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UTILIZATION OF FRC TENSION ZONE FOR REINFORCEMENT REDUCTION IN SLABS- A SIMPLIFIED APPROACH

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Abstract: The use of Steel Fiber Reinforced Concrete (SFRC) as a structural material is increasing day by day. One of the main advantages of fiber-reinforced-concrete is that the cracked-concrete below neutral axis in a cross-section can be considered up to some extent. Complicated equations exist for taking into account the tension zone of FRC. In this work, a simplified equation for estimating the tensile force of SFRC is proposed to calculate the nominal moment capacity of slabs. Flexural strengths of plain concrete (PC) and SFRC are investigated to study the effect of steel fibers on reinforcement reduction in slabs. Modulus of rupture (MoR), corresponding deflection, energy absorption (E), toughness index (TI) and density are determined experimentally. The mix design of 1:3:2:0.7 (cement: sand: aggregate: water) is used for preparing PC. Steel fibers with a fiber content of 5%, by mass of cement, and 5 cm length are used for preparing SFRC. Prisms of standard size are cast for both PC and SFRC and tested as per ASTM standards. It is found that MoR, E and TI of SFRC are increased by 43%, 667% and 423%, respectively, compared to that of PC. Rebars in SFRC are reduced up to 25% resulting in reduction of 12% material cost of slab.

1 INTRODUCTION

Reinforced concrete slab is one of the most important structural elements because of the necessary component of every framing system. Slabs also acts as diaphragm in some framing systems where beam are avoided such as flat slab and flat plate. The purpose of slab diaphragm is to transmit earthquake/ wind force to horizontal resisting elements and to keep the structure together during earthquake in such a way that it acts as single entity. Hence, the diaphragm should have the desired strength to resist the maximum load induced. Strength of diaphragm slabs is related to their deflection / bending. Bending of slab is related to flexural strength of concrete. ACI states the flexural strength of concrete is 10 to 15 % of compressive strength, due to which flexural strength of concrete is ignored in tension side and steel reinforcements are provided to increase flexure strength and control deflection. Steel reinforcement is normally most expensive among all materials used in construction of slabs. Achieving the desired strength at lower cost is the need of the day. Economy can be achieved either by reducing amount of steel reinforcements or concrete cost. Use of fibers can be another option to reduce reinforcement. Beshara et al. (2012) reported that the effect of SFRC in tension zone should not be neglected. Fibers are being used to enhance the mechanical properties of concrete since ancient times. The use of fibers improves concrete-matrix after it has cracked thus improving its toughness. Significant increment in mechanical properties of bridge deck slab was reported by Khan and Ali (2016) by the use FRC. Plain concrete fails abruptly when ultimate load is achieved but FRC keep on carrying loads even at large deflection. Steel fibers have been used as reinforcement in concrete since 1960 in United States (ACI 544.1R-96). So, they can be used for the enhancement of concrete flexural strength and reduction in the conventional reinforcement to economize the cost of structure. Steel fibers normally have high tensile strength and elastic modulus as compared to other fibers. There is no effect of corrosion on them as alkaline environment of concrete matrix protects them.

Mohod (2012) determined the tensile and compressive strength of concrete reinforced with steel fibers of varying content i.e. 0.25%, 0.50%, 0.75% 1% 1.5% and 2% by volume of cement. Hooked end steel fibers of 60 mm length were used. Significant enhancement in the strength of steel fiber reinforced concrete was found. 0.75% fiber content was optimized for flexural strength of the beam. Amit Rana (2013) reported that modulus of rupture of SFRC was enhanced up to three times as compared to normal concrete. Efficient resistance under impact load and increment in fatigue strength up to 1.5 times was also observed. Addition of steel fibers also made material less porous and eliminated shrinkage cracks. Jagadeesh (2016) observed an increment of about 38% in the MoR of concrete having steel fibers of aspect ratio 65. Split tensile strength was also increased up to 70% as compared to normal concrete. Ghaffar et al. (2014) reported decrease in workability and density with increase in fiber content when 60 mm long steel fibers were used in concrete. Improvement in compressive, flexure strength and ductility were also observed in SFRC. Pandit and Jamkar (2013) determined the mechanical properties of high strength concrete by use of steel fibers. It is found that increment in the split tensile strength was more significant as compare compressive and flexure strength. Increase in flexure and compressive strength of concrete reinforced with steel fibers was also reported by Harle and Tantarpale (2014). Mohammadi et al. (2008) discussed the use of steel fibers with different length (50 and 25 mm) in concrete and examined its mechanical properties. It was observed that use of a mix of short and long fibers yields better results. 65% long and 35% short fibers should be used in concrete for better results in mechanical properties. But more increase in the workability was observed with the use of short fibers. Yazıcı et al. (2007) reported significant increase in mechanical properties of concrete by the use of steel fibers. About 11-54% increase in split tensile strength, 3-81% in flexure strength and 4-19 % in compressive strength was found in SFRC as compared to PC. It was concluded that significant improvement in flexure strength of SFRC can be achieved by increasing volume fraction and aspect ratio of steel fibers. Decrease in pulse velocity of SFRC was also observed. Song and Hwang (2004) reported about 19-98% increase in split tensile strength and 28-126% in modulus of rupture by the inclusion of steel fibers in high strength concrete. Increase in compressive strength of SFRC was also observed.

Barros and Figueiras (1999) tested wire mesh concrete reinforced slab strips under bending with varying percentages of steel fibers. The load-carrying capacity was improved significantly by the use of steel fibers. Cracks' spacing and opening was also reduced. Khaloo and Afshari (2005) studied the bending behavior of steel fiber reinforced concrete slabs. A design method was also proposed based on allowable deflection. Fourteen mixtures with four miscellaneous fiber volume fractions, two fiber aspect ratios and two concrete strengths were designed. The slabs of size 820 x 820 x 80 mm were used. Improvement in the energy absorption capacity of slabs was observed by the incorporation of steel fibers without effectively increasing the ultimate flexural strength of SFRC slabs. Generally, longer fibers provided slightly higher energy absorption capacity. Energy absorption capacity of the SFRC slabs was increased by the increase in concrete strength. Nikeshram et al. (2016) conducted experiments on steel fiber reinforced concrete slab with partial replacement of coarse aggregate. It was found that flexure properties of concrete were efficiently improved by the use of steel fibers. Fall et al. (2014) performed experiments on SFRC two-way slab and studied the load redistribution behavior. Load carrying capacity of two-way slabs was significantly enhanced by the use of steel fibers. In SFRC combined with ordinary steel bars, additional cracks with narrower width developed as compared to the slabs reinforced with ordinary steel bars alone. Hrynyk and Vecchio (2014) reported that the SFRC slabs exhibited better performances as compared with normal slabs under impact loading. Increased slab stiffness and reduced crack spacing's and widths was observed by the addition of end-hooked steel fibers. The increment in impact resistances, stiffness's, and displacement capacities of the SFRC slabs is related with the volume fractions of steel fibers used. Alani et al. (2012) conducted experiments on 6 x 6 x 0.15 m SFRC ground slab and found that there is significant increase in the mechanical properties of concrete as compared to Code's theoretical value. It was suggested that great care should be taken while mixing fiber in the mix.

Beshara et al. (2012) investigated the use of steel fibers in high strength concrete and developed a formula for the flexural design of HSFRC. Whitney (1942) stress strain diagram, which is the basis for the design equation of beams and slabs, was modified to incorporate the effect of FRC in the tension side as it was previously ignored because PC is very weak in tension. Modified stress strain diagram is shown in figure 1. Design formula for steel fiber reinforced concrete is given below:

[1] $M_n = \rho\ b\ d\ f_y\ (d-\beta c/2) + T_f\ [(d + c - \beta c)/2]$

Where T_f (Tensile strength of concrete) = $1.64\ v_f\ (l_f/\Phi)\ b\ t_f$ (Found experimentally in this research)

t_f = tensile strength of fiber, v_f = volume fraction and l_f/Φ = aspect ratio of fiber

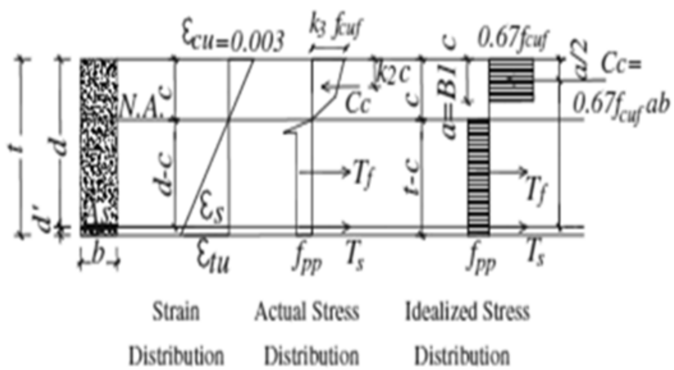

Figure 1. Stress Strain Diagram (Beshara et al. 2012)

As per author's knowledge, no research has been done on steel fibers for the reinforcement reduction in slab. As the slab and beams follows the same design procedure, so Beshara et al. equation can be used for slabs as well. Area of steel from ACI and Beshara et al. equations is computed and their difference is reported. T_f in the Beshara et al. equation is found experimentally and taken as 50% of the enhanced flexural load of SFRC.

2 EXPERIMENTAL PROCEDURE

2.1 Raw materials

For the preparation of plain concrete, ordinary Portland cement, local sand, normal size aggregate (≤1/2 inch) and drinking water was used. For preparing SFRC, same ingredient with addition of steel fibers (SF) having 50 mm length and 0.5 mm diameter was used. SFs were in ready to mix condition.

2.2 Mix design and casting procedures

Cement, sand, aggregate and water with a ratio of 1:3:2:0.7 respectively are used for preparing plain concrete. 2 cm long steel fibers with a fiber content of 5% by mass of cement are used for preparing SFRC. The mix design for SFRC was the same as that of the PC. The drum type concrete mixer was used in preparing concrete. For preparing PC, the mixer was rotated for six minutes after putting all materials in the mixer along with the water.

For preparing SFRC, a different approach was adopted. Materials were put in the mixer layer by layer to prevent from balling effect of fibers. One third part of aggregate, sand, cement and steel fibers were spread into the mixer in one layer. Same procedure was repeated until the complete materials were placed into the mixer. After complete placing of materials into the mixer, approximately three quarters of the water was added, and the mixer was rotated for three minutes. Then the rest of the water was added and the mixer was again rotated for three minutes. Then molds were casted by spreading the concrete in three layers and tamping each layer 25 times with rod. After two days specimens were demolded and placed into curing tank for 28 days. Lines were marked on all specimens for clear recognition of cracks.

Figure 2. Steel Fibers

2.3 Specimens

Beams (10 x 10 x 45 cm) were prepared for PC and SFRC. A set of two samples for each PC and SFRC were produced. Labels PC and SF were used for PC and SFRC, respectively.

2.4 Testing procedure

Slump test for fresh concrete and density, modulus of rupture (MoR) and corresponding load deflection curve for hardened concrete specimens were performed. Compressive strength of 10.3 Mpa was taken from a parallel studied conducted on same mix design of SFRC by a colleague (not in published form).

2.4.1 Slump of fresh concrete and density of hard concrete

Slump tests were performed for both PC and SFRC as per ASTM C143. PC and SFRC were also tested as per ASTM C138 to find their densities.

2.4.2 Modulus of rupture (MoR)

Beamlets were tested according to ASTM C78 to find the modulus of rupture (MoR), corresponding deflection (Δc), load at first crack (P_{crack}) and maximum deflection (Δc) using mid-point loading.

3 TEST RESULTS AND ANALYSIS

3.1 Slump and density

Slump test values for PC and SFRC are shown in Table 1. SFRC has same slump as that of PC as shown in Figure 3. Table 1 also shows the Densities of Plain concrete and SFRC. Increase in density of SFRC was observed as compared to PC because of the greater density of steel fibers.

Table 1: Slump Test Result

Type	w/c ratio	Slump (mm)	Density (Kg/m3)
PC	0.7	50	2229
SFRC	0.7	50	2260

Figure 3. Slump Test for SFRC & PC

3.2 Modulus of Rupture (MoR)

The modulus of rupture for PC and SFRC are shown in Table 2. Almost 44% increase in MoR was observed for SFRC as compared to PC. Abrupt failure was observed in PC but SFRC keeps on taking load after maximum load. Deflection up to 20 mm was also observed for SFRC samples as shown in Figure 4. The observed ductility in SFRC was due to fibers. Failure of specimen is presented in Figure 5.

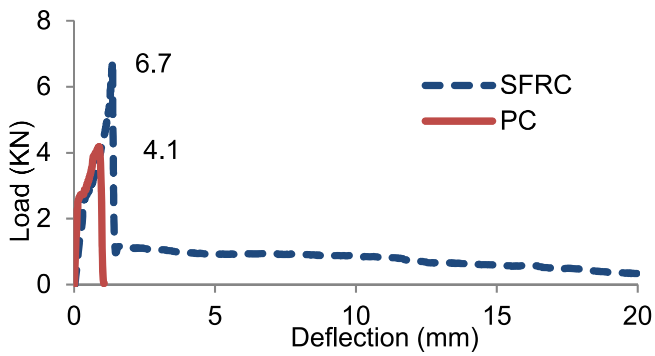

Figure 4. Load-Deflection Curve

Table 2: Loads, MoR and Deflections

Specimen	Max. Load, P_m (kN)	Ultimate Load, P_u (kN)	F.S/ MoR, MPa	%, Difference	Max. Deflection, Δ mm
PC	4.19	0.04	2.26	-	3.3
SFRC	6.04	0.23	3.26	+44 %	20

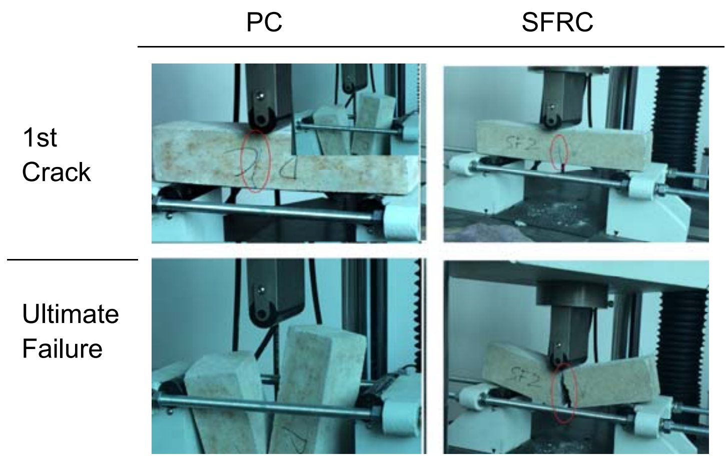

Figure 5. MoR test for PC and SFRC

3.3 Flexural Energy Absorption

Energy absorption is very important aspect especially in case of FRC. It is found by calculation the area under load-deflection curve. Table 3 shows the energy absorption and toughness indexes of PC and SFRC. The total energy absorbed by SFRC is seven times more than that of PC. Toughness index for SFRC is also 5 times greater than that of PC.

Table 3: Energy Absorption and T.I

Specimen	E_m (U_p to P_m) (kJ)	E_u (P_m to P_u) (kJ)	T.E (kN.s)	T.T.I (-)
PC	3	0	3	1
SFRC	4.4	18.5	23	5.23

E_m= energy absorbed up to max. load, E_u = energy absorbed from max. load to ultimate load, T.E = total energy absorbed, T.T.I = Total toughness Index = T.E / E_m

4 DISCUSSIONS

As it is evident from the test result that there is significant increment in the flexural strength, corresponding deflection, energy absorption and toughness index due to the incorporation of steel fibers in concrete. Increment is 44%, 557%, 667% and 423% respectively with respect to plain concrete. It can also be seen from figure 5 that specimen didn't break even at ultimate load and the failure was not brittle. It is also evident even from naked eye that steel fibers didn't break at specimen's failure but there were actually pulled out. Hooked ended or long fibers can be used to avoid fiber pull out.

ACI design equation didn't incorporate concrete in tension zone because it is weak and have brittle failure. But in case of FRC, concrete's brittle failure changes to ductile and there is also increment in the concrete tensile/ flexural strength. Hence design equation reported by Beshara et al. (2012) can be incorporated to reduce the reinforcement of slabs. As MoR is almost same as of tensile strength of concrete, so it can be used for design purpose. Comparison of MoR values for PC and SFRC is done and their difference is found and 50% of that value is used as T_f in Bashara's equation.

To understand the possible reinforcement reduction in slabs by the use of tension zone, a design example is solved with a assumed slab panel of 20 x 20 ft. with 50 psf superimposed load and 40 psf live load. Designed thickness is 6 inches and 40 grade steel is used. Area of steel was computed for both design equations i.e. ACI design equation and Bashara's equation. There is 25% reduction in reinforcement of slab as shown in table 5. Value of f'_c for PC and SFRC is taken from a parallel study conducted by a colleague (not in published form).

Table 4: Comparison for Area of Steel

Design Method	Moment k-ft	As (required) in^2	As (provided) in^2	% Reduction
ACI 318	11	1.32	1.32 Φ6-4"	-
Beshara et. al (2012)	11	1.02	1.06 Φ6-5"	25%

Furthermore, as design equations for beams, biaxial columns and footings are same as that of slab, this result may also be used for beams as well.

A cost-effective comparison can also be done for the same slab panel with same steel reinforcement in both directions. Quantity of steel is calculated and it is found that almost 343 kg (20%) of steel can be saved by using SFRC. From the Figure 6, it is clear that cost is reduced up to 12% by using SFRC and Beshara et al. (2012) design equation even though unit cost of SFRC is 25% more than that of PC. Cost reduction is mainly because of the reduction in the steel quantity. When the area of slab increases, there will be further reduction in cost.

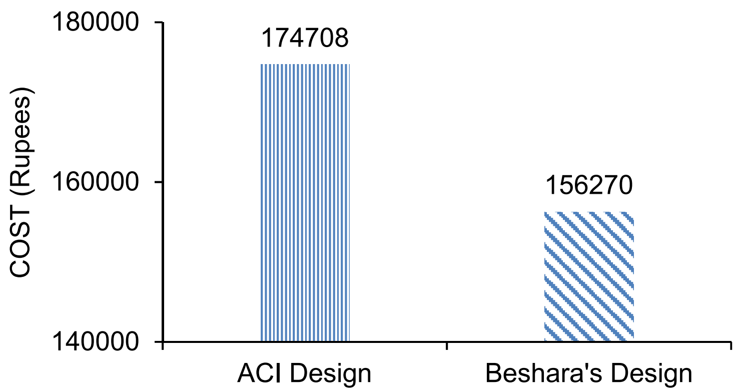

Figure 6: Cost Comparison

5 CONCLUSIONS

PC and SFRC were made with same mix design of 1:3:2:0.7 except 5% steel fibers by mass of cement were added to SFRC. Beamlets were cast for both PC and SFRC and their behavior under flexure were studied. After the analysis of experiments' results, following are the conclusions:

- Slump of SFRC is same as that of PC. However, an increase of 1% in density of SFRC is also observed with respect to PC.
- Flexural strength of SFRC is increased up to 44% with respect to PC. Post cracking behavior of concrete was improved significantly i.e. maximum deflection for SFRC was almost seven times greater than PC which indicates the increased ductility.
- Energy absorption of SFRC is seven times greater than that of PC and toughness index is also increased.

- SFRC can be utilized for reduction in slab's reinforcement up to 25%, which can ultimately result in saving 12% slab's cost (in design example).
- The results of this study may also be extended for other structural elements like beams, biaxial column and footings.

6 RECOMMENDATIONS

Following are the recommendation for future studies:

- Effect of steel fibers combined with conventional steel rebars may also be studied.
- Effect of super plasticizer in SFRC should also be studied.

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