Experimental Study on the Behaviour of Spirally Reinforced SCC beams

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Abstract— Normally, shear reinforcement of concrete beams consists of traditional stirrups. Replacing the individual stirrups by a continuous spiral can reduce the labour cost for production of the reinforcement cage and improves the shear capacity and ductility in beams. In this paper the use of spiral shear reinforcement in Self Compacting Concrete (SCC) is investigated by testing of 12 reinforced concrete beams in a static two-point bending test**.** Further, 12 additional beams with an advanced rectangular spiral reinforcement that has shear-favourably inclined vertical links is also presented and tested as shear reinforcement.

In this paper the shear span to depth ratio is kept constant as 1.952 and four spacing (80, 100, 120, 150 mm) are adopted. During the tests, crack evolution is monitored, and the fracture mechanisms of the beams are analysed and compared. The behavior of the shear-critical beams is studied through the load–deflection curves, ultimate load values, vertical deflections measurements and crack propagation during static tests.

Test results clearly indicate that using rectangular spiral shear reinforcement improved the shear capacity and ductility of beams compared with traditional individual closed stirrup beams. Furthermore, the results showed that SCC yields a more favourable critical crack evolution compared to CVC (Conventional Vibrated Concrete).

Keywords— Self Compacting Concrete (SCC), Spiral reinforcement, Shear failure, Beam, Crack pattern, Shear-critical beams.

INTRODUCTION

The use of self-compacting concrete (SCC) is steadily increasing, mainly in the precast industry, and a large amount of research has been conducted on the fresh and hardened properties of SCC. However, relatively little research has been carried out on the structural behaviour of SCC.

In comparison with a vibrated concrete (VC) of the same strength class, self-compacting concrete (SCC) typically has a lower coarse aggregate content and, possibly, a smaller maximum aggregate size. This may result in reduced aggregate interlock between the fracture surfaces of a SCC. Since aggregate interlock plays an important role in the shear strength of slender beams, SCC beams may have shear strength lower than that of similar VC beams, but studies on that subject are still limited. By the use of small percentage of transverse reinforcement the shear capacity of beams can be increased.

All reinforced concrete beams require shear reinforcement, calculated or minimum ratio. Theoretically, calculated shear reinforcement is only required when the externally applied shear force V exceeds the design shear resistance of the member without shear reinforcement. However, for various reasons, including avoiding brittle fracture, minimum shear reinforcement should be provided. Both minimum and calculated shear reinforcement is in the shape of vertical or inclined individual stirrups.

The use of continuous spiral reinforcement can be considered more effective in construction compared to individual vertical stirrups due to the fact that the spiral reinforcement is made of spirally shaped cage that can be quickly installed into place which reduces the time and labour costs significantly. The spiral reinforcement enhances the strength and ductility capacity due to the confining of concrete core.

Reinforced concrete column-beam joints, columns and in filled frames with rectangular members and rectangular spirals as shear reinforcement have already been tested under cyclic loading. The experimental results of these tests showed that the spiral reinforcement improved the overall seismic performance and increase maximum loading energy absorption and ductility capabilities of beam column joints [19,20].

Recently the use of rectangular continuous spiral reinforcement in reinforced concrete beams with rectangular cross sections has been studied. De Corte and Boel [12] tested 24 beams to assess the effectiveness of using spiral reinforcement in beams. The results showed that spiral reinforcement performs equally well compared to individual stirrups, and the self-compacted concrete yields a better critical crack evolution compared to conventional concrete. They recommend that more tests are required to establish boundaries for the inclination angle and the type of concrete used.

Considering the behaviour of shear critical members, it is stressed that the shear failure of RC beam is characterized by the inclination of the diagonal cracking. It has been proved that the amount of the steel stirrups along with the amount of the steel stirrups along with the amount the main tension reinforcement and the span-to-depth ratio control the inclined shear cracking [21]. It is stressed that common continuous spiral reinforcement comprises of two vertical links with opposite inclination and therefore, only one of these links has the right inclination to resist against the applied shear.

SIGNIFICANCE OF THE WORK

A. Scope of the Work

The earlier studies reveals that using rectangular continuous spiral reinforcement in reinforced concrete beams is a new promising technology that could enhance the shear strength of beams as well as the ductility.

Beams with advanced spiral which have shear favourable inclined vertical links are proposed in the present study to check the shear capacity as well as improved ductility performance.

B. Objective of the Work

The objective is the introduction of continuous rectangular reinforcement and advanced spiral reinforcement for reinforcing the concrete structures other than normal vertical steel stirrup and to check the shear capacity of such beams compared with conventional steel beams.

C. Methodology

The methodology of the work consists of:

(1) Selection of self compacting concrete grade; S25

(2) Mix design for S25 grade SCC

(3) Casting beam specimens of normal RC beams, Normal SCC beams, Continuous spiral reinforcement and advanced spiral reinforcement.

(4)Conducting three point loading test using 50t loading frame.

(5) Study on the obtained results

MATERIAL TESTS

The materials selected for S25 mix were OPC (Ordinary Portland Cement) 53 grade BHARATHI CEMENTS, fly ash collected from Coimbatore, M sand as fine aggregate, 20 mm size coarse aggregates, water and Master Glenium SKY 8233 as admixture. Each material except the admixture was tested as per the specifications in the relevant IS codes. The results are provided in Table I. The beam is reinforced with continuous rectangular spiral reinforcement. There were 4 groups of reinforcement pattern according to the spacing provided (SP80, SPA80, SP100, SPA100, SP120, SPA120, SP150, SPA150). The first part indicates the type of reinforcement pattern, SP indicating continuous spiral, SPA indicating the advanced spiral and the numerical part indicating the pitch spacing.

TABLE I

MATERIAL TEST RESULTS

Test	**Material**	**Equipment Used**	**Values Obtained**
Specific Gravity	Ordinary Portland Cement	Le-Chatelier Flask	3.15
Specific Gravity	Fine Aggregates	Pycnometer	2.7
Specific Gravity	Coarse Aggregates	Vessel	2.94
Specific Gravity	Fly ash	Le-Chatelier Flask	2.13

(a) (b)

(c)

Fig. 1 (a) traditional vertical stirrup, (b) continuous spiral reinforcement, (c) advanced spiral reinforcement

MIX DESIGN

Many different test methods have been developed in attempts to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval and most of them have their adherents. Many trail mixes were prepared and comparing the test results with the standard values. Mix proportioning values are given in Table II.

TABLE II

S25 MIX PROPORTIONING

Cement (Kg/m^3)	561

Fly ash	99
Fine aggregate (kg/m^3)	1055.275
Coarse aggregate (Kg/m^3)	623.158
Water (l/m3)	167.45
Water cement ratio	0.2537
Mix ratio	1:1.6:0.9

EXPERIMENTAL INVESTIGATION

A. Experimental Procedure

Thirty, 1250 mm long, concrete beams with a 150 × 200 mm was included in this experimental investigation. Six beams were casted as control specimens with vertical steel stirrups using M25 mix and S25 mix. Details of specimens cast are shown in Table IV. Four sets of beams were made up of using Continuous spiral reinforcement and each set with spacing 80 mm, 100 mm, 120 mm, 150 mm. Further, another Four sets of beams with Advanced spiral reinforcement with the same spacing ass discussed above were cast. The steel RC beams were designed as per IS 456:2000 specifications. The main lower reinforcement was 2-12 mm in diameter and 6 mm diameter stirrups for all beams.

All beams were casted using Self Compacting Concrete. The beams were cured using jute bags with room temperature for 28 days. The compressive strength of the concrete mix was measured after 28 days using standard cubes. The mean compressive strength for the mix was 27.6 MPa.

TABLE III

DETAILS OF SPECIMENS CAST

Sl. No:	**Number Of Beams**	**Designation Used**	**Flexure bar type**	**Shear reinforcement type**	**Spacing Adopted**
1	3	SP80	HYSD Steel	Mild Steel	80
2	3	SPA80	HYSD Steel	Mild Steel	80
3	3	SP100	HYSD Steel	Mild Steel	100
4	3	SPA100	HYSD Steel	Mild Steel	100
5	3	SP120	HYSD Steel	Mild Steel	120
6	3	SPA120	HYSD Steel	Mild Steel	120

7	3	SP150	HYSD Steel	Mild Steel	150
8	3	SPA150	HYSD Steel	Mild Steel	150

SP- Continuous spiral

SPA-Advanced spirals

B. Test Procedure

The shear strength of the specimens was tested using a 50 ton loading frame. A dial gauge was attached at the bottom of the beam to determine the deflection at the centre of the beam. The effective span of the beam is taken as 990mm in the case of 1250mm beam. A proving ring of 500kN is connected at the top of the beam to determine the load applied.

The shear strength of the beam is tested as a three point loading system using a hydraulic jack attached to the loading frame. The behaviour of beam was observed from beginning to the failure. The loading was stopped when the beam was just on the verge of collapse. The first crack propagation and its development and propagation were observed. The values of load applied and deflection were noted. The load in kN is applied with uniformly increasing the value of the load and the deflection under the different applied loads is noted. The applied load increased up to the breaking point or till the failure of the material.

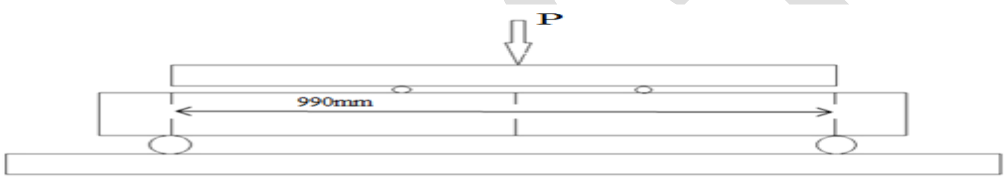

Fig.2 Schematic Set Up of Testing

EXPERIMENTAL RESULTS

A. Load Deflection Behavior

Due to increase in the load, deflection of the beams starts, up to certain level the load v/s. deflection graph will be linear that is load will be directly proportional to deflection. Due to further increase in the load, the load value will not be proportional to deflection, since the deflection values increases as the strength of the materials goes on increasing material loses elasticity and undergoes plastic deformation.

The deflection and the corresponding load, of SCC beam with spiral and advanced spiral reinforcement is compared with normal RCC and SCC beams with vertical stirrups

The load values and corresponding deflection of normal RCC beam (CS), SCC beams with vertical stirrups, beams with spiral and advanced spiral reinforcement is given in Table IV.

Flexural cracks and shear-flexural cracks were formed in the mid-span and quarter span respectively of all the tested beams. No shear failure of the beam was observed since the loading was limited. The maximum load values (P_{max}) and maximum vertical deflection (δ_{max}) at midspan is given in table 6.1 and observed that the maximum load is carried by the beams with advanced spirals with spacing 120 mm.

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TABLE IV

DEFLECTION AND CORRESPONDING LOAD

Deflection	**Load**									
Mix	**M25**	**S25**	**SP 80**	**SPA 80**	**SP 100**	**SPA100**	**SP 120**	**SPA120**	**SP 150**	**SPA150**
0.1	8.15	16.3	33.415	49.715	50.54	53.56	54.667	56.668	51.98	52.612
0.2	32.6	40.75	73.35	97.8	164.63	174.7	185.89	225.73	158.34	179.58
0.3	65.2	74.98	107.58	163	185.67	213.6	211.9	230.85	173.76	217.85
0.4	91.28	100.25	133.66	228.2	197.23	220.16	261.62	246.75	220.93	237.6
0.5	130.4	138.55	172.78	250.8	236.35	255.77	279.55	269.95	250.36	265.5
0.6	171.15	173.6	197.23	268.95	255.5	275.25	270.58	287.92	257.89	275.7

Fig.3 and 4 indicates the load-deflection curve of spirals and advanced spirals respectively. The test results clearly indicates that using rectangular spiral reinforcement increases the maximum load that the beams can sustain compared with the control beams. In figure 6.1 and 6.2 performance is best followed by SP 120 and SPA 120 regarding maximum load and ductility. Beams with spiral reinforcement nominal spacing 120mm exhibited around 55% increase in load carrying capacity with respect to control beams with closed stirrups. Beams with spiral reinforcement at nominal spacing 150 mm exhibited an increase in load bearing capacity of 48% when compared with control beams with closed stirrups.

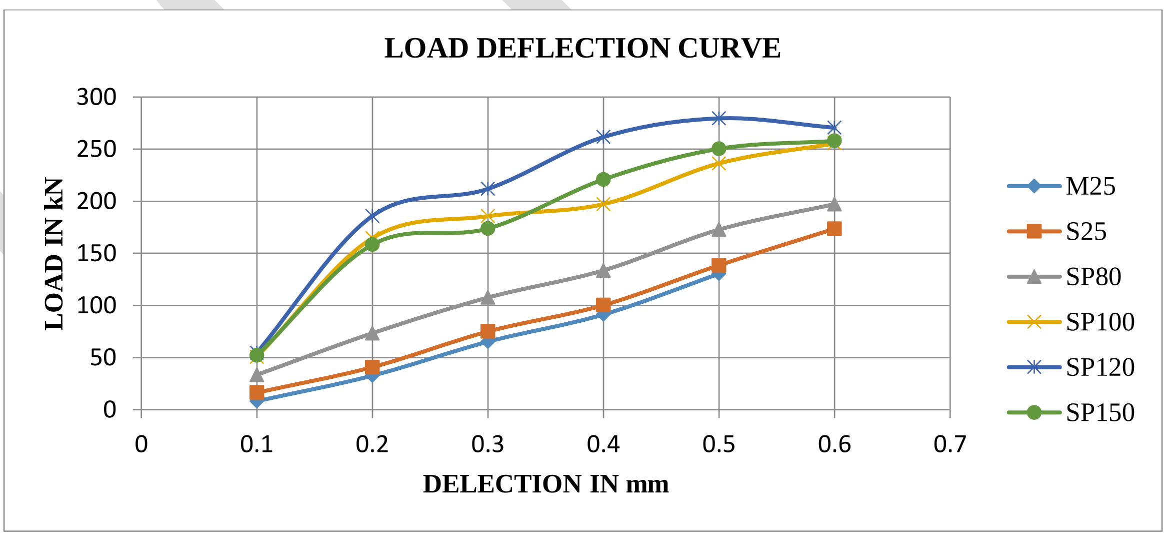

Fig.3 Load - deflection curve of Continuous Spiral reinforcement

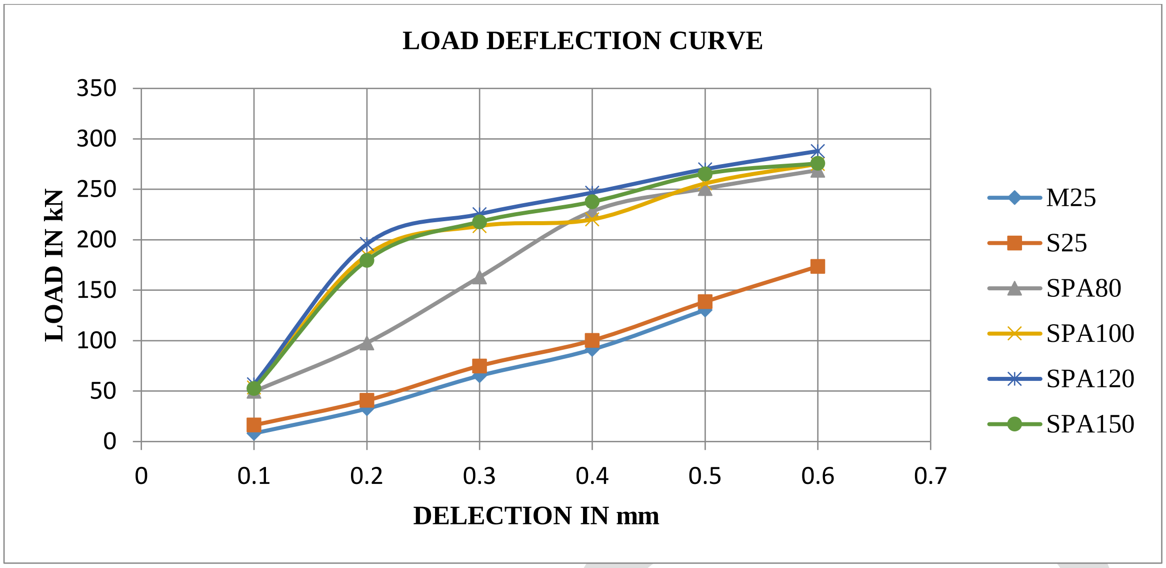

Fig.4 Load - deflection curve of Advanced Spiral reinforcement

B. Load Carrying Capacity

TABLE V

ULTIMATE LOAD OF BEAMS

Beam Specimen	Ultimate Load (kN)
SP80	197.23
SPA80	268.95
SP100	255.5
SPA100	275.25
SP120	270.58
SPA120	287.92
SP150	257.89
SPA150	275.7

It's concluded that there is also an improvement in shear for beams with rectangular continuous spiral reinforcement. The improvement in shear capacity and ductility are mainly attributed to the fact that the continuous spiral have favourable inclination to applied shear and meet the potential shear cracks.

Incase of traditional stirrups, the developed axial force in the stirrups is a function of the observed shear angle.whereas, the developed axial force in the spiral stirrups is a function of the observed shear angle and the inclination angle of the spirals. It's also concluded that the spiral reinforcement increases the compressive strength of concrete through enhancing the confinement of the concrete.

The most favourable inclination angle was found to be 80^0.This inclination angle provides the optimistic inclination of the front legs and the back legs to the imposed shear and thus expected to meet the potential shear crack normally. On the other hand, if the inclination angle of spiral reinforcement is under 80^0, only one set of rectangular spiral legs would have favourable inclination to the applied shear.

C. Ductility

Evaluation of the experimental results in terms of middle span deflection ductility in order to check the efficiency of applied rectangular spiral reinforcement in the post-peak behaviour of the beams is done. Although shear critical beams exhibit brittle behaviour in this study, the deformation ductility factor μ_{80}, has been employed in order to examine the post-peak behaviour of the spirally reinforced beams. This factor is defined by the following relationship:

$$\mu_{u80} = \frac{\delta_{peak}}{\delta_{u80}}$$

δ_{u80} = post-peak deformation at the point where the remaining strength is equal 80% of the observed peak strength and

δ_{peak} = the deformation at the observed ultimate shear strength

The values of the deformation ductility factor, μ_{u80}, of the tested beams are presented in table 6.2. The purpose of the use of this index is just to examine quantitatively if the spiral reinforcement could provide some flexural characteristics to the shear critical beam. From these values its observed that, the increase in amount of the shear reinforcement causes an improvement in the behaviour after the peak load. This enhancement seems to be more apparent in the beams with transverse reinforcement spacing at 80 mm. although all the tested beams are shear-critical beams and no ductility would be expected, the spirally reinforced beams with advanced spirals and shear favourably inclined links exhibited some flexural characteristics, demonstrating this way an improved post beak behaviour. The values of displacement ductility factor should be within the range of 3-5.

TABLE IV

DUCTILITY FACTOR

MIX	M25	SCC25	SP80	SPA80	SP100	SPA100	SP120	SPA120	SP150	SPA150
δ_{peak}	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
$\delta_{u,80}$	0.26	0.18	0.24	0.2	0.26	0.22	0.28	0.26	0.26	0.24
μ_{80}	2.31	3.33	2.50	3.00	2.3	2.73	2.14	2.31	2.31	2.50

D. Crack Pattern

Regarding the overall performance of the tested beams with spiral reinforcement, the first flexural cracks were formed at bottom surface in the maximum moment region at the midspan of the beams when the applied load was approximately 100 kN that is approximately 50 kN. As the applied load increased, the cracks began to spread out through the length of the beams and became gradually inclined towards the neutral axis of the beams. These values vary among different beams depending on transverse reinforcement ratios (ρ_t) and spacing of the stirrups for each group. Due to the limitation of the capacity of loading frame, the loading was stopped before 300 kN and the shear failure which was anticipated didn't occur.

Monitoring of the crack pattern for traditional stirrups and spirals reveals that the crack pattern during static tests could be considered identical and failure mechanism is identical. These findings support the effectiveness of using rectangular continuous spiral.

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CONCLUSIONS

Thirty RCC beams were tested using a static four-point bending set-up to study the effect of using continuous rectangular spiral reinforcement as transverse reinforcement. The behaviour of shear critical beams was studied through monitoring the load-deflection curve, ultimate load values and crack propagation during static tests. The results showed that using rectangular spiral shear reinforcement improved the shear capacity and the ductility of beams compared with traditional individual closed stirrups beams regardless of pitch spacing and inclination angle of stirrups. Beams with spiral reinforcement spacing at 120 mm exhibited 55% increased capacity with respect to the beams with stirrup. Furthermore beams with advanced spiral spacing 120 mm exhibited 65% increased load carrying capacity. The crack pattern for traditional stirrups and spiral beams were identical and the failure mechanism was practically equal.

Moreover, a middle span deflection ductility index has been adopted in order to evaluate the efficiency of the spiral reinforcement in the post-peak part of the tested shear-critical beams. The beams with advanced spirals with spacing 80 mm exhibited higher deformation ductility value of 3, demonstrating this way improved post-peak deformation capacity compared to the beams with equal quantity of commonly used stirrup.

REFERENCES:

[1] IS 10262: 2009 [mix design]

[2] IS 456-2000

[3] IS 4031-1988 [Standard consistency of cement]

[4] IS 2720(Part III) [Specific gravity of cement]

[5] IS 12269- 1987 [Fineness of cement]

[6] IS 2386 (Part-III)-1963 [Fine aggregates]

[7] IS 383:1970 [sieve analysis]

[8] IS 2386 (part-iii)-1970 [coarse aggregate]

[9] EFNARC-Specifications and Guidelines for Self Compacting Concrete

[10] P.D Zararis,“ Shear strength and minimum shear reinforcement of reinforced concrete slender beams”, ACI Structural Journal, Vol 100(2), pp 203-214,2003.

[11] P.D Zararis, I.P Zararis, “Shear strength of reinforced concrete slender beams with or without axial forces”, ACI Structural Journal, Vol 106(6), pp 782-789, 2009.

IJERGS

[12] D.C Wouter, Boel Veerle, "Effectiveness of spirally shaped stirrups in reinforced concrete beams", Science Direct, Journal of Engineering Structures, Vol 52, pp 667-675,2009.

[13] S.Nasim et al,"Experimental investigation of reinforced concrete beams with spiral reinforcement in shear", Science Direct, Journal of Construction and Building Materials, Vol 125, pp 585-594,2016.

[14] K.G Karyannis, C.E Constantin, "Shear tests of reinforced concrete beams with continuous rectangular spiral reinforcement", Science Direct, Jounal of Construction and Building Materials, Vol 46, pp 86-97,2013

[15] K.G Karyannis, C.E Constantin, "Shear capacity of rectangular beams with continuous spiral transversal reinforcement", Science Direct, Journal of Engineering Structures, Vol 12, pp 379-386, 2013

[16] B.K Kolhapure, "Shear behaviour of reinforced concrete slender beams using high strength concrete", IJRET, pp 79-84,2013

[17] Haddadin M.J et al, "stirrup effectiveness in reinforced concrete beams with axial force", Journal of Structural Division, Vol 94(3), pp 227-238,1997

[18] Saatcioglu M et al, "Strength and ductility of confined concrete, Journal of Structural Engineering", Vol 118(6), pp 1590-1607,1992

[19] A.G. Tsonos, "Cyclic load behaviour of RC beam-column sub assemblages of modern structure"s, ACI Structural journal, Vol 104(4), pp 468-478,2007

[20] D. J Kakaletsis, C.G Karyannis, G.K Panagopoulos,"Effectiveness of rectangular spiral shear reinforcement on infilled RC frames under cyclic loading", Journal of Thin walled structures Part B, Vol 98, pp 443-453,2016