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A Detailed Investigation of Crack and Failure Study of Steel Fibre Reinforced Concrete Beams

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Abstract

This paper describes the experimental investigation behavior of crack and modes of failure of twelve beams consisting plain and fibre reinforced. The micro cracking characteristics, modes of failure, cracking loads, crack widths were investigated thoroughly. Based on these findings we have developed an equation to calculate the first cracking load and ultimate load. It relates with area of elliptical section as well as concrete strain along the load path. From the course of investigation we have observed that in deep beams, elliptical shape concrete strain distribution was observed along the load path.

Keywords: Steel fibre reinforced concrete, modes of failure, cracking loads, crack widths, Ulimate laod.

Introduction

The Indian Standard Code (IS 456-2000) specifies that a beam shall be deemed to be a deep beam when the ratio of effective span to overall depth, L/D is less than 2.0 for a simply supported beam and 2.5 for a continuous beam [1-3]. Many studies were carried out to understand the strength and behavior of deep beams. The nonlinear distribution of stress, lateral buckling and other pertinent effects, the stress distribution in deep beams is very different from the simple bending theory of beams. This is because the presence of vertical stresses was created due to the support reaction and normal stresses was obtained due to applied loads and shearing deformations [4,5].

Generally, cracks occurred within the concrete it lost their stiffness. In order to overcome these problems researchers have investigated to incorporate steel fibers to control crack characteristics [6,7]. Fibre reinforced concrete is a composite material in which steel or other fibres are introduced in the concrete so as to improve the ductility and other properties of concrete. The main objective of using steel fibres in concrete has always been to alter and improve the properties of the brittle matrix. The, SFRC has remarkable improvements in tensile strength, crack resistance, crack control, durability, fatigue resistance, impact resistance, abrasion resistance etc [8].

Therefore the main objective of the work was to analyse the effects of various parameters such as crack charecteristics , ultimate load , maximum crack width, Diagonal cracking load and Deflection at yield load and mode of failure. In order to predict the failure mode we do not have a general equation. The present study is an experimental attempt to overcome this anomaly within the range of experimentation reported here and to enable the designer to incorporate changes in the design.

Experimntal Nvestigation

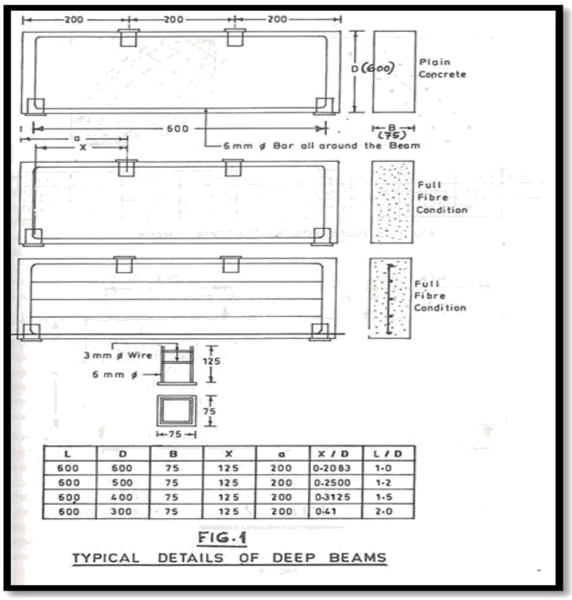
Test specimens

Twelve steel fiber reinforced concrete deep beams, simply supported on a span of 600 mm were tested under two-point loading. The width of the web in all the beams was kept 75 mm. The beams were divided into three series.

Each series consisted of four beams with span to depth ratio of 1.0, 1.2, 1.5 and 2.0 respectively.

The first series of beams (P series) was of plain cement concrete, the second series (F series) was concrete with steel fibers, and the third series (FSH series) was fibrous concrete width horizontal web reinforcement.

In order to prevent premature bond and anchorage failure at the support region, the main bar of each beam was anchored to steel plates at the ends with a nut-and-washer arrangement. The support and loading points of deep beams were adequately reinforced to prevent failure due to local crushing of concrete. Details of the test specimens and the arrangement of reinforcement and support details are given in Fig.1.



L	D	B	X	a	X / D	L / D
600	600	75	125	200	0·2083	1·0
600	500	75	125	200	0·2500	1·2
600	400	75	125	200	0·3125	1·5
600	300	75	125	200	0·41	2·0

FIG.1
TYPICAL DETAILS OF DEEP BEAMS

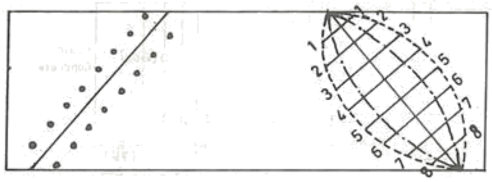
Figure 1: Typical details of Deep Beams

The steel fibers used in the steel plates at the ends with a nut-and-washer arrangement. The support and loading points of deep beams were adequately reinforced to prevent failure due to local crushed basalt were used as fine and coarse aggregates, respectively. A concrete mix of 1:2:4 by weight with a water/cement ratio of 0.55 was used for all the beams. Three cubes and three cylinders were made from each mix.

Testing

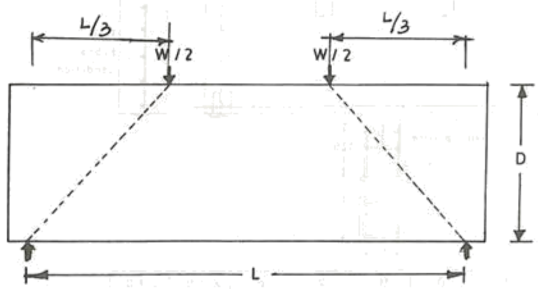
All the beams were tested on a specially provided bending bench of a compression testing machine under two-point loading until they no longer sustained any further loading.

Mid-span deflection was recorded with the help of 10 KN load throughout the testing. Crack propagation was traced in pencil and the end points were marked to correspond with the loading stage at which they appeared or progressed further. Concrete strain was also measure along the load path using Demac gauges until the complete failure of the beam was observed.



Section	Pts	1-1	2-2	3-3	4-4	5-5	6-6	7-7	8-8
Strain	2 2 KN	0.5×10^{-4}	1.0×10^{-4}	0.75×10^{-4}	1.65×10^{-4}	0.2×10^{-4}	0.6×10^{-4}	0.25×10^{-4}	0.35×10^{-4}
At	2 5KN	14.55×10^{-4}	12.35×10^{-4}	14.75×10^{-4}	14.85×10^{-4}	16.85×10^{-4}	13.0×10^{-4}	11.6×10^{-4}	15.5×10^{-4}

FIG 2 STRAINS ACROSS DIAGONAL CRACK



BEAM LOADING

FIG. 2

Figure 2: Strains Across Diagonal crack

Results and Discussion

Crack Patterns and Modes of Failures

The crack patterns of all the beams were tested in this present investigation. It was observed that all beams exhibited flexural and diagonal tension cracks. Flexural cracks developed at the region of maximum moment. All the flexural cracks were observed in the lower half depth of the beams. The results revealed that the most of the beams (except for the P series), the width of the flexural cracks was less than 0.1 mm at failure. These cracks were found to have little effect either on the mode of failure or on the ultimate load.

Two types diagonal tension cracks observed in the test specimens. I) first type the diagonal tension cracks originated from the inner edge of the reaction bearing plate to the outer edge of the loading plate. These types of cracks were decreased gradually in the presence of fibre reinforced concrete beams. These cracks triggered the failure of the beam or else they brought the beam to its eventual collapse.

ii) Second type of diagonal cracks opened at a distance of D/4 from the soffit with load increments. The rate of progress of these cracks was gradually decreased as the diagonal cracks which is originated in the vicinity of inner edge of the loading bearing plate. Web reinforcement which is crossed the diagonal cracks was helpful in arresting their propagation. The diagonal cracks so formed were nearly parallel to each other with a “strut like” appearance between the loading points.

The complete failure of the beams was observed to occur in one of the following ways:

1. All plain concrete beams collapsed by flexure with a flexural crack near to the mid span. This type of failure was observed in beams of the P series.
2. The diagonal tension failure observed in all the beams of the F and FSH series. It was observed by splitting of the beam in the direction of a line inner edge of the reaction bearing plate at the support to the outer edge of the loading plate.
3. The shear failure was predominantly observed in beams of the FSH series. It was indicated by crushing of the “strut like” portion of the concrete along the plane of the diagonal cracks and was followed by crushing in the web.

Diagonal Cracking and Ultimate Loads

For P and F series of beams, the load which causes the formation of the flexural crack. The first diagonal crack is considered to be the ultimate load. However, in the cause of deep beams after the development of diagonal cracks, they can still support additional load before failure, depending on the growth of diagonal cracks. Based on these findings the primary cause of failure was diagonal cracking load and the subsequent reserve of strength beyond the load due to the presence of longitudinal and web reinforcement.

Proposed Formula For The Determination of The Ultimate Shear Strength of SFRC Deep Beams.

Based on these test results, we have proposed the following formula for the determination of the ultimate shear strength of SFRC deep beams. Elliptical strain distribution along the load path was adopted. The formula was developed on the basis of splitting of an elliptical section whose major axis lies on a line joining the load point and support. The main advantage of the proposed formula is very simple and straight forward and also there is no need to assuming values of constants as is usually done in various other know formulae.

The ultimate shear capacity is given by

$$Vu_2 = \frac{1.5 f_t bd}{\sqrt{1+0.75\,(a/d)^2}} + \frac{f_y}{2\sqrt{1+(a/d)^2}} \sum A(y/d+0.4)\sin\alpha \longrightarrow (1)$$

Where f_y is the yield stress of the reinforcement.

Table -1 shows the ultimate loads for all the beams (except for the P series) were computed by using the above equation. From this investigation, it was observed that the proposed formula and observed test results are in good agreement.

Table 1: Measured ad Computed Diagonal Cracking Loads and Ultimate Loads

Beam Mark	**Diagonal cracking load**		**Ultimate loads**		**Wu /Wu (KN)**	**Mode of failure**
	Measured Wct (KN)	**Computed Wc (KN)**	**Measured Wut (KN)**	**computed Wc (KN)**		
P 60	190	182.4	283	274.0	1.03	S
P 50	130	118.8	240	227.0	1.05	F-S
P 40	80	74.7	225	199.0	1.13	F-S
P 30	55	52.9	125	130.4	0.958	F-S
F 60	210	198.1	450	410.0	1.12	S
F 50	200	183.8	360	344.0	1.05	S
F 40	125	109.6	330	296.0	1.15	F-S
F 30	80	76.3	250	224.0	1.11	F-S
FSH60	240	216.8	495	530.0	1.07	S
FSH50	180	173.7	385	418.0	0.92	S
FSH40	160	151.3	360	352.0	1.02	F-S
FSH30	125	127.5	270	256.0	1.05	F-S

Maximum Crack Widths

Maximum crack widths and concrete strains, crack patterns and their behavior were observed. The maximum crack widths were recorded with surface concrete strains, for all beams and their variation in relation to L/D, percentage of fibres, web reinforcement and load were studied. In deep beams, a large part of the load is transferred to the supports directly through compression struts formed directly between the load and the support point. This kind of load transfer mechanism commonly leads to shear, in the form of splitting failure. The tensile stresses in concrete in the direction normal to ultimate crack are much higher than the tensile strength of concrete, which justifies the formation of the cracks observed in the experiment. Some studies have also been carried out on the shear behavior of steel fibre reinforced concrete deep beams, proving the efficiency of steel fibres as shear reinforcement. It was observed in the present investigation that steel fibres act like small diameter bars, closely spaced and randomly distributed, causing an increased number of hair cracks, which are preferable to a few wider cracks. Furthermore, crushing and spalling of the concrete at load and support regions, due to bearing stresses or anchorage failure at end supports was also reduced due to the overall rigidity provided by steel fibres in concrete material.

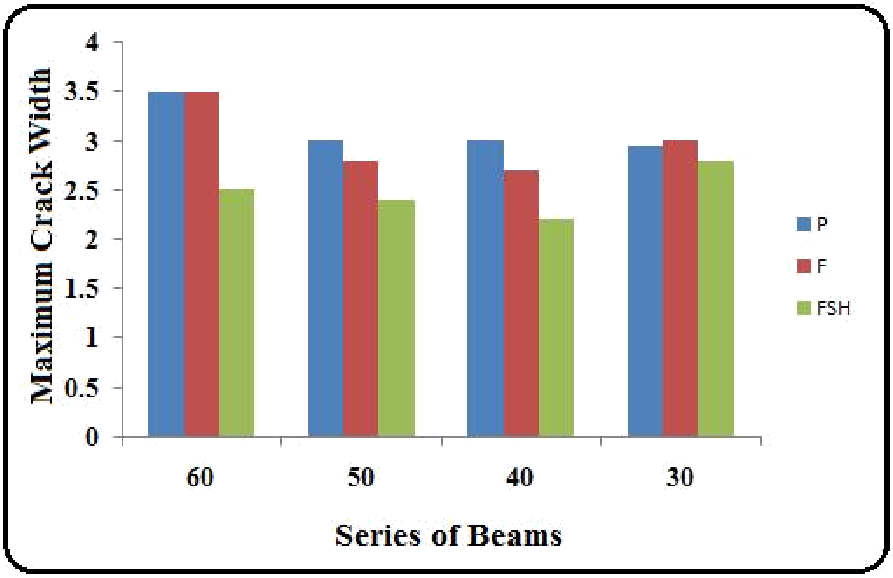


Figure 3: Maximum Crack widths

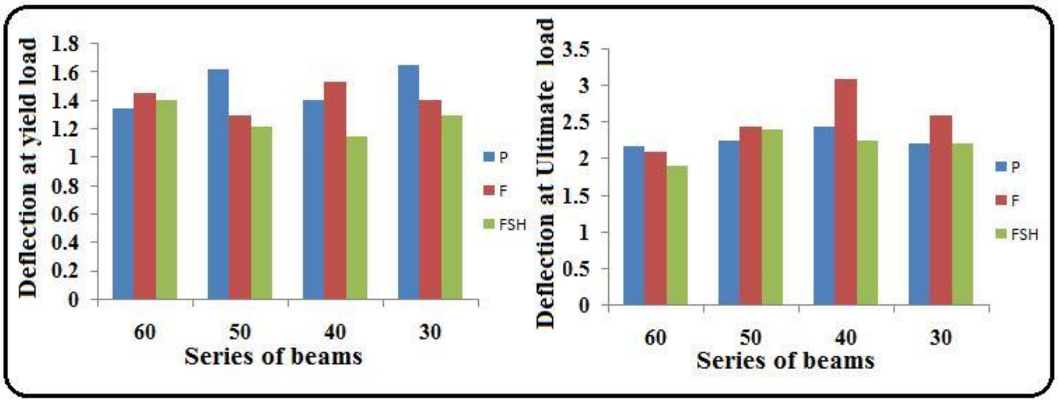


Figure 4: Deflection at yield load

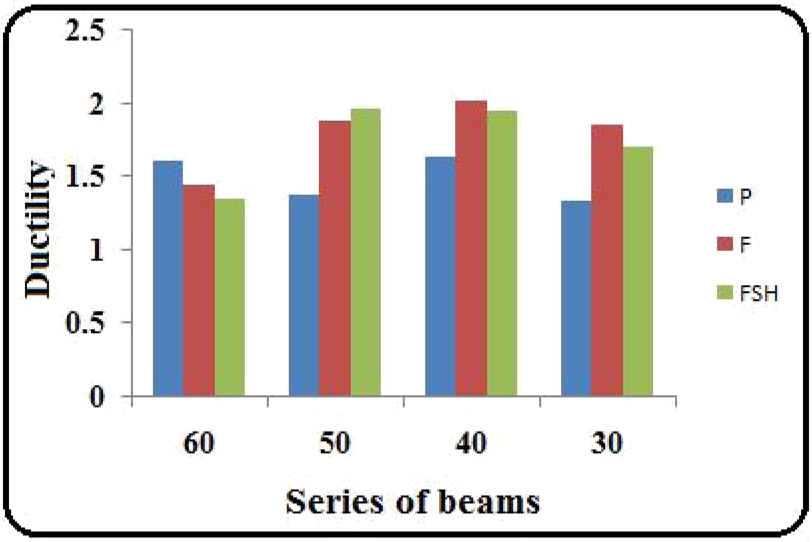


Figure 5: Ductility

Conclusions

Based on the test results, the following conclusions are made.

1. A large reduction in crack width is observed when fibre percentage varies from 0 to 1%.
2. The effect of main tensile steel reinforcement on crack width restriction is small and is of the order of 20 to 30%.
3. The large area under the load-deflection curves especially for fibre reinforced concrete beam indicates more ductile behavior.
4. The influence of the fibre reinforcement on crack width is to restrict its width.
5. The maximum crack width increases with increasing L/D ratio and X/D ratio.

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