IJSRD - International Journal for Scientific Research & Development| Vol. 5, Issue 02, 2017 | ISSN (online): 2321-0613

To Study and Optimization of Strength of the RC & SFRC

Mr.Shivam Srivastava[1] Mr.Ritesh Mall[2]
[1]M.Tech Student [2]Assistant Professor
[1,2]Department of Civil Engineering
[1,2]Suyash Institute of Information Technology Hakkabad Gorakhpur, 273016 (UP).India

Abstract— The Steel fibers have widely been used in the past to reinforce brittle materials in many nonstructural applications such as concrete, tunneling lining, etc. On the basis of numerous earlier studies, ACI 318-11 [2011] has recently accepted the steel fiber as a minimum shear reinforcement replacement with minimum 0.76% volume fraction for both reinforced concrete and fiber reinforced concrete members. However, not much previous research has talked about the strength behavior of fiber reinforced concrete (FRC). As the ACI 318-11 for tension-controlled sections, net the tensile strains in the outermost layer of the steel, □t, should be greater than or equal to 0.006. In this project, six large scale reinforced concrete beams with or without the steel fiber along with some material test were tested. Our experimental investigations indicated that even with inclusion of small percentage volume of fraction of the steel fiber (Vf =0.76%) could not only increase the ductility and shear strength of the SFRC beam. but also change the failure pattern by increasing usable strain in the concrete and steel. Any standard material test results have to ensure the FRC. . Various tests were carried out in order to assess peak and residual strength, stiffness, strain hardening and softening, toughness and the other post crack properties. It could be used to optimization of the peak strength, residual strength, toughness stiffness and different SFRC mixtures with and without steel fiber.

Key words: Reinforced Concrete (RC), Steel Fiber Reinforced Concrete (SFRC), ASTM C1609, strength

I. INTRODUCTION

Due to its relative low cost of concrete is widely used as construction material although the fact that it is neither as strong nor as tough as steel. Plain concrete is brittle in nature and has a low tensile strength and strain capacity ahead loading, which is lead to limited resistance to tensile stress and cracking. The mechanical properties of concrete can be enhanced through the beginning of reinforcing steel that has high tensile strength and ductility. Steel has been broadly used in the form of rods, wire, and fiber as a reinforcing material in conventional reinforced concrete (RC), and steel fiber reinforced concrete (SFRC). presents the overall background into which the work is placed. The stimulation for the research is presented. It has two most important parts: first, the behavior of steel fiber reinforced concrete, and second, the development of a simple and reliable material evaluation method for reinforced concrete.

A. Testing of SFRC beams

Determining the amount of longitudinal reinforcement is one of the most important aspects of the design of a typical reinforced concrete (RC) The shear capacity of a beam is checked after determining the strength and then the required shear reinforcement is added based on the code's necessities. In general, the design process will ensure that the beam will fail due to in case of flexure when overloaded, rather than shear, which is positive because shear failure is brittle and less unsurprising. In order to avoid precipitate shear failure, enough shear reinforcement should be provided. Beam sections are generally designed to be tension in which case the amount of longitudinal steel reinforcement in the section is governed by certain limits to make certain that the steel yields, the concrete reaches its crushing strain (i.e., $\square_{cu}$, which is approximately 0.004 as specified by the current ACI code [2011]). If the unnecessary steel is used then the concrete strain may reach its ultimate value before the steel yields, causing a brittle, compressive failure to occur with little observable warning.

B. Simple and Reliable Material Testing of FRC

Although material properties resulting from any standard material test methods not accurately represent the actual properties of the fiber reinforced concrete (FRC) used in the structural members, these test results can ensure that the FRC has at least been batched suitably and can give indications of probable performance when used in structures. On the other hand, an ideal material test method for the FRC needs to account for many factors. Mindess et al. [(2003]) suggested that, for a suitable the FRC evaluation method, there should be low inconsistency in any measurement of a given property; it should be able to quantify certain criteria with regard to the FRC's mechanical performance in terms of the strength, crack resistance, toughness, and should also reflect the characteristics depict by a load versus deflection curve. An ideal material test method should be as self-regulating as possible of the specimen size and geometry. The fundamental significance is that it can be used for both specification and quality control of the FRC mixtures.

C. Material Test Methods

The standard material test methods have to be used to evaluate the material properties of fiber reinforced concrete (FRC) in order to the ensure that the FRC was batched properly. These tests should also give indications of fiber reinforced concrete performance if it is used in structures. An ideal material test method for the FRC needs to account for many factors. Mindess et al. (2003) recommended that the toughness and residual strength parameters obtained from the fiber reinforced concrete material tests should satisfy the following criteria:

D. Existing Material Test Methods

Different types of material tests are used to determine the fundamental properties of plain and reinforced concrete. some of the material tests that were used or compared and analyzed in the experimental investigations carried out during track of the research work are discussed in the following paragraphs. ASTM C1609 strength Testing of Fiber Reinforced Concrete Beams ASTM C1609 [ASTM, 2010] is the standard test method of fiber reinforced concrete beams for determining the strength performance using a beam under a third-point loading system. This is the only optional method by ACI 318-11 Figure shows a typical test setup to performance the ASTM C1609 test. It is a third-point loading fixture with the two hinged supports and the two loading points on the top of the beam.

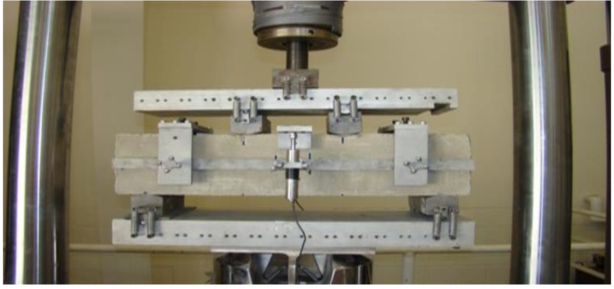

Fig. 1a: Typical ASTM C1609 strengthTest Fixtures [ASTM 2010]

Beam size	Net Deflection rate to	Net Deflection rate for
100) inches (mm)	L/600 0.003 to 0.005 in/min (0.06 to 0.12 mm/min)	L/600 to end of test 0.003 to 0.009 in/min (0.05 to 0.15 mm/min)
150) inches (mm)	0.003 to 0.005 in/min (0.06 to 0.12 mm/min)	0.003 to 0.010 in/min (0.05 to 0.22 mm/min)

Table 1A: ASTM C1609 Net Deflection Testing Rates [ASTM 2010]

L= Support Span 12 inches for 15 inches beam; 15 inches for 20 inches beam

E. Direct Tensile Testing

The direct tensile test method is the method by which one can identify the key properties of the FRC; such as strain-hardening or strain-softening, the elastic modulus, and the stress versus strain relationships under the tension. These are the constitutive properties of the FRC that are useful for the modeling and design of the FRC structural members [Naaman, et al., 2007]. . The central portion has a square cross-section with a dimension of 5 × 5 inches. This dimension was selected to ensure more uniformly distributed fibers while maintaining a appropriate weight for laboratory handling the Tests were carried out by a closed-loop, servo-controlled machine with a loading rate of approximately 0.003 inches/minute

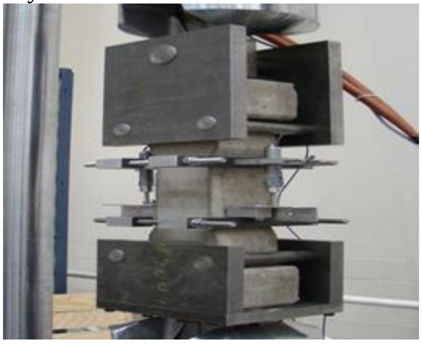

Fig. 1b: Geometry and Dimensions of the Direct Tensile Specimen Used at UT-Arlington [Chao et al, 2011]

F. Compressive Strength Test

The standard cylinder test is the most commonly used and relatively low cost test designed to measure the compressive strength of hardened concrete. Cylinders typically are tested in specially designed large capacity machine which is capable of soundtrack the load required to crush the cylinder. Cylinder ends typically are capped to ensure smooth contact with the testing machine loading at heads (Figure 2.29). When a cylinder is loaded in compression then microscopic internal cracking begins at about 31% of the ultimate load. since these cracks grow, the cylinder gets shorter and fatter. Cracks originally form around the aggregate particles and eventually branch out and link together. ASTM C39 [ASTM, 2011] testing requires that cylinders be loaded at a rate of 25 to 50 psi per second; a higher load rate can be used up .

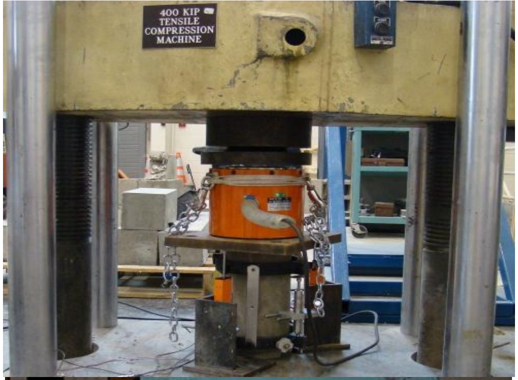

Fig.1c: show Test setup for obtain Compressive Stress-strain relation

G. Biaxial Loading Condition for SFRC

Demeke and Tegos (1994) carried out the experiments in order to study the biaxial effect of SFRC. They residential a tension-compression test (applying load by pushing and pulling) to study the effect of the biaxial stresses as shown in Figure 2.36. biaxial test started to decrease rapidly

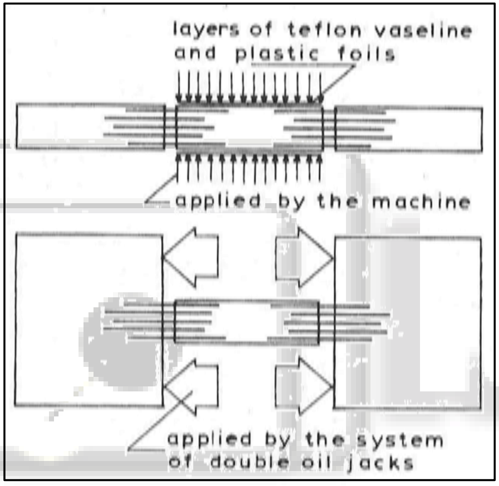

Fig. 2:

H. Experimental Investigation: Large-Scale Fiber Reinforced Concrete (SFRC) Beams

The large-scale experimental programs mainly consisted of the two phases. In the first phase, two specimens having longitudinal tensile reinforcement agreeable the tension-controlled requirements as per ACI 318-11, were arranged and tested. The first specimen was a steel fiber reinforced concrete (SFRC) beam named as SFRC#1-1, which was ready without the minimum web shear reinforcement. For comparison purpose, reinforced concrete (RC) beam namedRC#1-1 was prepared and reinforced with slightly less than the minimum web shear reinforcement as per the ACI 318-11 provision

The second phase consisted of four specimens: two reinforced concrete (RC#2-1 and RC#2-2) with longitudinal tensile reinforcement agreeable tension-controlled requirements as per ACI 318-11 and minimum web shear reinforcements, as required by ACI 318-11, and two SFRC specimens. The first SFRC specimen (SFRC#2-1) had a high longitudinal tensile reinforcement ratio which made this specimen not practiced as tensioned-controlled, and with small amount of stirrups that is less than the design requirement for a reinforcement concrete beam. The second SFRC specimen (SFRC#2-2) had longitudinal tensile reinforcement agreeable the tension controlled requirement as per ACI 318-11 and only one stirrup at the center of the beam was used for purposes. All SFRC specimens had the same volume fraction of steel fibers (0.76%).

I. First Phase of Large Scale Experiments

In this case, two specimens were prepared and tested. Both beams have identical geometries: 14 ft (169 inches) in length, 16 inches in width, 2 ft (24 inches) in height, and an effective depth of 22 inches. The span length between supports is 12 ft (144 inches). As shown in Figure 3.1, five strands (0.6 inches diameter stressing strand, ASTM A416, Grade 271 and stress-relieved) were stressed by using the stressing jack system at a local precast plant (Hanson Pipe & Precast Plant, Grand Prairie, Texas).

The dial pressure gage was monitored while the pressure was applied by professional workers at the plant. Initial stressing of 190 ksi was applied to each strand, which in turn gave an average initial stress of 380 psi in each beam.

Specimen	Total length (in.)	Total height (in.)	Effective depth (in.)	Shear reinforcement	Longitudinal reinforcement ratio (ρ)	Average stress in concrete (psi)
RC#1-1	168	24	21	2-legged #3@15 inches c/c	0.30 % (2-#3 and 5 strands)	380
SFRC # 1-1	168	24	21	2-legged 2-#3*	0.30 % (2-#3 and 5 strands)	380

*for construction purposes only

Table 2: Summary of Design Properties of Specimens Used in the First Phase of Experimental Program

J. Steel Fibers;

The steel fibers used in the first phase of the experiment were Dramix RC-80/60-BN fibers manufactured by the Bekaert Cooperation. The steel fibers are doubled-hooked at their ends and glued into bundles by the dissolvable

Shape	Length (L)	Diameter (D)	Aspect ratio (D/L)	Tensile strength
Doubled-hooked ends	2.38 inches	0.030 inches	82	153 ksi

Table 3: Mechanical Properties of Steel Fibers Used in the First Phase [1]

3 Dramix RC-60/80-BN of the Steel Fibers, Manufactured by the Bekaert Corporation 3.2.2.2 Concrete Mix

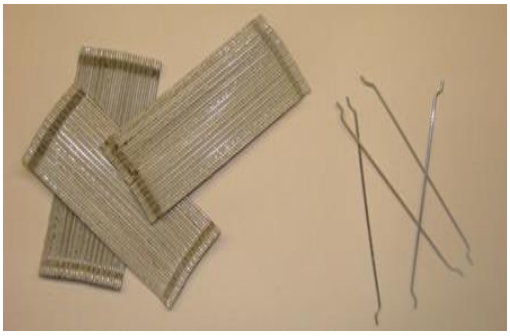

Fig. 3:

All materials were provide by the local precast plant (Hanson Pipe & Precast Plant, Grand Prairie, Texas). To Concrete was mixed using the local precast plant facilities (Figure 3.4) and transported to the stressing bed. Type I cement, river sand, and crushed limestone of ¾ inches maximum size were used. The mix proportion used for the first phase is shown in Table 3.3.

Types of concrete	Cement (Type 1)	Sand [1]	Coarse aggregate[2]	Water	Steel fiber	Compressive strength[3]
RC	1.00	1.14	0.68	0.40	-	5764 psi
SFRC V_f = 0.76%	1.00	1.14	0.68	0.40	0.09	5471 psi

Table 1B: Mix Proportions and to Compressive Strength of Concrete used in the First Phase

For the SFRC mix, the steel fibers were simply added manually at the last stage of the mixing process. The weights of all the materials were calculated and dumped into a mixing drum by an automation system, except for for the steel fibers. previous to mixing, the steel fibers were calculated and placed beside the mixing drum.

The Second Phase Experimental Program ,Materials[Steel Fibers] In the second phase of the experimental of program, different types of end hooked steel fibers (Maccaferri long, FF3) were used .The properties of the fibers are listed in the Table 3.5. Compared to Bekaert RC-80/60-BN fibers FF3 steel fibers have a shorter length, equivalent.

Fig. 1d: Example Photo of Glued Fiber (Remaining Intact)

Shape	Length (L)	Diameter (D)	Aspect ratio (D/L)	Tensile strength
Doubled-hooked ends	2 inches	0.04 inches	68	160 ksi

Table 1C: the mechanical properties of steel fibers used in the second phase experiment [1]

Figure 3.24: Uniformly Distributed Steel Fiber in Second Phase Specimens

1) The Concrete Mix

Types of concrete	Cement (Type 1)	Fly Ash Class C	Sand [1]	Coarse Aggregate [2]	Water	Steel Fiber	Comp. strength [3]
RC	1.00	0.50	1.70	1.0	0.60	-	5408
SFRRC V_f=0.75%	1.00	0.50	1.70	1.0	0.60	0.13	5251

Table 1D: Mix Proportion and Compressive Strength of the Concrete Used in the Second Phase

1) ASTM Natural River sand (Fineness modulus=2.58)
2) Crushed limestone with maximum size of ¾ inches
3) The strength was measured by test six number of 4×8 inches concrete cylinders cast concurrently with large-scale beams

2) Bending Testing

This tests were carried out for both phases of the experiment. The test is carried out as the ASTM C1609 (ASTM 2010) for the third point of the bending test method using a closed-loop servo controlled machine (Figure 3.41). Six specimens were tested for every phase with fiber reinforced concrete.

Fig. 4: Typical Photos from Third Point of Bending Test (ASTM C1609)

Specimens	Cement (Type-I)	Sand	Coarse aggregate[3]	Water	Steel fiber	Super plasticizer[9]
RC (control)	1.00	1.98	2.73	0.35	0	0.014
SFRC-X*-050					0.102 [4]	
SFRC-X-075					0.153 [5]	
SFRC-X-100					0.205 [6]	
SFRC-X-150					0.312 [7]	
SFRC-X-200					0.423 [8]	

Table 1E: Mix Proportion (By Weight) Used in the First Phase

4) Maximum size = ¾ in;
5) 0.51% of volume fraction;
6) 0.76% of volume fraction;
7) 1.00% of volume fraction;
8) 1.51% of volume fraction;
9) 2.01% of volume fraction;
10) Super plasticizer: High Range Water Reducing Admixture;

Specimens name	Steel fiber type	Volume of fraction	Number of specimens
RC	-	-	
SFRC R-050	Type 1 (Royal)	0.51 %	
SFRC R-075		0.76 %	10 for each set, total 120
SFRC R-100		1.01 %	
SFRC R-150		1.51 %	
SFRC R-200		2.01 %	
SFRC BS-050	Type 2 (Bekaert short)	0.51 %	
SFRC BS-075		0.76 %	
SFRC BS-100		1.01 %	
SFRC BL-050		0.51 %	
SFRC BL-075	Type 3 (Bekaert long)	0.76%	
SFRC BL-100		1.01 %	
SFRC BL-150		1.51 %	6
	Total numbers of specime		128

Table 1F: Specimen Information Used the First Phase[A]

Specimens name	Steel fiber type	Fiber volume fraction	Number of specimens
RC	-	-	3
SFRC R-075	Type 1 (Royal)	0.76 %	4 for each set, total 28
SFRC R-100		1.01 %	
SFRC R-150		1.51 %	
SFRC R-200		2.01 %	
SFRC BS-075	Type 2 (Bekaert)	0.76 %	
SFRC BS-100		1.01 %	
SFRC BS-150		1.51 %	
SFRC BL-075	Type 3 (Bekaert)	0.76 %	3 for each set, total 9
SFRC BL-100		1.01 %	
SFRC BL-150		1.51 %	
	Total numbers of specimens		40

Table 1G: Specimen Information Used Second Phase[B]

Specimens name	Steel fiber type	Fiber volume fraction	Number of specimens
SFRC R-075	Type 1 (Royal)	0.76 %	4 for each set, total 16
SFRC R-100		1.01 %	
SFRC R-150		1.51 %	
SFRC R-200		2.01 %	
SFRC BS-050	Type 2 (Bekaert, short)	0.51 %	4 for each set, total 16
SFRC BS-075		0.76 %	
SFRC BS-100		1.01 %	
SFRC BS-150		1.51 %	4 for each set, total 16
SFRC BL-050	Type 3 (Bekaert, long)	0. 51%	
SFRC BL-075		0.76 %	
SFRC BL-100		1.01 %	
SFRC BL-150		1.50 %	
Total numbers of specimens		48	

Table 1H: Experimental Program of this Fourth Phase

II. EXPERIMENTAL RESULTS

, the experimental investigation was carried out in the two phases. In the first phase, two large-scale concrete beam specimens with longitudinal reinforcement satisfying the minimum reinforcement for concrete flexure member as the ACI 318-11 were tested. First specimen was concrete beam with minimum web shear reinforcement and the second specimen was SFRC beam without minimum web shear reinforcement. For SFRC specimen, 0.76% volume fraction of steel fibers was used. The second phase consisted of four large scale concrete beam specimens, two RC beams with longitudinal reinforcement satisfying the minimum reinforcement for concrete flexure member as the ACI 318-11 and minimum required web shear reinforcements by the ACI 318-11 and two SFRC specimens. The first SFRC specimen was a beam with high longitudinal tensile reinforcement ratio and less web shear reinforcement. The second SFRC beam specimen consisted of longitudinal reinforcement satisfying the minimum reinforcement for concrete flexure member as the ACI 318-11 and with just one web shear reinforcement at center for fabrication purpose. All SFRC beam specimens consisted of 0.76% volume fraction of obsessed at end steel fiber.

A. *First phase specimen: RC#1-1*

In first phase one RC beam specimen (RC#1-1) was prepared and tested for comparison purpose with the second SFRC beam specimen (SFRC#1-1).

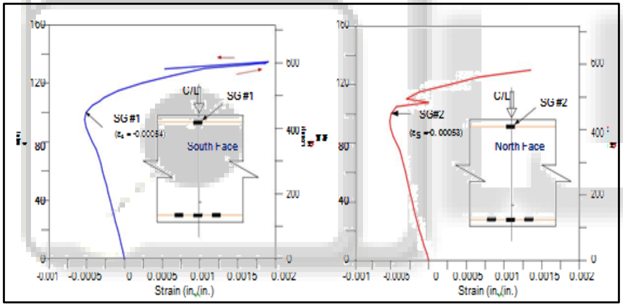

Fig. 2a: show Load versus Strain in Compression Steel for RC#1-1 Specimen

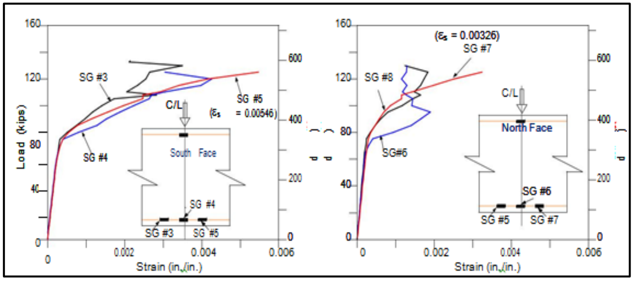

Fig. 2b: show Load versus Strain in Tension Steel for RC#1-1 Specimen

Close To compression fiber exhibited maximum strain value of 0.0032 at applied load of 130 kips. All other strain gauges which were installed farther from the compression zone (at lower depth) have shown the smaller values, which is reasonable. It can be seen from the Figure 5.7 that values of all surface concrete strain gauges are well below the theoretical ultimate value of concrete strain (0.004) as the ACI code. Maximum strain shown by the surface strain near top concrete fiber is order of 0.0020 (negative), whereas strain at mid depth is order of 0.00177 (positive).

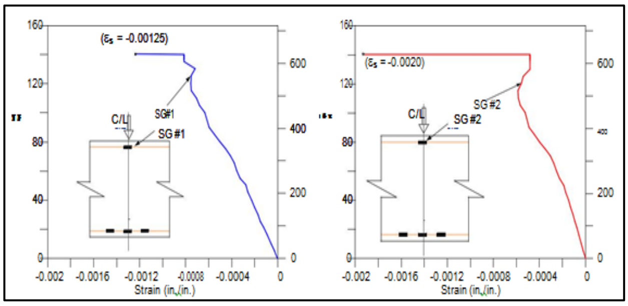

Fig. 2c: show Load versus Strain in Compression Steel for SFRC#1-1 Specimen

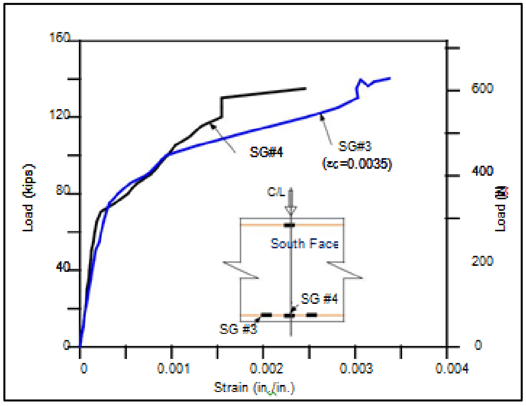

Fig. 2d: show Load versus Strain in Tension Steel for SFRC#1-1 Specimen

it can be shown the strain gauge CG #1 which close to compression fiber exhibited maximum strain value of 0.0045 at applied load of 142 kips. CG #2 and CG #3 have shown strain value of 0.0049 and 0.0032 respectively which are higher than the ultimate design concrete strain (0.004) as the ACI code. All other the strain gauges which were installed at lower depth of the beam have shown smaller values as expected.

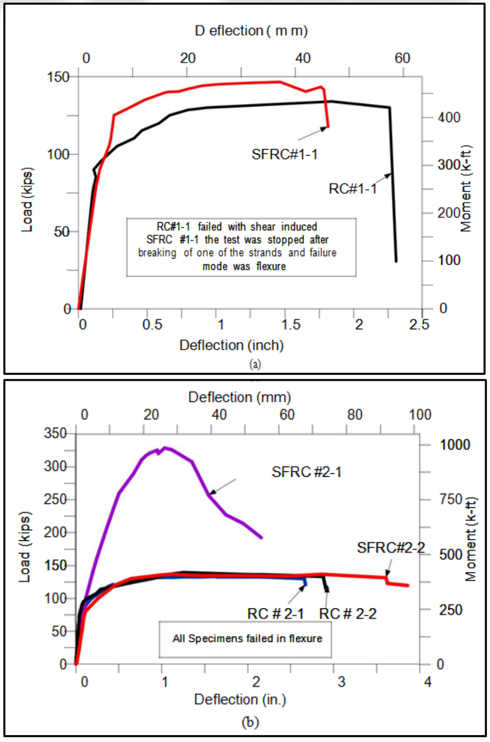

Fig. 2e: show Comparisons of Load Deflection Curves

Specimen	left - mid	Location right - mid	Average	Maximum
	SG #1	SG #2		
RC#1-1	0.00054	0.00053	0.0006	0.0006
SFRC#1-1	0.00125	0.00194	0.0017	0.0019
RC#2-1	0.00011	0.00042	0.00027	0.00042
RC#2-2	0.00033	0.00044	0.0005	0.00042
SFRC#2-1	0.00246	NW	0.00246	0.00246
SFRC#2-2	0.00126	0.00057	0.0011	0.00126

*Note: NW means the strain gauge was not working.

Table 2A: Strains in Compression Steel

Specimen	Location						Average	Maximum
	5 in left	left mid	5 in rt.	5 in left	right mid	5 in rt.		
	SG #3	SG #4	SG #5	SG #6	SG #7	SG #8		
RC#1-1	0.00350	0.00426	0.00547	0.00184	0.00191	0.00325	0.0034	0.0055
SFRC#1-1	0.00245	0.00337	NW*	NW*	NW*	NW*	0.0029	0.0034
RC#2-1	0.00893	0.00427	0.00552	0.00395	0.00437	0.00274	0.0050	0.0089
RC#2-2	0.00411	0.00326	0.00671	0.00964	0.00264	NW*	0.0053	0.0096
SFRC#2-1	0.00631	0.00838	0.00412	0.00857	0.00545	NW*	0.0066	0.0086
SFRC#2-2	0.00292	0.00438	0.01389	0.00975	0.01137	0.00670	0.0082	0.0139

*Note: NW means the strain gauges were not working

Table 2B: Strains in Tension Steel

Specimen	Rotation (rad.)			
	Experimental			Analytical
	At yield	At Peak Load	At Load of Ultimate Deflection	[Namaan, 2004]
First Phase				
RC#1-1	0.0020	0.0241	0.0300	0.019
SFRRC #1-1	0.0017	0.0230	0.0233	0.018
Second Phase				
RC#2-1	0.0014	0.0214	0.0355	0.019
RC#2-2	0.0022	0.0160	0.0387	0.026
SFRC#2 - 1	0.0025	0.0105	0.0246	0.006
SFRC#2 -2	0.0024	0.0383	0.0485	0.019

Table 2C: Comparison of Rotation with the Experimental and

III. CONCLUSIONS

the experimental works carried out during the course of the dissertation work. Experimental investigations and results with large-scale concrete beams with and without steel fibers , as a simple and reliable alternative the tensile test method are presented SFRC beams (0.76% V_f) showed ductile failure even without conventional shear reinforcement, which potentially saves labor and costs of the material, as well as time required for the construction With the addition of the steel fibers, the shear reinforcement required in the section with higher amount of the longitudinal reinforcement can be significantly reduced without having premature shear failure. thus the beams with larger tensile steel reinforcement ratio can still to be tension-controlled and show the ductile failure, which leads to a smaller and more efficient of the section. This is particularly advantageous for long span beams (for example RC girders for a bridge) wherever the self-weight is the dominating load.

Tensile force due to steel fiber, $F_{ft} = \sigma_{cu} b (D - d_n) = 72.1 kips$

Tensile force due to tensile reinforcement $F_{st} = A_s f_f \quad = 13\ kips$

Tensile force due to prestress, $F_{ps} = A_{ps} f_{ps} = 188\ kips$

Compression forced due to concrete $F_c = \frac{0.85 f_{cu}}{\epsilon_{cu}}\left(\epsilon_u - \frac{\epsilon_0}{3}\right) b d_n = 273 kips$

Compression force due to compression reinforcement

$$F_{sc} = \frac{d_n - d'}{d_n} \epsilon_u E_s A'_s = 0.40\ ksi$$

For ACI, $k_2 = 0.425 d_n = 1.42\ in$

$$M_n = F_c(d_n - k_2) + F_{sc}(d_n - d') + F_{st}(d_{st} - d_n) + F_{st}\left(\frac{D - d_n}{2}\right) + F_{ps}(d_{ps} - d_n)$$

$= 4818.7\ k.in = 401.6\ k.ft$

$> 1.2 M_{cr} = 216.84\ k.ft$ *Minimum ratio is satisfied*

Check for reinforcement steel reaches to yield stress or not

$f_s = \frac{d - d_n}{d} \varepsilon_u E_c = 460\ ksi > 60 ksi$ *tension bar yeilds*

$f'_s = \frac{d_n - d'}{d_n} \varepsilon_c E_s = 8.86\ ksi < 60\ ksi$ *compression bar do not yeild*

REFERENCE

[1] ASTM C1609/C1609M-10, “Standard Test method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading),” ASTM International, West Conshohocken, PA, 2010, 9 pp

[2] Aveston, J., Mercer, R. A., and Sillwood, J. M. "Fibre Reinforced Cements – Scientific Foundation for Specifications," *Proceedings of National Physical Laboratory Conference*, UK, 93-103

[3] Batson, G., Jenkins, E., and Spatney, R. (1972), "Steel Fibers as Shear Reinforcement in Beams," *ACI journal Proceedings*, 69(10), pp. 640-644

[4] Bentur, A, and Mindness, S. “Fiber Reinforced Cementitious Composites,” 2nd edition published 2007 by Taylor and Francis 2 Park Square, Milton Park, Abingdon, Oxon, OX 14 4RN

[5] Bernard, E. S., “Behaviour of Round Steel Fibre Reinforced Concrete Panels under Point Loads,” Materials and Structures, 33, 2000, pp.181-188
[6] Bernard, E. S. and Pircher, M., “Influence of Geometry on Performance of Round
[7] Determinate Panels Made with Fiber Reinforced Concrete,” Engineering Report No.
[8] CE10, School of Civil Engineering and Environment, UWS Nepean, Kingswood NSW, Australia, January, 2000
[9] Bernard, E. S., “The Influence of Strain Rate on Performance of Fiber-Reinforced
[10] Concrete Loaded in Flexure,” Cement, Concrete, and Aggregates, CCAGDP, American
[11] Society for testing and Materials, Vol. 23, No. 1, June 2001, pp. 11-18
[12] Bernard, E. S. and Pircher, M., “The Influence of Thickness on Performance of Fiber-
[13] Reinforced Concrete in a Round Determinate Panel Test,” Cement, Concrete, and
[14] Aggregates, CCAGDP, American Society for testing and Materials, Vol. 23, No. 1, June 2001, pp. 27-33.
[15] Bernard, E. S., “Correlations in the Behaviour of Fiber Reinforced Shotcrete Beam and
[16] Panel Specimens,” Materials and Structures, 35, 2002, pp.156-164
[17] Bortolotti, L., “Double Punch Test for Tensile and Compressive Strength in Concrete,” IACI *Materials Journal*, Vol, 85-M4, Jan.- Feb., 1988 pp. 26-32
[18] Chao, S.-H., Cho, J.-S., Karki, N., and Yazadani, N., “FRC Performance Comparison:
[19] Direct Tensile Test, Beam-Type Bending Test, and Round Panel Test,” *ACI Special Publication 2011*, pp. 395-405
[20] Carmo, Ricardo N.F do and Lopes, Sergio M.R. “Available Plastic Rotation in Continuous High Strength Concrete Beams,” NRC press web site Canada Oct. 2008
[21] Can. J. Civ 35: pp. 1152-1162 Chen, W. F., “Double Punch Test for Tensile Strength of Concrete,” *ACI Materials Journal*, 1970, pp. 993–995
[22] Chen, W. F., “Limit Analysis and Soil Plasticity,” Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York, 1975, Chapter 11, pp. 501-541.
[23] Chen, W. F., M. ASCE and Yuan R. L., “Tensile strength of concrete: Double-Punch Test,” *Journal of Structural Division, Proceeding of American Society of Engineers*, Vol. 106, No ST8, August, 1980 pp.1673-1693