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Use of Steel Fibers as Shear Reinforcement for Deep Beams in Shear-an Experimental Study

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Abstract:
The present paper deals with the experimental investigation on effects of steel fiber on the shear strength of deep beams and compared to verify replacement of shear reinforcement in deep beams. The grade of concrete is M25 with three steel fiber volume fraction (0.5,1.0 and 1.5%) and the beams are of three different shear span to effective depth ratios (0.60,0.80 and 1.0) and combination of web reinforcement. Crimped steel fibbers of length 50 mm and mean diameter of 0.5 mm giving an average aspect ratio of 100 are used. Cubes of size 150 mm are used for compressive strength test. The effective span to overall depth ratio varies from 1.9 to 1.96 so as to achieve the desired shear span to effective depth ratio (a/d). A total of 54 beams were tested to failure under two-point top loading. The test results indicate that the fibres have significant influence on shear strength of longitudinally reinforced concrete deep beams. Shear strength increases with increasing fibre volume and decreasing shear span to effective depth ratio. The results of experimentation show that the steel fibres can replace the conventional shear reinforcement for the deep beams.

Keywords: deep beam, steel fiber reinforced concrete, shear span, shear strength, volume fraction.

I. INTRODUCTION

The use of short and discrete steel fibers has been well established as reinforcement which increases the crack resistant of the cement based materials. The steel fibers have been found effective mainly to increase the resistance against impact, abrasion and crack propagation. [1, 2]The recent studies have shown that steel fibers can also be useful in improving the shear strength of the concrete [3]-[9]. Somehow, the use of steel fibers will be more attractive and beneficial if conventional stirrups can be eliminated, which reduces reinforcement congestion in beams particularly the deep beams. Deep beams are having relatively small values of span-to-depth ratio. As per code provisions of different countries a beam shall be considered as deep beam when the ratio of effective span to overall depth ratio is less than 2.0 for simply supported beam and 2.5 for continuous beams. [10] The ACI-318 (2008), Section 11.7.1 defines the deep beam based on two criteria: as clear span to depth ratio ($L/D<4$) and shear span to depth ratio ($a/d<2$) [11]. Reinforced concrete deep beams have very useful structural applications such as pile caps, water tanks and tall buildings. Because of their geometrical proportions, they develop mechanism of force transfer quite different from that in slender beams and their strength is likely to be controlled by shear rather than flexure provided with nominal amount of longitudinal reinforcement. The failure of the deep beam is in shear and the shear is resisted by shear reinforcement. If the spacing between the reinforcement is less then it is quite difficult to achieve full compaction of concrete. The shear may be resisted by using steel fibres instead of shear reinforcement (i.e. vertical reinforcement and side face reinforcement). Generally three types of cracks, namely flexure, flexure shear and shear develop in deep beams under applied load, depending upon L/D ratio, tensile and web reinforcement, shear span to depth ratio [5]. These cracks ultimately cause the deep beams to fail. Apart from these cracks, deep beams also fail due to crushing at their supports or loading points due to insufficient anchorage of the tension reinforcement within the beams themselves.

II. EXPERIMENTAL PROGRAM

2.1 Test material: Ordinary Portland cement of grade 53, natural (river) sand of fineness modulus of 3.35 and crushed aggregate of maximum size 10mm were used. The grade of concrete is M25 with mix proportion of 1:1.36:2.33 by weight with water cement ratio of 0.45 was kept constant for all beams. The crimped steel fibbers of 0.5 mm diameter with aspect ratios of 100 were used.

2.2 Specimen details: All the beams were of rectangular cross section with effective span of 600 mm and width 140 mm. The specimens were divided into three series as, series A with (a/d) = 0.6, series B with (a/d) = 0.8 and series C with (a/d) = 1.0. For series 'A' and 'B' the depth of beam was taken 315 mm with (L / D) = 1.9. For series 'C' the depth of beam was taken 315 mm with (L/ D) = 1.96. The effective span to overall depth ratio was varied from 1.9 to 1.96 so as to achieve the desired shear span to effective depth ratio (a/d) In order to study the shear strength of steel fiber reinforced deep beams, total number of 54 specimens [09 Control Specimens (without fibers and shear reinforcement), 27SFRC Deep Beams with longitudinal steel approximately 1% and fiber fraction using crimped steel fibers with volume fraction (0.5, 1.0 and 1.50 %) and 18 beams with longitudinal steel and shear reinforcement]. All beams of series 'A' and 'B'are of size 145mm x 315mm x 900mmwere casted. Two bars of 16mm diameter as longitudinal reinforcement were used in all deep beams of series (A, B& C). In all RCC beams, without steel fibers, horizontal web reinforcement was consisting of two bars of 10 mm diameter. Vertical web reinforcement was 0.13 % in the shear span and the details of stirrups in different cases were, for (a/d) = 0.60 – 8 mm diameter @ 80 mm c/c, for (a/d) = 0.80 – 6 mm diameter @ 88 mm c/c, for (a/d) = 1.00 – 6 mm diameter @ 150 mm c/c.

2.3 Test procedure: Both the surfaces of beams were cleaned and white washed to aid for the observations of crack development during testing. The beams were tested to failure under two – point top loading in Universal Testing Machine of capacity 1000 kN. The first crack load and the ultimate load were determined.

Figure.1. Test Setup of UTM with Roller Base for Shear

III. RESULTS AND DISCUSSIONS

Table I shows the average shear load capacities of different beams loaded with different shear span to depth ratio and fiber volume fraction. From Table 1, it is evident that the ultimate shear load carrying capacity at first crack as well as ultimate load increases with increase in fiber volume content from 0.5% to 1.5% for all the series considered in this study. For Beam Series 'A' (a/d=0.60), the enhancement in ultimate shear strength capacity is observed to be increased by 3.16%, 4.99%, and 6.15% for fiber volume fraction 0.5%, 1%, 1.5% respectively as compared with control specimens without fibres and shear reinforcement. The shear reinforcement of 0.25% and 0.50% enhances the ultimate shear strength by 2.74% and 12.14% respectively at a/d=0.60. The improvement in shear capacity for series 'B'(a/d=0.8) due to addition of steel fibres is noticed as 5.54% for volume fraction 0.5%, 6.98% for volume fraction 1% and 16.84% for volume fraction 1.5%. The shear strength of series 'B' is found to increase by 3.89% and 9.72% for A_{sv} = 0.25% and 0.50% respectively. Similarly the enhancement in shear capacity for series 'C' (a/d=1) is observed 3.44%, 6.42%, and 12.15% increase for fiber volume 0.5%, 1% and 1.5 % respectively. While the shear reinforcement of 0.25% and 0.50% increases the ultimate shear strength by 6.88% and 7.11% respectively. The effect of shear span to depth ratio is evaluated by comparing the results of different series for same volume fraction but different a/d ratios. It reveals that the ultimate shear strength capacity of SFRC deep beams decreases by 17.09% for 0.5 % fiber volume fraction for change in shear span ratio 0.60 to 0.80 and further decreases by 12.25% as the shear span to depth ratio increases from 0.80 to 1.This trend resembles to the findings of previous researchers.[12]-[14]. Similar trend is found for beams reinforced with shear reinforcement without fibers. For shear reinforcement of 0.25%, the decrement of 12.45% for variation in shear span ratio from 0.60 to 0.80 and 13.72% for change in a/d from 0.80 to 1 is observed. While for shear reinforcement of 0.5%, the shear capacity reduced by 16.56% for change in a/d from 0.60 to 0.80 and 17.19% for range of a/d from 0.80 to 1. The percentage reduction in shear strength for variation in a/d ratio is summarized in Table 2.

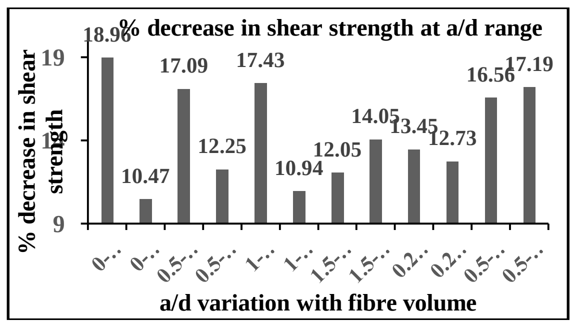

Figure.2. percentage decrease in shear strength

Table.1. Summary of test results on sfrc deep beam

Beam Series	No. of Beams	Beam Dimensions(mm) L x B x D	a/d	V_f %	A_{sv} %	Average V_{cr} (kN)	Average V_u (kN)	$v_u=V_u$/ bd (MPa)
A	3	600 x 140 x315	0.60	-	-	146.50	248.20	6.01
	3			0.5	-	159.80	256.00	6.20
	3			1	-	163.70	260.60	6.31
	3			1.5	-	173.20	267.20	6.47
	3			-	0.25	158.70	255.00	6.17
	3			-	0.50	180.30	279.50	6.76
B	3	600 x 140 x315	0.80	-	-	115.00	201.10	4.87
	3			0.5	-	132.25	212.20	5.14
	3			1	-	137.40	216.20	5.21
	3			1.5	-	151.70	235.00	5.69
	3			-	0.25	130.50	220.40	5.34
	3			-	0.50	142.00	233.00	5.64
C	3	600 x 140 x315	1	-	-	104.50	180.20	4.36
	3			0.5	-	116.20	186.50	4.51
	3			1	-	120.70	192.00	4.64
	3			1.5	-	130.50	202.00	4.89
	3			-	0.25	117.60	192.80	4.66
	3			-	0.50	124.50	197.00	4.67

From Table II and Figure 2, fiber percentage value of 1% shows minimum decrease in shear strength with increase in the range between 0.80 to 1.00 of shear span to depth ratio which is the vital factor affecting load carrying mechanism of deep beam. While the fiber fraction of 1.5% shows minimum decrement of shear strength for a/d ratio from 0.60 to 0.80. But the general trend is decrease in shear strength with increase in a/d ratio.

Table.2. Ultimate shear strength variation with respect to a/d ratio

Fiber Volume fraction (%)	(a/d) range	Asv (%)	% reduction in 'V_u'
0	0.60-0.80	-	18.96
	0.80-1.00	-	10.47
0.5	0.60-0.80	-	17.09
	0.80-1.00	-	12.25
1.00	0.60-0.80	-	17.43
	0.80-1.00	-	10.94
1.5	0.60-0.80	-	12.05
	0.80-1.00	-	14.05
-	0.60-0.80	0.25	13.45
	0.80-1.00		12.73
-	0.60-0.80	0.50	16.56
	0.80-1.00		17.19

IV. CONCLUSIONS

The experimental work carried on 54 deep beams defines the behavior of beams with varied volume fiber ratio, shear span to depth ratio and usefulness of steel fibers as an alternative to the shear reinforcement for the considered prime parameters.

a) The shear strength capacity of deep beams increases with increase in fiber volume fraction. At lower fibre volume content of 0.5%, the shear reinforcement shows more load carrying capacity.
b) Increase in shear span to depth ratio causes decrease in shear strength of deep beams. The optimum volume content that shows comparatively low decrement of shear strength with increase in shear span to depth ratio is 1% for 0.80< a/d < 1 and 1.5% for 0.60< a/d < 0.80.
c) The comparison between shear strength of steel fibre reinforced deep beams and plain deep beams with shear reinforcement reveals and supports the possibility of replacing shear reinforcement fully or partially with steel fibres.

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