DOI: 10.15415/jotitt.2013.12008

# Effect of Steel Fibers on Reinforced Concrete Opening Corners

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**Abstract** In the design of reinforced concrete structures, much of the attention is embarked towards calculation of the strength of basic structural elements like beams, columns and slabs. Comparatively lesser emphasis has been laid on the detailing, corresponding strength and behavior of corner joints, especially those subjected to opening moments as in the case of cantilever retaining walls, bridge abutments, channels, rectangular liquid retaining structures, beam column joints under earthquake loads. The detailing of reinforcement should be easier and simpler in order to expedite the construction process. At the same time structural member should satisfy the fundamental requirements of strength expressed in terms of controlled cracking and ductility. The result of a comprehensive experimental programme to evaluate the structure behavior of opening corners having U type detailing; corners reinforced with fibers is presented in this paper. The parameters of investigation are: strength measured in terms of joint efficiency, ductility, and crack control. A substantial increase in post-cracking tensile strength, ductility and crack control can be achieved by adding steel fibers to the concrete. Therefore U type detailing system investigated previously was tested afresh with crimped-type flat steel fibers having aspect ratio of 30 and 50 at different percentage volume fractions of 0.5%, 1.0%, 1.5% and 1.75%. The investigations indicate that in the specimen, there is a 30%-35% gain in efficiency with increase in volume fraction up to a certain limit beyond which there is a drop in mix workability and joint efficiency.

**Keywords:** Opening corners; Joint efficiency; Crimped fibers; Aspect ratio; Volume fraction

Journal on Today's Ideas – Tomorrow's Technologies, Vol. 1, No. 2, December 2013 pp. 113–122

CHITKARA UNIVERSITY

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## 1. INTRODUCTION

The principles of detailing and the structural behavior of simple structural members such as beams and columns are well established. On the other hand, the detailing, strength and behavior of corner joints, especially those subject to opening moments as in the case of cantilever retaining walls, bridge abutments, channels, rectangular liquid retaining structures and portal frames, has not been conclusively determined. Strength of corner plays a primary role in influencing the structural behavior of the joint more so in the case of opening joints or corners. The reinforcement details must be such that its layout and fabrication is easy and the structural member should satisfy the fundamental requirements of strength expressed in terms of joint efficiency, controlled cracking, ductility and last but not the least, ease and simplicity of construction. In general, the failure of opening corners is invariably characterized by the low tensile strength of concrete resulting in the initiation of a splitting tensile crack originating at the re-entrant corner and gradually moving out along the corner diagonal towards the exterior corner. Extensive tensile cracking in the concrete and the inability of the detailing system to carry the principal tensile forces in the joint which eventually tend to push out the exterior part of the joint, thus reducing the lever arm, mark the terminal failure stage.

It is evident that in the absence of a rational detailing system, the corner concrete has no ability to sustain the resultant diagonal tensile force and a premature brittle failure characterized by low toughness and ductility is imminent.

Results of experiments conducted by Wahad et al. (1998) shows that a substantial increase in the post cracking tensile strength can be obtained by including steel fiber in the matrix, with these fibers acting as crack arrestors and enhancing the ductility and energy absorption capacity of the member in question. Since, the tensile response of concrete plays a decisive role in influencing the behavior of opening corners, it is worthwhile to explore the application of steel fiber reinforced concrete corners subjected to opening moments.

## 2. EXPERIMENTAL PROGRAMME

U type detailing system was investigated. The shape and size of specimens, loading arrangements and instrumentation of the specimens are illustrated in figure 1:

Various shapes of the test specimens are possible and the portal type shape was selected for this investigation because of the case of testing which it affords (the specimen being tested in the horizontal position, lying on frictionless support on the ground) and the two $90^0$ corners in the specimen allowing for

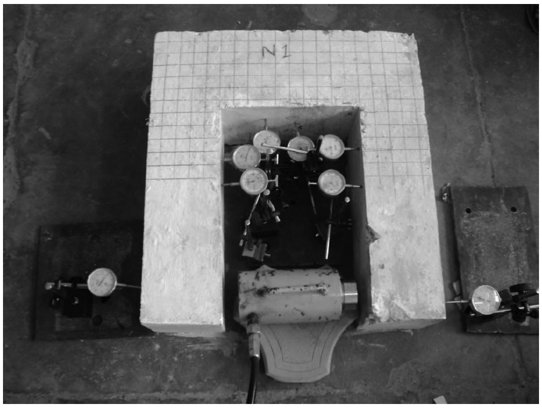

**Figure 1:** Showing shape and size of specimens, loading arrangements and instrumentation of the specimens.

cross-checking of results. Different nine types of specimens were casted using different types of fibers having two different aspect ratios & having volume fractions of 0.5%, 1.0%, 1.5% and 1.75%.

## 3. MATERIALS

In all the specimens, 12mm-Φ Tor steel bars [conforming to IS 1786-1985[5]] were used as main steel with 0.75% tension reinforcement. The stirrups were fabricated using 8mm-Φ Tor steel. The hanger bars consisted for 6mm-Φ plain bars. Minimum shear reinforcement as per specifications of IS 456-1978 was provided.

Cement of 43 Grade PPC was used in the concrete mix of proportion by weight 1:2.23:2.53 (cement: fine aggregate: coarse aggregate). The water-cement ratio was 0.42. The steel fibers used in the specimens, procured from a firm in Nagpur, were an aspect ratio of 30 and 50.

The specimens were casted on level ground in the casting yard using mild steel formwork. Prior to casting, the forms were coated with shuttering oil on the inside surface. Cover blocks of 25mm thickness were used to give the desired cover to the steel. The concrete was prepared using a tilting type concrete mixer and due care was taken during preparation of the mix to avoid fiber balling. Use of an immersion vibrator ensured good compaction of concrete. The specimens were stripped after 24 hours of casting and covered with jute bags, which were kept moist by periodically sprinkling them with water. Curing in this manner was carried out for 15 days after which the specimens were left in the laboratory till the time of testing which was nominally 28 days after the day of casting. Control specimens consisting of 150 mm side cubes were also casted with each specimen to determine their compressive strength.

All specimens were tested under pure positive (opening) moment using the basic loading arrangement shown in figure 1. The monotonically increasing load was applied in increments using a manually operated hydraulic jack. A time interval of around 10 min was given between two increments of load so as to allow the crack growth to stabilize. The applied load was measured using a sensitive proving ring. Deflections and consequent changes in the corner angles were measured using dial gauges having a least count of 0.01 mm. The loading arrangement, location of the dial gauges on concrete and steel is shown in figure 1.

As the test progressed, load reading, horizontal displacements of the specimen legs at each stage of loading, development and propagation of cracks, load at first crack and the mode of failure of the specimen were noted. The control specimens were tested on the same day as the corner specimens and their test results are summarized in Table 1.

**Table 1 :** Showing detail of Test Specimens

| Specimen number | Cube strength, MPa | Fibre volume fraction (crimped fibres) | Fibre aspect ratio |
|---|---|---|---|
| N1 | 44.75 | 0% | nil |
| N2 | 51.22 | 0.5% | 30 |
| N3 | 52.19 | 1.0% | 30 |
| N4 | 49.14 | 1.5% | 30 |
| N5 | 47.3 | 1.75% | 30 |
| N6 | 48.36 | 0.5% | 50 |
| N7 | 47.64 | 1.0% | 50 |
| N8 | 53.54 | 1.5% | 50 |
| N9 | 51.86 | 1.75% | 50 |

## 4. EXPERIMENTAL RESULTS AND DISCUSSION

Because of the exploratory nature of the investigation, as a lower bound, a 0.5% volume fraction of fibers were added to each specimen. It was anticipated that observable structural behavioral changes would manifest at this volume fraction of fibers. Further, investigation with different aspect ratio and higher volume fraction of fibers would hinge upon the nature of results obtained with 0.5% volume fraction. The dimensions of the specimens were so selected that the calculated ultimate moment of resistance (nominal strength, $M_{UC}$) for Section II (in the horizontal leg of the specimen, figure 2) is about 30% higher than that for section I (in the vertical leg of the specimen, Figure 2) Section I-I is accordingly the design section. The corner joint is expected to transfer the moment from the weaker member framing into the corner to the stronger member. The theoretical ultimate moment of resistance of section I-I is taken as the reference value for computing joint efficiency. The failure moment ($M_{ut}$) determined experimentally is compared with the nominal theoretical ultimate moment of resistance ($M_{uc}$) of the design section. The value $M_{ut}$ / $M_{uc}$ x 100 is a measured of the efficiency of the joint. This value must be greater than or atleast equal to 100% in order that the joint may be pronounced as strong as the weaker cross section framing into it.

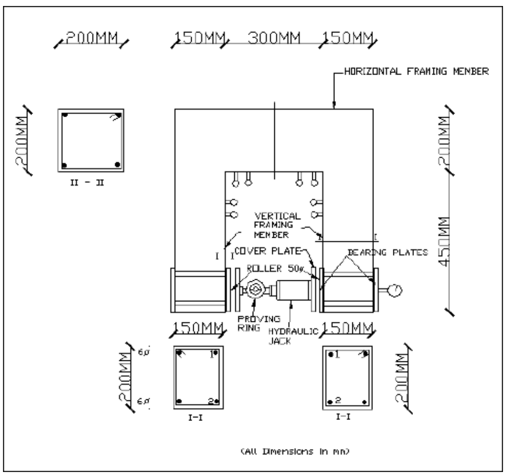


**Figure 2:** Test Setup plan.

## 4.1 Specimens with Variable Volume Fraction

U type detailing system was selected for further investigations (B Singh et. al 2003) because of its adaptability, ease of fabrication and a reasonably good structural performance when compared with other detailing systems. Five specimens, namely N1, N2, N3, N4 and N5 were cast with fiber volume fractions of 0%, 0.5%, 1%, 1.5% and 1.75%, respectively using 30-mm long crimped-type flat steel fibers. The other four specimens, namely N6, N7, N8 and N9 were cast with fiber volume fractions of 0.5%, 1%, 1.5% and 1.75%, respectively using 50-mm long crimped-type flat steel fibers.

Considerable difficulties were experienced in making a homogeneous and workable mix with 2% volume fraction of fibers. During the process of addition and mixing of fibers in the mixer, the fibers had a tendency to clump together and it was difficult to obtain a uniform dispersion of fibers in the matrix. Attempts to introduce 2% volume fraction of fibers in a trial batch were totally unsuccessful and the mix had to be abandoned thus restricting the upper bound of the fiber volume fraction under investigation to 1.75%.

The load deflection curves for specimens N1, N2, N3, N4 and N5 are presented in figure 3 and for specimens N6, N7, N8 and N9 are presented in figure 4. As the volume fraction increased from 0% to 0.75% and then on to 1.25% and 1.50%, there is an increase in the peak load hence in the efficiency of the specimens. Further increase in the volume fraction from 1.5% to 1.75% resulted in a drop in the load at failure.

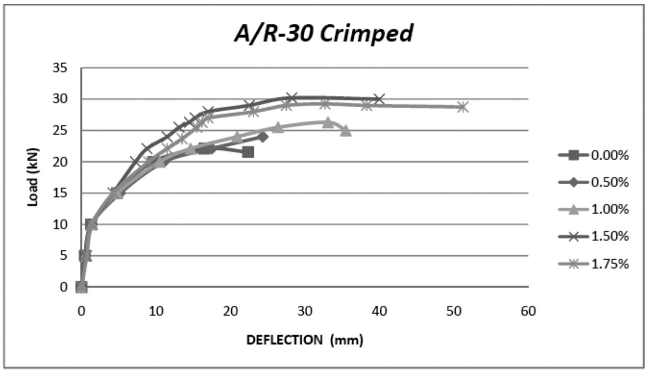


**Figure 3:** Showing variation of deflection with load for aspect ratio 30 with different volume fraction ratio

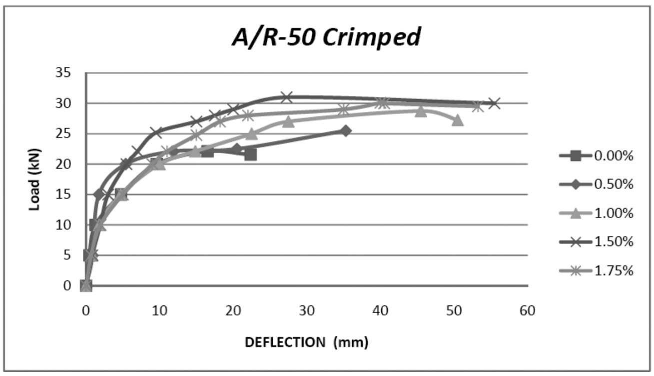


**Figure 4:** Showing variation of deflection with load for aspect ratio 50 with different volume fraction ratio

**Table 2:** Test Results

| Specimen number | Fibre Volume Fraction | Aspect ratio 30 | Aspect ratio 50 | Theoretical ultimate moment, $M_{uc}$, | Test Failure Moment, $M_{ut}$, | Corner Efficiency $M_{ut}/M_{uc}$x 100), % |
|---|---|---|---|---|---|---|
| | | | | (kNm) | (kNm) | |
| N1 | 0% | Nil | Nil | 11.74 | 11.271 | 96 |
| N2 | 0.5% | 100% | Nil | 12.56 | 12.24 | 97.45 |
| N3 | 1.0% | 100% | Nil | 12.678 | 13.413 | 105.07 |
| N4 | 1.5% | 100% | Nil | 12.302 | 15.402 | 125.19 |
| N5 | 1.75% | 100% | Nil | 12.07 | 14.91 | 123.59 |
| N6 | 0.5% | Nil | 100% | 12.20 | 13.005 | 106.56 |
| N7 | 1% | Nil | 100% | 12.11 | 14.66 | 121.04 |
| N8 | 1.5% | Nil | 100% | 12.84 | 15.912 | 123.91 |
| N9 | 1.75% | Nil | 100% | 12.638 | 15.376 | 121.67 |

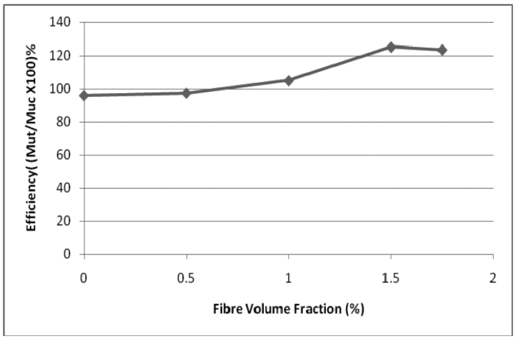


**Figure 5:** Showing variation of Corner efficiency with volume fraction ratio for aspect ratio 30.

### 4.2 Specimens with Fiber Reinforced Concrete

U type detailing promises to some extent the confining action of the loop by filling out the corner while at the same time, offering considerable ease in fabrication. The failure pattern of N2 was not very different from that of N1.

The terminal stage of the test was marked by a long crack more or less normal to the corner diagonal, which has a tendency to push the outer part of the corner away thus resulting in a reduced lever arm and failure of the specimen. Nearly 12% gain in efficiency was obtained for N2 when compared with N1. The addition of fibers in N2 resulted in better control of cracking, thus increasing the strength and stiffness of the joint. The efficiencies of all the test specimens are given in table 2.

The efficiencies of all the test specimens are compared in figure 5 for aspect ratio 30 and in figure 6 for aspect ratio 50. For aspect ratio 30 and 50 a combined graph is plotted and is shown in figure 7.

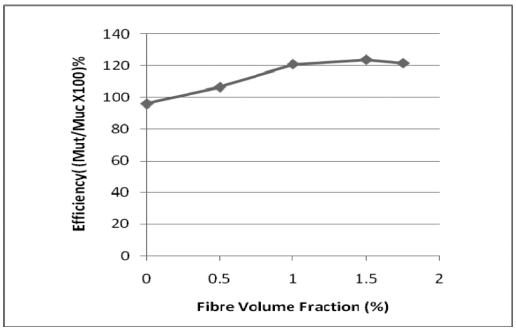


**Figure 6:** Showing variation of Corner efficiency with volume fraction ratio for aspect ratio 50.

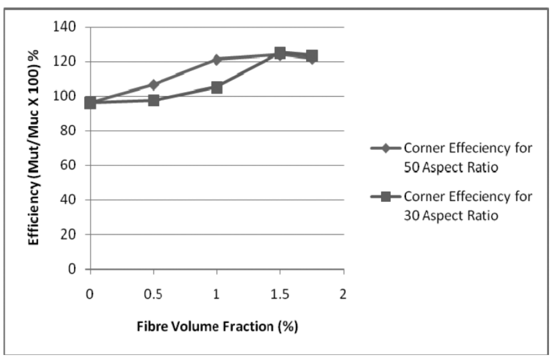


**Figure 7:** Showing comparison of Corner efficiency with volume fraction ratio for aspect ratio 30 and 50.

Toughness may be determined as the area under the load-displacement curve. By adding fibers even at a comparatively lower volume fraction of 0.5%, a marked improvement in the toughness and ductility of N1 was observed. Specimens with fibers were able to sustain a significant proportion of their peak loads at large deflections. None of the specimens with fibers exhibited explosive type of failure, and spalling and disintegration of concrete at load leading to the peak value was markedly reduced.

*of equal significance is the substantial increase in toughness (ability to carry a substantial* part of the peak load at large deflections) with increasing fiber volume fraction of the fiber reinforced specimens, which may be quantitatively expressed as the area under the load-deflection curve and expressed in a normalized manner by the toughness index.

It is usual to express the toughness index as the ratio of the area under the load-deflection curve up to some specified observed deflection to the area up to deflection corresponding to first visible crack.

Pending resolution of the criteria for determination of the limiting deflection, it can be qualitatively stated that there is an unmistakable increase in the toughness of the specimens with increase in fiber volume fraction

## 5. CONCLUSIONS

1. The addition of fibers even at a relatively low volume fraction of 0.75% results in observable improvements in structural behavior. Fibers alone may not be able to resist the primary forces acting on the joint but in combination with a rational detailing system, fibers offer the promise of a significant improvement in ductility, toughness and serviceability behavior as well as 30% - 45% increase in joint efficiency.
2. In fibrous concrete specimens, with various volume fractions of fibers of aspect ratio 50 and 30, especially at fiber volume fraction of 1.00% and above, significant gain in corner efficiency, improvement in the ductility and toughness vis-à-vis non-fibrous concrete specimens were observed. An almost ductile response was obtained for specimens with a fiber volume fraction of 1.50% and above. Large specimen deformations preceded the failure stage, which was marked by widening of cracks and fiber pull-out. The trends in the ductility indices calculated for these specimens bear out this observation. It was not possible to incorporate more than 1.75% volume fraction of the fibres in the concrete mix due to the unworkable nature of the resulting concrete mix. Hence, 1.75% volume fraction of the fibers seems to be the practical upper limit, which can be effectively used in concrete.

3. There is a gain in the strength as well as the toughness as the fiber volume fraction as increased to 1.50%, which appears to be the optimum for the fiber type under investigation beyond which the mix becomes unworkable and the specimen efficiency is hampered.

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