# Experimental Study on Moderate Deep Beam In Shear Introducing Steel Fiber Reinforced Concrete

**Mr. Ajit Anandrao Desai[1], Prof. Mr. J. S. Kanase[2], Prof. Mr.V. S. Shingade[3]**
[1, 2, 3] Department of Civil Engineering
[1, 2, 3] Trinity College Of Engineering And Research Pisoli, Pune-48

***Abstract****- The experimental work is carried out to evaluate the shear strength of steel fiber reinforced concrete Moderate deep beams without stirrups. For this 27 beams are cast. The beams are tested under two-point loading as per IS after 28 days curing. Fiber fraction is kept as 0%, the shear span-to-depth ratio (a/d ratio) for beams is varies as 1, 1.5 and 2 for specimen series-I. Fiber fraction is varies as 0.25%, 0.50 and 0.75%, the shear span-to-depth ratio (a/d ratio) for beams is kept as 1.5 for specimen series-II. Fiber fraction is kept as 0.50%, the shear span-to-depth ratio (a/d ratio) for beams is varies as 1, 1.5 and 2 for specimen series-III. The cube compressive strength is estimated. The experimental results are compared with theoretical results obtained from empirical equations and design codes. Also the experimental results are compared with the equations put forth by the other researchers and codes to estimate the shear strength of the steel fiber reinforced concrete Moderate deep beams without stirrups.*

***Keywords***- Hook End Steel Fiber, Moderate Deep Beam without Shear reinforcement, Shear strength, Ultimate strength, shear span to Effective depth ratio

## I. INTRODUCTION

In general, Beams are structural elements loaded as simple beams in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction. Beam can be classified in to three categories as per its span to depth ratio namely Shallow or Normal Beam, Moderate Deep Beam and Deep Beam.

As per Indian standard code IS 456:2000 (Page No:51, Clause No:29.1),a beam shall be said tobe Deep Beam when the ratio of clear span to overall depth i.e. L/D is less than :
2.0 for simply supported beam and
2.5 for continuous beam.

As per ACI-ASCE Committee 426 Classified abeam with shear span (a) to depth (D) ratio less than 1.0 as a Deep Beam and beam with a/D exceeding 2.5 as an ordinary Shallow /Normal Beam in between these two limits is categorized as a Moderate Deep Beam. It was observed that different codes of practice consider the span to depth limits to define simply supported deep beam as per practice. The CIRIA guide 2 provides supplementary rules for Deep Beams i.e. the beams having span to depth ratio < 2 are Deep Beam.

In general, it can be classified as,

| | |
|---|---|
| Shallow/Normal Beams | L/D ≥ 6.0 OR a/D> 2.5 |
| Moderate Deep Beams | 2.0 < L/D 6.0 OR 1.0 <a/D< 2.5 |
| Deep Beams | 0.5 < L/D ≤ 2.0 OR a/D< 1.0 |

Deep beams are shear predominant and shallow beams are flexure predominant. In Moderate Deep Beam flexure predominance or shear predominance depends on percentage of tension reinforcement. Moderate Deep Beam and Deep Beam are shear predominant members and generally fail in brittle shear mode. Reinforced concrete Moderate deep and Deep Beams have many applications in building structures such as transfer girders, wall footings, foundation wall caps, floor diaphragms, and shear walls. Continuous deep beams occur as transfer girders in multi-story frames

Many reports published over the past decades, confirm the effectiveness of steel fibers as shear reinforcement. Fibers are used to boost the shear capacity of concrete or to replace, in part, the vertical stirrups in reinforced concrete structural members, which reduce reinforcement congestion. But, shear strength of Moderate deep beams is highly influencing character. The great number of parameters that affect the beam strength has led to a limited understanding of shear failure. These parameters include fiber volume fraction, type of fiber, aspect ratio, size effect, percentage web reinforcement, a/d ratio, properties of concrete and steel. It is necessary to know the exact effect of addition of different fiber volume fraction and different shear span-to-depth ratio on shear strength of deep beam. Such an evaluation is needed for designing code which will recognize the contribution of steel fibers to the shear strength of reinforced concrete beams.

## II. RESEARCH SIGNIFICANCE

The application of fiber to R.C.C. structural members would be one of the major areas of use in structural engineering. The fibers to R.C.C. have got an existing future in construction in days ahead. The objective of the present experimental investigation was to evaluate ultimate shear strength of Steel Fiber Reinforced Concrete moderate deep beams without stirrup. The purpose of this article is to present the results of investigations where the stirrups were replaced by steel fibers as shear reinforcement. The object was also to understand the deflection and the cracking behavior of SFRC moderate deep beam without stirrups.

## II. EXPERIMENTAL INVESTIGATION

### Test materials

Ordinary Portland cement of 53 grade, natural river sand having fineness modulus of 2.8 and maximum size of 4.75 mm as a fine aggregate, and natural basalt gravel of maximum size 20 mm and 10 mm as coarse aggregate were used. The concrete mix proportion was (M30) 1:1.7:2.4 (cement: fine aggregate: coarse aggregate) by weight with fiber volume fraction of 0%, 0.25 %, 0.50% and 0.75% by volume of concrete and water cement ratio of 0.45 kept constant for all beams. The Hook end Steel fibers were used. All beams were provided with anchor bars along with nominal 0.38 % by volume of concrete HYSD bars of grade Fe 415 as main longitudinal tension reinforcement without any web reinforcement. There are three series of beams. For the first series of beams there are three cubes, each contains 0% of steel fiber. For the second series of beams there are total of nine cubes from which first three contains 0.25% of steel fiber, next three contains 0.50% of steel fiber and last three has contains 0.75% of steel fiber. And last series of beams has three cubes each having 0.50% of steel fiber. All specimens were cured at least for 28 days. Dimensions of the each beam are 150mm x 150mm x 700mm and that of each cube is 150mm x 150mm x150mm.

### Specimen Details

Total 27 simply supported beams were tested up to failure. All beams of specimen series-I, II and III were of rectangular cross-section, 150 mm wide and 150 mm deep having clear span of 600 mm. Two bars of 12 mm diameter and two bars of 08 mm diameter were provided as longitudinal reinforcement. Grade of longitudinal reinforcement is Fe-500.
All 27 beams are divided into three series having same cross section and longitudinal reinforcement. Each series having nine beams. In the first series of beams, steal fiber is kept constant (0%) and Shear span-to-depth ratio is varies as 1, 1.5 and 2.In the second series of beams shear span-to-depth ratio is kept constant (a/d=1.5%) and steal fiber varies as 0.25%, 0.50% and 0.75%. In third series of beams steal fiber is kept constant at 0.5% and shear span-to-depth ratio varies as 1, 1.5and2.

### Testing Procedure

The beams were kept on universal testing machine and leveled horizontally with level tube. The beams were tested under gradually applied load on Universal Testing machine (UTM). Three dial gauges (Least Count = 0.01 mm) were used at the bottom of beam to measure the deflections as shown in Fig. 1. Initiation or appearance and propagation of cracks, first crack load, ultimate load and modes of failure of beam were noted. At every stage of loading the process of detecting and marking of new cracks and measuring the propagation of all cracks were continued up to the failure of the beam.

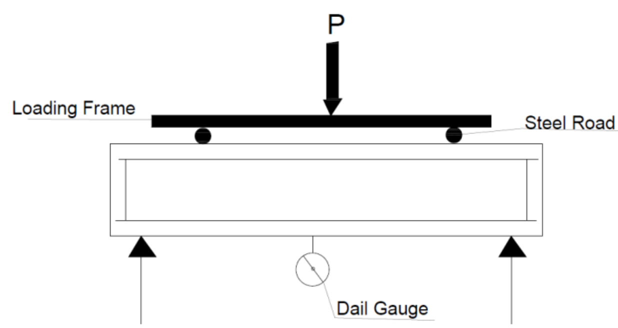


Figure 2.1 Beam Specimens under UTM

Figure 2.2 Compressive Testing Machine (CTM)

Figure 2.3 Universal Testing Machine (UTM)

### 2.1 Cube Compressive Strength

The results of cube compressive strength for specimen series-I, II & III after 28 days curing are obtained and are presented in Table 2.1.

| Cube Designation | % Fiber Content | Cube Compressive Strength (N/mm2) | Average Cube Compressive Strength (N/mm2) |
|---|---|---|---|
| C01 | 0 | 45.20 | 44.90 |
| C02 | | 44.80 | |
| C03 | | 44.70 | |
| C11 | 0.25 | 46.80 | 47.40 |
| C12 | | 47.55 | |
| C13 | | 47.85 | |
| C21 | 0.50 | 52.20 | 51.10 |
| C22 | | 51.45 | |
| C23 | | 50.55 | |
| C24 | | 50.35 | |
| C25 | | 51.20 | |
| C26 | | 50.75 | |
| C31 | 0.75 | 52.75 | 52.58 |
| C32 | | 52.45 | |
| C33 | | 51.55 | |

The maximum value of compressive strength is 52.58 N/mm2 and it is obtained for 0.75 % fiber content. It is observed from Table 2.1that the compressive strength of concrete increases with increase in percentage fiber content, but there is not much increase in compressive strength of concrete containing 0.75 % fiber when compared to concrete with 0 %, 0.25 % & 0.50% fiber.

### 2.2 Central Deflection of Beams

### 2.2.1 Central Deflection of Beam Specimen Series-I

Results of central deflection of beam specimen series-I are presented in Table4.2The graph of central deflection with respect to load is presented in Figure 4.1

Table 2.2: Results of Central Deflection for Beam Specimen Series-I, mm

| **0% Fiber Content a/d-1** | | **0% Fiber Content a/d-1.5** | | **0% Fiber Content a/d-2** | |
|---|---|---|---|---|---|
| **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** |
| 00 | 0.00 | 00 | 0.00 | 00 | 0 |
| 05 | 0.00 | 05 | 0.01 | 05 | 0.02 |
| 10 | 0.01 | 10 | 0.03 | 10 | 0.04 |
| 15 | 0.02 | 15 | 0.04 | 15 | 0.06 |
| 20 | 0.04 | 20 | 0.06 | 20 | 0.10 |
| 25 | 0.06 | 25 | 0.08 | 25 | 0.15 |
| 30 | 0.09 | 30 | 0.11 | 30 | 0.19 |
| 35 | 0.10 | 35 | 0.15 | 35 | 0.24 |
| 40 | 0.14 | 40 | 0.18 | 40 | 0.29 |
| 45 | 0.16 | 45 | 0.22 | 45 | 0.34 |
| 50 | 0.18 | 50 | 0.27 | 50 | 0.38 |
| 55 | 0.20 | 55 | 0.33 | 55 | 0.45 |
| 60 | 0.23 | 60 | 0.40 | 60 | 0.51 |
| 65 | 0.30 | 65 | 0.46 | 65 | 0.57 |
| 70 | 0.35 | 70 | 0.52 | 70 | 0.62 |
| 75 | 0.40 | 75 | 0.58 | 75 | 0.67 |
| 80 | 0.46 | 80 | 0.62 | 80 | 0.71 |
| 85 | 0.52 | 85 | 0.67 | 85 | 0.76 |
| 90 | 0.57 | 90 | 0.72 | 90 | 0.78 |
| 95 | 0.74 | 95 | 0.78 | 97.2 | 0.82 |
| 100 | 0.83 | 100 | 0.86 | | |
| 105 | 0.93 | | | | |
| 109.2 | 1.01 | | | | |

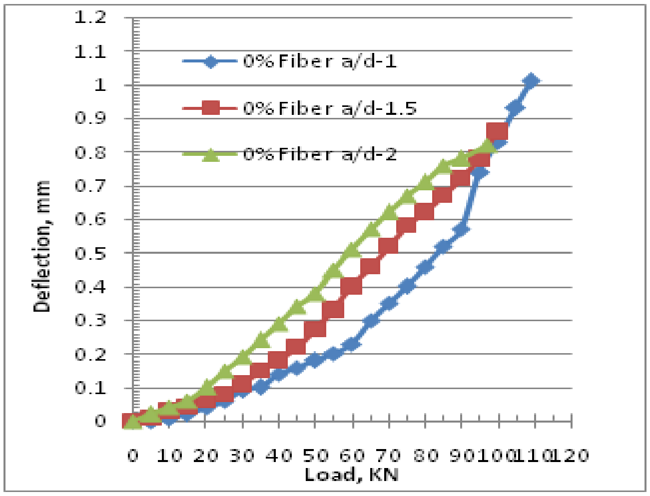


Figure 2.4: The Graph of Central Deflection with respect to Load, Specimen-I

From Table 4.2 and Figure 4.1 it is observed that, deflection increases with decreases in a/d, there for deflection is inversely proportional to a/d. There is considerable increase in deflection for beam of a/d-1.

### 2.2.2 Central Deflection of Beam Specimen Series-II

Table 2.3: Results of Central Deflection of Beam Specimen Series-II, mm

| **a/d-1.5 , 0.25% Fiber Content** | | **a/d-1.5, 0.50% Fiber Content** | | **a/d-1.5, 0.75% Fiber Content** | |
|---|---|---|---|---|---|
| **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** |
| 00 | 0.00 | 00 | 0.00 | 00 | 0.00 |
| 05 | 0.01 | 05 | 0.01 | 05 | 0.00 |
| 10 | 0.02 | 10 | 0.02 | 10 | 0.01 |
| 15 | 0.03 | 15 | 0.04 | 15 | 0.02 |
| 20 | 0.05 | 20 | 0.05 | 20 | 0.04 |
| 25 | 0.08 | 25 | 0.07 | 25 | 0.05 |
| 30 | 0.09 | 30 | 0.08 | 30 | 0.08 |
| 35 | 0.12 | 35 | 0.11 | 35 | 0.10 |
| 40 | 0.15 | 40 | 0.14 | 40 | 0.12 |
| 45 | 0.21 | 45 | 0.18 | 45 | 0.15 |
| 50 | 0.25 | 50 | 0.22 | 50 | 0.19 |
| 55 | 0.32 | 55 | 0.26 | 55 | 0.22 |
| 60 | 0.36 | 60 | 0.31 | 60 | 0.26 |
| 65 | 0.42 | 65 | 0.35 | 65 | 0.31 |
| 70 | 0.46 | 70 | 0.41 | 70 | 0.36 |
| 75 | 0.52 | 75 | 0.46 | 75 | 0.41 |
| 80 | 0.59 | 80 | 0.51 | 80 | 0.46 |
| 85 | 0.67 | 85 | 0.57 | 85 | 0.51 |
| 90 | 0.73 | 90 | 0.64 | 90 | 0.56 |
| 95 | 0.76 | 100 | 0.73 | 95 | 0.61 |
| 100 | 0.81 | 105 | 0.78 | 100 | 0.66 |
| 105 | 0.85 | 110 | 0.83 | 105 | 0.70 |
| 110.48 | 0.88 | 115 | 0.87 | 110 | 0.73 |
| | | 120 | 0.91 | 115 | 0.77 |
| | | 124.72 | 0.94 | 120 | 0.80 |
| | | | | 125 | 0.84 |
| | | | | 130 | 0.91 |
| | | | | 135 | 0.97 |
| | | | | 138.9 | 1.01 |

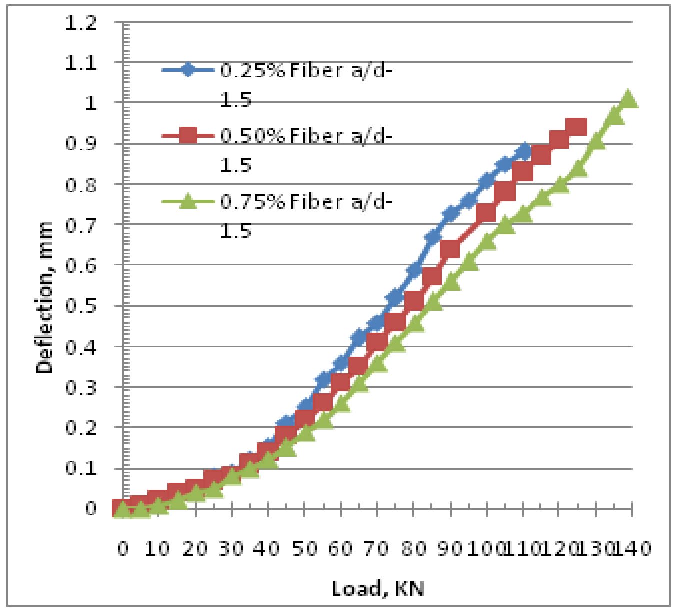


Figure 2.5: The Graph of Central Deflection with respect to Load, Specimen-II

From Table 2.3, Figure 2.5, it is observed that, deflection increases with increase in fiber content, there for deflection is directly proportional to fiber content. There is considerable increase in deflection for beam of 0.75% Fiber content.

### 2.2.3 Central Deflection of Beam Specimen Series-III

Table 2.3: Results of Central Deflection of Beam Specimen Series-III, mm

| **0.50% Fiber Content a/d-1** | | **0.50 % Fiber Content a/d-1.5** | | **0.50% Fiber Content a/d-2** | |
|---|---|---|---|---|---|
| **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** | **Load (KN)** | **Deflection (mm)** |
| 00 | 0 | 00 | 0 | 00 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| 05 | 0 | 05 | 0.01 | 05 | 0.01 |
| 10 | 0.01 | 10 | 0.02 | 10 | 0.03 |
| 15 | 0.02 | 15 | 0.05 | 15 | 0.06 |
| 20 | 0.04 | 20 | 0.07 | 20 | 0.09 |
| 25 | 0.06 | 25 | 0.1 | 25 | 0.14 |
| 30 | 0.08 | 30 | 0.14 | 30 | 0.19 |
| 35 | 0.12 | 35 | 0.18 | 35 | 0.24 |
| 40 | 0.18 | 40 | 0.22 | 40 | 0.28 |
| 45 | 0.24 | 45 | 0.27 | 45 | 0.33 |
| 50 | 0.29 | 50 | 0.33 | 50 | 0.38 |
| 55 | 0.36 | 55 | 0.39 | 55 | 0.43 |
| 60 | 0.42 | 60 | 0.46 | 60 | 0.49 |
| 65 | 0.49 | 65 | 0.52 | 65 | 0.54 |
| 70 | 0.55 | 70 | 0.59 | 70 | 0.58 |
| 75 | 0.61 | 75 | 0.65 | 75 | 0.62 |
| 80 | 0.67 | 80 | 0.7 | 80 | 0.65 |
| 85 | 0.72 | 85 | 0.75 | 85 | 0.69 |
| 90 | 0.75 | 90 | 0.79 | 90 | 0.72 |
| 95 | 0.78 | 95 | 0.82 | 95 | 0.75 |
| 100 | 0.82 | 100 | 0.86 | 100 | 0.78 |
| 105 | 0.85 | 105 | 0.89 | 105 | 0.81 |
| 110 | 0.88 | 110 | 0.93 | 110 | 0.84 |
| 115 | 0.92 | 115 | 0.98 | 114.04 | 0.88 |
| 120 | 0.95 | 120 | 1.01 | | |
| 125 | 0.99 | 124.72 | 1.04 | | |
| 130 | 1.02 | | | | |
| 135 | 1.08 | | | | |
| 139.96 | 1.11 | | | | |

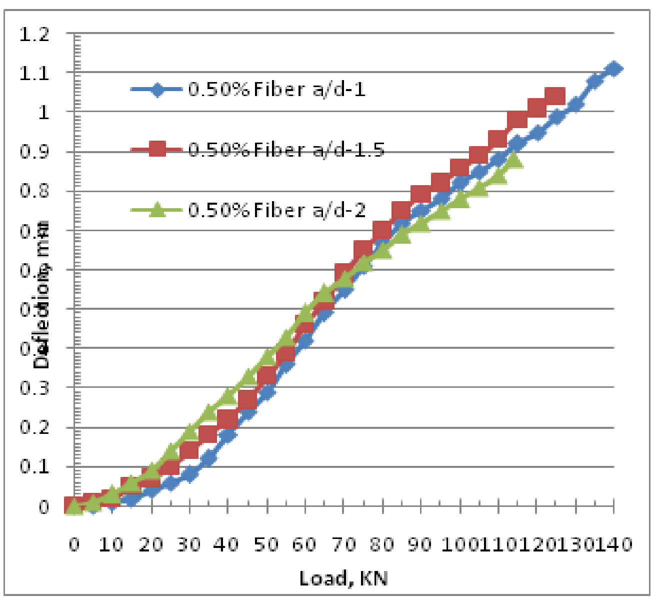


Figure 2.6: The Graph of Central Deflection with respect to Load, Specimen-III

From Table 2.3, Figure 2.6, it is observed that, deflection increases with decreases in a/d, there for deflection is inversely proportional to a/d. There is considerable increase in deflection for beam of a/d-1.

**2.3 Calculation Ultimate of Shear Stress**

**2.3.1 Ultimate Shear Stress for Beam Specimen Series-I**

Results of ultimate shear stress for specimen series-I are presented in Table 2.4.

Table 2.4: Ultimate Shear Stress for Specimen Series-I, $N/mm^2$

| Beam Designation | Failure Load (KN) | Average Failure Load (KN) | Ultimate Shear Stress ($N/mm^2$) | Average Ultimate Shear Stress ($N/mm^2$) |
|---|---|---|---|---|
| A11-0%-1.0 | 53.20 | 54.6 | 2.98 | 3.06 |
| A12-0%-1.0 | 54.50 | | 3.05 | |
| A13-0%-1.0 | 56.10 | | 3.14 | |
| A21-0%-1.5 | 52.23 | 53.26 | 2.93 | 2.98 |
| A22-0%-1.5 | 53.60 | | 3.00 | |
| A23-0%-1.5 | 53.96 | | 3.02 | |
| A31-0%-2.0 | 45.5 | 48.6 | 2.55 | 2.72 |
| A32-0%-2.0 | 48.3 | | 2.71 | |
| A33-0%-2.0 | 52 | | 2.91 | |

From Table 2.4, the maximum value of ultimate shear stress 3.06 $N/mm^2$ is observed at a/d-1 with 0 % of fiber content and it shows shear stress increases with decease of a/d.

**2.3.2 Ultimate Shear Stress for Beam Specimen Series-II**

Results of ultimate shear stress for specimen series-I are presented in Table 2.5.

Table 2.5: Ultimate Shear Stress for Specimen Series-II, $N/mm^2$

| Beam Designation | Failure Load (KN) | Average Failure Load (KN) | Ultimate Shear Stress ($N/mm^2$) | Average Ultimate Shear Stress ($N/mm^2$) |
|---|---|---|---|---|
| C11-0.50%-1.0 | 54.97 | 55.24 | 3.08 | 3.09 |
| C12-0.50%-1.0 | 56.25 | | 3.15 | |
| C13-0.50%-1.0 | 54.50 | | 3.05 | |
| C21-0.50%-1.5 | 64.17 | 62.36 | 3.59 | 3.49 |
| C22-0.50%-1.5 | 61.67 | | 3.45 | |
| C23-0.50%-1.5 | 61.25 | | 3.43 | |
| C31-0.50%-2.0 | 69.30 | 69.45 | 3.88 | 3.89 |

| | | | | |
|---|---|---|---|---|
| C32-0.50%-2.0 | 70.9 | | 3.97 | |
| C33-0.50%-2.0 | 68.15 | | 3.82 | |

From Table 2.5, it is observed the maximum value of ultimate shear stress 3.89 N/mm2 is observed at 0.75% of fiber content and it shows shear stress increases with increase in fiber content.

**2.3.3 Ultimate Shear Stress for Beam Specimen Series-I**

Results of ultimate shear stress for specimen series-I are presented in Table 2.6.

Table 2.6: Ultimate Shear Stress for Specimen Series-II, $N/mm^2$

| Beam Designation | Failure Load (KN) | Average Failure Load (KN) | Ultimate Shear Stress ($N/mm^2$) | Average Ultimate Shear Stress ($N/mm^2$) |
|---|---|---|---|---|
| C11-0.50%-1.0 | 68.45 | 69.98 | 3.83 | 3.92 |
| C12-0.50%-1.0 | 71.50 | | 4.00 | |
| C13-0.50%-1.0 | 69.99 | | 3.92 | |
| C21-0.50%-1.5 | 64.17 | 62.36 | 3.59 | 3.49 |
| C22-0.50%-1.5 | 61.67 | | 3.45 | |
| C23-0.50%-1.5 | 61.25 | | 3.43 | |
| C31-0.50%-2.0 | 56.26 | 57.02 | 3.15 | 3.19 |
| C32-0.50%-2.0 | 56.40 | | 3.16 | |
| C33-0.50%-2.0 | 58.40 | | 3.27 | |

From Table 2.6, it is observed the maximum value of ultimate shear stress 3.92 $N/mm^2$ is observed at a/d-1 with 0.50% of fiber content and it shows shear stress increases with decease of a/d.

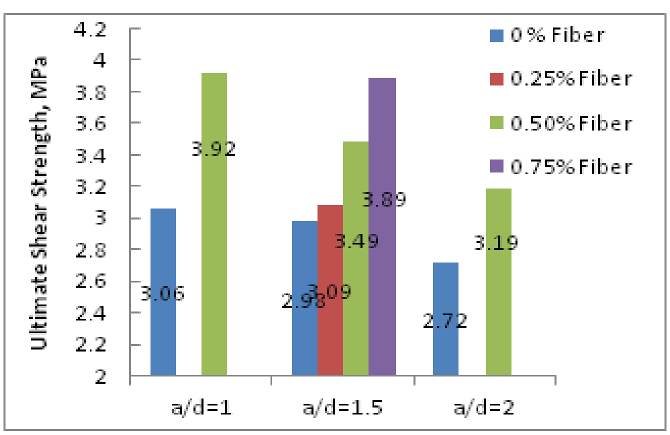


Figure 2.7: Ultimate Shear Strength of Concrete with respect to a/d Ratio and % Fiber Content

From Table 2.4, 2.5, 2.6 and Figure 2.7, it is observed that ultimate shear stress is directly proportional to percentage fiber content and inversely proportional to a/d ratio.

**2.4 Percentage Increase in Ultimate Shear Stress**

Results of percentage increase in ultimate shear stress are presented in Table 2.7

| a/d Ratio | % of Fiber | Ultimate Shear Stress (N/mm2) | Increase in Ultimate Shear Stress (%) |
|---|---|---|---|
| 1 | 0% | 2.72 | 0 |
| 1.5 | | 2.98 | 9.56 |
| 2 | | 3.06 | 12.5 |
| 1.5 | | 3.09 | 0 |
| | | 3.49 | 12.94 |
| | | 3.89 | 25.89 |
| 1 | 0.50% | 3.19 | 0 |
| 1.5 | | 3.49 | 30 |
| 2 | | 3.92 | 43 |

From Table 2.7, percentage ultimate shear stress of beam increased with increase of fiber content& decrease of a/d.

**2.5Cracking Shear Stress**

**2.5.1 Cracking Shear Stress for Specimen Series-I**

Results of cracking shear stress for specimen series-Iare presented in Table 2.8.

Table 2.8: Cracking Shear Stress for Specimen Series-I, $N/mm^2$

| Beam Designation | Load (KN) | Average Load (KN) | Cracking Shear Stress ($N/mm^2$) | Average Cracking Shear Stress ($N/mm^2$) |
|---|---|---|---|---|
| A11-0%-1.0 | 36.70 | 36.88 | 2.06 | 2.07 |
| A12-0%-1.0 | 36.35 | | 2.04 | |
| A13-0%-1.0 | 37.58 | | 2.11 | |
| A21-0%-1.5 | 36.02 | 35.72 | 2.02 | 2.02 |
| A22-0%-1.5 | 35.16 | | 2.01 | |
| A23-0%-1.5 | 35.97 | | 2.02 | |

| | | | | |
|---|---|---|---|---|
| A31-0%-2.0 | 33.70 | 33.89 | 1.89 | 1.9 |
| A32-0%-2.0 | 33.31 | | 1.87 | |
| A33-0%-2.0 | 34.67 | | 1.94 | |

From Table 2.8, it is observed that, the maximum value of cracking shear stress 2.07 N/mm$^2$ is observed at a/d-1 with SF 0% and it shows cracking shear stress is inversely proportional to a/d.

### 2.5.2 Cracking Shear Stress for Specimen Series-II

Results of cracking shear stress for specimen series-II are presented in Table 2.9.

Table 2.9: Cracking Shear Stress for Specimen Series-II, N/mm$^2$

| Beam Designation | Load (KN) | Average Load (KN) | Cracking Shear Stress (N/mm$^2$) | Average Cracking Shear Stress (N/mm$^2$) |
|---|---|---|---|---|
| B11-0.25%-1.5 | 36.65 | 36.83 | 2.05 | 2.06 |
| B12-0.25%-1.5 | 37.50 | | 2.10 | |
| B13-0.25%-1.5 | 36.33 | | 2.04 | |
| B21-0.50%-1.5 | 42.78 | 42.04 | 2.40 | 2.36 |
| B22-0.50%-1.5 | 41.11 | | 2.30 | |
| B23-0.50%-1.5 | 42.24 | | 2.37 | |
| B31-0.75%-1.5 | 51.33 | 51.46 | 2.88 | 2.89 |
| B32-0.75%-1.5 | 50.64 | | 2.84 | |
| B33-0.75%-1.5 | 52.42 | | 2.94 | |

From Table 2.9, the maximum value of cracking shear stress 2.89 N/mm$^2$ is observed at 0.75 % of fiber content with a/d- 1.5 and it shows cracking shear stress is directly proportional to fiber content.

### 2.5.3 Cracking Shear Stress for Specimen Series-III

Results of cracking shear stress for specimen series-III are presented in Table 2.10.

Table 2.10: Cracking Shear Stress for Specimen Series-III, N/mm$^2$

| Beam Designation | Load (KN) | Averag e Load (KN) | Crackin g Shear Stress (N/mm$^2$) | Average Crackin g Shear Stress (N/mm$^2$ ) |
|---|---|---|---|---|
| C11-0.50%-1.0 | 48.90 | 50.72 | 2.74 | 2.84 |
| C12-0.50%-1.0 | 55.00 | | 3.08 | |
| C13-0.50%-1.0 | 48.26 | | 2.70 | |
| C21-0.50%-1.5 | 42.78 | 42.04 | 2.40 | 2.36 |
| C22-0.50%-1.5 | 41.11 | | 2.30 | |
| C23-0.50%-1.5 | 42.24 | | 2.37 | |
| C31-0.50%-2.0 | 38.80 | 39.34 | 2.17 | 2.20 |
| C32-0.50%-2.0 | 40.29 | | 2.26 | |
| C33-0.50%-2.0 | 38.93 | | 2.18 | |

From Table 2.10, the maximum value of cracking shear stress 2.84 N/mm$^2$ is observed at a/d -1 with SF-0.50 % and it shows cracking shear stress is inversely proportional to a/d.

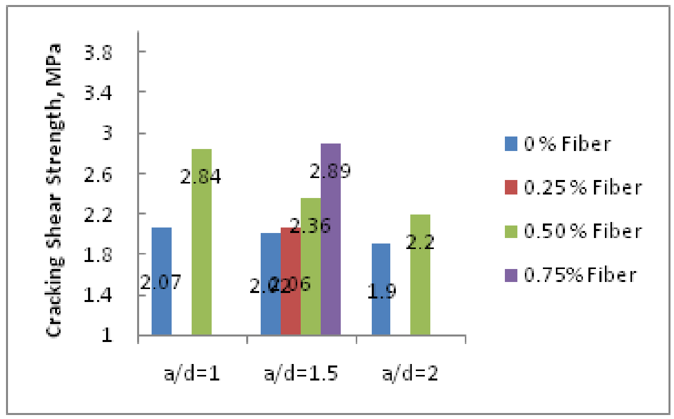


Figure 2.8: Cracking Shear Stress of Concrete with respect to a/d Ratio and % Fiber Content

From Table 2.8, 2.9, 2.10 and Figure 2.8, it is observed that cracking shear stress is directly proportional to percentage fiber content and inversely proportional to a/d ratio.

### 2.6 Percentage Increase in Cracking Shear Stress

Results of percentage increase of cracking shear stress are presented in Table 2.11.

| a/d Ratio | % of Fiber | Ultimate Shear Stress (N/mm2) | Increase in Ultimate Shear Stress (%) |
|---|---|---|---|
| 2 | 0% | 1.90 | 0 |
| 1.5 | | 2.02 | 6.32 |
| 1 | | 2.07 | 8.95 |
| 1.5 | 0.25% | 2.06 | 0 |
| | 0.50% | 2.36 | 14.56 |
| | 0.75% | 2.89 | 40.29 |
| 2 | 0.50% | 2.20 | 0 |
| 1.5 | | 2.36 | 7.27 |
| 1 | | 2.84 | 29.09 |

From Table 2.11, cracking shear stress of beam increases with increase in fiber content, but decrease with respect to increase in *a/d* ratio.

## III. INDENTATIONS AND EQUATIONS

Three design models, namely, equation of Londhe, equation of Mansuret al. and equation of Khuntiaet al. are used to estimate the ultimate shear strength of the moderate deep beam specimens.

### 3.1 Evaluation of Mansur *et al.*[2] Equation (1986)

Table 3.1: Calculation of Shear Strength by Mansur's Equation, KN

$$V_{frc} = \left(0.16\sqrt{f'c} + 17.2\rho\frac{d}{a} + 0.41\tau F\right)bd, \rho = 0.021, \tau = 0.66\sqrt{f'c}, F = V_f\frac{l_f}{d_f}$$

| Beam Designation | $f'c$ | F | $\frac{d}{a}$ | $V_{MANSUR}$ | $V_{TEST}$ | $V_{TEST}/V_{MANSUR}$ |
|---|---|---|---|---|---|---|
| A-0.00%-1.0 | 44.90 | 0 | 1.00 | 25.585 | 54.60 | 2.134 |
| A-0.00%-1.5 | 44.90 | 0 | 0.67 | 23.457 | 53.26 | 2.270 |
| A-0.00%-2.0 | 44.90 | 0 | 0.50 | 22.360 | 48.60 | 2.173 |
| B-0.25%-1.5 | 47.40 | 0.2 | 0.67 | 30.641 | 55.24 | 1.803 |
| B-0.50%-1.5 | 51.10 | 0.4 | 0.67 | 38.551 | 62.36 | 1.618 |
| B-0.75%-1.5 | 52.58 | 0.6 | 0.67 | 46.041 | 69.45 | 1.508 |
| C-0.50%-1.0 | 51.10 | 0.4 | 1.00 | 40.679 | 69.98 | 1.720 |
| C-0.50%-1.5 | 51.10 | 0.4 | 0.67 | 38.551 | 62.36 | 1.618 |
| C-0.50%-2.0 | 51.10 | 0.4 | 0.50 | 37.463 | 57.02 | 1.522 |
| | | | | | Mean | 1.818 |

### 3.2 Evaluation of Londhe's [22] Design Equation (2011)

Table 3.2: Calculation of Shear Strength by Londhe's Equation, KN

$$V_c = \alpha\left[\left(1 - 0.30\frac{a}{d}\right)\sqrt{0.80f_{ck}}bd\right], \alpha = 0.35$$

| Beam Designation | $f_{ck}$ | $\frac{a}{d}$ | d | $V_{LONDHE}$ | $V_{TEST}$ | $V_{TEST}/V_{LONDHE}$ |
|---|---|---|---|---|---|---|
| A-0.00%-1.0 | 44.90 | 1.00 | 119 | 31.58 | 54.60 | 1.728 |
| A-0.00%-1.5 | 44.90 | 1.5 | 119 | 24.812 | 53.26 | 2.147 |
| A-0.00%-2.0 | 44.90 | 2.00 | 119 | 18.045 | 48.60 | 2.693 |
| B-0.25%-1.5 | 47.40 | 1.50 | 119 | 25.493 | 55.24 | 2.167 |
| B-0.50%-1.5 | 51.10 | 1.50 | 119 | 26.469 | 62.36 | 2.356 |
| B-0.75%-1.5 | 52.58 | 1.50 | 119 | 26.850 | 69.45 | 2.587 |
| C-0.50%-1.0 | 51.10 | 1.00 | 119 | 33.688 | 69.98 | 2.077 |
| C-0.50%-1.5 | 51.10 | 1.50 | 119 | 26.469 | 62.36 | 2.356 |
| C-0.50%-2.0 | 51.10 | 2.00 | 119 | 19.250 | 57.02 | 2.962 |
| | | | | | Mean | 2.341 |

### 3.3 Evaluation of Khuntia*et al.*[16]Equation (1999)

Table 3.3: Calculation of Shear Strength by Khuntia's Equation, KN

$$V_{frc} = (0.167\alpha_1 + 0.25F)\sqrt{f'c}\,bd, \alpha_1 = 2.5\frac{d}{a}, F = V_f\frac{l_f}{d_f}$$

| Beam Designation | $f'_c$ | $\frac{d}{a}$ | d | $V_{KHUNTIA}$ | $V_{TEST}$ | $V_{TEST}/V_{KHUNTIA}$ |
|---|---|---|---|---|---|---|
| A-0.00%-1.0 | 44.90 | 1.00 | 119 | 49.93 | 54.98 | 1.101 |
| A-0.00%-1.5 | 44.90 | 0.67 | 119 | 33.25 | 53.26 | 1.600 |
| A-0.00%-2.0 | 44.90 | 0.50 | 119 | 24.998 | 48.60 | 1.944 |
| B-0.25%-1.5 | 47.40 | 0.67 | 119 | 40.31 | 55.24 | 1.370 |
| B-0.50%-1.5 | 51.10 | 0.67 | 119 | 48.233 | 62.36 | 1.293 |
| B-0.75%-1.5 | 52.58 | 0.67 | 119 | 55.398 | 69.45 | 1.254 |
| C-0.50%-1.0 | 51.10 | 119 | 119 | 66.033 | 69.98 | 1.059 |
| C-0.50%-1.5 | 51.10 | 0.67 | 119 | 48.233 | 62.36 | 1.293 |
| C-0.50%-2.0 | 51.10 | 0.50 | 119 | 39.396 | 57.02 | 1.447 |
| | | | | | Mean | 1.373 |

### 3.4 Summary Test

Table 3.4: Comparison Equation with respect to Mean Value of $V_{TEST}/V_{EQUATION}$

| Reference | Equation | Mean $V_{TEST}/V_{EQUATION}$ |
|---|---|---|
| Mansur *et al*. (1986) | $V_{frc} = \left(0.16\sqrt{f'c} + 17.2\rho\frac{d}{a} + 0.41\tau F\right)bd$ | 1.818 |

| | | |
|---|---|---|
| Londhe (2011) | $V_c = \alpha\left[\left(1 - 0.30\frac{a}{d}\right)\sqrt{0.80 f_{ck}}\,\mathrm{bd}\right]$ | 2.341 |
| Khuntia*et al*. (1999) | $V_{frc} = (0.167\alpha_1 + 0.25F)\sqrt{f'c}\,\mathrm{bd}$ | 1.373 |

it is observed that the equation proposed by Khuntia*et al*. gives satisfactory results for shear strength of SFC concrete beams without stirrups as compared to the equations proposed by other codes and researchers. The equation proposed by Mansur *et al.* gives good results for shear strength of steel fiber reinforced concrete beams. The results given by Ciria Guide-2 and Londhe's equation are on higher sides

## IV. CONCLUSION

Based on the test results and verification with other authors following conclusions can be drawn.

1. The cracking shear strength and ultimate shear strength increases with increasing percent fiber content and decreasing *a/d* ratio.
2. The addition of steel fibers increases the compressive strength of concrete. However, there is not much increase in compressive strength of concrete containing 0.75 % fiber as compared with compressive strength of concrete with0.25 % fiber.
3. Increase of ultimate load by 25.89 % for beam containing 0.75 % fibers with a/d 1.5 was observed when compared with beam containing 0.25% fibers with a/d 1.5.
4. Increase of ultimate load by 12.50 % for beam containing 0 % fibers with a/d 1 was observed when compared with beam containing 0% fibers with a/d 2.
5. Increase of first cracking load by 40.29 % for beam containing 0.75 % fibers with a/d 1.5 was observed whencompared with beam containing 0.25% fibers with a/d 1.5.
6. Increase of ultimate load by 8.95 % for beam containing 0 % fibers with a/d 1 was observed when compared with beam containing 0% fibers with a/d 2.
7. The equation proposed by khuntia et al. gives satisfactory results for shear strength of concrete Moderate deep beams without fibers.

The equation proposed by Mansur *et al.* gives good results for shear strength of steel fiber reinforced concrete Moderate deep beams.

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