STEEL FIBER REINFORCED CONCRETE HAUNCHED BEAMS

[1]Mehmet Eren GÜLŞAN, [2]Khalid T. Fadhil AL-SAMMARRAIE,

[3]Safaa Y. Hamad Al DARRAJI

[1,2&3] Gaziantep University, Civil Engineering Department
[1] gulsan@gantep.edu.tr, [2] civil.kha@gmail.com, [3] safaayaseen75@gmail.com

Abstract

There is an architectural, structural and economic importance of the study of the reinforced concrete haunched beams (RCHBs). In this study, mechanical behavior of steel fiber reinforced concrete haunched beams was investigated. The study included 8 self-compacted concrete beams (7 of which are RCHBs and one of which are prismatic beams), Two different ratios of steel reinforcement were considered. The stirrup reinforcement was used for half specimens. Three steel fiber ratios (0%, 0.5% and 1%) were adopted. Two angle of inclination which are 10^o & 15^o, were considered for the study. The results showed that load capacity of the beams was inversely proportional to the increase in the angle of inclination and was proportional to the increase in the ratio of the steel fiber. Effect of steel fiber was much more apparent, as the inclination angle of the haunched beams increased. Moreover, use of steel fiber reduced the crack width of all beams at failure leading to increase in the service life of the beams. the addition of fibers with sufficient ratio changed the failure mode of RC haunched beams without stirrups from shear to flexure mode. Therefore, the steel fibers can be considered as a suitable solution to replace the stirrups in the reinforced concrete haunched beams.

Keywords

Steel fiber, self-compacting concrete, Haunched beams, shear stress, failure mode

1. INTRODUCTION

Reinforced concrete haunched beams are used mostly in retaining walls, bridges, structural portal frames, industrial buildings and in many other engineering structures. In the literature review, it should be noted that all of the experiments related with steel fiber reinforced concrete (SFRC) beams have not reported the use of steel fiber in the haunched beams. For more than three decades, there has been a great interest in studying the use of steel fiber-reinforced concrete (SFRC) to improve the performance of reinforced concrete rectangular beams [1]. Many studies have shown that the use of steel fibers in prismatic beams without shear reinforcement can improve the shear strength and enhance the flexural failure and ductility [2].

In addition, some researches have shown that fibers can possibly replace the traditional shear reinforcement [3, 4]. The improvement in shear strength capacity is due to the ability of SFRC to hold out and redistribute diagonal tension stresses after the cracking occurs [1]. Through the bridging and controlling of diagonal tension cracks, the fibers significantly improve post-cracking strength, which leads to control of width and distribution of the cracks and enhancement in the shear performance [5]. The displacement capability is also increased by adding steel fibers to mix concrete. Recently, Parra- Montesinos [1] has submitted a large database of SFRC prismatic beam tests that include a large range of concrete, fiber, and different dimensions of beams. The analysis of the database depicted that steel fibers, if they were added in an adequate amount, can be used as an alternative to the minimum shear

Reinforcement of the prismatic beams that are subjected to shear forces equal to the range $0.5V_c$ to V_c (where V_c present the shear force in the concrete as known in ACI 318-08 design code) [6].

In the another study, You et al. [7] have shown that hooked end type steel fibers can partly replace shear reinforcement in reinforced self-compacting concrete prismatic beams.

Due to the inclination in the haunched beams, shear forces are more critical in haunched beams without stirrups. Therefore, effect of the steel fiber on the haunched beams can differ as compared to prismatic beams. This study aims to close this gap in literature

2. Objectives of the Study

The research objectives of the study can be listed as follows:

- To enhance the understanding of performance improvements that can be obtained from the use of steel fibers in haunched beams through studying the mechanism of the shear strength behavior of self-compacted steel fiber reinforced concrete (SCSFRC) haunched beams without stirrups.
- To examine if the use of the steel fiber with amount of 1% as shear reinforcement in haunched beams will contribute to providing adequate shear strength as compared to the use of minimum shear reinforcement.
- To study the effect of change in fiber ratio on the mechanical behavior of the haunched beam.
- To examine crack width, crack patterns, and post-cracking behavior of steel fiber reinforced haunched beams without stirrups.
- Comparison of the specimens containing the stirrups, which does not contain stirrups and the possibility of replace it by the steel fiber.

3. MODEL GEOMETRY

In this study, two RCHBs shapes were adopted according to angles of inclination, which are 10&15 degree. In addition to the haunched beams, one prismatic beam was produced in order to examine the effect of the inclination. Details of the beams are shown in Figures. 1-4.

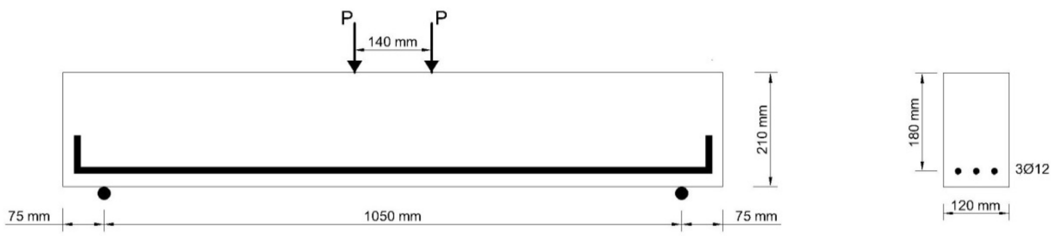

Figure 1. Prismatic Beam (B1)

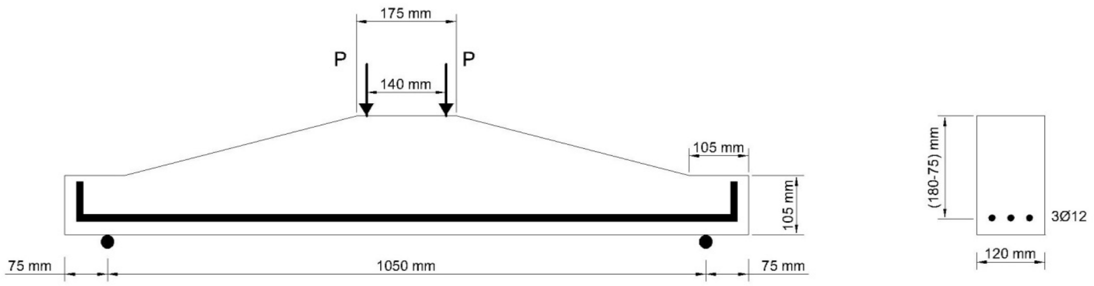

Figure 2. Haunched Beam 15° (B2, B3&B4)

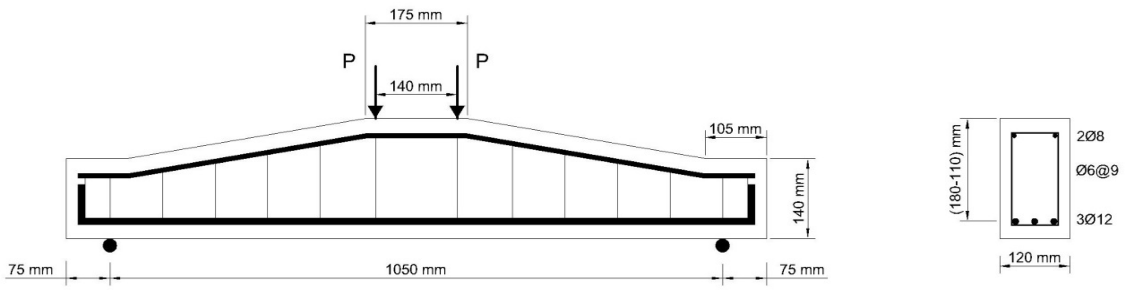

Figure 3. Haunched Beam 10° (B5&B6)

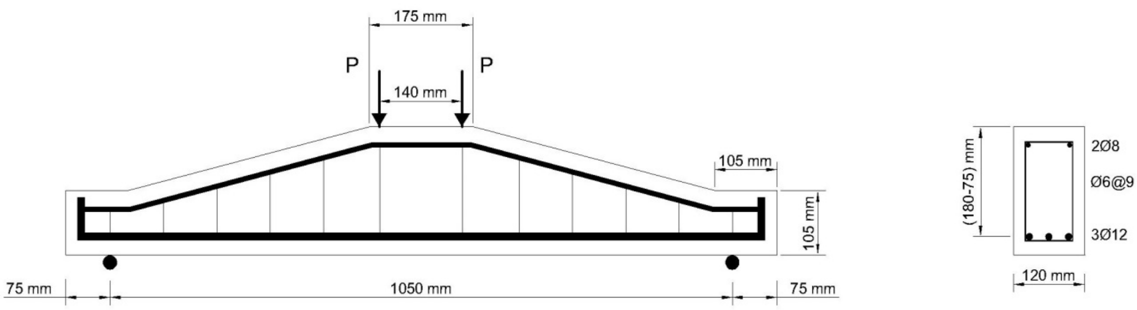

Figure 4. Haunched Beam 15° (B7&B8)

4. EXPERIMENTAL WORK

Tests were carried out on eight specimens, 7 RCHBs and 1 prismatic beams. All beams were tested under four-point loading test until failure. Failure load, last crack load, first crack load and central deflection, and crack width were accurately recorded during the testing process.

4.1 Materials

Crushed stone and crushed sand were used as coarse and fine aggregates with maximum size of 11 mm and 4 mm, respectively. The sand and gravel were brought from the same source to obtain the properties of self-compacting concrete (SCC). Ordinary Portland cement (type 32.5R) was used in each concrete mix. In order to obtain the required flowability of the concrete without segregation, Fly ash (type F) was used. The chemical properties are listed in Table 1.

Table 1 Chemical Properties of Fly ash (type F) and Portland cement (type 32.5R)

Chemical analysis	SiO_2	Fe_2O_3	CaO	$A_{l2}O$	MgO	SO_3	Na_2O + K_2O
Fly ash	56.2	6.69	4.24	20.17	1.92	0.49	2.36
Cement	20.4	3.9	63.0	4.9	1.7	2.0	0.9

A. Hooked-end steel fiber: Type 3D 35/ 45BG hooked-end steel fiber was used in this experiment as shown in Figure 5. Three percentages of steel fibers (0%, 0.5% and 1%) were used in reinforcing the specimens in order to investigate the influence of these percentages on the shear strength of SCSFRC beams. The properties of fibers are given in Table 2.

Table 2 Mechanical Properties of Steel Fiber Type 3D 35/45 BG

Fiber Type	DRAMIX 3D 45/35BG
Length	35 mm
Diameter (D)	0.75mm
Aspect Ratio (D/L)	45
Tensile Strength	1,225N/mm^2
Minimum Dosage	30Kg/M^3
Fiber Network	7,85Fiber/Kg
Presentation of Fiber	Glued

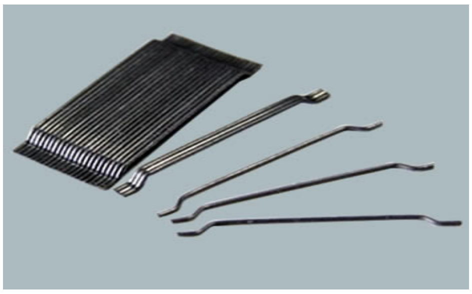

Figure 5. Hooked end steel fiber

It is also known that steel fiber reduces the workability of the fresh concrete. Therefore, high-performance of Super Plasticizer type (sika viscoCrete- Sf 18) was used in the mixes design for the production of self-compacting concrete (SCC) in the amount of (1.66% -1.917%) of the cement weight. The flow properties of (SCC) such as filling ability, segregation resistance, and passing ability were examined by the procedure of the Slump flow test, V-funnel test, and J-ring test and were found to be consistent with the specifications stated in EFNARC.

Three concrete mixes were designed for requirements, which were prepared to obtain a compressive strength close to 40 MPa. Two of these mixes were (SCSFRC) self-consolidating normal strength concrete which have varying steel fiber ratio (0.5% and 1%) and the last one was normal strength self-consolidating concrete (SCC) without fiber as control concrete. Details of all mixes are listed in Table 3.

Table 3 Quantities of concrete mixes

Type of mix	Steel fiber (%v_f)	Gravel Kg/m^3	Sand Kg/m^3	Cement Kg/m^3	Fly Ash Kg/m^3	Water Kg/m^3	Visco-Crete Kg/m^3
SCC	0	730	900	300	250	170	5
SCSFRC	0.5	730	900	300	250	170	5,5
SCSFRC	1.0	730	900	300	250	170	5,75

B. Steel Reinforcement: For the main longitudinal steel reinforcement, two different diameters were used. In the tension zone, a diameter of 12 mm steel bar was used, while for the compression zone, 8 mm diameter steel bar was used. For the steel stirrups, the diameter of 6 mm was used. All details regarding reinforcement are shown in Fig. 6.

Table 4 Steel reinforcement properties

Diameter (mm)	Yield Strength Mpa	Ultimate Strength Mpa
12	485	595
8	550	640

C. Formwork: Molds of the beams were produced from plywood, as shown in Fig. 7 in order to obtain smooth surface after concreting process.

D. Concreting: The concreting and loading tests were achieved in the laboratories of the Gaziantep University (Turkey). For each concrete mix, three cubes samples with dimension of 100*100*100 mm (width*length*height), three cylinder samples with dimension of 100*200 mm (diameter*height) were taken in order to measure compressive and tensile strengths of the concrete. After 24 hours passed from concreting, beams, cubes and concrete cylinders were placed in a water tank for curing for 28 days. The beams and samples were then removed from the water tank and the beams were painted with white concrete paint to observe cracks during the testing. After curing process finished, 8 beams were tested using a displacement controlled servo-hydraulic flexural testing machine of 500 kN maximum capacity. The load application was controlled using an advanced hydraulic system. All of the beams were tested under four point bending tests as displacement controlled. The displacement was applied using two rods at mid-span. The span between the two supports was 1200 mm; one of the supports was free to rotate and the other was fixed. The values of deflection were measured and recorded using two linear variable displacement transducers (LVDTs). TML-CPD transducers were used to read the displacement and NI cDAQ-9184 data acquisition from National Instrument was used as a data logger for recording the displacement.

Figure 6. Preparing Mold and steel reinforcement

Figure 7. Filling mold in concrete

5. Experimental setup

The load was applied by two rods of 3 cm diameter at mid-span of each specimen. The length between the two rods was 14 cm to achieve a constant moment region in the middle of the tested beam. The displacement was increased by a specialized displacement sensor of the loading machine with an increment of 0.2 mm/min until the beam collapsed or the displacement of the beam reached to 20 mm. The displacements were recorded by three linear variable displacement transducers LVDTs, which were located along the bottom of the tested beam. The first transducer was at the center, the second was at the right, and the third was at the left, as shown in Figure 8. The shear span to effective depth ratio (*a/d*) was 2.527 for all tested beams. One of the supporters was arranged to prevent the horizontal motion during testing. A high-resolution camera and a magnifying glass were used to observe the crack formations and propagations during the test.

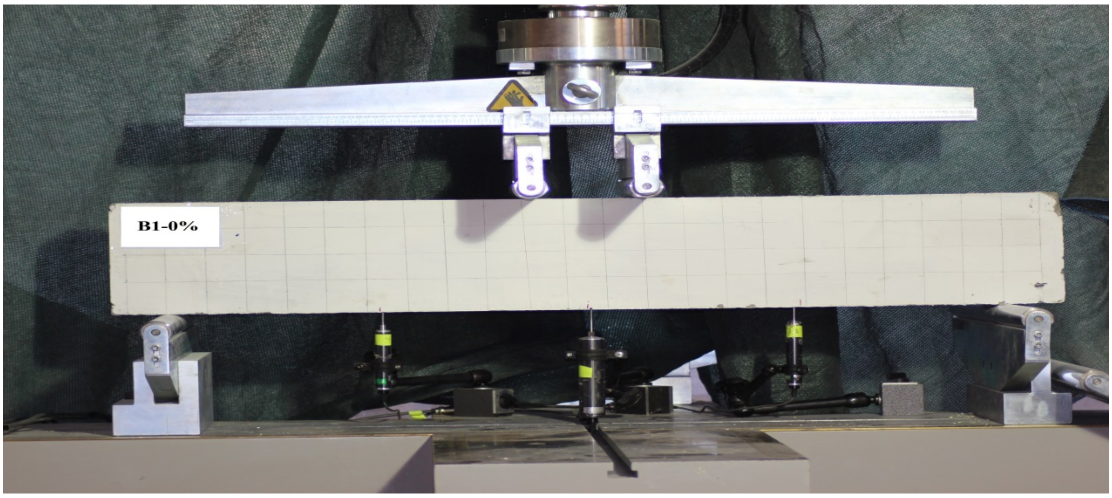

Figure 8. Test setup

6. RESULTS AND DISCUSSION

Compressive strength, splitting tensile strength of the concrete and load capacities of all tested beams are given in Table 5.

6.1 Effect of fibers content on shear strength

Influence of fiber percentage (V_f %) is related to splitting tensile strength of concrete. Thus, increasing the fiber ratio increases the tensile strength of the concrete. As a general conclusion, the load capacity of the beams increase considerably, as the amount of the fiber content is increased.

6.2 Mode of Failure:

- ***Group without stirrups***: The control specimens B1 and B2 (without steel fibers), as expected, failed by a brittle shear failure, where a diagonal shear crack suddenly caused the collapse of the beams, as shown in Figures 10 and 11. The load capacity and displacement were lower as compared to other specimens. The use of 0.5% steel fibers in the specimen B3 significantly increased the shear strength, but there is no change in the failure mode which is the shear failure. However, the failure is not sudden; there is warning before failure due to the bridging effect of the steel fibers, as shown in Figure 12. Likewise, the use of 1.0% fibers in B4 beam resulted in a large increase of the shear strength and displacement. The crushing and rupturing of concrete occurred in the top compression zone of constant moment region followed by the flexural failure, as shown in Figure 13. This explains that the increasing of the steel fiber is sufficient to convert the brittle shear failure to a flexural failure.

Table 5 Results of Specimens

Beam NO.	Fc^{-}	Ft_s	Load at first crack mm	First crack width mm	Max. Load 2P kN	Max crack width mm	(V_f) %	F.M.
B1	47.96	3.82	12.6	0.25	54.34	1.80	0	S
B2	44.50	3.77	13.3	0.22	49.56	1.30	0	S
B3	39.0	4.49	18.6	0.17	103.6	1.10	0.5	S
B4	40.5	5.03	28.8	0.13	138.3	0.65	1	F
B5	45	3.97	22	0.32	134	1.15	0	S
B6	50	4.18	30	0.28	138	1.10	0.5	F
B7	43	4.12	17	0.30	127	2	0	S
B8	50	4.18	20	0.33	138	1.7	0.5	F

Fc^{-} = compressive strength Ft_{s}= Splitting strength V_f = Steel Fiber Ratio

F.M.= Failure Mode F= Flexural S= Shear

- ***Group with stirrups***: It is noted in Table 5 that all of the beams, except one beam (B7), failed in flexural mode. The beam designated as B7 failed in shear mode. It was expected that the failure type was flexural in most specimens, since all beams were reinforced by stirrups. However, results of the study indicate that as the inclination of the haunched beam increases, the possibility of shear failure increases even if the beam is reinforced by stirrups. Furthermore, the failure mode of B8 beam shows that addition of steel fiber ensures the flexural failure mode in prismatic and haunched beams.

6.3 Cracks Propagation:

- ***Group without stirrups***: In all specimens, the first hairline cracks were flexural cracks which occurred in the constant moment zone, followed by an appearance of the shear cracks in the shear span. Other shear and flexural cracks appeared at higher levels of load. The crack widths were measured using a crack width apparatus. Regarding the specimens which contain steel fiber, it can be seen that the cracks width is less than the cracks width for the specimens without fiber as listed in Table 5. In general, the addition of fibers reduced the crack widths and resulted in a more spread cracking pattern, where many secondary cracks grew out of the main cracks in the flexural region and in the shear span. This phenomenon can be attributed to the ability of the fibers to transfer stresses into the concrete crossing a crack.
- ***Group with stirrups***: In general, the cracks originate normal to the flexure reinforcement and develop variously in higher load. The crack propagation in the beams reinforced by shear stirrups is like to each other for prismatic beams and haunched beams as shown

in the Figures 14-17. It can be noted from Table 5 that crack width of the specimens containing steel fiber (B6 & B8) is smaller than the width of the beams (B5 and B7) which do not contain steel fiber. This achieves one of the objectives of adding steel fiber by reducing thickness of the cracks. The thickness of the cracks has been observed and measured as shown in Figure 9.

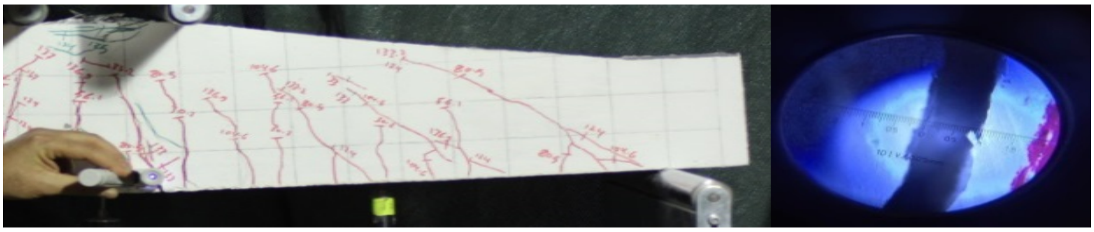

Figure 9. Cracks measurement

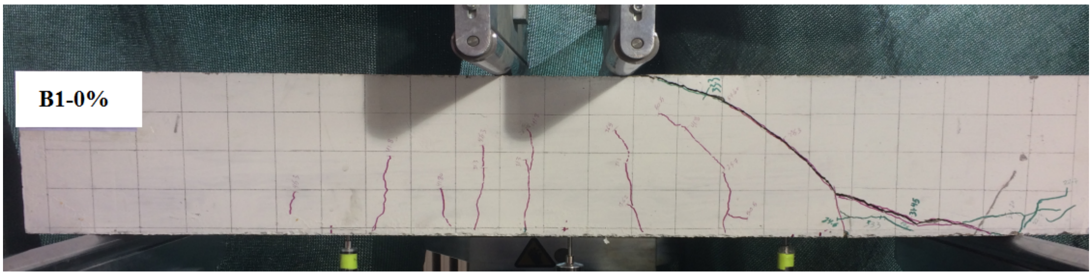

Figure 10. Beam B1 (Shear Mode)

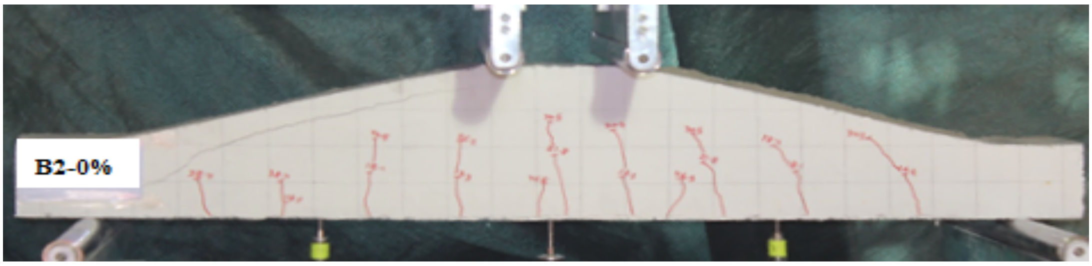

Figure 11. Beam B2 (Shear Mode)

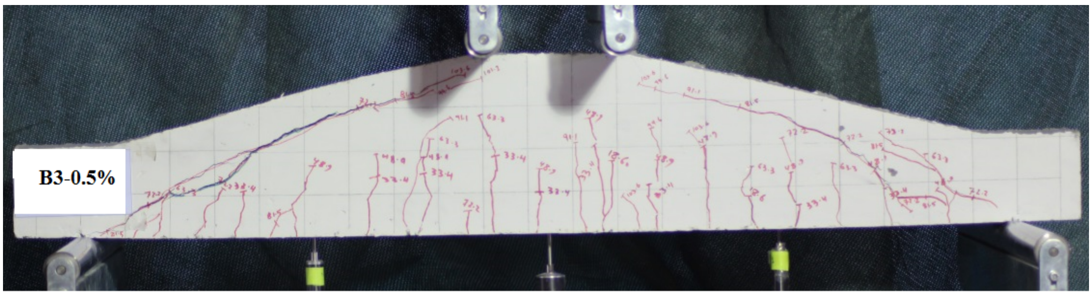

Figure 12. Beam B3 (Shear Mode)

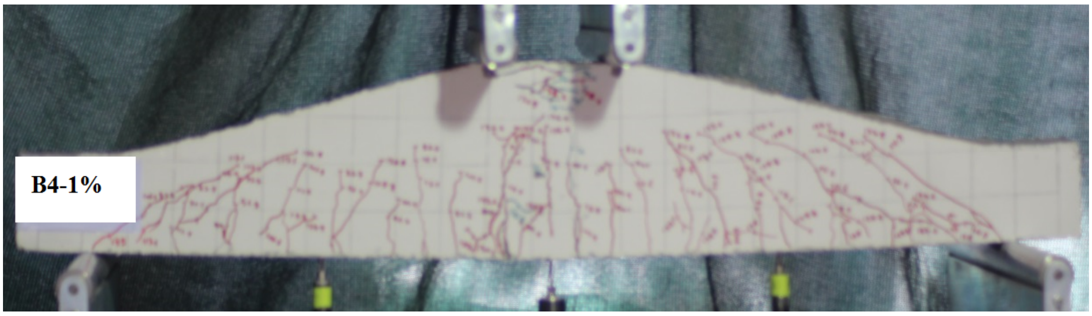

Figure 13. Beam B4 (Flexural Mode)

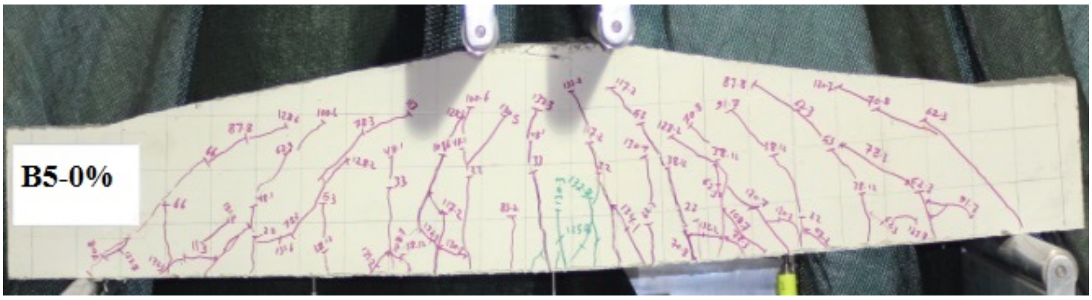

Figure 14. Beam B5 (Flexural Mode)

Figure 15. Beam B6 (Flexural Mode)

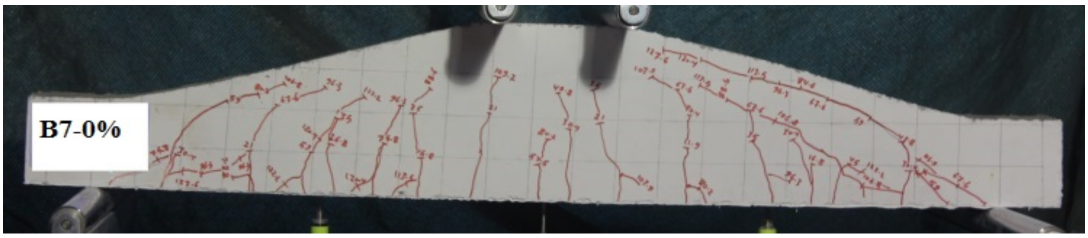

Figure 16. Beam B5 (Shear Mode)

Figure 17. Beam B6 (Flexural Mode)

6.4 Load Deflection relationship: Load and displacement were measured simultaneously during testing. Loads were measured via a load cell connected to the test machine, while displacements were measured by two LVDTs.

- ***Group without stirrups***: As shown in Fig. 18, as the steel fiber ratio increases, the load and deflection capacity of the haunched beam increases. The central displacement capacity of the specimen B2 (0% fiber) at the ultimate load was greater than the capacity of specimen B1 (0% fiber). As a general conclusion, the deflection capacity of haunched beam was more than the capacity of the prismatic beam, as shown in Figure 19. This increment can be explained by the ability of haunched beams to redistribute the cracks along the beam.

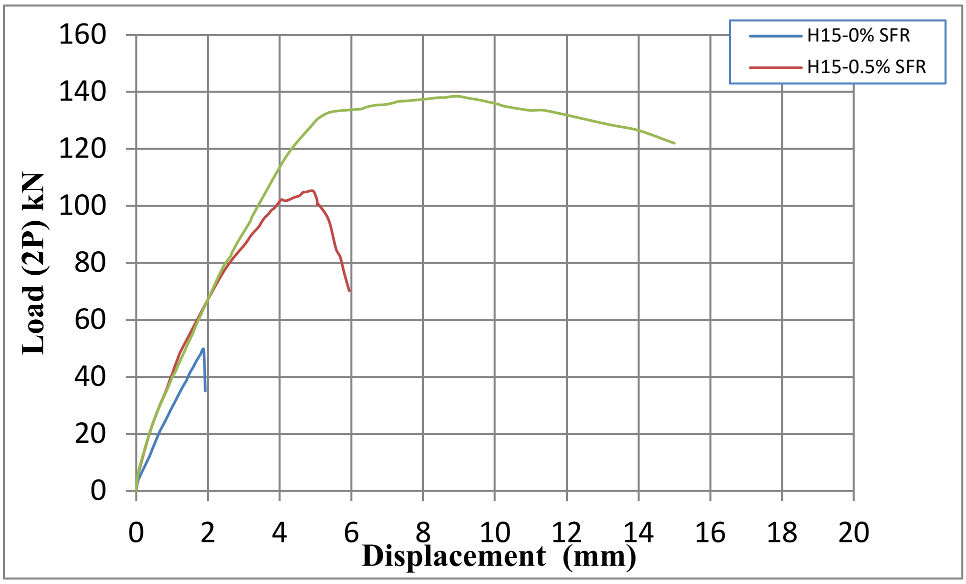

Figure 18. Relationship of loads-displacement for the specimens (B2, B3 and B4)

- ***Group with stirrups:*** Two specimens that have the same geometric shape (angle of inclination) through Figures. 20. Compared specimens in the Figures contain different amount of steel fiber (0 & 0.5%). The load–deflection curves show that in the There is a high similarity between them, and haunched beams with 10^{o} inclination angle regarding failure mode and load capacity. However, the relationship between load and deflection changes, as the angle of inclination increases. The load capacity and ductility decreases for the haunched beam with inclination angle of 15^{o} (B7). However, the capacity and ductility of this beam can be increased by the addition of steel fiber as shown in the load deflection behavior of B8 specimen Figure 21.

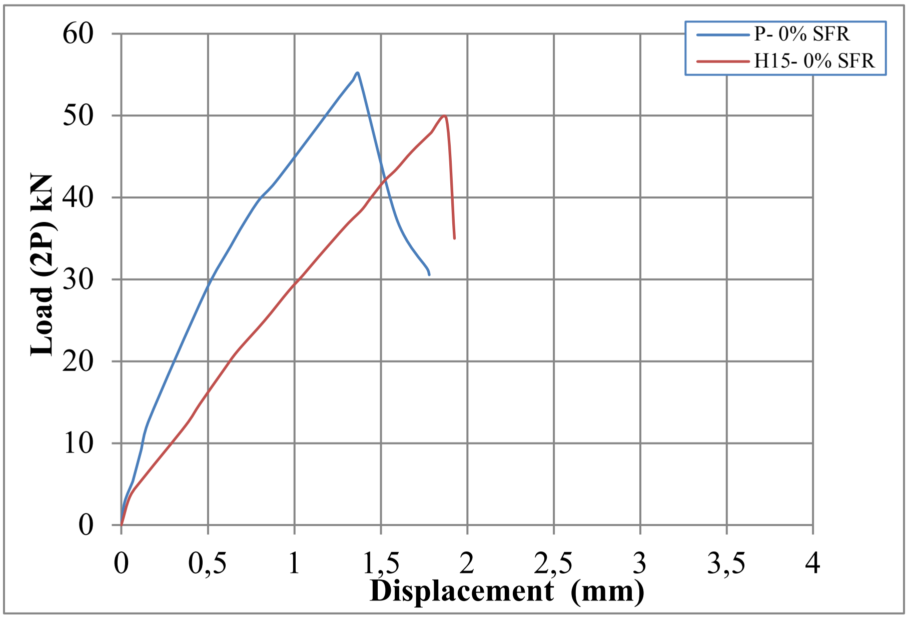

Figure 19. Relationship of loads- displacement for the specimens (B1) and (B2)

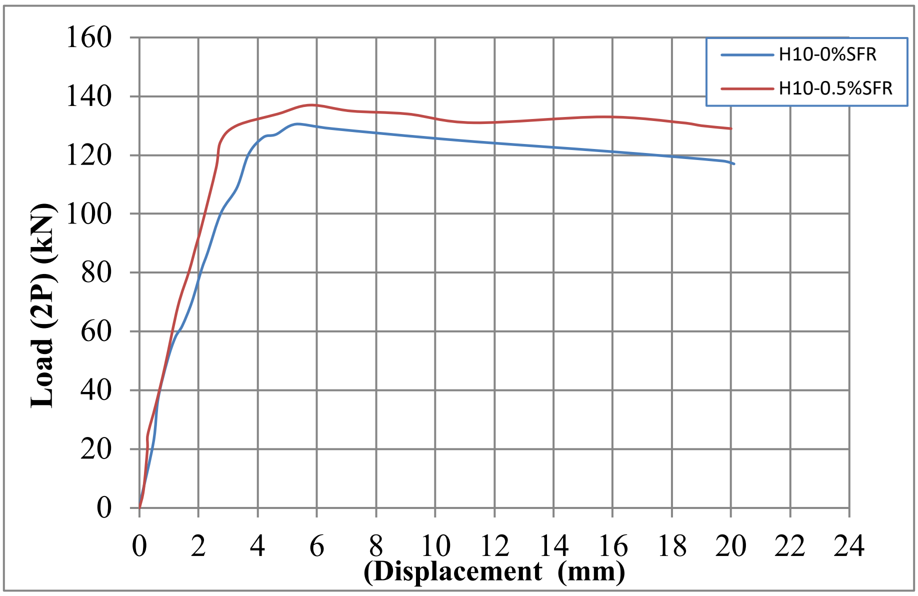

Figure 20. Relationship of loads- displacement for the specimens (B5) and (B6)

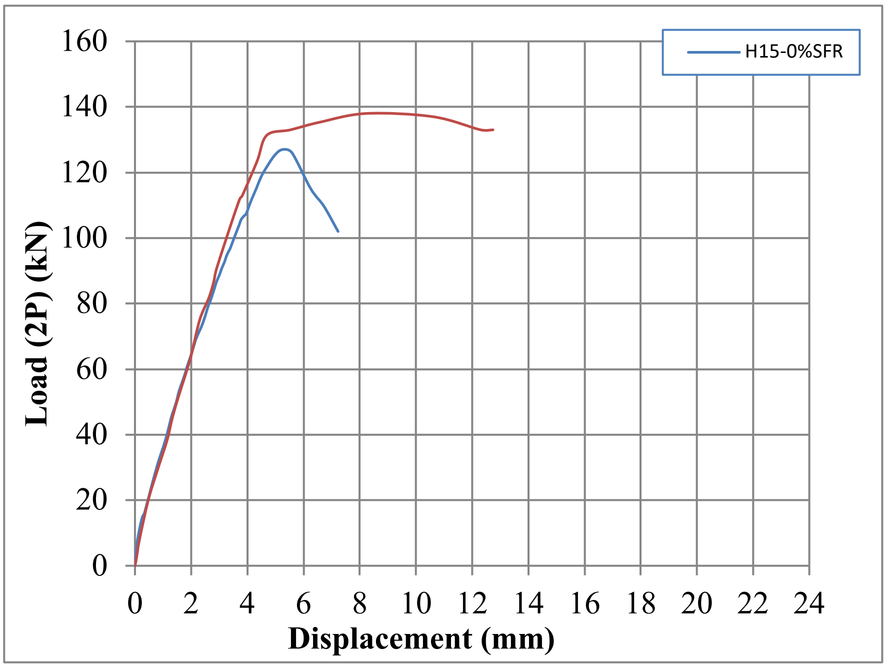

Figure 21. Relationship of loads- displacement for the specimens (B7) and (B8)

7. CONCLUSION

Eight beam specimens including one prismatic and seven haunched beams were produced from self- compacting concrete (SCC) and self-compacting steel fiber reinforced concrete (SCSFRC). The specimens were with and without stirrups, which tested under four point loading tests. All tests investigated the influence of two parameters, which were the steel fibers ratio and the inclination angle on flexural capacity, shear strength capacity, failure mode, displacement, and control post cracking in order to investigate the potential of replacing the minimum shear reinforcement by fibers. Based on the results of this experimental work, the following main conclusions can be drawn:

- For the specimens that without stirrups, addition of steel fibers leads to increase in the ultimate shear strength and the displacement of haunched beam. These increments have a positive relationship to the fiber ratio.
- Addition of a sufficient ratio of steel fibers (at least 1%) can convert the mode failure from brittle shear failure to a ductile flexural failure.
- Addition of fiber leads to decrease in the width and the spacing of the shear and flexural cracks. As a result, the fiber improves the toughness of the haunched beams.
- Whenever fibers ratio increases, shear stress in the critical section of the beam increases. However, the amount of increase decreases as the fiber ratio increases. For example, in the haunched beam, the addition of fiber as amount of 0.5% caused to an increase in the shear stress by 69%, while adding 1% steel fiber caused an increase of 78.6%.
- The addition of steel fiber enhances the post-cracking behavior of the haunched beams. This improvement is positively proportional to the amount of fiber ratio. Moreover, the warning was clear before failure of the beams containing steel fiber. This explains that the fiber can redistribute stresses in concrete.

- For the specimens without fiber, the displacement capacity of haunched beams was slightly more than the capacity of prismatic beam.
- Whereas the specimens that with stirrups, as the inclination of the hauched beam increases, load capacity of the beams decreases and the failure mode changes from flexure to shear even the mechanical properties of the concrete, main and shear reinforcement ratio are same with the correponding prismatic beams.
- For the use of steel fiber, it is suitable to use self-compacted concrete to avoid reduction of workability of concrete.
- Until 10^o of inclination of the haunched beams, mechanical behavior of haunched beams and prismatic beams are very similar. The load capacities of them are also near to each other. Therefore, design considerations of prismatic beams can be applied to the haunched beams whose inclination is low (for example 10^o).
- The use of steel fiber in the haunched beams that with and without stirrups reduces the crack width. This feature improves the service life of this type of structural elements in terms of facilitating the repair process in case of a potential rehabilitation. Therefore, fiber can be considered as one of the most effective and inexpensive solutions to prevent brittle and sudden failure in a haunched beam.
- In future studies, the current study can be expanded by the utilization of another type of fiber in reinforced concrete haunched beams. Furthermore, effectiveness of steel fiber on RC haunched beams can be investigated by the alteration of several parameters including main and shear reinforcement ratio and compressive strength of the concrete.

REFERENCES

[1] Parra-Montesinos, G. J., "Shear Strength of Beams with Deformed Steel Fibers," *Concrete International*, V. 28, No. 11, Nov. 2006, pp. 57-66.

[2] Minelli, F., "Plain and Fiber Reinforced Concrete Beams under Shear Loading: Structural Behavior and Design Applications," PhD thesis, Department of Civil Engineering, University of Brescia, Starrylink Editrice, Brescia, Italy, 2005, 429 pp.

[3] Lim, T. Y., and Paramasivam, P., "Shear and Moment Capacity of Reinforced Steel-Fibre-Concrete Beams," *Magazine of Concrete Research*, V. 39, No. 140, 1987, pp.148-160.

[4] Dinh, H. H.; Parra-Montesinos, G. J.; and Wight, J. K., "Shear Behavior of Steel Fiber-Reinforced Concrete Beams without Stirrup Reinforcement," *ACI Structural Journal*, V.107, No. 5, Sept.-Oct. 2010, pp. 597-606.

[5] Barragán, B. Failure and toughness of steel fiber reinforced concrete under tension and shear, PhD Thesis, Universitat Politecnica de Catalunya, Spain, 2002.

[6] ACI Committee 318-05. Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05). Farmington Hills (MI): American Concrete Institute; 2005.

[7] You, Z., Ding, Y., and Niederegger, C. (2010). "Replacing stirrups of self compacting concrete beams with steel fibers." Transactions of Tianjin University, Vol. 16, No. 6, pp. 411- 416.

[8] BS1881-116, "Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institute, London, 1983.

[9] ASTM. American Society for Testing and Materials. 2004. Standard test method for splitting tensile strength of cylindrical concrete specimens. C 496-04. West Conshohocken, PA.