International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 38-41

Experimental Study on Plastic Failure of Reinforced Concrete Beams

Mohammed Rahil Azeez
Research Scholar, Department of Civil Engineering,
REVA University, Yelahanka, Bangalore.

Bhojaraj M
Assistant Professor, Department of Civil Engineering,
REVA University, Yelahanka, Bangalore

M Ravikumar
Associate Professor, Department of Civil Engineering,
UBDT College of Engineering, Davanagere

Bhanulatha G N
Assistant Professor, Department of Civil Engineering,
REVA University, Yelahanka, Bangalore

Abstract
It is quite usual; members in a structure are subjected to stresses beyond elastic limit during various situations when members undergo some unpredicted heavier loads than it is designed for. The purpose of this study is to assess the behavior of RC Beam when stressed beyond its elastic limit. Hence an experimental analysis is carried out by casting simply supported beams of fixed dimensions and span with different reinforcement percentages. Four different reinforcement percentages were used and the beams were tested for 28 days strength. Tests were performed on loading frame by subjecting the beam to a single point load exactly at the mid span. Beams were stressed beyond the elastic limit by gradually increasing the load until the beams enter into fully plastic zone and rotate due to the formation of the plastic hinge. The corresponding deflections, stresses, elastic and plastic moments are calculated using Finite element analysis (FEA) program. From the results of experiment and FEA various conclusions were drawn.

Keywords: Reinforced Concrete Beam, Non-linear behavior, Flexural Strength, Plastic Analysis, Experimental investigation, Finite Element Analysis

Introduction

Beam is a member which is mainly subjected to flexure or bending. It is important to know the behavior of each type of beam before designing them in order to correctly place the reinforcement. When beam is subjected to external moment it causes bending which leads to tensile and compressive stresses in the cross section of the beam, and the nature of these stress depends upon the position of the fiber in the beam and also the type of support conditions. As long as the moment is small and does not induce cracking, the strains across the cross section are small and the neutral axis is at the centroid of the cross section.

As the load is increased, the extreme fiber of the beam cracks as the stress reaches the value of modulus of rupture. Most of these cracks are so small that they are not visible to the naked eye. At this stage, the maximum strains in concrete in tension and compression are still low; hence we can assume a linear stress-strain relation where the moment which causes the first crack is known as the cracking moment.

As the load is increased further, extensive cracking occurs. The cracks also widen and propagate gradually towards the neutral axis. The cracked portion of the concrete beam is ineffective in resisting the tensile stresses. The steel reinforcements come into play now, and there is sudden transfer of tension force from the concrete to the reinforcements in the tension zone. This results in increased strains in the reinforcements. If the minimum amount of tension steel is not provided, the beam will suddenly fail. The relative large increase in the tensile strains of the reinforcements results in an upward shifting of neutral axis with the deflections and rotations also increasing at faster rate, resulting in increased curvature at the cracked section.

If the loads are increased in addition, the tensile stresses within the reinforcement and the compression stress within the concrete enlarge further. The stresses over the compression section will turn into non- linear. However, the strain distribution over the cross section is linear. This is termed ultimate stage. At one point, either the steel or concrete will reach its respective capacity; steel will start to yield or the concrete will crush.

Description of Specimens

Eight numbers of Reinforced concrete beams of four different types (i.e.; two trials for each type) of size (0.15m x 0.25m x 2.0 m) are casted with varying percentage of reinforcement.

The concrete used for casting the reinforced concrete beam is conventional type of concrete of compressive strength 25 MPa. The reinforcement used is Thermo mechanically treated bar of tensile strength 550 N/mm2.Your paper must be in two column format with a space of 0.5cm between columns.

Table 1: Details of Beam

Beam No	Beam Size (mm)	A_{st} (mm^2) (Mid span)	A_{sc} (mm^2) (Mid span)
B1	150 x250x 2000	226	157
B2	150 x250x 2000	339	157
B3	150 x250x 2000	452	226
B4	150 x250x 2000	565	339

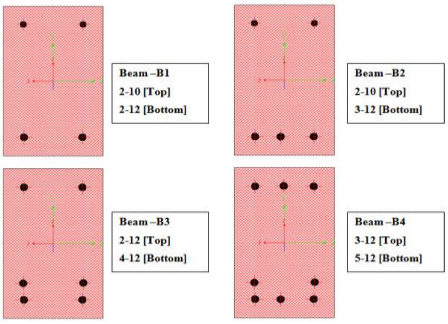

Figure 1: Section details of beams at mid span

Experimental Investigation

As shown in the figure below beams were subjected to single point loading exactly at mid span by using hydraulic loading cell. Dial gauges were arranged to the bottom of beam and hydraulic load is applied linearly until the beam undergoes ultimate plastic failure due to the formation of plastic hinge. Deflection of the beam was measured at each interval of 10KN load. The cracking load and the ultimate plastic failure load were recorded along with the corresponding deflection. The failure pattern of the beam beyond the elastic zone was observed carefully.

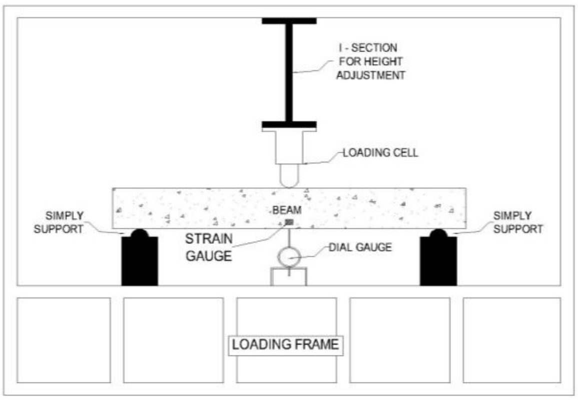

Figure 2: Loading Frame Setup

Figure 3: Specimen setup for testing on loading frame

Figure 4: During ultimate loading – Plastic hinge rotation

Figure 5: Crack pattern after failure

Figure 6: Shear failure at the support

Finite Element Analysis

One of the main objectives of this work is to study the behaviour of bending beyond the elastic zone. The experimental work carried out gave the cracking load and the ultimate load at which beam started rotation due to the formation of plastic hinge.

A finite element analysis was carried out in order to determine several parameters that couldn't be obtained experimentally and also to have a comparison with the experimental results obtained. The finite element application chosen in the present study was CSI SAP2000. The beams were modelled similar to the detailing provided in the experimental analysis and analysed to asses various parameters such as bending stresses, shear stress, elastic and plastic moments and deflections.

The various material properties adopted for the study such as properties of concrete and reinforcing bar are defined here in this step. The stress strain relationship of material is according to IS456-2000.

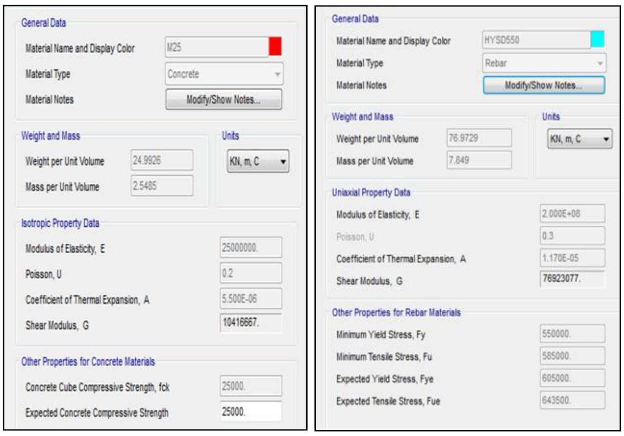

Figure 7: Material Properties

Results and Discussions

Results

Table 2: Ultimate load and failure type

Beam No	Cracking Load (KN) in elastic zone		Ultimate load (KN) in Plastic zone		Type of failure
	Trial 1	Trial 2	Trial 1	Trial 2	
B1	42 KN	44 KN	102 KN	105 KN	Pure flexure
B2	51 KN	53 KN	112 KN	116 KN	Pure flexure
B3	57 KN	55 KN	120 KN	118 KN	Shear failure
B4	59 KN	61 KN	125 KN	131 KN	Shear failure

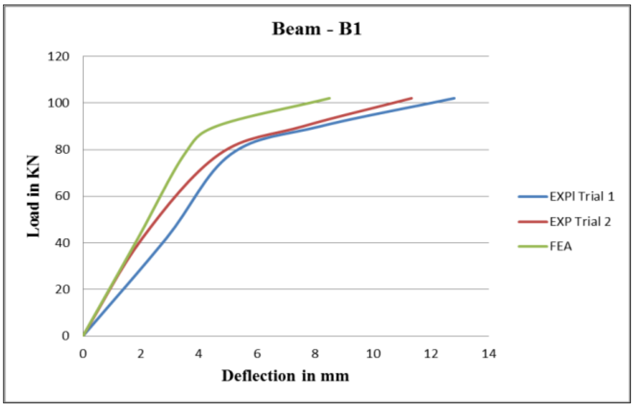

Figure 8: Mid span Deflection for Beam - B1

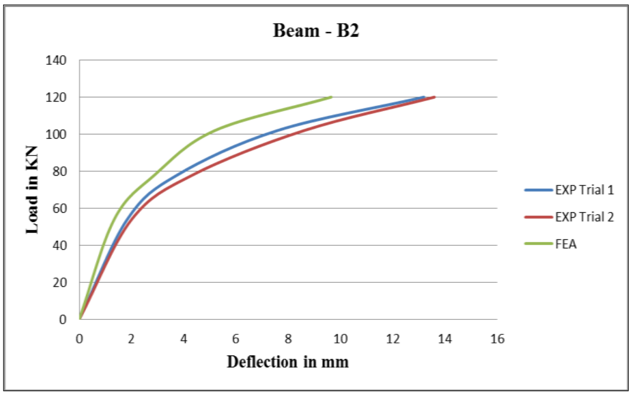

Figure 9: Mid span Deflection for Beam – B2

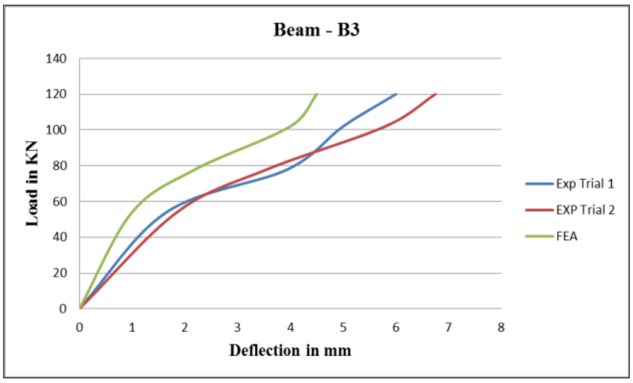

Figure 10: Mid span Deflection for Beam – B3

Figure 11: Mid span Deflection for Beam – B4

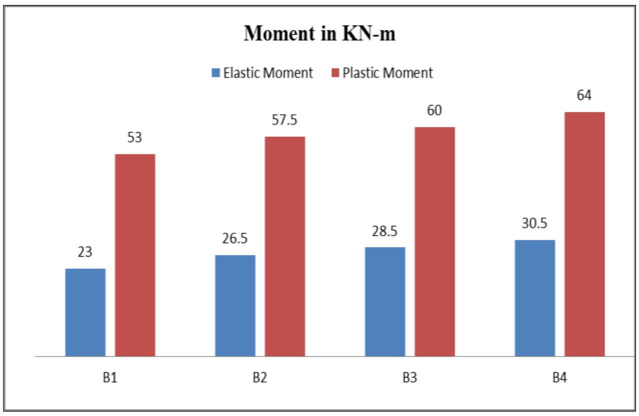

Figure 12: Max elastic and plastic moments

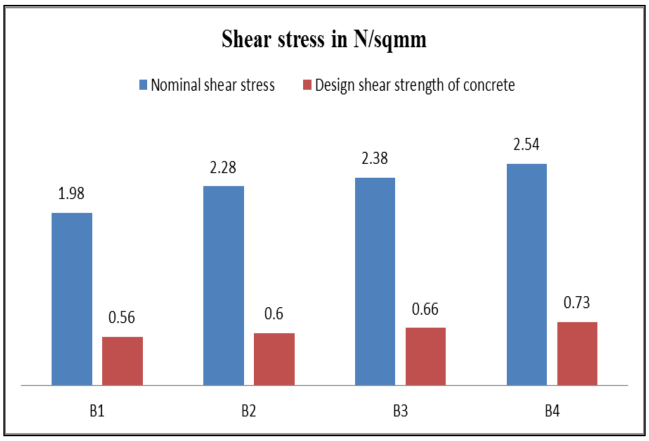

Figure 13: Shear stress comparison

Discussions

Beams B1 and B2 undergoes full plastic rotation exactly at the midpoint where the point load was applied. Type of failure observed in beams B1 and B2 was purely flexural.

Beams B3 and B4 undergoes shear failure at the supports before the beam reaches to plastic hinge rotation stage.

From the Mid span Deflection graphs it is observed that beams B1 and B2 undergoes maximum deflections of 12.00 mm to 14.00 mm before ultimate failure where as B3 and B4 undergoes less deflections 6.00 mm to 7.00 mm.

Beams B1 and B2 reaches to ultimate bending state where as beams B3 and B4 has undergone collapse due to shear failure before it reaches ultimate bending.

It is observed from the graphs that there is a 10 percent difference between the experimental and the FEA deflection values. Comparitively experimentally beam undergoes more deflections than found in FEA.

Conclusion

The following conclusions were drawn from the above study:

1. It is found out that the members have a large area of inelastic zone beyond the elastic zone only after which the beam undergoes complete failure. Almost a beam can take twice the amount of elastic failure load to undergo plastic failure.

2. It is observed that in a simply supported beam undergoing pure flexural failure a plastic hinge is formed at the maximum bending point just before it undergoes complete collapse.

3. It is found out that beams loaded beyond the elastic zone undergo pure flexural failure up to certain percentage of reinforcement beyond which shear failure of beam comes into picture.

4. It is found out that beams undergoing pure flexural failure undergo maximum deflection whereas beams undergoing shear failure couldn't reach maximum deflection as the member reaches maximum shear stress before it could reach maximum bending stress.

5. It is found out that in order avoid complete shear failure even in plastic zone an increment in the shear reinforcement in necessary along with the increment of longitudinal reinforcement to maintain the limiting shear stress so that the beam reaches the plastic hinge formation stage.

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