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STEEL FIBERS AS REPLACEMENT OF WEB REINFORCEMENT FOR RCC DEEP BEAMS IN SHEAR

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ABSTRACT

Test data are presented on the shear strength of a series of reinforced cement concrete (RCC) deep beams with three steel fiber volume fractions (0, 1.0 and 1.25%), three shear span to-effective depth ratios (0.75, 1.0 and 1.25) and three combinations of web reinforcement. A total of 18 beams were tested to failure under two-point top loading. The test results indicate that the fibers have significant influence on the shear strength of a longitudinally reinforced concrete beams. Shear strength increases with increasing fiber volume and decreasing shear span to-effective depth ratio. Steel fibers can replace the conventional web reinforcement in RCC deep beams.

Keywords: Deep beams, shear span, steel fiber, volume fraction, web reinforcement,

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1. INTRODUCTION

Deep beams are recognized by relatively small values of span-to-depth ratio. As per codal-provisions given by Bureau of Indian Standards [1] 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. Reinforced concrete deep beams have very useful structural applications such as pile- caps, water tanks and tall buildings. Because of their proportion 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 [2-4].

It has been well established that the use of discrete steel fibers of short length and small diameter as reinforcement improves the strength and deformational characteristics of cement based matrices [5]. Most of the properties of fibrous concrete can be used to enhance the behaviour of concrete members reinforced with conventional bar reinforcement [6-8]. The use of steel fibers is particularly attractive if conventional stirrups can be eliminated, which reduces reinforcement congestion.

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An experimental programme was, therefore, conducted to study the effectiveness of steel fibers as web reinforcement in reinforced concrete deep beams. The parameters of study were the volume fraction of fibers, shear span -to- effective depth ratio and percentage of web reinforcement. The results of 18 simply supported beams tested in this programme are compared with the predicted values using conventional reinforced concrete analysis [2-3,9-10] The test results indicate that addition of steel fibers in RCC deep beams results in an increase in ultimate shear strength and better crack control. Steel fibers can also be used either to boost the shear capacity or to replace the web reinforcement in conventional RCC deep beams.

2. EXPERIMENTAL PROGRAMME

2.1 General

A total of 18 simply supported deep beams were tested. All beams were of rectangular cross section, 90mm wide and 260mm deep with 2 bars of 10 mm diameter as longitudinal reinforcement. The effective span to overall depth ratio was varied from 1.69 to 2.5,so as to achieve the desired shear span- to-effective depth ratio (a/d). The test specimens were divided into three series, namely, series A for a/d =0.75, series B for a/d =1.0 and series C for a/d =1.25. Each series consisted of six types of deep beams with different amount of web reinforcement and varying volume fraction of steel fibers. The details of the test beams are given in Figure 1 and Table 1.

Table 1. Details of test beams

Beam	L_e,mm	Le/D	a/d	s_v (mm)	ρ_v %	s_h (mm)	ρ_h %	v_f %
1A	440	1.69	0.75	-	-	-	-	-
2A	440	1.69	0.75	250	0.25	107.5	0.58	-
3A	440	1.69	0.75	-	-	-	-	1.0
4A	440	1.69	0.75	-	-	-	-	1.25
5A	440	1.69	0.75	125	0.5	107.5	0.58	-
6A	440	1.69	0.75	250	0.25	71.6	0.87	-
1B	600	2.3	1.0	-	-	-	-	-
2B	600	2.3	1.0	250	0.25	107.5	0.58	-
3B	600	2.3	1.0	-	-	-	-	1.0
4B	600	2.3	1.0	-	-	-	-	1.25
5B	600	2.3	1.0	125	0.5	107.5	0.58	-
6B	600	2.3	1.0	250	0.25	71.6	0.87	-
1C	650	2.5	1.25	-	-	-	-	-
2C	650	2.5	1.25	250	0.25	107.5	0.58	-
3C	650	2.5	1.25	-	-	-	-	1.0
4C	650	2.5	1.25	-	-	-	-	1.25
5C	650	2.5	1.25	125	0.5	107.5	0.58	-
6C	650	2.5	1.25	250	0.25	71.6	0.87	-

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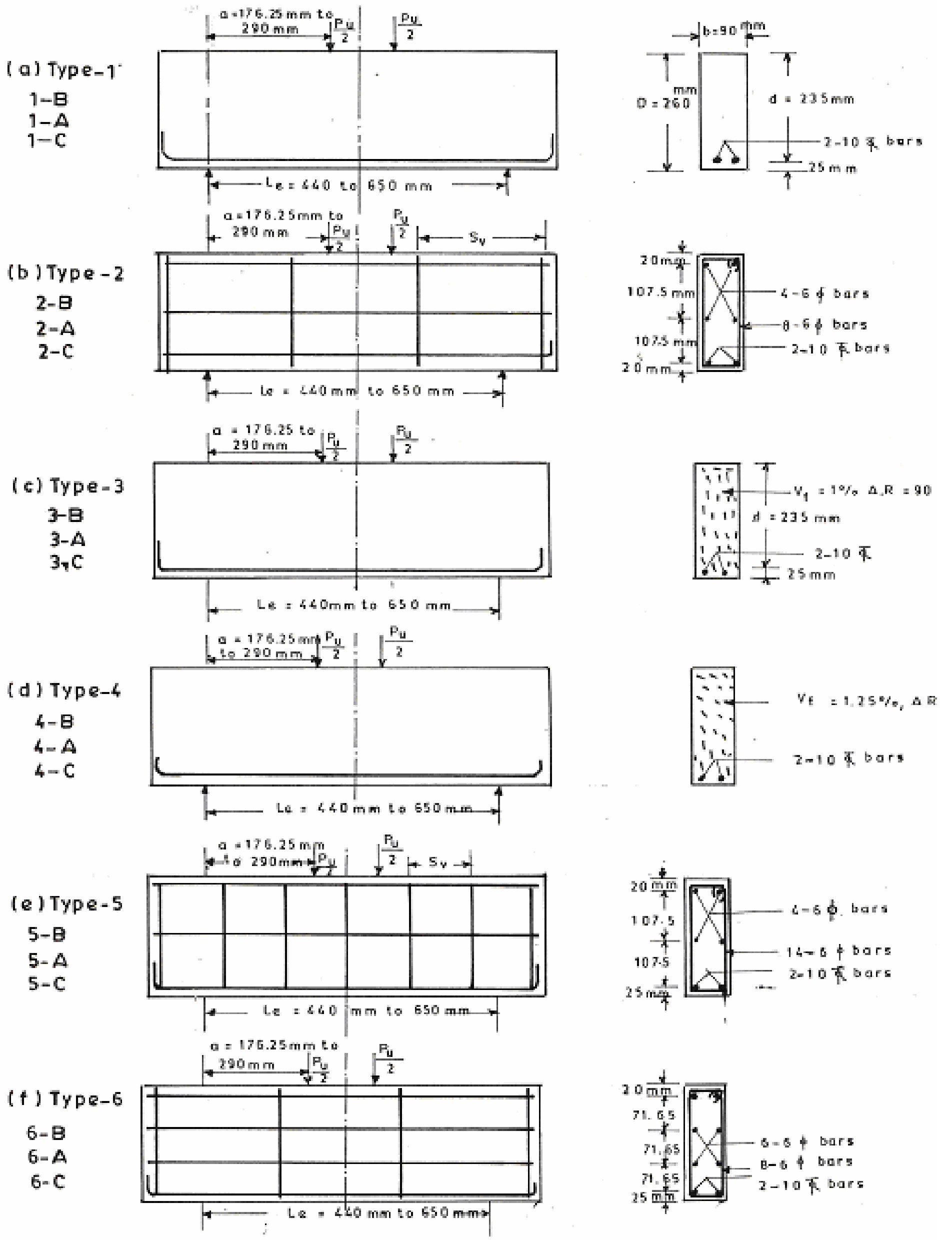

Figure 1. Reinforcement details of test beams

2.2 Material used and casting of test beams

The steel fibers used in the investigation were of diameter of 0.45mm and length of 40.5mm, straight in length having an aspect ratio of 90. Concrete mix M20 was prepared using ordinary Portland cement of 53 grade, river sand and crushed aggregates of 10mm max. size in proportions of 1:1.39:2.35 (by weight) with a water-cement ratio of 0.54.

During mixing balling-up of steel fibers was overcome by feeding the fibers into the mix in small quantities at a time. When the fibers were uniformly spread over the mix, the

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mixture was poured into the beam moulds and compacted on a vibrating table. Compaction was done in three layers until the mould was full. Control cubes of size 150mm and cylinders of 150mm diameter and length 300mm were also cast at the time of casting of the beams. The beams and control specimens were kept under room temperature for about 24 hours before demoulding and then cured for 28 days under wet gunny bags.

2.3 Testing of specimens

Both the surfaces of the beams were white washed to aid to the observations of crack development during testing. The beams were tested to failure under two-point top loading. The beams were simply supported on two adjustable rollers on the loading frame as shown in Figure 2 .The loading was applied through 500 KN hydraulic jack at a uniform rate and values for deflection at mid-span, first crack load and ultimate load were noted. The test results are shown in Table 2.

Table 2. Test results of beams and control specimens

Beam	**f_{cu} (N/mm^2)**	**f_t (N/mm^2)**	**P_{cr} (KN)**	**P_u (KN)**	**$2P_{u1}$ predicted by ACI Method (KN)**	**$2P_{u2}$ predicted by Kong, Robins & Sharp Method (KN)**
1A	28.9	2.83	83.0	158.0	151.88	149.82
2A	28.9	2.83	93.0	173.0	205.07	163.60
3A	32.1	3.54	113.0	181.0	156.28	176.43
4A	33.5	3.82	118.0	188.0	158.21	186.93
5A	28.9	2.83	113.0	183.0	211.40	163.60
6A	28.9	2.83	108.0	173.0	228.26	173.15
1B	28.9	2.83	83.0	143.0	133.92	130.21
2B	28.9	2.83	88.0	148.0	185.12	141.21
3B	32.1	3.54	98.0	168.0	138.23	154.00
4B	33.5	3.82	103.0	173.0	140.00	167.50
5B	28.9	2.83	98.0	169.0	192.96	150.25
6B	28.9	2.83	98.0	159.5	207.03	148.10
1C	28.9	2.83	66.0	123.0	123.67	113.50
2C	28.9	2.83	68.0	128.0	174.25	124.50
3C	32.1	3.54	98.0	156.6	128.00	134.50
4C	33.5	3.82	103.0	161.0	129.80	153.00
5C	28.9	2.83	83.0	145.25	182.20	135.40
6C	28.9	2.83	93.0	142.0	195.60	130.10

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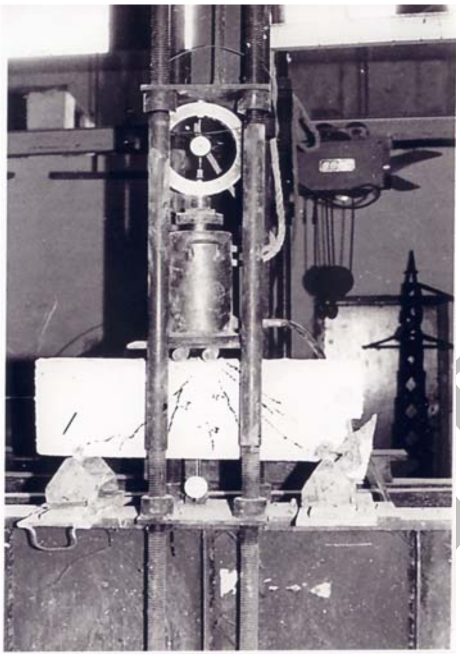

Figure 2. Test set- up

3. TEST RESULTS AND DISCUSSION

3.1 Behaviour of beams under load and failure modes

Typical load-deflection (at mid span) relationships are shown in Figure 3 for the beams series C with a/d ratio of 1.25. As the web reinforced increased, both the first crack and maximum applied load increased. For beams having volume fraction of fibers as 1.0%and 1.25% maximum load applied was more than for the beams containing web reinforcement. No cracking was observed in any beam up to about 50 percent of ultimate load. At about 52-60 percent of ultimate load a diagonal tension crack formed in beams without steel fiber. Whereas in beams with steel fibers first diagonal crack formed at about 58-65 percent of the ultimate load almost in the middle of the shear span. As the load was increased inclined cracks propagated towards the support and loading points. Further increase in load resulted in the propagation and widening of the existing cracks leading to shear failure. The tested beams are shown in Figure 4.

It is evident from Table 2 and Figure 5 that ultimate strength decreased with increasing a/d ratio in all types of beams. Decrease in shear span reduced the occurrence and extent of flexural cracking. For example, in beam series C, which had a/d ratio 1.25, flexural cracks formed first within the constant-moment region(near midspan), and later, diagonal cracks formed within the region of constant shear leading to failure. In case of beam series B (a/d = 1.0), both flexural and diagonal cracking occurred almost simultaneously, whereas for beam series A (a/d = 0.75), diagonal cracks lead to failure.

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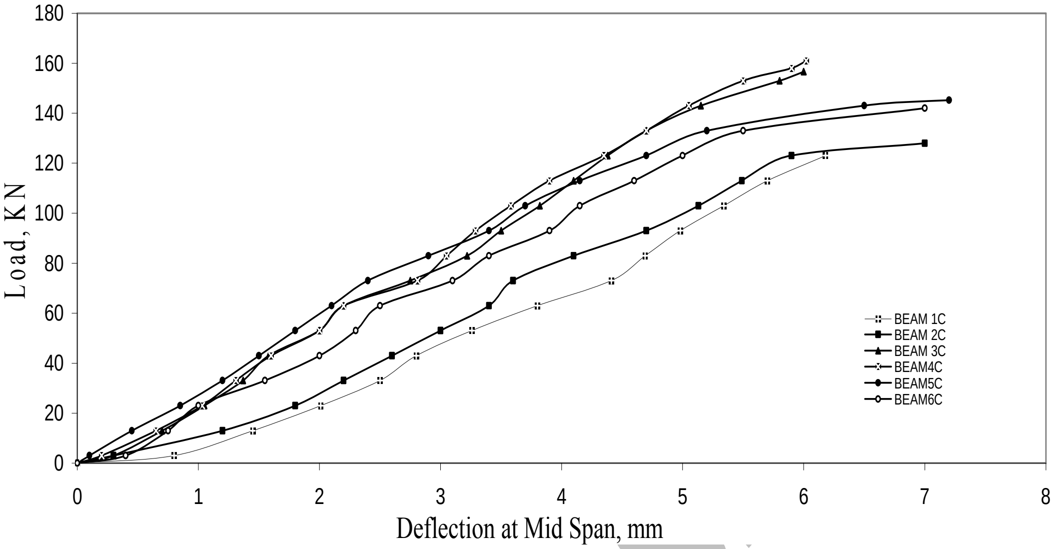

Figure 3. Typical load-deflection curves (a/d=1.25)

Figure 4. Cracking pattern and mode of failure for tested beams

3.2 Effect of volume fraction of steel fibers

Addition of steel fibers in the concrete mix significantly influenced the cracking behavior and ultimate strength of deep beams. For example beams of Type-1 of each series, which

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contained no fibers and without web reinforcement, exhibited a sudden formation of a long inclined crack. On the other hand, inclined cracks went through a slow process of widening and extension in beams of Type-3 and Type-4 with 1% and 1.25% of fiber content and without web reinforcement. The flexural and shear cracks were spaced more closely as the volume of fibers increased. This lower rate of crack propagation in fiber reinforced beams may be attributed to the restraint provided by the steel fibers that bridge the cracks, thus contributing to post cracking strength.

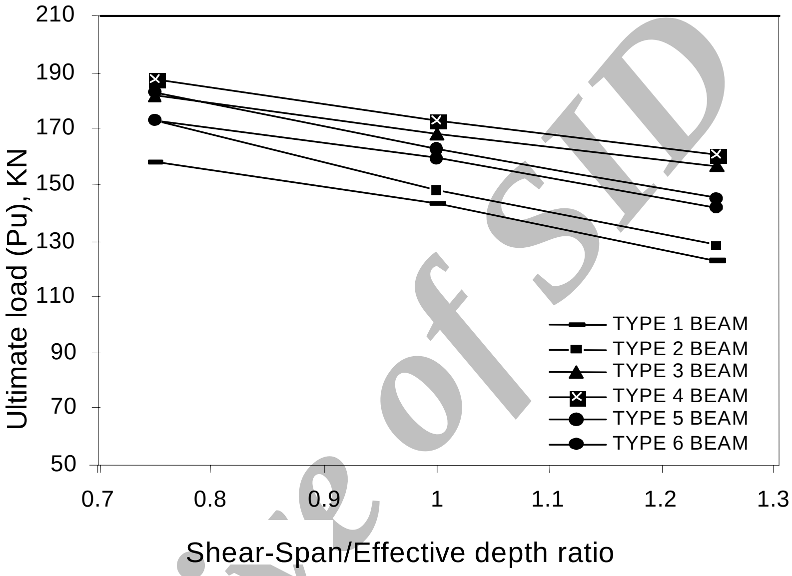

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Figure 5 .Ultimate load v/s shear -span to effective depth ratio

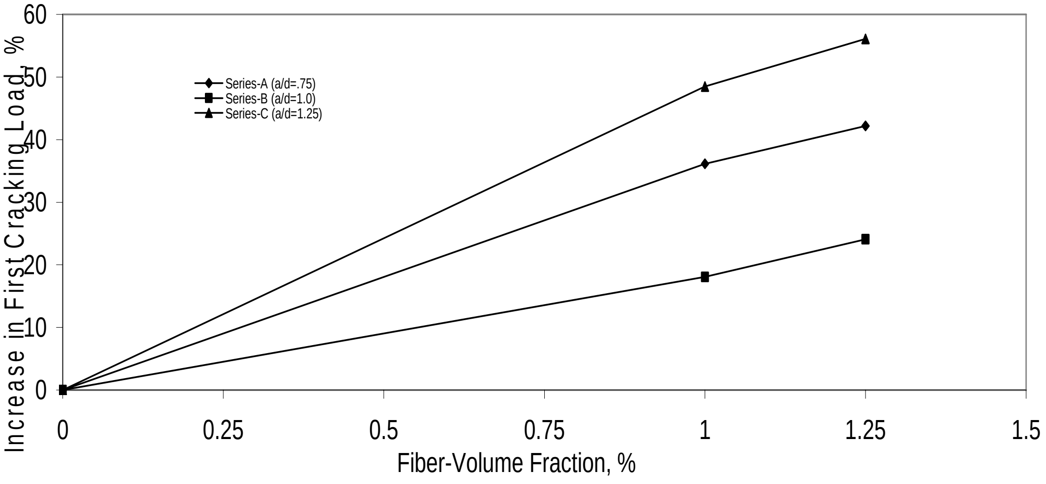

Figure 6 a. Influence of fiber volume fraction on increased ultimate load

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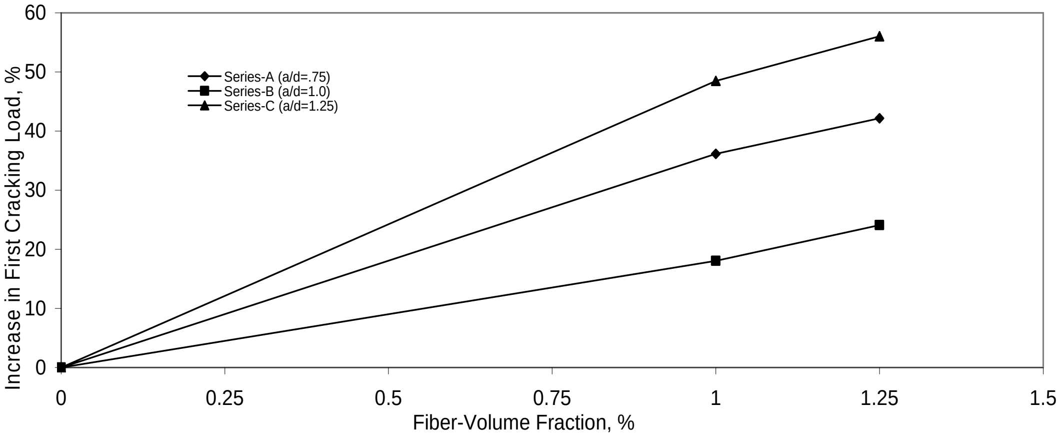

Figure 6 b. Influence of fiber volume fraction on increased first cracking load

Figure 6a and Figure 6b show the variation of first cracking and ultimate load of beams in shear with 0,1.0 and 1.25 percent volume fraction of fibers for three different a/d ratios of 0.75,1.0 and 1.25. In general an increase in the volume fraction of fibers leads to increased cracking strength due to delayed formation and subsequent propagation of flexural and inclined cracks. As observed from Table 2 for each series the beams reinforced with steel fibers carried maximum load at first crack and failure when compared with beams provided with web reinforcement. For example, increase in the first crack and ultimate load of beam 4A containing 1.25 percent of steel fibers over beam 1A was 42 percent and 19 percent respectively. Maximum increase of 56 percent in first cracking load for beam 4C was observed when compared with 1C. These results support the use of steel fibers as an alternative to conventional web reinforcement is deep beams.

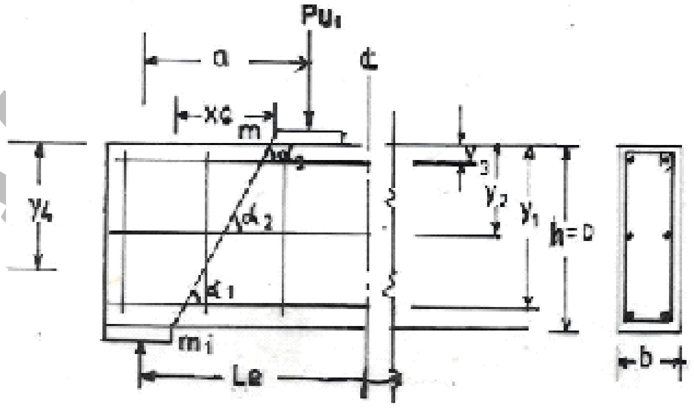

Figure 7. Notations in Kong, Robins and Sharp method

3.3 Prediction of ultimate shear strength

The development of a general simple formula to predict the shear strength of fiber reinforced

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RCC deep beams is critical to the successful application of fibers as shear reinforcement. From the test results reported here, it appears that the important parameters influencing ultimate shear strength are the tensile and flexural strengths of concrete, the shear-span to effective-depth ratio *a/d*, the reinforcement ratio *ρ*, and the beam depth.

Design equations for prediction of shear strength of RCC deep beams as proposed by ACI-318-1995 method [9] and Kong, Robins and Sharp [2,3] have been used here to predict the ultimate shear strength of the beams.

3.4 ACI –318-1995 Method

The shear strength at the critical section (at a distance a/2 from the support) is given below

$$P_{u1}=P_c + P_s \tag{1}$$

$$P_c = (3.5- 2.5\ M_u/V_u d)\ (1.9\sqrt{f_c'} + 2500\ \rho\ V_u d/M_u)\ bd \tag{2}$$

$$P_s = [(A_v/ 12\ s_v)\ (1+L_n/d)+(A_h /12\ s_h)\ (1-L_n/d)\ ]\ f_y.D \tag{3}$$

3.5 Kong, Robins and Sharp Method

The following expression has been suggested for prediction of shear strength of reinforced concrete deep beams for L_e/D ratio ranging from 1 to 3.

$$P_{u2}= C_1\,(1-0.35\ x_e / D)\ f_t\ .\ b\ .\ \overset{n}{\underset{i=1}{D}} + C_2\ \sum A_i\ .\ y_i / D\ .\ \sin^2 \alpha_i \tag{4}$$

Where C_1 = an empirical coefficient equal to 1.05 for normal weight concrete and 0.75 for light weight concrete.

C_2 = an empirical coefficient equal to 100 N/mm^2 for plain round bars and 225 N/mm^2 for deformed bars.

The predicted values of ultimate shear strength and observed shear strength are tabulated in Table 2. For the beams tested in the programme the ratio of predicted values to the experimental values of shear strength ranges from 1.01 to 1.10 using Kong, Robins and Sharp method and from 0.75 to 1.24 using ACI 318-1995 method. The comparison shows that the predicted values are in close agreement with the experimental values.

4. CONCLUSIONS

Based on the test results presented in this study the following conclusions can be drawn.

1. The inclusion of short steel fibers in concrete mix provides effective shear reinforcement in deep beams and provides better crack control and deformation characteristic of beams.
2. Both the first crack strength and ultimate strength in shear increase with the provision of web reinforcement. More significant increase was found for the fiber reinforced

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beams because of their increased resistance to propagation of cracks.

3. Shear strength increases with increasing fiber content and decreasing a/d ratio.
4. The theoretical prediction of ultimate shear strength on the basis of methods used in the study gives results close to the observed values in most of the beams tested.
5. Maximum increase of 56 percent in first cracking load for beam containing 1.25 percent of fibers was observed when compared with beam containing no web reinforcement. Also for all the beams tested in this programme maximum shear strength was attained in beams reinforced with steel fibers followed by beams containing web reinforcement. These results support the use of steel fibers as an alternative to conventional web reinforcement is deep beams.

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NOTATIONS

a = shear span measured from center of loading to center of support
A_h = area of horizontal web reinforcement with in a distance S_h
A_i = area of web bars which includes the main longitudinal reinforcement
A_{st} = area of main longitudinal reinforcement
A_v = area of vertical web reinforcement within a distance Sv

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b = width of beam
d = effective depth of beam
D = overall depth of beam
f_c' = cylinder compressive strength of concrete
f_t = split tensile strength of concrete
f_{cu} = cube compressive strength of concrete
f_y = yield strength of main longitudinal reinforcement.
h_a = Active height = h or L_e, whichever is less
L_e = effective span of beams as measured from center to center of support
L_n = clear span measured from face to face of the support
n = total number of web bars.
M_u= factored moment at the critical section
P_{cr} = first inclined cracking load
P_c = nominal shear strength provided by concrete when diagonal cracking results from combined shear and moment
P_s = nominal shear strength provided by web reinforcement
P_u = ultimate load applied to the beam at failure
P_{u1}, P_{u2} = predicted values of shear strength
s_h = spacing of horizontal web reinforcement
s_v = spacing of vertical web reinforcement
v_f = volume fraction of steel fibers
V_u = nominal shear strength of concrete as per ACI-318-1995
x_e = clear shear span measured from inside edge of block at support to outside edge of bearing block at loading point
y_i = depth of a bar measured from top of the beam
α_i = angle between mm_l and horizontal
ρ = ratio of main longitudinal reinforcement, As/b.d
ρ_h = ratio of horizontal web reinforcement, $A_h/b.S_h$
ρ_v = ratio of vertical web reinforcement, $A_v/b.S_v$

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