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FLEXURAL BEHAVIOR OF R.C. TWO-WAY SLABS WITH OPENING STRENGTHENED WITH CFRP SHEETS

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ABSTRACT

This paper present a study of the flexural behavior of reinforced concrete two-way slabs with opening strengthened by Carbon Fiber Reinforced polymer sheets.
The experimental work included testing 10 specimen two-way slabs with opening, which include 4 control specimens and 6 strengthened with CFRP sheets. The dimensions of the slab specimens are (800 × 800) mm, (70) mm depth and they were made of normal strength concrete. The reinforced concrete slabs containing a single eccentric and concentric opening strengthened by CFRP sheets, has been investigated, also the behavior of unstrengthened slabs and the slab without openings has been studied. These slabs were arranged in four groups and four layout of CFRP sheets has been considered. The slabs were tested with uniformly distributed loads and simple supports on the four edges. The results showed that the load-carrying capacities have been increased of the slabs with openings strengthened with CFRP sheets when compared with the slabs without strengthening.

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Introduction

The structure need to be renovated due to many cases. These cases are required for openings. In some instances the requirement for opening was one of the most generally issues occurred in the structural engineering when deals with R.C. slab, placing new elevators, staircases, fire protection pipes, plumbing, additional skylights, air conditioning, ventilation and heat ducts, and general services (electricity, wiring ducts and telephones), additionally engineering perspectives are needed through the current floor slab. According to the character of improvement, the opening can be in the positive or negative moment region of the slabs leading to make problems that problems can't be addressed to use a similar way [1].

The ACI 318 Building Code [2] allows for opening of any dimensions in the new slab, provides that an analysis is performed that demonstrates that both strength and serviceability necessities are fulfilled (ACI 318-11 13.4.1). The analysis for slabs containing openings could be complex and time consuming, as an alternative the ACI 318 Code gives rules and confinements for opening size and location. The analysis could be waived if the designer satisfies those rules. The researchers below have investigated the structural behavior of slabs with openings strengthened with CFRP sheets.

Hameed, 2012 [3] investigate the flexural behavior of fourteen R.C. slab with openings of different sizes, shapes and locations. One slab without openings have been tested for comparison. The dimensions of the slabs were (60×60×8) cm and four concentrated loads has been applied to the tested slabs. The slabs were rested on simply supported and loaded incrementally up to failure. The strength and rigidity of slabs were decreased of about (20-75%) due to the presence of openings and depending on the shape, location and size of these openings. The ultimate strength was decreased in slabs with square openings of about (5%) from those of circle openings with area equal to the area of square opening. The slabs with eccentric openings (at distance 5 cm from center in the two directions) were showed a reduction in the carrying capacities of about (30%) of those with central openings of the same size and shape.

Salman T. S., 2013 [4] investigate experimentally and analytically the punching shear capacity of interior slab-column connections for panels with openings, strengthened with (CFRP) sheets. 16 RC flat plate models has been constructed with dimensions (1000×1000×70) mm and loaded by a central column of dimensions (150×150) mm. The plates have been rested to simple support on the four edges. The result showed that the CFRP using gave an enhancement in the flexural stiffness and shear capacity of slab-column connections.

Al-Fatlawi and Abed, 2015 [7] presented a study of the performance of the two-way RC slabs without opening, with one central opening and two openings having area equal to the area of one opening**.** Also, studying the effect of Strengthening by using CFRP sheets bonded to tension face, and the effect of the provided length of CFRP sheets. 16 R.C. slabs of dimensions (1050×1050×80) mm and using high strength concrete have been tested under uniformly distributed load with simply supported on the four edges. The results showed that the ultimate load capacity have been decreased in the unstrengthened slabs with openings, in compared with the control solid slab. The using of CFRP on the strengthening leads to a significant improvements in the "cracking load" and ultimate load.

Elsayed and Amer, 2015 [8] investigated the feasibility of restoring the original strength and stiffness lost in two-way simply supported R.C. slabs due to the creation of openings the slabs dimensions were (1.5×1.5×0.06 m) and tested under uniformly distributed load. The flexural failure was happened in all slabs due to the yielding of steel.

Experimental Program

The experimental work consists of preparing and testing 10 normal strength concrete slabs. These slabs have been divided into four groups. The first group consists of one slab without opening without strengthening (SC). The second group consists of three slabs with one central square opening (150 × 150) mm. The third group consists of three slabs with one square opening (150×150) mm at a distance (100×100) mm from a corner edge of specimen, and the fourth group consists of three slabs of one square opening (150×150) mm at distance (100×325) mm from a corner edge of specimen. All the groups have one control slab (without strengthening) and the other strengthening with CFRP sheets.

Specimens Description

All the slabs dimensions were (800×800×70) mm with the distance between the supports of 700 mm and effective depth of 50 mm and flexural reinforcement was Φ8 mm @108 mm in two directions to ensure flexural failure.

CFRP strips installed around the opening on the tensile face of the slab using four schemes: first scheme including an installation of CFRP strips on the tension face and around the opening of the slab. The strip had a 50 mm width, 0.166 mm thickness, and its length was 250 mm greater than the length of the opening, 125 mm from each side. Moreover, the inclined strip (45^0) were installed with length equal to the diagonal length of the opening, width of 50 mm, and thickness of 0.166 mm which provided at each corner of opening. The second scheme was similar to the first scheme in details, but the provided length of perpendicular CFRP strips were equal to slabs length (800 mm). The third scheme including an installation of CFRP strips around the opening of the slab, the strip had a 50 mm width, 0.166 mm thickness, and its length was 100 mm longer than the opening length, 50 mm from each side. The fourth scheme was similar to the third scheme in details, but the provided length of CFRP strips were equal to slabs length (800 mm). The slab specimens has been divided into four groups in this study, as shown in Table (1) and Fig. 1.

1- SC: one control solid slab (without opening and without strengthening).
2- (S1, S1.1, and S1.2):three slabs with one central opening (150×150) mm.
3- (S2, S2.1, and S2.2):three slabs with one square opening (150×150) mm at a distance (100×100) mm from a corner edge of specimen.
4- (S3, S3.1, and S3.2):three slabs with one square opening (150×150) mm at distance (100×325) mm from a corner edge of specimen.

Materials

Cement

Ordinary Portland cement has been used in this study, which satisfying the Iraqi specification no.5 / 1984 requirements [9].

Fine Aggregate

In this study, the normal sand from Al-Zubair area in Basrah city was used.The sand was sieved at sieve of size (4.75mm) to isolate the aggregate particle of size greater than (4.75mm), which comply with limits of the Iraqi specification no.45 / 1984 [10].

Coarse Aggregate

The crushed gravel from Al-Zubair area in Basrah city of maximum size of 10 mm was used. The coarse aggregate satisfying the Iraqi specification no.45 / 1984 [10].

Water

Potable water has been used for casting and curing of concrete

Superplasticiser

A superplasticiser type daracem sp3 was used in this study, which is used to reduce water and increase workability of concrete. It is in form of liquid and instantly dispersable in water. Table (2) shows some properties of Daracem SP3 (according to the manufacturer editions).

Steel Reinforcement

In this study bar of 8 mm diameter has been used as flexural reinforcement placed in the tensile zone of the slab with spacing of 108 mm. the yield strength was 460 n/mm^2 and the ultimate strength was 686 n/mm^2 determined from tensile test. Table (3) shows the characteristics of reinforcing bars.

Carbon Fiber Reinforced Polymer (CFRP) Strips

The kind of Carbon Fiber Fabric used in this study isSikaWrap300 C/60. CFRP fibers when loaded in tension, do not exhibit any plastic behavior before rupture. The tensile behavior of CFRP fibers is characterized as a linearly elastic stress-strain relationship up to failure. The properties of the CFRP shown in Table (4) which were taken from manufacturer's specification (technical data sheet of sika 2009 n0.1) [5].

Epoxy Resin

It consist of two compounds; part **A** is white paste, part **B** is dark gray paste. The mix proportion of part **A** and part **B** is 4:1 by weight. The properties of this resin taken from manufacturer's specification are shown in Table (5) [6].

Concrete Mix Proportions

Normal strength concrete was used to cast twenty slabs which are made of NSC. The mix was chose of 1:2:3 (by weight) cement, sand, gravel respectively and 0.5 water cement ratio. The above mix has been selected to get a compressive strength of about 25 MPa at age of 28 days and slump of about 120 mm. The selected mixes and the corresponding water-cement ratio has been presented in Table (6).

Table 1. The Schemes Details

Scheme No.	Width (mm)	Thickness (mm)	Length of vertical and horizontal strip (mm)	Length of inclined strip (mm)
1	50	0.166	40	21
2	50	0.166	80	21
3	50	0.166	25	------
4	50	0.166	80	------

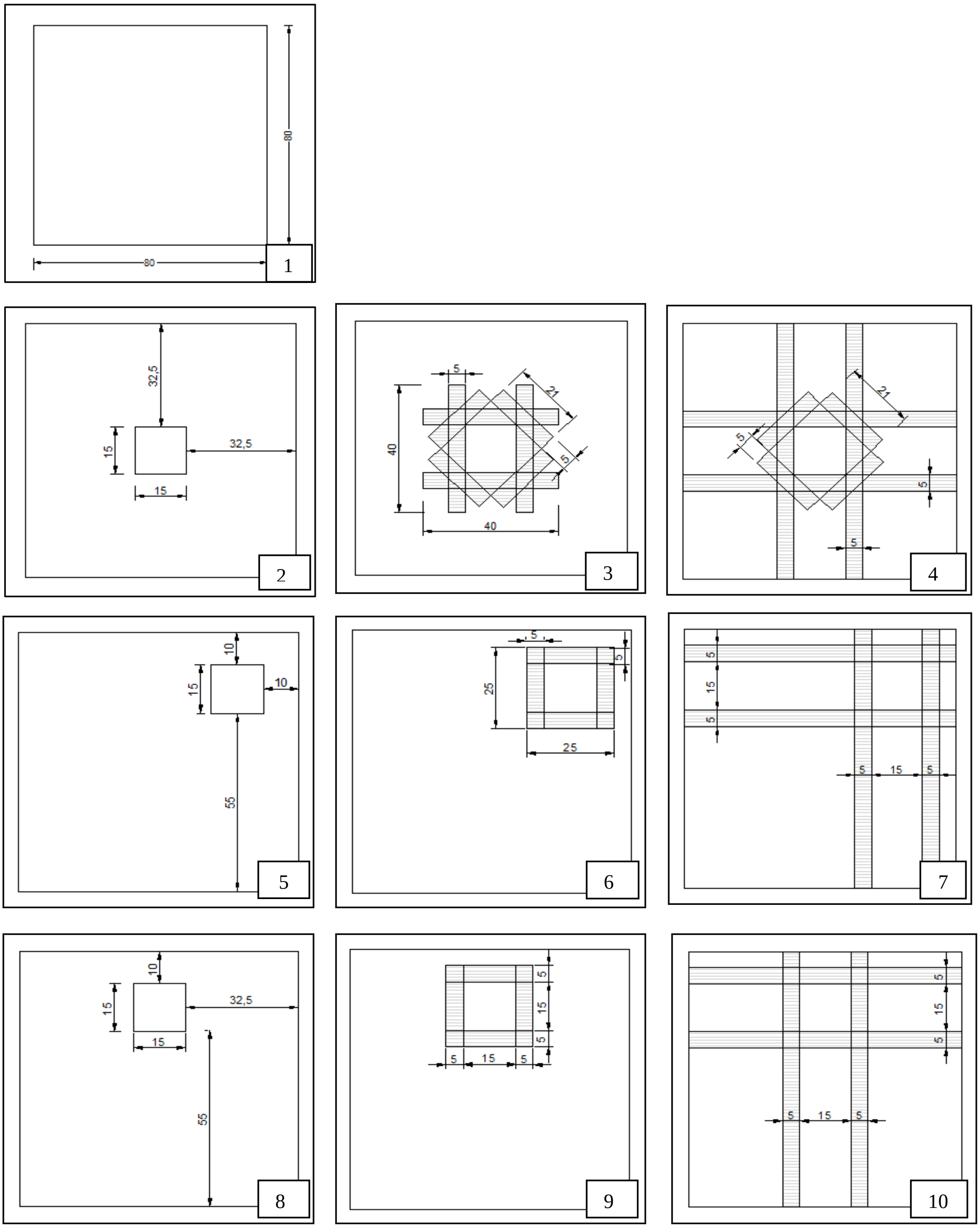

Figure 1: Details of tested specimens: (1) bottom view of slab (SC), (2) bottom view of slab (S1), (3) bottom view of slab (S1.1) first scheme, (4) bottom view of slab (S1.2) second scheme, (5) bottom view of slab (S2), (6) bottom view of slab (S2.1) third scheme, (7) bottom view of slab (S2.2) fourth scheme, (8) bottom view of slab (S3), (9) bottom view of slab (S3.1) third scheme, (10) bottom view of slab (S3.2) fourth scheme.

Table 2. Some Properties of Daracem SP3

Properties	Remarks
Dry Substance	approximately 95%
PH 10% SOL.	4.5/0.5
Chloride Content	traces
Toxicity	non-toxic

Table3. Reinforcing Steel Properties

properties	Remarks
Diameter (mm)	8
Area (mm^2)	50.27
Weight (kg/m)	0.395
Yield Strength (MPa)	460
Ultimate Strength (MPa)	686
Elongation%	11

Table 4. Properties of carbon fiber Fabric

properties	Remarks
Type	Sika Wrap 300 C/60
Weight (g/m^2)	300
Thickness (mm)	0.166
Tensile strength (MPa)	3900
Tensile E-modulus (MPa)	230000
Elongation%	1.5

Table 5. Properties of the Epoxy Resin

properties	Remarks
Appearance	Part A: white Part B: gray
Mixing ratio	A:B 4:1
Open time min.	30 (at+35°C)
Tensile strength (MPa)	30
Tensile E-modulus (MPa)	4500
Elongation%	0.9

Table 6. Concrete mix detail

properties	Remarks
Type of aggregate	natural crushed gravel
Cement content (Kg/m^3)	350
Mix proportion(by weight)	1:2:3
W/C(by weight)	0.5
Slump (mm)	120
f'_c7-day (MPa)	19.1
f'_c28-day (MPa)	25

Preparation of Specimens

Wooden moulds were used with dimensions of (800 × 800 × 80) mm to cast the specimens. The inner surface of the moulds cleaned and oiled to prevent the attachment with the concrete. The details of the reinforcement and the wooden moulds shown in Fig. 2.

Installation of CFRP Strengthening System

In any strengthening application, the crucial part was the bond between the FRP and the surface of concrete. Before the CFRP sheet has been applied to the bottom of the slabs, the surfaces of the concrete were grinded by the electrical hand grinder to uncover the aggregate and to get a clean surfaces, and without pollutants such as dirt, and cement dust as shown in Fig.3. After that the CFRP sheets have been cut according to the lengths and width required. Then the two compounds of adhesive (Sikadur-330) A (white) and B (gray) were mixed in 4:1 ratio respectively with an electric drill of low speed, until the uniform gray color was obtained, by a special tool (brush) the adhesive paste has been applied uniformly to both carbon fiber and the concrete surface. The strips were put on the concrete surface, then applied pressure with a ribbed roller in the fibers direction properly seat the sheets. After the completion of the CFRP strips installation, before the date of testing in two days, all the slabs surface have been painted white to easily detect the propagation of cracks. Fig.3 shows the steps of installation of CFRP sheets.

Test Set up, Loading Procedure and Instrumentation

Fig.4 shows the universal testing machine in the College of Engineering, University of Basrah, Engineering Materials Laboratory. The machine of a maximum capacity 2000 kN which has been used for test the slab specimens. The slabs were tested with simple support on all sides each 700 mm long. A box of internal dimensions (700×700×100) mm made of steel plate of thickness 2 mm opened from the top and bottom zones and covered with a nylon in the internal surface, has been used to carry the sand and set over the slab as a part of the uniformly distributed load. In order to prevent the fall of sand from the opening, wood cube of dimension equal to the opening dimension. Deflection was recorded in each loading stage using dial gauge with accuracy 0.01 mm per division. The deflections were measured at the center of slab for all slabs except slabs (S1, S1.1 and S1.2) the deflection were measured at a distance (7.5) cm from the center of slab.

Test Results and Discussion

The results have been analyzed based on cracking behavior, vertical deflection, and failure mode, which included the first cracking load and ultimate load. The experimental results are presented and compared the strengthening slabs with slab without strengthening (control slab) in the same group, the results showed that the external strengthening of R.C. slabs by CFRP sheets gave a better enhancement in comparison with control slab in these groups**.**

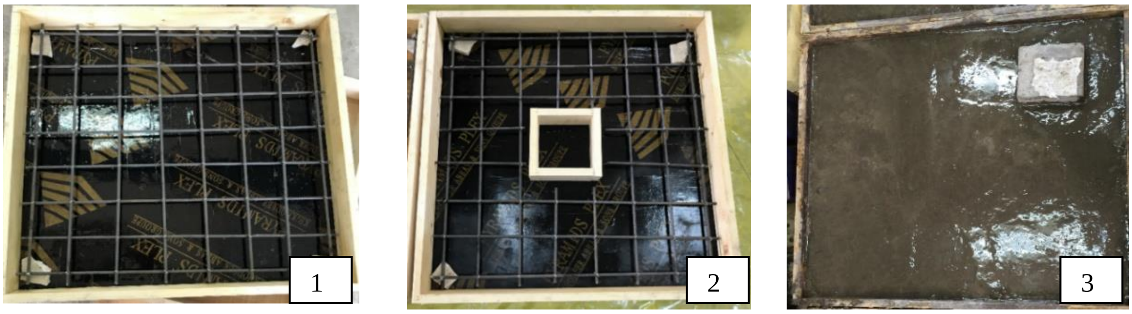

Figure 2: Specimen preparation and casting: (1) Wooden mould and reinforcement of slab (SC), (2) wooden mould and reinforcement of slabs (S1, S1.1, S1.2), (3) casting of slab (S2).

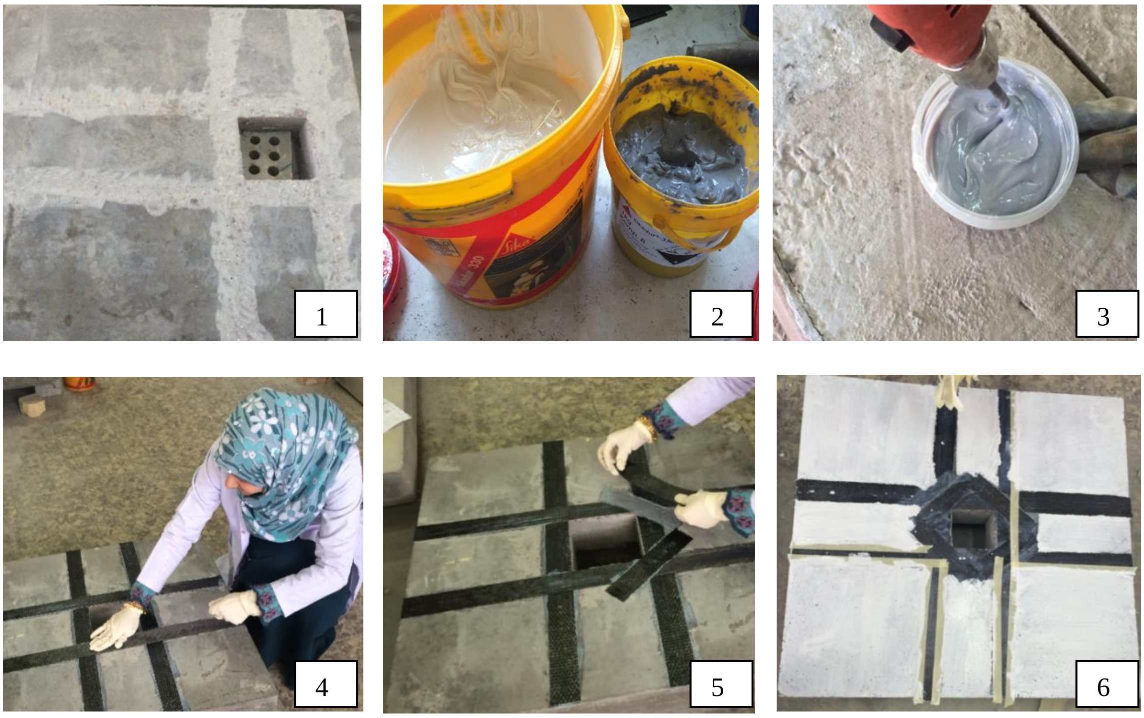

Figure 3: Concrete surface preparation and installation of CFRP sheets: (1) grinded the bottom surface of the concrete, (2) the two compounds of adhesive (Sikadur-330), (3) mixing the adhesive, (4) and (5) putting the strips on the concrete surface, (6) painting the slab.

Figure 4: Testing Machine

First Cracking Loads

Table (7) presented the first cracking load obtained from the experimental work, and the comparison with the slab (SC). Generally, the first crack load in slabs with opening and without strengthening was less than the strengthened slabs. The other slab specimens strengthened with four schemes showed different values in first cracking load.

Ultimate Loads and Failure Modes

Table (8) shows the ultimate load and the failure mode of slabs containing openings of different location strengthened using CFRP sheets and the comparison with the control solid slab. The result showed that the strengthening increased the ultimate load.

The difference in ultimate load depends on the proportion of the measured ultimate load for each slab with respect to the measured ultimate load for the control solid slab.

Cracking Patterns

The slabs under flexural load behaved in the expected form. It was gradually loaded until the initiation of cracking. First cracks began at load of 102 kN/m^2 for solid slab (SC). For slab with central opening began at load 80 kN/m^2, while for slab with opening at a distance (100×100) mm from a corner edge of specimen began at load 67 kN/m^2, and for slab with openings at distance (100×325) mm from a corner edge of specimen began at 81 kN/m^2. The flexural cracks in slabs without opening started at the center of the slab and in the slabs with opening started at the corners of opening, then propagated diagonally toward supports, under increasing load.

For the strengthened slab with first and third scheme, the first crack was observed at the end of the strip of CFRP. Due to load increment, these cracks spread diagonally, around the CFRP laminates and expanded rapidly. The slabs strengthened with the second and fourth scheme show different crack pattern due to the "CFRP sheets" presence and the provided length, which was equal to specimen clear span. Fig.5 shows the mode of failure for the slabs.

Deflections

The measurement of deflections for all slabs have been taken till failure. Two dial gages have been placed at different locations in order to measure the deflection of slabs.Fig.6 to Fig.9 shows the comparison of load deflections curves of all the reinforced concrete slabs in this study. It was observed that the presence of opening in the slab causes a decrease in stiffness and an increase in deflection at the same stage of loading. The CFRP sheets presence was improved the behavior of slabs with strengthening when compared to the control solid slab (SC) and slab without strengthening in same group by increased the load and decreasing the deflection.

Table 7.First cracking loads of the slabs

Specimen	First cracking load (kN/m^2)	Difference in cracking load compared with SC, (%)
SC	102	N/A
S1	80	-21.6
S1.1	112	+9.8
S1.2	120	+17.6
S2	67	-34.3
S2.1	71	-30.4
S2.2	74	-27.5
S3	81	-20.6
S3.1	100	-2.0
S3.2	116	+13.7

Table 8.The ultimate load capacity and failure mode of tested slabs

Specimen	Ultimate load (kN/m^2)	Difference in ultimate load compared with SC (%)	Failure mode
Sc	306	-----	flexural failure
S1	269	-12.1	flexural failure
S1.1	322	+5.2	flexural failure without debonding in CFRP sheets
S1.2	330	+7.8	debonding
S2	196	-35.9	flexural failure
S2.1	200	-34.6	flexural failure without debonding
S2.2	214	-30.1	debonding
S3	280	-8.5	flexural failure
S3.1	303	-0.98	flexural failure without debonding
S3.2	339	+10.8	debonding

Figure 5: mode of failure for slabs

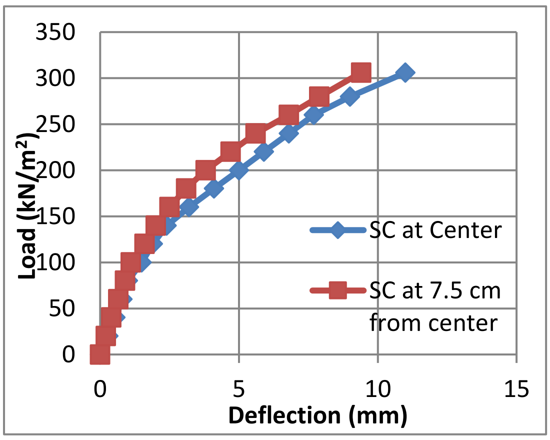

Figure 6: Load-deflection curve for group (1) (slab SC)

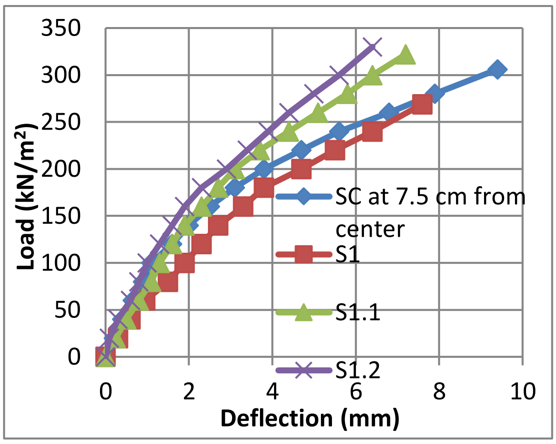

Figure 7: Load-deflection curve for group (2) (slab S1)

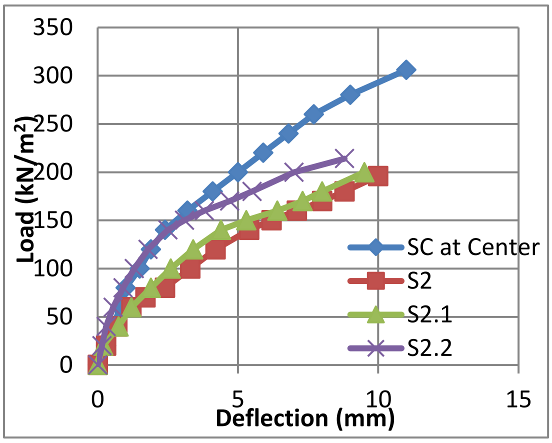

Figure 8: Load-deflection curve for group (3) (slab S2)

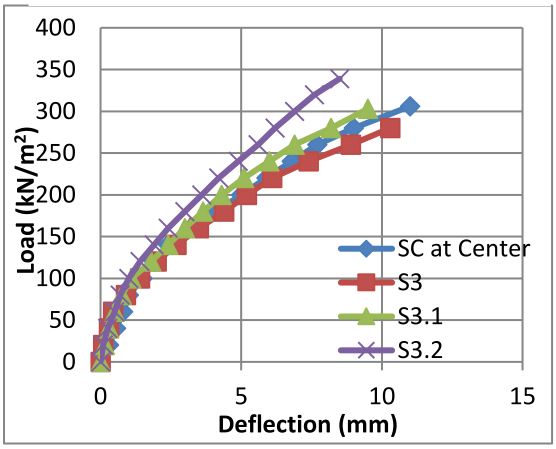

Figure 9: Load-deflection curve for group (4) (slab S3)

CONCLUSION

The following point illustrate the conclusions obtained from the experimental study.

1. Decrease in stiffness due to presence of openings in slabs.
2. The presence of opening at a distance (100×100) mm from a corner edge of specimen gave the least value of ultimate load, and the strengthening by CFRP sheets shows a minimum effect.
3. Delaying the appearance of crack and reducing the crack width of the reinforced concrete two way slab with openings when strengthened with CFRP strips.
4. Increase in ultimate load of reinforced concrete two way slabs with openings strengthened by CFRP sheets.
5. Increase in the stiffness of the R.C. two-way slabs with openings and strengthened by CFRP sheets by the second and fourth scheme, and reduced the deflection at the same stages of loading.

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