

Shear Performance of Steel Fibers in Reinforced Concrete Beams



K.Padmanabham, G. Satya Ravi Teja

Abstract: Over the past few decades, a significant growth was observed on utilization of steel fibers in Reinforced Concrete (R.C) members. Past research studies on hybrid concrete endorsed optimum utilization of steel fibers (1.5% by volume) as it effectively contributed to improve flexural properties of reinforced concrete members such as R.C beams and slabs. But the contribution of fibers against shear resistance mechanism of R.C beams are not identified well in the previous research. In this context an experimental program was conducted to find Shear contribution and associated Parameters of fibers in the Steel Fiber Reinforced Concrete (SFRC) beams. A series of test programmes are conducted on three full scale reinforced concrete beams (NSF: No steel fibers, BSF1: Steel fibers in shear span, BSF2: Steel fibers in full span) with different configuration of shear reinforcement by using varied range of SFRC in the tested beam. The test results evaluated on the basis of strength and durability aspects at service loads and limit of failure conditions. The results concluded that the presence of steel fibers in reinforced concrete beam significantly contributed to induce shear resistance mechanism and ductile property of R.C beam. This improvement observed in BSF2, when the SFRC constituted in shear span region and the rest of R.C beam arranged with minimum conventional stirrups as shear reinforcement. Further the steel fibers possess good compatibility with concrete and steel reinforcement, which enhance mechanical and serviceability conditions of R.C beam such as shear strength, ductility, stiffness with respect to strength and deflection, crack width during serviceability conditions of the beam.

Keywords: Failure mechanism, SFRC beams, Shear contribution, Steel fibers.

I. INTRODUCTION

Research communities are striving to improve plastic properties of reinforced concrete members and to mitigate brittle failures induced during high shear conditions. In this context researchers identified perceptive options such as addition of admixtures and fiber composite material with green concrete or by changing the reinforcement detailing aspects of concrete members. But the later induce constructability issues and design constrains such as reinforcement fabrication and placement in the structural members. Although the design codes (ACI, NZS,BS,IS) established threshold limit on utilization of steel reinforcement in R.C members such as beams,

columns and slabs, the researchers identified successive methods such as introducing admixture or fiber component elements, and use of geo-polymers or different composites in concrete to improve plastic properties of R.C elements.

In this process the researchers found good suitability of steel fibers due to its compatibility and coexistence with green concrete. The use of steel fibers in R.C beams endorsed to improve shear strength and durability to mitigate or delay the brittle shear failure conditions of beams [1], [2]. Experimental works of researchers [4],[6],[8] found that the substantial use of steel fibers in reinforced concrete will enhance the ductility and delay the failure mechanism of beam [3]. Subsequently, fibers contributed significant role to improve shear strength [1], [3], and stiffness [6],[10] as it possess uniform stress distribution within R.C beams. Although the contribution of reinforcement steel and concrete against shear failure mechanism of beams are well-established in the previous research and well addressed by design codes (ACI, NZS, BS, IS), the shear resistance mechanism of steel fibers alone are not identified if fibers are used various locations of beam such as in shear span or full span of with or without confined confinement as the conventional practice of shear resistance is developed by use of stirrups or bent up bar reinforcement. Since the tensile properties of random fibers are significantly influence shear resistance mechanism of R.C beams [3], there is a need for further investigations to identify unique contribution of steel fibers against shear resistance mechanism. This helps to encourage the designers for more versatility against utilization of fibers.

II. RESEARCH SIGNIFICANCE

The shear performance of reinforced concrete significantly influenced by ductile property of R.C beam at failure. To improve the ductility, the design codes established threshold limitation on use of steel reinforcement. Hence further improvement of plasticity may endorsed by addition of steel fibers in R.C beams [1], [2]. But the contribution of fibers against shear resistance mechanism of SFRC beams are not identified well by the previous research. Due to this reason most of the designers obviated to use SFRC in present R.C construction practice. This paper focused on issues related to contribution of steel fibers against shear resistance mechanism of R.C beams.

III. SCOPE AND STUDY LIMITATIONS

Scope of this work briefly summarized under shear resistance mechanism of fibers in SFRC beams. Although the Researchers conducted experimental program on holistic application on utilization of steel fibers in various component parts of structure,

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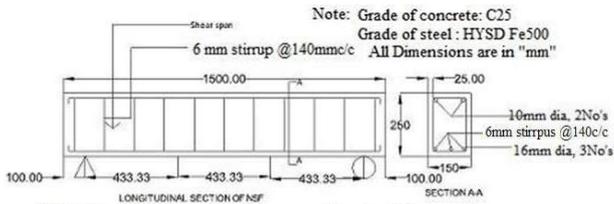
the evaluations with respect to beams are not related to utilize the SFRC at designated location such as SFRC at shear span location or in full span conditions of beam with absence of conventional shear reinforcement in beams. The application and the failure conditions of beam considered as de-lamination of bond between of fibers by tension

IV. EXPERIMENTAL TEST PROGRAMME

1. Details of test specimens

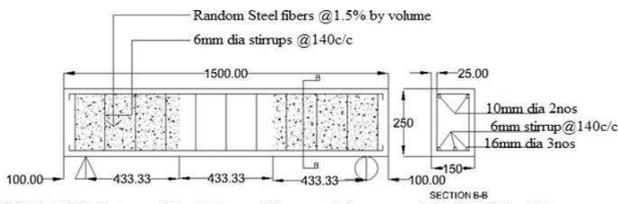
An experimental programme conducted on three full scale beams of size 1500x250x150mm casted with M25 grade concrete, and Fe500 steel and beams are configured as NSF,BSF1,BSF.2

(NSF: No steel fibers with conventional shear reinforcement of R.C beam, BSF1: Steel fibers used in shear span and rest of the beam with conventional steel reinforced concrete, BSF2: Steel fibers in full span without conventional shear reinforcement).Optimum dosage of steel fibers (as per literature 1.5% volume fraction) are mixed with M25 grade concrete.The concrete design of tested beams are proceed as per I.S 456-2000, I.S.10262-2016.The testing is aimed to promote shear failure of R.C beam and the post failure conditions are assessed by de-bonding of fibers under tension. As per the design calculations, load at serviceability condition of beam was calculated as 100kN point with load factor 1.50.



NSF: Control R.C beam with conventional reinforcement
Figure: 1a

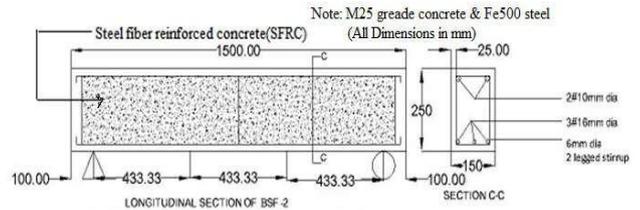
Test specimen NSF is represented by Figure:1a, and is taken as control beam of M25 grade concrete (in the absence of steel fibers) and conventional stirrup reinforcement used for shear resistance mechanism of beam. In this specimen, shear resistance mechanism is provided by both steel and concrete



BSF 1: R.C Beam with minimum Shear reinforcement & SFRC in Shear span
Figure : 1b

Test specimen BSF.1 is represented by Figure 1b, where the pouring of SFRC carried in shear span zone of the beam only and the rest of beam poured with M25 grade conventional concrete with use of minimum conventional shear reinforcement in the form of stirrups. In this specimen, shear resistance mechanism is provided by both steel , concrete and fibers.

scope of this study limited to shallow SFRC beams where the Bernoulli’s theorem of flexural rigidity is perfectly valid. Shear failure of beam considered under static load



BSF.2: SFRC Beam without conventional Shear reinforcement
Figure:1c

The test specimen BSF2 is represented by Figure 1C, and the pouring of SFRC by adding 1.5% steel fibers in M25 grade conventional concrete and the pouring of concrete done over the entire beam that possess without conventional shear reinforcement. The considerations are given to evaluate both shear capacity and confinement effects of beam. In this specimen, shear resistance mechanism and confinement of beam was provided by concrete and fibers only.Stirrup reinforcement not considered for shear resistance mechanism.

Table-1

Tested Beam label	Cross section Details (mm)	Effective span (mm)	Shear span to Effective depth ratio	Flexural Reinforcement		W/C ratio	Compressive strength (N/mm ²)	% of Fibers used	Shear Reinforcement
				Bottom	Top				
NSF	150 250	1300	1.99	3#16 ϕ	2#10 ϕ	0.5	32.60	0	6 ϕ stirrups @ 140 c/c
BSF-1	150 250	1300	1.99	3#16 ϕ	2#10 ϕ	0.5	39.65	1.5	6 ϕ stirrups @ 140 c/c
BSF-2	150 250	1300	1.99	3#16 ϕ	2#10 ϕ	0.5	39.65	1.5	No Stirrups

Reinforcement details of tested Beams-NSF,BSF1,BSF2

B. Material Testing & Specifications

Cement (OPC-53), Fine aggregate (River sand Zone II) and Coarse aggregate (20mm) used to prepare M25 grade concrete. Random steel fibers used to mix with conventional concrete at optimum dosage of 1.5% by volume of concrete. Plasticizers are not mixed during preparation of concrete mix and 0.50 water cement ratio considered during preparation of concrete. Steel fibers possess aspect ratio (length/diameter) as 30 with hooked type fibers used (Ref: figure.2) in concrete. Cylindrical specimens used to determine the mechanical properties of concrete such as splitting tensile strength and modulus of elasticity tested concrete.

Table-2

Dia of Bar -mm	Cross section -mm ²	Yield stress -MPa	Ultimate stress. MPa
6	28.2	312	410
10	78.5	510	624.4
16	201.06	573	692.3

Mechanical properties of steel Reinforcement



Table.2 refers the properties of steel fiber where the fibers mixed at 1.5% by volume in concrete at shear span of beam BSF-1 and other beam with 1.5% of steel fibers at full span of beam without stirrups. Hooked steel fibers are spread randomly with irregular orientation that firmly holds the brittle cracks in the concrete and resists shear failures happened due to development of principal tensile stresses under pure shear conditions of beam. To determine the mechanical properties of conventional concrete and SFRC cylindrical specimen samples of concrete are used in the laboratory with use of Uni-axial compression machine and Splitting tensile testing machine to find concrete properties with cylindrical specimen middle of columns.

Table 3

Property	Unit	Value
Diameter	mm	1
Length	mm	30
Aspect ratio	Length/dia	30
Density	kN/m ³	78.5
Tensile strength	MPa	1178

Properties of Hooked Steel Fibers



Hooked Steel Fibers used with Random orientation in Reinforced concrete

Figure: 2

C. Experimental Test Setup

This experiment was conducted to verify shear failure mechanism of shallow beams by using steel fibers (shear span/depth <2) at static load conditions. The test set up is based on hydraulic load control testing machine where three series of specimen beams (NSF,BSF1,BSF2) are tested under static load conditions using loading frame of 1000 kN capacity. The sequence of loading was controlled by digital control record unit. Two point load conditions are created (A & B) to evaluate shear failure mechanism of beams, where the point loads (A&B) are applied at 1/3 span of beam from each support. The mid span deflections of each load increment of beam (10kN) measured with analogue dial gauge system that was arranged at span of the beam and located its bottom face. While testing of the beams, supports are provided with hinge and roller conditions at each end. Initially the test setup is focus on to generate load deflection curves at service and ultimate failure conditions of the beam. The appeared cracks on the beam during increment load conditions are measured at each stage with microscope until the ultimate failure of beam happend.

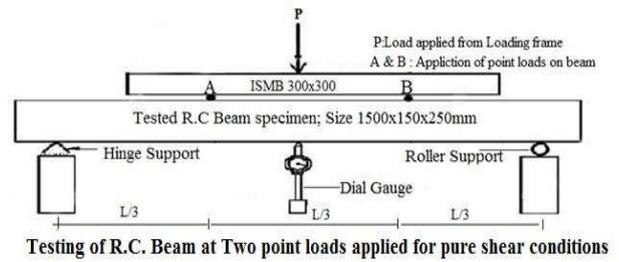
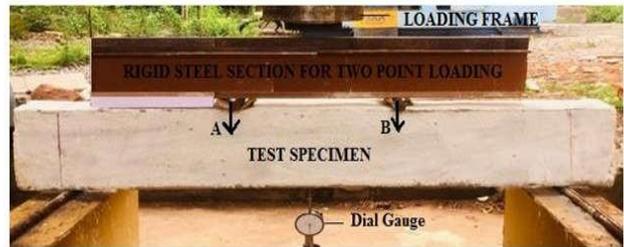


Figure 3



Experimental Test Setup of R.C Specimen beam (NSF,BSF1,BSF2)

Figure 4

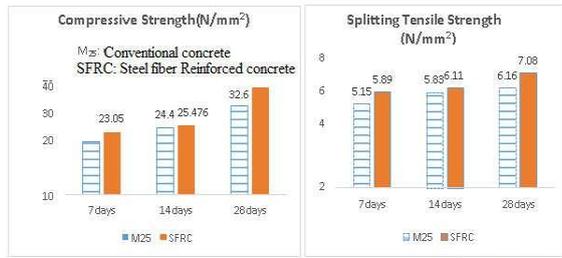
V. EXPERIMENTAL OBSERAVTIONS

The test results shows shear mode of failure at ultimate loads in the beams and corresponding observations are made for peak load, ultimate shear capacity, ultimate deflection, ultimate moment, and shear crack width at service and ultimate load. In the first series of the testing of control beam (NSF) was initiated by the formation of secondary crack at mid span of beam (Moment 17.32kN.m) and as the load increases on test specimen the subsequent development of primary crack occurred in the shear zone at moment capacity 23.81 kN-m. By further increment of load (10kN/minute) the shear cracks are formed at shear zone (primary cracks) and expanded at an inclination of 48° and beam intends to fail at moment 49.79 kN.m. The crack width at failure was observed as 20mm.

In the second series of testing the beam BSF1 ,primary crack initiated at mid span and at moment capacity 17.32 kN-m. As the load increasing on beam specimen the primary cracks started in shear zone and progressed at35° and the observed moment capacity is 25.98 kN.m. By subsequent increment of sequential loading, the primary crack at shear span expanded widely and progressed and the shear failure observed at moment capacity 56.29 kN.m. The crack width at failure was measured as 18mm.

In the third series of test programme, the load deflection test on specimen beam BSF-2 observed the formation of secondary crack are initially started at moment of 10.82 kN.m in the flexure zone of beam. As the loads tends to increasing at 10kN/minute the formation of primary crack initiated at shear zone and progressed at inclined angle 42° and at initial moment capacity of 19.48kN.m. Further increasing of loads makes the cracks propagate towards compressive zone of beam. The cracks are widening progressively till the ultimate failure of beam happended at the moment capacity of 45.46 kN.m . The crack width at failure was measure as 26mm.

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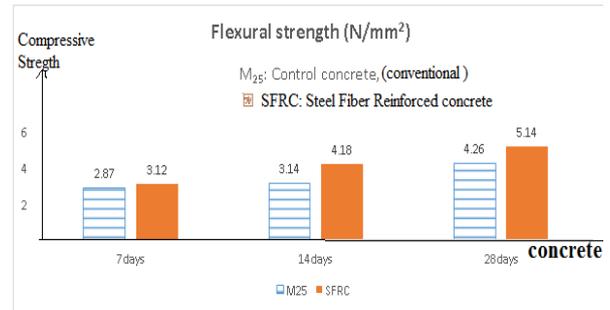


Compressive cube strength of concrete (Conventional & SFRC)

Figure 5a

Cylindrical splitting Tensile strength of concrete (conventional & SFRC)

Figure 5b



Flexural tensile strength of concrete (Conventional & SFRC)

Figure: 6



Fig: 6a

Cube compressive testing machine



Fig: 6b

Universal testing machine (Splitting Tensile strength)



Shear mode of failure in Beam:BSF 1

Figure 8b

The specimen beam using fiber reinforced concrete at full span of beam represented by BSF-2 which is observed by development of flexure crack at mid span of beam at reaction load of 25kN and the corresponding moment is observed as 10.82kN-m. The static loads are applied at increment of 10kN/minute, and further application of loads, primary cracks are developed in shear span and progressed towards compression zone of beam that makes an angle at 41° with horizontal axis. Finally the beam intends to fail at ultimate shear load 105kN with ultimate moment of 45.46kN-m. The mode of failure is referred in fig:8c



Shear Mode of failure in BSF2 beam using steel fiber concrete

Figure 8C

The tested beams (NSF,BSF1,BSF2) are failed at different ultimate loads due to incorporation of steel fibers in the beams. In the beam NSF, the initial flexural crack developed at mid span of beam at reaction load of 40kN. The shear resistance of control beam(NSF) provided by conventional shear reinforcement in the form of two legged stirrups and the beam intended to fail at reaction of 115kN (Vu) and at ultimate moment of 49.795kN.m (Mu). In the NSF beam, the shear cracks are developed at intended failure surface of 42° angle and Shear mode of failure occurred as shown in figure 8a.

Shear Failure of R.C conventional Beam NSF (Fig.8a)



Fig: 8a

The specimen beam BSF1, with fiber reinforced concrete (1.5% fibers by volume) used in shear span was noted in figure 8b. In the initial stage of testing the beam was subjected to develop flexure crack at mid span at reaction load 80kN and the corresponding moment was observed as 17.32kN-m. As the load increment proceed at 10kN/minute, primary cracks are developed in shear span of beam and progressed towards compression zone of beam at angle 38.6° with horizontal plane. Finally the beam failed in shear at ultimate load of 130kN and the ultimate moment of beam is 56.29kN-m. Refer the following figure 8b

At Ultimate and Service loads the test results are shown in the following Table.4

Table 4

Specimen label	Moment at first crack (kN-m)	At Service Load				At Ultimate Load					
		Moment (kN-m)	Shear force (kN)	Shear stress (MPa)	Deflection (mm)	Crack width (mm)	Moment (kN-m)	Shear force (kN)	Shear stress (MPa)	Deflection (mm)	Crack width (mm)
NSF	17.32	33.19	76.66	2.35	3.662	0.21	49.79	115	3.53	6.4	20
BSF-1	17.32	33.19	76.66	2.35	3.106	0.126	56.29	130	3.99	6.54	18
BSF-2	10.82	33.19	76.66	2.35	3.989	0.306	45.465	105	3.225	5.71	26

Test results of Beams NSF,BSF1,BSF2 at Service and Ultimate loads

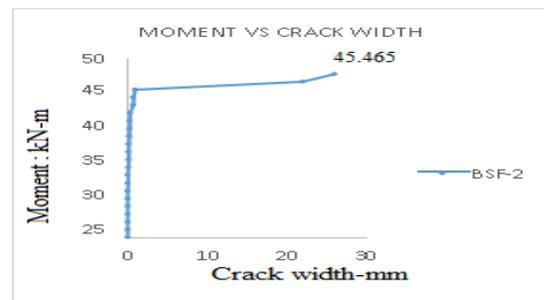
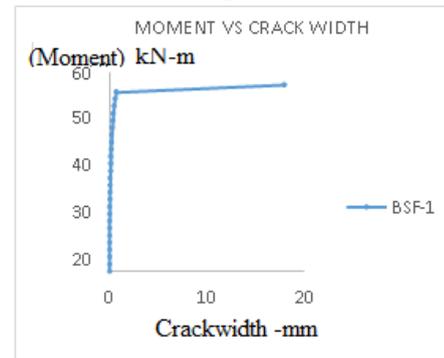
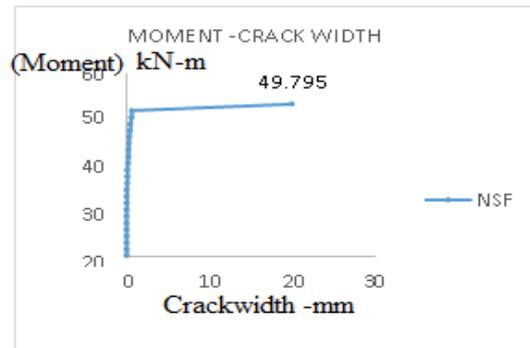
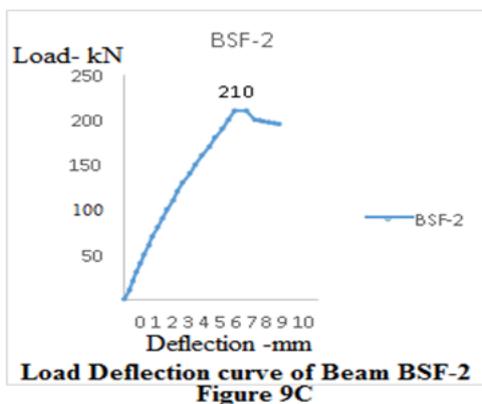
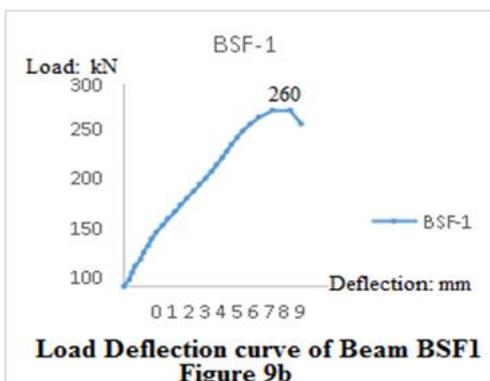
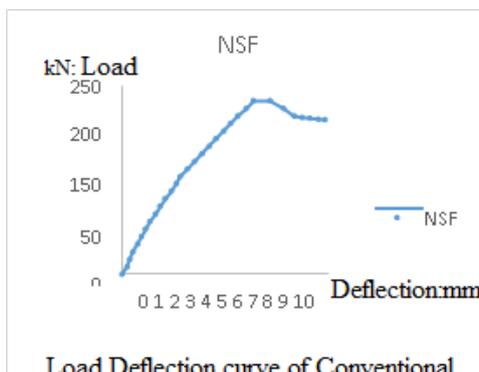
The test results of theoretical and experimental programme of beams NSF,BSF1,BSF2 are compared in the table 5

Table .5

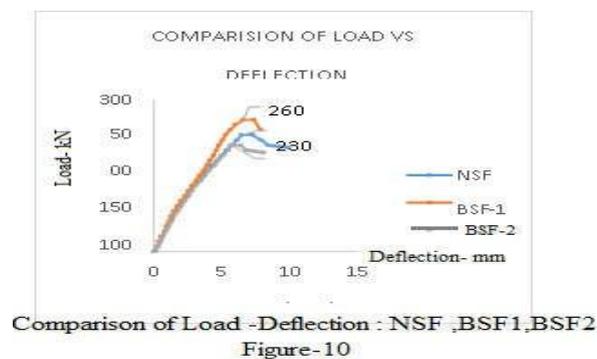
Specimen label	Shear span to effective depth ratio	f_{ck} (MPa)	Theory				Test			$V_u(\text{test})$ / $V_u(\text{theory})$
			V_c (kN)	V_s (kN)	V_u (kN)	M_u (kN-m)	V_u (kN)	Shear stress	M_u (kN-m)	
NSF	1.99	32.60	25.9	66.45	92.3	21.65	115	3.553	49.795	1.24
BSF-1	1.99	39.65	25.9	66.45	92.3	21.65	130	3.993	56.29	1.4
BSF-2	1.99	39.65	25.9	66.45	92.3	21.65	105	3.225	45.465	1.08

VI. ANALYSIS OF TEST RESULTS

A) Load-Deflection curves of tested Beams (NSF, BSF1, BSF2)



VII. PERFORMANCE OF TESTED BEAMS (NSF,BSF1,BSF2)

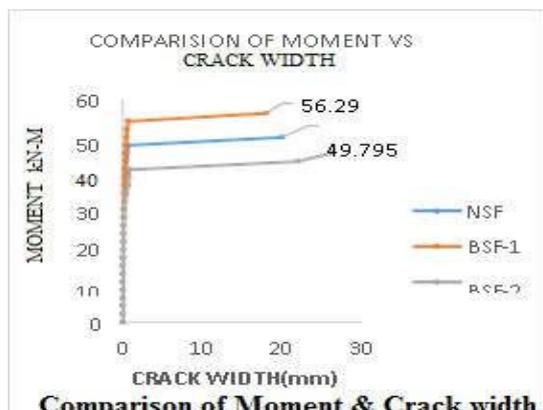


(Notations of Tested Beams Used)

NSF: Beam with No Steel Fibers

BSF-1: Beam with Steel fibers used in shear span

BSF-2: Steel fibers in full span of Beam



Beams: NSF,BSF1,BSF2
Figure 11

VIII. CONCLUSIONS

Based on above experimental test results the following conclusions are drawn for strength and serviceability performance of tested beams (NSF, BSF1, and BSF2).

1. Use of steel fibers in shear span will increase the shear capacity of beam (BSF1) by 13% when compared with conventional shear reinforced beams NSF.
2. Shear capacity of steel fiber reinforced concrete beams (BSF-2) reduced by 4% when compared with conventional shear reinforced beam NSF. The test results enumerated the influence of confinement of steel fibers and improvement of shear capacity as the stirrup reinforcement in conventional beams may replace with fiber reinforced concrete.
3. Stiffness of beam increased by 9.7% when the steel fibers used in shear span (BSF1) when compared with conventional shear reinforced beam (NSF). Similarly, stiffness of beam BSF2 is decreased by 2.43% when compared with NSF.
4. Deflection of fiber reinforced concrete beam (BSF-2) reduced by 5% when compared with conventional shear reinforced beam (NSF) as the fibers provide good stiffness and confinement
5. Crack width in beam reduced by 10% in the presence of steel fibers used in shear span as mentioned in BSF1, and crack width increased by 23% in BSF2. Both situations are compared with NSF beam.

IX. STUDY RECOMMENDATION S

1. Based on the experimental results, this study recommends the replacement of stirrups in the conventional beams with steel fiber reinforced concrete used in shear span zone of beam and rest of portion with minimum stirrup reinforcement to meet effective shear resistance mechanism.
2. Based on test results the study reconfirmed the optimum use of 1.5% (Volume fraction) steel fibers as suggested by the previous experimental works, as it significantly contribute to enhance the shear capacity and service performance of R/C beam.

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