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FEA of Steel Fibre Reinforced Beam Curved in Plan

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Abstract: In the era of modern construction techniques and the increasing demand of aesthetic appearance of structure, beams curved in plan have found significant utilization within bridge structures, balconies, dome rounded corner buildings, water tanks etc. Concrete, the most consumable construction material has various advantages, however, one of the limitations of concrete is its low tensile strength. To compensate this limitation, fibres are added to concrete. The demand of steel fibre in construction technique is increasing as steel fibre gives high tensile strength and ductility. By adding steel fibre in reinforced concrete beam, the ultimate strength of beam can be enhanced. Finite Element Method or Finite Element Analysis is a tool used to simulate the beam in virtual environment. The objective of this study is to analyse the flexure behaviour of beam curved in plan. The curved beam with subtended angle of 45^0 and 60^0 containing fibre fraction of 0%, 0.5% and 1% by volume of concrete is used. To validate the curved beams modelled in Abaqus software, the experimental test is performed on three simply supported straight beams and same beams are analysed in Abaqus software. The straight beam contained the same fraction of 0%, 0.5% and 1% by volume of concrete.

Keyword: Curved Beam, Finite Element Analysis, Flexure Behaviour, Steel Fibre, Steel Fibre Reinforced Concrete, Ultimate Load Carrying Capacity.

I. INTRODUCTION

Concrete is one of the most prominent construction materials and its consumption is increasing with time throughout the globe. One of the major characteristics of the plain concrete is low tensile strength, that is concrete is a brittle material. Thus, concrete require strengthening before it can be used extensively as construction material. Historically, this reinforcement has been done in the form of continuous reinforcing bars which could be placed in the structure at the appropriate locations to endure the imposed tensile and shear stresses. Fibres, instead of continuous, are short discontinuous, and are randomly distributed throughout the concrete to produce a new construction material, known as Fibre Reinforced Concrete (FRC). It is important to note that fibre reinforcement is not a substitute for conventional reinforcement. Fibres and steel bars have different roles to play in the modern concrete technology, and there are many applications in which both fibres and continuous reinforcing bars are used [2]. Reinforced concrete horizontally curved beams are widely used in many fields, such as in construction of modern highway intersections, raised freeways, rounded corners of buildings, circular balconies etc. A horizontally curved beam, loaded transversely to its plane, is subjected to torsion in addition to bending and shear and hence, the critical analysis of such members is very complex. Therefore, it has become necessary to employ numerical analysis procedures to satisfy safety and economic requirements. One such procedure is the Finite Element Method. [3]

II. FINITE ELEMENT ANALYSIS

Finite Element Analysis in Abaqus software includes creation of parts, assigning properties to parts, assembling of parts, application of load and boundary conditions, meshing of parts and submission of job.

A. Modelling of Beams

In Abaqus software, beam part is created using solid homogeneous material. The steel bars, stirrups and fibres are created using wire element. For concrete, Concrete Damage Plasticity model developed as in [4] is used and for steel bars, fibres and stirrups plastic properties are used. To mesh the concrete beam, C3D8 element (a 3-D solid, 8-node linear brick element) is used and the size of the mesh is 30 mm. T3D2, a 2-D linear truss element is used for steel bars, stirrups and fibres and mesh size is 30 mm, 20 mm and 5 mm respectively. Curved beam is fixed at both the ends and subjected to gradually increasing uniformly distributed load. Curved beams modelled in Abaqus is discussed in Table II.

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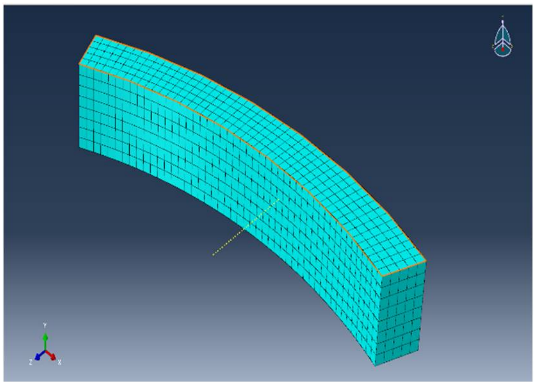

Fig. 1 Meshing of beam

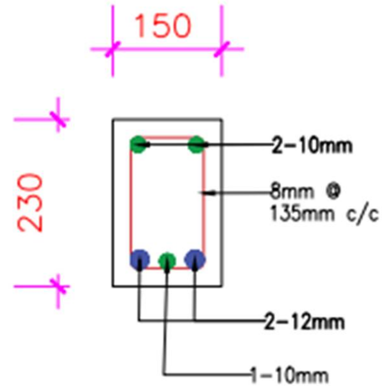

Fig. 2 Cross-section of beam

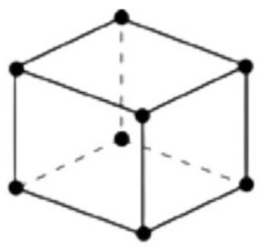

Fig. 3 C3D8 Element

Fig. 4 T3D2 Element

TABLE I
MATERIAL PROPERTIES

Material properties	Brief
28-days compressive strength of concrete	27.2 MPa
Grade of steel bar	FE500
Tensile strength of Fibre	1200 MPa
Aspect ratio of fibre	50
Fibre length	30 mm
Fibre diameter	0.6 mm

TABLE II
DETAIL OF MODELLED BEAMS IN ABAQUS

Name of the beam	Dimension	Fibre fraction	Subtended Angle
CB45-0-S	230x150x1500 mm	0%	45^0
CB45-0.5-S	230x150x1500 mm	0.50%	45^0
CB45-1-S	230x150x1500 mm	1%	45^0
CB60-0-S	230x150x1500 mm	0%	60^0
CB60-0.5-S	230x150x1500 mm	0.50%	60^0
CB60-1-S	230x150x1500 mm	1%	60^0

B. Finite Element Analysis

Analysis is performed using Abaqus explicit with step time of 0.1 second. To reduce the analysis time, multiple processors are used in CPU parallelization. Load-deflection curve and deformed shape are plotted under visualization module. Total reaction force and deflection obtained from analysis are plotted on X and Y axis respectively.

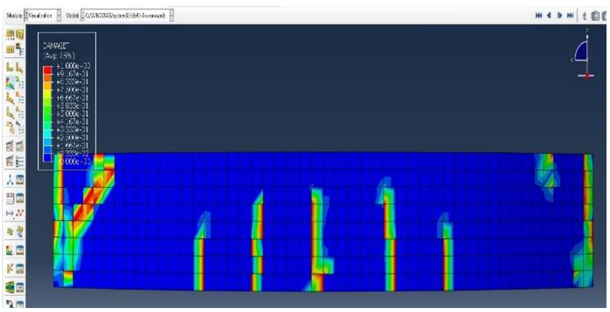

Fig. 5 Deformed Shape for CB45-0-S Beam

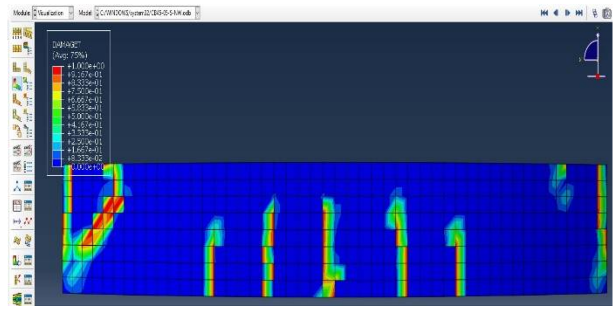

Fig. 6 Deformed Shape for CB-0.5-S Beam

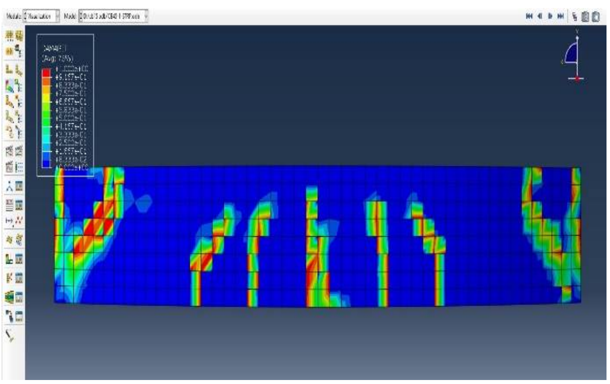

Fig. 7 Deformed Shape for CB-1-S Beam

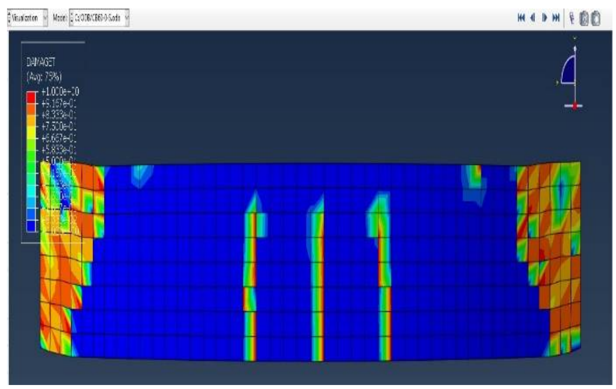

Fig. 8 Deformed Shape for CB60-0-S Beam

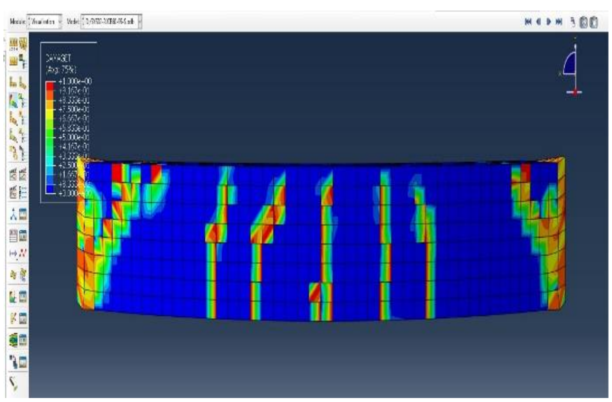

Fig. 9 Deformed Shape for CB60-0.5-S Beam

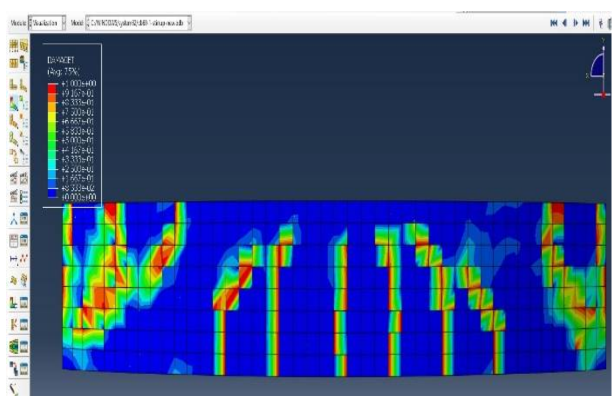

Fig. 10 Deformed Shape for CB60-1-S Beam

III. RESULT OF ANALSYIS

Curve for the ultimate load carrying capacity and corresponding deflection is plotted for SFRC beam curved in plan with subtended angle of 45^0 and 60^0 with steel fibre fraction of 0%, 0.5% and 1% by volume.

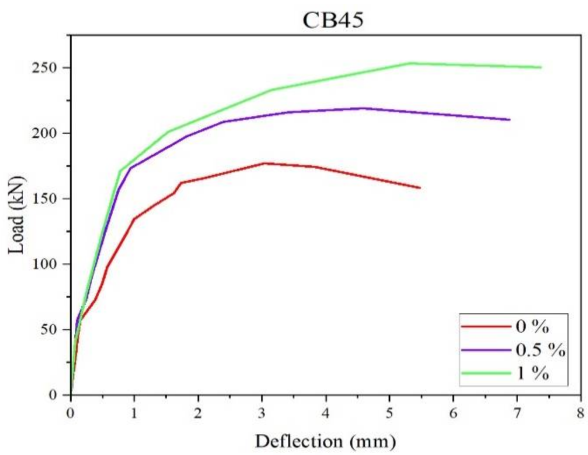

Fig. 11 Load-Deflection Curve of CB45 Beam

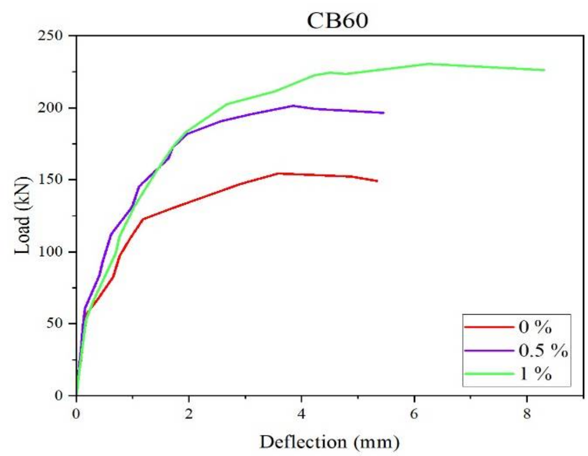

Fig. 12 Load-Deflection Curve of CB60 Beam

TABLE III
FLEXURAL CAPACITY OF CURVED BEAMS FROM FEA

BEAM	Load	Deflection
CB45-0-S	177.02	3.04
CB45-0.5-S	219.26	4.58
CB45-1-S	253.57	5.31
CB60-0-S	154.47	3.58
CB60-0.5-S	201.34	5.19
CB60-1-S	230.29	6.24

IV. VALIDATION OF BEAM

Experimental study is performed on straight beam and the same is validated in Abaqus. Three simply supported straight beams with fibre fraction of 0 %, 0.5 % and 1 % by volume are used in this study. The cross-section of the beam is 230 mm×150 mm×1500 mm. Ordinary Portland cement of grade 43 is used, locally available river sand passing through 4.75 mm sieve as per IS: 383 (2016) is used for fine aggregate, Crushed stones that retained on a 4.75 mm sieve is used as per IS: 383 (2016) for coarse aggregate and Thermo-Mechanically-Treated (TMT) bars of grade FE500 is used as steel reinforcement. Hooked end fibres of aspect ratio 50 and tensile strength of 1200 MPa are used to carry out the experimental procedure. The beam is tested in a Universal testing machine and the center-to-center distance between supports is kept 1200 mm. Same beam is modelled and analyzed in Abaqus software and the results between them shows good relation.

TABLE IV
DETAILS OF BEAMS MODELLED IN ABAQUS AND CASTED FOR EXPERIMENT

Name of the beam	Dimension	Fibre fraction
SB-0-S	230x150x1500 mm	0%

TABLE V
ULTIMATE LOAD CARRYING CAPACITY FROM FEA AND EXPERIMENT

Beam	Ultimate Load Carrying Capacity (kN)	
	FEA	Experimental
SB-0-S	124.57	119.47
SB-0.5-S	160.82	151.89
SB-1-S	198.05	184.7

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Fig. 13 Casting of Beam

Fig. 14 Steel fibre reinfroced concrete

Fig. 15 Hooked end steel fibres

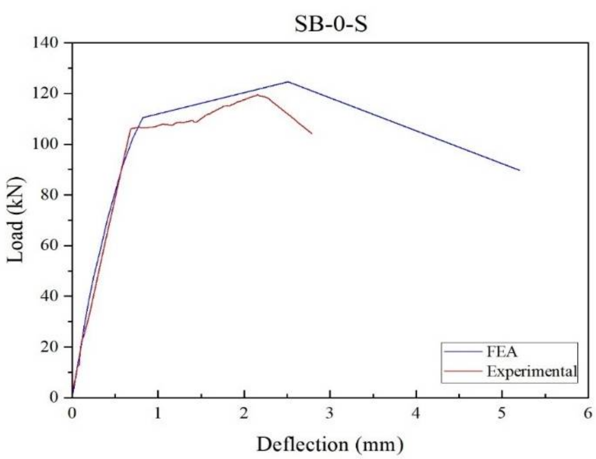

Fig. 16 Load Deflection Curve For SB-0-S

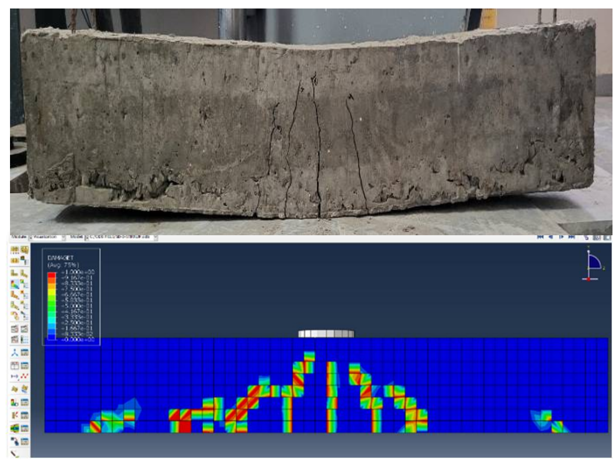

Fig. 17 Deformed Shape For SB-0-S

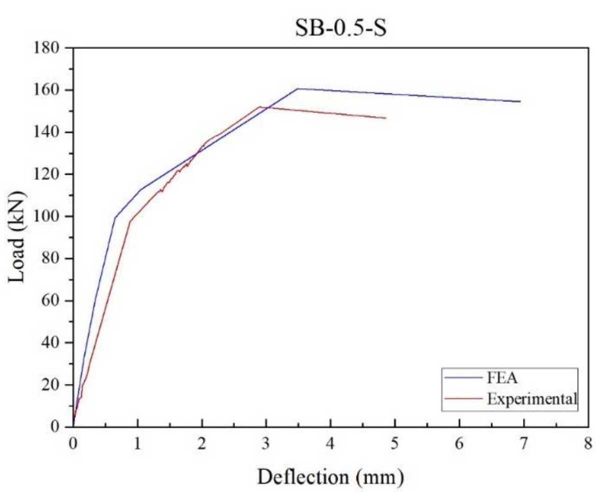

Fig. 18 Load Deflection Curve For SB-0.5-S

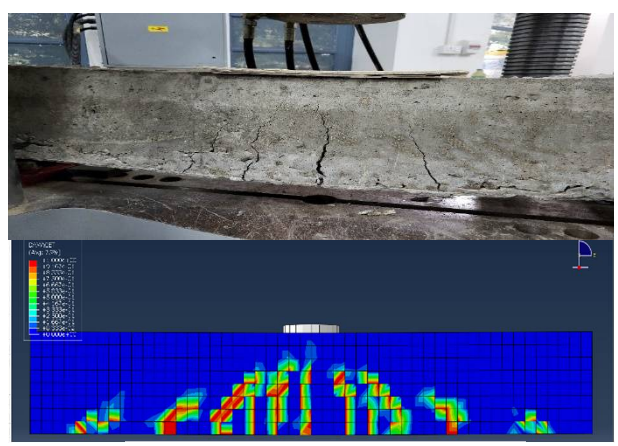

Fig. 19 Deformed Shape For SB-0.5-S

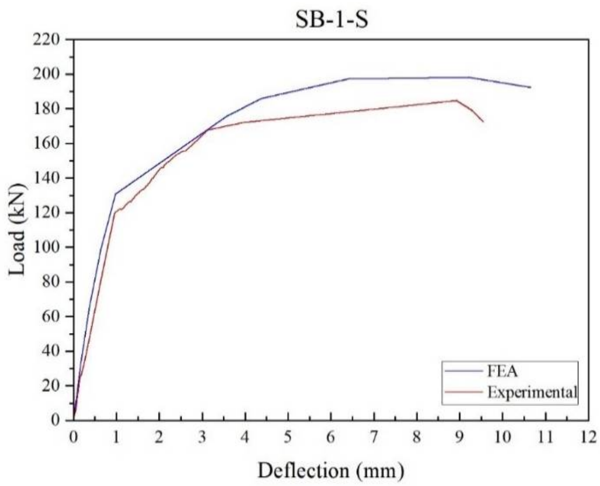

Fig.20 Load Deflection Curve For SB-1-S

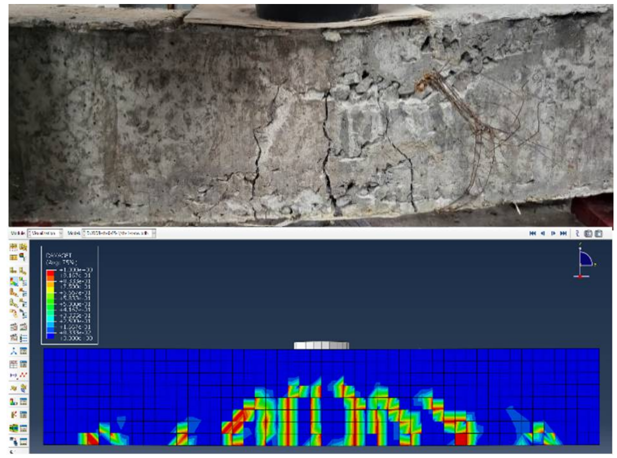

Fig. 21 Deformed Shape For SB-1-S

It is observed that the load deflection curve obtained from Finite Element Analysis is slightly different as compared to experimental study. This may be due to the microcracks in concrete which may occur because of shrinkage or due to handling of beam. On the other hand, in case of Abaqus software, the finite element models do not consider the microcracks as the beam is assumed to be solid homogenous material. Another reason could be that in Abaqus modelling there is perfect bond between the bars, fibre and concrete, as bars and fibres are perfectly embedded in concrete, however this assumption would not be true for experimental study [1].

V. CONCLUSIONS

From the Finite Element Analysis of Steel fibre reinforced beams in the research work, following conclusions can be drawn.

1) On adding steel fibres in the beam, flexural capacity for beam with subtended angle of 45^0 is increased by 42.24 kN and 76.55 kN on increasing the fibre from 0 % to 0.5 % and 1 %.
2) On adding steel fibres in the beam, flexural capacity for beam with subtended angle of 60^0 is increased by 46.87 kN and 75.82 kN on increasing the fibre from 0 % to 0.5 % and 1 %.
3) Curved beam with subtended angle 45^0 has higher ultimate load carrying capacity as compared to the beam with subtended angle of 60^0.
4) Results from experimental study and results from FEA in Abaqus software shows good correlation.

VI. ACKNOWLEDGEMENT

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