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Experimental Investigation on the Impact of Micro-Steel Fibers on the Flat Slabs' Punching Shear Resistance

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Abstract: This research examined the effects of micro-straight steel fiber percentage and column form on the punching shear of SFRC slabs. Fibers made of micro steel with a diameter of 0.2 mm and a length of 13mm with an aspect ratio equal to 65 were used. The fiber content varied between 0.5%, 1%, and 1.5% by volume. Four different types of concrete mixes were adopted and tested. Experimental results showed that when the percentage of steel fibers in SFRC increased, its compressive strength, flexural strength, splitting tensile strength, and direct tensile strength improved. This investigation applied a monotonic load to eight cast slabs (two each of conventional concrete of square and circular column sections of the equivalent area while the other six slabs were made with steel fiber concrete. The dimensions of each slab were (920 × 920 × 80) mm. Each slab specimen had essential, edge-based support with square and round column sections. It has been demonstrated that slabs with square column sections endured a relatively higher ultimate load than slabs with circular column segments when the steel fiber dosage was 0.5% or 1.0%. Still, at a steel fiber dosage of 1.5%, circular column segment slabs approached the ultimate load of square column segment slabs. The heterogeneous behavior in concrete can be attributed to the random and unequal distribution of steel fibers throughout the material. There were only flexural fractures visible on the tensile face of the slab. New fractures emerged in the center of the slab as the load increased.

التحقيق التجريبي لتأثير ألياف الفولاذ الدقيقة على مقاومة قص التثقيب في الألواح المسطحة

بان علاء سلمان، رافع فليح حسن
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الخلاصة

كرس هذا البحث لدراسة السلوك العملي لمقاومة القص الثاقب للسقوف الخرسانية ذات الرص الذاتي تحت تأثير التحميل الاحادي الاتجاه. جميع السقوف لها نفس مقاومة الانحناء ونفس الابعاد (920*920*80) ملم. يتضمن البرنامج العملي صب وفحص ثمانية الواح تتضمن المتغيرات الرئيسية المعتمدة في البحث الحالي شكل العمود (دائري، مربع)، نسبة الالياف المضافة بنسب (0.5%, 1.0%, 1.5%) من حجم الخرسانة. أظهرت النتائج ان اضافة الالياف الى السقوف تحسن قوة الانضغاط وقوة الانحناء وقوة الانقسام وقوة الشد المباشر مقارنة مع الخرسانة الغير مقواة بالألياف. وكانت النتائج ذات المقطع العرضي المربع لها حمل اقصى اعلى قليلا من تلك التي لها مقطع عرضي دائري عند نسبة الالياف (0.5%, 1.0%) وعند نسبة الالياف 1.5% فأن الحمل الاقصى للمقطع العرضي الدائري مقارب للحمل الاقصى للمقطع العرضي المربع ويعزى السلوك غير المتجانس للخرسانة الى التوزيع العشوائي وغير المتكافئ للألياف في الخرسانة ولم يكن هنالك سوى شقوق انحناء مرئية على وجه الشد للسقف وظهرت شقوق جديدة في مركز السقف مع زيادة الحمل المطبق عليه.

الكلمات الدالة: الالياف الحديدية، دقيقة، القص الثاقب، الخرسانة المسلحة.

1.INTRODUCTION

Flat slab describes a building with a reinforced concrete floor that does not employ beams or girders to transfer the floor's weight to the building's columns. Rapid construction, minimal depth solutions, layout flexibility, clean surfaces and utilities -free layout, flying formwork, horizontal soffits, and more space and latitude contribute to the cost savings that may be realized when opting for a slab. More benefits are possible with this layout. Foundation and column loads decreased [1]. One of the primary dangers of using such plates is the potential for shear failure at low loads. Punching fractures happen suddenly, inconspicuously, and with minimal flexibility, leading to a slow collapse, i.e., (the spread of loss from a localized location, causing more extensive damage than the original site) [2]. While the exact causes of shear failure remain a mystery, several tactics have been used to counteract it. The punching and shearing equipment break down into one of three distinct stages. The first is the spread of a crack that started in the plate tensile zone at the loading point face as a result of the bending and shear. The second phase involves the plate tightening the reinforcement close to the strained location. In the third stage, the reinforcement's compression zones are vulnerable to bending and shear cracking. [3] [4]. Adding steel fibers to the FRC slab could boost its tensile strength, ductility, and energy dissipation, and improved the slab-to-column connection's performance [5]. In recent studies, steel or synthetic fibers were added to concrete to increase its tensile strength and compensate for its low flexibility [6, 7] results in a more fragile substance than regular concrete. Steel fiber reinforced concrete (SFRC) has piqued scientists' curiosity because of its potential to enhance the functionality of concrete buildings. Compared to regular concrete, SFRC enhances concrete beams' shear strength and other mechanical characteristics [8, 9]. The short fibers' random arrangement provides stretch reinforcement once bridging fractures have developed. Matrix fibers can tolerate high loads in the post-crack condition due to their high tensile strength and suitable attachment to the matrix [10]. Specimen performance can be improved by adding MSSF to concrete mixtures, which slows the load-vertical motion curve after final loading, especially under concentric loads [11]. Initial tear strength highly depends on fiber volume and shape [12]. The concrete performance is significantly affected by how and where steel fibers are distributed throughout the material [13, 14]. Abdulhameed [15] Studied the fiber reinforced concrete slab punching shear strength. The primary variables tested were the concrete compressive strength (between 35 and 65 MPa), column diameter (75, 100, and 150 mm), volume fraction between 0 and 1.0 % and steel fiber aspect ratio between 50 and 133 %. The experimental findings indicated that the shear strength increased when more fibers were added to the boards. All boards used in the tests were (800 × 800 x 60) mm in size. It was demonstrated, for instance, that a 48% increase in breaking load occurred when the volume percentage of steel fibers raised from 0.0 to 1.0% and the fiber content also changed the location of the critical shear perimeter surrounding the loaded area. Siva and Mallika [16] experimentally studied small-scale flat plates, i.e., nine SFRC and three conventional through their paces. Consequently, the fracture toughness of the glass fiber-reinforced boards significantly enhanced, the piercing strength significantly increased, and the connection integrity between the columns is greatly strengthened. It was discovered that the shear stress reduced with increasing sample size, and the fiber-reinforced boards crumpled more plastically than the non-fiber boards. Al-Shaikhli [17] used square and triangular reinforced concrete slabs to create six scaled-down specimens. The reactive powder concrete (RPC) slabs' punching shear strength of various shapes was experimentally tested. A superplasticizer cement mixture with steel fibers and silica fume was added for high flexibility and strength constituting reactive powder concrete. Three samples of the same size were separated into three groups, each containing a different percentage of steel fibers (0%, 0.5%, and 1.0%). The results demonstrated that the punching shear strength of square slabs with a steel fiber content of 0.5% and 1% increased by roughly 37% and 100%, respectively. This growth amounts to approximately 0.5% and 1% of the overall volume, while around 53% and 100% for triangular plates with steel fibers, respectively. Concrete's flexural strength was studied by Hassan et al. [18], who emphasized the effects of using Polyvinyl Alcohol (PVA) as an internal cure. The first factor studied in between 25 and 50 % of the total slab thickness, was the slab specimens supported by two simple supports on opposite sides and subjected to a linear force along two lines perpendicular to the supports. The results demonstrated that the PVA increased the load capacity by 47.4% and 55.6% however, it decreased the maximum deflection by 28.6% and 50.3% for solid slabs. Also, the PVA increased the load capacity by 34.7% and 35.6% however, it decreased the maximum deflection by 18.6% and 25.7% for bubble slabs. Yahyia and Murtada [19] included the construction and testing of five slabs, four of which are made of concrete and had different fine aggregate radios of 75%, 50%, 25%, and 0% to achieve different densities (2207, 1792, 1536, and 1310 kg/m3). Another slab made of normal concrete, with a 2414 kg/m3 density, served as a reference slab with a 2414 kg/m3 density. The results indicated that decreasing the slab's density from 2414 kg/m3 to 1310 kg/m3 by reducing the fine aggregate in concrete from 100% to 0% had a higher impact on the first crack load than that on the ultimate load of two-way slabs, as the first crack load decreased with percentages of 16.7%, 33.3%, 38.9%, and 61.1%, while the ultimate load decreased with percentages of 7.3%, 21.3%, 46.3%, and 56.1%, In addition, decreasing the slab's density caused cracks to form and spread rapidly. Slab failures tended towards brittleness as cracks diffuse and grow rapidly and wider. Using Bubbles in the slab is a revolutionary way to eliminate the concrete in the middle of the conventional slab; however, as this concrete provides no structural function and adds a significant amount of dead weight to the structure, using a bubble in the slab could weaken the slab and reduce its efficiency by ten percent. Ahmed et al. [20] tested five slabs (1760 mm × 420 mm × 125 mm) : one solid slab without bubbles and steel fiber, one bubble slab without fiber, and three bubble slabs with three different fiber percentages. The first crack appeared at 13 kN in solid slabs and 11 kN in bubble slabs, however at 18 kN, 22 kN, and 24 kN in steel fiber bubble slabs, with a transition from brittle sudden shear failure for the bubble slabs to ductile flexural failure at 1.5% steel fiber content.

2.EXPERIMENTAL PROGRAM

2.1. *Apparatus and Procedures*

Flat slabs, a common structural element in a building, are vulnerable to punched shear failure under very light loads. The influence of column form on the shear strength and behavior of slab sticking under monotonic load has yet to be studied. Under a static-concentrated load, this research examines the FRC slabs' punch shear behavior and strength with columns of varying shapes.

2.2.*Experimental Procedure*

2.2.1.*Materials*

The steel fiber concrete (SFRC) mixtures were employed in this investigation. Table 1 a briefly descries the materials used. This work studied deformed reinforcing steel bars with nominal diameters of 8 mm for the slab and 4 mm for the column.

Table 1 Material Description

Material	Description
Cement	the typical Portland cement (Type I). A product complies with "Iraq's specification No. 5/1984"[21].
Fine aggregate	sand (sieved over 150mm sieve) conforms to the Limits of "Iraqi specification No. 45/1984 for Zone"[22].
Coarse aggregate	Gravel (sieved 14mm sieve) conforms to the Limits of "Iraqi Specification No. 45/1984 for Zone"[23].
Super Plasticizer	The Sika ® Viscocrete 5930-L admixture complies with ASTM-C 494 Types G and F. [24]
Steel fibers	Straight steel fibers with a diameter of 0.2 mm and a length of 13 mm had an ultimate tensile strength of up to 2500 MPa.
Water	Clean water from the tap was used for blending and curing.

2.2.2.*Experimental Sets*

In the experimental program, eight square slabs were cast and tested using a monotonic load, including two squared- slabs of conventional concrete while the other six slabs were made with steel fiber concrete. Each slabs has the same dimensions (920mm by 920mm by 80mm) and reinforcement. The specimen slabs were loaded onto the machine. Steel frames measuring 700mm ×700mm (length × width) were placed over the load locations to prevent tension concentration on the top surface of the slabs at loading. All slabs were loaded to failure in a concentrated load test on the column center. The failure occurred when the slab collapsed suddenly at the same time that the dial gauge in the area where the column contacts the slab stopped reading. The ultimate load was recorded. The main objective was to evaluates the slabs' ultimate load know each sample's failure type, and compare the normal samples with the reinforced samples using fibers. Table 2 displays the overall data and features of the examined slabs. This study focuses on two primary variables to determine their effects:

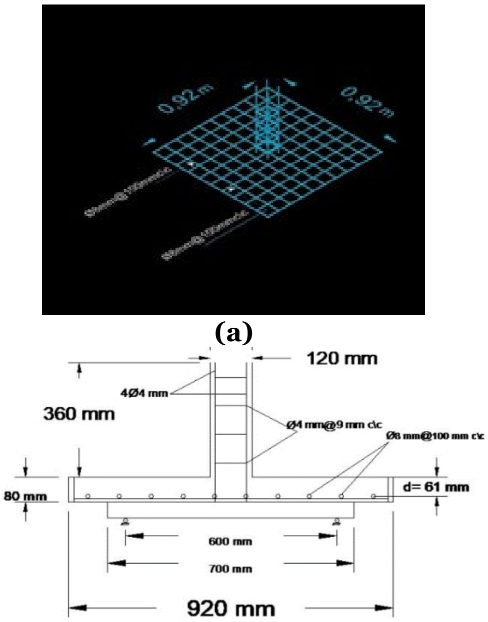
1- Micro-straight steel fibers were used in different proportions and compared with standard concrete.
2- Column shapes, i.e., square and circular sections.

Table 2 The Tested Slabs.

Slab Symbol	Column Shape	Dimension of Column (mm)	Straight Steel Fiber Fraction
CN	Circular	120	zero
SN	Square	110×110	zero
CS0.5%	Circular	120	0.5%
CS1.0%	Circular	120	1.0%
CS1.5%	Circular	120	1.5%
SS0.5%	Square	110×110	0.5%
SS1.0%	Square	110×110	1.0%
SS1.5%	Square	110×110	1.5%

2.2.3.Slabs Data

The adopted program included casting and testing two normal concrete and six FRC-reinforced concrete two-way slabs with a single column, made from the self- compacted concrete mix. Each slab had a dimension of (920×920×80) mm., substantial slab sample had the same cover thickness of 15mm. Tension faces with square and circular column sections were reinforced with a deformed 8 mm rod with 100 mm c/c spacing. The column was available in two configurations: a 110x110 mm square column and a 120 mm diameter circular column with the same equivalent area. The slabs details are listed in Table 2. All square and circular columns were reinforced with 4mm deformed wires. The reinforced slabs in the present study are shown in further detail in Fig. 1.



(a)

(b)

Fig.1 Details of Specimens Cross-Section (a) Reinforcement Three-Dimension View and (b) Section in a Slab.

2.2.4. Design of Concrete Mix

The FRC was constructed using the proportions of the materials shown in Table 3. The flow test in Table 4 determines the workability of conventional and FRC mixes, as shown in Plate 1 [25]. The steel fibers percentage were 0.5%, 1.0%, and 1.5% of the total volume of this compound.

Table 3 Mix Proportions.

Constituent	Cements (kg.m-3)	Fine Agg. (kg.m-3)	Coarse Agg. (kg.m-3)	Water (kg.m-3)	Super Plasticiser (1/100 kg cement)	Fiber amount (%) by Volume	Fiber amount (%) by Volume	Fiber amount (%) by Volume
mount	500	775	825	190	5	0.5	1.0	1.5

Table 4 Slump flow.

Index of Mixes	Slump flow	
	D(mm)	T50 cm (sec)
Mix-R	845	5.6
Mix-M0.5%	794	5.8
Mix-M1.0%	754	6.1
Mix-M1.5%	706	6.8
Mix-H0.5%	804	5.7
Mix-H1.0%	745	6.2
Mix-H1.5%	692	7.2

Plate 1 Flow Test.

2.2.5. Concrete Mixing Procedure

Careful mixing is required to produce the proper workability for casting slabs in wood molds; see plates (1, 2). A mixer is used to prepare concrete. Throughout the study, a mixing procedure recommended by [26, 27] was employed to produce FRC quickly:

1- Before installing the reinforcing steel frame, the utilized molds were greased.
2- After first weighing all the dry components, including the two heaviest living elements (sand and cement), the mixer contents were thoroughly blended. Hereafter, water was included in the concrete mix.
3- After laying down a layer of polyethylene, concrete was put in a mixer and then polished to a smooth finish.
4- The formwork was taken down as soon as the concrete dried and set.

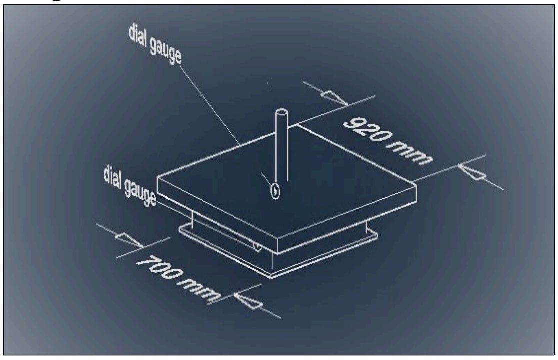
5- After twenty-eight days, all specimens were removed from the curing basin.

Plate 2 depicts how the slabs were cast.

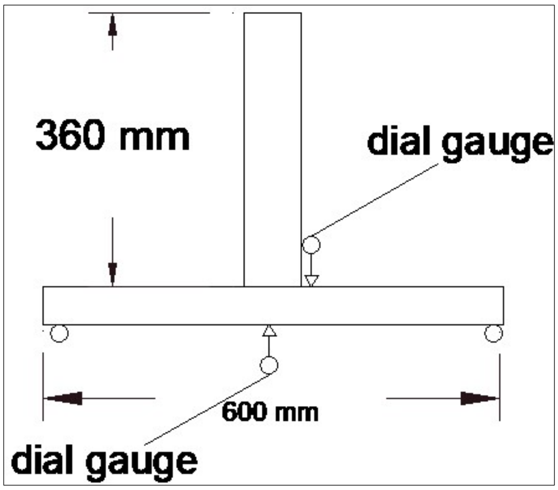
Plate 2 Slab Casting.

2.2.6. Test Setup

Cleanup and white paint were used to examine the crack development in the slab samples. In addition, there were marks on the slabs that marked the loading point and the dial gauge. A 700 mm x 700 mm (length x width) frame was mounted above the stress point to prevent loads from concentrating stress at the top of the slab, as shown in Fig. 2. Plate 3 displays the dimensions of 920mm×920mm×80mm with a clear span (600mm) on the board on the testing apparatus. Each slab was loaded until it reached the failure point. The failure occurred when the slab collapsed suddenly at the same time that the dial gauge in the area where the column contacts the slab stopped reading. The ultimate load was recorded with (0.1) the rate of loading. The main objective was to evaluate the ultimate load of the slabs, know the type of failure for each sample, and compare the normal samples with the reinforced samples using fibers.



(a)



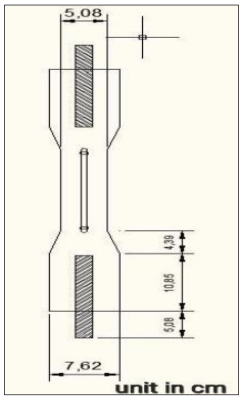
(b)

Fig.2 Details of Slab with Frame (a) Slab with Frame Three-Dimension View, (b) The Dial Gauge Position.

Plate 3 Testing of Slabs.

2.2.7.FRC Mixes' Mechanical Properties

Cubes with dimensions of (150 × 150 × 150mm) were cast for the compressive strength test. Samples for the direct tension test, as seen in Fig. 3, besides cylinders and prisms of (100 x 200) mm and (100 x 100 x 400) mm to test the splitting strength and bending strength, respectively, were cast. The average findings from the three samples are shown in Table 5.



(a)

(b) **(c)**

Fig. 3 The Direct Tension Test (a) Scale of Sample, (b) Mold of Sample (c) The Sample on Test.

Table 5 The Specimens' Results.

Type of test	Fiber Percentage	Strength (MPa)
Compressive Strength f_{cu}	0.5	50.2
	1	55.2
	1.5	59.8
Direct Tensile Strength f_t	0.5	3.7
	1	4.5
	1.5	6.3
Split- Cylinder Strength f_{ct}	0.5	5.5
	1	6.1
	1.5	8.0
Modulus of rupture f_r	0.5	7.5
	1	8.4
	1.5	9.7

3.RESULTS AND DISCUSSION

The ultimate load, associated with deflections, and the load-deflection relationship were included in the test results. Table 6 displays the experimental test results.

3.1. The Ultimate Load P_u

The ultimate loads of the square column section slabs increased by approximately 11.64% and 24.24% compared to the standard slab of steel fiber dose of 0.5% and 1.0%, respectively, with a maximum load of 32.21% obtained with the 1.5% dose. The ultimate load of the cylindrical test plate increased by 2.57% and 2.79% compared to the standard slab with a steel fiber content of 0.5% and 1.0%, respectively, where the highest load was 34.31% with a composition of 1.5%. The ultimate load of the square column section plate was higher than that of the cylindrical section slab of the steel fiber contents by 0.5 and 1.0 %. In contrast, the ultimate load for a cylindrical section panel was the approach for a square column section slab for 1.5 % steel fiber contents. Because the stress concentrated in the corner of the square column, the maximum load value fluctuated, which accelerated the failure.

Table 6 Results of Slabs Specimen Testing.

Designation of Slab	Column Shape	Column Dimension (mm)	Ultimate Load (Pu)(kN)	Deflection at ultimate load (mm)	Max column Penetration (mm)	Mode of Failure
CN	Circular	120	144.14	7.25	1.01	Punching Sudden
SN	square	110×110	144.5	6.3	0.6	Punching Sudden
CS0.5%	Circular	120	147.84	6.49	1.1	Punching Somewhat Gradual
CS1.0%	Circular	120	148.16	9.95	1.58	Punching & Flexural
CS1.5%	Circular	120	193.6	9.82	1.4	Punching & Flexural
SS0.5%	square	110×110	161.32	7.1	0.59	Punching Somewhat Gradual
SS1.0%	square	110×110	179.52	8.74	0.74	Punching Somewhat Gradual & Flexural
SS1.5%	square	110×110	191.04	12.8	2.16	Punching Somewhat Gradual & Flexural

3.2. Load-Deflection Curves

The column penetration, the contact area between the column and the slab, is shown in Figs. (3) and (4). The deflection measured from the lowest slab basket is shown in Figs. (5) and (6). Plates with a cylindrical cross-section showed an increase in shear deflection of around 29.19% and 35.45% for steel dosages of 1.0% and 1.5%, respectively, compared to regular plates. In contrast, the deflection reduced for a shear of 0.5%. It costs roughly 10.48% less than traditional boards. It was found that the column penetration in slabs with a circular section increased by 8.91 %, 56.44 %, and 38.61 % relative to the typical disc increase for steel loadings of 0.5 %, 1.0 %, and 1.5 %, respectively. The square column section plates had 23.33 %and 260.0 %more column penetration than regular plates for 1.0 and 1.5 % steel contents. The column penetration decreased by around 1.67% at the 0.5% dose mostly because the percentage of steel fibers increase resulted in an uneven distribution of those fibers, which in turn caused a non-uniform connection.

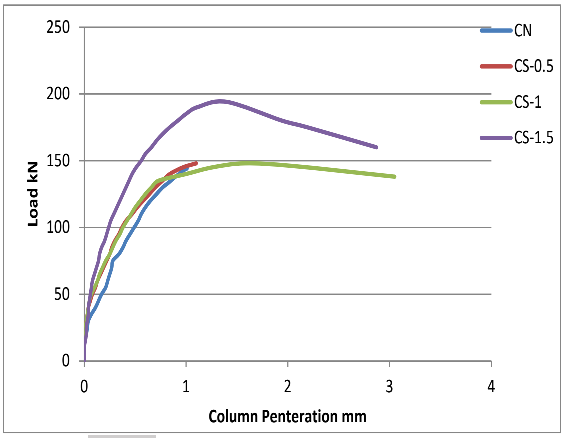


Fig.3 Load-Column Penetration Relationship for Slabs of Circular Column Section.

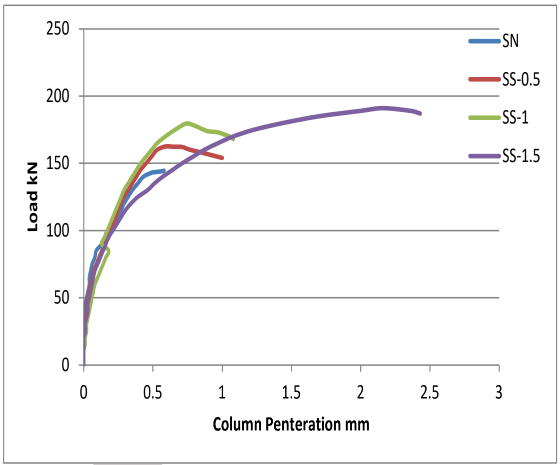


Fig.4 Load-Column Penetration Relationship for Slabs of Circular Column Section.

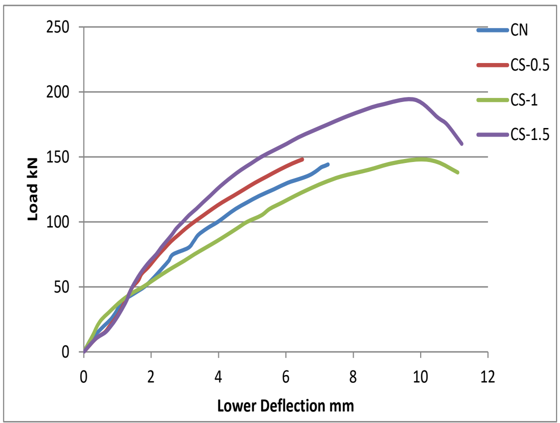


Fig.5 Load-Column Deflection Relationship for Slabs of Circular Column Section.

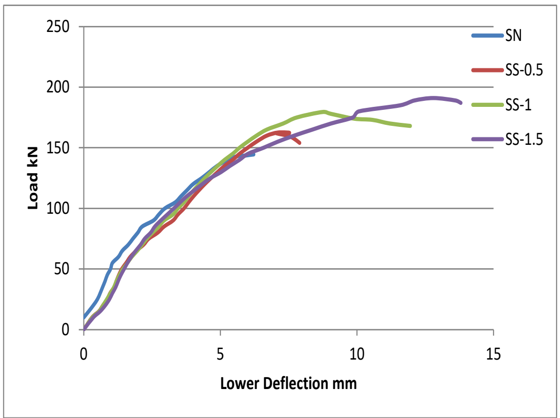


Fig.6 Load-Column Deflection Relationship for Slabs of Square Column Section.

3.3. Relationship Between the Shape of the Column and the Fiber Percentage

Fig. 7 shows the effect of the column shape used with the slab on the ultimate load. It was found that the ratio of the maximum load of the slab with a square column to the maximum load of the circular column when using straight steel fibers. At a percentage of fiber of 0.5%, the result was close, with a little height in the square column. The square column was better than the circular column at this ratio. The same is applied to normal concrete, followed by the fiber percentage of 1.0%. The square column was also better than the circular one. Whereas, at a ratio of 1.5% of fibers, the circular column had a higher bearing strength than the square column. Perhaps this is because the presence of fiber in concrete increased its bearing strength, particularly after the cracking stage. After all, fibers prevent fissures from propagating. In addition, the load distribution of the square column was superior to that of the circular column due to its right angles reducing column penetration into the slab. However, increasing the percentage of fibers to 1.5% caused an irregular distribution within the concrete, resulting in a lower final load ratio. Thus, the ultimate load values for the circular column were greater than those for the square column.

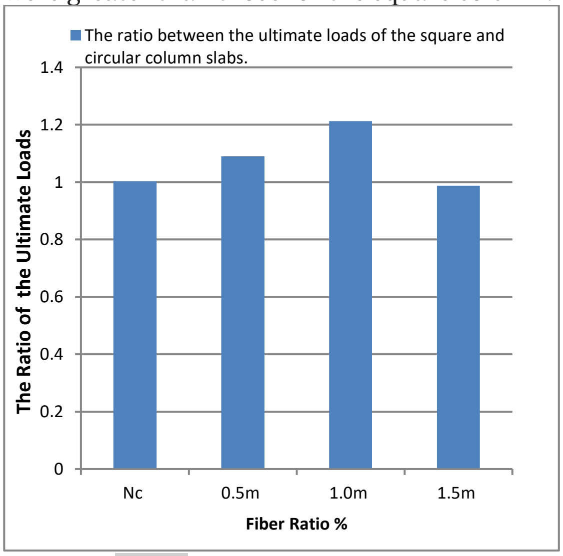


Fig. 7 Impact of the Ratio Between the Ultimate Loads of the Square and Circular Column Slabs with the Fiber's Ratio.

3.4. Crack Pattern for Slabs

Shear failure at the lower deflection gauge occurred in all eight tested concrete slabs with steel fiber reinforcing. The slabs were subjected to a monotonic loading test, where the applied load gradually increased until failure occurred. The tensile face of the slab showed only a few tiny flexural fractures. The slab began to break at the edges as the load continued to increase, and further cracks opened up in the middle. Plates (4) and (5) explain that a few flexural fractures formed on the tensile face of the slab, and as the load increased, shear cracks and additional cracks from the mid-rise in stress emerged as well. The punching area was added to the samples, as listed in Table 7. Plate 6 shows the punching area of a model (CN). When using steel fibers in concrete, the punching area of the samples decreased, as the decrease rates, at the slabs with a circular column section were 70.15%, 49.05%, and

59.51%. While the decrease rates at the slabs with a square column section were 69.59%, 37.09%, and 34.56% at the percentage of fibers of 0.5%, 1.0%, and 1.5%, respectively.

Table 7 Punching Area for Samples.

Slab Symbol	Punching Area(mm)	Percentage Decrease by Area %
CN	278254.25	-
SN	229586.16	-
$CS_{0.5\%}$	83053.27	70.15
$CS_{1.0\%}$	141772.34	49.05
$CS_{1.5\%}$	112677.56	59.51
$SS_{0.5\%}$	69828.28	69.59
$SS_{1.0\%}$	144417.39	37.09
$SS_{1.5\%}$	150236.72	34.56

CN

$CS_{0.5\%}$

$CS_{1.0\%}$

$CS_{1.5\%}$

Plate 4 Cracking Pattern for Circular Column Slabs.

SN

$SS_{0.5\%}$

$SS_{1.0\%}$

$SS_{1.5\%}$

Plate 5 Cracking Pattern for Square Column Slabs.

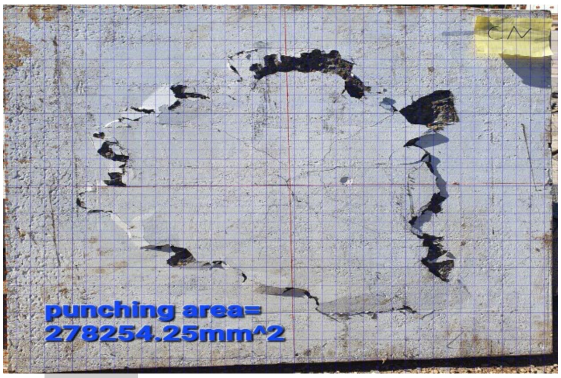


Plate 6 Punching Area of (CN) Sample.

4. CONCLUSIONS

Four different types of concrete mixes were adopted and tested. Fibers made of micro-steel were studied in different percentages. This investigation applied a monotonic load to eight cast slabs, i.e., two each of conventional concrete of square and circular column sections of the equivalent area, while the other six slabs were made with steel fiber concrete. The following conclusions can be drawn based on the experimental work's findings:

- Experimental results showed that when the percentage of steel fibers in SFRC varied between 0.5%, 1%, and 1.5% by volume, its compressive strength, flexural strength, splitting tensile strength, and direct tensile strength improved.
- For steel fiber percentages of 0.5% and 1.0%, the ultimate loads for slabs with square column sections were marginally higher than those with circular column sections. In contrast, 1.5% of the maximum load was used to get close to slabs with square and round column sections. Due to stress concentration in the corners of a square column, failure occurred at a lower ultimate load.
- Plates with a circular cross-section showed a rise in the shear deflection of roughly 29.19% and 35.45% when exposed to steel dosages of 1.0% and 1.5%, respectively, compared to typical plates. In contrast, at a shear decrease of 0.5%, the deflection dropped by About 10.48%.
- It was found that the column penetration of the slabs with the cylindrical section increased by around 8.91 %, 56.44 %, and 38.61 % compared to the regular slabs when the steel usage was 0.5 %, 1.0 %, and 1.5 %, respectively. Square column section plates had 23.33 %and 260.0 %more column penetration than normal slab for 1.0 % and 1.5 % steel contents, respectively. Around 1.67 % lowered column penetration at the 0.5% use level compared to conventional slabs.
- Because of the high percentage of steel fibers and their irregular distribution, it may exhibit random, non-uniform behavior.
- On the tension surface, the flexural crack was nearly invisible. The slab developed fractures appearing more in the center as the stress level increased.
- When using steel fibers in concrete, the punching area of the samples was reduced because the results were better in the circular column section slabs.

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