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Non-Linear Analysis of Steel Fiber Reinforced Pre-stressed Concrete T-beam

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***Abstract*— This paper presents an assessment of the flexural behavior of five prestressed high strength concrete beams containing steel fibers investigated using three-dimensional nonlinear finite elemental analysis. The main parameters varied in the tests were: fiber volume fractions (0%, 1.0% and 2.0%), fiber location (full depth and partial depth over full length). A three-dimensional nonlinear finite element analysis was conducted using ANSYS 5.5 general purpose finite element software to study the flexural behavior of both fully and partially prestressed fiber reinforced concrete beams. Influence of fibers on the concrete failure surface and stress–strain response of high strength concrete and the nonlinear stress–strain curves of prestressing wire and deformed bar were considered in the present analysis. In the finite element model, tension stiffening and bond slip between concrete and reinforcement (fibers, prestressing wire, and conventional reinforcing steel bar) have also been considered explicitly. A comparison of results from analysis on all 5 specimens confirm that, inclusion of fibers over a partial depth in the tensile side of the prestressed flexural structural members was economical and led to considerable cost saving without sacrificing on the desired performance.**

Keywords*— SFRPC, prestressed concrete, steel fiber, flexural strength.

INTRODUCTION

High-strength concrete is preferred in prestressed concrete members, as the material offers high resistance in compression. In the anchorage zone the bearing stresses being higher, high strength concrete is invariably preferred to minimize the costs. High strength concrete is less liable to shrinkage cracks, has a higher modulus of elasticity and a reduced creep strain, resulting in smaller losses in the applied initial prestress. High strength together with the desired ductility may be achieved by introducing small discrete fibers into the concrete matrix.

Investigations have been conducted to assess the suitability of the use of steel fiber reinforcements together with normal concrete containing conventional reinforcement to improve the structural behavior. The main objective of most of these studies have been the estimation of ultimate strength and the behavior of beams having steel fibers along with the conventional reinforcement over the entire loading[1].

Advances in the material technology have pointed out the addition of steel fibers in concrete to improve the main characteristics of concrete, such as, stiffness, toughness, and ductility. Some compression tests using normal strength concrete with fiber reinforced specimens show that the addition of fibers may cause a decrease in compressive strength. However, a considerable amount of increase in the tensile strength of the fiber reinforced specimens is observed in split cylinder tests [2].Torsional behavior of fiber reinforced prestressed concrete have also been studied [3–5].

II. MODEL DETAILS AND TEST VARIABLRS

In this study, a total of five SFRPSC beam specimens were manufactured and tested as summarized in Table 1. Specimens were named according to the fiber volume fraction (F0 or F1). As shown in Fig. 1a, the specimens had a T-shaped cross-section, and were 300 mm in height and 100 mm in web width. For all specimens, eight deformed bars with a diameter of 13 mm (D13) were placed in the concrete flange, and two deformed bars with a diameter of 22 mm (D22) were placed on the tension side. In addition to the tension reinforcement, one strands with a diameter of 12.7 mm were placed in the P1 specimens. Fig. 1b, D10 stirrups with two legs were placed on the right side of the specimens at spacings of 130 mm. Length of beam 2200mm and their effective prestressing forces (Pe) on the strands were about 129kN. The concrete compressive strength 65MPa. Fe415 steel reinforcements were used for the reinforcing bars, and 1860 MPa low-relaxation strands were used for the prestressing strands.

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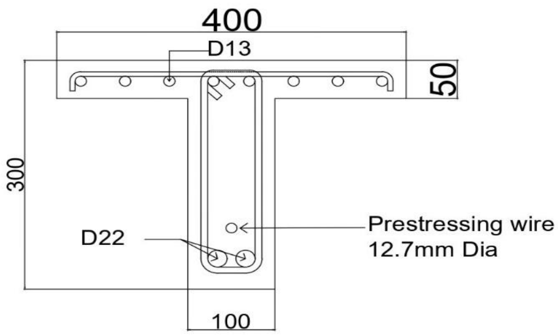
Figure1. a. Section properties and specimen details.



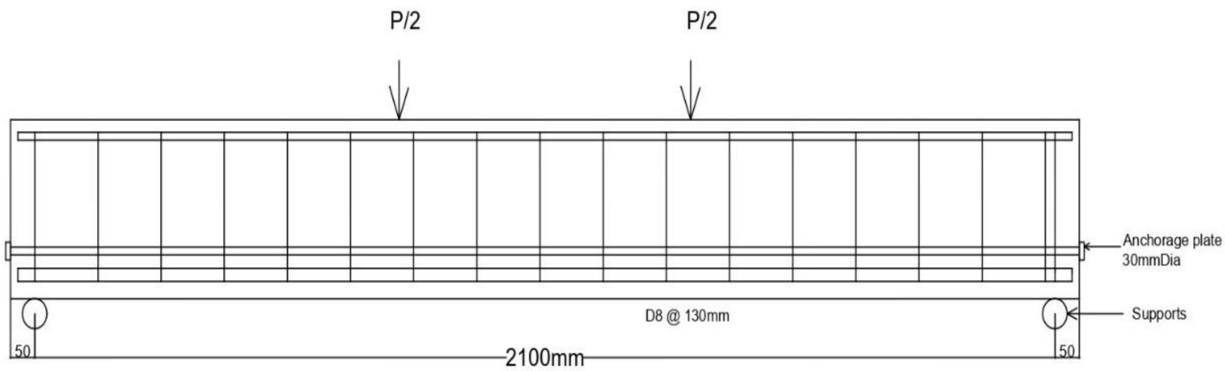


Figure 1.b Section detail

Nomenclature

Notation

A_f cross-sectional area of fiber

E_c initial tangent modulus of fiber reinforcedconcrete

f_c uniaxial ultimate cylindrical compressivestrength plain concrete

f_{cf} uniaxial cylindrical compressive strengthof SFRC

f_{ck} cube compressive strength of plain concrete

f_{ckf} cube compressive strength of fiber reinforced concrete

f_t uniaxial ultimate tensile strength of plainconcrete

P applied load

P_c peak load

b_t shear retention factor for open crack

b_c shear retention factor for closed crack

δ central deflection

μ Poisson's ratio for plain concrete

μ_f Poisson's ratio for SFRC

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FINITE ELEMENT MODELLING

FE model used for the analysis of fiber reinforced prestressed specimens. The mesh employed for the study had element 50 mm element size was used. To simulate the behavior of prestressing wires and deformed bars, LINK8 (truss) element from the ANSYS 5.5 library have been used. The interface behavior between the concrete and reinforcement (prestressing wire and reinforcing bar) has been modelled using COMBIN14 (spring) elements. . The mild steel stirrups and stirrups hangers in the flexure zone have also been modeled using truss (LINK8) elements, assuming perfect bond between these elements with concrete. Due to the three dimensional nature of the problem, the model was generated with three-dimensional element. The generated finite element model , where solid65 brick elements have been used for concrete with 50x50x50 mm elements size along the length of the beam and link 180 element used for reinforcement.

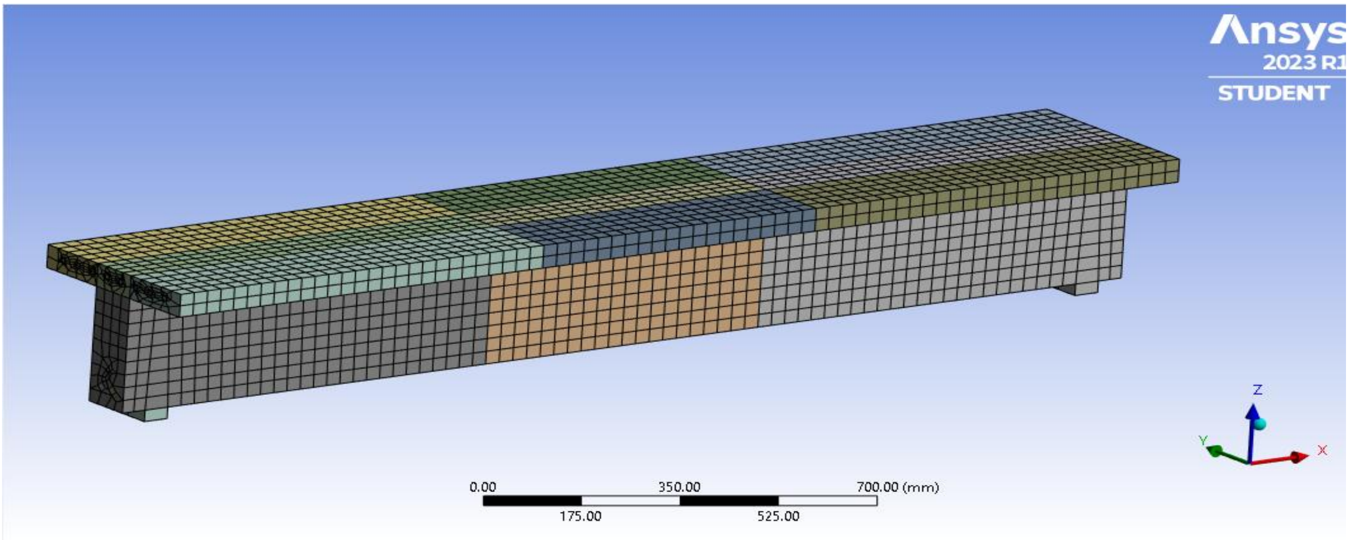

Figure 2. meshing of beam model

MATERIAL PROPERTIES

i) Concrete elements

Table 2 shows the basic material properties used in FE analysis. The crack interface shear transfer coefficient for open cracks was assumed to range from 0.1 to 0.5 while for closed cracks the shear transfer coefficient was assumed to range from 0.7 to 0.9 as shown in Table 2. Properties of fiber reinforced concrete like cube compressive strength, cylindrical compressive strength, modulus of rupture, modulus of elasticity, poissons ratio and Strain at peak compressive stress are calculated by using models as follows[6].

(a) cube compressive strength (f_{ckf}) = (f_{ck})+ 0.014*(f_{ck})*(RI)+ 1.09(RI) MPa.

(b) cylindrical compressive strength (f_{cf}) = 0.84*(f_c) + 0.046*(f_c)*(RI)+ 1.02(RI)

(c) modulus of rupture (f_{flf}) = 0.97(f_c)^0.5+ 0.295*(f_c)^0.5*(RI)+ 1.117(RI) MPa.

(d) modulus of elasticity (E_{cf}) = E_c + 2440.2*(RI) MPa

(e) possions ratio (μ_{cf}) = μ_c + 0.03704*(RI)

(f) Strain at peak compressive stress $\acute{\varepsilon}_{ocf}$=493.4(f f_c)^0.3943+3.5788(f_c)*(RI)+ 484.95*(RI)*10^6

Table 1. Concrete material properties used in FE analysis for flexure critical prestressed beam specimens

Sl	Beam	v_f	f_{cf} (MPa)	f_t (MPa)	b_t	b_c	μ	E_c (GPa)

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1	T-FF/f0	0	60	5.42	0.3	0.9	0.2	38.72
2	T-FF/f1.0	1.0	64.62	5.93	0.3	0.9	0.222	40.19
3	T-FF/f2.0	2.0	69.415	8.62	0.3	0.9	0.244	41.65
4	T-PF/f1.0	1.0	64.62	10.13	0.3	0.9	0.222	40.19
5	T-PF/f2-0	2.0	69.415	8.21	0.3	0.9	0.244	41.65

ii) Fibers
The effectiveness of steel fibers in increasing the tensile strength of the concrete, at least partially, depends on the number of fibers per unit cross-sectional area of concrete.

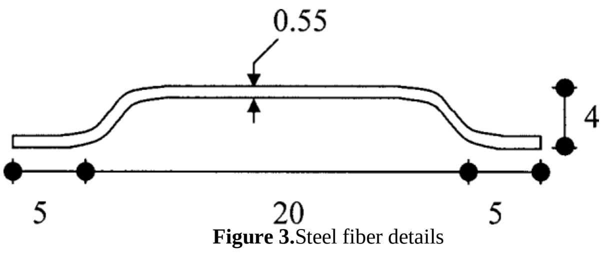

Figure 3. Steel fiber details

iii) Prestressing wires and deformed bars
the present study, the prestressed wire and deformed bar (in the partially prestressed beams), stirrups, and stirrups hanging bar were simulated using LINK8 truss elements. The points on the nonlinear material properties of the stress strain curve for prestressed wire and deformed bar were input into the ANSYS modelling. The effect of prestress was modeled as an effective initial pre-strain applied on each prestress wire truss element uniformly.

RESULTS AND DISCUSSIONS
Addition of fibers increased the cracking and reduces the deformational characteristics. As seen from the load deflection curve in Fig.4 (a, b and c) . From an examination of these load deflection curves of both test and FE analysis (Fig. 5(a) and (b)), it is seen that inclusion of fibers, only in half the depth on the tensile side, is effective in bringing about the improvements in the deformational characteristics to almost at par with those obtained with full depth fiber reinforced beams, from the initial loading stage up to the ultimate load. Full depth fiber inclusion imparts increased *ductility and* preserves the structural integrity of the members up to the ultimate stage.

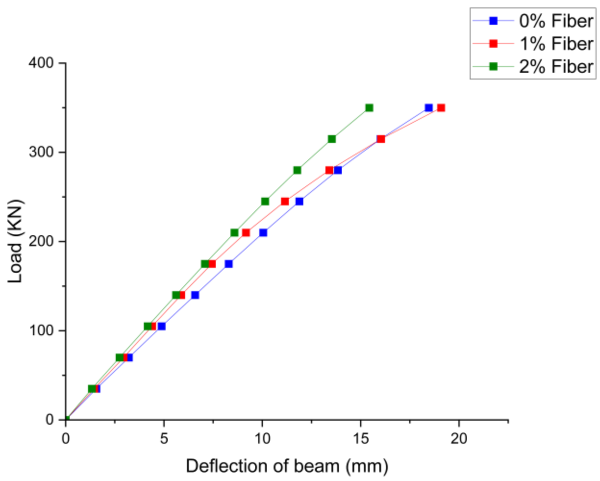

Figure 4.a- load deflection curve for fully filled 0%,1% and 2% fiber reinforced prestressed concrete beam

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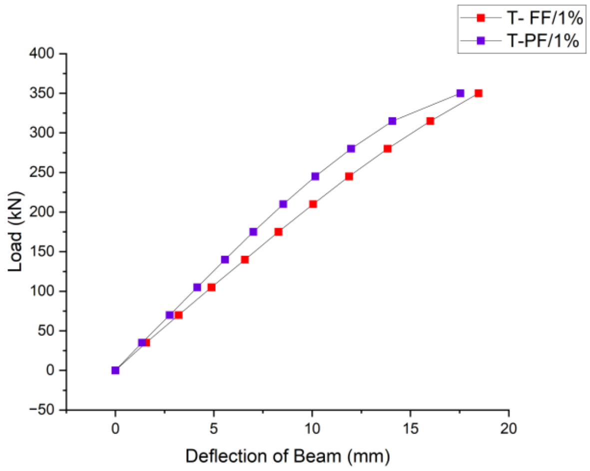

Figure 4.b- load deflection curve for fully filled 1% fiber and partially filled 1% fiber reinforced prestressed concrete beam

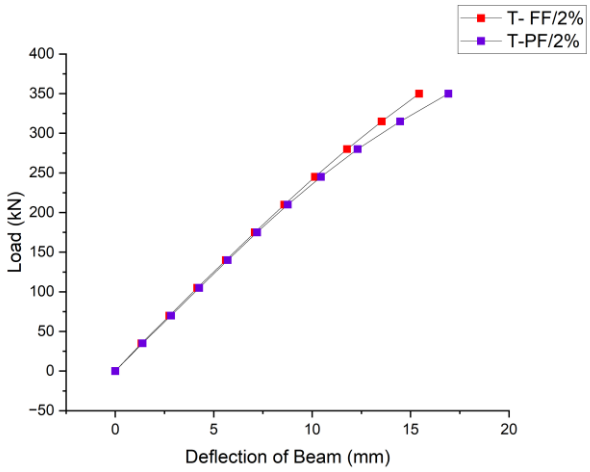

Figure 4.c- load deflection curve for fully filled 2% fiber and partially filled 2% fiber reinforced prestressed concrete beam

Figure 4. (a, b and c) shows the typical finite element results comparison with test results at four stages of loading for the selected beam specimen having no fibers and fully filled over the length (T-FF/0), 1% fibers and fully filled over the length (T-FF/1.0), 2% fibers and fully filled over the length (T-FF/2.0), 1% fibers in web portion and zero fibers in flange portion and fully filled over the length (T-PF/1.0), 2% fibers in web portion and zero fibers in flange portion and fully filled over the length (T-PF/1.0).

5. CONCLUSIONS

Based on the comparison of the FE analysis of 5 prestressed beam containing fibers at various locations and varying fibers volume fractions, the following conclusions were drawn:

1) (1)Addition of trough shape steel fiber to high strength concrete, caused an decreases the deformational characteristics.

(2)Inclusion of fibers over a partial depth in the tensile side of the prestressed flexural structural members would be economical and lead to considerable cost saving in the design without sacrificing on the desired performance in the area of building elements particularly in precast construction where quality may be maintained. Full depth fiber reinforced members would be necessary in some special structures subject to large strain rates of loading.

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