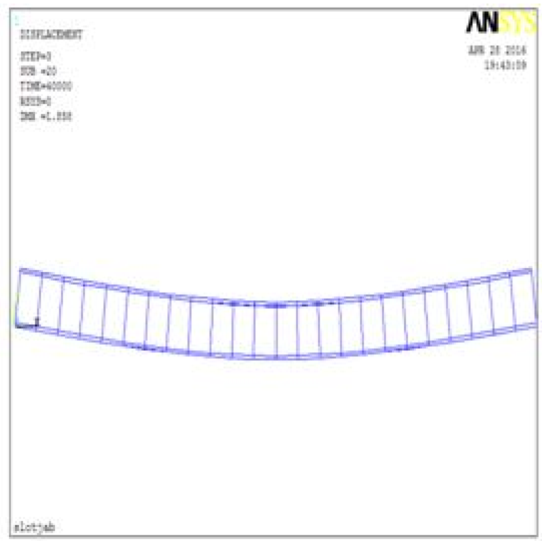

Fig.6 deflection in beam specimen

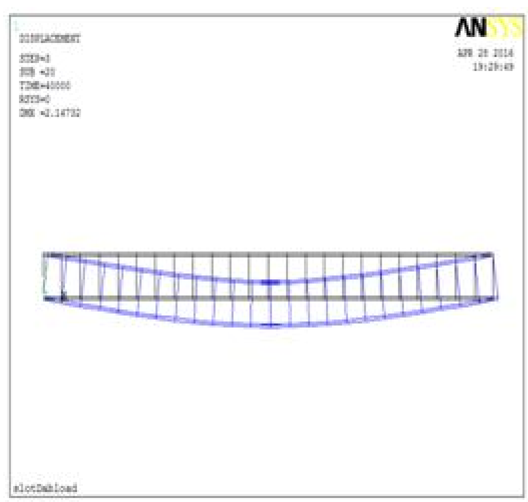

Fig.7 deformed &undeformed beam specimen

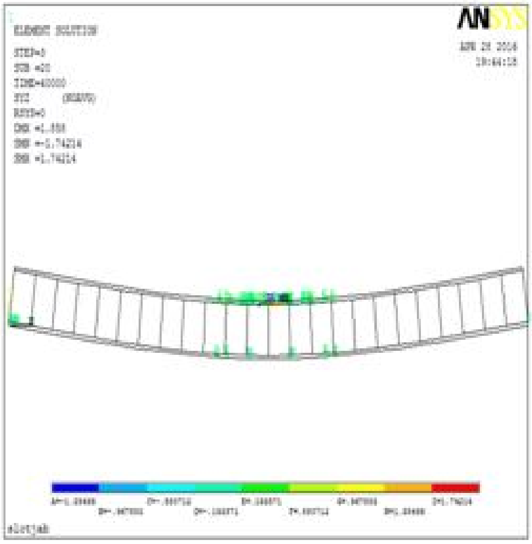

Fig.8 shear-stress in YZ direction in beam specimens

Figures 9 to 11 represent load deflection curve for RCC beam specimen of different grade of concrete. In these specimens, because of reinforcement, the load at elastic limit as well as the failure load was observed higher. The deflections measured for all the specimens.

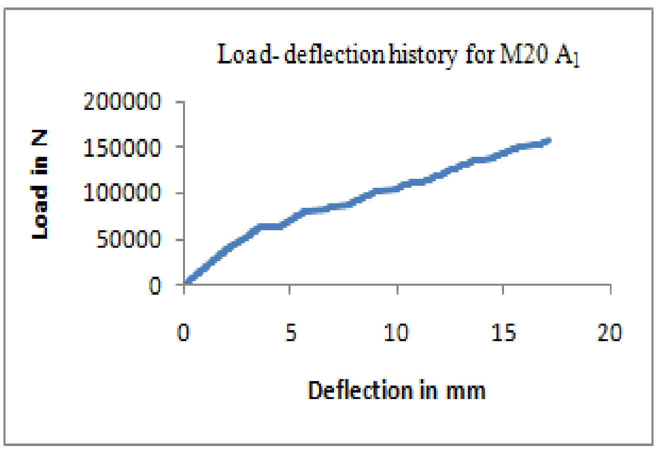

Fig.9 Load-Deflection curve for A_1

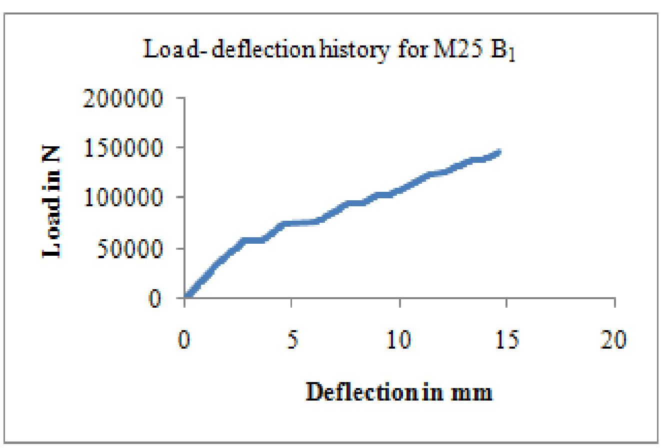

Fig.10 Load-Deflection curve for M25 B_1

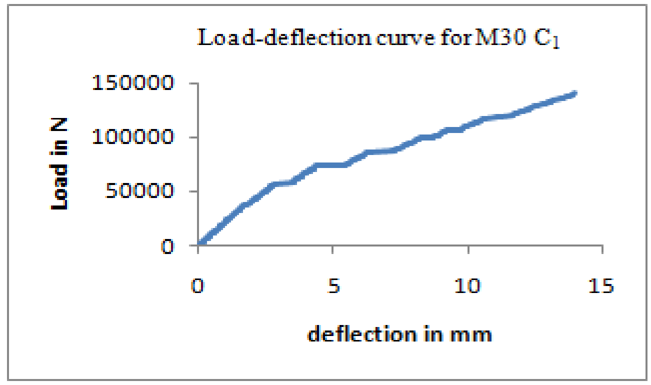

Fig.11 Load-Deflection curve for M30 C_1

4.1 EVALUATION OF 'E' OF RC BEAM FOR DIFFERENT GRADE OF CONCRETE

1. For a beam subjected to mid-point loading the deflection formula is as follows:

$$\delta = \frac{5wl^4}{384\,EI} + \frac{Wl^3}{48EI}$$

2. For a beam subjected to two- point loading the deflection formula is as follows:

$$\delta = \frac{5wl^4}{384\,EI} + \frac{23Wl^3}{648EI}$$

Where *w* is self-weight of beam in N/mm and W is the load at failure in N. The value of deflection is substituted in the above equations for each case. By substituting proper values of w, W, *l*, and I, the remaining unknown value i.e., E is evaluated. The value of W substituted in this expression is corresponding to first crack.

Table 5: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity (N/mm^2)
A_1	0.34%	79092.00
A_2	0.47%	81020.60
A_3	0.54%	82033.24
A_4	0.60%	83844.39
A_5	0.74%	840782.9

Table 6: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity(N/mm^2)
B_1	0.34%	91506.81
B_2	0.47%	92841.30
B_3	0.54%	94029.80
B_4	0.60%	94269.60
B_5	0.74%	95018.30

Table 7: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity (N/mm²)
C_1	0.34%	102047.6
C_2	0.47%	102805.8
C_3	0.54%	102948.7
C_4	0.60%	103807.6
C_5	0.74%	104038.2

Table 8: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity (N/mm²)
D_1	0.34%	70964.7
D_2	0.47%	71007.5
D_3	0.54%	71193.4
D_4	0.60%	72619.4
D_5	0.74%	74017.3

Table 9: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity (N/mm²)
E_1	0.34%	81617.7
E_2	0.47%	82947.12
E_3	0.54%	83165.45
E_4	0.60%	85302.38
E_5	0.74%	85562.27

Table 10: Percentage of Compression Steel and corresponding "E" value of Reinforced Concrete

Model No.	% of Compression Steel	Modulus of Elasticity (N/mm²)
F_1	0.34%	90671.10
F_2	0.47%	92001.60
F_3	054%	93333.40
F_4	0.60%	96362.70
F_5	0.74%	97080.48

V. CONCLUSION

1. It has been observed from the above result that the Modulus of Elasticity for RCC is more than the Modulus of Elasticity of PCC and hence deformations are expected to be on lower side.
2. It has been found from the result that Modulus of Elasticity of RCC beam in increase with the increase in percent of compression reinforcement for all grade of concrete (M20, M25, M30) under midpoint loading test.
3. It has been found that the Modulus of Elasticity of beam specimens increase with the increase in percentage of compression reinforcement for all grade of concrete (M20, M25, M30) under two-point loading test.
4. Further, It has been found that the increase in percentage of steel reinforcement increases the flexural rigidity of the beam specimens.

VI. SCOPE FOR FUTURE WORK

Additional work may be undertaken in the determination of modulus of elasticity:

1. Analysis can be carried out for higher grades of concrete(i.e. M35, M40 and M45)in order to obtain the Modulus of Elasticity on wider scale.
2. Analysis can also be extended for different depth of beam specimens.
3. Further the boundary conditions of the beam can also be varied.
4. Effect of change in spacing of shear reinforcement can also studied.

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