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Efficiency of Steel Fiber on Carrying Capacity of Short Square Columns

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Abstract

An experimental investigation is carried out to find the beneficial effect of adding steel fiber to reinforced concrete square columns. Hooked end steel fiber type is used in this investigation. The aspect ratio is 60 and the percentages of the steel fiber that added to the concrete are 0.5%, 1.0% and 1.5%. The experimental work consists of fabricated twenty columns to observe the effect of steel fibers on the axial and bending moment capacity. The specimens are classified into five groups according to the applied load on it. Each of these groups is consisted of four columns having different steel fiber ratios (0, 0.5, 1.0 and 1.5) %. The columns are tested under concentric, eccentric with variable eccentricities and two-point loading. All tested columns in a one group having the same dimensions, same interior reinforcement and were tested under one applying–load and they have a square cross-section with a dimension of (100 × 100) mm. Specimens with steel fiber results are compared with the control specimen of their own (columns mad of plain concrete). The results showed that increasing steel fiber ratio is caused an increasing in the first cracking load and an increase in the ultimate load for all tested columns.

Keywords: Steel Fiber; Column; Axial Capacity; Moment Capacity.

1. Introduction

The building material that widely used in the world is concrete, and its brittle properties are considered the most important disadvantage. The failure of a structure happens because of the brittleness of concrete bring about destructive property damage and loss of life. This disadvantage may be overcome by the addition of steel fibers to the concrete that will convert concrete to a ductile material.

Mix steel fiber with cement, fine aggregate and coarse aggregate will obtained the steel fiber reinforced concrete (SFRC). The addition of steel fiber to the concrete improves it in the flexural strength, shear, impact strength, torsional strength, fatigue strength, tensile strength, and failure toughness and shock resistance in addition ductility. Steel fiber used in the concrete resists the spread of cracks because of the bonding force between the concrete and the steel fiber.

It is particularly valuable in reducing cracks because of concrete shrinking in a hot climate. Furthermore, the excellent ductility of SFRC renders this material worthy for military purposes such as building an underground security structure against shelling.

In this work, the effects of adding different hooked end steel fiber ratios to reinforced concrete square columns have been investigated, through experimental tests done on twenty specimens.

The effectiveness of the addition of steel fibers in concrete columns subjected to an axial load has been studied by many researchers. Adding steel fibers within the concrete leads to reduction in workability and increase in concrete strength and ductility [1]. The addition of steel fiber to the concrete columns leads to an increase in the carrying capacity and converts the cover spalling from a sudden technique to a gradual technique [2]. When adding 0.5% steel fiber the

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ductility increases about 165%, 150% and 135% for high, normal and low strength concrete, respectively [3]. The strength of high performance concrete column with 0.75% steel fiber increases by 42% and 21% for aspect ratio 60 and 100, respectively [4]. The ductility of SFRC columns influences by the steel fiber aspect ratio [5]. The normalized capacity of the ultra-high performance fiber reinforced concrete columns reached well above 1 due to the contribution of steel fibers to confinement [6]. The use of two or more types of fibers in a suitable combination may potentially improve the overall properties of concrete and also result in performance concrete [7]. The addition of steel fibers enabled the column to have considerably higher peak and ultimate axial strains and peak dilatation values [8].

The effects of the presence of steel fibers in the eccentrically loaded reinforced concrete square short columns have been studied by several researchers. The addition of steel fibers in reinforced concrete columns can lead to an increase in peak load carrying capacity of the column and a significant improvement in the post-peak response of the column [9]. Ductility will increase when steel fiber is added into the cover of the concrete column [10]. The addition of steel fibers affects load–deflection behavior, ultimate strength capacity, ductility and confinement of eccentrically loaded high strength reinforced concrete columns [11]. Steel fibers reduce cracks on columns surface, especially shear cracks, and prevent cracks from getting wider during the loading until crushing of concrete in compression [12]. The feasibility of steel fibers as a substitute for transverse reinforcement in reinforced concrete columns is further confirmed [13]. The bending stress of fiber reinforced concrete columns is larger than that of reinforced concrete columns [14]. The enhancements in the strength and ductility of the columns reinforced with hybrid steel fibers are due to the functions of macro and micro steel fibers [15]. Volume fraction of steel fiber has a great influence on both the structural behavior and failure modes of specimens [16].

2. Experimental Program

2.1. Manufacturing of the Models

The total number of specimens is 20 divided into five groups, each containing four columns. In each group, the first column made of ordinary reinforced concrete, while the second, third and fourth columns made of SFRC with steel fiber ratio of (0.5, 1.0 and 1.5) %, respectively. All columns specimens have a square cross-section with the dimensions of (100×100) mm. The following details the dimensions of the specimens and reinforcing steel for each specimen in the same group. Group A having four columns specimens, the total length was 330 mm. The load was applying in the center of a column to obtain eccentricity equals zero, and so the column is under pure axial load, as shown in Figure 1. In Groups B, C and D, each group having four columns specimens, the total length of each specimen was 630 mm. The specimens have been molded in a manner that permits to apply an eccentric force. The load is applied with eccentricity equals to (60, 120 and 80 mm), respectively from the center of the column, to get a column subjected to axial force and bending moment. Figure 2 illustrates the dimensions and details of steel reinforcement of these specimens. Also, Group E has four columns specimens; the total length of each specimen was 430 mm. The two forces are applied in the side of the column, to obtain eccentricities equals infinity, to get a column subjected to a pure moment loading case, see Figure 3 Table 1 shows the details of the columns specimens tested in this study.

Table 1. Details of specimen’s column

Group	No. of columns	Eccentricity (mm)	S teel fiber ratio (%)	Length (mm)	Main steel bar	Tied steel
A	4	0	0, 0.5, 1.0, 1.5	330	4 ϕ8	ϕ4 @ 85 mm
B	4	60	0, 0.5, 1.0, 1.5	630	4 ϕ8	ϕ4 @ 85 mm
C	4	120	0, 0.5, 1.0, 1.5	630	4 ϕ8	ϕ4 @ 85 mm
D	4	180	0, 0.5, 1.0, 1.5	630	4 ϕ8	ϕ4 @ 85 mm
E	4	∞	0, 0.5, 1.0, 1.5	430	4 ϕ8	ϕ4 @ 85 mm

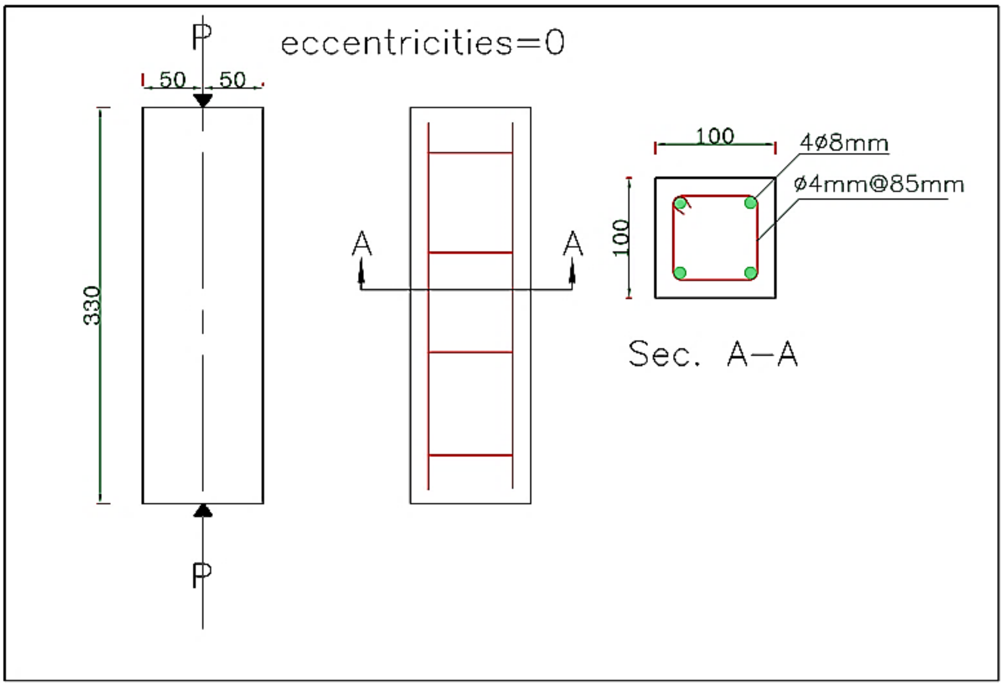


Figure 1. Column specimen under pure axial load (eccentricity = 0)

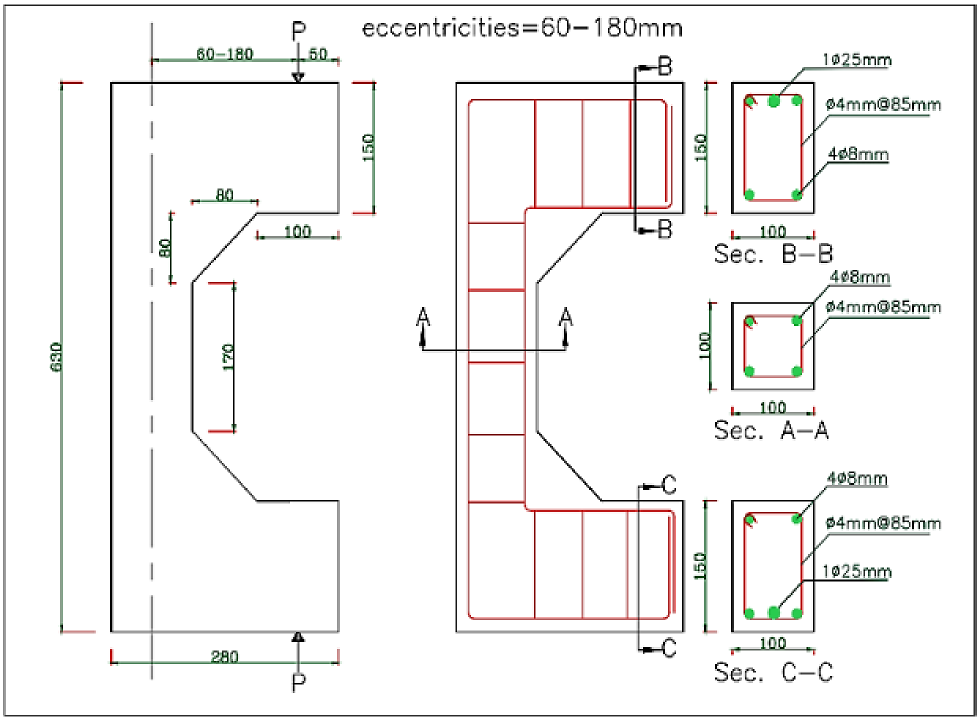


Figure 2. Column subjected to axial force and uniaxial moment (eccentricity = 60, 120 and 180 mm)

Reinforcements used in this study are deformed steel. It is made in Ukraine where three sizes (with diameters of (4, 8, and 25) mm) were used in one model some place. The main longitudinal reinforcement in the column is (4ф8 mm) and the stirrups is (ф4 mm @ 85 mm). A φ25 mm diameter reinforcement bar has been used in the tensile and compression zones in the region near the support, to ensure that the moment is translate to the center of the column.

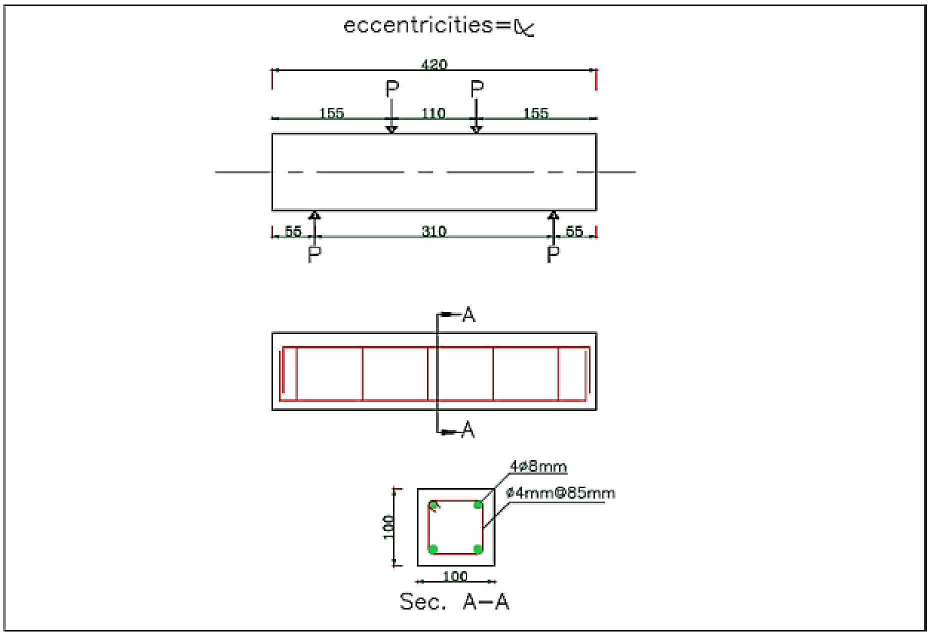


Figure 3. Column subjected to inside two forces (eccentricity = ∞)

2.2. Material Properties

2.2.1. Cement

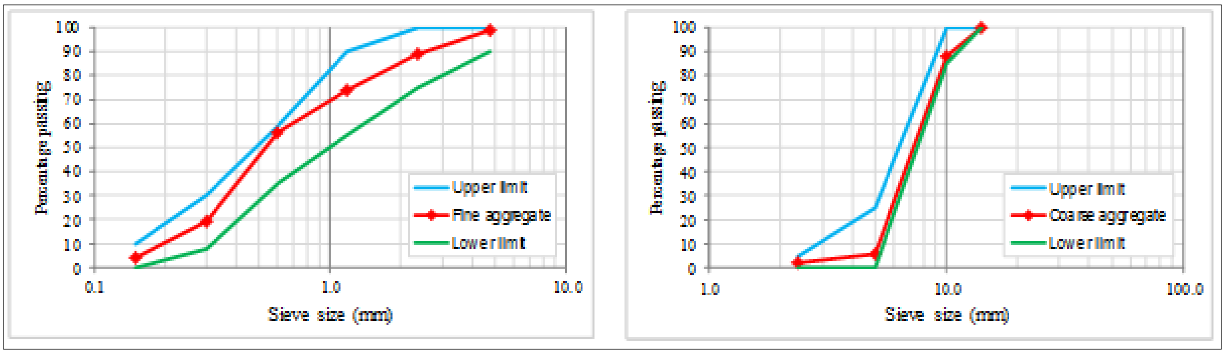
The cement used in the concrete mixing is an Ordinary Portland Cement (Type I) and was supplied from (Taslooja) factory in Karbala, which is product of the United Cement Company.

2.2.2. Fine Aggregate

Natural sand from BAHR EL-NAJAF (Abn Melu) region in Iraq was used for concrete mixes of this research. The fine aggregate was passing a 4.75 mm (No. 4) sieve and retained on a 0.075 mm (No. 200) sieve. The grading curve of the fine aggregate as per IQS No. 45/1984 Zone (2) [17] is shown in Figure 4-a. Sand was successful in the chemical and physical tests carried out it in a specialized laboratory.

2.2.3. Coarse Aggregate

Crushed gravel was used graded with a maximum size of 10 mm. This size was obtained by the work of a special sieve with a maximum opening of 10 mm and was manually passing. The grading curve of the coarse aggregate as per IQS No. 45/1984 [17] is shown in Figure 4-b. The gravel was washed manually by pure water to get rid of salts and Sulphates. The source of the gravel was Al-Nibaii region.



(a) (b)

Figure 4. Grading curve of: (a) Fine aggregate, (b) Coarse aggregate

2.2.4. Steel Fiber

Steel fiber used in this research is a product from AKM Company, which is a Turkish manufacturing and it is a hook end type. The length of the steel fiber is 30 mm, and the diameter is 0.5 mm the aspect ratio (length /diameter of the fiber) of fibers is 60. The steel fiber satisfied the requirements of ASTM A820 / A820M-16 [18], and the tensile strength of the steel fiber was 1570 MPa. Figure 5 shows the steel fiber that was used in this research.

Figure 5. Hook end steel fiber

2.3. Concrete Mix Design

By using the British method (BS8500 Part 1 [19] and Part 2 [20]) in the mix design of concrete, the mixing proportion [cement: sand: coarse aggregate] was (1:1.4:2.15) by weight, and the water-cement ratio was (0.43). This proportion was selected to provide concrete with an average cubic compressive strength of 40 MPa. It's evident that the w/c is comparatively high since the mixing was wiped out June month (when a temperature at the laboratory was regarding 45°C, and therefore the evaporation of water was in a very high range). The combination contents for (1 m^3) of concrete volume unit is given in Table 2.

Table 2. Concrete mix proportions for (1 m^3) of concrete

Cement (kg/m^3)	450
Sand (kg/m^3)	700
Gravel (kg/m^3)	1100
Water (lit./m^3)	195
Water cement ratio (%)	0.43%

2.4. Testing Procedure

After the columns were removed from the water at 28 days' age, they were cleaned and painted in order to clarify the crack propagation, as shown in Figure 6. Each column was classified, the place of support points, loading points and the accurate setup of the testing equipment was defined. The columns were put in the machine test on the supports top and bottom simply supported. all columns were tested under two-point loading and with different distances from the center line of the column and those distances were 0, 60, 120 and 180 mm, to ensure that the column be exposed to different axial loads and bending moments, see Figure 7. There are five specimens of columns in which eccentricity equals Infinity, which necessitated the change of sported and the adjustment of the testing machine where the column was tested as a simply supported beam. The load was equally divided into two point loads, which were transferred to the concrete beam through a distribution beam, which is supported by the I section steel, this test setup is done for obtaining the pure bending capacity of the column specimens.

Figure 6. Columns specimens before testing

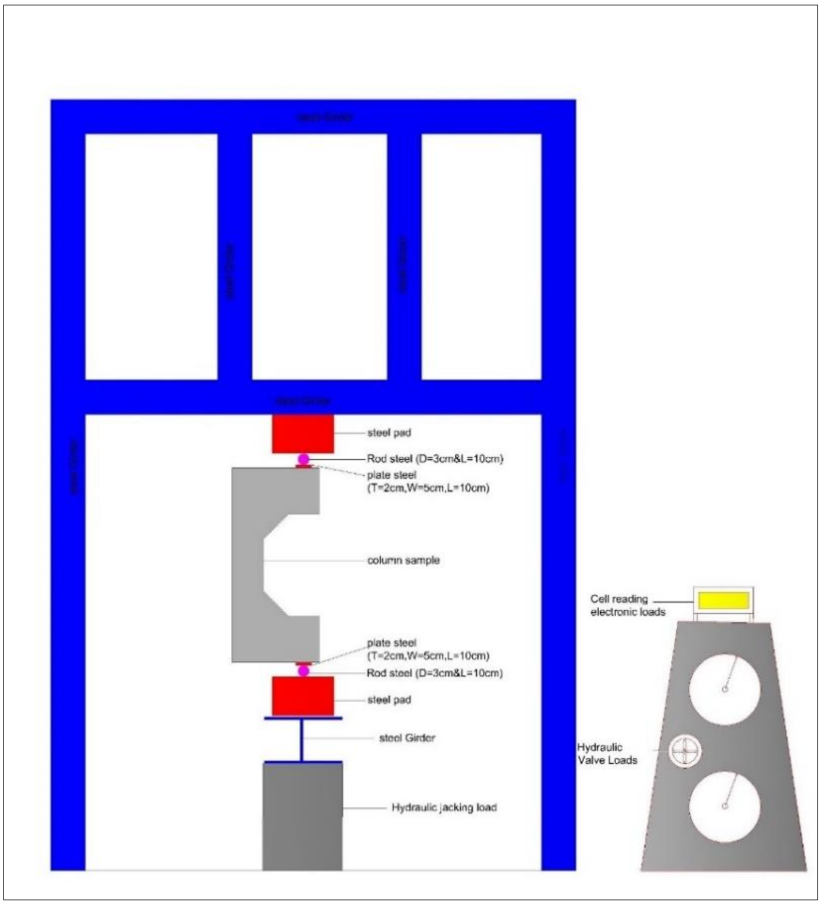


Figure 7. Schematic drawing of test set

3. Results and Discussion

3.1. Columns Behavior

In the first stage, linear behavior of the load response was obvious. This stage covers the region up to first cracking loads. Within this stage, the materials still elastic and no cracks occur within the tested specimens. In the second stage, vertical, diagonal and flexure cracks in tension face of specimens were started. Those cracks were developed as the load increases. Finally, within the third stage, as the load approaches its ultimate value, the rate of increasing stresses in tension and compression zones is substantially exceeding the rate of increase within the value of applied load until failure occur.

3.2. First Cracking Loads of Tested Columns

Table 3 summarizes the first crack appearance load for all the tested columns in Groups A, B, C and D. It can be noticed that the increase in steel fiber ratios leads to delay the appearance of the first cracks for both vertical and flexure cracks, and it had been observed that vertical cracks were appeared before flexure cracks because of the applying of both the axial force (P_n) and bending moment (M_n) on the tested columns (i.e., the eccentricity with a different value).

Table 3. Summary of first cracking loads for group A, B, C and D tested columns

Group	Column nomenclature	Eccentricity (mm)	Steel fiber percentage (%)	First cracking Load (kN)	Reduction of first cracking load (%)
A	CO-1-E=0	0	0%	75	-----
	CO-6-E=0	0	0.5%	115	53.3%
	CO-11-E=0	0	1%	175	133.3%
	CO-16-E=0	0	1.5%	203	170.6%
B	CO-2-E=60	60	0%	35	-----
	CO-7-E=60	60	0.5%	45	28.5%
	CO-12-E=60	60	1%	65	85.7%
	CO-17-E=60	6	1.5%	80	128.6%

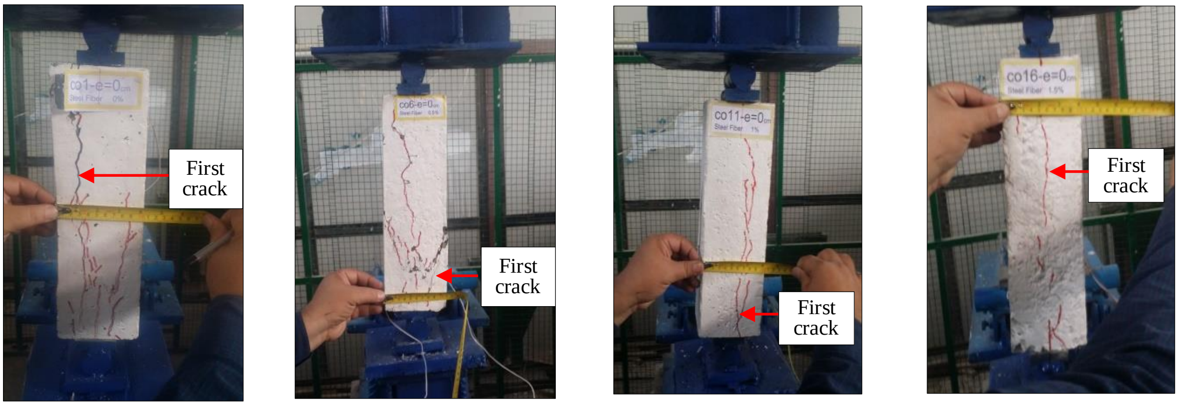
C	CO-3-E=120	120	0%	12.5	-----
	CO-8-E=120	120	0.5%	22.5	80%
	CO-13-E=120	120	1%	27.5	120%
	CO-18-E=120	120	1.5%	32.5	160%
D	CO-4-E=180	180	0%	7.5	----
	CO-9-E=180	180	0.5%	12.5	66.7%
	CO-14-E=180	180	1%	17	126.6%
	CO-19-E=180	180	1.5%	20	166.6%

Figure 8 displays the cracks pattern and the first crack position for the columns of Groups A, B, C and D. In Group A, the first crack was a small vertical crack on one face of the tested column (splitting crack) and soon spread and other mostly vertical cracks, with varying widths, appeared on all faces. The failure occurred when the load carrying capacity of the column was reached.

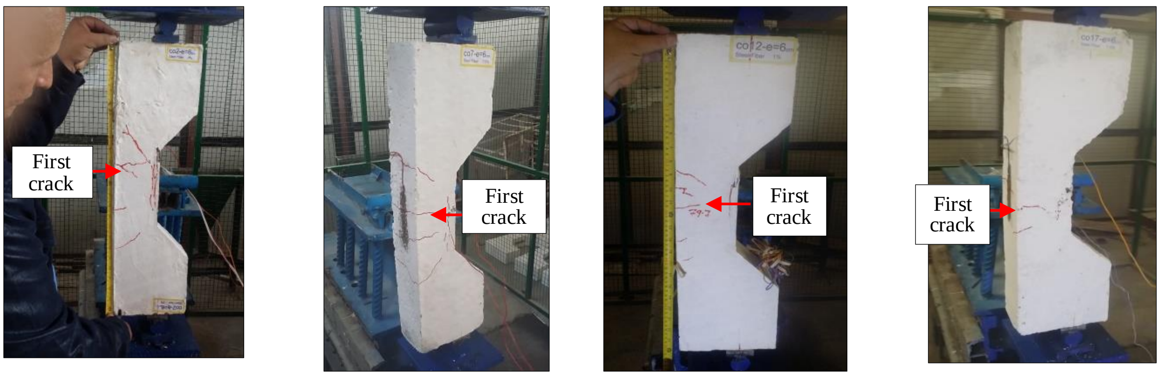
In Groups B, C and D, the first crack was a small horizontal crack on tensioned side face of the tested column (flexural crack). As the applying load increased, more horizontal cracks appeared on the same face and spread on the two adjacent faces. The failure occurred when the concrete crushed in the far face.

3.3. Ultimate Loads for Different Tests

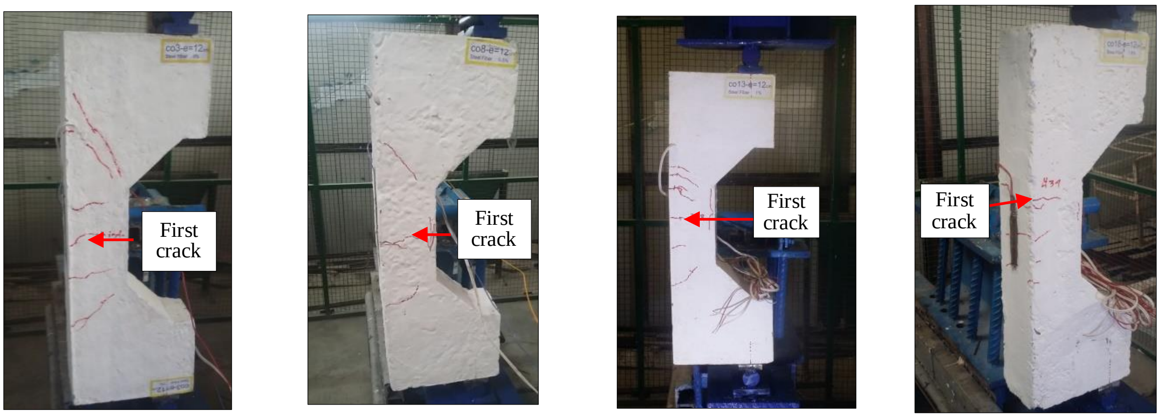
Table 4 summarizes the values of ultimate load of tested columns with different steel fiber ratios. In Group A, the columns are subjected to a concentric compression load only. The maximum percentages of the increase in ultimate loads were (43.1, 59.1 and 87.3) % for columns made of SFRC, which contained the ratios of steel fiber (0.5, 1.0, and 1.5) %, respectively. In Groups B, C, D and E the tested columns were subjected to an axial load and variable bending moment (i.e., the eccentricity = (60, 120 and 180) mm). The maximum percentages of the increase in ultimate loads were (6, 26.5 and 39.2) %, (20, 37.2 and 51) %, (11.3, 34.9 and 43.6) % and (3%, 11% and 14.2%) for columns made of SFRC having ratios equal to (0.5, 1.0, and 1.5) %, respectively. And from this table it could be notice that the increase in the steel fiber ratio in columns will increase the ultimate loads for it compared to the columns made of ordinary reinforced concrete (reference columns), and will increase the carrying capacity of these columns.



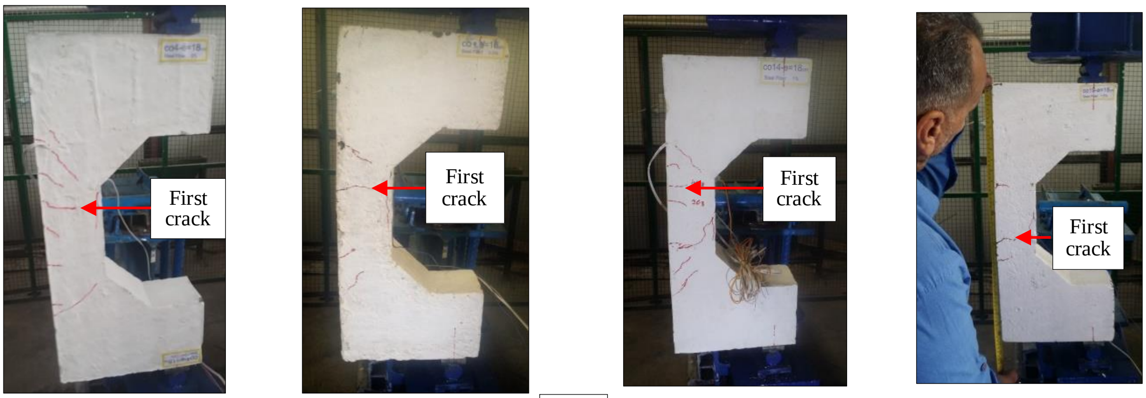
(a)



(b)



(c)



(d)

Figure 8. Cracks pattern for columns of: (a) Group A, (b) Group B, (c) Group C, (d) Group D

Table 4. Effect of increasing steel fiber ratios on ultimate loads

	Column Nomenclature	Steel fiber percentage (%)	Eccentricity (mm)	Ultimate load (kN)	Increasing in Ultimate Load %
A	CO-1-E=0	0%	0	128.8	Reference
	CO-6-E=0	0.5%	0	184.3	43.1%
	CO-11-E=0	1%	0	205	59.1%
	CO-16-E=0	1.5%	0	241.3	87.3%
B	CO-2-E=60	0%	60	63	Reference
	CO-7-E=60	0.5%	60	67	6%
	CO-12-E=60	1%	60	79.7	26.5%
	CO-17-E=60	1.5%	60	87.7	39.2%
C	CO-3-E=120	0%	120	29	Reference
	CO-8-E=120	0.5%	120	34.8	20%
	CO-13-E=120	1%	120	39.8	37.2%
	CO-18-E=120	1.5%	120	43.9	51%
D	CO-4-E=180	0%	180	19.5	Reference
	CO-9-E=180	0.5%	180	21.7	11.3%
	CO-14-E=180	1%	180	26.3	34.9%
	CO-19-E=180	1.5%	180	28	43.6%
E	CO-5-E=∞	0%	∞	173	Reference
	CO-10-E=∞	0.5%	∞	178	3.1%
	CO-15-E=∞	1%	∞	191.7	11%
	CO-20-E=∞	1.5%	∞	197.2	14.2%

Figures 9 to 13 demonstrate the relation between the tested column's ultimate load and the steel fiber percentage for the columns of Groups A, B, C, D and E. As the added percentage of the steel fiber to the concrete increases, the ultimate load of the column increases too. This increase is due to the enhancement that the steel fiber provided to the concrete under both compression and tension.

Accomplished experimental tests showed that the ultimate axial strength in centrally loaded SFRC columns increased in comparison with ordinary concrete column. Such increase of strength was governed by provided steel fibers, which resist the spread of cracks in concrete.

Although the load carrying capacity of the tested specimens decreased with the increase of external load eccentricity, still steel fibers have contributes on the ultimate axial strength.

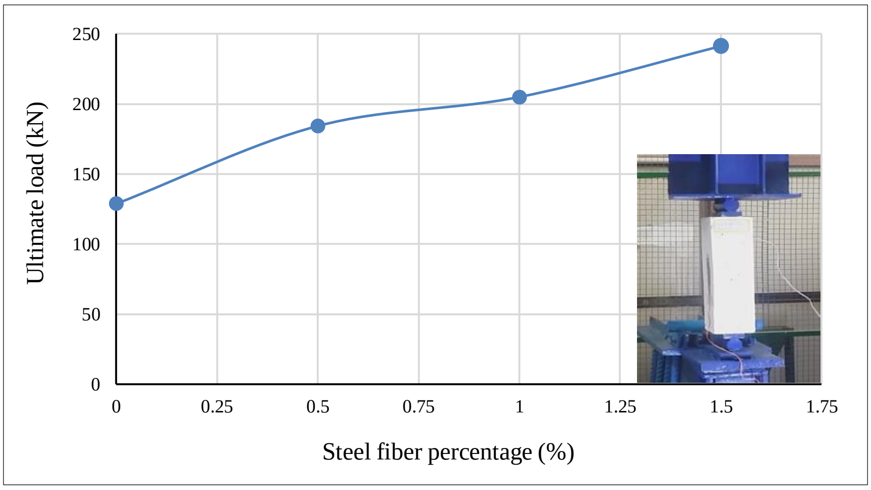


Figure 9. The relation between the tested column's ultimate load and the steel fiber percentage for the columns of Group A (e = 0)

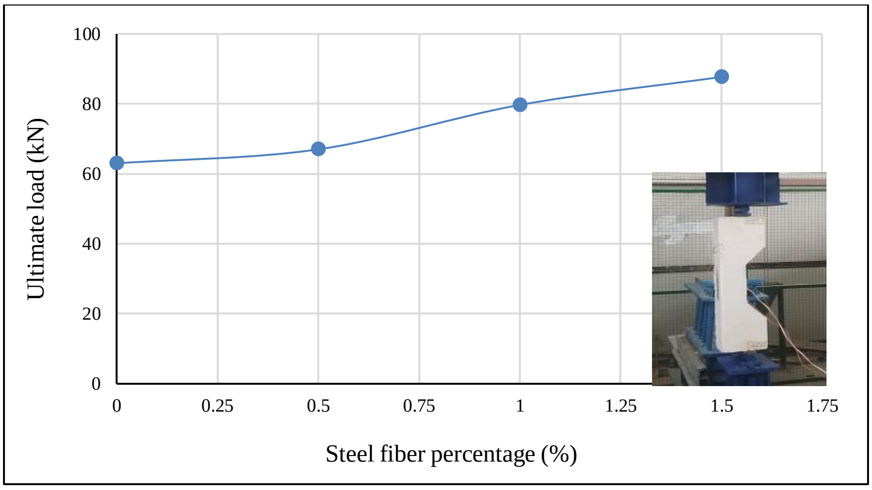


Figure 10. The relation between the tested column's ultimate load and the steel fiber percentage for the columns of Group B (e = 60 mm)

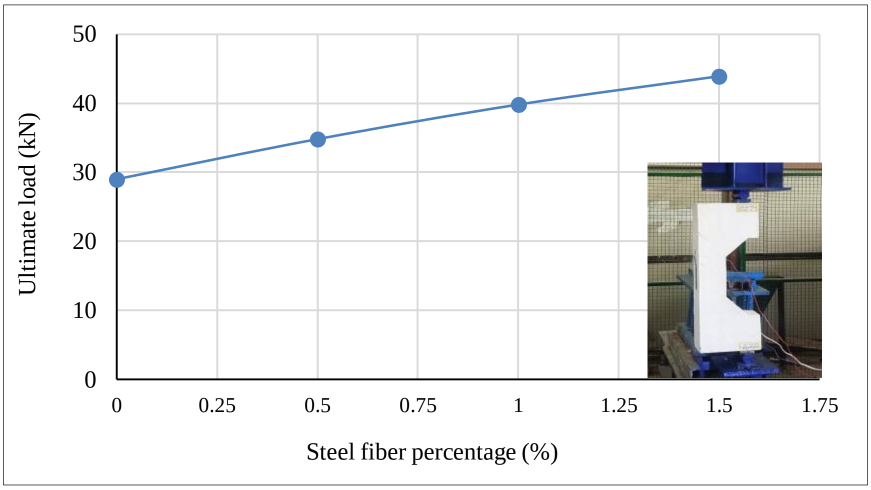


Figure 11. The relation between the tested column's ultimate load and the steel fiber percentage for the columns of Group C (e = 120 mm)

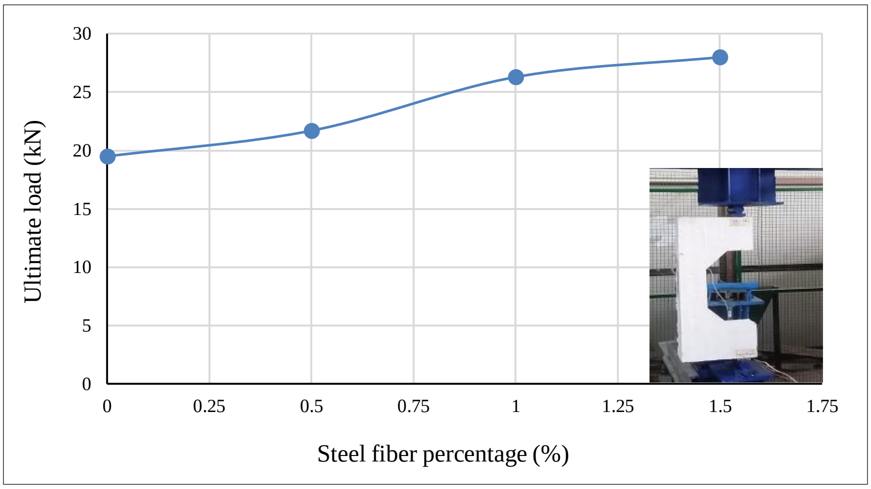


Figure 12. The relation between the tested column's ultimate load and the steel fiber percentage for the columns of Group D (e = 180 mm)

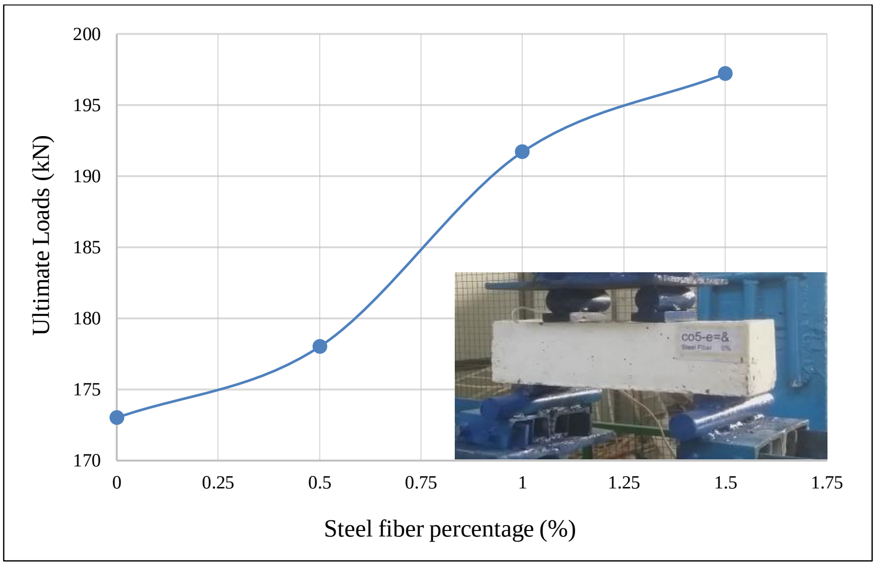


Figure 13. The relation between the tested column's ultimate load and the steel fiber percentage for the columns of Group E (e = ∞)

The load versus time of Group A is shown in Figure 14. The loading rate changed obviously after first crack initiated.

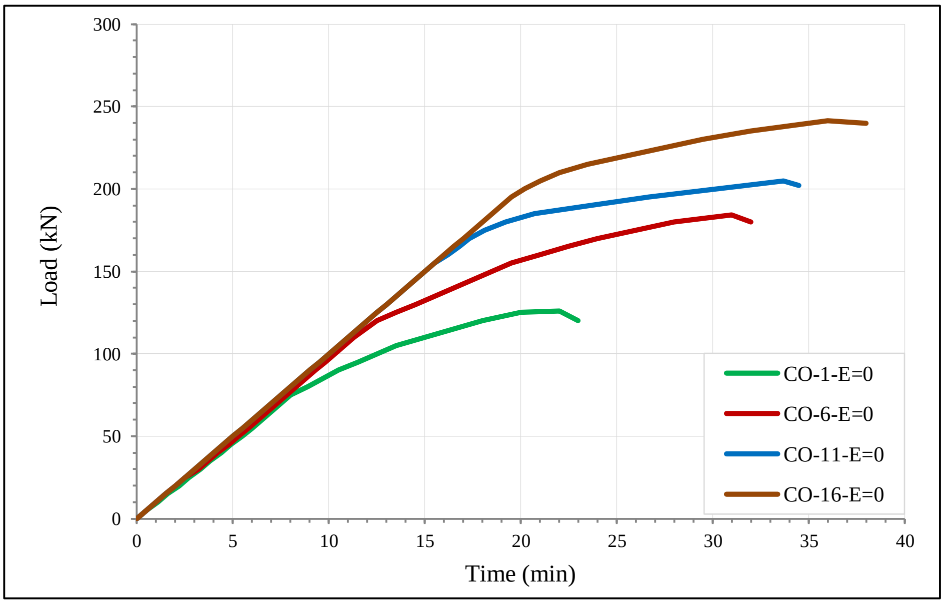


Figure 14. Load versus time of Group A (e = 0)

4. Conclusion

The following are the conclusions of this study:

- Presence of the steel fiber in reinforced concrete columns caused increasing in their first cracking loads, which subjected to a same load case compared to the column made of reinforced concrete only.
- The load conduct of the reinforced concrete square columns, which contain different ratios of steel fiber (0.5, 1.0 and 1.5) % for the interaction diagram curve, shows that the axial load capacity of SFRC column for point A are increased by 43.1%, 59.1% and 87.3%, respectively compared to the control column (i.e., columns made of plain concrete).
- As increasing of the steel fiber ratio in the columns made of SFRC was observed a decrease in the number of cracks

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