Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 8, No. 2, June 2020, pp.1024-1034

Strengthening of self-compacting reinforces concrete slabs using CFRP strips subjected to punching shear

Nagham T. Al-Shafi'i[1], Sara S. Faraj[2], Zainab M. Hussein[3]

[1] Department of Civil Engineering, College of Engineering, Mustansiriyah University
[2] Department of Civil Engineering, Al-Esraa University College
[3] Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University

ABSTRACT

This research is conducted to investigate the behavior of self-compacting reinforced concrete slabs strengthened by CFRP laminates in a stitching way under the impact of punching shear strength. In this study, trail mixes are carried out to perform high strength self-compacting concrete (f_c'=72.3 MPa). Two groups of specimens were assessed in this study. The first group (A) involves three solid slab specimens, while the second group (B) includes three slab specimens with an opening in the shear zone. Two variables were included in these experiments, namely, the effect of strengthening by CFRP laminate and the effect of high strength self-compacting concrete. The outcomes were discussed based on cracking load, ultimate punching shear capacity, crack patterns, and load-deflection response. The results showed that strengthening by CFRP enhanced the ultimate punching shear capacity by (23%-65%) and increased the deflection by (33%-79.5%).

Keywords: Strengthening, Self-compacting concrete, Ultimate punching shear capacity, CFRP Deflection, Cracking load

Corresponding Author:

Nagham T. Al-Shafi'i
Department of Civil Engineering, College of Engineering, Mustansiriyah University, Iraq
E-Mail: dr.nagham_tariq@uomustansiriyah.edu.iq

1. Introduction

Reinforced concrete slab supported by concrete columns without beams is called a flat slab. Usually, flat slabs are fitted for the construction of asymmetrical column layout like rumps and floor with curved slope. Several benefits can be gained from using flat slabs such as depth solution, flat soffit, and flexible design layout.

Although construction with flat slabs considered an expensive affair that gives immense freedom to architects and engineers for the luxury of design, the most hazardous element of this structural system is the slab–column connection due to its sensitivity to brittleness and unexpected failure of punching shear. This type of failure can occur when the columns are based directly on the slab, or because a large load is centered on a relatively small area of the slab. For correct design, it is possible to avoid this type of failure by several measures, including choosing a suitable thickness for the slab, right dimensions of the head of the column, in addition to enhancing reinforcement in the shear area.

Recently, the rehabilitation and strengthening of structural members received considerable attention. The use of composite materials such as glass fibers, carbon, and fiber-modified polymers with aramid leads to a significant reduction in the cost of construction and materials, in addition to saving labor. The excellent mechanical properties of the composite fiber types have made them a successful alternative to the usual modification techniques, as they have traits, including relatively lightweight and straightforward formulation, slow relaxation, high tensile strength, and high resistance to corrosion [1].

Chen and Li [2] have conducted a study concerning enhancing the performance of reinforced concrete slab–column connection subjected to punching shear using glass FRP (GFRP) laminates. The outcomes of this study have revealed that the GFRP sheets markedly enhanced the punching shear capacity of the slab- column joints due to the external reinforcement supplied by the fiber sheets.

Soudki et al. [3] conducted experimental research dealing with the interior reinforcement of concrete slabs utilizing CFRP strips through testing for punching shear. The variables considered in this research were the amount and configuration of CFRP sheets, which linked externally to the bottom surface of the sample (tension face). The outcomes of this research demonstrated an enhancement in punching shear capacity up to 29% for the tested slabs. This enhancement depended on the orientation and configuration of CFRP sheets. Also, this investigation reveals that there is no significant improvement in punching capacity due to increasing the amount of the CFRP laminate.

Sharaf et al. [4] studied the effect of strengthening by externally CFRP strips on full-scale slab-columns failed in punching shear. The variables of this experimental work were the amount and configuration of CFRP sheets. The results indicated that the strengthening by CFRP delay in the initiation of flexural cracks of the slabs. The increase in punching shear resistance of the modified slabs was better than that for unmodified slabs by 16%.

Thus, in the previous several years, many studies have considered the shear failure mechanism of self-compacting concrete (Lin et al. [5]). Punching shear is brittle. The mode of failure which occurs without warning. An increase in fine aggregate content of SCC members may be a cause for concern, as it is believed to lead to a decrease in the shear strength of a structural member. Lin et al. [5] found that the increase in fine content may cause a reduction in aggregate interlock, which is considered as the main resisting factor for shear stresses in beams. The most recent construction technique alleviates this problem is by using high strength self-compacting concrete rather than using traditional shear reinforcement to enhance the capacity of the flat slab.

In the case of flat floor systems, there is usually a need to create new elements that need openings near the columns. These openings are required for many reasons, such as ventilation, heating, sanitary, electrical ducting, and air conditioning. The presence of openings could reduce the quantity of concrete liable for resisting shear strength and unbalanced torque, which in sequence reduces the shearing ability to punch in the slab-column bonding area. Hence, the bonding area is more susceptible to brittle and punching shear failure. Guan [6] and Moe [7] investigated the case of failure in footing and reinforced concrete slabs in shear. A wide range of tests was conducted on a diversity of slabs with openings close to the columns.

A study done by Hognestad et al. [8] investigated the interior connection of the column with a lightweight aggregate concrete slab supplied with openings (Guan [6]). Several investigations have been conducted, including openings in the vicinity of square columns El-Salakawy et al. [9], Teng et al. [10], and Bompa and One [11].

2. The Experimental Work and Specimens Preparation

This experimental program consists of examining two groups of slab specimens cast with self-compacting concrete; group A and group B. Table 1 shows the description of the tested samples.Materials and Research Methodology

The main objective of the experimental work was to study the efficacy of modification of reinforced concrete slab specimens provided for punching shear utilizing CFRP sheets, also, to investigate the effects of openings in the critical area (near the column area) and the impact of concrete strength (f_c').

Samples of the slabs prepared for examination were square, with a length of 450 mm and a thickness of 50 mm. The specimens were sustained along the four edges with a cleared plate of 420 mm for both directions.

The reinforcement of specimens was by one bottom layer of (6 mm in diameter) steel bars and arranged to give an average effective depth of 42 mm and steel ratio of 0.005. Figure 1 demonstrates the reinforcement dimensions and details for the tested samples.

Table 1. The description of the tested specimens

Specimen		**Description**
Group A	S1	Solid slab without strengthening by CFRP casting with normal self-compacting concrete
	S4	Solid slab modified by CFRP casting with normal self-compacting concrete
	S6	Solid slab modified by CFRP casting with high strength self-compacting concrete
Group B	S2	slab with opening without strengthening by CFRP casting with normal self-compacting concrete
	S3	slab with opening strengthened by CFRP casting with normal self-compacting concrete
	S5	slab with opening strengthened by CFRP casting with high strength self-compacting concrete

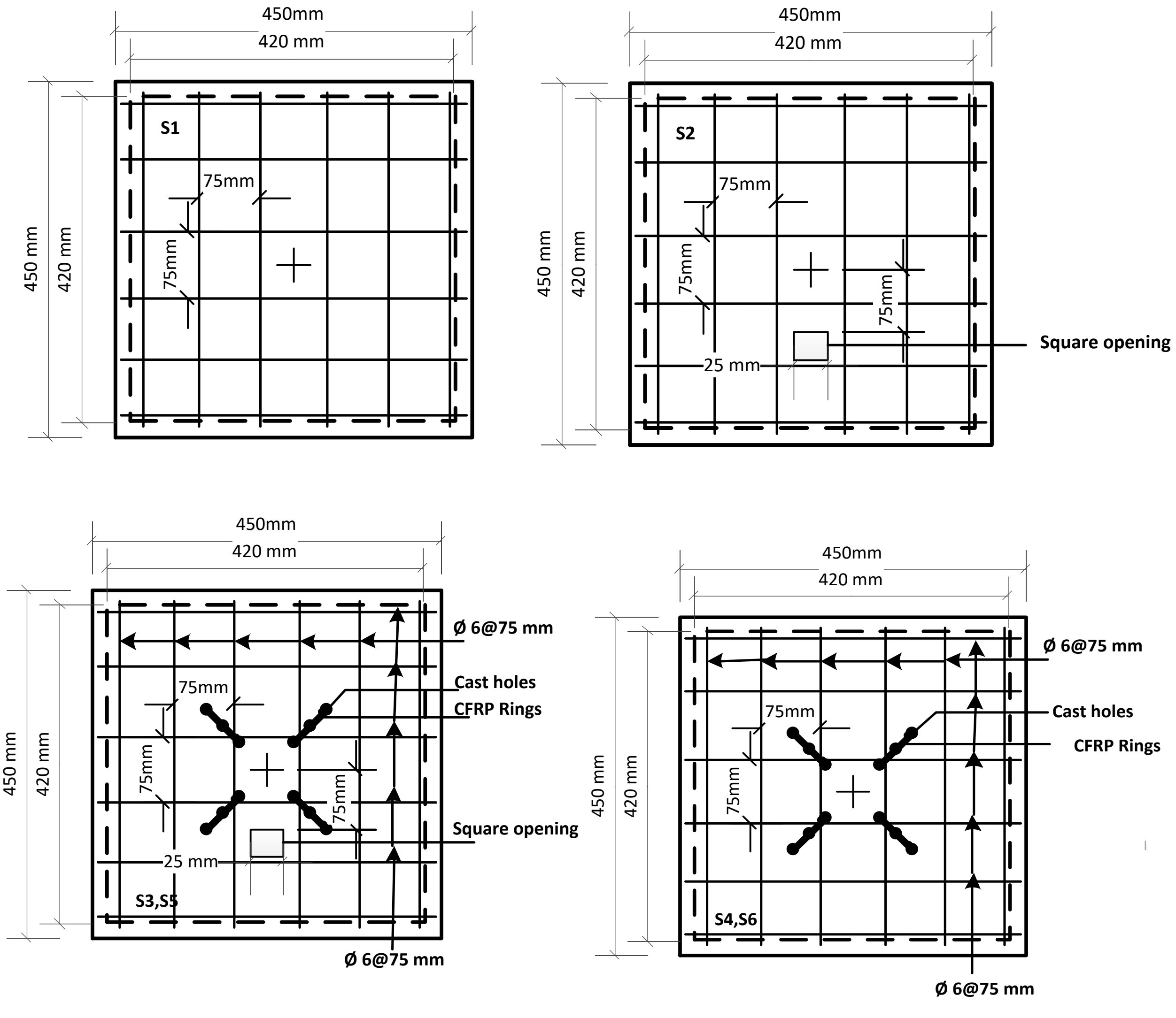

Figure 1. The reinforcement dimensions and details of the tested specimen

The slab specimens were reinforced with CFRP laminates cast with the same patterns of 10 mm diameter openings, as presented in Fig 2. The gaps were later utilized to strengthen the specimens by CFRP sheets. The steel reinforcement was separated similarly in each sample, taking into account that the steel bars did not interfere with the specified gaps for CFRP sheets.

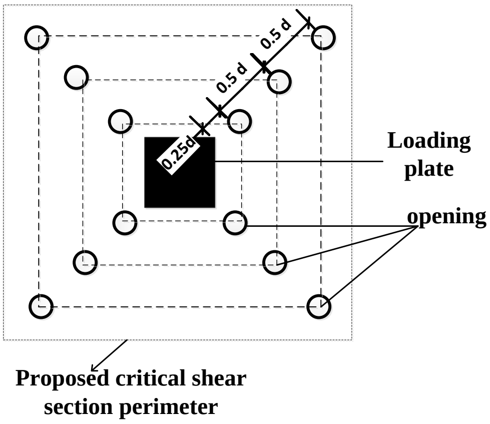

Figure 2. Shear reinforcement arrangements of the tested specimens

The slab specimens have three sets of peripheral lines of the shear reinforcement, where the divisions between the sequential lines were 0.5d. The primary edge was equitable 0.25d from the periphery of the loading plate for samples. The slab sample items and characteristics of materials are as shown in Table 1.

The CFRP sheets were joined to the slab samples through cutting the long thin strands that could move across the gaps located in the sample. The CFRP strands were drenched with epoxy and circled consistently between the sets of openings a few times, in a stitch like way, till the ideal measure of CFRP sheet that traverse the depth of the slab is achieved.

The solid ring of reinforcement has confined the concrete from the continuous loop of CFRP laminate. An odd number of shear reinforcement lines were put so that the outer two rings of CFRP share a specific gap. The common opening contributes to doubling the reinforcement provided by CFRP, as shown in Fig 2. Subsequently, the remaining voids were encapsulated by epoxy.

2.1 Materials

The descriptions and specifications of the materials that are used in this work are detailed below:

2.1.1 Concrete

Ordinary portland cement from Taslouja (Type I) was utilized in this study, according to the Iraqi specification No.5 / 1984 [12]. The coarse aggregate was a 10 mm maximum size crushed gravel from Al-Niba'ee region. The natural sand was delivered from Al-Ukhaider district, Karbala, and used with a 2.72 fineness modulus according to the Iraqi standard specification No. 45/ 1984 [13].

Table 2. Details of the Tested slabs

Group	**Slab designation**	**Concrete type**	***f'_c* (MPa)**	***SF%***	**Shear reinforcement**		**Hollow dimensions (mm*mm)**
					s/d	**$A_{)CFRP}$, mm^2 for three peripheral lines**	
A	S1	NSCC	32.5	-	0	-	-
	S4	NSCC	32.5	-	0	62.3-124.6-62.3	-
	S6	HSCC	72.3	5	0	62.3-124.6-62.3	-
B	S2	NSCC	32.5	-	0.5	-	25*25
	S3	NSCC	32.5	-	0.5	62.3-124.6-62.3	25*25
	S5	HSCC	72.3	5	0.5	62.3-124.6-62.3	25*25

The super-plasticizer that is utilized in this investigation is Glenium 51 (High Range Water-Reducing Concrete Admixture). This admixture is approved by ASTM C494-05 specifications [14]. It is used to enhance flowability with silica fume to produce SCC. Table 3 demonstrated the standard properties of Glenium 51, according to the producer.

Table 3. Technical Description of Glenium 51*

Form	**Color**	**Relative density**	**PH**	**Viscosity**	**Transport**	**Labeling**
Viscous liquid	Light brown	1.1	6.6	128 +/- 30 CPS@ 20° C	Not classified as dangerous	No hazard label required

* From Manufacturer Catalogue

Cement is partially displaced by the limestone powder filler to promote the specific features. In group (B), silica fume was used as a mineral admixture to enhance the properties of concrete. The physical and chemical properties of silica fume were consistent with ASTM C1240-05 requirements [15].

Cylinders and prisms for the control tests were cast and stored for each slab and tested at the same time of slab testing. The average testing results of the cylinder strength test were 32.5 N/mm2 and 72.3 N/mm2 for standard and high strength self-compacting concrete, respectively. The testing procedure was carried out at a concrete age of (28) days.

Water - For both the mixing and curing process of concrete, tap water was used in this work.

2.1.3 Steel Reinforcement

The Reinforcing steel bars that were used in the current investigated were 6 mm in both directions. Three samples of each bar were examined under the tension loads as per ASTM A615/A615M-05a requirements [16]. Table 4 shows the properties of the rebar used.

Table 4. The testing Result Rebar used in this study

Steel Bar diameter (mm)	**Yield Stress (MPa)**	**Failure Stress (MPa)**	**Elongation (%)**
6	620	732	7.5

2.1.4 Polymeric Carbon Fibers (CFRP)

The carbon fiber used in this work to strengthen concrete panels were of type (Sika Wrap Hex-230c). The maximum tensile modulus and tensile strength for each unit width of the CFRP sheet were experimentally found to be 77.6 MN/m and 98.4 kN/m, respectively. The average thickness of CFRO sheets was 0.89 mm, while the rupture strain was 1.33%.

2.1.5 The Epoxy Adhesive

The Epoxy Adhesive used in this work was (SikaDur-330). This material is considered one of the most suitable materials that are used for gluing the CFRP sheets on the surface of the concrete slab. This type of adhesives has a moderate intensity viscosity and consists of two parts: white color glue material (Resin A), and the hardener material (Hardener B) of dark grey color. The mixing ratio for the two substances was 1:4.

2.2 Mix Design

The process of designing self-pressed concrete mixtures requires high accuracy. Many trial mixes were manufactured in the Laboratory of Constructional Materials, College of Engineering, Mustansiriyah University. The SCC mixture is designed in compliance with EFNARC 2002 [17] specifications to match the properties of fresh SCC. In the present research work, new trial mixes are performed to gain a higher value of compressive strength using the same procedure.

Table 5 contains the detailed quantities of materials by total mixture weight SCC per cubic meters for the two types of concrete (NSCC with f_c'=32.5 MPa and HSCC with f_c'=72.3 MPa) that was assumed in this study.

Table 5. The Quantities of SCC mixes per cubic meters

Group	**Mix name**	**Cement (kg)**	**Limestone powder (LSP) (kg)**	**Water (liter)**	**Sand (kg)**	**Gravel (kg)**	**Super plasticizer (liter)**	**Silica fume (kg)**
A	NSCC	400	170	190	797	767	7.4	0
B	HSCC	550	50	165	855	767	20	27.5

Three standard tests were implemented to ensure the compliance of SCC mixes to the requirements, namely, T50 cm Tests, Slump Flow, and L-Box Test. The properties for the fresh mix were presented in Table 6. The results showed that the features were within the standards.

Table 6. Workability test results for SCC

Method		**Result**	**Property**	**Limitations [18]**
Slump Flow	D(mm)	750	Filling ability	650-800
	T_{50cm}(sec.)	3.8	Filling ability	2-5
V-Funnel	$T_{y\ (sec.)}$	8.7	Filling ability	6-12
	Time increase, $T_{y\ 5min.\ (sec.)}$	2.1	Segregation resistance	+ 0.3
L-Box	-	0.9	Passing ability	0.8-1.0

2.2.1 Preparation of the Specimens and Testing

A wooden mold with precise dimensions of (450x450x50) mm has been utilised. Each mold consists of a bed and four movable sides. The sides were attached to the bed by screws. Before putting the concrete paste in the templates, steel wire reinforcement mesh was installed at the bottom face of the panel's mold, as presented in Fig 3. The openings were created using cork cube with a size of (25×25×40 mm) for S2, S3, and S5 sample types. After 28 days of curing in a water bath, the specimens were dried at laboratory temperature and painted white to facilitate observing the specimens during the test. The slab specimens have been installed on the testing machine and modified so that the centerline, supports, load point, and dial gauge were in their proper positions.

The hydraulic universal testing machine (MFL system) has been utilized to examine the slab specimens. The slabs were tested by subjecting the concentrated loads, which are given by a central column of dimensions (30 X 30) mm. The loading process was carried out in increments at stages. The deflection was measured at the center of the slab at each loading stage using a dial gauge of (0.01 mm) accuracy.

Figure 3. Specimen preparation and casting

3. Results and Discussion

3.1 The Cracking Loads

The results exhibited in Table 7 show that the cracks have occurred at a shearing force of (54.3 %), (43.2 %) and (25.7 %) of the ultimate load of group A slab specimens (S1, S4, and S6), respectively. In comparison, the cracks have occurred at a shearing force of (65.3 %), (43.7 %), and (28.3 %) of the ultimate load of group B slab specimens (S2, S3, and S5), respectively.

3.2 Crack Patterns

Figure 4(a) shows the shear fractures at the compressed surface of group A failed slab specimens, while Fig 4 (b) shows the shear fractures at the compressed surfaces of group B failed slab specimens.

3.3 Ultimate Punching Shear Capacity

The ultimate load punching shear failure of tested specimens of group A is listed in Table 7. The results have revealed that strengthening of the specimen (S4) by CFRP laminate has increased its ultimate load by 27% as compared with the control specimen (S1) (without strengthening). Likewise, increased the strength of concrete of specimen (S6) (f_c'=72.3 MPa) has increased the ultimate load by (65%) as compared with the specimen (S4), which was cast with standard self-compacting concrete (= 32.5MPa). The results of the ultimate load punching shear failure of specimens with openings of group B are listed in Table 7.

The strengthening of the specimen (S3) by CFRP laminate has increased the ultimate load by (23%) as compared with the control specimen (S2) (without strengthening). Likewise, increasing the strength of the concrete of the sample (S5) (f_c'=72.3 MPa) has increased the ultimate load by (56%) as compared with the specimen (S3) which was cast with standard self-compacting concrete (=32.5 MPa).

Table 7. Cracking and ultimate load for tested specimens

Specimen		**Cracked loads (KN)**	**Ultimate loads (KN)**	**% increasing in ultimate load with respect to specimen S1 for group A or with respect to S2 for group B**
Group A	S1	10.1	18.6	0%
	S4	10.2	23.6	27%
	S6	10	38.9	109%
Group B	S2	11.3	17.3	0%
	S3	9.3	21.3	23%
	S5	10	33.3	92.5%

S1 S4 S6

Figure 4a: Specimens group A

S2 S3 S5

Figure 4 b: Specimens group B

Figure 4. Cracking pattern for Group A & B

3.4 Deflection Response

The load-deflection curves for the tested specimens are demonstrated in Fig 5. Generally, all load-deflection curves have similar behavior with three stages. The first stage is a linear relationship within the load and deflection part that is described as an elastic zone, and the first crack happens at the end of this stage. The second stage is following the linear part within load and deflection, in which the yielding of steel reinforcement transpires at the end of this zone. The third stage of deflection is extended to increase up to failure point. When comparing the tested specimens of group A, there is a significant increase in deflection at failure for the specimen (S4) that is strengthened by CFRP by (39.5 %) as compared with the specimen (S1) (without strengthening). Whereas, specimen (S6) cast with high strength self-compacting concrete and strengthened by CFRP exhibited increased deflection by about (68%) as compared with the specimen (S4) cast with normal self-compacting concrete strengthened by CFRP.

When comparing the tested specimens with openings of group B, there is a significant increase in deflection at failure for the specimen (S3) strengthened with CFRP by about (79.5%), as compared with the specimen (S2) (without strengthening). Specimen (S5) cast with high strength self-compacting concrete and enhanced by CFRP exhibited increased deflection by about (33%) as compared with the specimen (S3) cast with standard self-compacting concrete and strengthened by CFRP.

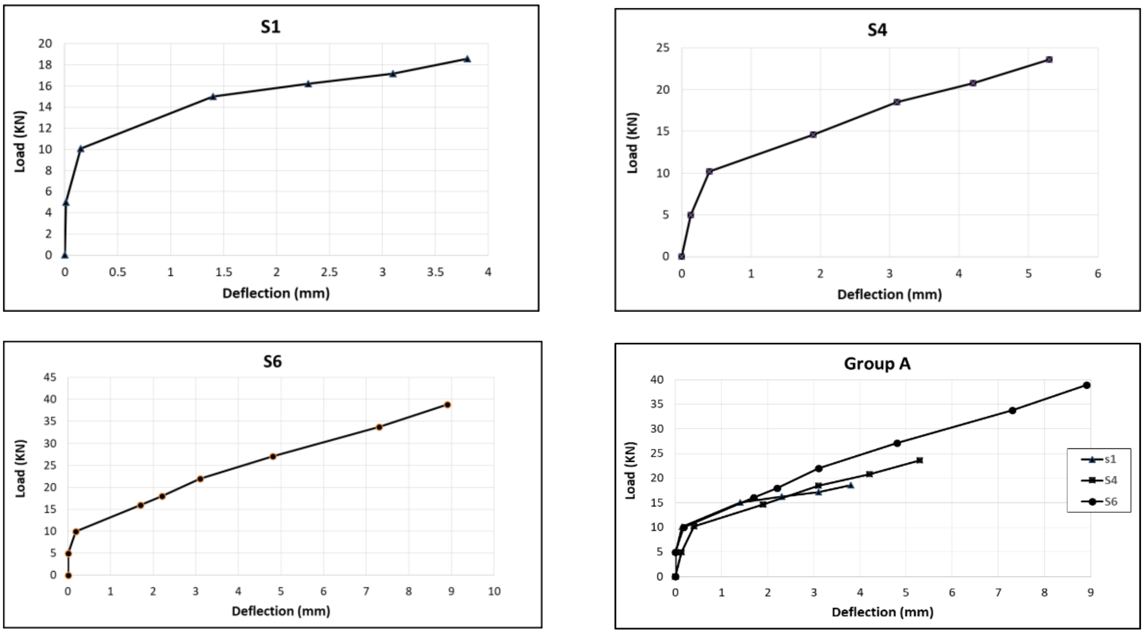

Figure 5.a. Load-Deflection curves for Specimens set (A)

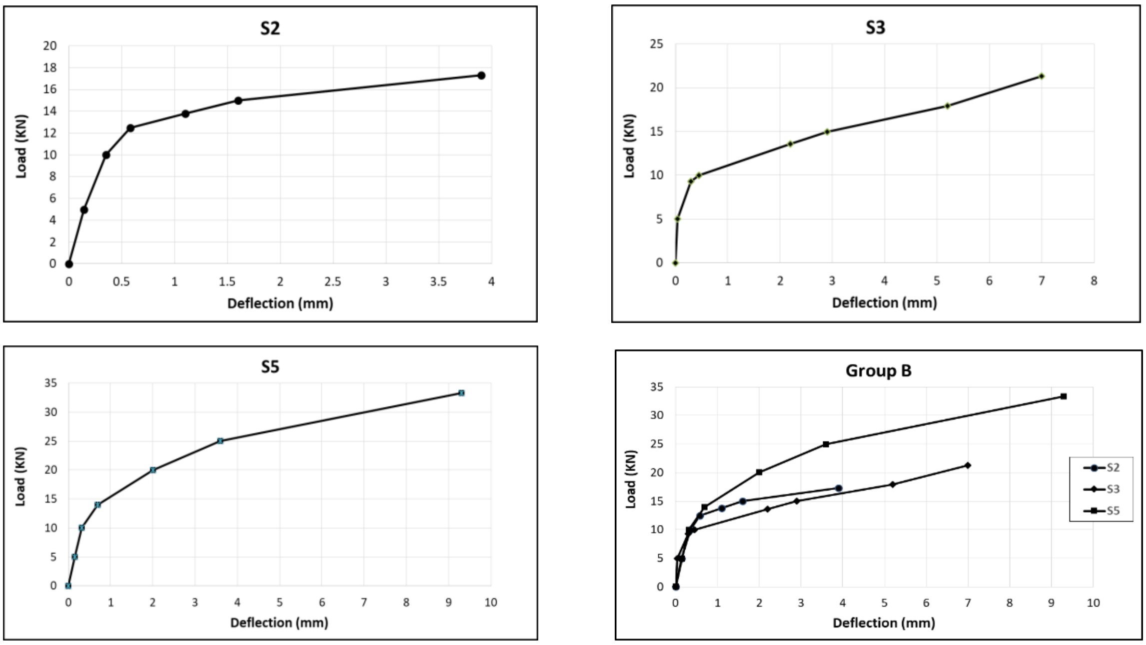

Figure 5.b. Load-Deflection curves for Specimens set (B)
Figure 5. Load-Deflection curves of the tested Specimens

4. Conclusions

1. Trail mixes are carried out to perform high strength self-compacting concrete (f_c^'=72.3 MPa).
2. According to the experimental outcomes, the ultimate shear capacity of high strength self-compacting concrete for the tested slabs had been raised about (65%) compared with standard self-compacting concrete. In comparison, the ultimate shear capacity of high strength self-compacting concrete for slabs with an opening had been raised about (56%) compared by the standard self-compacting concrete sample.
3. Strengthening of the tested slabs with CFRP increased the ultimate punching shear capacity by (27%)

while strengthening with CFRP of tiles with opening increased the ultimate punching shear capacity by (23%).

4. There is a significant increase in deflection at failure for specimen strengthened with CFRP by (39.5%) as compared with specimen without strengthening. In comparison, the increasing rate becomes (79.5%) for the specimen with opening enhanced by CFRP.
5. There is a significant increase in deflection at failure for the specimen strengthened with CFRP cast with high strength self-compacting concrete by (68%) as compared with the specimen bolstered by CFRP cast with standard self-compacting concrete. In comparison, the increasing rate becomes (33%) for the specimen with opening strengthened with CFRP cast with high strength self-compacting concrete.

Acknowledgment

The authors would like to thank the College of Engineering at Mustansiriyah University (www.uomustansiriyah.edu.iq), Baghdad-Iraq, for its support in the present work.

Nomenclatures

f_c'	Concrete compressive strength (MPa)

Abbreviations

ASTM	American Society for Testing and Materials
CFRP	Carbon Fiber-Reinforced Polymer
FRPs	Fiber-Reinforced Polymer
GFRP	Glass Fiber-Reinforced Polymer
SCC	Self-Compacting Concrete

Reference

[1] SHEIKH, Shamim A.; HOMAM, S. Mukhtar. A decade of performance of FRP-repaired concrete structures. In: *Proceedings of the ISIS-SHM 2004 Workshop. Winnipeg, Manitoba, Canada*. 2004.

[2] Chen, Cheng-Chih, and Chung-Yan Li. "Punching shear strength of reinforced concrete slabs strengthened with glass fiber-reinforced polymer laminates." *ACI Structural Journal* 102.4: pp. 535. (2005)

[3] Soudki, Khaled, Ahmed K. El-Sayed, and Tim Vanzwol. "Strengthening of concrete slab-column connections using CFRP strips." *Journal of King Saud University-Engineering Sciences* 24.1:pp. 25-33. 2012

[4] Sharaf, Mohamed H., Khaled A. Soudki, and Michael Van Dusen. "CFRP strengthening for punching shear of interior slab–column connections." *Journal of Composites for Construction* 10.5:pp. 410-418. 2006

[5] Lin, Chien-Hung, and Jiunn-Hung Chen. "Shear behavior of self-consolidating concrete beams." *ACI Structural Journal* 109.3: 307. 2012

[6] Guan, Hong. "Prediction of punching shear failure behaviour of slab-edge column connections with varying opening and column parameters." *Advances in structural engineering* 12.1: pp.19-36. 2009

[7] Moe, Johannes. *Shearing strength of reinforced concrete slabs and footings under concentrated loads*. Portland Cement Association, Research and Development Laboratories, 1961.

[8] Hognestad, Eivind, Richard C. Elstner, and J. A. Hanson. "Sheer Strength of Reinforced Structural Lightweight Aggregate Concrete Slabs." *Journal Proceedings*. Vol. 61. No. 6. 1964.

[9] El-Salakawy, Ehab F., Maria Anna Polak, and Monir H. Soliman. "Reinforced concrete slab-column edge connections with openings." *Structural Journal* 96.1: pp.79-87. 1999

[10] Teng, Susanto, et al. "Punching shear strength of slabs with openings and supported on rectangular columns." *Structural Journal* 101.5: pp. 678-687. 2004

[11] Bompa, D. V., and T. Onet. "Behaviour of Symmetric Flat-Slab Connections with Openings in the Control Perimeter." *Scientific Bulletin Series D: Mining, Mineral Processing, Non-Ferrous Metallurgy, Geology and Environmental Engineering* 24.2: pp. 111. 2010

[12] Iraqi Specification, No. 5. Portland cement. *Central Organization For Standardization And Quality Control*, Ministry of Planning, Iraq. 1984

[13] Iraqi Specification, No.45, "Aggregate from Natural Sources for Concrete and Constructions", (1980), (in Arabic)

[14] ASTM-C494-05. Standard Specification for Chemical Admixtures for Concrete. *American Society for Testing and Material*. 2005

[15] ASTM C 1240. Standard Specification for Use of Silica Fume as a Mineral Admixture in Hydraulic-Cement Concrete, Mortar, and Grout. *American Society for Testing and Material,* 04(02), pp.1-6. 2003

[16] ASTM A615/615M-05a (2005). Standard Specification for Deformed and Plain Carbon Structural Steel Bars for Concrete Reinforcement. *American Society for Testing and Material standard*, 01(02).

[17] EFNARC. Specification and Guidelines for Self-Compacting Concrete. *Association House*, 99 West Street, Farnham, Surrey GU9 7EN, UK, 21. 2002

[18] ASTM C 1240-05, Standard Specification for Silica Fume Used in Cementitious Mixtures. *American Society for Testing and Material standard*, 1-7. 2005