ANALYTICAL INVESTIGATIONS ON REINFORCED CONCRETE BEAMS

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Abstract - *Structural analysis is used to assess the behavior of engineering structures under the application of various loads. Commonly used structural analysis methods include analytical methods, experimental methods and numerical methods. Analytical methods provide accurate solutions with applications limited to simple geometrics. Experimental methods are used to test prototypes or full scale models. There are various finite element software packages such as ATENA, ABAQUS, Hypermesh, Nastran and ANSYS. ANSYS (Analysis System), an efficient finite element package is used for nonlinear analysis of the present study.*

This paper presents an attempt made to study the analytical investigations done on flexural behavior of reinforced concrete beams. The grades chosen for the investigation were M-30, M-40 and M-50. For analytical study, the beam specimen of 100x200x2000mm was considered. The percentage of reinforcement was varied in the range of 1.10, 1.30 and 1.70 for the mixes designed. It was observed that the results obtained with finite modeling software ANSYS were in par with the experimental values of reinforced concrete beams.

Key Words: **ANSYS, Compressive strength, Flexural strength, Deflection, percentage of reinforcement**

1. INTRODUCTION

Concrete is the most widely used construction material in the world. It is often referred to as the universal material. Its annual consumption is around 20 billion tons per year, which is equivalent to 2 tons per every living person, speaks of immense potential which can affect the economy of a country [1]. Jayajothi [2] conducted experimental investigations on reinforced concrete beams strengthened in flexure and shear by fibre reinforced polymer laminates and compared the results with the analytical model and finally concluded that the results obtained with analytical model are in match with the experimental results. Anthony J. et al [3] made an attempt to study behavior of reinforced and prestressed concrete beams using ANSYS. In his model he studied on crack behavior, load-deflection curve of control beam, behavior of reinforcement etc., and finally noticed that the results of analytical model are comparable with experimental work. Amer Ibrahim [4] studied the behavior of RC beams by ANSYS. He concluded that the results obtained from finite element models are in good agreement with the test data. The analytical results were slightly on the conservative side as compared with the conventional concrete. Barbosa et al. [5] considered the practical application of nonlinear models in the analysis of reinforced concrete structures and the consequences of small changes in modeling. The best results were obtained from the elastoplastic-perfectly plastic, work-hardening models that reached ultimate loads, very close to the predicted values.

1.1 Experimental Investigations

Materials:

The following materials have been used in the experimental study [6]

a) Ordinary Portland cement having specific gravity 3.15, confirming to IS: 8112-1989 [7].
b) Fine aggregate: Sand confirming to Zone –III of IS:383-1970 [8, 9] having specific gravity 2.61 and fineness modulus of 2.70.
c) Coarse aggregate: Crushed granite metal confirming to IS:383-1970 having specific gravity 2.70 and fineness modulus of 6.80.
d) Water : Clean Potable water for mixing
e) Superplasticizer : Conplast (SP-430) having specific gravity 1.205 confirming to IS: 9103-1999 [10]

Details of tests conducted and specimens used are given in Table 1. Tests were conducted on specimen of standard size as per IS:516-1959 [11].

Table -1: Details of tests conducted

Type of test	Size of specimen	No. of specimen cast for different grades
Compressive strength (Cube)	150x150x150mm	3
Flexural strength (Beam)	100x200x2000mm	3

1.2 Mix design of conventional concrete

The details of mix design and its proportions for different grades of OPC are given in Table 2 as per IS:10262-2009 [12]. The details of design mix and its proportions are presented in Table 2.

Table 2 : Final mix proportions with conventional concrete for various grades

Grade	M30	M40	M50
W-C ratio	0.45	0.40 (SP=1%)	0.35 (SP=1.5%)
Water (kg/m³)	197	148	148
Cement (kg/m³)	438	370	370
Fine aggregate (kg/m³)	640	809	807
Coarse aggregate (kg/m³)	1128	1137	1134
Density (kg/m³)	2403	2408	2411
Mix proportions	0.45:1:1.46:2.57	0.40:1:2.19:3.07	0.35:1:2.18:3.07
Slump (mm)	110	98	90
Compressive strength (MPa)	35	52	63

1.3 Flexural test setup

The beam specimens were 100mm wide and 200mm deep in cross section. They were 2000mm in length and simply supported over an effective span of 1900 mm. The clear cover of the beam was 25mm. The beams designed for different grades were under reinforced; the percentages of tensile reinforcement used are given in Table 3. The test specimen was mounted in a loading frame of 1000 kN capacity.

The load was applied on two point of 633 mm away from centre of the beam towards the support. The beams were cleaned and white washed with a thin coat of white surface to facilitate the detection of cracks and the propagation of cracks. Dial gauges are used having a magnetic base. The least count of dial gauge was 0.01 mm and can measure deflection of 5mm has after which has to rested. The points at which dial gauges to be fixed were cleaned.

Table 3 Details of beams with percentage reinforcements

Grade of concrete	% of tensile reinforcement	Reinforcement provided		Stirrups
		Top	Bottom	
M30	1.10	2-Y10	2-Y12	Y8@125cc
M40	1.30	2-Y10	3-Y12	Y8@125cc
M50	1.70	2-Y10	3-Y12	Y8@125cc

2.0 Finite Element modeling

Analytical methods provide accurate solutions with applications limited to simple geometrics. Numerical methods are the most sought-after technique for engineering analysis which can treat complex geometries also. Among many numerical methods, finite element analysis is the most versatile and comprehensive numerical technique in the hands of engineers today. The finite element method has become very popular among engineers and researchers as it is considered to be one of the best methods for solving complex engineering problems efficiently.

2.1 Element type

2.1.1 Concrete (Solid 65) : The concrete in RCC works is directly subjected to compressive loads, hence to model a beam the prime importance will be given for the stress-strain relation in compression. For the present study the solid 65 is taken as an element to model the concrete. The features of solid 65 element is that it has eight nodes with three degrees of freedom at each node. It is capable of plastic deformation, cracking in three orthogonal directions, and crushing.

2.1.2 Reinforcing steel (3D SPAR-LINK 8)

Reinforcement is modeled through link 8. Link 8 is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. The material property assumed for the modeling is given in Table 4.

Table 4 Material properties for ANSYS

Material Property	Values
Modulus of elasticity	22360 N/mm²
Ultimate uniaxial compressive strength	30 and 40 N/mm²
Poisson's ratio	0.20
Shear coefficient for open crack	0.30

2.2 Beam model in finite element analysis

The beam was modeled with the required parameters as presented in the previous sections. The beams were modeled, the schematic representation of meshing, rebar arrangement and application of load on the model etc., are as shown in Fig. 1 and 2. The sequence of modeling operation was with the same guidelines mentioned, in ANSYS manual version 12. [13].

3.0 Results and Discussions

3.1 Behaviour of beams

The beam specimens used in this investigation were tested under two point static loading until failure. The most common thing observed was as the load on the beam increased, it started to deflect and flexural cracks developed along the span. The entire beam specimen failed in the same fashion due to yielding of the tensile steel (primary tension failure) followed by crushing of concrete at the compression face (secondary compression failure). During the testing of beams the events that occurred are first cracking, yielding of the tensile reinforcement, crushing of concrete at the compression face and spalling of concrete cover as shown in Fig. 3.

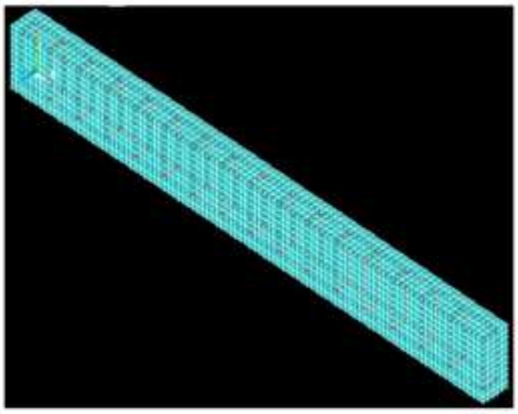

Fig. 1 Beam model in ANSYS after meshing

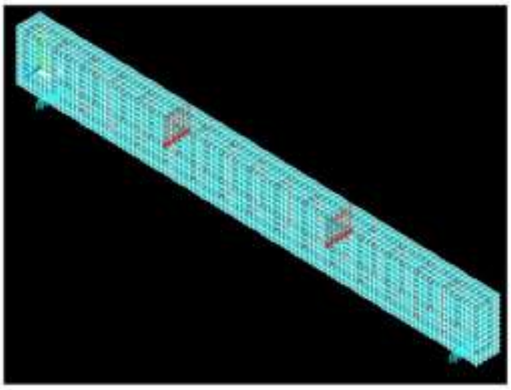

Fig. 2 Beam model with reinforcement and application of load

Fig. 3 Beam tested in flexural

3.2 Flexural capacity

The details of test beam specimens are presented in Table 5. The flexural capacity of the beams was influenced by the longitudinal tensile reinforcement ratio and the concrete compressive strength. As the longitudinal tensile reinforcement ratio increased, the flexural capacity of the beams increased significantly. Based on ultimate capacity of the beam, the service moment of the same was determined by dividing the obtained ultimate moment with factor of safety. The flexural capacity varied more or less marginally with the increase in the compressive strength of the concrete.

Table 5 Parameters observed on reinforced beam

Grade of concrete	First crack Load (kN)		Ultimate Load (kN)		Deflection	
	Experimental	ANSYS	Experimental	ANSYS	Experimental	ANSYS
M30	9.4	9.9	47	50	20	21
M40	13.8	14.3	69	74	16	17
M50	13.2	14.6	66	72	16	17

4.0 Validation of analytical values with experimental results

4.1 Load-deflection curve

Deflection is also discussed as one of the important serviceability limit states and it is to be satisfied in the design of structures. IS:456-2000 [14] recommends a ratio of (L/d) ≤ 20, which is sufficient to restrict the deflections to an in case of simply supported beam. The load deflection curves obtained from the experimental investigations are compared with the analytical results as presented in Fig. 4 to 6. From the data, it was observed that the analytical approach has good correlation with the experimental values. The analytical results were about 8 to 14% more than that of the experimental values on an average. The range of values was on conservative side, when visualized with first crack load on finite element analysis. As the load increases the trend of results were in close with experimental values. The change observed may be due to the incompatibility to account the material properties assigned in the model as compared with the experimental beam. One more reason may due to the assumption done in finite element analysis that the bond between the reinforcing steel and concrete is perfect, but this may not be true in actual test beam, as we notice that there will be some amount of slip that has under gone when the loading on the specimen starts. The marginal difference in values was due to meshing of elements in the model. The typical deflection observed in finite element analysis is presented in Fig. 7.

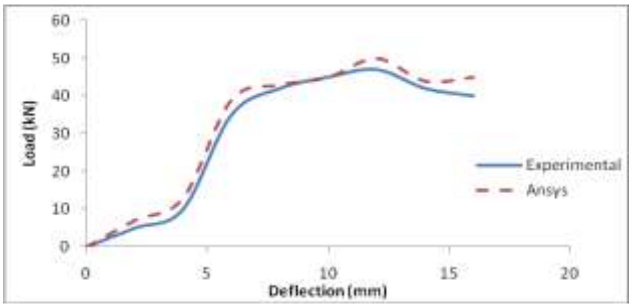

Fig. 4 Load Vs Deflection for M30 grade

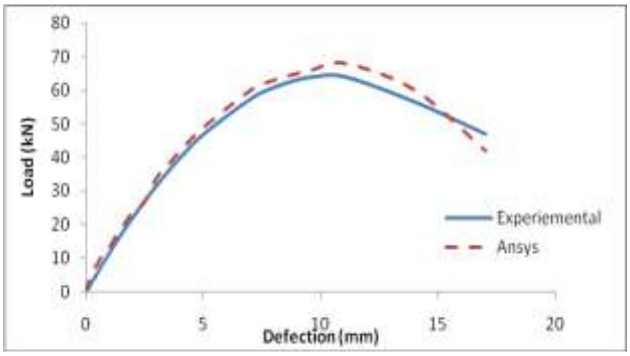

Fig. 5 Load Vs Deflection for M40 grade

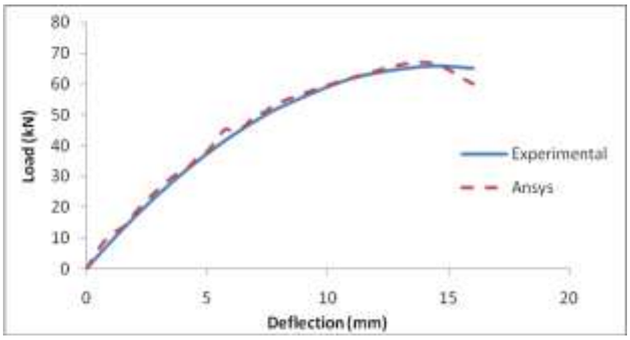

Fig. 6 Load Vs Deflection for M50 grade

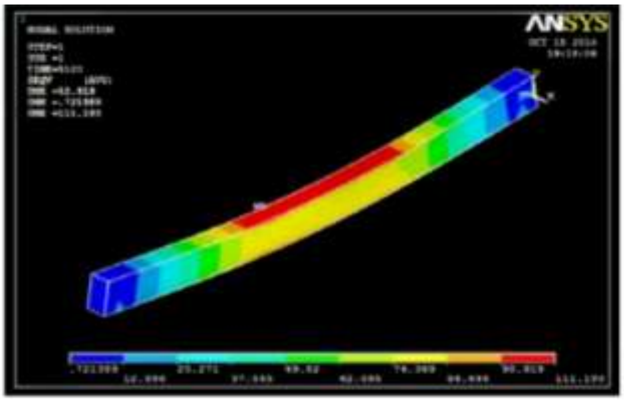

Fig. 7 Deflection of the beam observed in ANSYS

5. CONCLUSION

The reinforced concrete beams were modeled in finite element analysis package ANSYS. The results obtained were validated with the experimental values. In most of the cases, analytical approach was on conservative side. The change observed may be due to the incompatibility to account the material properties assigned in the model as compared with the experimental beam.

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