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A Study on Flexural Behavior of High Performance Concrete Beams using ANSYS

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Abstract: *A concrete beam is a structural element which carries load primarily in bending. Bending phenomenon causes a beam to undergo in tension and in compression. Beams carry vertical gravitational forces and can also be used to carry horizontal loads. These loads carried by beam are transferred to foundation. The beam compression section is designed to resist buckling and crushing, and tension section is designed to resist tension. Understanding the response of beam during loading is crucial for the development of an overall efficient and safe structure. Many methods have been adopted to study response of structural components. Recently Finite Element Analysis is also used to analyze structural components. In this paper, two point, single point and UDL bending analysis is carried out and behavior of the beam are analyzed and discussed. Finite Element software ANSYS 11.0 is used for modeling and analysis by conducting non linear static analysis.*

Keywords: *Finite Element Analysis, Two point loading, Single point loading, UDL*

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I. Introduction

Experimental based testing is widely used to analyze every individual element of structure and effect on concrete strength under loading condition. This experimental method is the method which produces real life response, this is very time consuming, and use of materials for the purpose of testing can be quite costly. Finite element analysis method is also used to study these structural components. Unfortunately the attempts made to accomplish this in early days were also very time consuming. The use of computer software to model elements are much faster, and extremely cost effective. To fully understand the capabilities of finite element computer software, one must look back to experimental data and simple analysis. Data obtained from the finite element analysis is not useful unless the necessary steps are taken to understand what is happening within the model that is created using the software. Also, executing the necessary checks along the way is key to make sure that what is being output by computer software is valid(4).

Finite element method is a numerical analysis method that divides the structural element into smaller parts and then simulates static loading conditions to evaluate the response of concrete. The use of this technique is increasing because of enormous advancement of engineering and computer knowledge. This method respond well to nonlinear analysis as each component possesses different stress-strain behavior. The response of each element is expressed in terms of a finite numbers of degrees of freedom characterized as the value of an unknown function at a set of nodal points.(8)

In reality most of the problems are non linear in nature. Hence nonlinear analysis is an effective tool to obtain exact solutions. Nonlinear behavior of reinforced concrete beam is complex due to various parameters. Non-linearity may be geometric or material nonlinearity. Material nonlinearity contains nonlinear stress strain relationship of material and hence modulus of elasticity is not a unique value. In this study, nonlinear finite element analysis is carried out using ANSYS. Many attempts have been made by past researches to predict the behavior using ANSYS. Thus in present study an attempt is made to perform nonlinear finite element analysis to analyze the high performance reinforced concrete beam for different loading conditions and with and without steel plates.

II. Problem considered for study

To study the concrete strength and individual component of member under various loading conditions experimental analysis is widely carried out. This experimental method provides the actual behavior of the structure. But as this method is very expensive and time consuming Finite Element Analysis is also used to analyze these structural components.FEA is a method used for the evaluation of structures, providing an accurate prediction of the components response which are subjected to various structural loads. The use of FEA has been the preferred method to study the behavior of concrete as it is much faster than the experimental method and is cost effective.

2.1 Geometry of beam

The geometry of full size beam is 2300mm x 150mm x 300mm. The span between two support is 2000mm. the beam is simply supported by providing hinged support at one end roller support at the other end. Two point loads, single point loads are applied at the midspan of the beam and uniformly distributed load is applied throughout the entire span of the beam. M80, M100 grade of concrete and Fe 415 steel is used. The details of the high performance RC beams are shown in fig 1.

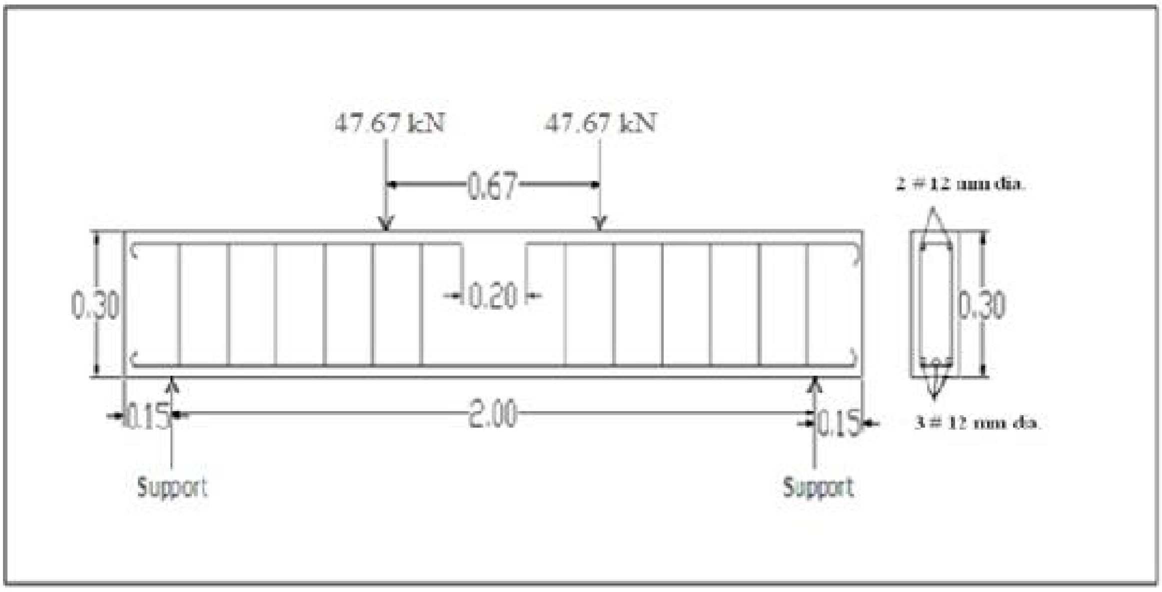

Fig 1 : Beam considered for the study

III. Material properties

3.1 Concrete properties.

Concrete is a brittle material and has exhibit different behavior in compression and tension. The tensile strength of concrete is typically 8-15% of the compressive strength. The modulus of elasticity of concrete is calculated as 47170 Mpa as per IS 456:2000. Poisson's ratio is 0.175. The shear transfer coefficient for open and closed crack are 0.3 and 0.9 respectively. Uniaxial tensile cracking stress is -1. Concrete material properties are shown in table 1 below.

3.2 Steel Reinforcement

The steel reinforcement in high-performance RC beam is of grade Fe 415. The steel for the finite element models has been assumed to be an elastic, perfectly plastic material and identical in tension and compression. In this study for steel reinforcement Poisson's ratio of 0.25 is used for all reinforcing bars. Steel plates were provided at the location of supports and loading points in FE model in order to provide a more even stress distribution over the support and loading areas. Elastic modulus of 213150Mpa and Poisson's ratio of 0.25 were used for the plates. Steel plates were assumed to be linear elastic material.[8]

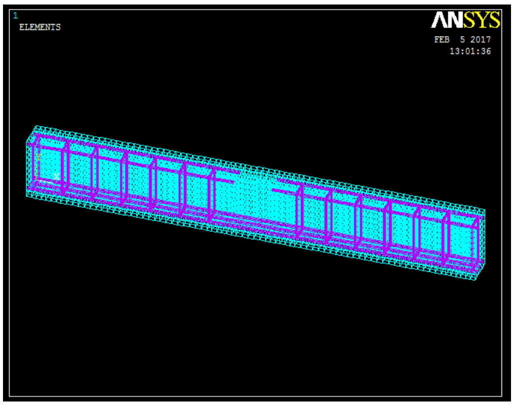

Fig 2 : Steel reinforcement pattern

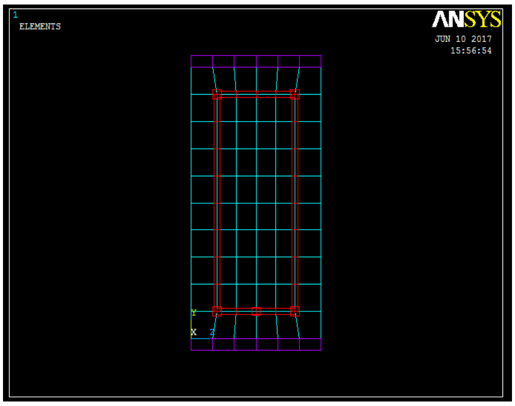

Fig 3 : Section of Steel reinforcement

3.3 Compressive uniaxial stress strain relationship

The ANSYS program requires the uniaxial stress strain relationship for concrete in compression. The Solid65 element requires linear isotropic and multilinear isotropic material properties in order to model concrete beam properly. The multilinear isotropic material uses the Von-Mises failure criterion to define the failure of the concrete.(4) Simplified stress strain relationship for concrete in compression is obtained and is shown in Fig 2.

	Element type	**Material properties**		
		Linear isotropic		
		EX(MPa)	47170	
		PRXY	0.175	
		Multilinear isotropic		
		Reference point	Strain	Stress(MPa)
		1.Point	0.000249	10
		2. Point	0.0005	20
		3. Point	0.0008	30
		4. Point	0.00011	40
		5. Point	0.0014	50
		6. Point	0.00185	60
		7. Point	0.0023	70
		8. Point	0.00295	72.5
		Concrete		
		ShrCf-Op.	0.3	
		ShrCf-Cl	0.9	
		UnTensSt. (MPa)	-1	
		UnCompSt.(MPa)	-1	
		BiCompSt.	0	
		HydroPrs.	0	
		BiCompSt.	0	
		UnTensSt.	0	
		TenCrFac	0	
2.	Solid45	**Linear isotropic**		
		EX(MPa)	213150	
		PRXY	0.25	
3.	Link8	EX(MPa	213150	
		PRXY	0.25	

Table no :1 Material properties

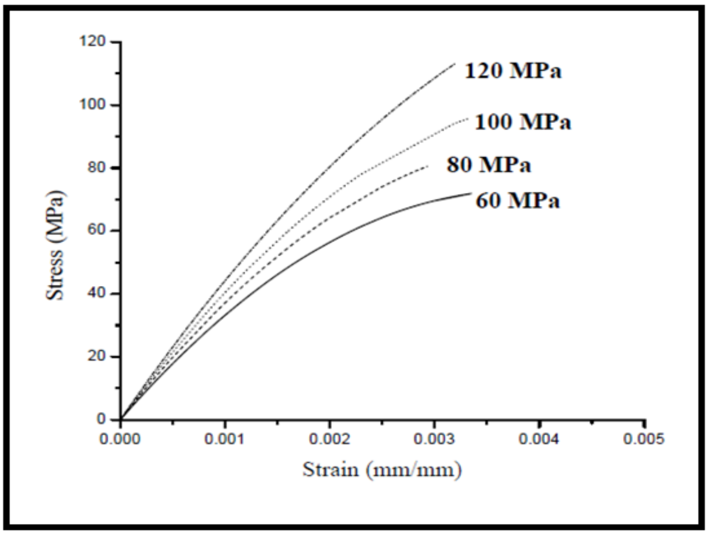

Fig 4 : Simplified uniaxial stress-strain curve for concrete.

3.4 Methodology

The high-performance concrete beam of size 150 x 300 x 2300 mm (M80, M100 grades of concrete) with different percentage of longitudinal reinforcement ratio 0.179 ρ_b, 0.251 ρ_b, 0.210 ρ_b were modeled using finite element method software . The beams were modeled using ANSYS software, they are analyzed for flexural behavior for different loading conditions and with and without steel plates. The properties maximum compressive stresses, maximum tensile stresses and maximum deflections are studied.

IV. Elements used for modeling

Concrete beam is modeled using Solid65 element which has three degrees of freedom at each node. Steel plates are modeled using Solid 45 element. Link180 spar element is used to model steel reinforcement.

4.1 Modeling of reinforced concrete beam.

The beam, plates and supports are modeled as volume. First a block of concrete beam is modeled and it is copied number of stirrups time to model a full beam. The dimensions of concrete volume are as shown in table 2.

Table no :2 Dimensions for Concrete, Steel Support and Steel Volumes

ANSYS	Concrete(mm)		Steel Plate(mm)		Steel Support(mm)	
X1,X2 X- coordinates	0	150	475	575	25	125
Y1,Y2 Y-coordinates	0	300	150	162.5	0	-12.5
Z1,Z2 Z-coordinates	0	150	0	150	0	150

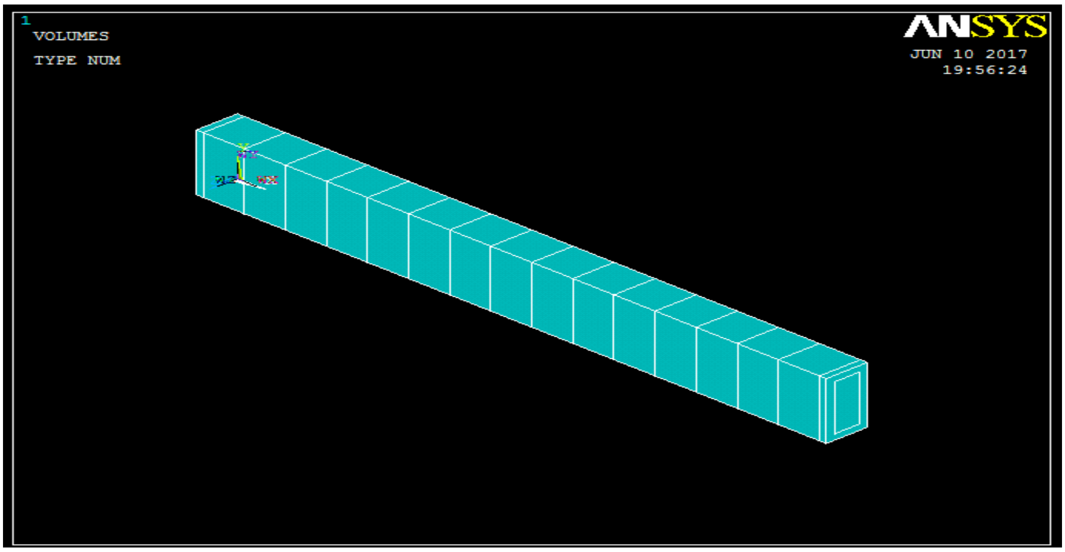

Fig 5. Volume created in ANSYS

4.2 Loading and Boundary conditions

To constraint the model Displacement boundary conditions are needed to get unique solution. To ensure that model acts in the same way as the experimental beam, at points of symmetry boundary conditions need to be applied, and wherever the supports and loading exist. The support was modeled as a roller support at one end and other end as a hinged support. A single line of nodes on the plate were given constraint in the UY, and UZ directions.

V. Type of Analysis

A nonlinear structural behavior is performed to study the nonlinear material behavior of concrete beam. ANSYS 11.0 employs:"Newton-Raphson" method to solve nonlinear problems. In order to predict the nonlinear behavior of beam, the load is sub divided in to series of load increments. The load increment can be applied over several load steps. The number of load steps required for the study is given and the time for each load step is mentioned.

VI. Results and Discussions

6.1 Compressive stress comparison for beams with different loading conditions

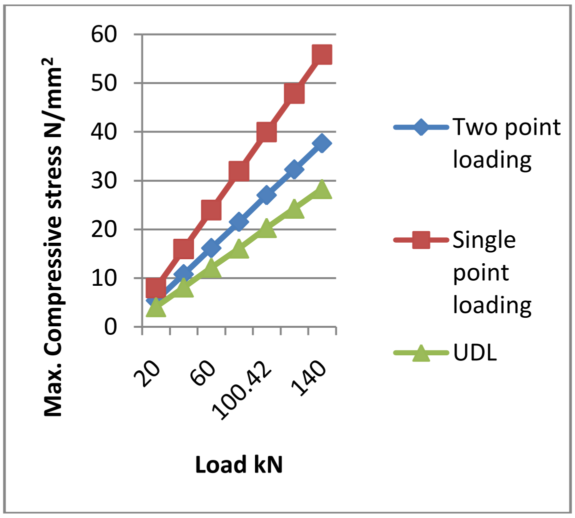

Fig 6: Load vs. Compressive stresses

Table:3 Compressive stresses for different Loading conditions

Grade of concrete	ratio	Two point loading	Single point loading	UDL
M80	0.179	5.419	7.977	4.086
	0.251	5.378	7.967	3.966
	0.210	5.384	7.93	4.033
M100	0.179	5.432	7.814	4.103
	0.251	5.319	7.804	3.988
	0.210	5.404	7.809	4.052

A study is performed on the beam to study the change in the behavior of stresses of the beam for different types of loading. When single point load is applied the compressive stresses of the beam were increased by 46% and when uniformly distributed load along the beam was applied the compressive stresses were decreased in average by75%.

6.2 Tensile stress comparison for beams with different loading conditions

comparison in the tensile stresses for flexural behavior of tensile stresses of high performance reinforced concrete beam is also studied for different longitudinal ratios.(0.179,0.251,0.210). load vs tensile stresses graph for all three longitudinal ratio's are done and behavior of beam is studied.

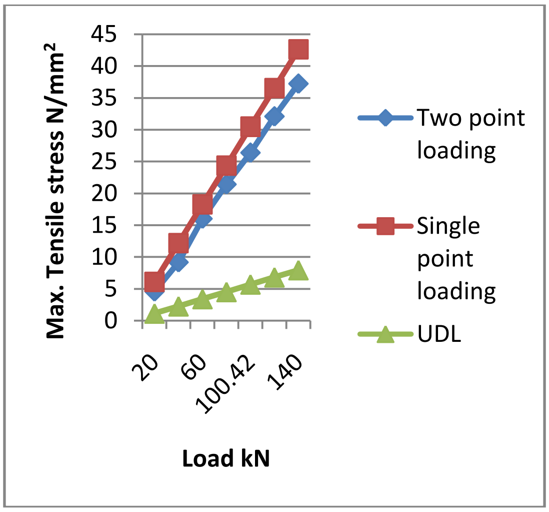

Fig 7: Load vs. Tensile stress

Table 4: Tensile stresses for different loading conditions

Grade of concrete	ratio	Two point loading	Single point loading	UDL
M80	0.179	4.595	6.092	1.133
	0.251	4.578	6.078	1.135
	0.210	4.587	6.086	1.131
M100	0.179	4.608	6.173	1.136
	0.251	4.499	6.159	1.138
	0.210	4.607	6.167	1.134

6.3 Deflection comparison for beams with different loading conditions

The change in the deflection of the beam during all three different types of loading for both grades of concrete for three different longitudinal ratio is observed. Deflection is more in case of single point loading, and is less in case of uniformly distributed load when compared to two point loading. It is also observed that deflection is slightly reduced as grade of concrete increases.

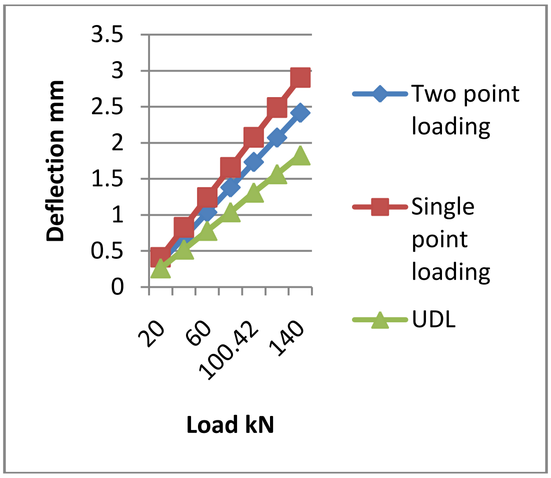

Fig 8: Load vs. Deflection

Table 5: Deflection for different loading Conditions

Grade of concrete	ratio	Two point loading	Single point loading	UDL
M80	0.179	0.334	0.417	0.262
	0.251	0.341	0.409	0.257
	0.210	0.345	0.414	0.260
M100	0.179	0.328	0.398	0.250
	0.251	0.325	0.391	0.245
	0.210	0.328	0.395	0.247

6.4 Effect of steel plates at support and loading points

SOLID 45 element which is bonded with the SOLID 65 element is used at the loading points and the support, in order to analyze the beam as same as it is tested during experimental work. The steel plates are also included to overcome the stress concentration problems. The loadings and the support conditions are applied at the nodes of the Solid 45 element and the effect of steel plates on the behavior of reinforced concrete beam is studied.

6.5 Comparison of load vs Tensile stress for beams with and without steel plates.

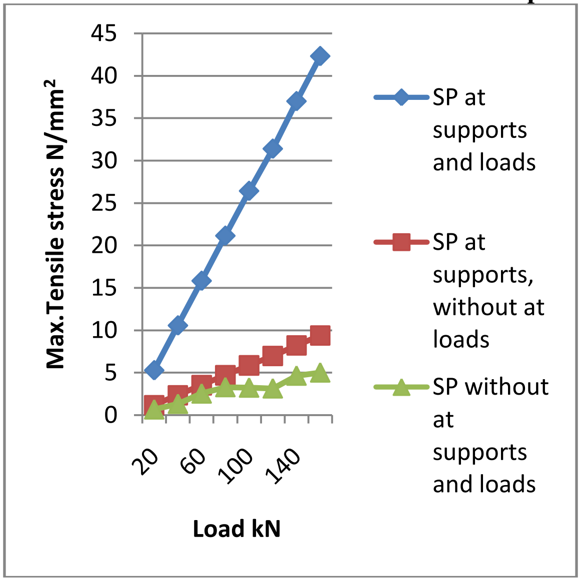

Fig 9: Load vs Tensile stress

Table 6: Tensile stresses without steel plates

Grade of concrete	ratio	With SP at Supports and loads	With SP at supports and Without at loads	Without SP at supports and loads
M80	0.179	5.478	1.167	0.687
	0.251	5.478	1.168	0.658
	0.210	5.535	1.165	0.658
M100	0.179	5.395	1.170	0.663
	0.251	5.280	1.171	0.671
	0.210	5.390	1.168	0.661

VII. Conclusions

In this study, the behavior of high performance reinforced concrete beam is analyzed using finite element analysis method. The beam is analyzed for different types of loadings and with and without steel plates for three different longitudinal ratios and for two different grades of concrete. The parameters used to control this study are steel plates, different types of loadings. After compiling and analyzing the results from each test, the following conclusions can be made.

1. Reinforced concrete beam can be modeled and analyzed using ANSYS software and obtain correct results and can be best alternative for laboratory tests.
2. When steel plates at loading points and support conditions is removed, results are not accurate. The beam without steel plates shows inaccurate results. Hence for accurate analysis in modeling steel plates are to to be included.
3. When single point loading is applied, induced compressive stresses are increased in by 46.42%. Tensile stresses and deflections are increased by 20%.
4. In case of uniformly distributed loads stresses and deflections are reduced by 75% compared to two point loading.
5. Steel reinforcement and grade of concrete effects the deflection as the amount of steel reinforcement and grade of concrete increases, deflection decreases slightly.

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