PREDICTION OF THEORETICAL SHEAR STRENGTH OF STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE

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ABSTRACT. Of all the different kinds of failures in concrete, shear failure is a sudden and brittle and occurs abruptly without any prior warning. To avoid these types of failures in concrete, beams are traditionally reinforced with stirrups at closer spacing based on design. The present study is aimed at studying the shear behaviour of steel fibre reinforced self-compacting concrete and predicting a theoretical equation for evaluating the shear strength. In the experimental study, two grades of self-compacting concrete (SCC30 and SCC70) were considered. A total of 16 shear deficient beams were cast and tested for two shear span to depth ratios (a/d) of 2 and 3 for both without and with steel fibres. By analysing the cracked portion of the beam an equation to predict the theoretical shear strength was proposed. The comparison between experimental shear strength and theoretical shear strength was found to be in good agreement with a percentage error in all the cases is less than 15% and also ratio of theoretical to experimental shear strength in most of the cases was found to be 1.02.

Keywords: Self-compacting concrete, steel fibres, shear strength

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INTRODUCTION

Self-Compacting Concrete (SCC), originally established by Okamura in 1986 [Okamura et al. 1998; Okamura 1999], is a well thought-out solution to solve the above stated problems. Self-Compacting Concrete (SCC) as the name itself indicates does not require external effort in compacting the concrete. It compacts itself under its own weight only [Ozawa.K et.al, 1995]. Owing to the above property, it needs no vibration, hence no sound pollution, reduces the labor cost and can be compacted to every place of the formwork without undergoing any significant segregation, predominantly in congested reinforcements [Ouchi et.al, 1996]. Shear failure of conventional reinforced concrete beams usually occurs by tensile failure of concrete in shear span. For this reason, shear failure in general is sudden and brittle and in practice, shear reinforcement in the form of stirrups are incorporated to prevent this type of failure, and to increase the shear strength of the beams. [S. A.-Ta'an and J. R.-Feel, 1990]. Addition of steel fibers in concrete, improves the post cracking behaviour and enhances the flexural-tensile strength. In recent years, application of use of short steel fibers in concrete has increased tremendously. Many researchers used steel fibers as partial shear reinforcement instead of traditional reinforcement (stirrups). Steel fibers in reinforced concrete help in bridging crack faces and increases the ultimate load carrying capacity by delaying the failure of the specimen [Narayanan R, and Darwish, I.Y.S, 1987; Furlan and Hanai, 1997; Yang, Y., 2014; Arslan et al , 2017] Steel Fiber Reinforced Concrete (SFRC) is a composite material that is characterized by enhanced post-cracking behavior due to the capacity of fibers to bridge the crack faces if they are present in sufficient amount. Steel fibers are used to increase the shear capacity of concrete and also to partially replace the lateral ties (stirrups) in RC structural members. The addition of steel fibers in an RC beam increase its shear strength, and if sufficient amount of steel fibers are added, a brittle shear failure can be modified to a ductile behavior and also reduces the crack width [Yining Ding et.al, 2011]. In Self compacting concrete, fracture plane is relatively smooth due to the presence of lesser amount and small size of coarse aggregate as compared to that of vibrated concrete. Due to the presence of comparatively lesser amount and smaller size of coarse aggregate in SCC, the fracture planes are relatively smooth as compared to that of Normal Vibrated Concrete (NVC), this reduces the shear resistance of concrete by reducing the aggregate interlock between the fracture surfaces. To overcome this defect, steel fibers can be added which can improve the crack resistance of SCC [Kim KS et al, 2012]. The difference between Steel Fibre Reinforced Self-Compacting concrete (SFRSCC) and traditional Fibre Reinforced Concrete (FRC) is that the fibre content of FRC is mainly determined by the post-cracking behaviour, whereas the fibre content of SFRSCC is mainly restricted by the workability of fresh SCC. SFRSCC combines the advantages of both SCC and FRC [Cuenca et.al, 2015]. The addition of steel fiber in SCC combines the benefits of fresh properties and enhances the tensile properties in the hardened state. The key parameters that influence the shear behavior of reinforced concrete beams are: shear span-to effective depth ratio (a/d), grade of concrete (f_{ck}), and percentage of longitudinal reinforcement (l_t), area of shear reinforcement (s_v), volume fraction of fibers (V_f) and angle of crack (□). The present study aims at predicting the shear strength of steel fiber reinforced SCC.

EXPERIMENTAL PROGRAMME

In the present study a total of 16 shear deficient beams were designed and cast for two grades of SCC i.e. SCC30 and SCC70. Two shear span to effective depth ratios with a/d of 2, 3 were considered to study the effect of shear span to depth ratios (a/d). The dimensions of the beam were fixed as 100x200x1200mm with a clear span of 1100mm. All beams were tested under four-point loading. For compressive strength, standard cube moulds of size 150mm x 150mm x 150mm made of cast iron were used. For split tensile strength, standard cylinder moulds of 150 mm φ x 300mm made of cast iron were used. For flexural strength 100 x 100 x 500 mm of standard prism moulds were used according to IS: 516-2004. In the present study, the dosage of steel fibers is 0.5% by volume of concrete. From the literature, it was found that 0.5% dosage of steel fiber is optimal for self-compacting concrete based on fresh and hardened properties. [Tomasz Ponikiewski and Grzegorz Cygan, 2011]. Table: 1 shows the details of the 16 beams cast and tested with different a/d ratio, spacing of stirrups and percentage of steel fiber per volume of concrete.

Table 1 Details of beams

S.No.	Beam Designation	a/d	Stirrups Spacing ,mm	Fiber content Kg/m^3
		a/d=2		
1.	SCC30-NS	2	No stirrups plain beam	-
2.	SFRSCC30-NS	2	No stirrups fibrous beam	38
3.	SCC30-180	2	180	0
4.	SFRSCC30-180	2	180	38
5.	SCC70-NS	2	No stirrups plain beam	-
6.	SFRSCC70-NS	2	No stirrups fibrous beam	38
7.	SCC70-180	2	180	-
8.	SFRSCC70-180	2	180	38
		a/d=3		
9.	SCC30-NS	3	No stirrups plain beam	-
10.	SFRSCC30-NS	3	No stirrups fibrous beam	38
11.	SCC30-270	3	270	0
12.	SFRSCC30-270	3	270	38
13.	SCC70-NS	3	No stirrups plain beam	-
14.	SFRSCC70-NS	3	No stirrups fibrous beam	38
15.	SCC70-270	3	270	-
16.	SFRSCC70-270	3	270	38

Materials Used for Experimental study

The materials used in the present study are conforming to Indian standard codes.

Cement: Cement used in the present was 53 Grade Ordinary Portland cement confirm to **IS: 12269-2013**. The specific gravity of the cement was 3.15 and the initial and final setting times were 40 min and 540 min respectively.

Fly Ash: Fly ash confirming to **IS: 3812-2013** is used as mineral admixture. The fly ash used in the present study was obtained from NTPC Ramagundam (India) and is of type Class F. The specific gravity of fly ash used in the present study was 2.2.

Fine Aggregate (FA): The fine aggregate used in the present study was conforming to Zone-II according to **IS: 383-2016.** It was obtained from a nearby river source. The specific gravity was 2.65, while the bulk density of sand was 1.45 gram/c.c.

Coarse Aggregate (CA): Crushed granite was used as coarse aggregate. Coarse aggregates of 20 mm nominal size was obtained from a local crushing unit which was well graded aggregate according to **IS: 383 -2016.**The specific gravity was 2.8, while the bulk density was 1.5 gram/c.c.

Water: Potable water was used in the experimental work for both mixing and curing of specimens.

Silica Fume: It is an ultrafine powder with an average particle diameter of 150 nm was used in the present study according to **IS: 5388-2003.** The specific gravity of silica fume is generally in the range of 2.2 to 2.3 and specific surface area of silica fume ranges from 15,000 to 30,000 m^2/ kg.

Super plasticizer (SP): In the present study poly carboxylic ether based high range water reducing admixture confirming to **ASTM C494-2010** obtained from Chyrso Chemicals, India commonly called as super plasticizers was used. Major advantage of using super plasticizer is to improve the flowing ability of high performances concretes at lower water-cement ratio.

Steel fiber: Crimped steel fiber (from Apex Encon Projects Pvt Ltd., New Delhi, India) with a nominal diameter of the fiber 0.5 mm and cut length 30mm with aspect ratio of 60 were used according to **ASTM A820-2001**. The tensile strength and modulus of elasticity of fiber is 850 MPa and $2.1x10^5$ MPa respectively.

Tension *reinforcement:* TMT bars of 12 mm and 16 mm diameter of grade Fe 500 confirming to **IS: 1786-2008** whose yield strength was 500 N/mm^2 and of length 1160mm were used as tension reinforcement and 6mm Ø mild steel bars whose yield strength was 290 N/mm^2 was used as stirrups (shear reinforcement) and also for top compression reinforcement.

Reinforcement Details

The dimensions and typical reinforcement details for two grades designated SCC30 and SCC70 and for shear span to depth ratios (a/d) 2, 2.5 and 3 are shown in Figures 1 to 6. For designing beams as shear deficient, larger spacing of stirrups was considered. The stirrup spacing was varied in the shear span. SCC beams consist with 30MPa strength consists of 2-12mm Ø TMT bars as longitudinal reinforcement, 2-6mm Ø mild steel bars as compression reinforcement. Similarly, SCC beams with 70 MPa strength consists of consist of 2-16 mm and 1-12mm Ø bars as longitudinal reinforcement, 2-6mmØ mild steel bars as compression reinforcement. Two legged 6mm Ø steel was used as stirrups.

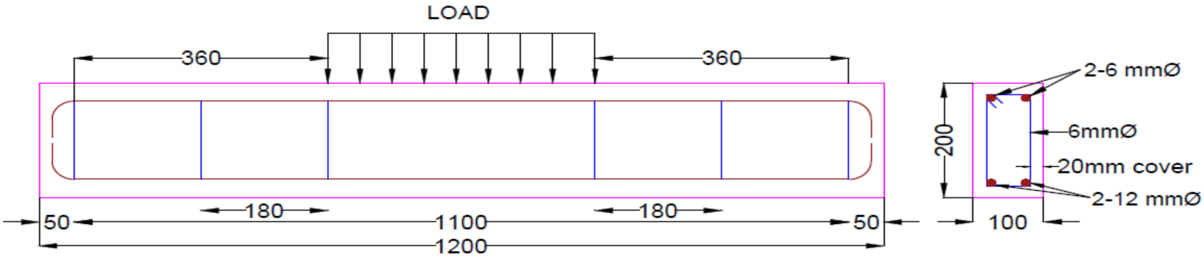


Figure 1 Reinforcement details for SCC30 with a/d=2

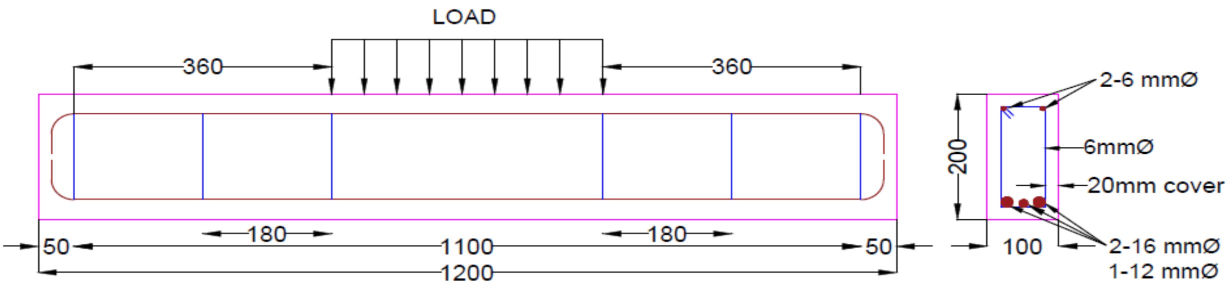


Figure 2 Reinforcement details for SCC70 with a/d=2

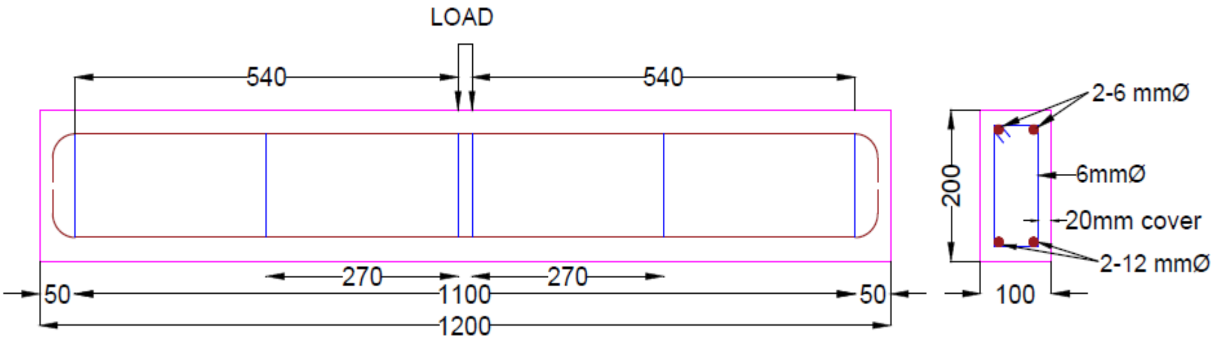


Figure 5 Reinforcement details for SCC30 with a/d=3

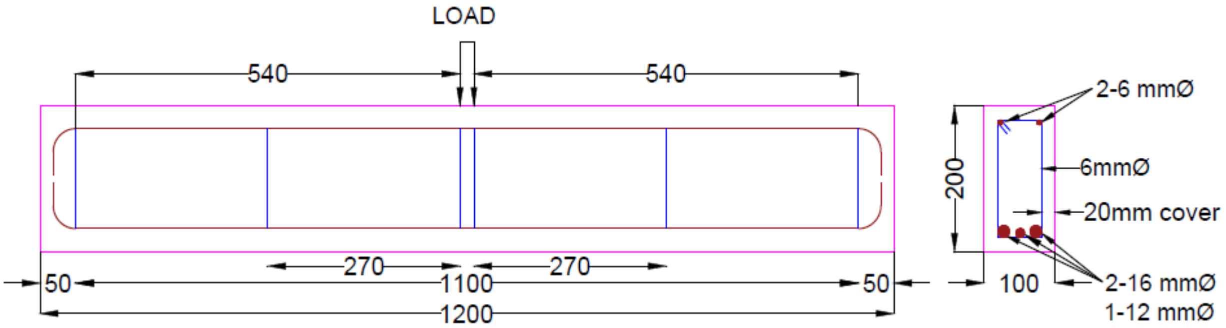


Figure 6 Reinforcement details for SCC70 with a/d=3

*All dimensions are in mm

Mix Proportions

Self-Compacting Concrete (SCC) mixes are designed using a rational mix design method **(*Rao et al 2013*)**. The details of mix proportions are presented in Table 2. Trial mixes were carried out by varying superplasticizer dosage and binder content. The fresh properties were evaluated as per **EFNARC** specifications.

Table 2 Mix proportions of M30 and M70 grade SCC

MIX	CEMENT (kg/m^3)	FLYASH (kg/m^3)	SILICA FUME (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	WATER (kg/m^3)	W/B	SP (kg/m^3)
SCC30	350	324	0	746	945	203	0.30	5.73
SCC70	600	226	48	780	874	247	0.28	6.03

Fresh Properties of SCC30 & SCC70 grade SCC without and with steel fibers

The details of fresh properties for M30 and M70 grades SCC without and with steel fiber were shown in **Table 3.**

Table 3 Fresh properties of SCC30 and SCC70 without and with fiber

GRADE OF CONCRETE	SCC30		SCC70		EFNARC 2005	
Dosage of Fibers	0%	0.5%	0%	0.5%	Min.	Max.
Slump Test, mm	750	620	720	680	550	800
T_{50} Slump flow, sec	3	5	2.5	4	2	5
V funnel, sec	6	6.5	10.5	11.5	6	12
V funnel @ T_5 min, sec	7.5	8.5	12	14	6	15
J-ring, sec	3	8	3	7	0	10

It can be seen from Table **3** that, addition of steel fibers has reduced the flow properties but satisfied the **EFNARC 2005** specifications. Figure 6 shows the various tests conducted on workability of SCC.

a) Slump flow b) J-ring c) V-funnel

Figure 6 some tests on workability of SCC

Hardened properties of Self compacting concrete without and with steel fiber

The details of hardened properties of M30 and M70 grades of SCC without and with steel fibers at the age of 28 days were shown in **Table 4**. All the tests were done as per **IS: 516-2004** specifications.

Table 4 Hardened properties of SCC30 and SCC70 28 days

	SCC30			SCC70		
DOSAGE OF STEEL FIBERS	COMPRESSIVE STRENGTH (MPA)	SPLIT TENSILE STRENGTH (MPA)	FLEXURAL STRENGTH (MPA)	COMPRESSIVE STRENGTH (MPA)	SPLIT TENSILE STRENGTH (MPA)	FLEXURAL STRENGTH (MPA)
0%	39.67	3.67	3.98	78.25	5.04	5.34
0.5%	48.76	4.34	4.87	86.66	5.85	6.41

RESULTS AND DISCUSSIONS

At the end of the required curing period, the beams were tested on two point loading under 1000kN Dynamic testing machine. From the recorded data, the shear load vs deflection graphs were plotted and ultimate shear strength was also calculated. The area under load vs deflection curves (Toughness) for M30 and M70 grade SCC without and with steel fibers is also evaluated. The ultimate load and shear strength values of 24 beams tested for shear span to depth ratio 2 and 3 are presented in Tables 5 and 6.

Table 5 Ultimate load and shear strength of fibrous and non-fibrous SCC beams for a/d=2

DESIGNATION	ULTIMATE LOAD KN	ULTIMATE SHEAR STRENGTH (V_u) (MPA)	DEFLECTION (MM)	TOUGHNESS (KN-MM)
		NASCC30		
SCC30-0	62.28	1.73	3.74	112.42
SFRSCC30-0	77.32	2.14	5.18	152.03
SCC30-180	95.67	2.66	4.18	234.27
SFRSCC30-180	117.92	3.28	6.90	464.1
		NASCC70		
SCC70-0	88.43	2.45	3.58	228.50
SFRSCC70-0	101.69	2.55	4.08	440.70
SCC70-180	115.70	3.21	4.92	365.7
SFRSCC70-180	159.75	4.44	5.90	525.03

**0 indicates beams with no stirrups (plain beam)*

Table 6 Ultimate load and shear strength of fibrous and non-fibrous SCC beams for a/d=3

DESIGNATION	ULTIMATE LOAD (KN)	ULTIMATE SHEAR STRENGTH MPA	MAX. DEFLECTION (MM)	TOUGHNESS (KN-MM)
		NASCC30		
SCC30-0	48.42	1.34	3.84	101.45
SFRSCC30-0	50.84	1.41	5.68	134.89
SCC30-270	62.30	1.73	4.16	167.50
SFRSCC30-270	93.45	2.60	6.55	359.40
		NASCC70		
SCC70-0	68.49	1.90	3.48	208.29
SFRSCC70-0	71.32	1.98	4.48	374.11
SCC70-270	86.77	2.41	3.66	197.70
SFRSCC70-270	131.27	3.65	5.40	440.70

**0 indicates beams with no stirrups (plain beam)*

Influence of Steel fiber on shear strength

Figures 7-10 shows the comparison of load deflection curves of SCC30 and SCC70 grade concrete among SCC and SFSCC beams for different shear span to depth ratios (a/d) 2, 2.5 & 3. It can be observed that.

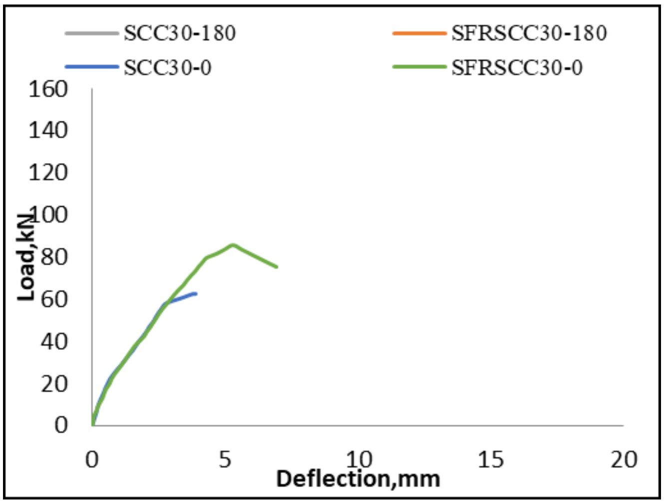
1. The SCC30-0 beam with no stirrups and steel fibers has failed suddenly in shear, due to addition of steel fibers the load carrying capacity of SFRSCC30-0 beams has increased by

24%. The beam with stirrups and steel fibers i.e. SFRSCC30-180, has shown higher load carrying capacity and the failure mode has changed from brittle failure to ductile mode. Due to combined effect of steel fiber and stirrups, the ultimate shear strength was increased by 90% compared with SCC30-0.

2. The similar behaviour was observed in the case of higher grade (SCC70) concrete.
3. The SCC30-180 beam shows both lower load carrying capacity and brittle failure pattern compared to the SFRSCC30-180, addition of steel fibers has increased the load bearing capacity by 23.25 % and also maximum deflection corresponding to ultimate load increased by 65.07%.
4. Similarly, the SCC30-360 beam also shows both lower load carrying capacity (F_u =86.77 KN) and brittle failure pattern compared to the beam with steel fibers (SFSCC30-360).
5. In case of high grade concrete (SCC 70), addition of steel fibers has increased the ultimate shear strength by 38.07% and also maximum deflection corresponding to ultimate load increased by 19.91%. Due to the combination of stirrups and steel fibers, the ultimate shear strength is increased by 80.7%. Same behaviour was observed for both the a/d ratios 2.5 & 3.
6. The failure pattern of the beam from brittle shear failure to ductile flexural- shear failure. The SCC beam without steel fibers failed soon after first diagonal crack has occurred.

Effect of shear span to depth (a/d) ratio on shear behavior of SCC beams for different stirrup spacing

From the experimental results it was observed that as the shear span to depth (a/d) ratio increased, the ultimate load and ultimate shear strength decreased. This may be attributed to the increasing principal tensile stresses in the shear span causing diagonal tension cracks which decrease the shear resistance of the beam. The addition of steel fibers improves the ductility and change the failure mode from a brittle shear collapse into a ductile flexural-shear failure. By keeping the stirrup spacing constant and adding steel fibers, ultimate shear strength increased because of the confining effect of steel fiber which will play a significant role before and after cracking. The combination of steel fibers and stirrups show a positive hybrid effect on shear behaviour and enhances the shear resistance of beam. Also, steel fibers can partially replace stirrups and ensure more ductility. As the grade of concrete increased, ultimate strength increased because the shear resistance of beam has increased. Figure 11 and 12 shows the variation of shear strength with shear span to depth ratio (a/d) for plain beams without stirrups and for beams with different stirrups spacing.



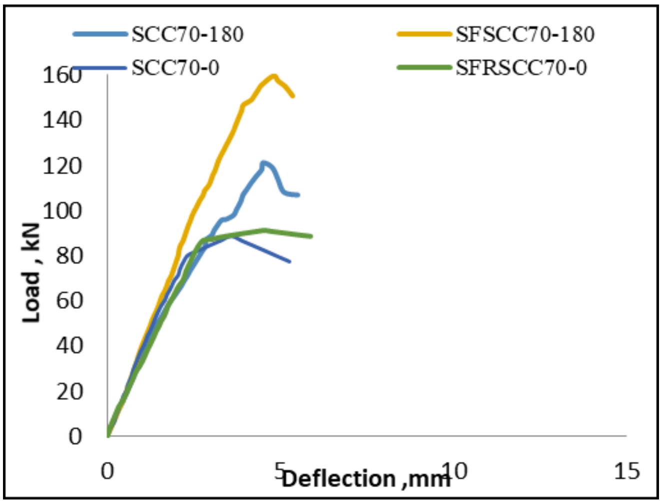
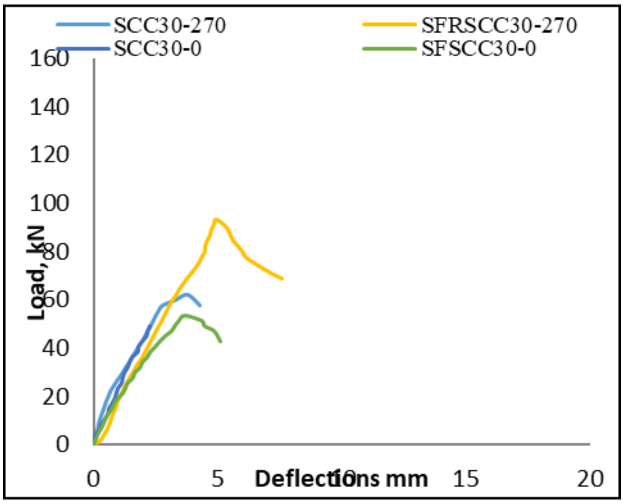


Figure 7 Load vs Deflection for SCC30 a/d=2

Figure 8 Load vs Deflection for SCC70 a/d=2



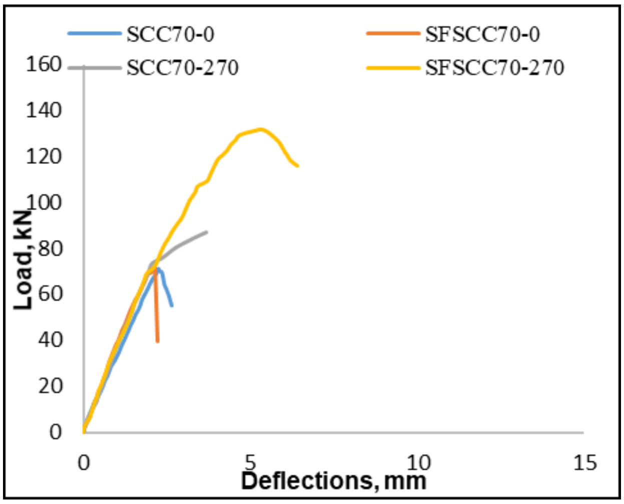


Figure 9 Load vs Deflection for SCC30 a/d=3

Figure 10 Load vs Deflection for SCC70 a/d=3

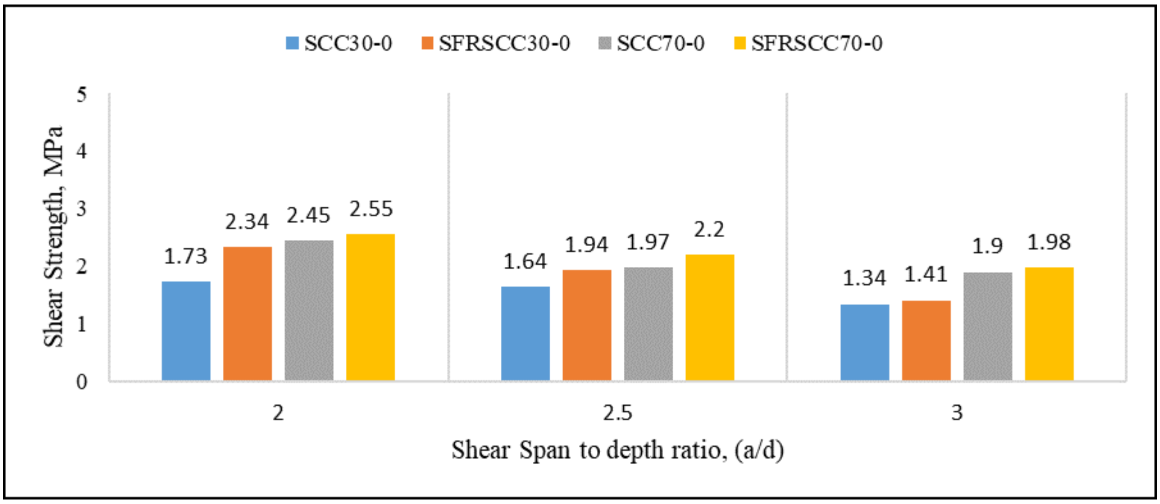


Figure 11 Shear Strength Vs Shear Span to depth ratio (a/d) for Plain beams

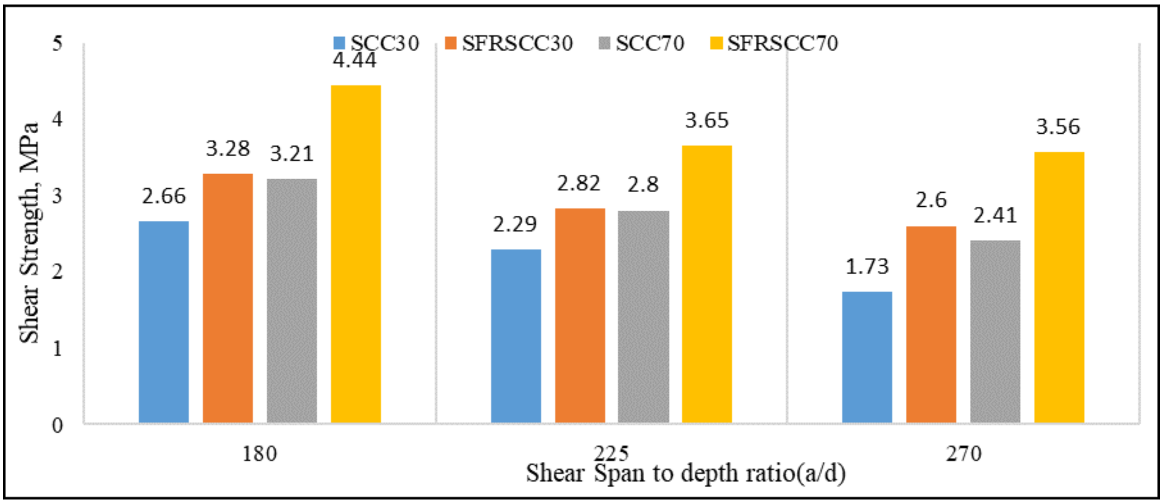


Figure 12 Shear Strength Vs Shear Span to depth ratio (a/d) for Plain beams

Angle of inclination (Ɵ)

Crack angle (Ɵ) was measured from the failure pattern of the beams and it is presented in the Tables 8 and 9 for SCC30 and SCC70. It was observed that as the shear span to depth ratio (a/d) increased from 2 to 3, there was a decrease in the crack angle, this can be attributed to the increase in the crack length as the shear span increased. From the obtained values, a plot among shear span to depth ratio (a/d) and angle of crack (Ɵ) is drawn.

Table 7 Crack Angle for SCC30 beams with 6mm Ø stirrup

S.NO.	BEAM DESIGNATION	a/d	STIRRUPS SPACING , MM	STIRRUP DIAMETER MM	CRACK ANGLE (Ɵ)
1.	SCC30-0	2	-	-	43.60
2.	SFRSCC30-0	2	-	-	43.47
3.	SCC30-180	2	180	6	43.60
4.	SFRSCC30-180	2	180	6	44.29
				Average:	43.52
5.	SCC30-0	3	-	-	36.53
6.	SFRSCC30-0	3	-	-	40.40
7.	SCC30-270	3	270	6	40.28
8.	SFRSCC30-270	3	270	6	43.33
				Average:	40.47

Table 8 Crack Angle for SCC70 beams with 6mm Ø stirrup

9.	SCC70-0	2	-	-	43.60
10.	SFRSCC70-0	2	-	-	44.43
11.	SCC70-180	2	180	6	44.57
12.	SFRSCC70-180	2	180	6	44.71
				Average:	44.20
13.	SCC70-0	3	-	-	39.81
14.	SFRSCC70-0	3	-	-	40.52
15.	SCC70-270	3	270	6	40.89
16.	SFRSCC70-270	3	270	6	42.14
				Average:	40.69

Figure 13(a) shows the variation of crack angle (ϴ) with respect to shear span to depth ratio whereas, Figure 13(b) shows the variation of average crack angle (ϴ) with respect to shear span to depth ratio.

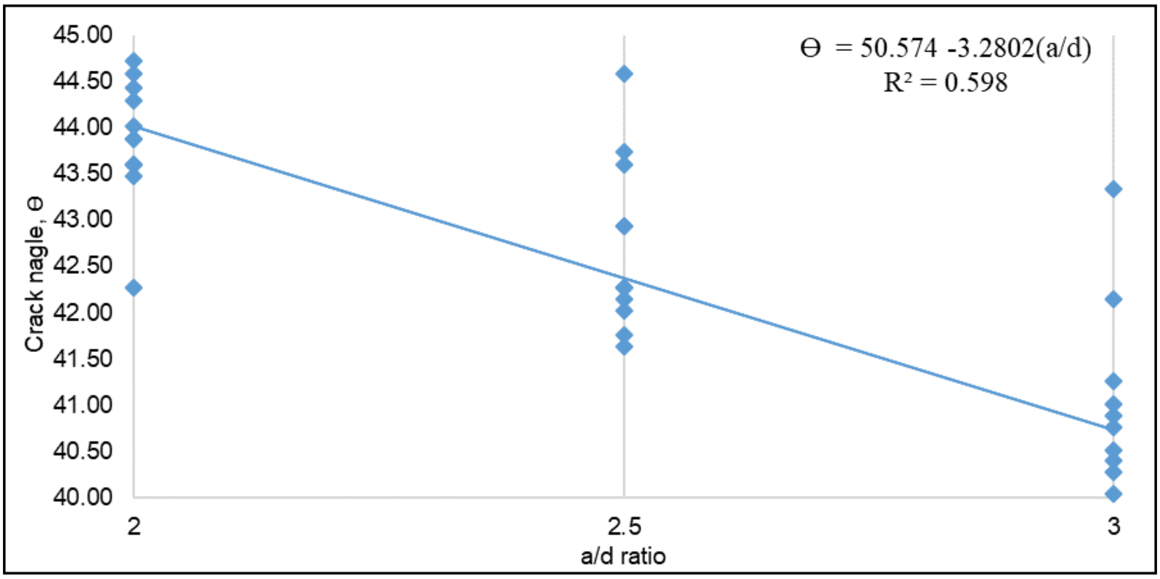


Figure 13(a) Crack angle vs a/d ratio

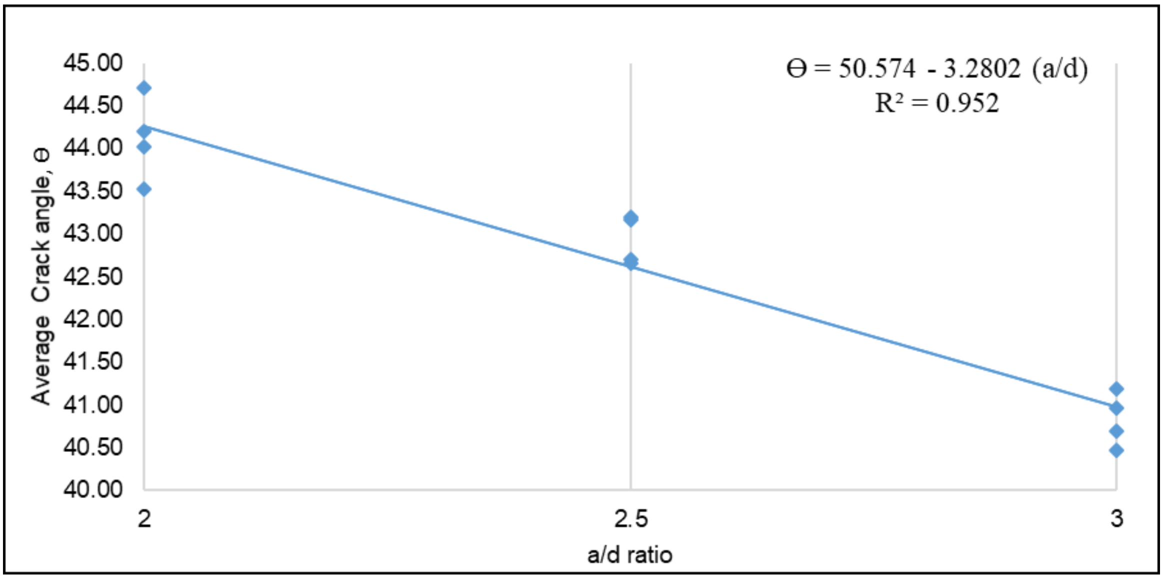


Figure 13(b) Average Crack angle vs a/d ratio

Prediction of Theoretical Shear Strength

The cracked portion of the beam is shown in Figure 14. The type of failure is split tensile failure and assuming the crack inclination is as "ϴ", the force acting on the surface of the crack as split tensile force (F_t). By resolving the force F_t along the y- direction, the vertical component of force F_t is "$F_t * \cos\theta$". Shear force (V_u) at the support is equivalent to $\mathbf{V_u} = \mathbf{V_{uc}} + \mathbf{V_{us}}$. Where V_{uc} = shear force taken by uncracked concrete and $\mathbf{V_{us}}$ = shear force taken by vertical stirrup.

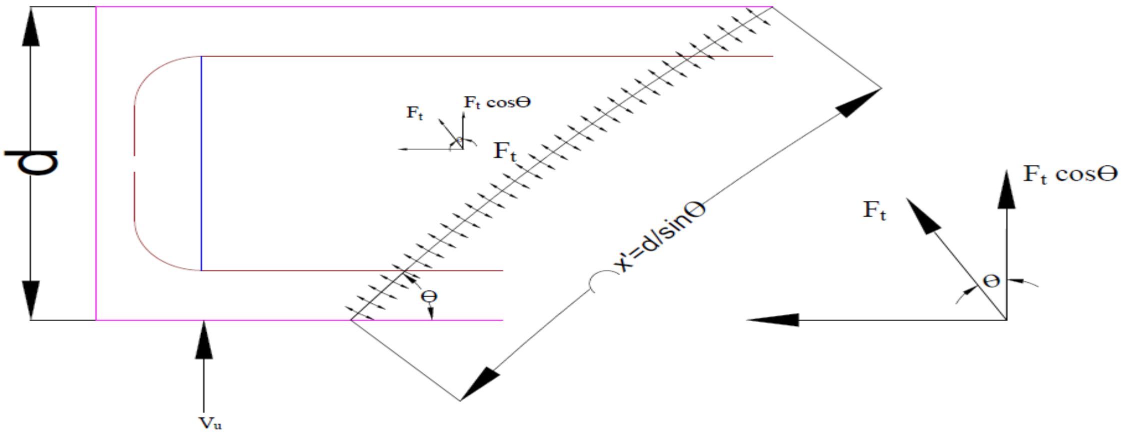


Figure 14 Cracked portion of the beam

Shear force taken by uncracked concrete is given by, $V_{uc} = x' * b * F_t * \mathrm{Cos}\theta$. **Eq (1)**

Where. F_t = Split tensile Strength of Concrete, b = width of the beam, x' = length of the crack, $x' = \frac{d}{\mathrm{Sin}\theta}$; d= depth of the beam and angle of inclination Θ = 50.459-3.2838(a/d) is obtained from the Figure 15(b); a/d= shear span to depth ratio.

Therefore, substituting the value of $x' = \frac{d}{\mathrm{Sin}\theta}$ in above Eq (1)

$$\mathbf{V_{uc} = x' * b * F_t * Cos\theta} \qquad \text{Eq (2)}$$

$$\mathbf{V_{uc} = \frac{d}{Sin\theta} * b * F_t * Cos\theta} \qquad \text{Eq (3)}$$

$$\mathbf{\frac{V_u}{d * b} = \frac{F_t\, Cos\theta}{Sin\theta}} \qquad \text{Eq (4)}$$

Shear strength of uncracked concrete is given by

$$\boldsymbol{\tau_c} = \mathbf{\frac{F_t}{Tan\theta}} \qquad \text{Eq (5)}$$

Similarly, Shear force taken by vertical stirrup ($\mathbf{V_{us}}$) is given by

$$\mathbf{V_{us} = \frac{0.87 * f_y * A_{sv}}{Cos\theta}} \qquad \text{Eq (6)}$$

Where; f_y = Yeild strength of the stirrup;

A_{sv} = Area of the shear strength

Therefore, Predicted Theoretical Shear Strength is given by:

$$\mathbf{V_u = V_{uc} + V_{us}} \qquad \text{Eq (7)}$$

$$\mathbf{V_u = Eq(3) + Eq(6)} \qquad \text{Eq (8)}$$

$$\mathbf{V_u = \left\{\frac{d}{Sin\theta} * b * F_t * Cos\theta\right\} + \left\{\frac{0.87 * f_y * A_{sv}}{Cos\theta}\right\} * k_1} \qquad \text{Eq (9)}$$

$k_1 = 0$, when crack does not cross the stirrup and $k_1 = 1$, when crack crosses the stirrup.

Comparison of Theoretical and Experimental Shear Strength

The theoretical shear strength obtained by predicted equation are compared with experimental results. The correlation among experimental and predicted shear strength is in good agreement. Table 10 shows the experimental and theoretical shear strength for SCC30 and SCC70 and percentage error. The percentage error in all the cases is less than 15 % with an average ratio of theoretical and experimental shear strength as 1.02. Figure 17 shows the plot among experimental and theoretical shear strength, the equation between experiential and theoretical shear strength is given by **$y = 0.9451x + 0.1722$; with an $R^2 = 0.9612$**

Table 10 Experimental vs Theoretical Shear Strength for SCC30 and SCC70

DESIGNATION	EXPERIMENTAL		THEORETICAL		% ERROR	THEORETICAL/ EXPERIMENTAL
	Load kN	Shear Strength, MPa	Load kN	Shear Strength, Mpa		
SCC30						
a/d=2						
SCC30-0	62.28	1.7	69.36	1.93	11.37	1.09
SFRSCC30-0	85.24	2.4	82.41	2.29	3.31	1.11
SCC30-180	95.67	2.7	97.93	2.72	2.36	0.97
SFRSCC30-180	117.92	3.3	118.63	3.30	0.60	0.94
a/d=3						
SCC30-0	46.81	1.3	43.67	1.21	6.69	0.95
SFRSCC30-0	48.59	1.3	48.06	1.33	1.09	0.93
SCC30-270	67.33	1.9	77.95	2.17	15.77	0.99
SFRSCC30-270	95.66	2.7	102.49	2.85	7.14	1.03
SCC70						
a/d=2						
SCC70-0	88.2	2.5	92.08	2.56	4.40	1.04
SFRSCC70-0	91.8	2.6	106.17	2.95	15.65	1.16
SCC70-180	115.56	3.2	112.09	3.11	3.00	0.97
SFRSCC70-180	159.84	4.4	162.54	4.52	1.69	1.02
a/d=3						
SCC70-0	68.4	1.9	68.84	1.91	0.65	1.01
SFRSCC70-0	71.28	2.0	80.74	2.24	13.27	1.13
SCC70-270	100.44	2.8	104.78	2.91	4.32	1.04
SFRSCC70-270	131.4	3.7	129.37	3.59	1.55	0.98
					Average	1.02

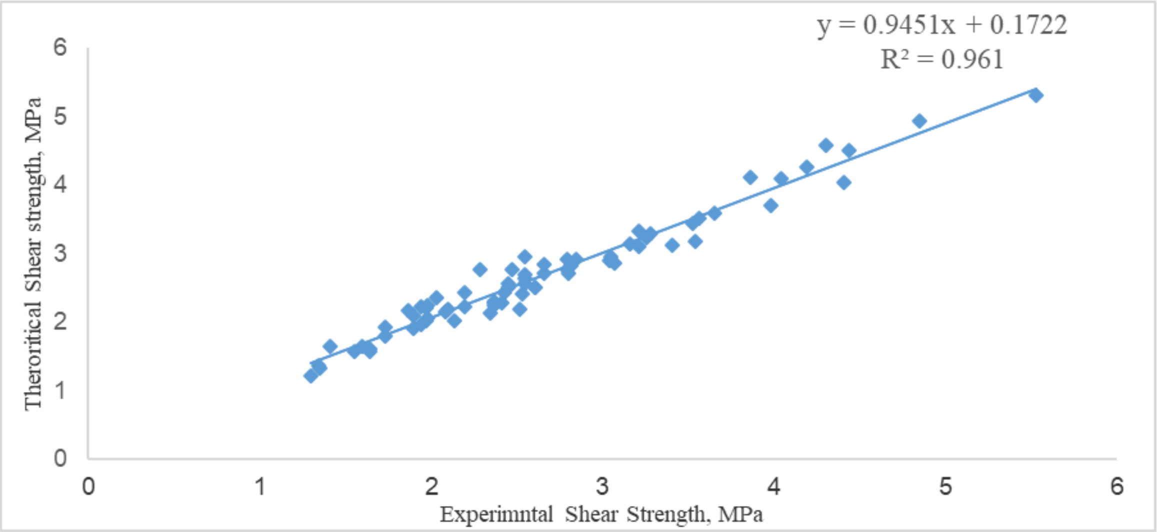


Figure 17 Experimental vs Theoretical Shear Strength for SCC30 and SCC70

CONCLUSIONS

Based on experimental and theoretical studies following conclusions are made.

1. The compressive strength was increased by 4.9% whereas, split tensile increased by 15.44% and flexural strength increased by 22.3% for normal strength concrete (30 MPa) with the use of maximum dosage of steel fibers (i.e. 0.5% by volume of concrete).
2. Similarly, in case of high strength SCC (70 MPa) due to addition of steel fibers, the compressive strength increased by 6.51%. The split tensile strength increased by 12% and flexural strength by 21.67% respectively with 0.5% dosage of steel fibers.
3. Due to addition of steel fibers, the ultimate shear strength increased by 36.8% and 15% in SCC30 and SCC70 respectively compared to plain beams. The failure mode was changed from a sudden brittle failure to a ductile flexural type failure.
4. Due to the combined effect of stirrups and steel fibers, the ultimate shear strength increased by 89.34% and 80.65% SCC30 and SCC70 compared to plain beams for beam with a/d=2 at 180 mm spacing.
5. With increase in the shear span to depth ratio from 2 to 3, the ultimate shear strength reduced by 5.2% and 22.54% for SCC30. Similarly, in case of SCC70, it is reduced by 19.59% and 22.44%.

6. As the shear span to depth (a/d) ratio increased, crack angle (Θ) is reduced and it is true for both grades SCC30 and SCC70.
7. Predicted Theoretical Shear Strength is given by:
    - $V_u = V_{uc} + V_{us}$
    - $V_u = \left\{\frac{d}{\mathrm{Sin}\theta} * b * F_t * \mathrm{Cos}\theta\right\} + \left\{\frac{0.87 * f_y * A_{sv}}{\mathrm{Cos}\theta}\right\} * k_1$ Where F_t = Split tensile strength of SCC and Angle of inclination Θ = 50.459 - 3.2802(a/d); a/d = shear span to depth ratio. $k_1 = 0$, when crack does not cross the stirrup and $k_1 = 1$, when crack crosses the stirrup.

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