Experimental Study of Flexural Behavior of Preflex SFRC-Encased Steel Joist Composite Beams

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Abstract

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This study investigates the behavior of encased steel composite beams in straight and preflex beams, constructed and tested at Civil Engineering Laboratory Building (CELB). Upwards camber is provided in the steel sections in steel angles and HSS tube in the composite beam encased in Steel fibers reinforced concrete (SFRC). Experimental procedure has been performed to study the flexural behavior of composite steel joists encased in SFRC. Compressive strength, tensile strength and modulus of rupture are computed. The physical properties of steel fiber reinforced concrete are calculated through testing at the UTA Civil Engineering Laboratory Building. Eighteen cylindrical (4”x8”) specimens, eighteen beams encased with Double angle (6”x6”x20”), eighteen beams encased with HSS steel beams (6”x6”x20”) were prepared and tested after 28 days of curing. The specimens were tested for their compressive strength, tensile strength, and modulus of rupture. The results showed that compressive strength increased by 45% with adding steel fibers of 1% by volume in concrete. Also, addition of 1% steel fibers by volume increases the tensile strength by 33% as compared to 0% steel fibers by volume. The experimental results showed that, cambering of double angles in concrete beam increases the ultimate load capacity by 10% while midspan deflection reduces by 25% relative to straight section in concrete beam. The study investigates flexural behavior HSS and double angle encased concrete beams, while results shows approximately similar performance for both type of beams. Use of steel fibers reinforced concrete is also an advantage to increase the flexural capacity of beam and to reduction in midspan. Adding 1% volume fraction of steel fibers to increases the ultimate load capacity by 30% and reduces the midspan deflection by 41% comparative to concrete without steel fibers. This study shows that, there

is significant improvement in the flexural capacity of beam with the provision of cambering and addition of steel fibers. Preflex Encased steel Joist Composite Beams are innovative structural members that provides more strength to structures with long spans like long span bridges, because it requires girders of large flexural capacity.

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1 INTRODUCTION

Many structures in Civil Engineering can be improved using Preflex beams. Tour Du Midi (1967) in Belgium is a High-rise structure used preflex beams because of its tensile and compressive benefits. Preflex beams perform well in flexural behavior and have large load bearing capacities. We can improve flexural strength of preflex beams with the use of SFRC.

Preflex girders are an innovative composite member that can support bridges and buildings that experience large service loads. There is very limited research in the area of preflex SFRC encased steel beams. Upward cambering increases the flexural behavior by introducing preflexing loads to the steel portion of the beam before construction. Encasing the beam with SFRC steel sections under this tension creates the composite beam. This preflex hybrid structure contains all the properties that are beneficial from concrete and steel.

This study progressively expanding on the benefits of preflex beams. The exploration of the two innovations in one composite structure provides better performance in flexural strength and less construction cost. The obtained results are compared to conventional longitudinally reinforced concrete beams without transverse reinforcement (SFRC).

1.1 Objectives

The main objective of this research is to study the flexural behavior of SFRC encased steel joist straight and preflex beams and compare the results to see how preflexing the beam improves the overall performance of beam relative to straight beam. The objective of this research consists of experimental study completed in two parts. The first part is to analyze straight beams with double angles and HSS sections. The second part is to preflex the beam and analyze it for the same parameters of steel fiber as done for the straight beam. Targets for each study are to collect the load-displacement values from experimental procedure to see how cambering contribute to a change in load capacity and to the midspan displacement. To accomplish these objectives, a laboratory testing of SFRC material is done to find compression, modulus of rupture and tensile strength.

1.2 Research Contribution

Bridge design industries will benefit from the research development of this field to save cost and design efforts for structures such as long spanning bridge girders. Design codes such as ACI (American Concrete Institute), ASCE (American Society of Civil Engineers), and AASHTO (American Association of State Highway and Transportation) have limited research on Preflex SFRC Encased Steel Composite Beams. Experiments available on this type of beams are beneficial for long span bridge girders. Flexural Capacity of beams can be increased by introducing upwards camber which also improve bridges that require high load bearing capacity girders. Preflex beams are lighter in weight beams and experience less deflection than commonly used prestressed concrete. With the use of Preflex SFRC Encased Steel Composite Beams, Bridge-design industries will find a decrease in construction cost and labor. Operation is made simpler because preflex technology can be applied during fabrication. More research on the benefits of preflex composite beams can improve on the results found and discussed in this study.

1.3 Outline for Thesis

This thesis is organized into the eight following chapters:

Chapter 1 – Introduction: Defines the two major studies that this thesis focuses on, and approaches that will be taken to achieve each study.

Chapter 2 – Literature Review: This chapter presents the background of experimental study and FEA of Preflex Beams and SFRC. This chapter discusses how preflex SFRC encased beams enhance current design methods in structural engineering.

Chapter 3 – Experimental Program: This chapter presents design and fabrication of preflex and straight beam specimens, test set-up and procedure, curing of all the specimens in this study.

Chapter 4 – Experimental Results and Analysis: This chapter presents the load-deflection response of preflex and straight beams with SFRC, compressive and tensile strength of cylinder specimens.

Chapter 5 – Summary and Conclusions: The findings of this research are summarized, and the conclusions are presented.

2 LITERATURE REVIEW

2.1 Advantages of Steel Fibers

Study on Steel fibers in reinforced concrete (SFRC) started to grow in 1960's. To reduce obstructive columns in high rise buildings, SFRC can be used. SFRC can also be used in long span bridges and to fulfil other engineering demands [16]. Steel fibers in concrete helps to reduce factors like early damage in structural members, maintenance of structural members and overall construction cost.

SFRC is very useful innovation in an engineering field. It can be used to strengthen the weaker mechanical properties of concrete. Modulus of rupture and ductility can be increased with the use of SFRC. While cracks in the concrete and construction and labor costs can be minimize using steel fibers in concrete [10]. Steel is light in weight which possesses higher capacity than concrete [11]. Normal concrete is very brittle while steel possesses ductility higher than concrete. As concrete is weak in tension, therefore low tensile allows the formation of “micro cracks” [13]. Concrete possesses less modulus of rupture (f_r) which results rapid cracks in concrete than steel, causing flexural failure. To avoid flexural and shear failure in structural members like beams, columns, and slabs, ACI code, chapters 6 and 13, provides requirements of longitudinal and transverse reinforcement (rebars and stirrups) [3]. Without changing material properties of concrete, steel rebars in concrete can be enhance the flexural capacity. Steel fibers can be added to concrete during mix design to create a hybrid material that performs well in compression and tension. These steel fibers can oppose the advancement of more cracks because of their residual strength, which is an advantage over normal concrete [15]. Figure 1 shows the difference in crack propagation between steel fibers in concrete and continuous concrete reinforcement.

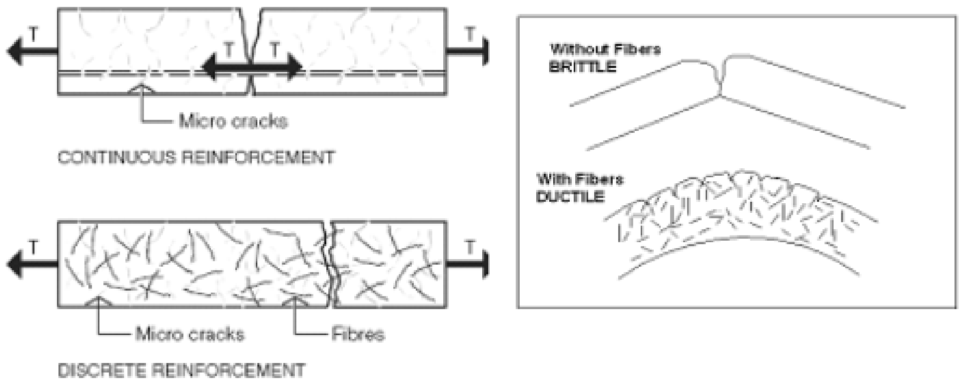

Figure 1 Steel Fibers in Concrete [10]

To maintain the workability of concrete, percentage of steel fibers added to concrete mix design should be maintain. The aspect ratio is also very important which can be calculated by fiber length (*l*) divided by diameter of fiber (*d*) [10].

2.2 Prestressed Beams

Prestressed concrete used in construction, substantially prestressed during production, which strengthens concrete against tensile forces. Concrete is weak against high tensile stress; therefore, flexural failure generates cracks in concrete [18]. To prevent such cracks in the concrete, prestressed concrete is used in the construction. Prestressing enhance the bending capacity of flexural members. Prestressing is done by applying tension to the rebars or tendons followed by prestress force, which generates upward camber in the beam. This upward camber helps to reduced overall deflection of the beam.

2.3 Preflex Beams

Preflex beams are pre cambered composite beams. Preflexing increases the bending capacity and stiffness of the beams and thus cracking decreases. Preflex girders have very high moment capacity, thus they can be used in bridge construction with heavy loads [18]. In the preflex beams, instead of tendons or rebars, steel joists are used. The process of preflexing is done by applying upward force over the span of the beam using propping and jacking systems [3]. The camber should be the amount of deflection that needs to be prevent [3].

A Finite Element Analysis study by Dr. Azzawi Nancy Varghese showed that preflex encased steel joists composite beams is beneficial structural members with enhance flexural capacity and the ability to reduces midspan deflection significantly [22]. Also, in comparison straight and preflex beam, the midspan deflection decreases by 35% [22]. A research by Hegger and Goralski shows the advantages of steel beams encased with normal concrete [12].

Experimental studies of moment-rotation re-analyzed using Finite Elements Method with ANSYS. This is a separate study, “Nonlinear Analyses Concrete Preflex Steel Beams Encased in Concrete” [8]. Experimental studies and FEM results are compared in this study. The FEA study examines the values of Moment-rotation curve for experimental, numerical study of straight beams and preflex beam are compared.

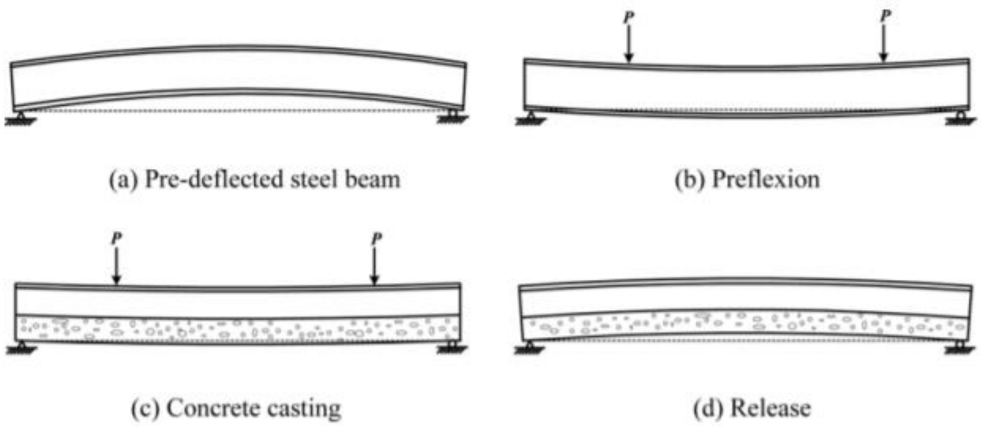

Figure 2 Preflex Beam Construction Stages

2.4 Advantages of Preflex Beams in Long Span Bridges

Long span bridges composed of either steel or concrete are susceptible to single point vulnerability and need to be designed against it [22]. From AASHTO LRFD section 6 on Steel Girders:

"*The criteria for a refined analysis is used to demonstrate that part of the structure is non-fracture critical has not yet been codified. Therefore, the loading cases to be studied, the location of potential cracks, degree to which the dynamic effects associated with a fracture are included in the analysis, and the fineness of the models and the choice of the element type should be agreed upon by the owner and the Engineer."* [1]

Girders in the long span bridges, combinations of the concrete and steel is used to decrease intense cracking. Preflex Encased steel joist composite beams can delay the progressive collapse by increasing the ductility of the members and postponing the crack propagation [22].

2.5 Finite Element Analysis of flexural behavior of preflex SFRC- Encased Steel Joist Composite Beams

A research by Dr. Raad Azzawi and Nancy Varughese investigates the behavior of encased steel composite beams within straight and preflex beams, using nonlinear analysis, ABAQUS FEA software has been adopted [22]. According to FEA, with upward camber of steel section, it is seen that preflex section can increase the ultimate load capacity by 10% while reduces the midspan deflection by 13% of the same beams without the preflex steel section [22]. Also, steel fibers play important role in the improvement of performance of the SFRC steel joist encased composite beams [22]. The addition of steel fibers will lead to a significant increase in tensile strength and modulus of rupture of concrete. Adding 1% steel fibers by volume can increase the load capacity by 33% and decrease midspan deflection by 70% relative to same beam using plain concrete. The increase in the steel fibers and cambering shows an improvement to the flexural capacity and cracking point of the beam, which will provide more strength to structures such s long span bridges [22].

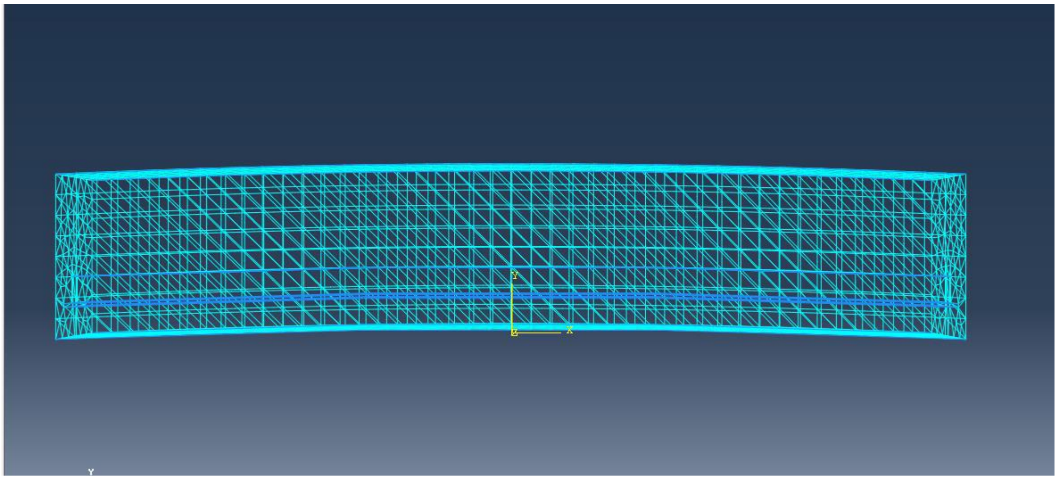

Figure 3 Preflex Beam in ABAQUS [22]

Table 1 Parametric Study I-Midspan Displacement Values [22]

Straight Beam Midspan Displacement (in)			
	Steel Fiber (%)		
Load (kips)	**0**	**0.5**	**1**
0	0	0	0
2	0.0034	0.0068	0.0026
4	0.0086	0.012	0.0062
6	0.015	0.015	0.011
8	0.025	0.018	0.0166
10	0.038	0.027	0.024
12	0.06	0.034	0.033
14	0.094	0.055	0.045
15	**0.46**	0.07	0.05
16		0.081	0.061
18		**0.3**	0.085
20			**0.23**

Table 2 Parametric Study II-Midspan Displacement Values [22]

Preflex Beam Midspan Displacement (in)			
	Steel Fiber (%)		
Load (kips)	**0**	**0.5**	**1**
0	0	0	0
2	0.0032	0.0026	0.0025
4	0.0078	0.0062	0.0057
6	0.013	0.01	0.0099
8	0.02	0.016	0.015
10	0.03	0.023	0.02
12	0.044	0.031	0.027
14	0.069	0.042	0.035
16	**0.3**	0.058	0.046
18		0.093	0.061
19		**0.25**	0.072
20			0.087
21			0.13
22			**0.2**

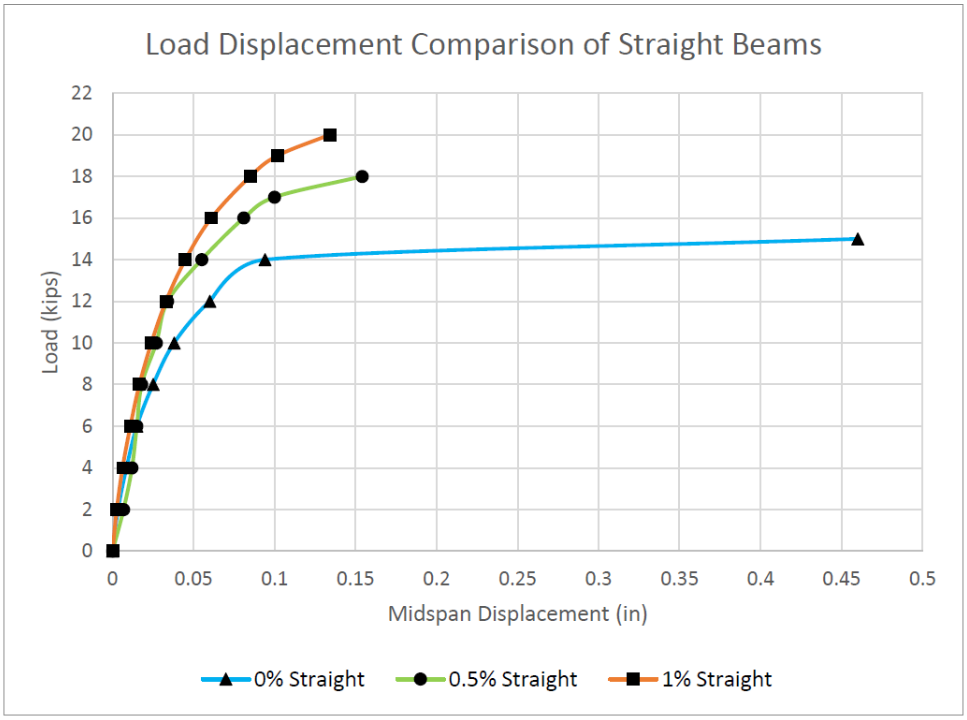

Figure 4 Load Displacement Comparison of Straight Beams [22]

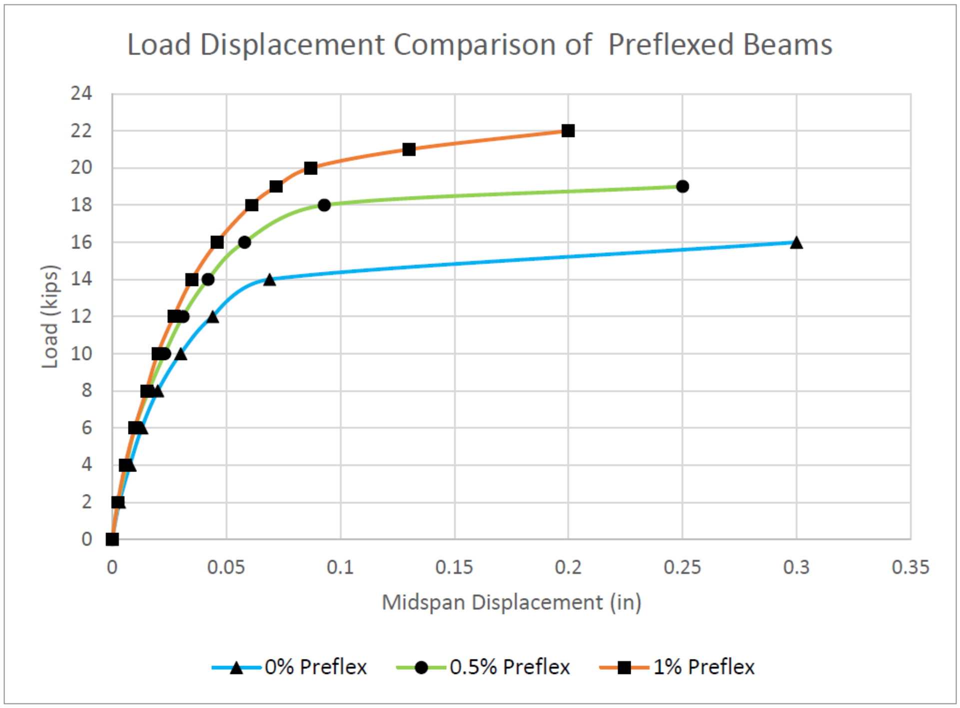

Figure 5 Load Displacement Comparison of Preflexed Beams [22]

3 EXPERIMENTAL PROGRAM

3.1 CONCRETE DESIGN MIXTURE

Based on given procedure in ASTM C192/C192M, material properties should be found [7]. Firstly, creating concrete mixture in the Civil Engineering Lab at UTA and add the volume friction, V_f. For 27cf batch, fine aggregate, cement, coarse aggregate, and water, must go into concrete mix. Quantities used in mixture of 27cf batch are shown in the table 1 and table 2. While the material properties of steel fibers are shown in table 3.

Table 3 Steel Fibers Material Properties

Length (in)	Diameter (in)	Tensile Strength (ksi)
1.3	0.02	174

3.2 FABRICATION OF TEST SPECIMENS

3.2.1 *Mixing Procedure*

Using above concrete mix design, mixing process has been done in The UTA civil Engineering Laboratory Building. Based on volume fraction of steel fibers (V_f) with 0% V_f of steel fibers, 0.5% V_f of steel fibers, 1% V_f of steel fibers, three batches of concrete been made. As per ASTM suggest for each test, the Freshly made concrete in the concrete mixer poured into mold [6]. Consolidation of concrete should be done to ensure to reduce voids in concrete. It will help to prevent honeycombing of concrete. Consolidation of concrete usually done by vibration, tapping. Tables 4 through 7 shows the mix design that casted and to be tested.

Table 4 Material Properties for Concrete Mix

	Cement	Fine Aggregate	Coarse Aggregate
Specific Gravity	3.15	2.82	2.5
Density (lb/cf)	196	176	160.68
Fineness Modulus		2.98	
Dry Rodded Weight (lb/cf)			99.2
Absorption Capacity %		0.8	2.5
Moisture Content %		0.13	1.1

Table 5 Mix Proportions for 27cf Batch for 0% Steel Fibers

Material	SSD (lbs)	Moisture Correction (lbs)	Mix Proportion (lbs)
Cement	680	NA	680
Coarse Aggregate	1263	17	1246
Fine Aggregate	1752	12	1741
Water	306	29	335
Steel Fibers	0		0
TOTAL	4001		4001

Table 6 Mix Proportions for 27cf Batch for 0.5% Steel Fibers

Material	SSD (lbs)	Moisture Correction (lbs)	Mix Proportion (lbs)
Cement	680	NA	680
Coarse Aggregate	1263	17	1246
Fine Aggregate	1752	12	1741
Water	306	29	335
Steel Fibers	20		20
TOTAL	4001		4001

Table 7 Mix Proportions for 27cf Batch for 1.0% Steel Fibers

Material	SSD (lbs)	Moisture Correction (lbs)	Mix Proportion (lbs)
Cement	680	NA	680
Coarse Aggregate	1263	17	1246
Fine Aggregate	1752	12	1741
Water	306	29	335
Steel Fibers	40		40
TOTAL	4001		4001

According to ASTM C143, slump tests are performed. With the help of 8" base, 12" tall and 4" top slump cone, these tests to be done. This cone is to be placed on solid and even base and should be filled with freshly made concrete in three equal layers. Every layer is to be rodded 25 times to assure compaction. After the third layer, the cone is carefully lifted. The true slump was measured from the top of the cone with the help of tape measure. As more fibers in the design mix, the workability was seen to be decrease. Slump test of mix has true slump of 3" for 1% V_f volume fraction of steel fibers. '

Figure 6 Slump Test

Figure 7 Slump Test of Concrete

Table 8 Slump Test Results

Steel % Concrete Mixture	% Fibers	Water/Cement Ratio	Slump Measurement (in)
PC 0%	0%	0.45	7
SFRC 0.5%	0.5%	0.45	4.5
SFRC 1%	1%	0.45	3

3.2.2 *Test Specimens*

The concrete molds for the compression test are nine cylinders of 4”x 8”. Three cylinders has been casted for 0%, 0.5% and 1% of volume fraction of steel fibers each. While molds for beams are 6”x 6”x 20” for the flexure test. The beams have been casted for double angles encased in concrete beams for 0%, 0.5% and 1% volume fraction of steel fibers, three beams for each. Upward camber of 0.5” is been introduced to beam. After pouring of concrete has been completed, specimens were cured within curing room in Civil Engineering Laboratory at UTA. Specimen left for curing for 28 days.

Figure 8 Cutting of HSS Steel Joists

Figure 9 Casting of Cylinder Specimen

Figure 10 Casting of Beam Specimen

Figure 11 Cylinders after 28 days

Figure 12 Humidity Controlled Room

3.3 TEST SET-UP AND PROCEDURE

3.3.1 *Compression Tests*

Compressive strength of concrete can be figure out using applying continuous load over the concrete cylinders until the failure occurs. These tests performed using compression testing machine in the CLEB at UTA. ASTM C39 gives use the procedure for the testing the cylinders of small sizes (4"x8") [4]. After the curing for 28 days, cylinders are ready to test. Place the concrete cylinder in the compression testing machine vertically on the platform. Apply the load continuously with rate of 300 lbs/sec without any shock at the top of cylinder until the specimen fails. Record the maximum load (***P***) where specimen gets failed. To calculate f_c', which the compressive strength can be found by equation 1. ***r*** represents radius of the cylinder.

$$F_c' = \frac{P}{\pi r^2} \qquad \text{Equation (1)}$$

Compressive Strength of Concrete

Figure 13 Cylinder Compression (4” x 8”) Test Setup

3.3.2 *Split Tests*

Split tests concrete is to determine tensile strength of concrete. ASTM C496 (Standard Test Method of Cylindrical Concrete Specimen) gives procedure for split tests for concrete cylinders. Size of the cylinder is 4” x 8”. The cylinder should be placed on the platform vertically and should apply the load across length of the cylinder with rate of 170 lbs/sec as shown in the figure [7]. Load should be applied without any shock.

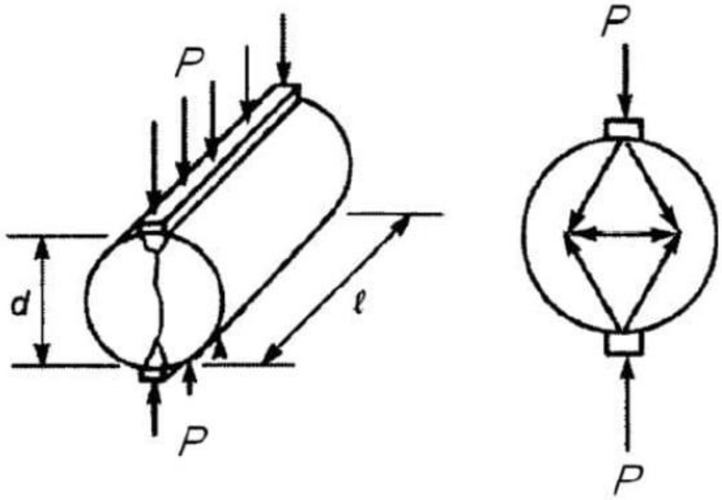

Figure 14 Split Test Typical Setup

Figure 15 0.5% Split Test

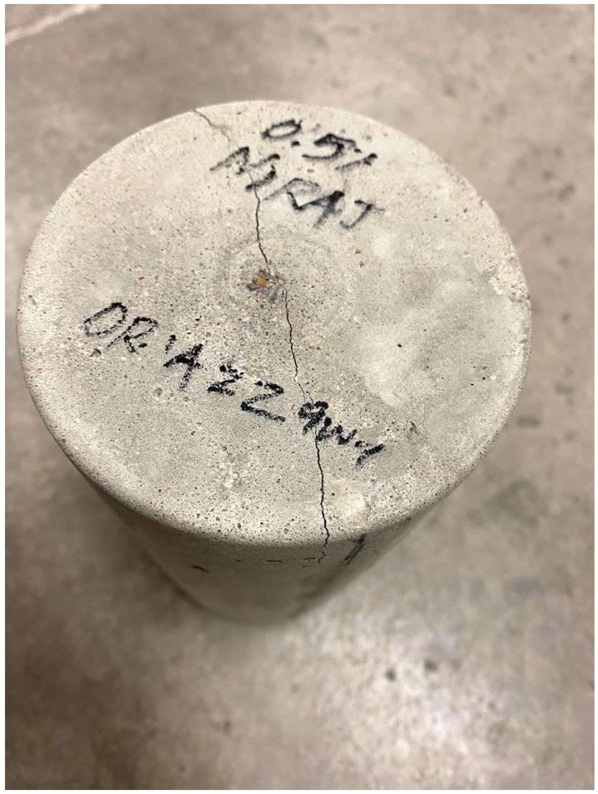

Figure 16 Cylinder at Ultimate Load

Record the breaking ultimate load ***P*** when specimen fails. Tensile strength of the specimen is calculated using equation 2.

$$ft = \frac{2P}{\pi LD} \qquad \text{Equation (2)}$$

Tensile Strength of Concrete

Where, $\boldsymbol{f_t}$ is the tensile strength of concrete in psi, ***L*** is the length of the cylinder and ***D*** is the diameter of the cylinder.

3.3.3 *Modulus of Rupture Test*

As per ASTM C78, three-point loading flexure tests is performed. Beams of size 6"x6"x20" are used. In three-point loading test method, half of the load is applied to each third of the beam's span length. In this test, maximum stress is at center 1/3 portion of the beam. The two-point loads are 6" apart from each other. The beam is supported 1" from the end. The load should be applied without any shock with the rate of 0.04 in/min. The breaking load (***P***) is then recorded. The flexural strength of the concrete is calculated by equation (3).

$$fr = \frac{PL}{BD^2} \qquad \text{Equation (3)}$$

Modulus of Rupture of Cylinder

Where, f_r is modulus of rupture in psi, ***L*** is the beam span, ***B*** is width of the beam and ***D*** is the height of the beam.

Figure 17 Modulus of Rupture Test Setup

Figure 18 Material Test System (MTS)

Figure 19 Specimen at Ultimate Load

3.3.4 *Steel Joist Properties*

3.3.4.1 Steel Angle Section Properties

Table 9 Steel Angle Section Properties

Size of Steel angle	Yield Strength, ***Fy*** (psi)	Ultimate Strength ***Fu*** (psi)	Elastic Modulus ***Es*** (ksi)
1.5" x 1.5" x 3/16"	36000	73000	29000

3.3.4.2 Steel HSS Section Properties

Table 10 Steel HSS section Properties

Size of HSS	Yield Strength, ***Fy*** (psi)	Ultimate Strength ***Fu*** (psi)	Elastic Modulus ***Es*** (ksi)
1.5" x 1.5" x 3/16"	36000	73000	29000

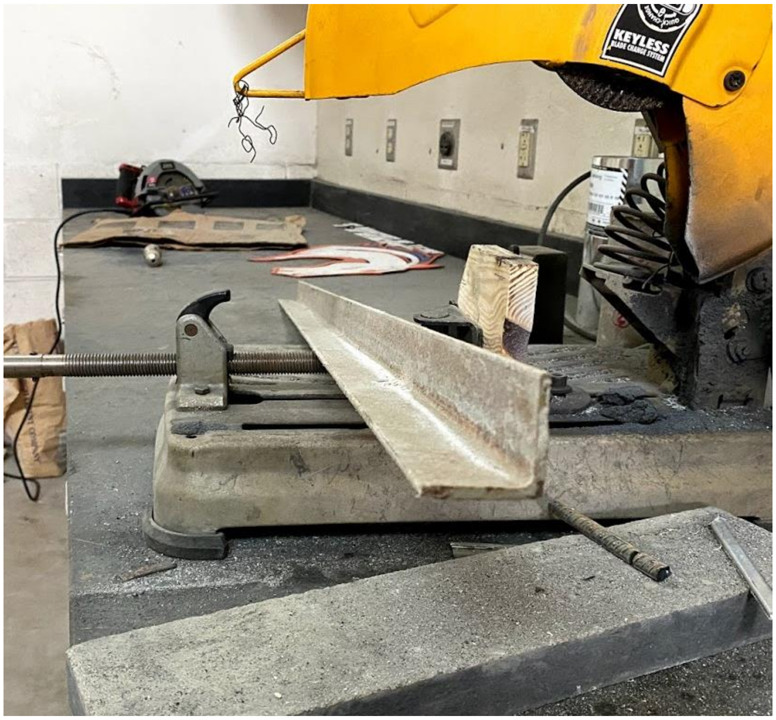

Figure 20 Steel Angle

Figure 21 HSS Steel Section

3.3.5 *Flexure Test of Encased Steel Joist Concrete Beams*

The main purpose of flexure test is to measure flexural modulus of concrete. Flexural testing measures the required force required to bend a beam. Flexural modulus is the indicative of how much a beam can deform before permanent deflection. The flexural test on the beams is conducted using procedure giving ASTM C293 with center point load test method [24].

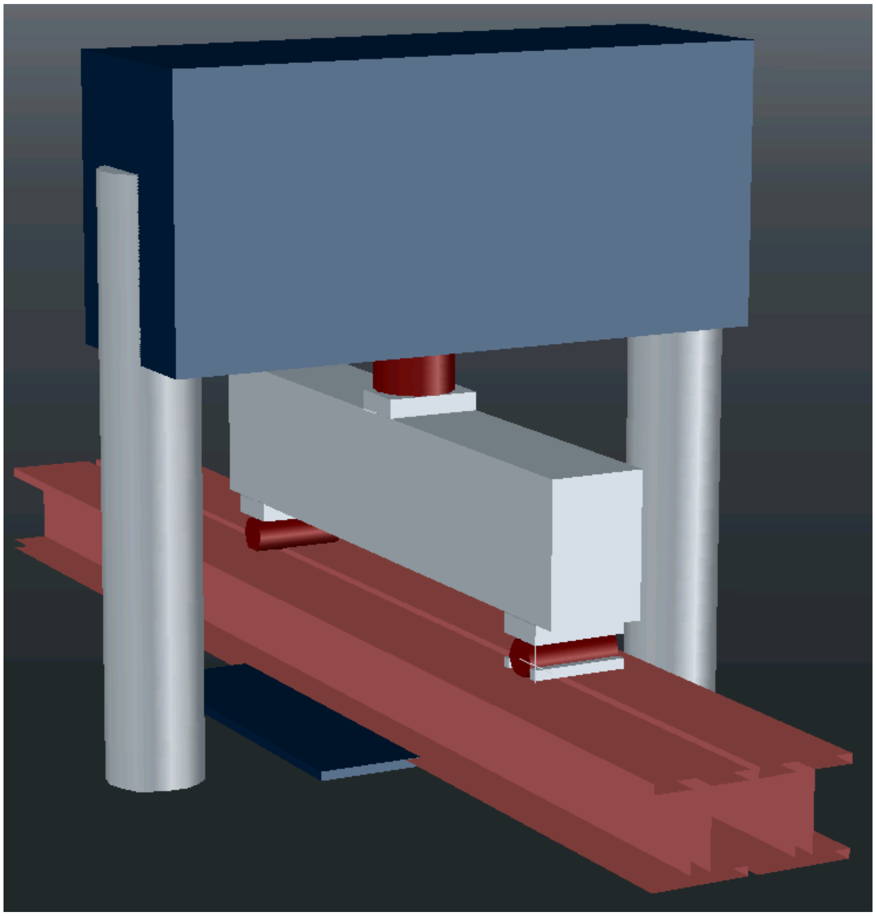

Figure 22 Typical test setup for Steel Joists Encased in Concrete Beams

Figure 23 Test setup for Flexure test

The flexure tests were for the Steel joist encased concrete beams. These beams tested using a 400-kip compression testing machine. The setup used for this test is simply supported. The machine has two cross-heads, at the top and at the bottom. Two steel beams are set at the bottom platform as shown in the figure 20. Roller has been placed on one steel beam while simple support has been placed on the other steel beam. The distance between these two supports is kept 18". While at the top platform of the machine, a roller has been attached. This roller is the loading point for the beam in the middle.

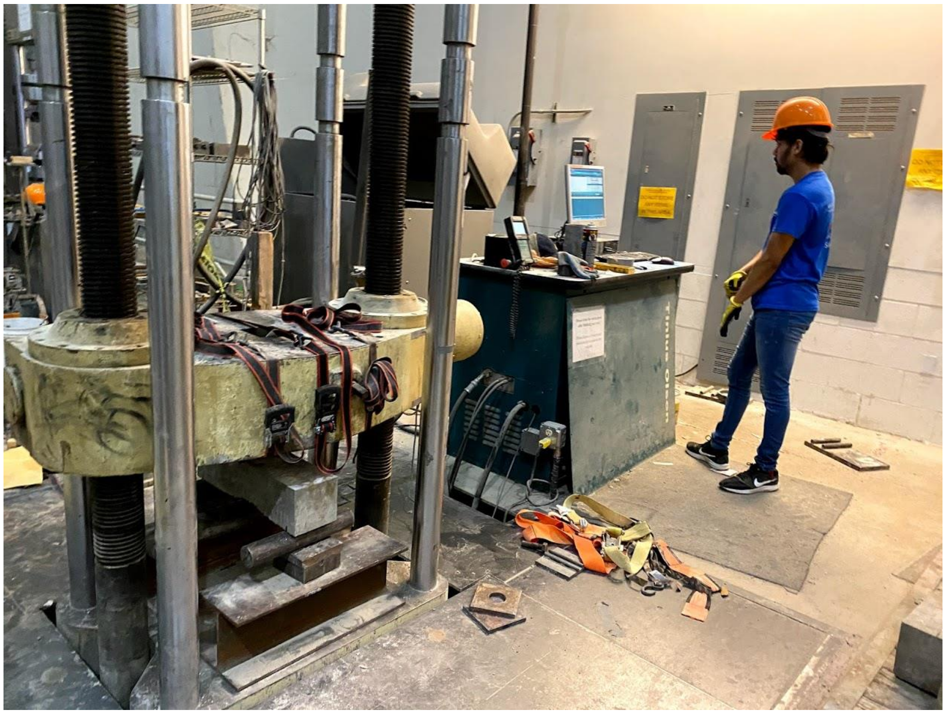

Figure 24 Flexural Testing of Steel Joists Encased in Concrete Beams

After the test setup is done, the beam is placed on two loading points. The hand finished surface of the specimen should not be in contact with upper loading point. This will ensure an acceptable contact between the specimen and loading points.

Once the setup is done, as shown in the figure 21, start the machine. Machine will come down to apply the load on the member. Load the member continuously with constant rate of 0.04 in/minute. Load should be applied without any shock.

The figure below shows the setup of for flexural testing of beam. With the constant rate of 0.04 in/minutes, for each volume fraction, three specimens have been tested. Record the ultimate load (***P***) when beam starts to crack.

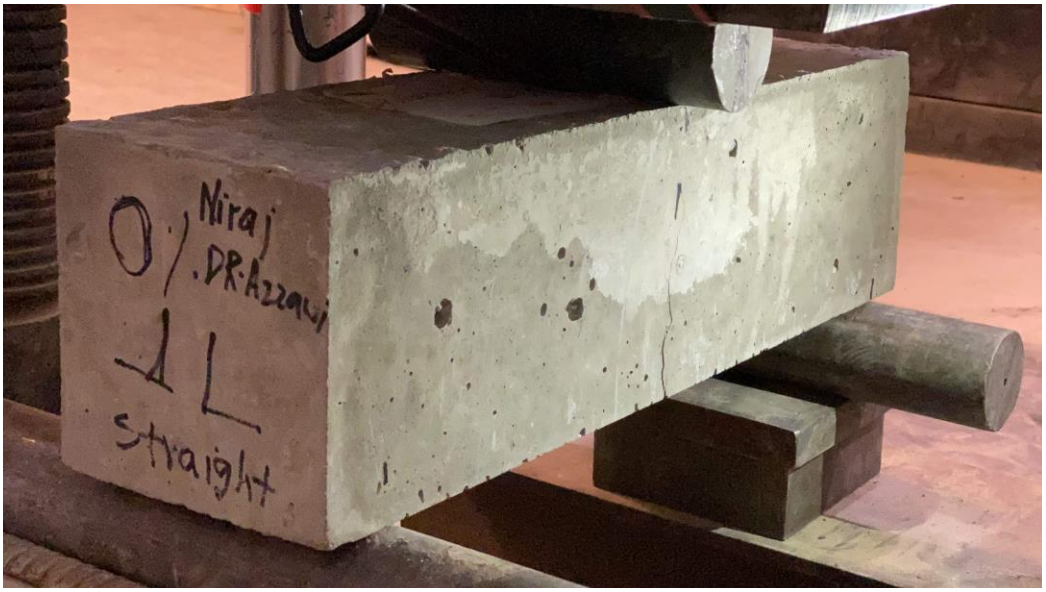

Figure 25 Beam failure and Cracks at Peak Load for 0%

Figure 26 Beam failure and cracks formation for Preflex Beam at Peak Load 0.5%

Figure 27 Beams failure and crack formation of 1.0% straight beam at peak load

Figure 28 Flexural Test Setup for Concrete Beams

Figure 29 Flexural Test Setup for Concrete Beams

Figure 30 Flexural Test Setup for Concrete Beams

4 EXPERIMENTAL RESULTS

4.1 SFRC MATERIAL PROPERTIES

4.1.1 *Compression Test of Concrete*

Values of compression strength of concrete found from lab testing has been summarized in table 10.

Table 11 Compression Test of Concrete

Compression Strength of Concrete, f_c' *(psi)*			
Volume fraction of Steel Fibers	0%	0.5%	1%
Cylinder 1	3230.54	3987.45	4692.18
Cylinder 2	3056.76	4356.32	4540.59
Cylinder 3	3387.65	4310.38	4789.26
Average f_c' (psi)	**3224.98**	**4218.05**	**4674.01**

Adding 0.5% steel fibers in concrete increases compressive strength by 30%, while adding 1% steel fibers in concrete increases compressive strength by 45%. This shows improvement in compressive strength can see by adding steel fibers in concrete.

4.1.2 *Split test for Concrete*

Table 11 summarize the tensile strength of concrete derived from lab testing. Results showed that addition of 0.5% by volume of steel fibers in concrete increases tensile strength by 25%. While, increasing steel fibers to 1% by volume of steel fibers increases tensile strength by 33%.

Thus, adding steel fibers in concrete significantly improves tensile strength of concrete.

Table 12 Compression Test of Concrete

Tensile Strength of Concrete, f_t' *(psi)*			
Volume fraction of Steel Fibers	0%	0.5%	1%
Cylinder 1	266	349	336
Cylinder 2	284	335	375
Cylinder 3	251	315	360
Average f_t' (psi)	**267**	**333**	**357**

4.1.3 *Modulus of Rupture of Concrete*

Table 13 Modulus of Rupture of Concrete

Modulus of Rupture of Concrete, f_r *(psi)*			
Volume fraction of Steel Fibers	0%	0.5%	1%
Beam 1	580	590	805
Beam 2	662	673	830
Beam 3	624	792	703
Average f_r (psi)	**622**	**685**	**779**

Just like compressive and tensile strength, Modulus of Rupture of concrete also increases with increase in the volume of steel fibers in concrete. Table 12 shows the values of modulus of rupture of concrete.

Modulus of Rupture increases 10% by adding 0.5 % steel fibers by volume in concrete. While addition of 1% steel fibers by volume increases modulus of rupture by 25%. Above results showed that, material properties of concrete increases with the increase in the volume fraction of steel fibers.

4.2 FLEXURE TEST OF ENCASED STEEL JOIST IN COMPOSITE BEAMS

Table 14 through 17 summarizes the results of flexure tests of Steel Joists encased in Concrete Beams with different volume fraction of steel fibers in concrete.

Experimental Study- Midspan Displacement Values

The load is applied on the beam at the center of the beam with a rate of 0.04 in/min. The maximum deflection will occur at the center of the beam as the load is applied on the middle of the beam. The values from experimental study can be seen in Table 14 through 17.

Table 14 Flexure Strength of Steel Angles Encased Concrete Straight Beams

Fiber Volume Fraction %	Specimen	Experimental Peak Load (lbs)	Numerical Analysis Peak Load (lbs)	Deflection by Experiment (in)	Deflection by Numerical Analysis (in)
0 %	1	13500		0.58	
	2	12650		0.57	
	3	11980		0.52	
	AVG.	**12710**	**15000**	**0.56**	**0.46**
0.5 %	1	15989		0.47	
	2	14354		0.40	
	3	15073		0.43	
	AVG.	**15108.33**	**18000**	**0.43**	**0.3**
1.0 %	1	17080		0.32	
	2	17650		0.35	
	3	16040		0.31	
	AVG.	**16923.33**	**20000**	**0.33**	**0.23**

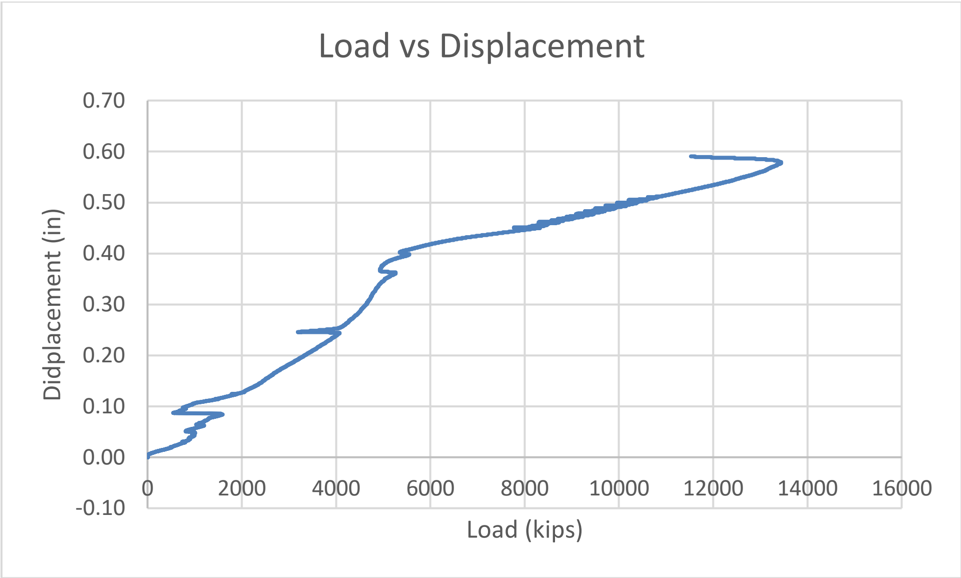

Figure 31 Load vs Displacement Graph for 0% Steel Fiber Straight Beam #1

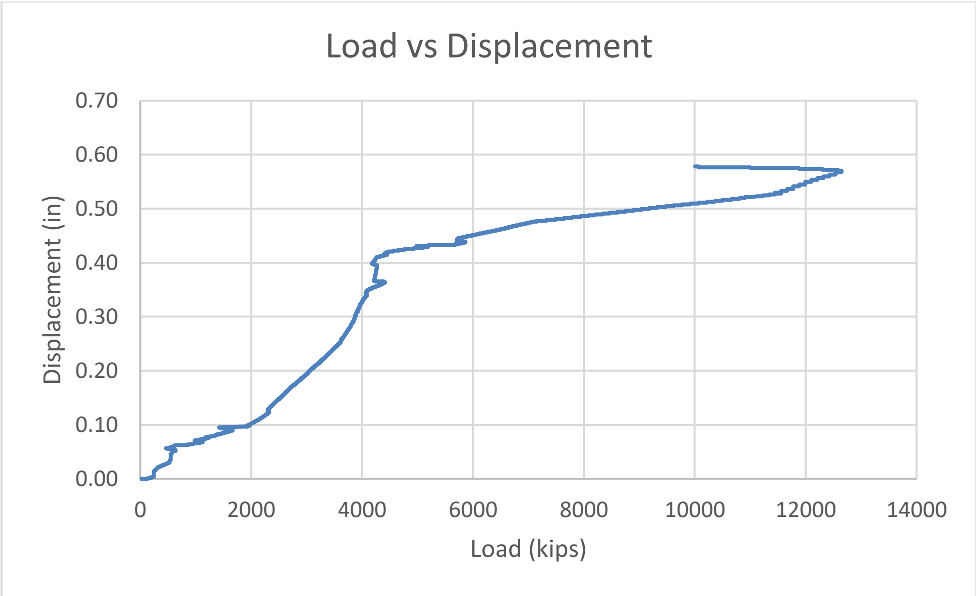

Figure 32 Load vs Displacement Graph for 0% Steel Fiber Straight Beam #2

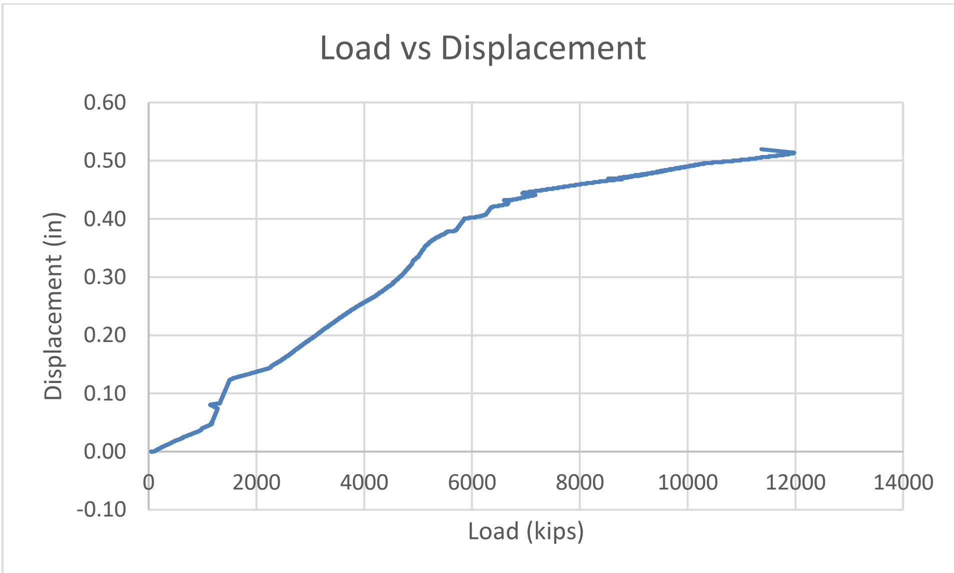

Figure 33 Load vs Displacement Graph for 0% Steel Fiber Straight Beam #3

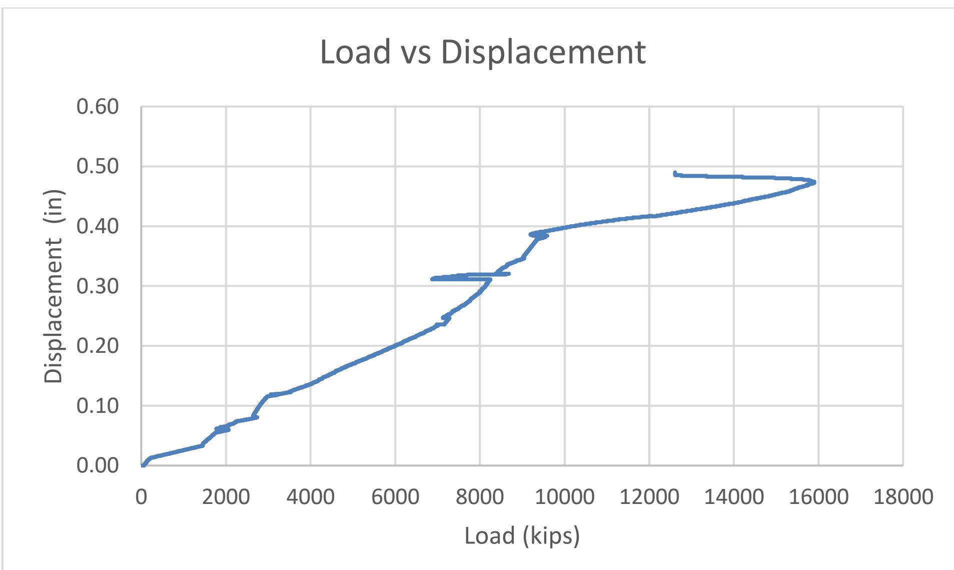

Figure 34 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam #1

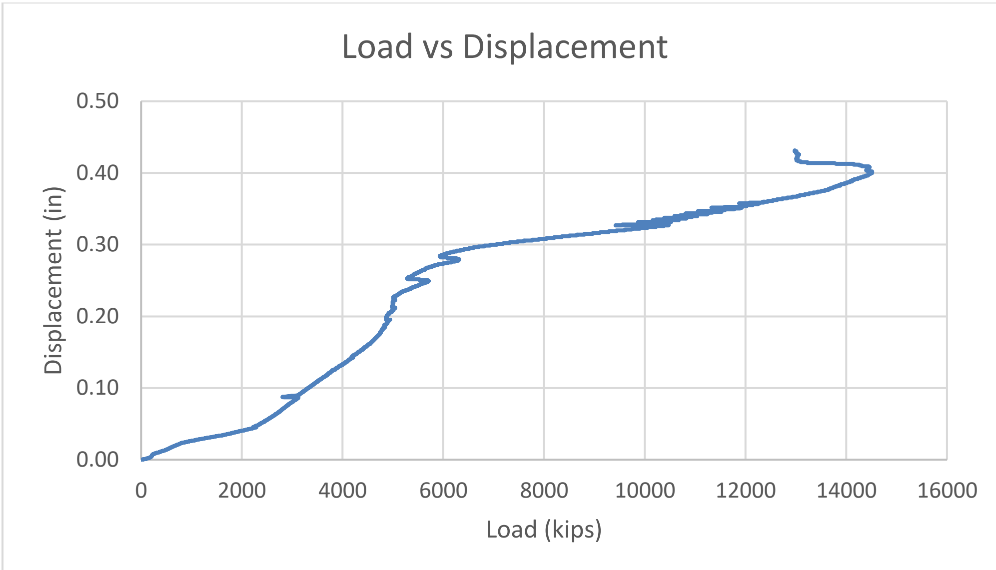

Figure 35 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam #2

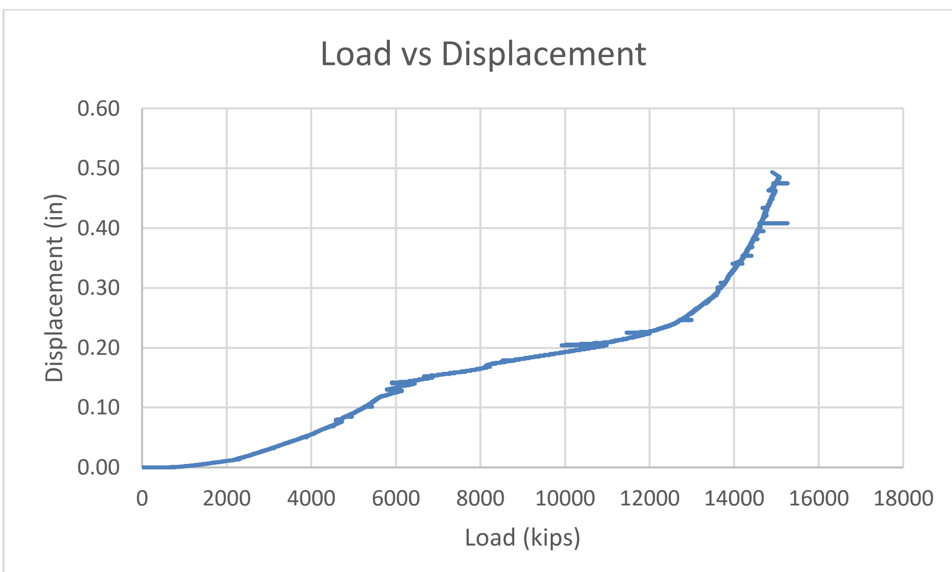

Figure 36 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam #3

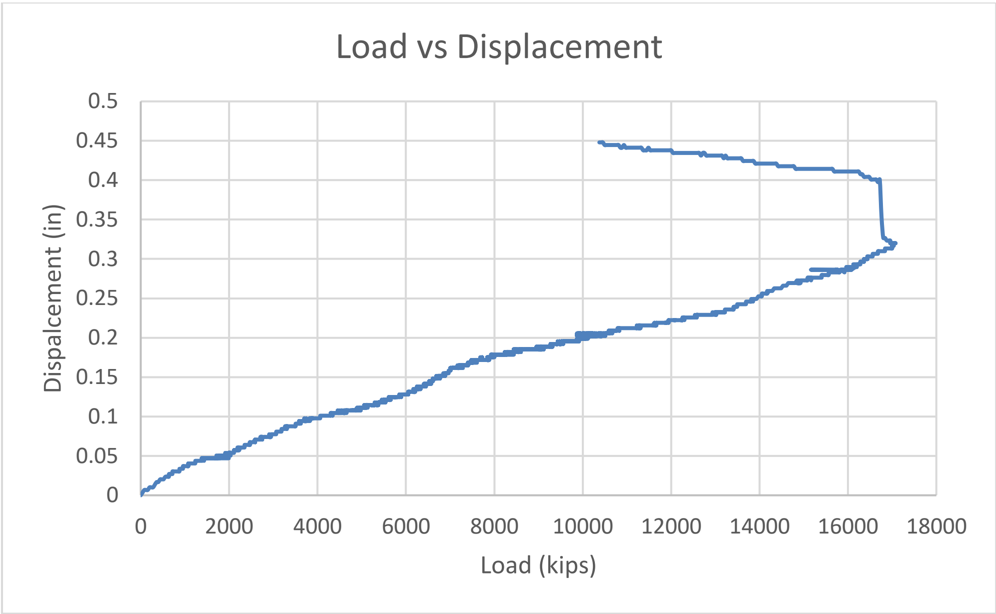

Figure 37 Load vs Displacement Graph for 1.0% Steel Fiber Straight Beam #1

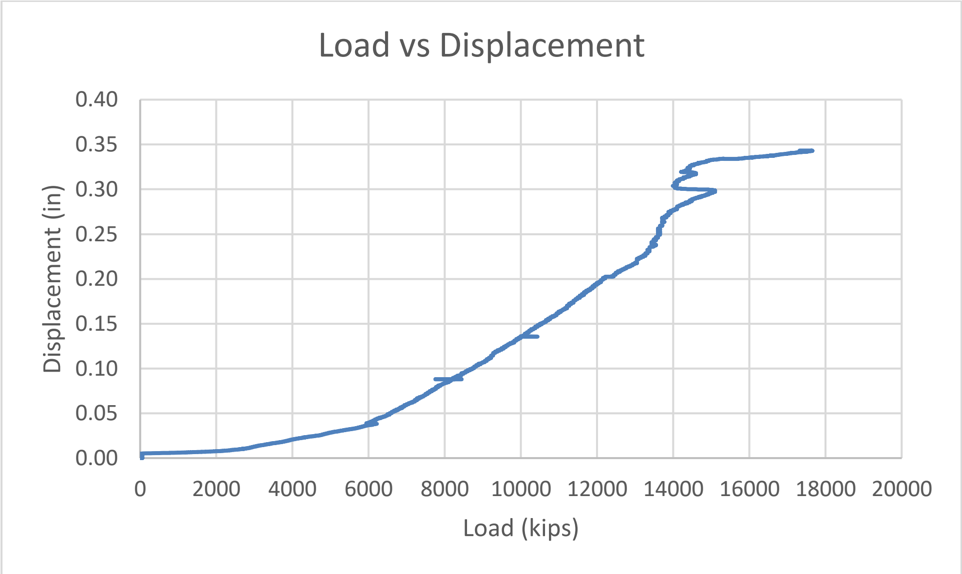

Figure 38 Load vs Displacement Graph for 1.0% Steel Fiber Straight Beam #2

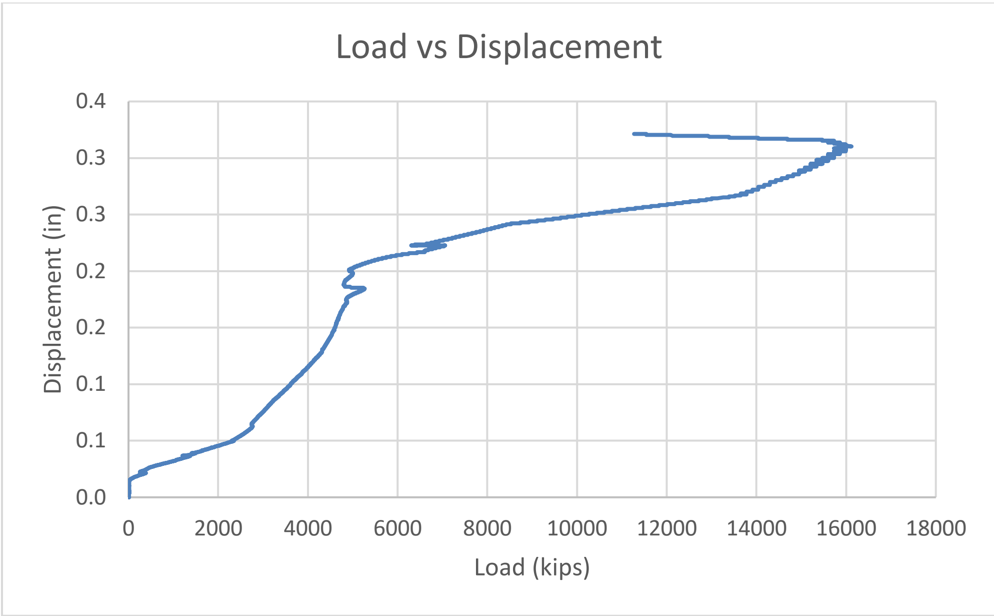

Figure 39 Load vs Displacement Graph for 1.0% Steel Fiber Straight Beam #3

Table 15 Flexure Strength of Steel Angles Encased Concrete Preflex Beams

Fiber Volume Fraction %	Specimen	Experimental Peak Load (lbs)	Numerical Analysis Peak Load (lbs)	Deflection by Experiment (in)	Deflection by Numerical Analysis (in)
0 %	1	13500		0.40	
	2	14680		0.43	
	3	13930		0.45	
	AVG.	**14060**	**16000**	**0.42**	**0.3**
0.5 %	1	15830		0.34	
	2	17880		0.36	
	3	16917		0.32	
	AVG.	**16876**	**19000**	**0.34**	**0.25**
1.0 %	1	19960		0.30	
	2	19650		0.27	
	3	17590		0.26	
	AVG.	**19066.67**	**22000**	**0.276**	**0.2**

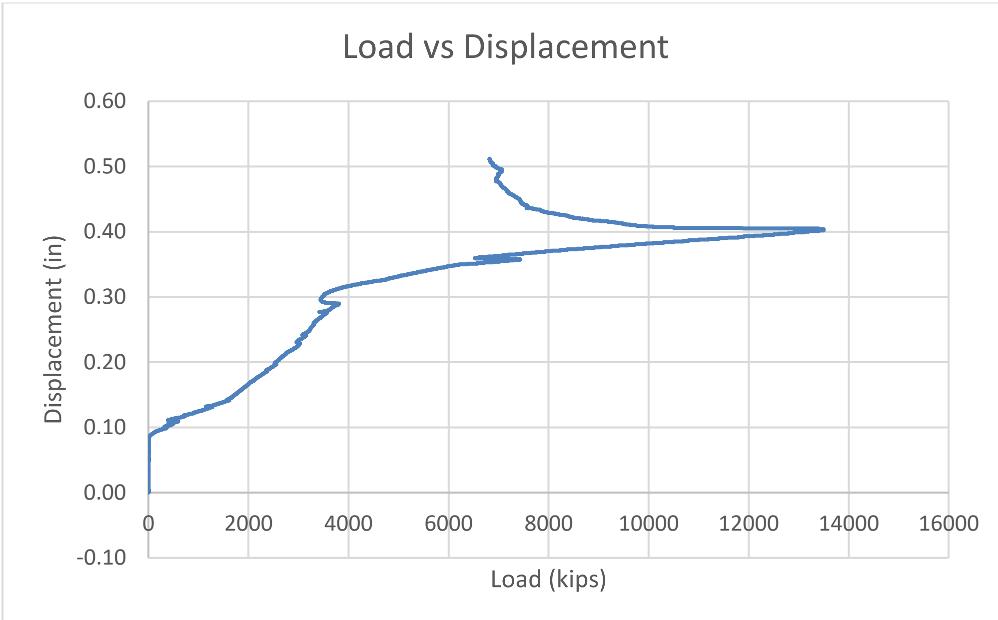

Figure 40 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam #1

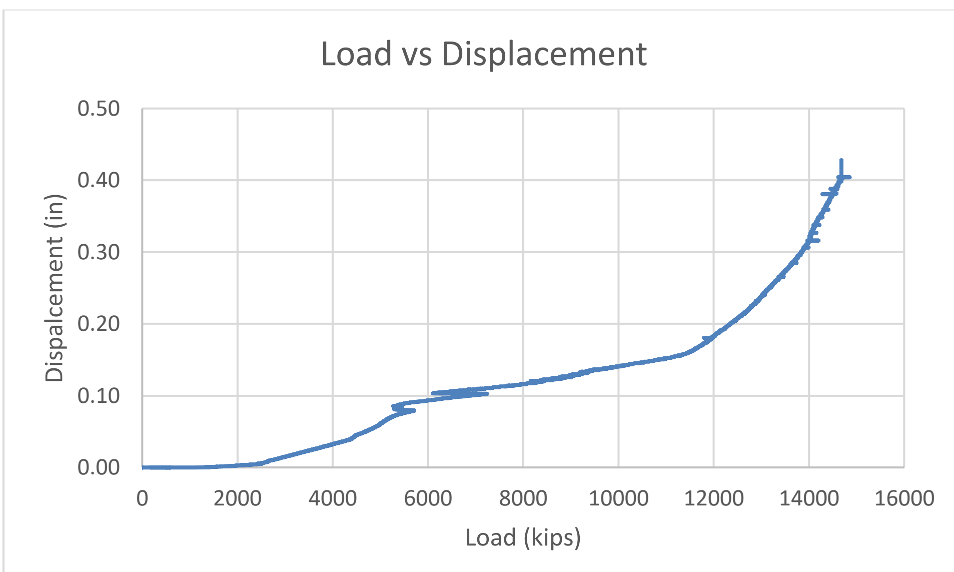

Figure 41 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam #2

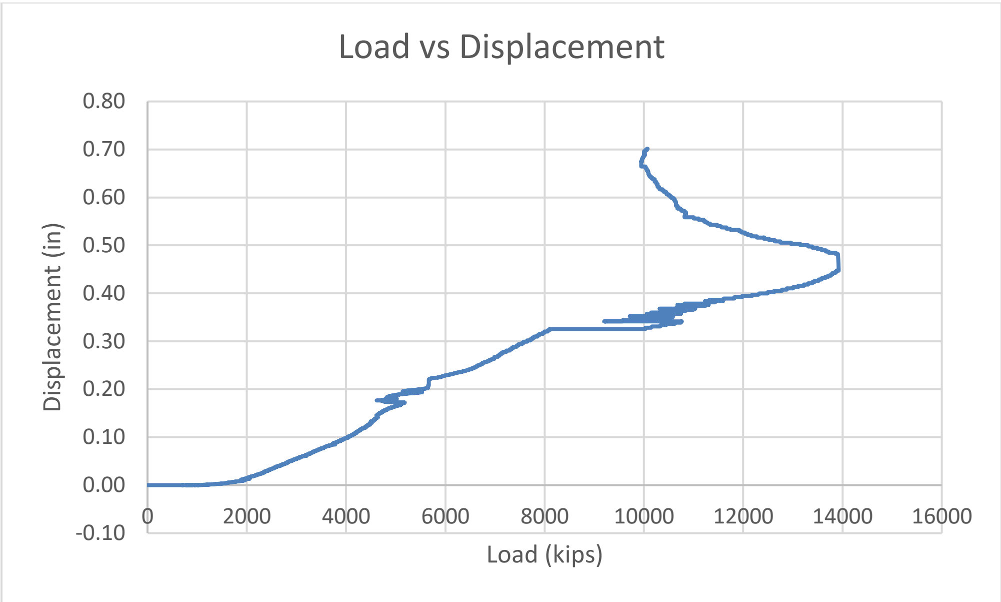

Figure 42 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam #3

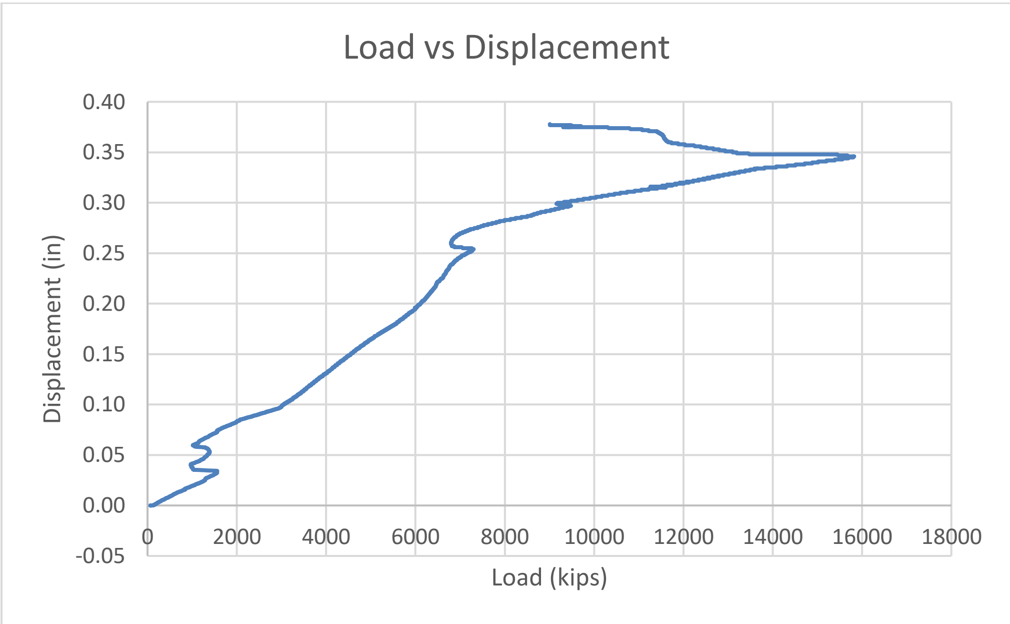

Figure 43 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam #1

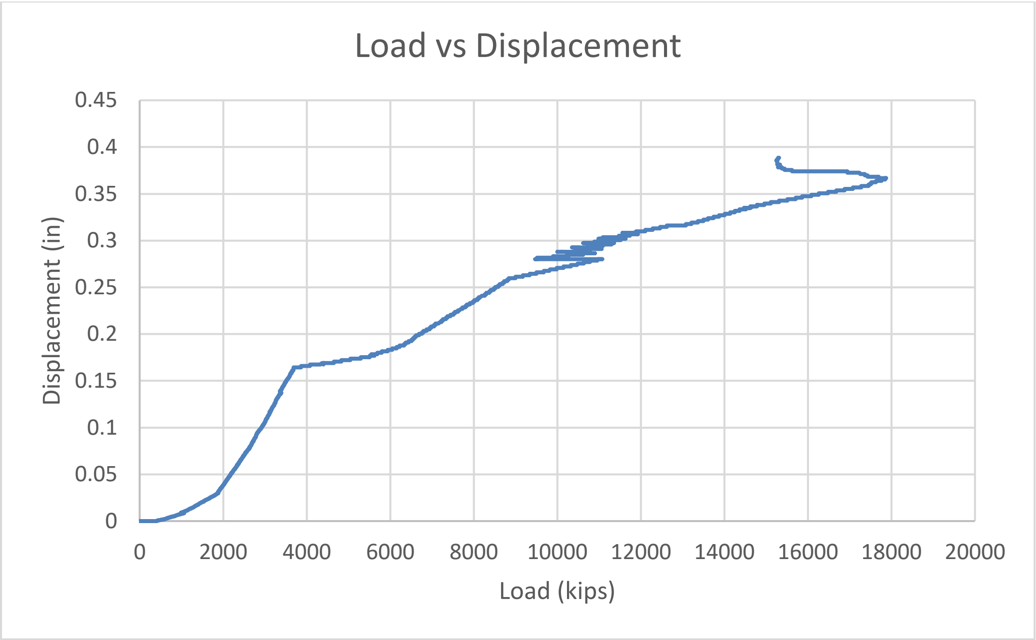

Figure 44 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam #2

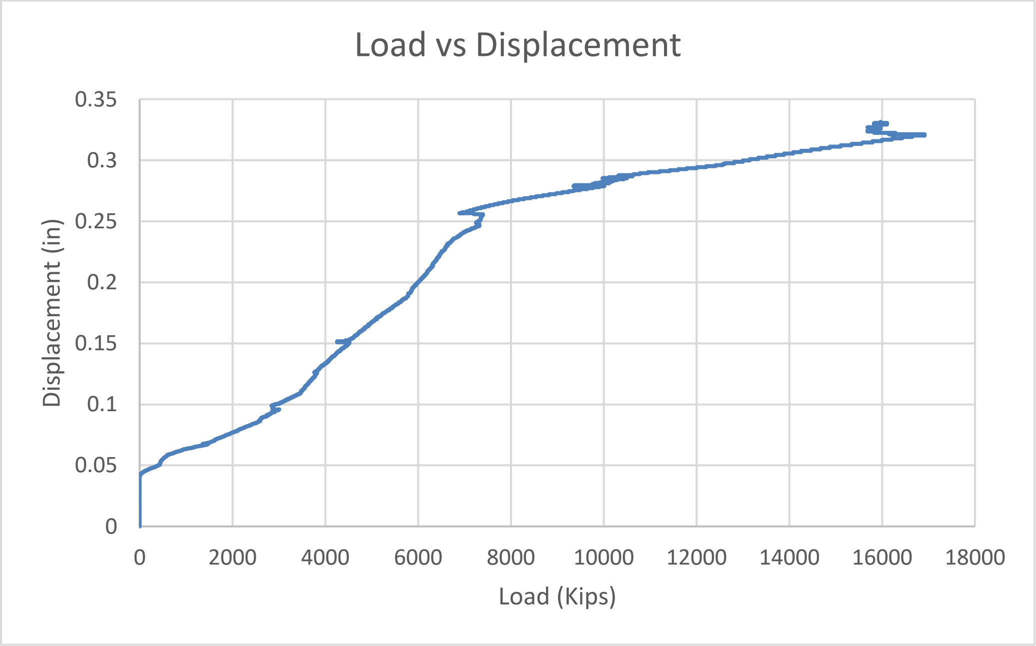

Figure 45 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam #3

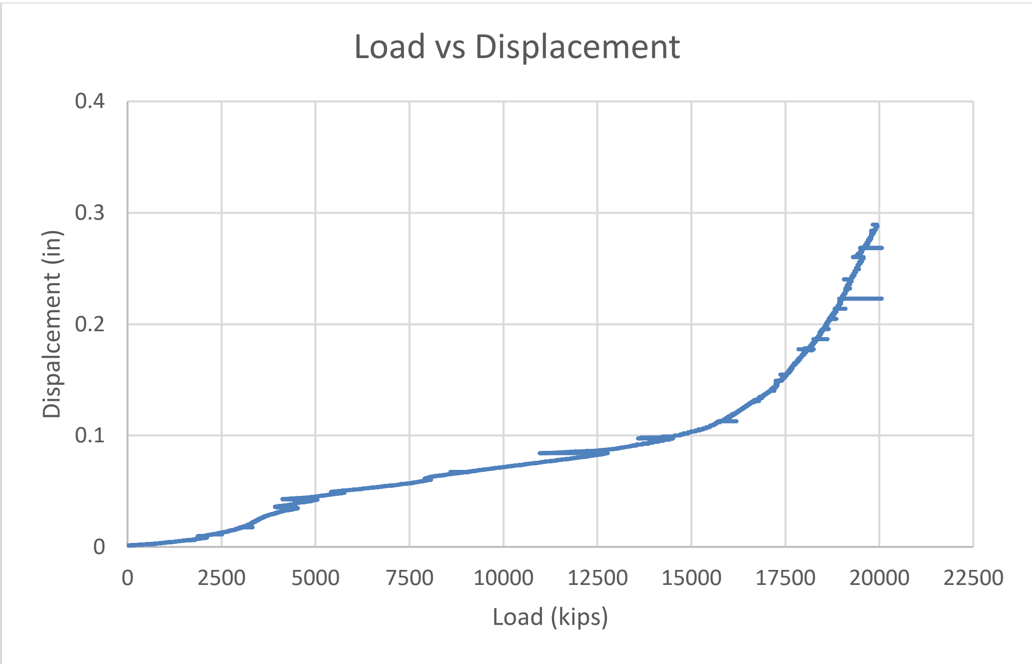

Figure 46 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam #1

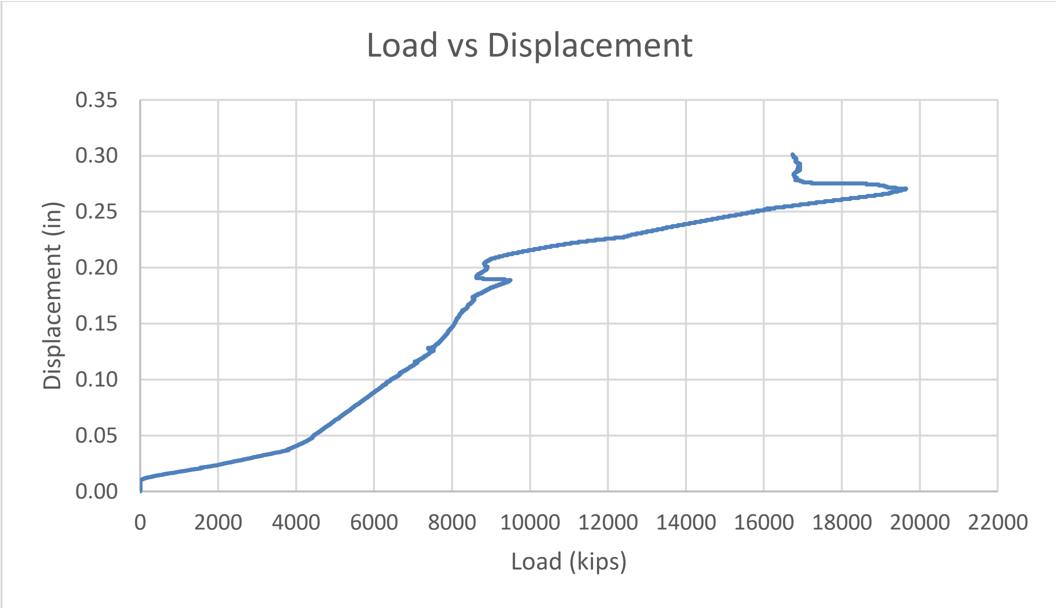

Figure 47 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam #2

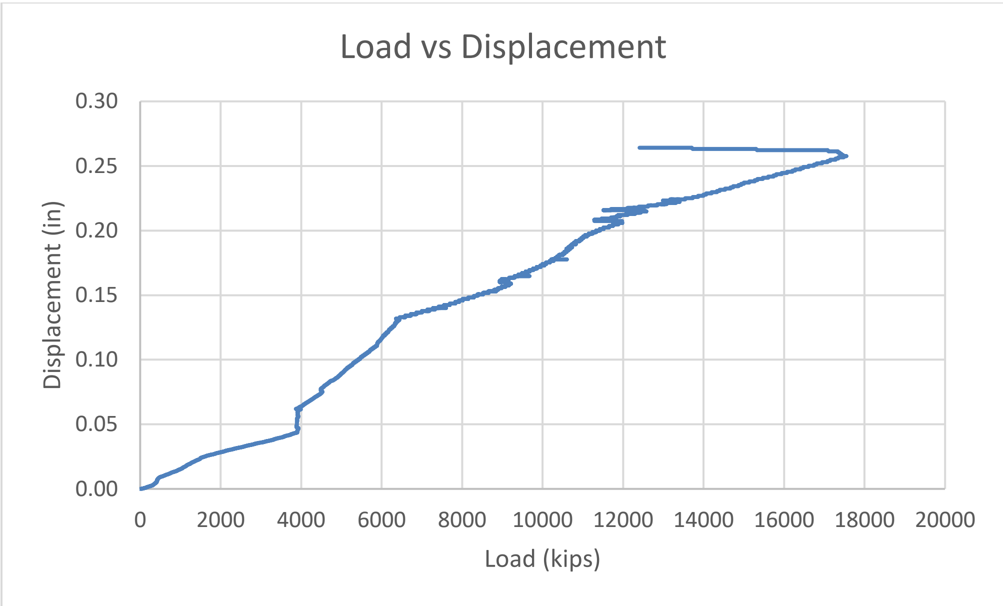

Figure 48 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam #3

Table 16 Flexure Strength of HSS Encased Concrete Straight Beams

Fiber Volume Fraction %	Specimen	Experimental Peak Load (lbs)	Deflection by Experiment (in)
0 %	1	14320	0.57
	2	12300	0.49
	3	12680	0.47
	AVG.	**13100**	**0.51**
0.5 %	1	13950	0.42
	2	15520	0.40
	3	16620	0.43
	AVG.	**15363.33**	**0.423**
1.0 %	1	16670	0.28
	2	18230	0.35
	3	17870	0.33
	AVG.	**17590**	**0.32**

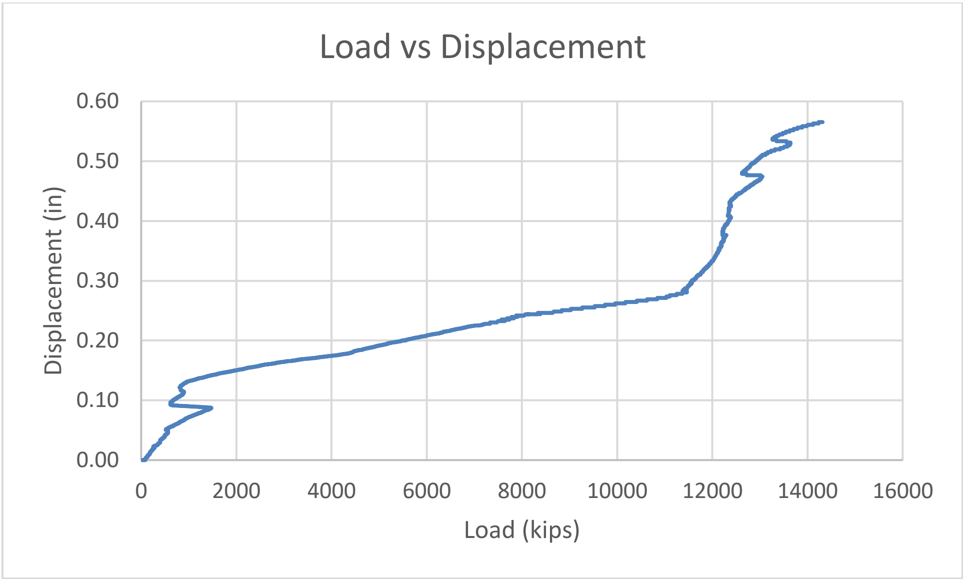

Figure 49 Load vs Displacement Graph for 0% Steel Fiber Straight Beam (HSS) #1

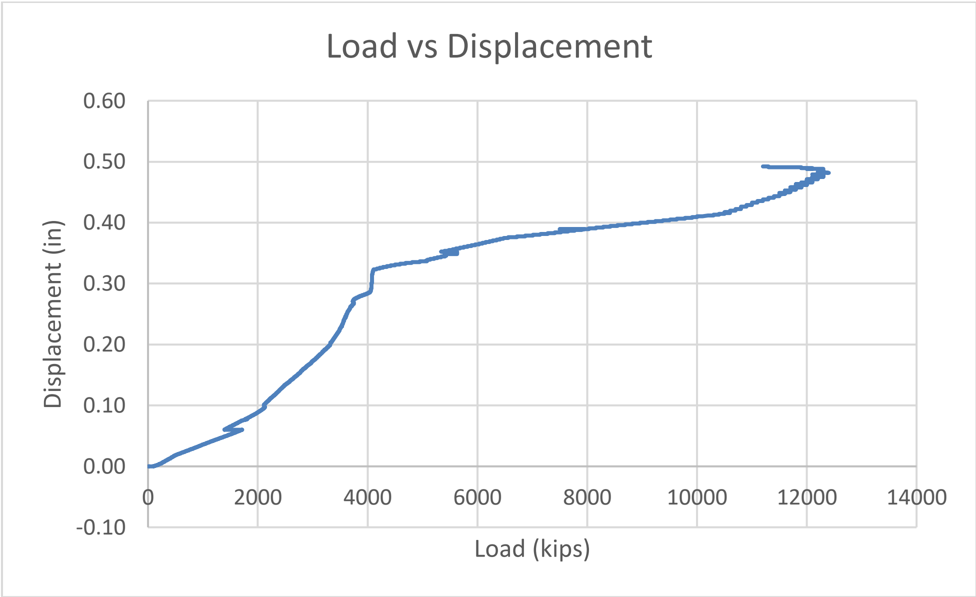

Figure 50 Load vs Displacement Graph for 0% Steel Fiber Straight Beam (HSS) #2

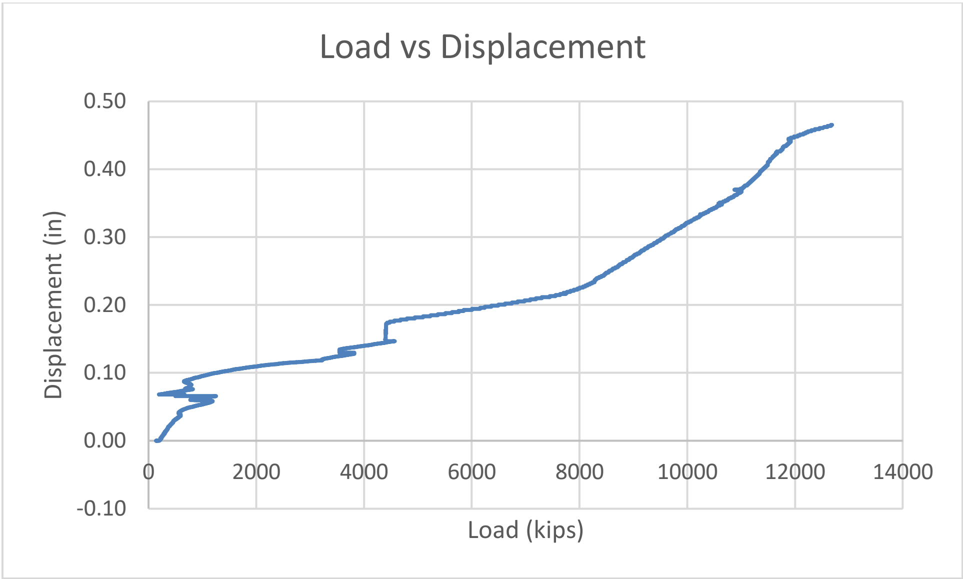

Figure 51 Load vs Displacement Graph for 0% Steel Fiber Straight Beam (HSS) #3

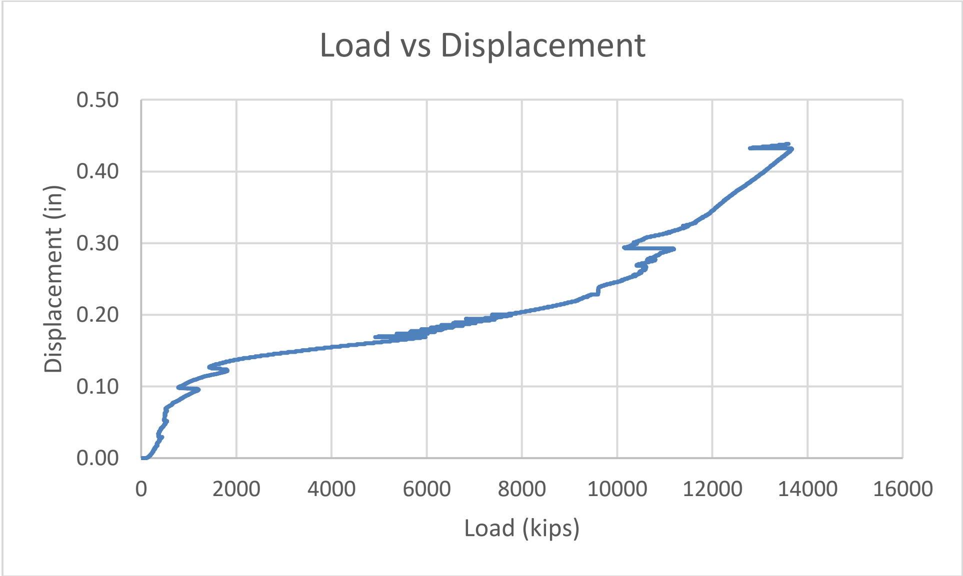

Figure 52 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam (HSS) #1

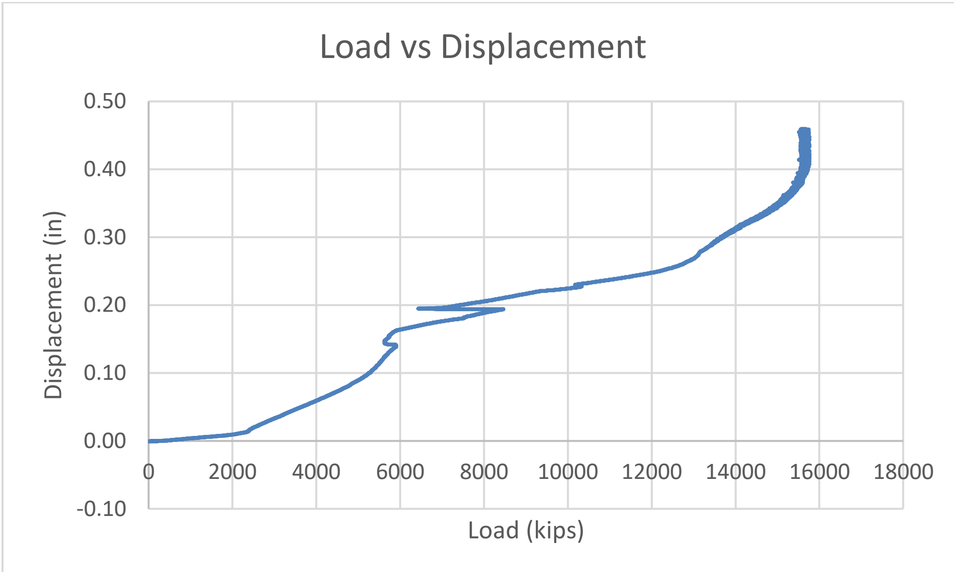

Figure 53 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam (HSS) #2

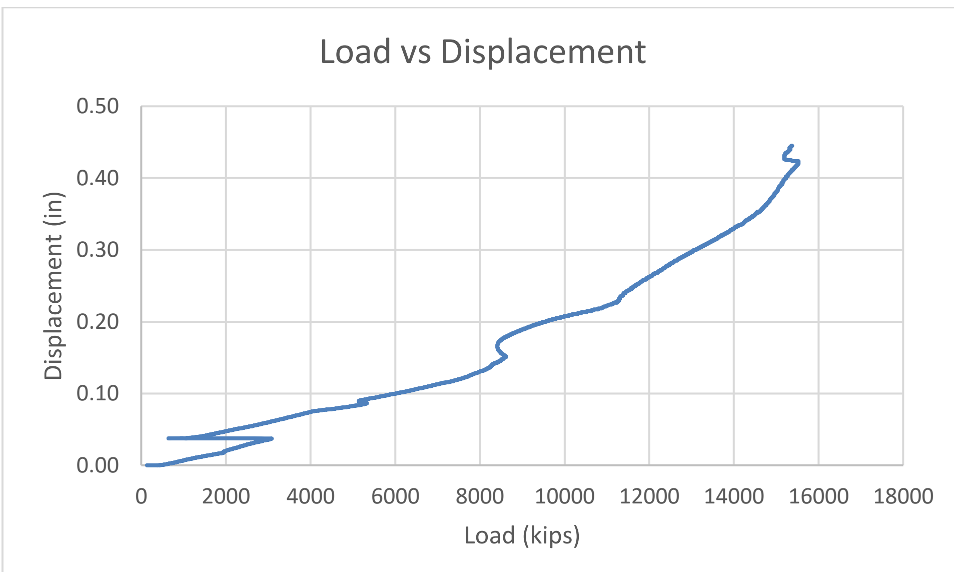

Figure 54 Load vs Displacement Graph for 0.5% Steel Fiber Straight Beam (HSS) #3

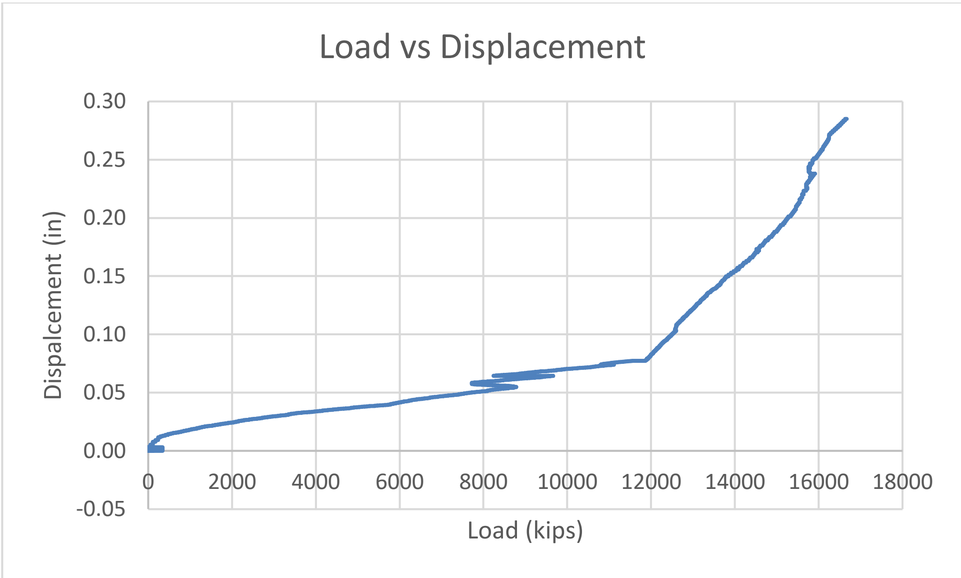

Figure 55 Load vs Displacement Graph for 1% Steel Fiber Straight Beam (HSS) #1

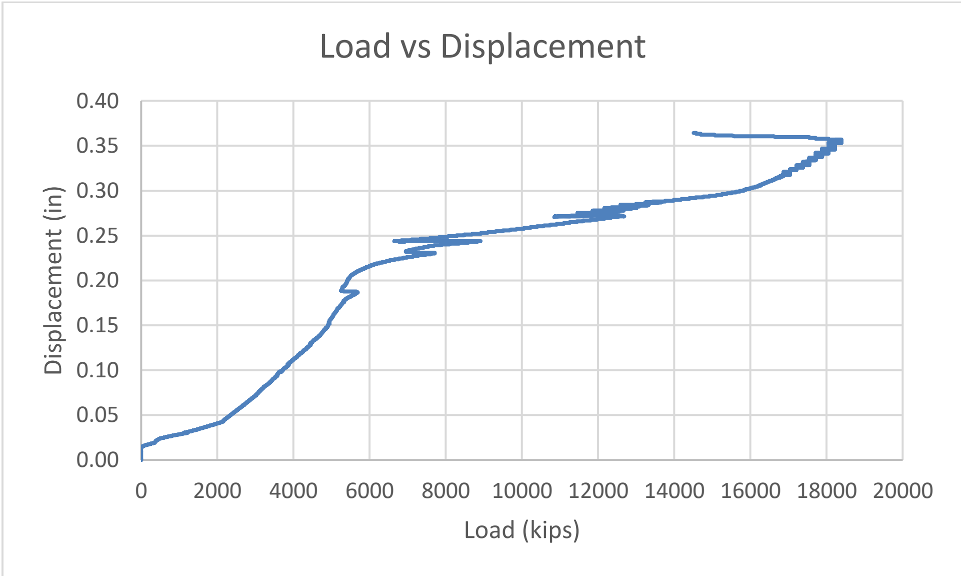

Figure 56 Load vs Displacement Graph for 1% Steel Fiber Straight Beam (HSS) #2

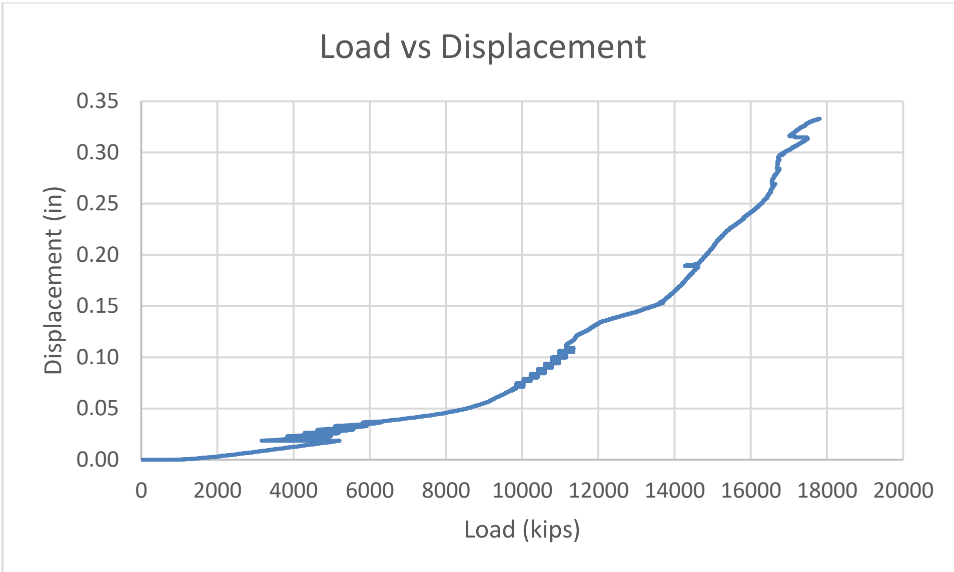

Figure 57 Load vs Displacement Graph for 1% Steel Fiber Straight Beam (HSS) #3

Table 17 Flexure Strength of HSS Encased Concrete Preflex Beams

Fiber Volume Fraction %	Specimen	Experimental Peak Load (lbs)	Deflection by Experiment (in)
0 %	1	13056	0.43
	2	14844	0.46
	3	14050	0.42
	AVG.	**13980**	**0.436**
0.5 %	1	17945	0.39
	2	16715	0.34
	3	17060	0.36
	AVG.	**17240**	**0.36**
1.0 %	1	20080	0.32
	2	19645	0.29
	3	18585	0.26
	AVG.	**19430**	**0.29**

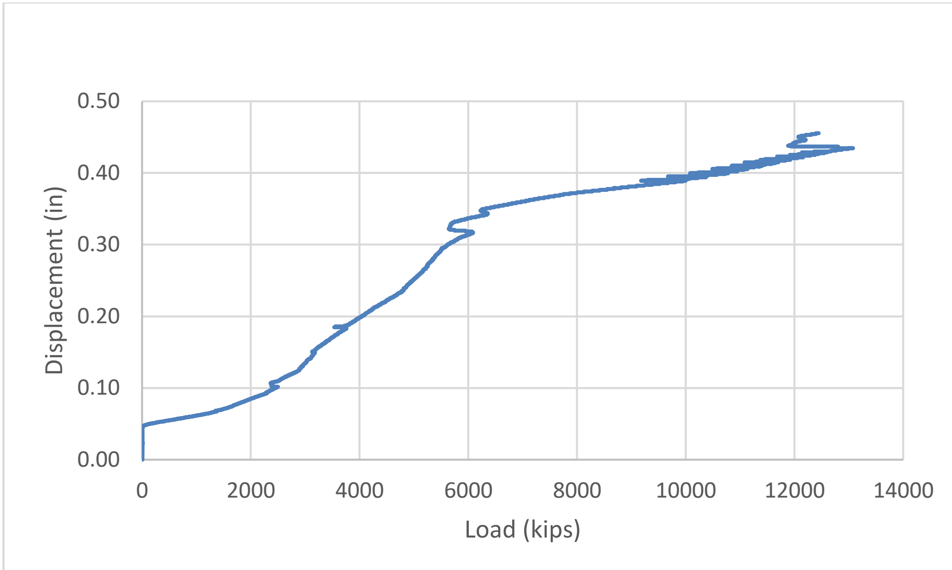

Figure 58 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam (HSS) #1

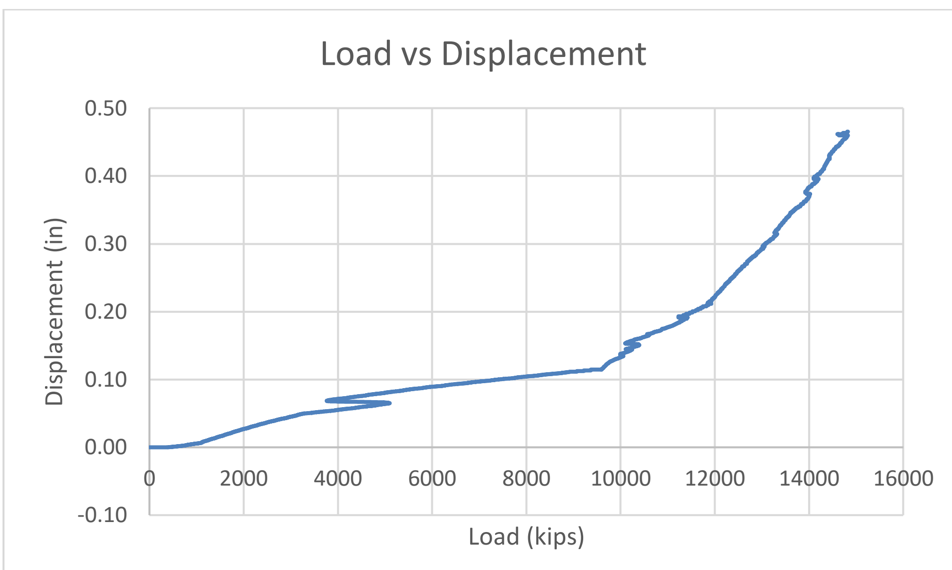

Figure 59 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam (HSS) #2

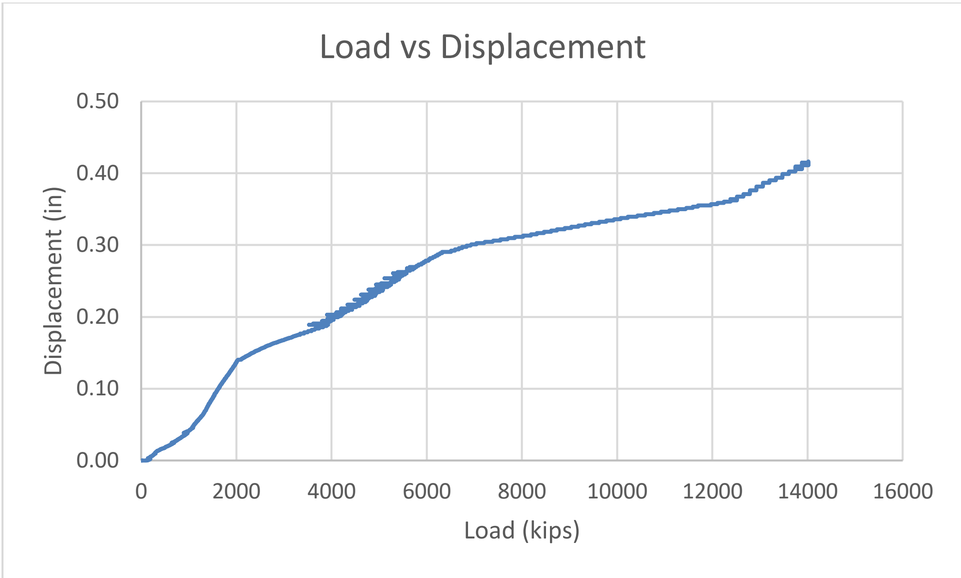

Figure 60 Load vs Displacement Graph for 0% Steel Fiber Preflex Beam (HSS) #3

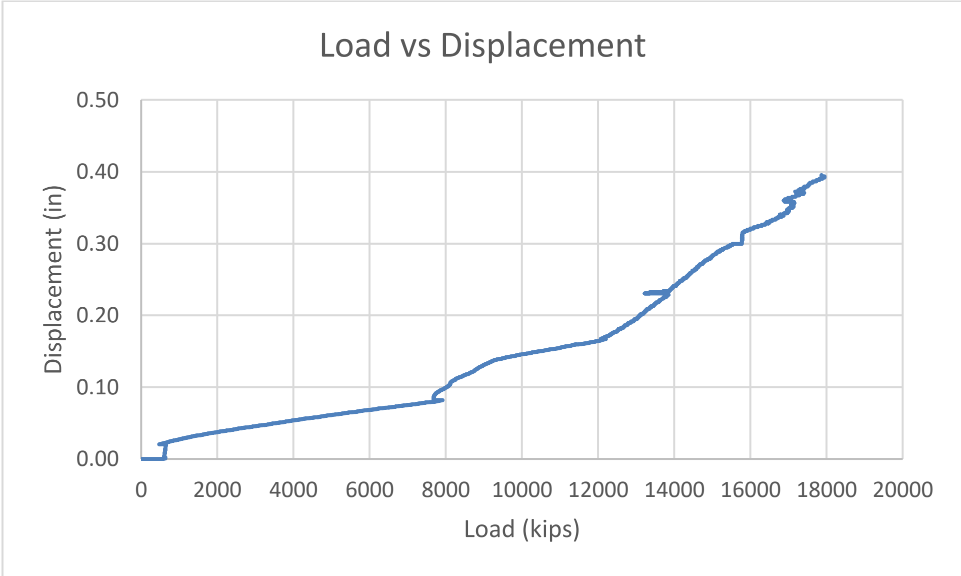

Figure 61 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam (HSS) #1

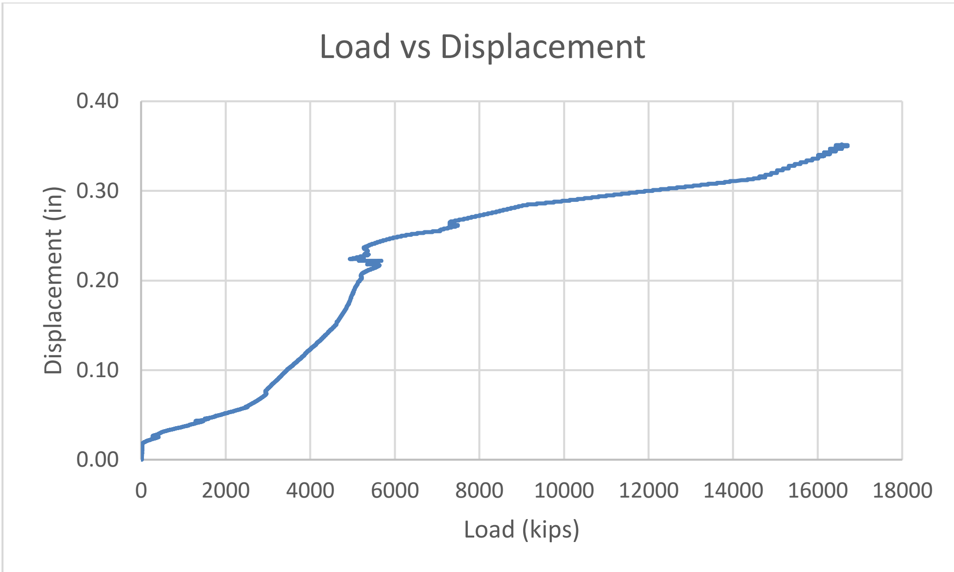

Figure 62 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam (HSS) #2

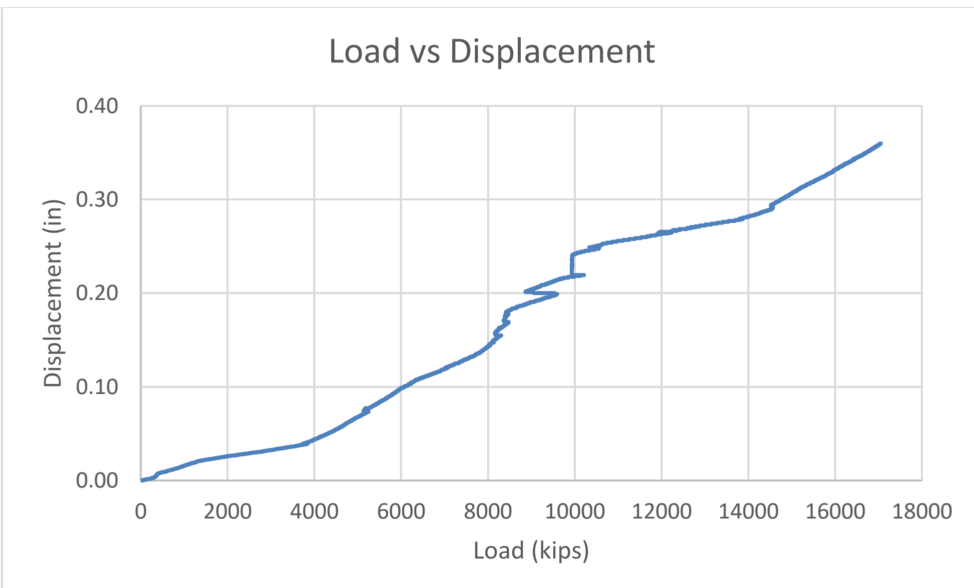

Figure 63 Load vs Displacement Graph for 0.5% Steel Fiber Preflex Beam (HSS) #3

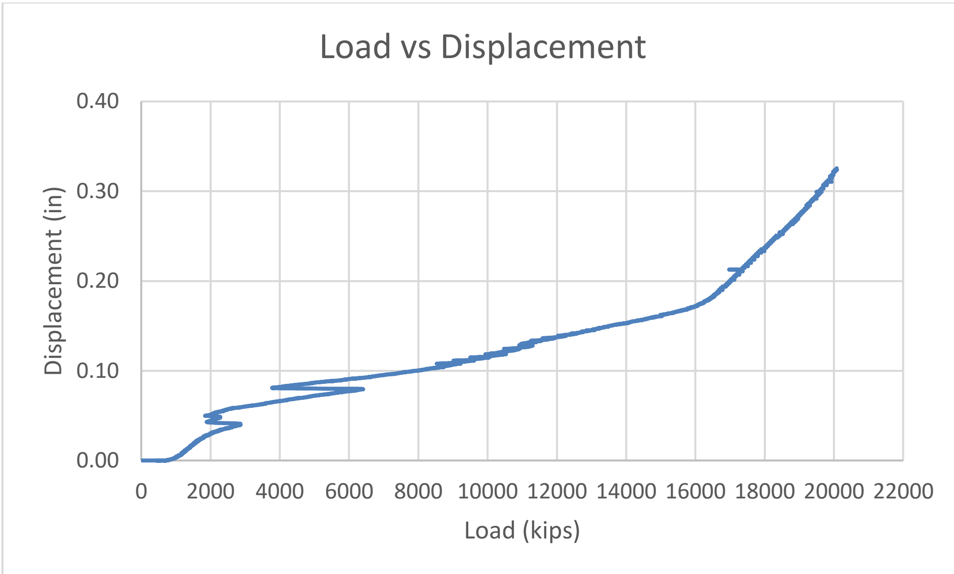

Figure 64 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam (HSS) #1

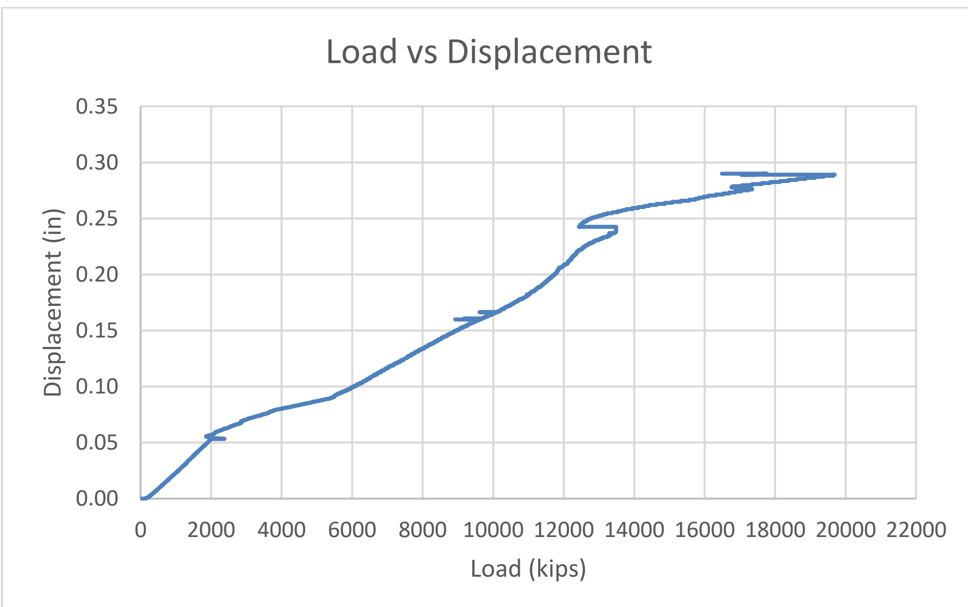

Figure 65 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam (HSS) #2

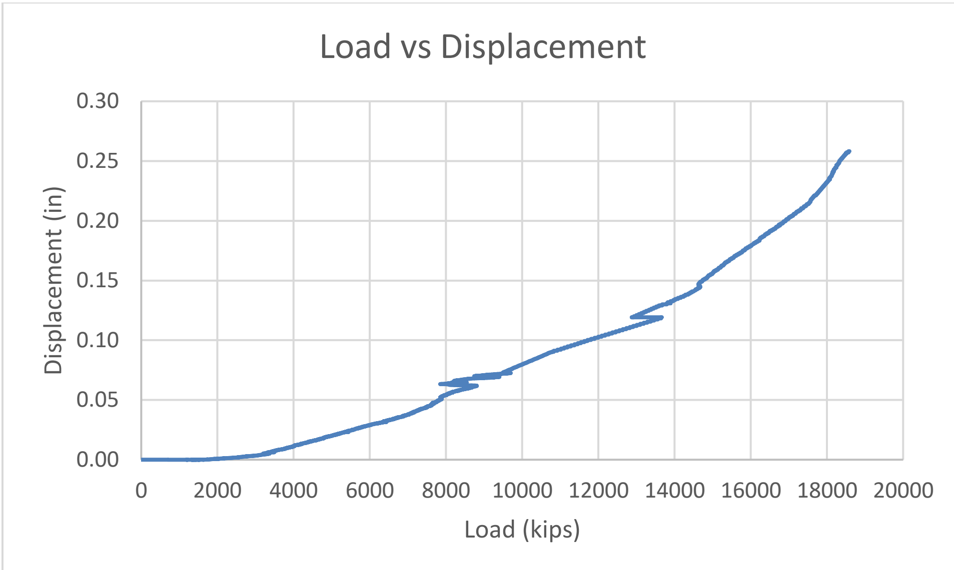

Figure 66 Load vs Displacement Graph for 1% Steel Fiber Preflex Beam (HSS) #3

4.3 DISCUSSION OF RESULTS

4.3.1 *Small Specimen Deductions*

Concrete is brittle in nature and very less in tensile strength. With addition of steel fibers, material properties of concrete increases. In the reinforced concrete with no steel fibers, tensile strength come from the chemical bond between the aggregate and the cement. Tensile strength of concrete increases with addition of steel fibers due to the bond between fibers and concrete. This result increase in the percentage of steel fibers in concrete increases the compressive strength, tensile strength, and modulus of rupture. Compressive strength increases 45% with the addition of 1% steel fibers by volume.

Modulus of Rupture of concrete increases by an average of 12% for every 0.5% of fiber by volume into the concrete mixture.

4.3.2 *Experimental Study Comparison*

4.3.2.1 Straight Beams

In the first experimental study, three composite beams with SFRC encased steel joists are tested for center point loading with a constant rate of loading of 0.04 in/min without any shock. Steel fibers proportion plays an important role in improvement of flexural capacity of specimen. With the increase in steel fibers from 0% to 0.5%, the ultimate load capacity increases by an average of 18% and reduces deflection by an average of 20%. While adding 1% steel fibers by volume increases ultimate load capacity by 35% and reduces deflection by an average of 45%. Beams with steel fibers 1% by volume possesses enhanced flexural capacity and reduced midspan deflection relative to 0% and 0.5% SFRC straight beams.

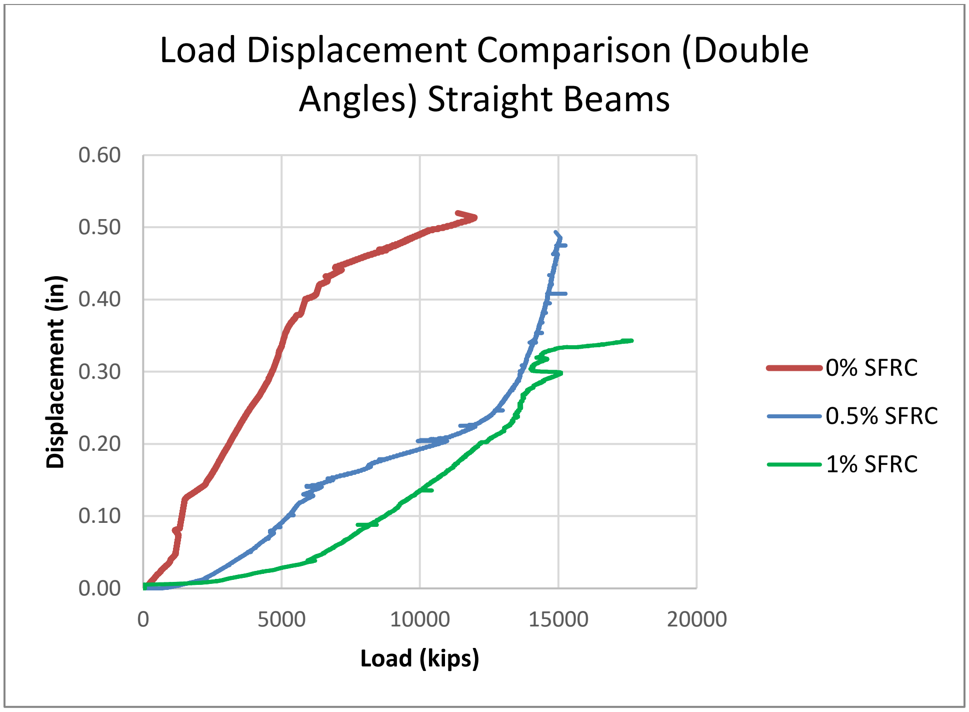

Figure 67 Load-Displacement for SFRC Straight Beams (Double Angles)

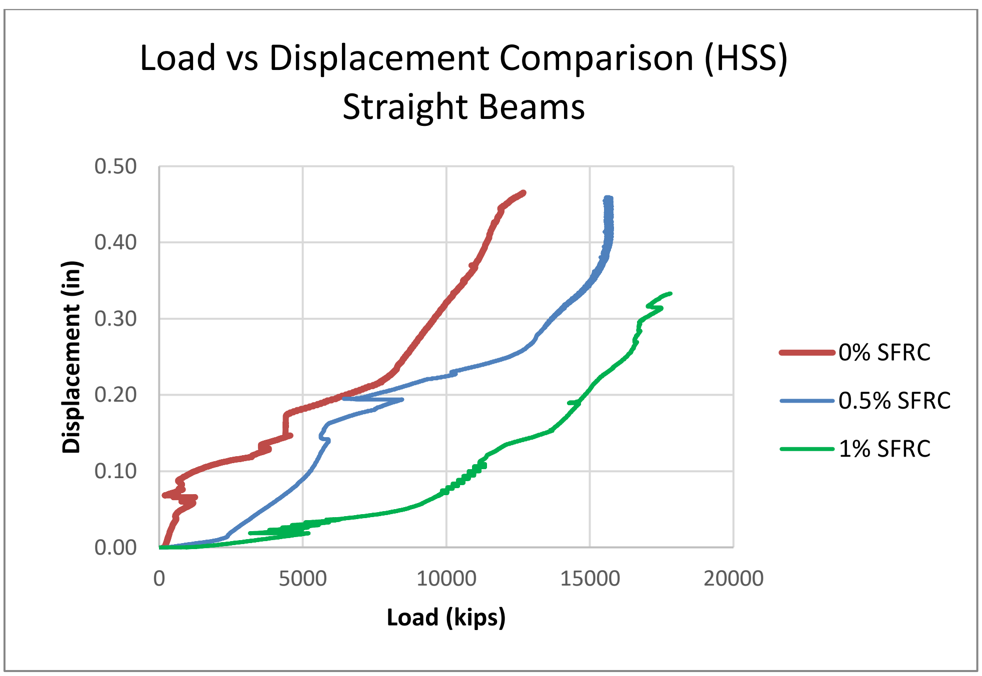

Figure 68 Load-Displacement for SFRC Straight Beams (HSS)

4.3.2.2 Straight vs Preflex Beams

The reason behind preflexing the SFRC encased steel joist composite beams is to reduce midspan displacement and to improve the flexural behavior. The question is whether the preflexing with various percentage of steel fibers in concrete will help to increase the additional flexural capacity to the beam. Comparing 0% SFRC encased double angles straight and preflex, preflexing beam help to improve the flexural capacity of beam by 10% and reduces the midspan displacement by 25%. Furthermore, 0% SFRC encased HSS straight and preflex, preflex beams shows improvement in flexural capacity by 8% and reduction in midspan displacement by 16%. Beams 0.5% SFRC Straight and Preflex encased double angles and HSS, the ultimate load capacity increases by an average of 12% and midspan displacement decreases by an average of 20%. For beams 1% SFRC Straight and Preflex encased double angles and HSS, the ultimate load capacity increases by an average of 12% and the midspan displacement decreases by an average of 15%.

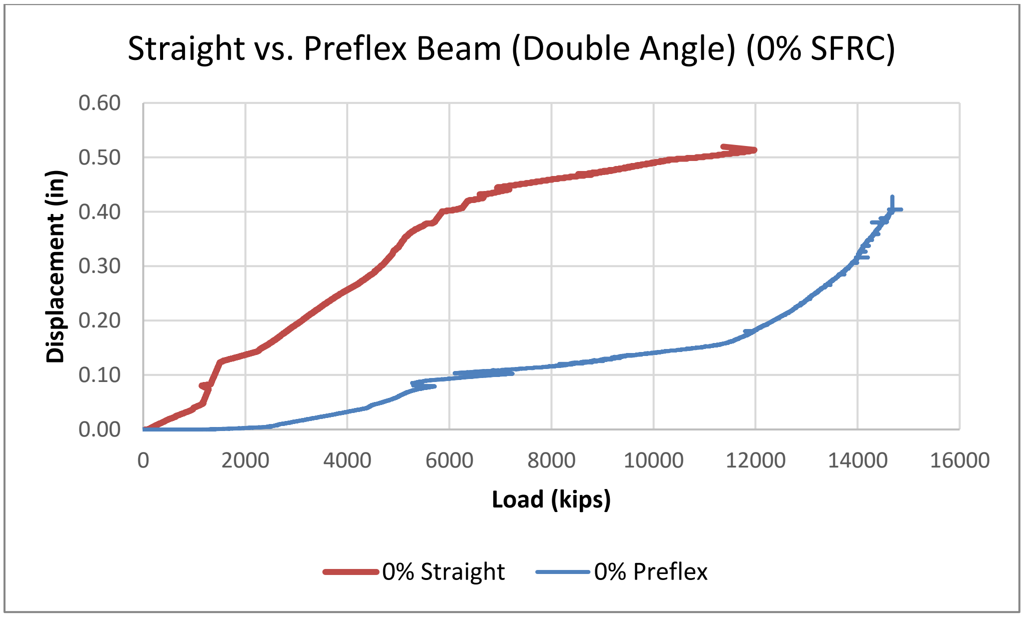

Figure 69 Straight vs. Preflex Beam (Double Angle) (0% SFRC)

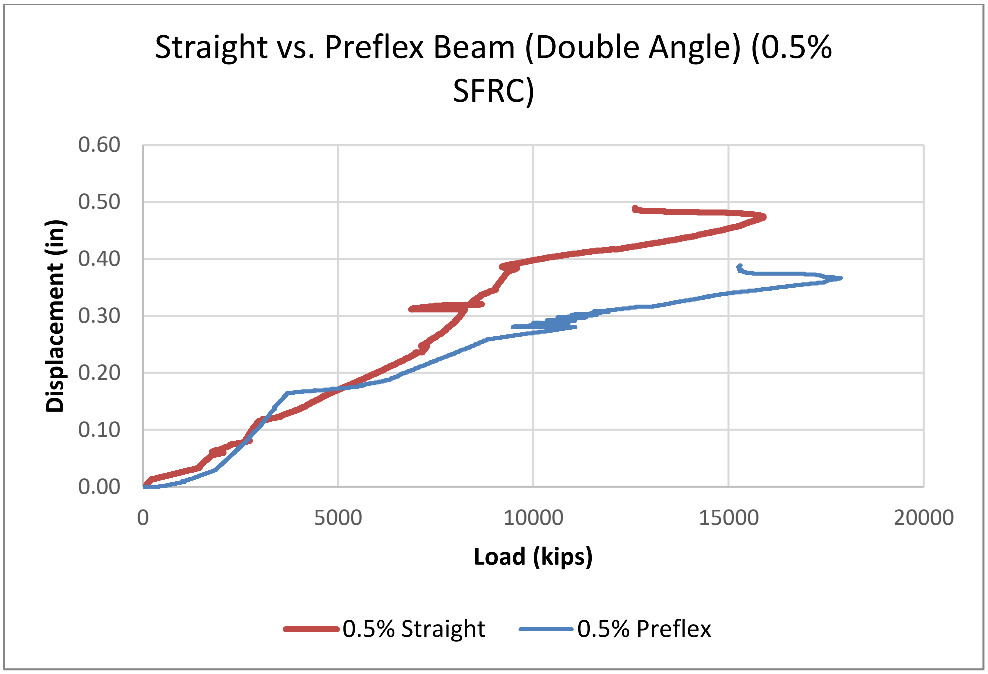

Figure 70 Straight vs. Preflex Beam (Double Angle) (0.5% SFRC)

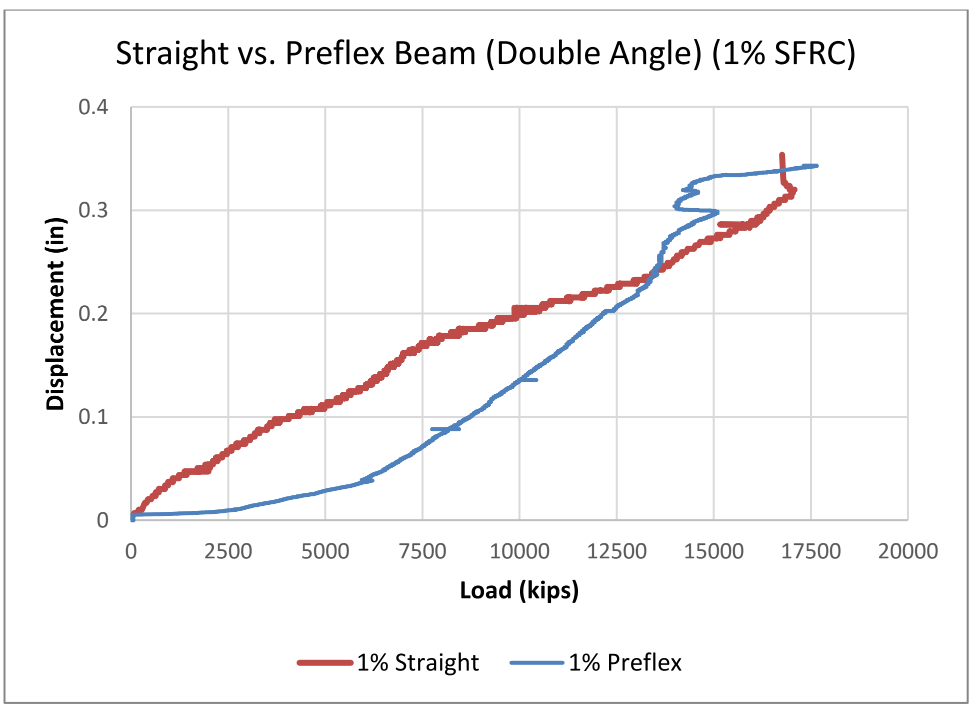

Figure 71 Straight vs. Preflex Beam (Double Angle) (1% SFRC)

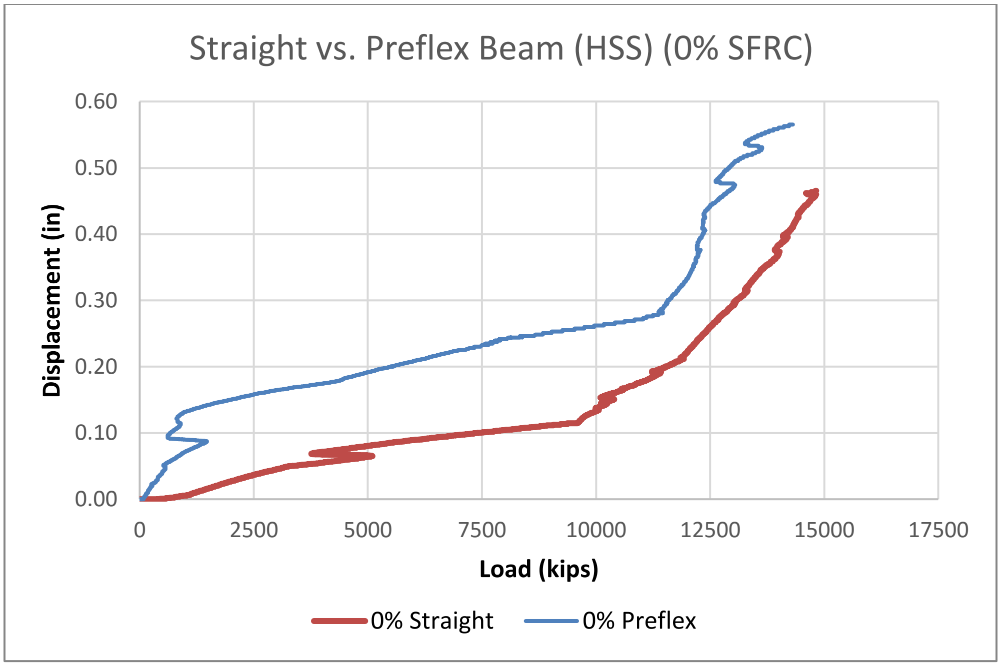

Figure 72 Straight vs. Preflex Beam (HSS) (0% SFRC)

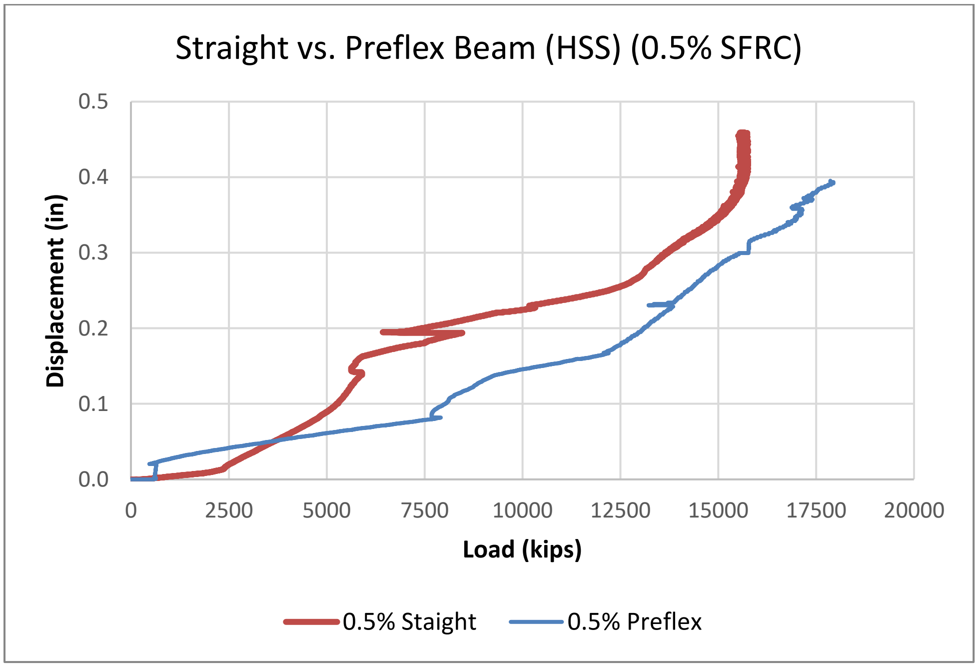

Figure 73 Straight vs Preflex Beam (HSS) (0.5% SFRC)

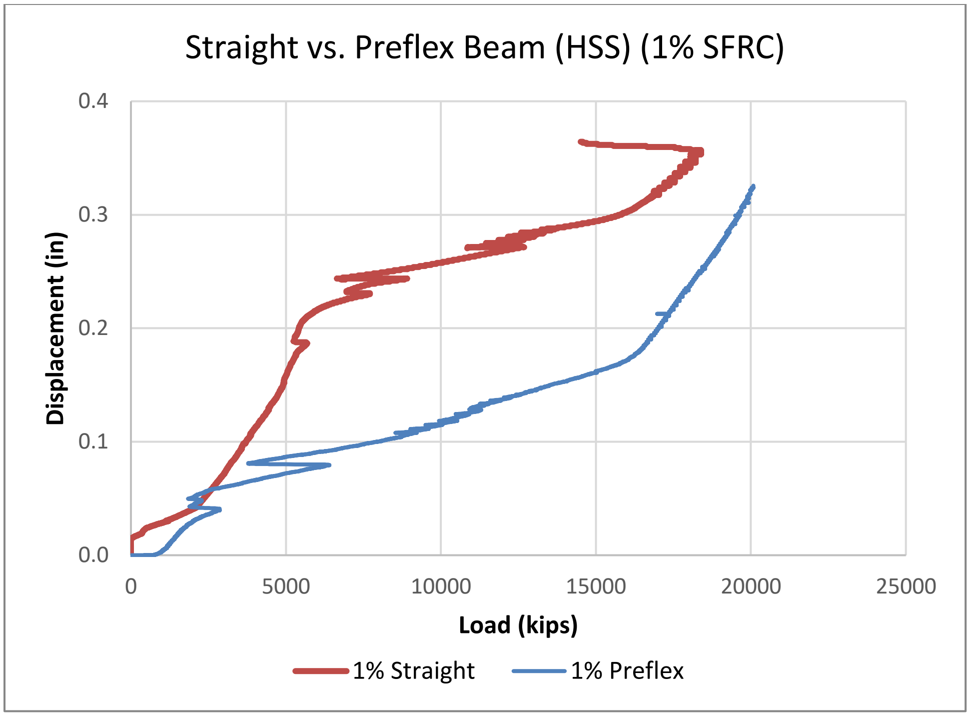

Figure 74 Straight vs Preflex Beam (HSS) (1% SFRC)

5 SUMMARY AND CONCLUSION

5.1 SUMMARY

In summary, the flexural behavior of Steel Joist Encased Straight and Preflex Concrete beams are studied and discussed in this research study. Steel joists encased concrete beams with various steel fiber volumes were produced and tested at Civil Engineering Laboratory Building (CELB) at the University of Texas at Arlington. This includes Double Angle encased concrete beams with different proportion of steel fibers and HSS encased concrete with different proportion of steel fibers. For material properties of concrete, cylinders (4" x 8") with different amount of steel fibers has been casted. To calculate the compressive strength of concrete, cylinders are tested using compression test setup to obtain peak load. Similarly, for tensile strength of concrete, cylinders are tested using split test setup to obtain cracking load. Similarly beams with different proportion of steel fibers are tested for modulus of rupture using two-point loading method using 55 kips testing machine at CLEB. The results for each specimen obtained and discussed. Obtained results showed that overall performance of Steel Joists Encased Concrete improves with the use of Steel Fibers. Furthermore, a total of 18 cylindrical specimens, 4-inch diameter and 8-inch height, were tested after 28 days curing using a compression testing machine per ASTM C39 and ASTM C496 standards. Similarly, Split test showed improved tensile capacity and improvement in failure mechanism of steel fiber reinforcement concrete compared to plain concrete specimens. In addition, a total of 9 beam specimens for modulus of rupture, 6in by 6 in. by 20 in. were produced and tested per ASTM C1609. The results showed improved flexural crack resistance and higher tensile load capacity of steel fiber reinforced concrete beams.

5.2 CONCLUSIONS

- Material Properties seen to be increased with addition of percentage of steel fibers. Adding 0.5% volume fraction of steel fibers into the concrete mix design increases compressive strength by 30%, while adding 1% steel fibers increases compressive strength by 45%.
- Furthermore, adding 1% volume steel fibers increases tensile strength by 35%. Modulus of Rupture of concrete increases by 25% with addition of 1% volume fraction steel fibers into concrete mix design.
- Adding of 0.5% and 1% volume fraction into the straight encased double angles concrete beams enhances flexural strength by 20% and 30% respectively, whereas deflection reduces by 23% and 41% respectively relative to 0% steel fiber volume fraction.
- In comparison of Preflex and Straight encased double angle composite beams, there is increase in flexural strength by 10%, 12% and 13% for 0%, 0.5% and 1% respectively. While reduction in midspan deflection is observed by 25%, 21% and 16% for 0%, 0.5% and 1% respectively.
- Experimental study on SFRC encased steel joists are close to available Finite Element Analysis.
- Comparing Experimental results with FEA results for double angle encased straight beams showed the difference of 20%.
- While experimental results of double angle encased preflex beams showed 15% difference relative to FEA results.

- SFRC encased HSS composite straight beams with 1% steel fibers, increases flexural capacity by 35% while reduces displacement by 37% relative to same beam with plain concrete.
- Comparing straight and preflex SFRC encased HSS composite beams, flexural capacity increases by 10% while deflection reduces by 15% for preflex beam with 1% by volume steel fibers.
- While comparing SFRC encased double angle composite beams with SRFC encased HSS composite beams, results are approximately similar, with percentage difference by 8%.
- Study showed that preflex SFRC Encased Steel Joist Concrete Beams shows improved performance comparative to Straight Beams.
- Preflex Beams experience less midspan deflection relative Straight beams.
- Slump test showed that addition of steel fibers into concrete reduces the workability of concrete.
- Addition of steel fibers into encased steel joists composite beams increases load capacity and reduces midspan deflection.
-

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