INVESTIGATIONS ON THE BEHAVIOR OF REINFORCED BEAMS WITH STEEL FIBRES UNDER FLEXURAL LOADING

SHUKLA Mukesh[1]

Abstract

An experimental investigation of the behavior of concrete beams reinforced with conventional steel bars and steel fibres and subjected to flexural loading is presented. An experimental program consisting of tests on steel fibre reinforced concrete (SFRC) beams with conventional reinforcement and reinforced concrete(RC) beams was conducted under flexural loading. SFRC beams include two types of beams containing steel fibres in two different volume fractions i.e. one percent and two percent. The cross sectional dimensions and span of beams were fixed same for all types of beams. The dimensions of the beams were 120mm x 240mm x1900mm.Tests on conventionally reinforced concrete beam specimens, containing steel fibres in different proportions, have been conducted to establish load –deflection curves and strain profiles. The various parameters, such as, first crack load, service load, ultimate load and stiffness characteristics of beams with and without steel fibres have been carried out and a quantitative comparison was made on significant stages of loading. It was observed that SFRC beams showed enhanced properties compared to that of RC beams. A modified procedure has been suggested to calculate the ultimate strength of the conventionally reinforced beams with steel fibres. The ultimate loads obtained in the experimental investigation were also compared with the theoretical loads for all types of beams.

Keywords : SFRC beams, RC beams, Steel fibres, Flexural loading

1. Introduction

According to ACI Committee Report 544 [1], the influence of steel fibres in the flexural strength of concrete is much greater than the direct tensile and compressive strengths.

Swami et al [2-4] have reported results of experimental investigations on the influence of steel fibres on the deformational behavior and ultimate strength of reinforced concrete beams. These investigations showed that while ultimate strength of SFRC had increased only marginally, the fibres arrested advancing cracks and increased the post cracking stiffness up to failure, which resulted in narrowed cracks and substantially less deformation.

[1] Shukla M., Associate professor, Bundelkhand Institute of Engineering & Technology, Jhansi-India . Email: mshuklabiet@rediffmail.com

A limited number of tests carried out by Hennant [5] showed that the increased deflection of light weight concrete beams due to the reduced modulus of the material could be significantly reduced by the addition of steel fibres in the concrete mix. Narayanan & Darwish [6] reported results of the tests conducted on 12 reinforced concrete deep beams including 11 containing steel fibres, provided to act as web reinforcement. These tests have shown that the inclusion of steel fibres in concrete deep beams resulted in enhanced stiffness and increased spall resistance at all stages of loading up to failure, and reduced crack widths.

2. Experimental program

2.1 Test specimens

Test specimens consist of 3 RC beams, 3 SFRC beams containing one percent steel fibres and 3 SFRC containing two percent steel fibres by volume of concrete. The cross sectional dimensions and span of beams were fixed same for all types of beams. The dimensions of the beams were 120mm x 240mm x1900mm. All beams were reinforced using three 10 mmϕ tor steel longitudinal bars at bottom face as main reinforcement. Two mild steel bars of 6mm diameter were used as hanger bar at top and also 6mmϕ mild steel closed stirrups were used @ 150 mm c/c spacing. Two types of SFRC beams specimens were cast using straight steel round fibres (.66 mmϕ) in two volume fractions of one percent and two percent with the described reinforcements. The ultimate tensile strength of steel fibres was 584.59 MPa. The aspect ratio of all fibres was kept constant at 75. The reinforced concrete beams were designated as RC1 – RC3 and the two types of steel fibre reinforced beams were designated as 1SFRC1-1SFRC3 and 2SFRC1-2SFRC3 respectively. Details of beam specimens are given in Fig.1

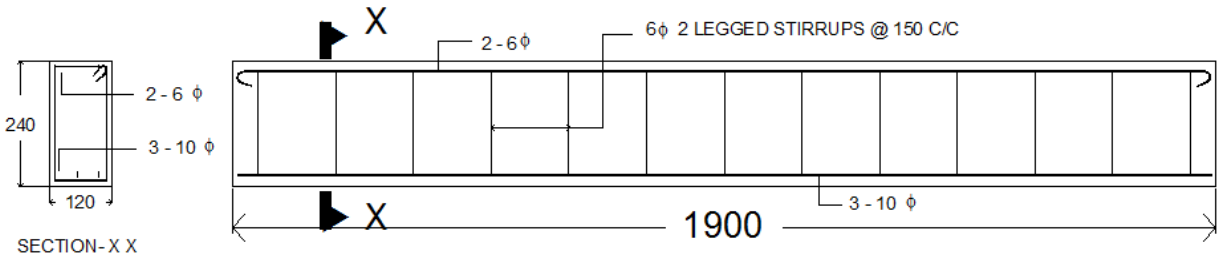


Fig1.Geometry and reinforcement details of beams *all dimensions in mm.*

2.2 Preparation of test specimens

For the preparation of specimens the concrete mix proportion was adopted was 1:1.6:2.42 by weight (cement: sand: coarse aggregate) with water cement ratio of 0.5. The concrete mix was designed to achieve strength of 20 MPa. 43 grade ordinary portland cement, natural river sand and stone aggregate were used in preparing the specimens. The maximum size of coarse aggregate was limited to 10 mm. Materials were weighed on balances and mixed in electrically operated tilting type mixer. First of all , coarse aggregates, sand, steel fibres (in case of fibrous mixes) and cement were mixed in dry form and after obtaining uniform mixing of these materials, required amount of water with suitable dose of admixture was added to mix. In the case of fibrous concrete uniform dispersion of the fibres in the mixes were tried to be maintained. In one batch 25 Kg cement, 40.0 Kg sand and 60.5 Kg coarse aggregate along with 12.5 litre of water were used. A suitable dose of admixture named CONFLO was added in mixes to improve the workability of mixes. The dose of admixture varied from 0.1% by volume of weight of cement for plain concrete mixes to as high as 0.5% volume of weight of cement for mixes containing two percent volume fraction of steel fibres. In one-day time 0.6-0.75 m3 of concrete was made in 10-12 batches. With this concrete eight beam specimens and control specimens; 10-12 cubes and 4-5 beams were cast. Steel fibres were cut from binding wires manually. For casting of beams wooden moulds were used. Beams were filled in 4-5 layers, each of approximately 50mm deep, ramming heavily and vibrating the specimens on vibrating table till slurry appears at surface of the specimen. In this way concrete was very well compacted. The side forms of moulds were stripped after 24 hours and then these beams were cured for 28 days in curing pond specially constructed for the investigation.

2.3 Loading arrangement

All beam specimens were tested under a loading frame of 500 kN capacity. Beams were simply supported over a span of 1700 mm. The load was applied through 250 kN capacity hydraulic jack connected to mechanically operated high-pressure oil pump. The load was distributed as two line loads kept apart symmetrical to centerline of beam on the top face. For line loads two 20mm ϕ steel rods were welded to a 20mm thick plate at 100mm c/c distance. A load cell of 100 kN capacity was placed between test frame and load distributor placed on the test specimen. Gap between test frame and plate was filled by spacers. Loading arrangement for beam specimens is shown in Fig.2.

2.4 Instrumentation

The beam specimens were instrumented for the measurement of maximum deflection at center of test beam. These measurements were made using a linear variable differential transformer (LVDT). A dial gauge of high precision was also placed near to LVDT to put a cross check on measurements.

In some cases, beam specimens were instrumented to measure longitudinal strains along the depth of beams. These measurements were made using demec gauge over a gauge length of 200mm.

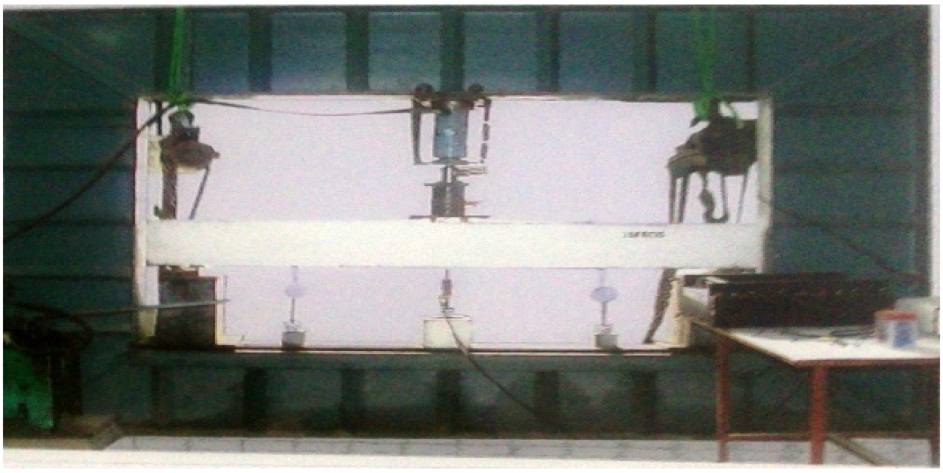


Plate 1. Testing of Beam Specimen

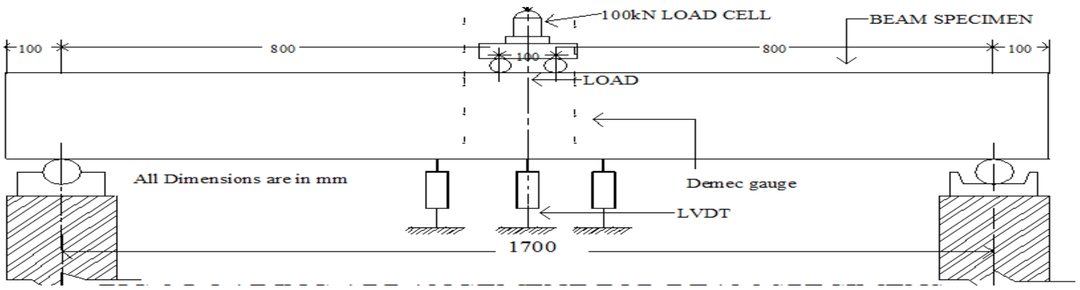


Fig2. Loading arrangement for beam specimen

2.5 Testing of beam specimens

The complete experimental program consists of testing of three types of beams under flexural loading . In all tests, type of specimens, loading arrangement, and instrumentation were same as shown in fig.2 & plate1. To investigate the behavior of beams under the flexural loading, flexural loading tests were conducted on a total of nine beam specimens.

3. Test results and evaluation

3.1 Failure mode

Crack patterns for all types of beams were observed to be identical. These are shown in plate 2 However failure modes of SFRC beams were different from that of RC beams regarding rate of crack propagation, widths of cracks, and number of cracks and behavior of concrete. SFRC beams showed more stiffness than that of RC beams. Cracks were wider and more in number in the case of RC beams compared to that of SFRC beams. After reaching to ultimate stage, spalling of concrete was not observed in the case of SFRC beams and concrete was in tact even after reaching to ultimate stage. This stage was assumed to reach when there was no increase in load and load –deflection curve became horizontal. Flexural cracks were straighter in SFRC beams compared to RC beams. The SFRC beams showed an increase of about 25 to 40% in first crack load over RC beams. Also, ultimate strength of SFRC beams with two percent fibre was found maximum in all types of beams and it showed an average increase of about 32% over that of RC beams. SFRC beams with one percent fibres also, showed an average increase of 15% in ultimate strength over RC beams. However, the load- deflection behavior was almost same for all types of beams. Before cracking, deflection was almost directly proportional to applied load. After first crack, though stiffness of beams reduced, the load deflection behavior remained linear till yield load. At yield flexural cracks developed at bottom face get widened but no crack was observed in compression zone i.e. at top face of beam. Consequently, the moment at nearby sections also crossed the first cracking moment resulting in development of more cracks on either side of central zone of beam. Beyond yield point, the deflection increased at a faster rate. As a result that the initial flexural cracks propagated upwards near to top face of beam in case of RC beams and up to a lesser depth from top in case of SFRC beams. Continuous loading causes excessive deflections thereby resulting in more and more widening of flexural cracks. In the case of RC beams, cracking of compression concrete was observed resulting in spalling of concrete pieces. However, this type of spalling of compression concrete was not observed in case of SFRC beams and concrete was found in tact even at ultimate stage where load became constant.

3.2 Load –deflection Curves and Strain Values

Typical load-deflection curves for RC beam and two types of SFRC beams are shown in Figs 3(a), 3(b) and 3(c). Strain values for full depth of beams were measured using demec gauge. These values over the depth of beams could be measured up to yield and little beyond the yield load. Thereafter, only maximum strains at outermost points could be measured because at high level, it was difficult to sustain the load for a time period essential to make observations. Strain values at loads corresponding to some significant stages in load deflection curves are presented in Table 1.1.

3.3 Load Capacity of Beam

The four major stages are observed on load deflection curves for all the beams. The load corresponding to stage 1, 2, 3, 4, on load deflection curves are designated as first cracking load (P_{cr}), Yield point load (P_y), maximum load (P_m), and ultimate load (P_u) respectively. These loads obtained from tests on all beam specimens are summarized in Tab. 1.

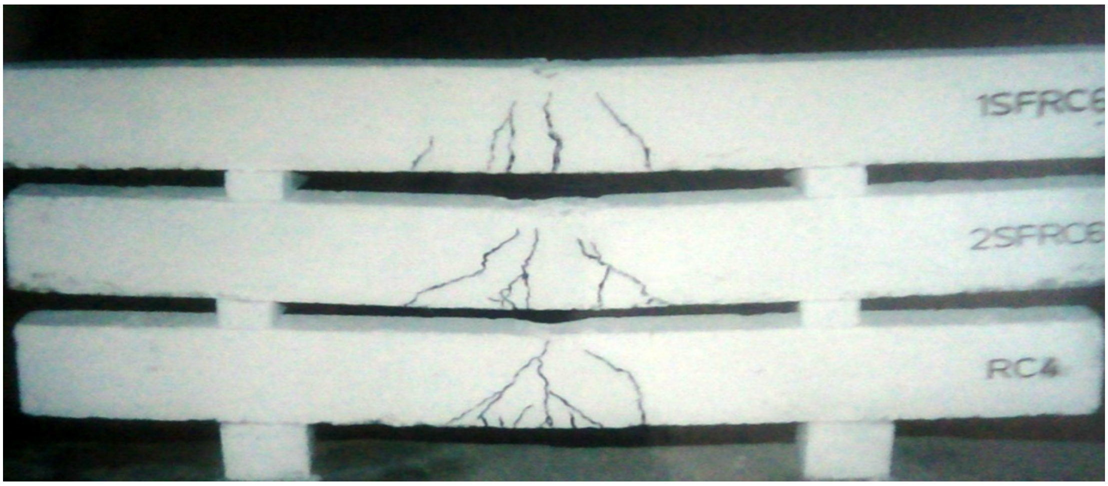


Plate 2. Failure mode of beam specimens

It is observed from tabulated values that in all tests type at all stages load capacities of SFRC beams are more than that of RC beams. It is also observed that SFRC beams containing two percent steel fibres showed much higher load capacities than that of RC beams and SFRC beams with one percent volume fractions of steel fibres. First crack load for RC beams ranged between 14.3 kN and 15.61 kN. The values of first crack load for SFRC beams with one percent fibres ranged between 16.94 kN and 19.07 kN. These values (P_{cr}) for SFRC beams with two percent fibres were obtained between 20.51 kN and 23.19 kN. The ultimate strength of RC beams was between 64.10 kN and 67.69 kN. SFRC beams with one percent fibres showed ultimate strength between 72.69 kN and 78.48 kN. The ultimate strength of SFRC beams with two percent fibres was obtained between 81.13 kN and 87.41 kN.

3.4 First crack load

The first crack load (P_{cr} in Tab.2) was determined from the dominant kink in the load deflection curve at initial stages of loading. All the SFRC beams showed significant increase in first crack load over reinforced concrete beams. This increase was about twenty five percent in case of beams containing one percent steel fibres. In the case of beams with two percent steel fibres, the increase in the first crack load was about forty percent.

3.5 Service load

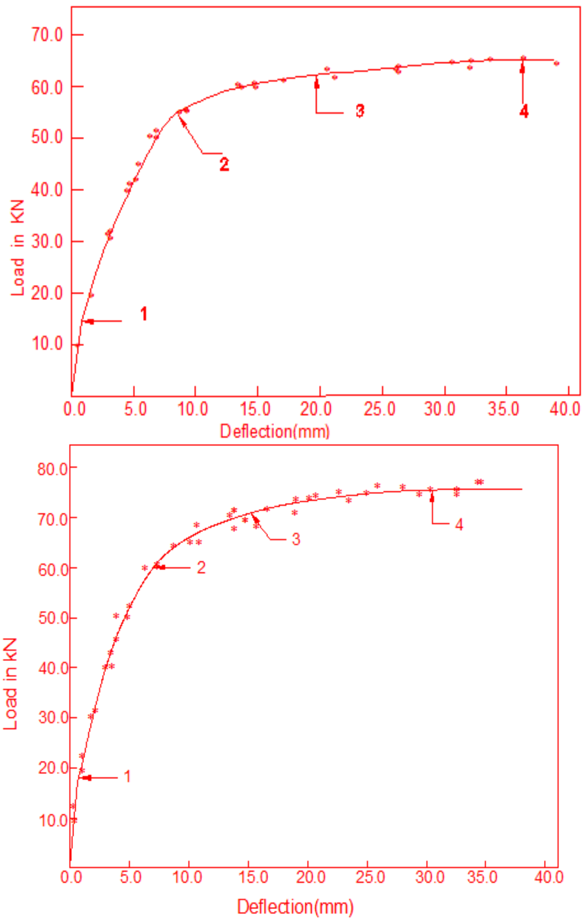
The performance of structures at the service loads is an important design consideration. An important benefit accruing to RC beams due to addition of fibres is the enhancement in their service load capacity. Considering control of deflection limit as per clause 23.2 of IS 456: 2000 [7] service load is reckoned as the applied load corresponding to a deflection of (1/ 350) of span. The average increase in service load when compared to that of RC beams ranged from 23% in the case of one percent SFRC beams to 39 % in the case of two percent SFRC beams.

3.6 Stiffness characteristics

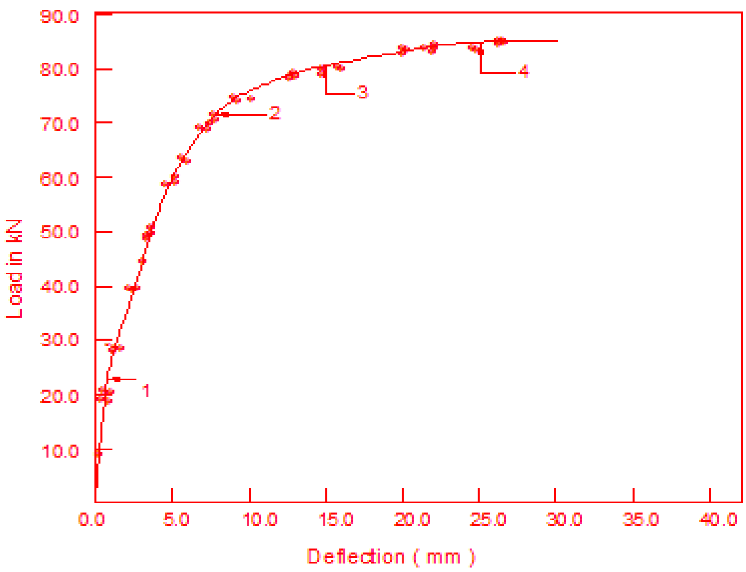
Fig.5 illustrates the typical load-deflection characteristics of all types of beams. Comparison shows clearly that the deflection of SFRC beams at all load stages is less than that of RC beams. Reduction in mid span deflection at ultimate stage was around 16.4 percent in the case of beams with one percent fibres where as it was around 28 percent in case of beams with two percent fibres. From these observations it is evident that SFRC beams showed better stiffness characteristics than RC beams.

3.7 Ultimate load

The SFRC beams with one percent volume fraction of fibres, showed an average increase of 15 % in ultimate load (P_u) when compared to RC beams while this increase was around 29% in case of SFRC beams with two percent fibres.



(a) RC beams (b) One percent SFRC



(c) Two percent SFRC

Fig.3. Load-deflection curves

Theoretical ultimate load for RC beams was calculated as per IS 456: 2000 [7]. The average cube strength of control specimens were used to determine the ultimate load of these beams and the theoretical load was compared with average ultimate load of RC beams tested under static loading.

The ultimate strength of SFRC beams were calculated as per the procedure suggested by Craig et al.[8] and Henager and Doherty[9] with modifications. The compressive stress distribution in concrete is adopted as per IS: 456 and contribution of fibre stress is taken constant below neutral axis (Fig.5). Maximum compressive strain in concrete is taken 0.0035 for fibrous concrete with one percent and 0.004 for fibrous concrete in case of fibrous concrete with two percent fibres [1].

Tab 1. Maximum strains at mid sections of beams at various stages of loading

Stage	RC1	1SFRC1	2SFRC1
At Yield point			
Load	53.5 kN	60.0 kN	71.3 kN
ε_c	0.00127	0.0016	0.0018
ε_t	0.00441	0.0046	0.0044
At point beyond Yield point			
Load	60.0 kN	68.0 kN	80.0 kN
ε_c	0.0028	0.0035	0.0038
ε_t	0.0095	0.010	0.0107
At Ultimate stage			
Load			
ε_c	64.2 kN	72.7 kN	84.3 kN
ε_t	0.0038	0.005	0.006
	0.015	0.0144	0.0144

ε_c - Compressive strain in concrete at top most fibre of beam

ε_t - Tensile strain in concrete at tension steel level

From the stress block shown in Fig.5, the total compressive force(C) is given by,

$$C = 0.36\, \sigma ck\, b\, xu \qquad (1.1)$$

Where σ_{ck} is the mean cube compressive strength of fibrous concrete and x_u is the depth of neutral axis. Compressive strength of concrete is assumed to be 0.67 times the cube strength of concrete and a partial safety factor for material equal to 1.5 is applied to the strength of fibrous concrete resulting in the design strength of $0.446\sigma_{ck}$. Depth of rectangular portion and parabolic portion of stress block are equal to ($3\, x_u$ /7) and ($4x_u$ /7)

. Hence, total compressive force is given by Equation 1.1 Centroid of the compressive force lie at a distance of 0.416 x_u from extreme compression fibre.

Total tensile force (T) is given by,

$$T = 0.87\ \sigma y\ Ast + \sigma t\ b\ (D - xu) \qquad (1.2)$$

Where, σ_y is the yield strength of reinforcing bar, A_{st} is the area of tension reinforcement and σ_t is the tensile stress in fibrous concrete and it is calculated as per ACI 544-4R [1] and given by,

$$\sigma t = 0.00772\ (l\ /df)\ \rho f\ Fbe \quad (MPa) \qquad (1.3)$$

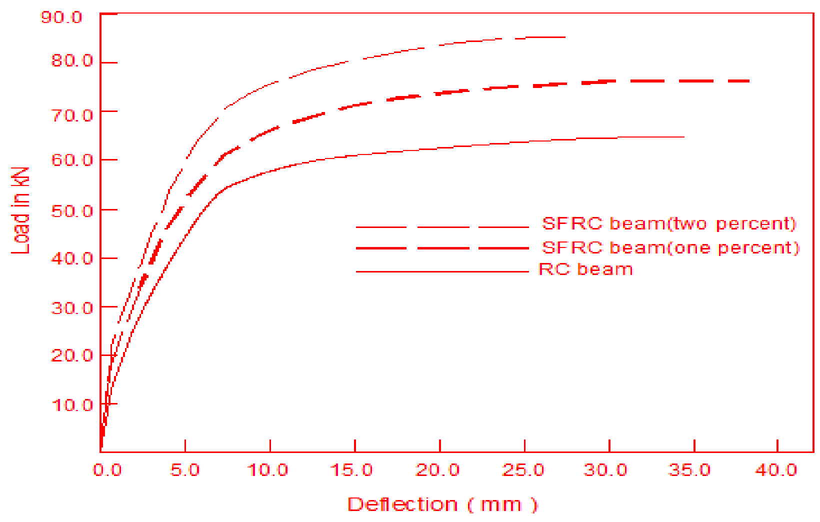


Fig.4 Comparison of load-deflection curves

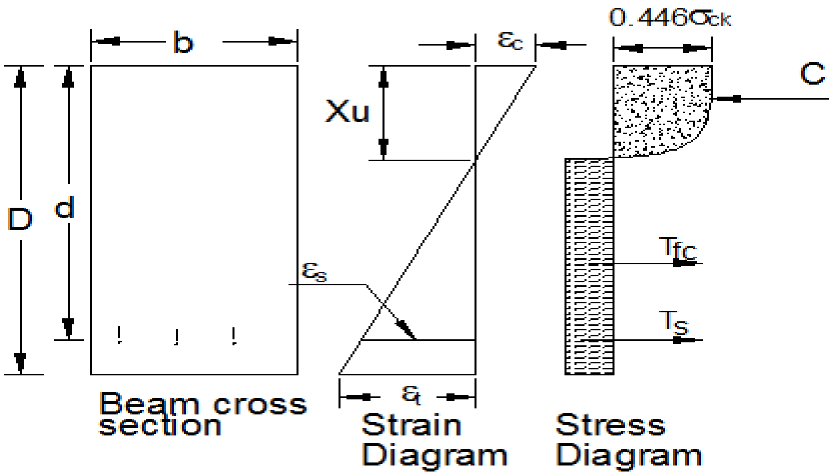


Fig.5 Analysis of SFRC beam

Where (l /d_f), is the aspect ratio of steel fibres, ρ_f is the percent by volume of steel fibres and F_{be} is the bond efficiency of the fibre, which varies from 1.0 to 1.2. In the present analysis, 1.2 was found appropriate and this correlated with test data.

Equating the total compressive force and total tensile force, the value of neutral axis can be obtained. The moment of resistance of beam is computed from:

$$MR = 0.87\ \sigma y\ Ast\ (d - 0.416\ xu) + \sigma t\ b\ (D - xu)[(D + xu)/2 - 0.416\ xu] \quad (1.4)$$

Using the above equation theoretical ultimate loads were calculated for SFRC beams. Ultimate loads are calculated by using mean compressive strength of control specimens and hence that may be compared with average of ultimate loads of beam specimens as obtained under monotonic loading. Comparison showed good agreement between calculated and actual loads. The ratios of calculated loads to actual loads in test beams ranged from0 .95 to 0.97. Hence, method can be used in assessing the flexural strength of beams reinforced with both fibres and bars. Table 1.2 shows theoretical ultimate load along with actual ultimate loads for all beams tested under static loading.

Tab. 2.Comparison of Experimental and Theoretical Loads

Sr no	Beam ID	P_{cr} (kN)	P_{sl} (kN)	P_u (kN)	δ_{cr} (mm)	δ_u (mm)	P_u(average) (kN)	P_u(theoretical) (kN)
1	RC1	14.30	38.36	64.21	1.25	37.40		
2	RC2	15.21	41.89	66.88	1.17	36.31	61.16	68.21
3	RC3	13.84	41.50	64.39	1.10	35.00		
1	1SFRC1	16.94	47.25	72.69	1.00	32.83		
2	1SFRC2	19.07	53.51	75.36	0.96	28.33	74.04	74.38
3	1SFRC3	17.84	48.60	74.07	1.12	29.78		
1	2SFRC1	22.30	57.97	84.28	1.00	26.50		
2	2SFRC2	20.52	56.18	81.13	1.05	21.17	83.26	80.55
3	2SFRC3	21.40	57.10	84.36	1.14	26.79		

4. Conclusions

An experimental study on the behavior of RC and SFRC beams under the static and loading is presented in this paper. The study consisted of tests on RC and two types of SFRC beam specimens under two point flexural loading.

Load-deflection curves under static loading are presented. Flexural behavior of RC beams and SFRC beams was investigated and a quantitative comparison was made on significant stages of loading.

Load-deflection curves under static loading are presented. Flexural behavior of RC beams and SFRC beams was investigated and a quantitative comparison was made on significant stages of loading. Following conclusions can be drawn from the study:

i. All the SFRC beams showed significant increase in first crack load over RC beams. This increase was about forty percent in the case of beams with two percent fibres and about twenty-five percent in the case of beams with one percent steel fibres.

ii. The performance of structures at service load is an important design consideration. The average increase in service load was twenty three percent and thirty nine percent in case of one percent SFRC and two percent SFRC beams respectively.

iii. From the observations it is evident that SFRC beams show better stiffness characteristics than RC beams.

iv. The SFRC beams with one percent volume fraction of fibres show an average increase of 15 % in ultimate load (Pu) when compared to RC beams while this increase is around 29% in case of SFRC beams with two percent volume fraction of fibres.

v. The ultimate strength of SFRC beams is theoretically calculated. Theoretical results compares well to the experimental results.

References

[1] ACI Committee Report 544: *Design consideration for steel fiber reinforced concrete*. ACI Struct. Journ. Sep.-Oct. 1988, pp. 563-580.

[2] Swamy, R.N., and Al-Noori, K.A. *Flexural behaviour of fibre concrete with conventional steel reinforcement.* Rilem Symposium on Fibre Reinforced Cement and Concrete. 1975 , pp.187-196.

[3] Swamy, R.N., Al-Taau, S.A., and Ali, S.A.R. *Steel fibers for controlling cracking and deflection*. Concrete Int: Design and Construction, Vol.1, No. 8, Aug. 1979, pp.41-49.

[4] Swamy, R.N., and Al-Taau, S.A..*Deformation and ultimate strength in flexural of reinforced concrete beams made with steel fibre concrete.* ACI Journal, Vol. 78, No.5, Sept.-Oct. 1981, pp. 395-405.

[5] Hennant, D.J.. *Steel fibres and light-weight beams.* Concrete, Vol. 6, No.8 Aug. 1972, pp. 39-40.

[6] Narayanan, R., and Darwish, I.Y.S.. *Fiber concrete deep beams in shear.* ACI Structural Journal, V.85, March-April 1988, pp. 141-149.

[7] IS:456. Code *of practice for plain and reinforced concrete*. Bureau of Indian Standards, 2000, New Delhi.

[8] Craig, R.J., Decker, J., Dombrowski, L., Laurencelle, R., and Federovich, J. *Inelastic behaviour of reinforced* fibrous *concrete*. Journal of Structural Engineering, ASCE, Vol.113, April 1987, pp.802-817.

[9] Henager, C.H. and Doherty, T.J.. *Analysis of reinforced fibrous concrete beams.* Journal of Structura Engineering, ASCE, Vol.102, Jan. 1976, pp.177-18.