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Experimental and Analytical Study on Flexural Behavior Of Curved Beams

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Abstract: This paper involves an experimental investigation on the flexural behaviour of curved beams and comparison of its results with conventional beams. Curved beams of size 1200 x 150 x 100 mm with varying initial curvature as 4000mm, 2000mm and the concrete strength as M40 is considered. Various reinforcement are provided in the curved beams to predict which reinforcement detail would give more resistant over maximum loading. The material properties of cement, fine aggregate, coarse aggregate and the compressive strength of concrete cube were found out. A total of 12 specimens of curved beams were casted with various combination of reinforcement along with three control specimens. The beams are tested under two point loading both horizontally and vertically. The deflection and maximum moment carrying capacity are investigated to understand its strength. Also analytical modelling is done to determine the ultimate moment carrying capacity using Finite Element Software ABAQUS to compare with the experimental model.

Keywords: Curved beams, ABAQUS**.**

1. INTRODUCTION

A beam in which the neutral axis in the unloaded condition is curved instead of straight or if the beam is originally curved before applying the bending moment, are termed as "Curved Beams". The beam theory can also be applied to curved beams allowing the stress to be determined for shapes including crane hooks and rings. When the cross section are small compared to the radius of curvature of the longitudinal axis the bending theory can be relatively accurate. When this is not the case even using the modified BernoulliEuler only provides approximate solutions.

One of the assumptions of the development of the beam bending relations is that all longitudinal elements of the beam have the same length, thus restricting the theory to initially straight beams of constant cross section. Although considerable deviations from this restriction can be tolerated in real problems, when the initial curvature of the beams becomes significant, the linear variations of strain over the cross section is no longer valid, even though the assumption of plane cross sections remaining plane is valid. Horizontally curved beams are frequently used in construction of bridges, Interchange facilities and balconies, because of the constraints in existing land use. The curved beam is a unique problem, which has drawn the attention of various investigators who have tried to solve it by different techniques including finite element. As a result, a number of curved beam elements have been developed. (1)

2. EXPERIMENTAL PROGRAM

This paper deals with the flexural behaviour of curved beams of various reinforcement details. To study the behaviour, 12 curved beams of length 1200 mm, width 150mm and depth 100mm having various initial curvature as 4000mm and 2000mm was casted using M40 grade of concrete. Concrete cube specimen of size 150mmx 150mm was casted to study the compressive strength of concrete. After 28 days curing, flexural two point load would be applied on the curved beams with suitable support condition. The experimental results of beams would predict the deflection, ultimate moment capacity, and gives the result that which reinforcement detail would give more resistant over torsional moment and control the diagonal tension cracks due to torsion

2.1.MATERIALS USED

2.1.1 Cement:

Ordinary Portland cement of (53 grade cement) confirming to IS: 81121989 is used. The properties of cement are given in the below Table 1.

2.1.2 Fine Aggregate:

Natural river sand of size below 4.75mm confirming to zone II of IS 383-1970 is used as fine aggregate. Laboratory tests were conducted for fine aggregate to determine the physical properties as per IS: 2368 (part III). The test results are shown in Table 1.

Table 1. Test Results

Sl. No	Tests	Results
1	Specific gravity	3.15
2	Initial setting time	80 minutes
3	Final setting time	453 minutes
4	28days compressive strength	45.33/mm^2

Table 2 . Properties of Cement

Sl. No	Tests	Results
1	Specific gravity	2.72
2	Fineness modulus	2.67
3	Bulk density	1806 kg/m^3
4	Water absorption	1.1%

2.1.3. Course Aggregate: Course aggregate used in this study consist of crushed stone of size 20mm. Laboratory tests were conducted on course aggregate to determine the different physical properties as per IS: 383-1970. The test results are shown in the table 3.

Table 3: Course aggregate Properties

Sl. No	Tests	Results
1	Specific gravity	2.67
2	Fineness modulus	2.67
3	Water absorption	0.6%

2.1.4 Superplasticizers*:* Conplast SP430 is based on Sulphonated Naphthalene Polymer and supplied as brown liquid instantly dispersible in water, having specific gravity of 1.220 to 1.225@ 30^{o}C

2.1.5 Reinforcements*:* High Yield Strength Deformed Steel Bars of 6mm, 8mm, 10mm, 12mm Diameter was used for the study. 8mm, 10mm, 12mm were used as longitudinal reinforcement and 6mm bars were used for lateral ties.

2.3 MIX PROPORTION

Design of concrete mixes involves determination of the proportions of the given constituents namely, Cement, Water, Coarse aggregate and Fine aggregate with admixtures if any. Workability is specified as the important property of concrete in the fresh state. For hardened state compressive strength and durability will be considered.

Fig .1 Reinforcement details

According to IS 10262 –2009 mix ratio for M40 grade is 1 : 2.56 : 3.26 : 0.4

2.4 REINFORCEMENT

The diameter of main reinforcement are 8mm, 10mm, 12mm and the lateral ties are 6mm. The lateral ties are spaced at a distance of 125 mm.

2.5 CASTING OF SPECIMENS

A total of 12 curved beams and 3 conventional beams of various reinforcement are casted. The concrete is poured inside the curved beam mould and by proper compaction the beam is casted. The cube was cased for finding the compressive strength of concrete

Fig .2 Curved Beam Mould

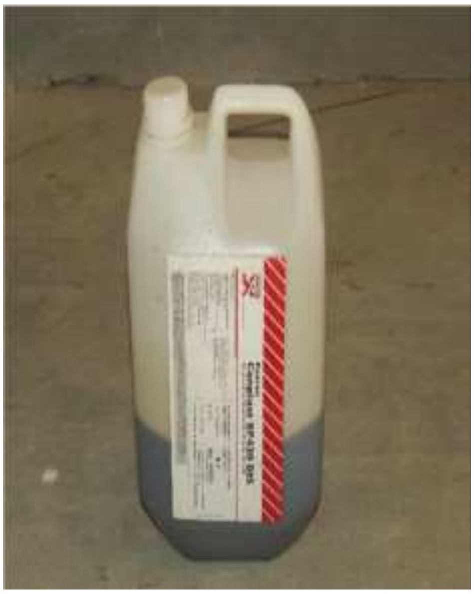


Fig 3: Superplasticizers

Fig.4 Casting of specimens

2.6 Testing Of Specimens

The cubes were tested in hydraulic compression testing machine. The cubes were tested on the same date of testing of their corresponding beams. The experimental values of cubes tested after 7days, 14days and 28 days.

Fig. 5 Testing of concrete cubes

Table. 4 Compressive strength of cubes

Grade of concrete	Tested days	Average Compressive Strength(N/mm^2)
40	7days	27
40	14days	36
40	28days	45.90

2.7 Test for Curved Beams

For the purpose of investigating the flexural behaviour of curved beams, a two point loading beam test was carried out for each specimen. This beam test provided a pure flexural zone in the presence of shear. The specimen was placed in the Universal Testing Machine in such a manner that the load was applied to the uppermost surface of the specimen. The load was applied without shock and increased continuously and the corresponding deflection was taken until the specimen reaches the ultimate load. The compression tests were conducted on companion concrete cubes on the same day and the average compressive strength was recorded

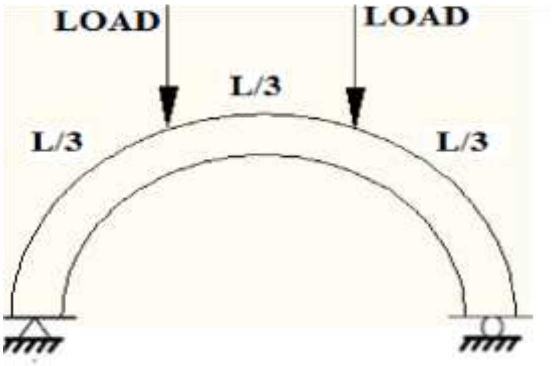


Fig .6 Diagrammatic Loading setup

Fig .7 Dial Gauges setup

Fig .8 Beam after Loading

2.8 Experimental Results

1. Compressive Strength

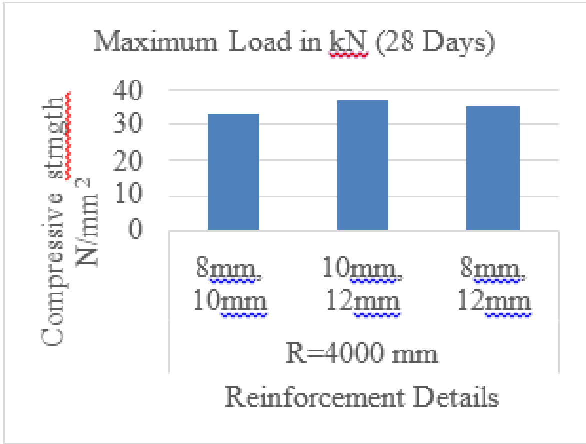


Fig. 9 Compressive strength of curved beams of initial curvature R=4000mm

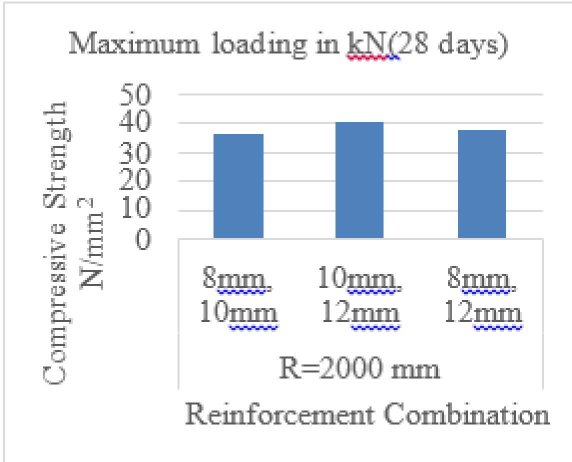


Fig .10 Compressive strength of curved beams of initial curvature R=2000mm

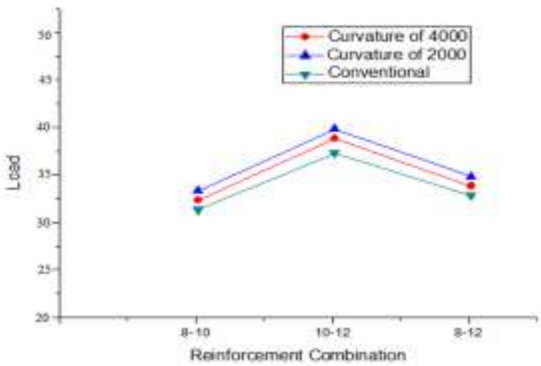


Fig. 11 Comparison of curved and conventional beams

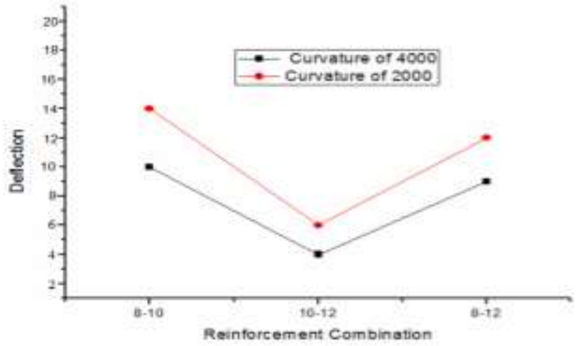
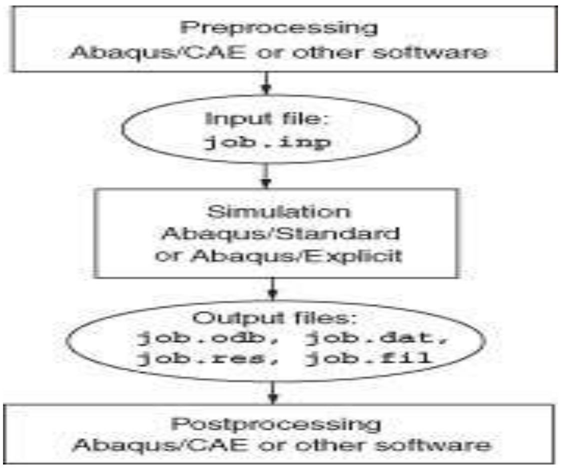


Fig .12 Maximum deflection of curved beams

3.FINITE ELEMENT MODELLING

FEM ABAQUS/standard software was used in this study. ABAQUS is highly sophisticated, general purpose finite element program designed primarily to model the behaviour of solids and structures under externally applied loading. A complete Abaqus analysis usually consists of three distinct stages: preprocessing, simulation and post processing. These three stages are linked together by files as shown below:



The model's details (geometry and properties of materials) were same as experimental specimen. Solid element types (C3DR8) were adopted to represent the concrete material, whereas the steel bars were represented by using threedimensional truss elements (T3D2). All the beams were simply supported, and the load was applied automatically with the values that are obtained from experimental results. The bonding between the steel and concrete was assumed to be perfect and represented in ABAQUS using an interaction element.

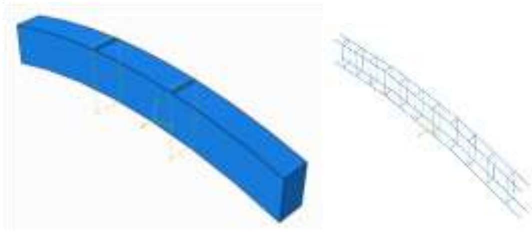


Fig .13 Modelling of beam&

Reinforcement steel

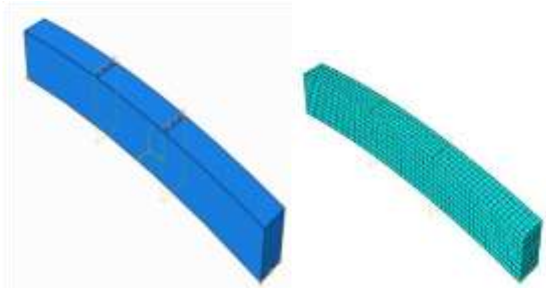


Fig 14. Loading of beam&
Meshing of beam

Two types of loading conditions were analysed in the analytical study to determine under which loading the beam is more resistant. They are vertical and horizontal loading. They were described in the figure below.

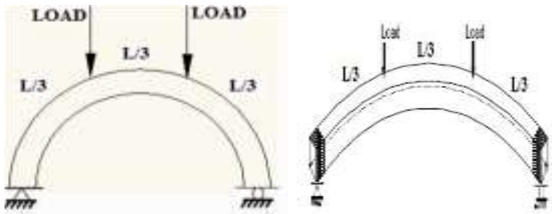
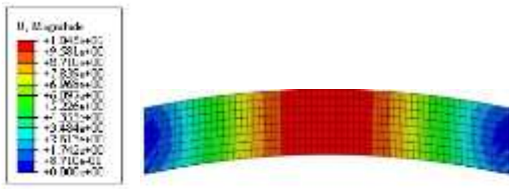


Fig 15. Horizontal and Vertical

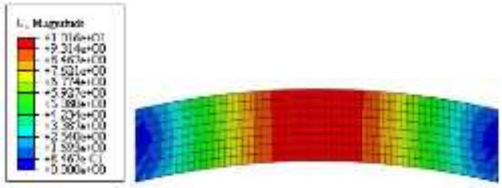
Analytical results

A) Curved beams (R=4000 mm) for vertical loading

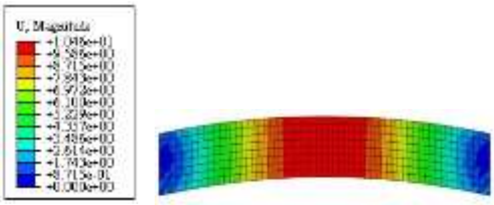
1. Deflection for R=4000 mm (8mm, 10mm)



2. Deflection for R=4000mm (10mm, 12mm)

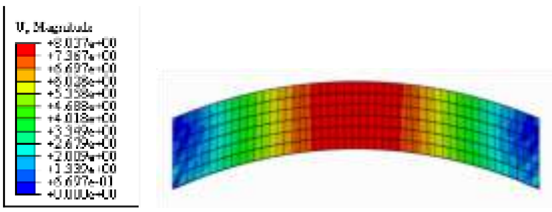


3. Deflection for R=4000mm (8mm, 12mm)

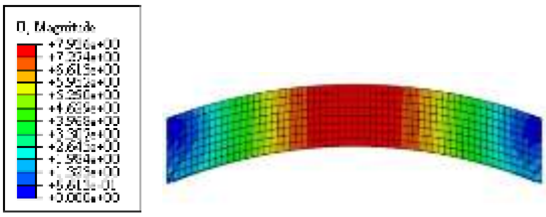


B) Curved beams (R=2000 mm) for vertical loading

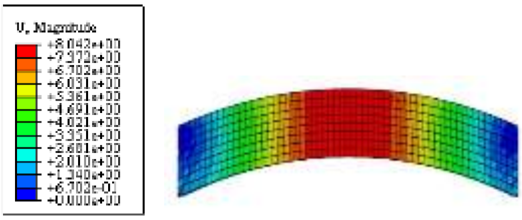
1. Deflection for R=2000 mm (8mm, 10mm)



2. Deflection for R=2000mm (10mm, 12mm)

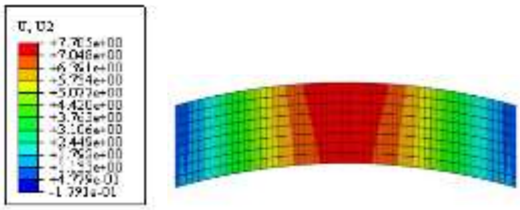


3. Deflection for R=2000mm (8mm, 12mm)

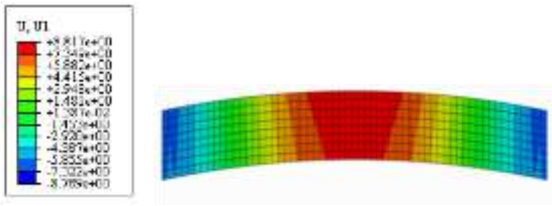


C) Curved beams (R=4000 mm) for Horizontal loading

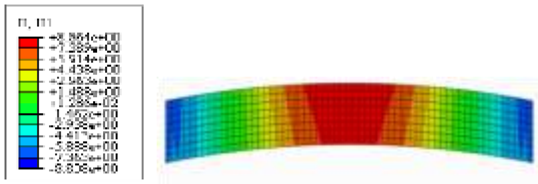
1. Deflection for R=4000 mm (8mm, 10mm)



2. Deflection for R=4000mm (10mm, 12mm)

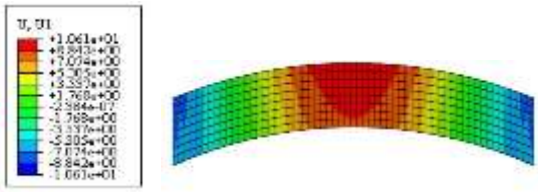


3. Deflection for R=4000mm (8mm, 12mm)

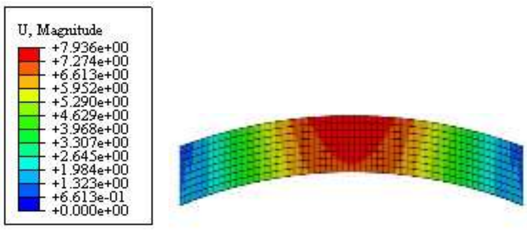


D) Curved beams (R=2000 mm) for Horizontal loading

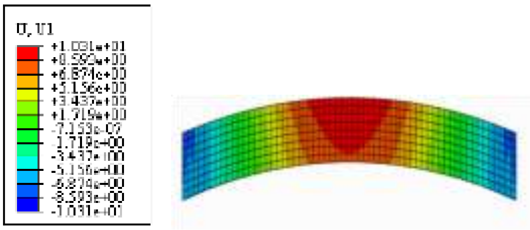
1. Deflection for R=2000 mm (8mm, 10mm)



2. Deflection for R=2000mm (10mm, 12mm)



3. Deflection for R=2000mm (8mm, 12mm)



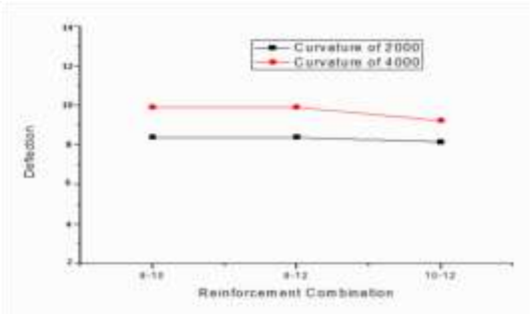


Figure .16 Deflection of the Curved

Beam

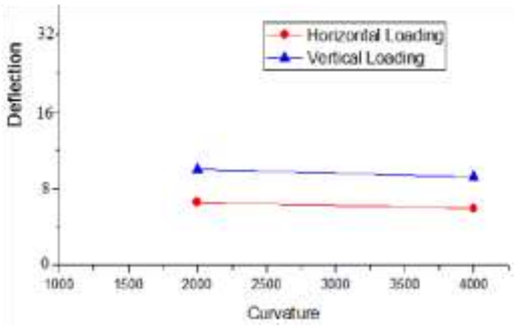


Figure .17 Deflection of the Curved beams in Different Loading Condition

Among the two loading condition, the horizontal loading condition gives out minimum deflection compared to vertical loading condition in various reinforcement combinations. So horizontal condition is recommended in curved beams.

4. CONCLUSION

- The ultimate strength of the curved beam is suspected to increase by 10-15% over the conventional rectangular straight beam.
- The sectional area can be reduced by using the curved beams with improved capacity.
- In a curved beam with a small curvature, the ultimate strength becomes large and for the curved beam with large curvature, the ultimate strength becomes small.
- In curved beams, the horizontal loading condition is recommended rather than vertical due to minimum deflection.

5. REFERENCES

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