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PERFORMANCE ENHANCEMENT OF RCC CONTINUOUS BEAMS WITH FIBRES – AN EXPERIMENTAL INVESTIGATION

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ABSTRACT
Concrete is the most versatile construction material being used in a wide and varied range of structures and elements all over the world. The versatility of concrete is due to the mould-ability to any conceivable shape. The high compressive strength of concrete and its amenability as a matrix in composites have enhanced its popularity. Concrete is a bi-strength material. It is very strong in compression and unfortunately owing to its micro-crack structure can take little or no tension. Inclusion of fibers has been found to be advantageous as strength, cracking characteristics, tensile, fatigue, impact resistance, toughness, ductility, improve. Fiber Reinforced Concrete (FRC) is emerging as a popular variant of concrete. Performance enhancement of RCC continuous beam with inclusion of synthetic fibers. An experimental study envisages to compare performance of two span continuous RCC beams where synthetic fibers have been dispersed throughout and also in discrete zones vis-à-vis conventional RCC beam.

Keywords: *Performance Enhancement, RCC Two Span Continuous Beam, Synthetic Fibers*

INTRODUCTION
Concrete is probably the most widely used man-made construction material in the world. In spite of this, it has some serious deficiencies, which but for its remarkable qualities of flexibility, resilience and ability to redistribute stresses, would have prevented its use as a building material. Concrete is inherently weak in tension and possesses, compared to other construction materials, a low specific modulus, limited ductility, and little resistance to cracking. Micro-cracks develop in the material during its manufacture due to inherent volumetric and micro-structural changes, and an essentially discontinuous, heterogeneous system thus exists even before any external load is applied. In addition to the low tensile strength, the material possesses little resistance to the low tensile crack propagation and hence, under load, the virgin micro-cracks develop at a low tensile cracking strain of the order of 100 x 10^{-6} m/m corresponding to 30-40 percent of the ultimate strength in compression, which on further loading eventually lead to uncontrolled growth of micro-cracks.(1)
To use concrete as a load-bearing element, therefore, it is necessary to impart tensile resistance properties to a concrete structural member. This has been achieved, long before, by the use of reinforcing bars, and more recently by the application of pre-stressing. Although both these methods provide tensile strength to the concrete member, they do not increase the inherent tensile strength of concrete itself. Thus the overall performance of the traditional reinforced concrete composite material is still effectively dictated by the individual performance of the concrete phase and the steel phase.
This has lead to the search for the new materials particularly two-phase composite materials in which the weak is reinforced with strong stiff fibers to produce a composite of superior properties and performance.
The small closely spaced fibers act like crack arresters substantially and improve static and dynamic strengths. FRC has found interesting applications due to inherent superiority over conventional plain and reinforced concrete in the properties like higher flexural strength, higher shear strength, shock resistance, better ductility and fatigue resistance. The properties of such fiber reinforced concrete will depend upon the properties of the fiber used.
Low modulus fiber, such as polypropylene and polyethylene are capable of large energy absorption. They are not generally used for the sake of improvement of higher strength. However, they impart toughness

and resistance to impact and explosive loads. High modulus high strength fibers such a steel, glass, carbon and asbestos, on the other hand, impart primarily improvements in strength and stiffness. Steel and polypropylene are mostly used as fibers in FRC, due to the considerations of aspects of economy, durability and adequacy.

The idea that concrete can be strengthened by inclusion of fibers was first put forward by Porter in 1910 but little progress was made in the development of this material until 1963 when Romualdi and Batson published their classic paper on this subject. Based on the principles of fracture mechanics, they showed that the cracking strength of concrete is increased by closely spaced fibers acting as crack arresters and established that the increased strength is inversely proportional to the square root of the fiber spacing. Since then there has been serious interest in fiber reinforced concrete and several interesting experiments have been carried out.

Several kinds of fibers such as steel, fibrillated polypropylene, nylon, asbestos, coir, jute, glass and carbon have been tried. While fiber structures such as polypropylene are found suitable in increasing the impact strength and in reducing the velocity of fragments under explosive loading, steel fibers are ideally suitable to increase flexural strength.

This experimental study envisages comparing performance of two-span continuous RCC beams where synthetic fibers have been dispersed through and also in discrete zones vis-à-vis conventional RCC beam.

Moment Redistribution and Plastic Hinge Formation

Consideration of the behavior of reinforced concrete beams and frames at and near the ultimate load is necessary to determine the possible distribution of bending moment, shear force and axial force that could be used in the design [(3)]. It is possible to use a distribution of moments and forces different from linear elastic structural analysis if the critical sections have sufficient ductility to allow redistribution of action to occur as the ultimate load is reached. Also, in countries that experience earthquakes, a further important design aspect is the ductility of the structure when subjected to seismic-type loading.

Figure 1 gives a typical moment-curvature curve for a section in which the tension steel is at yield strength at the ultimate moment. The curve is marled to indicate points at which the concrete starts to crack, the tension steel begins to yield, and spalling and crushing of concrete commences. A ductile section is capable of maintaining moment capacity at the nearer the ultimate value for large curvatures beyond the curvature at first yield.

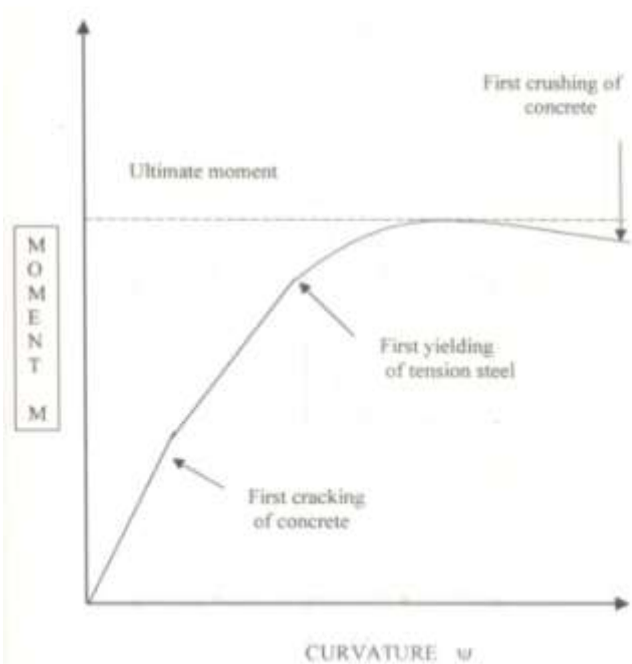

Figure 1: Typical moment curvature relationship for reinforced concrete flexural member

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Research Article

It is evident that the nonlinear nature of the moment-curvature relationship for reinforced concrete sections will cause some adjustment to the relative values of the bending moments if the structure is loaded into and beyond the service load range. In particular, because of plastic rotation at some section, it is possible for the bending moments to assume a pattern different from that derived from linear elastic structural analysis, and for all the critical positive and negative moment sections to reach their ultimate moments of resistance at the ultimate load. Thus moment redistribution can have a marked influence on the ultimate load of a statically indeterminate structure.

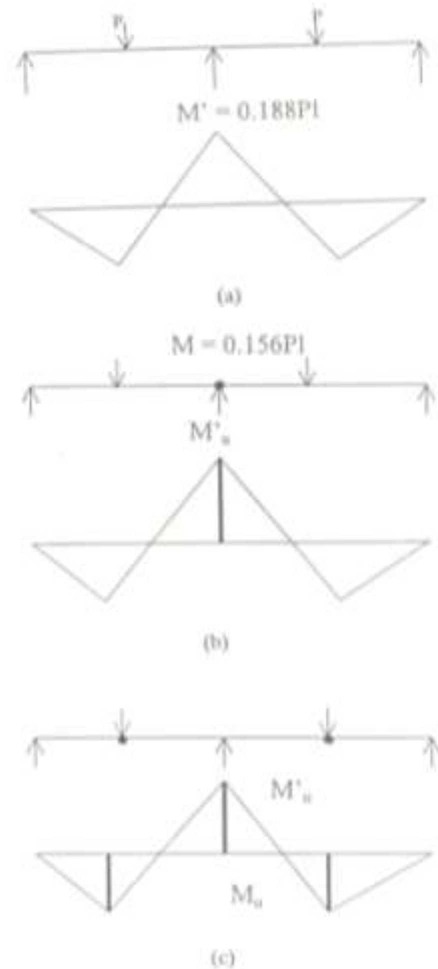

Figure 2: Formation of collapse mechanism

For a two-span continuous beam, having a uniform cross section as shown in Figure 2. It is assumed that the sections are adequately reinforced for shear, allowing the ultimate moments to be attained without shear failure. It is also assumed that the moment-curvature relationship for the sections is the idealized bilinear relationship for a ductile section shown in Figure 3 (a), all sections having the same constant flexural rigidity up to the ultimate moment and the moment remaining constant at the ultimate value at higher curvatures. At low loads, the distribution of bending moment due to the two concentrated loads will be in accordance with the elastic theory distribution [Figure 2 (a)]. The dead load of the beam has been neglected. As the applied loads are increased further, the ultimate moment of resistance will be reached at one critical section, say over the center support, before it is reached to other sections [Figure 2 (b)], the extent to which further load can be carried by the beam depends on the capacity for plastic rotation at the center support. If the section is brittle, the moment will decrease after reaching maximum

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[Figure 3 (a)], and the beam will fail suddenly without carrying any additional load. If the section is ductile, additional load can be carried because the plastic hinge at the center support rotates while maintaining its moment of resistance constant and moment redistribution will occur until the maximum positive moment in the spans also increase to ultimate values. Then the collapse mechanism as shown in [Figure 3 (c)] is formed. Figure 3 (b) traces the variation of the bending moment at the critical sections with load on the beam, assuming that the plastic hinge forms first at the center support.

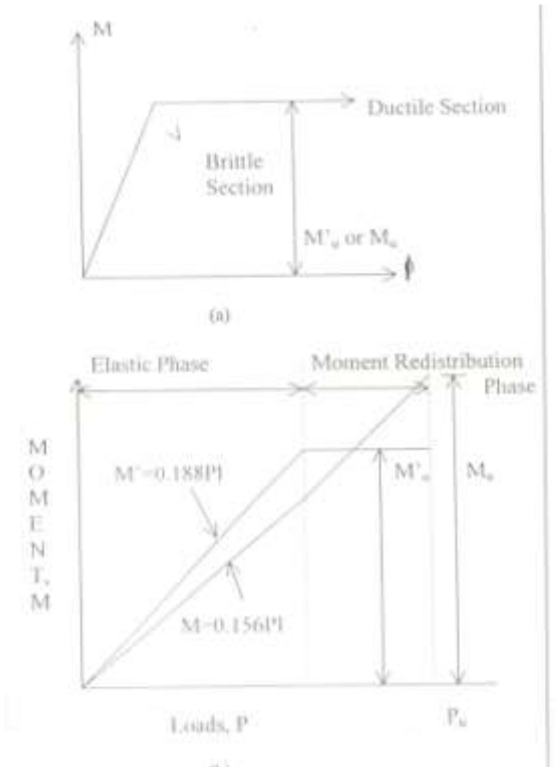

Figure 3: Moment redistribution

If sufficient rotation capacity of the plastic hinges is available, the bending moment distribution at the ultimate load may be quite different from that calculated using elastic theory and will depend on the ultimate moments of resistance of the sections. In reinforced concrete structures, the ductility at the first plastic hinges to form may be insufficient to enable full redistribution of moments to take place with the ultimate moment at each critical section. Thus, if moment redistribution is to be relied on, the availability of sufficient ductility at the plastic hinges must be ensured.

Experimental Investigation

An experimental investigation to study the performance enhancement of synthetic fiber reinforced two span continuous RCC beam is carried out. Three beams of five meter length, each span of 2400mm and of cross section 100mm x 200mm have been used. Of the three, one was the conventional RCC beam, other was the fully fiber reinforced RCC beam and the third beam was fiber reinforced at plastic hinge zones only, the beams are designated as CRCB, FFRB, and PFRB respectively. CRCB contains nil fiber, where as FFRB and PFRB contains 0.5% synthetic fibers (volume fraction of concrete).

Figure 4 shows the details of the reinforcement and the way the beam is loaded. Also Figure 5 shows a photograph showing deformation shape at the ultimate stage.

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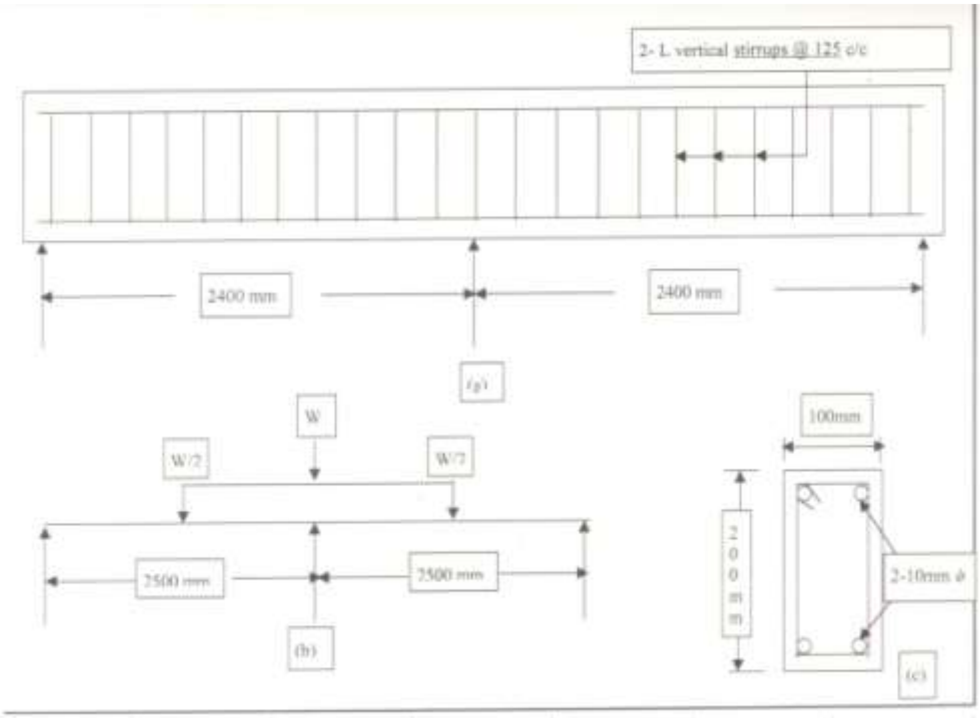

Figure 4: Details of reinforcement and loading

Figure 5: Deformation shape at ultimate stage

Synthetic fiber reinforced concrete with percentage of volume fraction to 0.5 was placed in the plastic hinge zone of 2.6 times the length of plastic zone. The length of plastic zone is calculated using lp = 0.05z + 0.5 d (where lp is the length of plastic zone, z is the distance from plastic hinge to the nearest point of zero moment and d is the effective depth). The total number of plastic hinges in a two span continuous beam is three, which include one at the center support and one each under the central point load. The position of the plastic hinge for the present continuous beam has been shown in Figure 6.

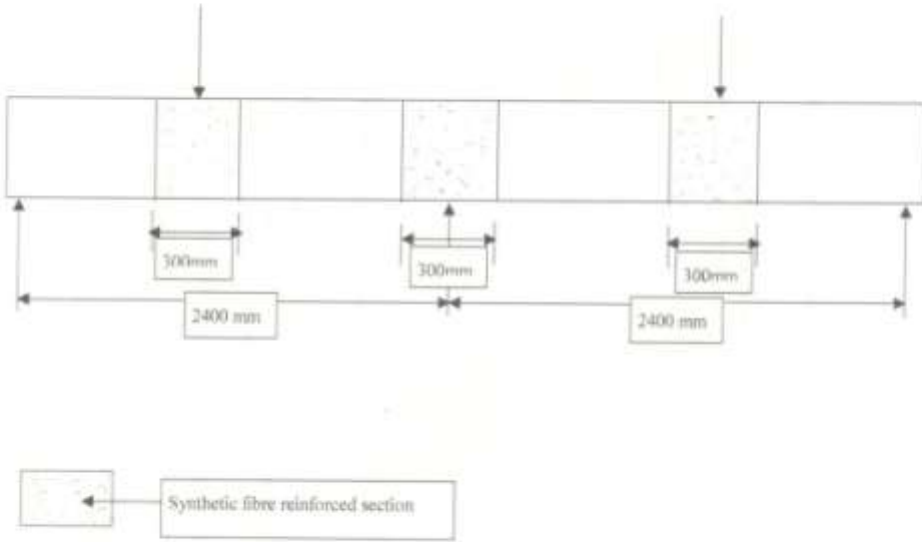

Figure 6: Beam with fiber reinforced at plastic hinges only

MATERIALS AND METHODS

Cement

Ordinary Portland Rajashree 43 grade cement was used in the present investigation. It was tested as per IS: 4031-1988 recommendations for hydraulic cement.

Aggregates

The locally available river sand has been used as fine aggregate. Physical tests on fine aggregate have been conducted. For coarse aggregate, 20 mm and down size granite metal has been used.

Reinforcing Steel

High yield strength deformed bars (HYSD), designated as Fe415, has been used for main reinforcement. The steel was tested for yield stress, and the result obtained was 463 MPa, designated as Fe250, have been used for shear reinforcement.

Synthetic Fibers

A synthetic fiber, which is readily available in the market under the trade name "GARWARE TWINE", is used as fiber reinforcing material. Its physical and engineering properties are presented in Table 1. As per specifications, "Garware Twine" is manufactured from high-density polyethylene and polypropylene. It is totally resistant to sea water, acids, alkali and chemicals. It does not absorb water and hence cannot rot. It has high breaking strength and high abrasion resistance as is less prone to wear and tear. In the present investigation, synthetic fiber of diameter 0.5mm as per specification has been used. The aspect ratio of 60 is maintained throughout the experiments (i.e., the length of fiber is 30mm).

Table 1: Physical and engineering properties of GARWARE TWINE

Sl. No.	Property	Value
1	Molecular formula	$(CH_2 - CH_2)_n$
2	Young's modulus	$7\ GN/m^2$
3	Melting point	85^0 C
4	Unit weight	$9.2\ kN/\ ^3$
5	Tensile strength (0.5mm diameter)	$127.4\ N/mm^2$

Proportioning of Concrete Mix

The proportion of M_{20} mix is obtained by referring to IS: 10262-1982 as recommended. The proportion of cement, fine aggregate and coarse aggregate were obtained as 1:1.40:2.89 respectively (rounded up as 1:1.5:3.00) and the water cement ratio is maintained as 0.5 throughout the investigation.

Formwork

The formwork consists of wooden box of internal dimensions 100mmx200mmx5000mm with the topside being kept opened. The side shutters, made of wooden planks, are connected to the base of wooden plank with angles, bolts and nuts. The wooden box is supported on small specimen beams spaced at regular intervals. Before placing of concrete and reinforcement, grease oil was applied on all internal sides of the mould.

Mixing of Fiber Reinforced Concrete

Mixing of conventional concrete and fiber reinforced concrete was done separately and simultaneously for partially fiber reinforced beam. The mixing process, continued for about 15 minutes, as given in the following steps., (i) The cement and fine aggregates are mixed dry thoroughly and uniformly in the specified proportions (ii)The required quantity of coarse aggregate is added to the above mix uniformly and mixed thoroughly (iii) To the above mix the calculated quantity of water spread and mixed thoroughly (iv) The above mix is spread uniformly and the required quantity of fiber is spread randomly and mixed thoroughly (the fiber is mixed to the wet concrete to ensure that there is no balling of fibers) and (v) Then the ingredients are mixed till the mix achieves uniform color.

Casting and Curing of Beams

The concrete was mixed in the required proportions and before placing of concrete in the mould, it was ensured that the grease oil is applied on all internal sides of the mould, and then the concrete was placed in the mould in three layers, tamped properly with tamping rods to ensure proper compaction and vibrated. Simultaneously six cubes along with each beam were cast as the control specimens of size 150mm x 150mm x 150mm. The control specimens were cured by fully immersing in the water tank. After seven days three cubes were tested for their strength and were found to have crossed the limits given in Table 5 of IS: 456-1978. After 28 days the other three cubes were tested for their strength. The average 28 days strength of the control specimen is tabulated in Table 2.

Table 2: 28 day strength of control specimens

Sl. No.	Beam designation	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)
1	CRCB	46	4.75
2	FFRB	50	4.95
3	PFRM *	45	4.69
4	PFRB **	49	4.90

* *Plain specimens*
** *Fiber reinforced specimens*

Test Setup

All the continuous beams, supported at each of their ends and in the center, were tested after 28 days of curing. All the beams were tested with 10 ton capacity proving ring fixed on the steel frames made up of rolled steel section. A spreader beam of depth 400mm was used to transfer the load onto the center of each span. Dial gauges having a least count of 0.01mm were used to measure the deflection under each point and at center support section. A cathetometer, sighting to a reference point under load in each span, was used to measure the deflection (as a check to the deflection measured by dial gauges and also at the ultimate stage it may be not possible to take reading through dial gauge). The widths of the cracks were measured with the help of crack measuring microscope having a least count of 0.02mm. Surface strains were measured by means of mechanical strain gauge (Demac gauge) of 200mm gauge length. Demac gauge points were fixed at three critical sections, namely center support and under loading points in each span. At each section Demac gauge points at eleven locations, overall the depth with center to center distance of 20mm was pasted with the help of araldite mix. Prior to testing the beams were whitewashed in order to get a clear picture of the cracks.

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Testing of Specimen

Initial reading of the dial gauges, Demac gauges, and cathetometer over the gauge points on the test specimens were taken before the start of the experiment. Then the loading through a hydraulic loading jack was started and continued in increments. Strains and deflections were noted at each increments of the loading. As the load is increased, cracks on the tension zone were observed. The widths of cracks at various load increments were taken with the help of crack measuring telescope. The loading was continued till the beams reached the ultimate stage. Figure 7 shows crack pattern for PFRB and Figure 8 shows crack pattern for FFRB.

Figure 7: Crack pattern for PFRB

Figure 8: Crack pattern for FFRB

RESULTS AND DISCUSSION

Cracking Load

Arresting of cracks to the extent possible is one of the main objects in adopting fiber reinforcement in conventional RCC beams. The observed and predicted loads are shown in Table 3 and Table 4. The beams with fibers have shown significant improvement in cracking load, the load at which the first crack is visible and it is up to this load, the load-deflection curve will be linear. The slope of this linear line will be given by the ratio of load to deflection.

The cracking load for the fully fiber reinforced beam (FFRB) showed an improvement of 24% over the conventional RCC beam (CRCB) and 18% over with fiber reinforced in plastic hinge zones (PFRB). The FFRB has gained 7.5% improvement in cracking load over PFRB.

Table 3: Load and moment values at mid-span

Sl. No.	Description	Theoretical value	Experimental value CRCB	FFRB	PFRB
1	Cracking load W_{cr} (kN)	6.12	10	13.22	12.22
2	Ultimate load W_u (kN)	28.70	30	38	36
3	Cracking moment M_{cr} (kN-m)	2.29	3.75	4.96	4.58
4	Ultimate moment M_u (kN-m)	11.48	11.25	14.25	13.5

Table 4: Load and moment values at mid-support

Sl. No.	Description	Theoretical value	Experimental value CRCB	FFRB	PFRB
1	Cracking load W_{cr} (kN)	5.075	10	12.22	11.22
2	Ultimate load W_u (kN)	28.70	30	38	36
3	Cracking moment M_{cr} (kN-m)	2.29	4.5	5.5	5.0
4	Ultimate moment M_u (kN-m)	11.48	13.5	17.1	16.2

Load Deflection Curves

Figures 9 and 10 present load-deflection curves at mid-span and at mid-support for conventional, partially reinforced and fully reinforced concrete beams.

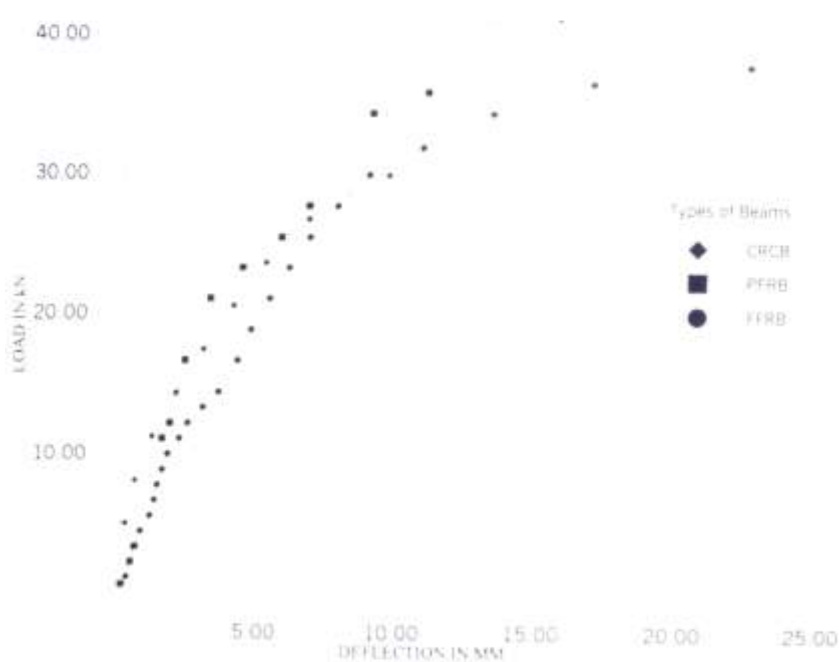

Figure 9: Load-deflection behavior at mid-span

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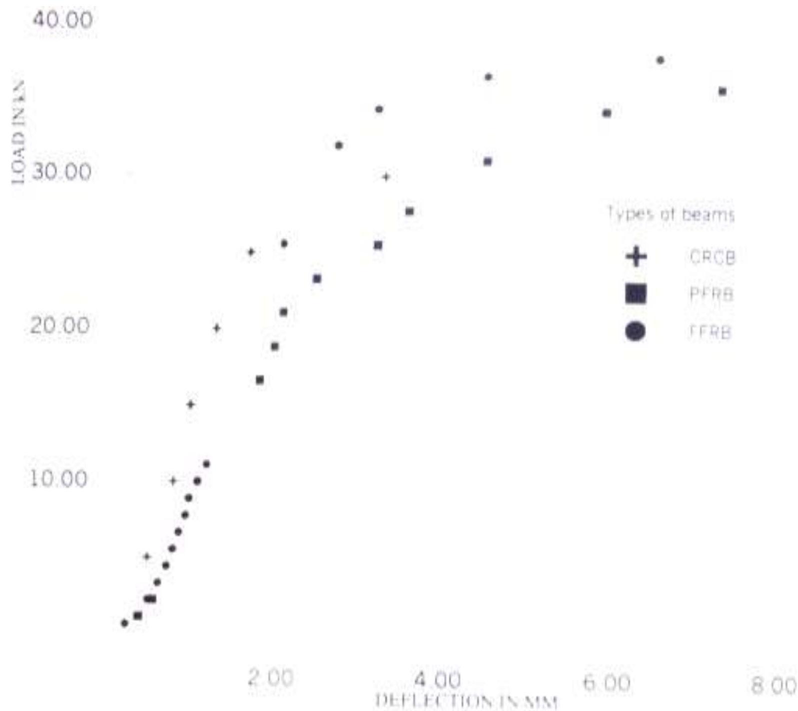

Figure 10: Load-deflection behavior at mid-support

Cracking Moment

Cracking moments for all the three beams are tabulated in the tables 3 and 4. It can be noted from the table that the observed cracking moment values for all the beams are much greater than the corresponding predicted theoretical values. In all the beams, observed cracking moments at support section are found to be greater than those at the mid-span section, there by confirming to bending moment constants (i.e., 0.188 for support and 0.156 for mid-span section within the elastic range). The percent increase in the cracking moment for FFRB and PFRB is 24% and 18% respectively over CRCB. However this increment is narrowed down by 12.5% and 5% in case of ultimate moment. Therefore it can be concluded that the addition of fibers throughout the beam improves cracking characteristics substantially.

Ultimate Load

The observed ultimate load was greater than theoretically assessed ultimate load in all cases. The increase in ultimate load is 21% for fully and 17% for partially fiber reinforced beams indicating that ultimate load carrying capacity do not vary much whether fibers are dispersed throughout or limited to discrete zones.

Ultimate Moment

Inclusion of fibers in R.C beams in order to impart ductility has resulted in increase of ultimate moment. In all the cases first plastic hinge has formed at support subsequently hinges have formed at load point. Increase in ultimate moment for FFRB is 21%, where as for PFRB is 17%. The FFRB shows 5% improvement over PFRB. The beneficial effect of improvement in strength can easily be recognized.

Moment-Curvature Relationship

From moment-curvature graphs it is observed that there is enhancement of 56% in curvature for FFRB and 22% for PFRB. The curvature obtained for FFRB is nearly two times larger than for CRCB. It may be concluded that FFRB accommodates large deformation before failure.

Ductility

The ductility factors have been calculated as the ratio of ultimate curvature to curvature at first yield. The ductility enhancements of 57% for FFRB and 22% for PFRB have been observed. This clearly indicates inclusion of synthetic fibers vastly improves ductility.

Strain Variation across the Depth

It is observed from the analysis of strain variation diagrams that the compression zones in CRCB beam is narrow compared to that of PFRB and FFRB. Large curvature variations are witnessed for the support section compared to the mid-span section. A perusal of the variation shows that the shift in neutral axis is more in CRCB compared to FFRB in the post cracking stage.

Crack Width Behavior

Figure 11 shows load-crack-width curves for CRCB, PFRB and FFRB. It is observed that the addition of fibers is effective in arresting the growth as well as propagation of cracks. This is due to the dissipation of part of the energy in destroying the bond between the fibers and matrix, thus the energy available for developing crack surface is considerably reduced. Crack patterns, width and propagation observed during the tests indicate superiority of performance of FFRB, PFRB and CRCB in that order.

The maximum crack width in case of CRCB was 2mm, while in FFRB it was 1.4mm and in PFRB it was 1.5mm. Thus, the inclusion of fibers aiming at the arrest of cracks resulted in a reduction of crack width in the range of 25% to 30%. At the ultimate load stage, the cracks in tension zone of CRCB opened up considerably. On the other hand the PFRB and FFRB exhibited more number of minute cracks, discontinuous and more evenly distributed.

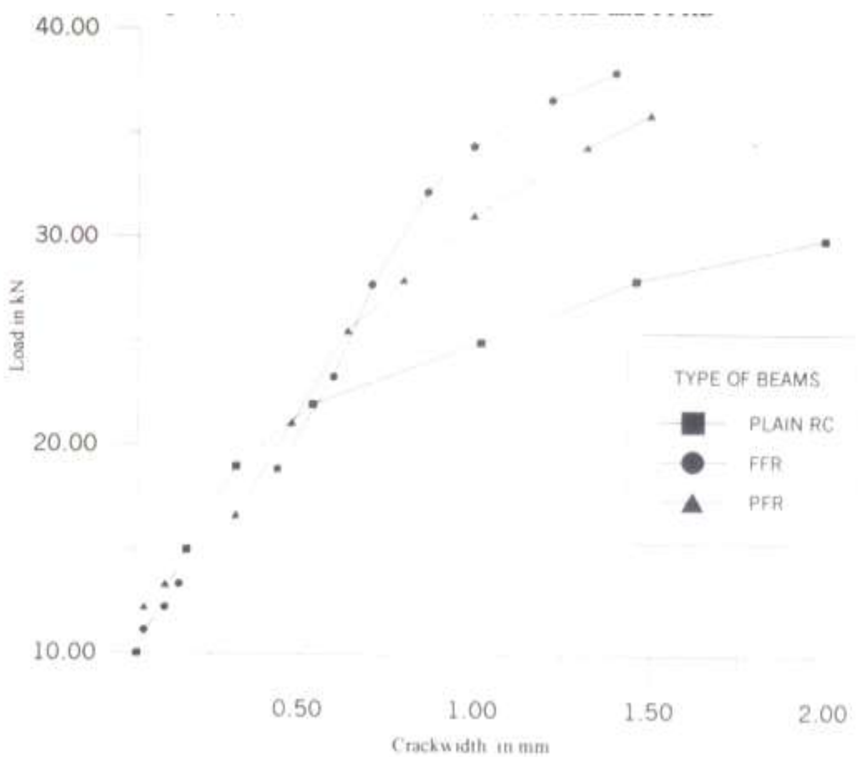

Figure 11: Load crack-width curves for CRCB, PFRB, and FFRB

Conclusions

The following conclusions are deduced from the present investigation.

- Inclusion of synthetic fibers enhances all-round performance.
- First cracking load and ultimate load increase with the inclusion of fibers. But the way in which fibers have been dispersed does not greatly influence the strength.
- Moment-curvature relationship, cracking characteristics and ductility are heavily dependent on the presence and the dispersion of fibers. Test results have clearly demonstrated the superiority of performance of FFRB, PFRB and CRCB in that order.
- The veracity of the assumptions of elastic and plastic theories of flexure has been confirmed.

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