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Ultimate Moment of Resistance of Steel Fiber Reinforced Self-compacting Concrete Beams

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ABSTRACT

Self-compacting concrete (SCC) has been accepted as a quality product and is widely used. A large number of studies are available with respect to several parameters, namely, flexural strength, load-deflection behavior, toughness, ductility, crack control, effects of beam dimensions, concrete filling sequence, flexural toughness parameters, etc., of fiber reinforced concrete. A suitable method is needed for estimating the ultimate flexural strength of steel fiber reinforced SCC (SFRSCC) beams. An experimental program was designed, and the test data have been used for the analytical study. Available analytical methods have been used, and their predictions are reported. An analytical method is also proposed to determine the ultimate moment of resistance of SFRSCC beams. A sectional analysis has been developed based on force and moment equilibrium equations. An iterative procedure involving updating of strain is employed. The predicted ultimate moment of resistance has been compared with the test data of 48 fiber reinforced SCC beams.

Key words: *Analysis, Concrete, Flexural strength, Moment of resistance, Self-compacting concrete.*

1. INTRODUCTION

The development of self-compacting concrete (SCC) marks an important milestone in improving the product quality and efficiency of the building industry. Steel fiber reinforced SCC (SFRSCC) combines the benefits of SCC in the fresh state and shows an improved performance in the hardened state compared with conventional concrete due to the addition of the fibers.

SCC was introduced in Japan in the late 1980's to overcome the congestion of steel reinforcement in case of heavily reinforced structures namely, seismic resistant structures. Since then several attempts have been made to study the properties of SCC.

Addition of short discrete randomly oriented steel fibers improves many of the engineering properties of conventional concrete. Fibers bridge cracks and retard their propagation and also decreases the width of cracks thereby improving the tensile strength or the post-cracking behavior. The presence of fibers in conventional concrete decreases the workability. To overcome this, steel fibers were incorporated in SCC leading to the development of SFRSCC.

In the present work, an experimental and analytical study is presented to determine the ultimate moment of resistance of SFRSCC beams.

2. LITERATURE REVIEW

Balaz and Kovacs [1] reported flexural tests on SFRSCC beams using different fiber content, fiber configuration, and shear reinforcements. Ganesan *et al.* [2] added steel fibers to high-performance concrete and reported that addition of 1% volume fraction of fibers, the first crack load increased by 25% and ultimate load by 15%, respectively. Balazs *et al.* [3] reported the flexural characteristics of SFR self-compacting beams Suji *et al.* [4] conducted experiments with fibrillated polypropylene fibers, with fiber volume ranging from 0.1 to 0.3%. The author concluded that there was 18.6-34.39% increase in the ultimate load carrying capacity of the beams containing fibers in comparison with the conventional concrete beams.

3. EXPERIMENTAL WORK

Cements confirming to IS standards are used. Locally available river sand, free from silt and organic matter was used. Locally available crushed granite aggregates passing through 12.5 mm and retaining on 4.75 mm was

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used, whose specific gravity was 2.66. Class F fly ash was used as cement replacement material for SCC mixes whose specific gravity was 2.4. Potable water free from injurious salts was used for both mixing and curing. Super plasticizer, Glenium B-233 was used for cement dispersion and viscosity modify admixtures, Glenium stream-2 was used for changing viscosity and resisting segregation. Steel crimped fibers of 30 mm length, aspect ratio 60, width of 2.5 mm was used, whose tensile strength varied between 400 and 600 MPa.

The beam dimensions were fixed as 2000 mm × 125 mm × 250 mm. The effective span of the beam was 1700 mm. Volume of fiber was varied between 0.32% and 2.22% as specified by ACI 318. Steel rods of diameter 8, 10, 12, and 16 mm were used as main reinforcement, whereas 8 mm diameter rods were used as stirrups, whose yield strength of reinforcement was 569 MPa. The results of the fresh property test of the mix have been shown in Table 1. The test data of the investigation is given in Table 2. Figure 1 shows the test setup of Steel fibre reinforced self compacting concrete beams under two point loading. Figure 2 Shows the load deflection curve of the deflected beams. In addition, test data of reference [1-6,8] were used in the analysis.

4. METHODS OF ANALYSIS

4.1. Suji et al. Method [4]

$$M_{uth} = (\sigma_u b(D - k_1 D) + A_s f_y) \times (d - 0.475 k_1 D)$$

$$k_1 = \frac{\sigma_u \times b \times (D - k_1 D) + A_s f_y}{0.8075 f_c' \times b \times D}$$

$$f_{ult} = \sigma_u = 1.34 f_t + (0.0016 + 0.84 \eta V_f) \tau_d (L/d)$$

$$f_t = \frac{f_r}{1.416}$$

$$f_r = 0.4 \left(f_{ck}\right)^{2/3}$$

Where,

M_{uth} = Theoretical moment of resistance, A_s = Area of steel, f_y = Yield strength of fibers, f_c' = Cylinder compressive strength, b = Beam width, h = Depth of beam, σ_u = Ultimate strength of fiber reinforced concrete, τ_d = Bond strength of matrix, V_f = Volume fraction of fibers, (L/d) = Aspect ratio of fibers, f_t = Tensile strength of fibers.

4.2. Azeldin and Thomas, Method [5]

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) + \sigma_t b \left(h - \frac{a}{\beta_1}\right)\left(\frac{h}{2} + \frac{a}{2\beta_1} - \frac{a}{2}\right)$$

$$a = \frac{\frac{A_s f_y}{b} + \sigma_t h}{0.85 f_c' + \frac{\sigma_t}{\beta_1}}$$

$$\sigma_t = 1.12 F_{be} \left(\frac{1}{d_f}\right) \rho_f$$

Where,

A_s = Area of steel, f_y = Yield strength of fibers, b = Beam width, h = Depth of beam, β = between 0.65 and 0.85, ρ_f = Volume fraction.

4.3. Proposed Method

This method is used to determine the ultimate moment SFRSCC beams, whose moment capacity is unknown. The ultimate moment is determined by summing up various moments as shown below,

$$M_u = M_c + M_t^1 + M_t^2 + M_t^3$$

Where,

$$M_c = \frac{2}{3} A \frac{\xi^3}{1 - \xi} h$$

$$M_t^1 = \frac{2}{3} B \alpha (1 - \xi)^2 h$$

$$M_t^2 = \frac{2}{3} C \beta (1 - \xi)^2 h$$

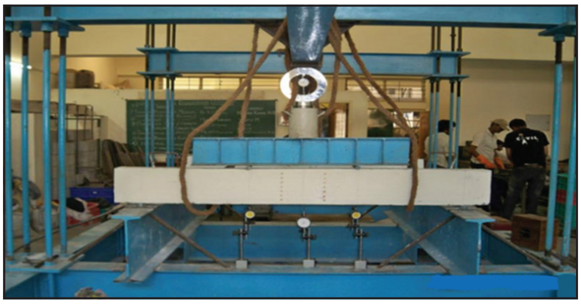

Figure 1: Test setup.

Table 1: Results of fresh properties [7].

Slump flow		V-funnel		Orimet
T50 (s)	Dia (mm)	T1 (s)	T5 (s)	T (s)
7.95	600	30.6	36.4	33.4
6.80	615	30.1	35.2	33.2
6.50	618	29.5	34.4	32.8

Table 2: Details of the tested beams [7].

Beam	Steel ratio (%)	V_f (%)	Pcr kN	Δcr mm	Pu kN	Δu mm
SCC 1	0.98	0.0	22	1.62	94	222.56
SCC 2	1.77	0.0	22	1.20	162	18.82
SCC 3	2.51	0.0	20	0.76	216	14.01
SFRSCC 4	0.98	0.5	22	1.02	108	29.85
SFRSCC 5	1.77	0.5	22	0.99	162	19.90
SFRSCC 6	2.51	0.5	20	0.78	224	17.13
SFRSCC 7	0.98	1.0	20	0.64	100	21.63
SFRSCC 8	1.77	1.0	20	1.12	158	17.72
SFRSCC 9	2.51	1.0	22	1.00	222	13.93

SFRSCC=Steel fiber reinforced self-compacting concrete

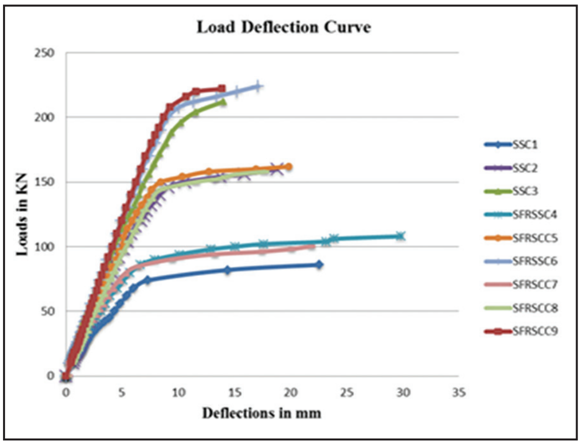

Figure 2: Load-deflection curve.

$$M_t^3 = \frac{1}{2}D(1-\beta)(1-\xi)^2 h$$

The terms A, B, C, and D are given below

$$A = \frac{1}{2}K_0\varepsilon_{t2}\zeta h^2$$

$$B = \frac{1}{2}(K_0 - K_1)\alpha\varepsilon_{t2}\zeta h^2$$

$$C = \frac{1}{2}K_1\beta^2\varepsilon_{t2}\zeta h^2$$

$$D = K_1\beta(1-\beta)\varepsilon_{t2}\zeta h^2$$

The value of K_1 when assumed as 32,000, the results were close to the required average and coefficient of variation. This assumption is only applicable to SFR concrete. In case of polypropylene fiber reinforced SCC (PFRSCC), the value of K_1 is assumed as 6600.

5. RESULTS AND COMPARISON

- The ratio of the theoretical to the experimental ultimate moment of resistance of the tested beams by Suji *et al*. method [4] was computed, and the average ratio is 1.48 and coefficient of variation (CV) is 0.2
- The ratio of the theoretical to the experimental ultimate moment of resistance of the tested beams by Azeldin and Thomas method [5] was computed, and the average ratio is 1.08 and CV is 0.11
- The ratio of the theoretical to the experimental ultimate moment of resistance of the SFRSCC beams by proposed method was computed, and the average ratio is 1.01 and CV is 0.07
- The ratio of the theoretical to the experimental ultimate moment of resistance of the beams (PFRCCC) by proposed method was computed, and the average ratio is 1.00 and CV is 0.056.

6. SUMMARY AND CONCLUSIONS

- An analytical study has been carried out to determine the ultimate moment of resistance of SFRSCC and PFRSCC beams
- An experimental data of 48 beams from four different investigations were used for the analytical study
- The analytical method has been developed based on equilibrium conditions. In general, the proposed method follows on similar lines of Balazs and Kovacs approach, but a value of K_2 of 32000 and 6600 for SFR beams and polypropylene fiber reinforced beams has been proposed. The ratio of computed to experimental moment of resistance on an average gives 1.01 and a CV of 7%, for SFRSCC, whereas for polypropylene fiber reinforced beams the values are 1.00% and 5.6%, respectively.
- The results show that the proposed method is able to determine satisfactorily the ultimate moment of resistance of SFRSCC and PFRSCC beams when compared to the available methods.

7. ACKNOWLEDGMENT

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***Bibliographical Sketch**

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