Strengthening of Reinforced Concrete One-Way Slabs with Opening using CFRP Strip in Flexural

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Abstract: ***The purpose of this study is to investigate the flexural behavior of reinforced concrete one way slab with opening and applying strengthening to them by using CFRP strip. Size, shape of the opening, length, and width of CFRP strip are the main parameters that are investigated in this experimental research. Three different squares opening of (150 mm, 200 mm and 250 mm) side and three different shape of opening with constant opening area (square, rectangle and circle), two length of CFRP strip of (500mm and 700mm), and two width of CFRP strip of (50mm and 100mm) are tested. These openings are situated in the maximum bending zone. Two series of test are done during experimental program. First set of experiments are done without strengthening and second set of test are done after strengthening with CFRP strips. Totally, nine test specimens are tested, including one reference specimen, five specimens without strengthening and three specimens with strengthening. CFRP strips are located along the openings and fixed using anchor bolts. Finally some evaluations of test results are done for determining the performance of strengthening techniques. Crack load, ultimate load, service deflection, ultimate deflection, concrete compressive strain, crack width, crack pattern, and failure mode are calculated and compared. By all these evaluations, the strengthening technique that can be applied easily, faster and required less workmanship is developed.***

Keywords: Reinforced concrete, one-way slab, opening, strengthening and CFRP strip.

1. Introduction

The technology is developing and demands for consumer goods is increasing every day, therefore producers require big machines and larger manufacturing factories to meet these needs. Each factory has its own unique structure, so each factory must be specially designed. While engineers and architects are designing these special structures, they require designs such that one fits all needs. These designs also include many challenges for situating cable channels, water and gas pipes, ventilation gaps and fire-extinguishing systems. Structures may need lots of openings of various sizes and shapes. Designers must compensate for the negative effects of these openings. Openings will reduce the load carrying capacity, stiffness, energy dissipation capacity and ductility of the slab [1, 2]. It is important to investigate strengthening technique for overcoming these negative effects of openings in the reinforcements of slabs by taking into account opening size and shape. During the last decade the use of fiber reinforced polymers (FRPs) for retrofitting and strengthening became a valid alternative because of their small thickness, and relative ease of application. FRP’s not only have the advantage of very high strength over conventional materials, but also are light weight and highly durable in many environments. The light weight of FRP makes rehabilitation techniques much easier in constricted spaces. In addition there is no need to have large equipment for FRP application. The strength and stiffness of a structure can be increased with very little increase in mass, distinctly advantageous from the seismic perspective. Carbon fiber reinforced polymers (CFRPs) have been widely used to strengthen reinforced concrete structures such as bridge girders, piers, beams, columns, slabs, beam-column joints as well as masonry structures.

2. Literature Review

Numerous tests have been conducted around the world to examine the behavior of structural members strengthened by using CFRP. These tests showed that this technique of strengthening is an effective and convenient method to improve the member strength and/or stiffness. CFRP can be used to increase the flexural capacity, and also increase the shear strength and stiffness of reinforced concrete (RC) beams [3, 4]. Similarly it is shown that the RC columns strengthened with CFRP jackets have higher strength and stiffness [5–7]. Strengthening of RC beam column joints with CFRP sheets showed that shear strength of the joints were improved significantly [8–10]. CFRP strips applied to tension regions of RC slabs increased the punching shear strength of the slabs significantly [11, 12]. Strengthening with CFRP strips is thought to be a suitable alternative for one way RC slab that are examined in this study.

Scott T., Shenghua H., Seo J. and Rudolf S. [13] aimed to strengthening of one-way slab by using different types of anchors in their study. They fixed the CFRP strips with anchors on upper face of the concrete. As a result of experiments, it is observed that the both ultimate capacity and deformation capacity increased at strengthened elements compared to the reference element.

Elgabbas F., El-Ghandour A., Abdelrahman A. and El-Dieb A. [14] have experimented different strengthening techniques at slabs with prestressed concrete in their study. They aimed to find the best strengthening details with trying various strip width and thickness. According the test results they have achieved an increase of capacity between 15% and 80%. There has been no significant change in the maximum displacement value.

Bouguerra K., Ahmed E., El-Gamal S. and Benmokrane B. [15] tested eight test elements as a bridge slabs with 3000 mm long and 2500 mm width in their study. As a variable they used slab thickness, concrete class, transverse reinforcement ratio and strengthening scheme. They found that, increase in shear capacity directly depends on the thickness of slab and concrete quality.

Al-Rousan R., Issa M. and Shabila H. [16] tested some strengthening technique with different layouts of CFRP strips in their study. They have determined that using CFRP strips contribute increase in maximum load carrying capacity of slabs.Also they have determined that, if the number of CFRP layers are increased, maximum carrying capacity will also increase.

Tamer E. and Khaled S. [17] compared the behavior of the CFRP strips with and without anchorages and referred to the advantages of each other. Although they had better results in terms of deformation of anchorage CFRP strips, the maximum load capacity of the slabs that are strengthened by using CFRP strips without anchorages are more than that of anchorage CFRP strips. Depending on the deformation values that they found anchor application gives better results in terms of the ductility.

3. Significant Research

The prediction of the placement of openings at the slabs cannot always be made during the design stage of the building. Sometimes after completing construction of the building, due to different reasons such as air conditioning system placement, heating and cooling ducts, placement of electric or other purpose cables or other infrastructure, openings are made at different size and shape. For these reasons, no extra reinforcement can be placed around the openings while producing the slab at the beginning. Authors thought that, application of CFRP strips around openings that are cut after slab is produced can be a proper choice. So the researcher decided to carry out an experimental study about RC one way slab with openings and effects of strengthening with CFRP strips on performance. Hence, the aim of this study was to investigate the flexural behavior of RC one way slab with opening (with different opening size and shape) and the use of CFRP strengthening alternatives systems to restore the flexural capacity of the RC slabs with large openings in the positive moment region. Tests were conducted on RC slabs with opening strengthened by CFRP strip to study the effect of length and width of CFRP strip.

4. Experimental Program

4.1 Test specimens and material

One way reinforced concrete slab specimens designed with the dimensions of 1400 mm length, 450 mm width and 90 mm thickness. Three different square opening of (150 mm, 200 mm and 250 mm) sides, three shape of opening with constant opening area (square, rectangle and circle), two length of CFRP strip (500mm and 700mm) and two width of CFRP strip (50mm and 100mm) are tested. These openings are situated in maximum moment zone and located at the axis of symmetry. Experimental program is arranged such that four series of specimens are tested. Totally nine specimens are manufactured. One of them is tested without opening as a reference specimen and remaining eight are tested with openings. Five of these eight specimens are tested without CFRP strip and the other three with CFRP strip. Properties of the specimens are given in Table (1). Geometrical dimensions and reinforcement details of the specimens are presented in Figure (1) and Figure (2).

Table 1: Properties of specimens

Specimen	Open shape	Open dim. (mm)	% Open	Strengthening	Length of CFRP-strip (mm)	Width of CFRP-strip (mm)	f_c' MPa
S1	---	---	0	---	----	---	40.8
S2	Square	200	7.4	----	---	---	41.1
S3	Square	150	4.2	----	----	----	40.3
S4	Square	250	11.6	----	----	----	40.5
S5	Rectangle	151×265	7.4	----	----	----	42.1
S6	Circle	D = 225.7	7.4	----	----	----	39.3
S7	Square	200	7.4	CFRP-Strip	500	50	42.3
S8	Square	200	7.4	CFRP-Strip	700	50	41.8
S9	Square	200	7.4	CFRP-Strip	700	100	41.0

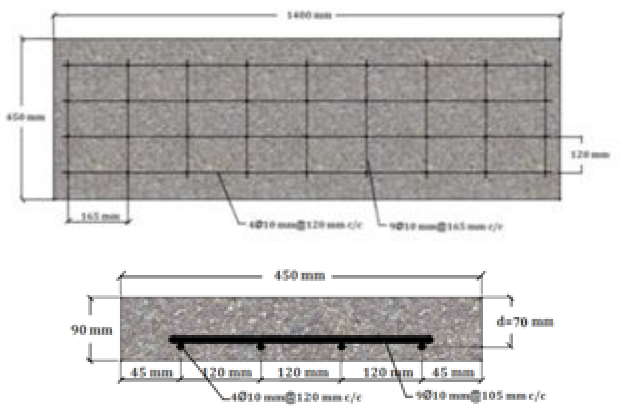
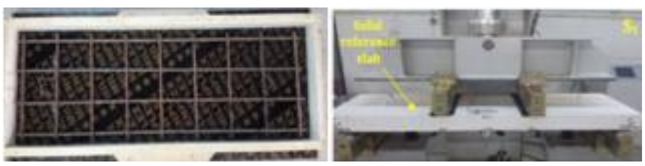


Figure 1: Dimensions and reinforcement details of specimens



a:S1 Reference slab (without opening)

b:S2 Square opening (200 mm)

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

c:S3 Square opening (150 mm)

Figure 2: Detailing of reinforced concrete slabs, cont,d

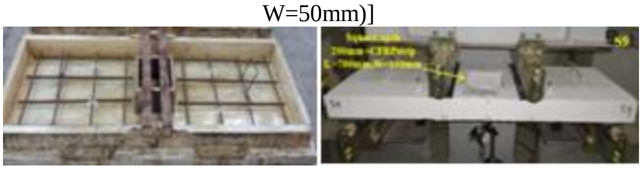
d:S4 Square opening (250 mm)

e:S5 Rectangle opening (151×265 mm)

f:S6 Circle opening (D=225.7 mm)

g:S7 [Square opening (200 mm) + CFRP strip (L=500mm, W=50mm)]

h:S8 [Square opening (200 mm) + CFRP strip (L=700mm, W=50mm)]



i:S9 [Square opening (200 mm) + CFRP strip (L=700mm, W=100mm)]

Figure 3: Detailing of reinforced concrete slabs

The longitudinal reinforcements are chosen as a 4 pieces of ϕ10 and longitudinal reinforcement ratio is appeared to be ρL = 1%. Reinforcement with ϕ 10 at each 165 mm is used as transverse reinforcement along the short direction. The reinforcements along the openings are cut before pouring the concrete. For the determination of compressive strength of concrete three standard cylindrical test samples with dimension of 150 × 300 mm was taken from each test element and tested. The cylindrical samples are kept in the same curing conditions with specimens and are tested in the same date in order to determine compressive strength of concrete. The concrete mix proportions are presented in Table (2). Targeted compressive strength of the concrete is 40 MPa and obtained concrete compressive strengths after testing are given in Table (1). Mechanical properties of reinforcements, which are used in the specimens, are presented in Table (3).

Table 2: Concrete Mix design

Reinforcement Diameter (mm)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Type
10	460	605	Deformed

Table 3: Mechanical properties of reinforcement

Mix designation	Cement kg/m3	Aggregate kg/m^3		Water kg/m^3	w/c for Slump 120±10 mm
		Sand	Gravel		
C40	400	850	950	200	0.50

The CFRP used in the strengthening application were (Sika CarboDurS512 and Sika CarboDurS1012) unidirectional flexible strip. The structural adhesive paste used for bonding the SikaCarboDur strips to the concrete substrate was (Sikadur-30) which is high-modulus high-strength two component (A and B) product, see Figure (3). Anchor bolts were used to anchoring CFRP strips to demonstrate the contribution of the CFRP to the ultimate strength. Holes for placing anchors were made in RC slabs, by electric drill as shown in Figure (4), of diameter 10 mm to provide a place for 9.5mm (bolt diameter) in the slabs at a spacing of (220 mm for specimen S7 and 320 mm for specimens S8 and S9) from the center of slabs. Square steel plates of dimensions (50mm×50mm for Sika CarboDurS512 and 50mm×100mm for Sika CarboDurS1012) and a thickness of (4 mm) were placed with bolts in the ends of each plate strips. They were used to fix the CFRP strip in the locations as shown in Figure (5).

(100 mm and 50 mm) wide CFRP strips (Sika CarboDurS512 and Sika CarboDurS1012) are used. Uniaxial CFRP strips are placed as a single layer for strengthening and two component epoxy adhesive is used for bonding. Layouts of the CFRP strips are shown in Figure (6). Before bonding of CFRP members onto concrete surface, special consideration was given to the slab tension face preparation. CFRP strip locations onto tension face of the slabs were roughened mechanically by a grinding machine down to aggregate level, and then grinded surface was brushed. Surfaces were vacuum cleaned for removing loose particles and dust. Prepared mixture of epoxy was spread over the grinded surface up to 2mm thickness approximately. CFRP strips were bonded on their predefined places at tension face of the slab. After bonding of CFRP strips, some pressure was applied on them by hand along the fiber directions to get rid of air bubbles entrapped between CFRP strips and concrete surface, and CFRP strips were soaked with applied epoxy on concrete, see Figure (7). The temperature during application was 20 ± 2 ċ in all cases. After bonding operations was completed, specimens were cured for 7 days under laboratory conditions before testing. Properties of CFRP strips and epoxy, which are suggested by the manufacturer, are presented in Tables (4) and (5).

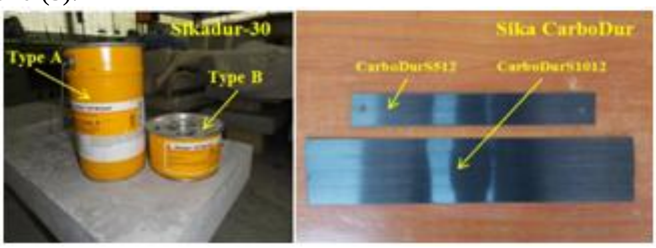
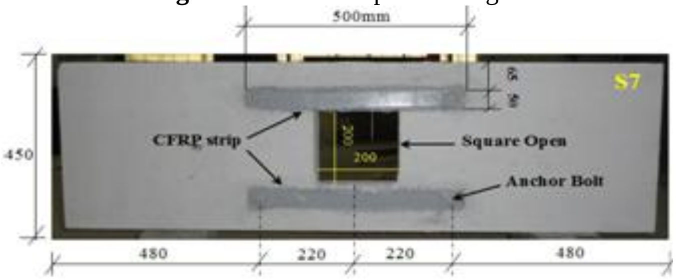


Figure 3: Manufactured forms of CFRP materials

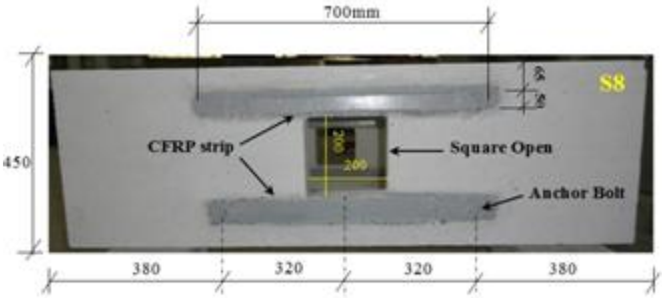
International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Figure 4: Making holes in RC slabs

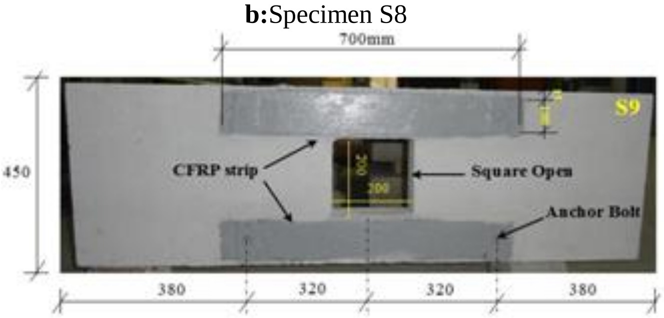
Figure 5: CFRP strip anchoring



a:Specimen S7



b:Specimen S8



c:Specimen S9

Figure 6: Strengthening schemes of specimens

Table 4: Properties of CFRP strip (Sika CarboDurS512 and Sika CarboDurS1012)*

Fiber type	High strength carbon fibers			
Base	Carbon fiber reinforced polymer with an epoxy resin matrix			
Shelf Life	Unlimited (no exposure to direct sunlight)			
Color	Black			
Tensile Strength	Mean Value 3100 MPa Design Value 2800 MPa			
Modulus of Elasticity	Mean Value 165000 MPa Design Value 160000 MPa			
Elongation at Break	1.69%			
Design Strain	0.85%			
Thickness	1.2 mm			
Temperature Resistance	>150°C			
Fiber Volumetric Content	>68%			
Density	1.60 g/cm3			
Physical Properties				
Product	Thickness	Width	Cross Sectional Area	Tensile Force
Type S512	1.2 mm	50 mm	60 mm^2	168 kN
Type S1012	1.2 mm	100mm	120 mm^2	336 kN

* Provided by the manufacturer

Table 5: Properties of Sikadur-30 (Impregnating Resin)*

Color	Light gray
Storage Conditions	Store dry at (4°-35°C). Condition material to (18°- 29°C) before using
Consistency	Non-sag paste
Pot Life	Approximately 70 minutes @ 23°C (1 qt.)
Mixing Ratio	Component 'A': Component 'B' = 3:1 by volume
Density	1.65 kg/l (mixed)
Tensile Properties (ASTM D-638) 7 day	Tensile Strength (24.8 MPa) Elongation at Break 1% Modulus of Elasticity (4482 MPa)
Flexural Properties (ASTM D-790)14 day	Flexural Strength (Modulus of Rupture) (46.8 MPa) Tangent Modulus of Elasticity in Bending (11721 MPa)
Shear Strength (ASTM D-732) 14 day	Shear Strength (24.8 MPa)

* Provided by the manufacturer

a:Removing the weak layer surface **b:**Cleaning the slab surface

c: Mixing the epoxy materials **d:** Applying of CFRP strip

Figure 7: Steps of strengthening by CFRP strip, cont,d

e:Specimen just after strengthening

Figure 7: Steps of strengthening by CFRP strip

4.2. Experimental Setup

A schematic view of the test setup and the arrangement of the measurement devices are shown in Figure (8). The specimens were constructed in the Structural Laboratory of the College of Engineering / Diyala University. All specimens were tested as simple beam under four point loading with shear span to effective depth ratio (a/d) equal to 5.71. Load on the midpoint of separator beam was divided symmetrically into two concentrated load and applied to the specimens. Load was applied with a 2000 kN capacity hydraulic jack and was measured with a 600 kN capacity load cell. Vertical deflections have been measured at three points (D1, D2 and D3) as central deflection and at under point of loads in both sides of the slab using a three dial gauges of (0.01mm) accuracy with (50mm) total stroke. The dial gauges have been attached to the soffit of the tested slabs. All specimens were instrumented with one concrete strain gauge bonded on the top surface of the slab at the center. The concrete strain gauge used in the experimental program was type PFL-30-11-3L from TML, with the following characteristics: wire-type, with a resistance of 120.4 ± 0.5 Ω, a gauge factor of 2.13 ± 1%, a gauge length of 30 mm and a gauge width of 2.3 mm with a maximum strain of 2%; see Figure (9 b). The strain gauge was bonded, using CN-E cyanoacrylate adhesive, to the previously treated surface of the slab with PS-XC09F two component adhesive; see Figure (9 c and d). Figure (9 a) shows the arrangement of the concrete strain gauge. The load was increased gradually at increments of (2.5 kN) to record the deflection up to failure. To measure crack widths, an optical micrometer with an accuracy of (0.02mm), as shown in Figure (10), was used for all beams specimens. The slab surfaces were painted with white color to make it easy to see the crack and measured it, as shown in Figure (11).

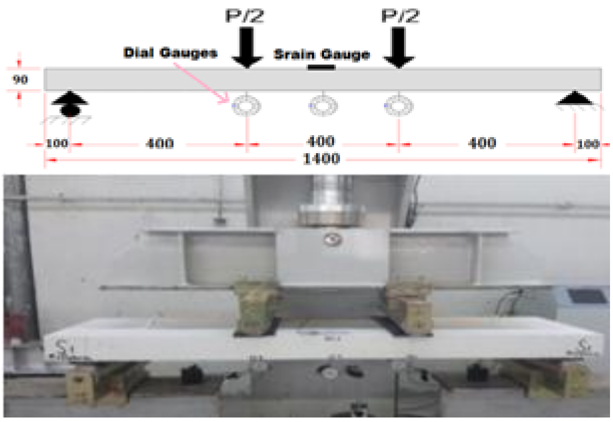


Figure 8: Test setup and instrument

Figure 9: Strain gauge type, Arrangement, and Adhesive materials

Figure 10: Optical micro-meter

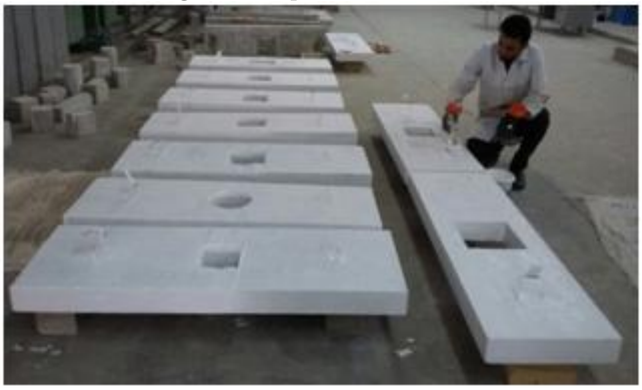


Figure 11: Painted the RC slabs with white color

5. Experimental results and discussion

5.1 Load-deflection behavior

Deflection profile was measured along the length of tested slabs (at the center of slabs, 200mm from the center along X-axis in both sides) by means of (0.01 mm) dial gauges, and readings from this gauge were recorded for each load increment. The deflection profiles for all specimens are shown in Figures (12) to (20). When a reinforced concrete slab is subjected to a gradual load increase, the deflection increases linearly with the load in an elastic manner. After the cracks start developing, deflection of the slab increases at a faster rate. After cracks have developed in the slab, the load-deflection curve is approximately linear up to the yielding of flexural reinforcement after which the deflection continues to increase without an appreciable increment in load. The force–displacement graphs of the specimens are grouped according to opening size, opening shape, length of CFRP strip strengthening and width of CFRP strip strengthening which are the fundamental variables of this study, and presented in Figures (21) to (24).

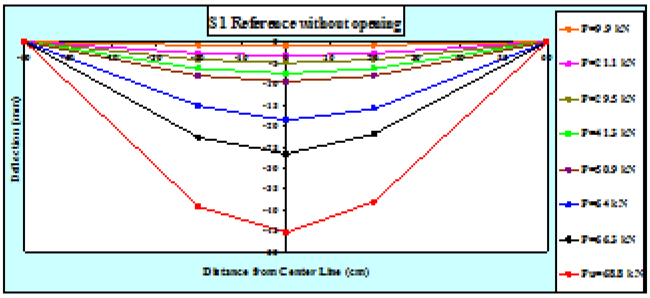


Figure 12: Deflection profile for specimen S1

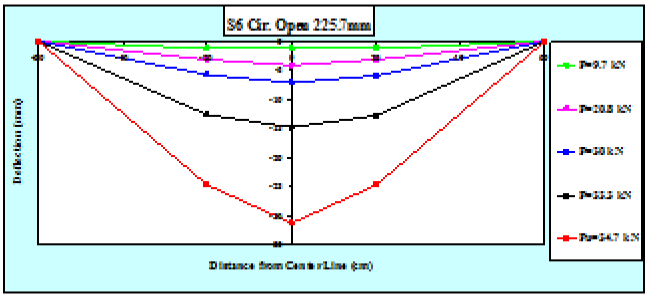


Figure 17: Deflection profile for specimen S6

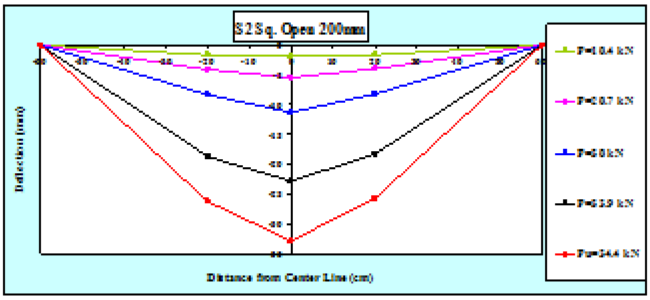


Figure 13: Deflection profile for specimen S2

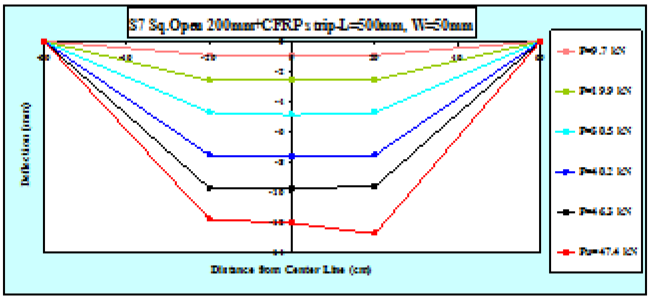


Figure 18: Deflection profile for specimen S7

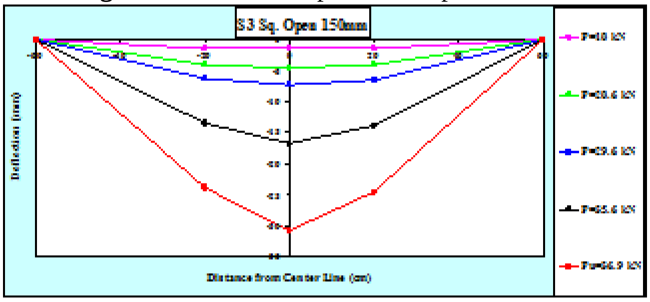


Figure 14: Deflection profile for specimen S3

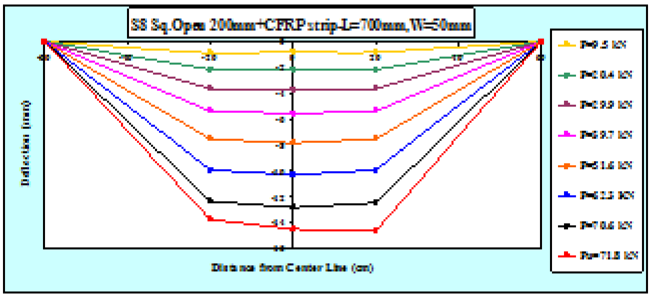


Figure 19: Deflection profile for specimen S8

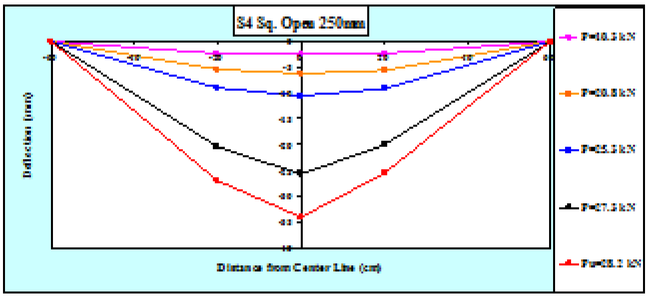


Figure 15: Deflection profile for specimen S4

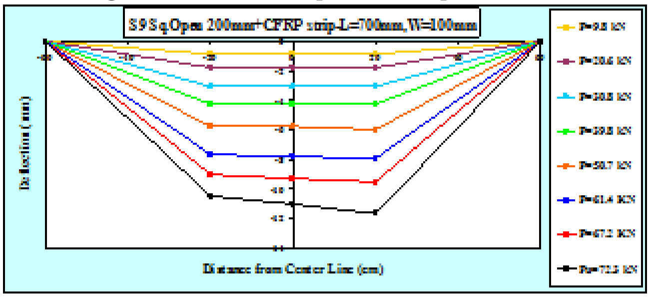


Figure 20: Deflection profile for specimen S9

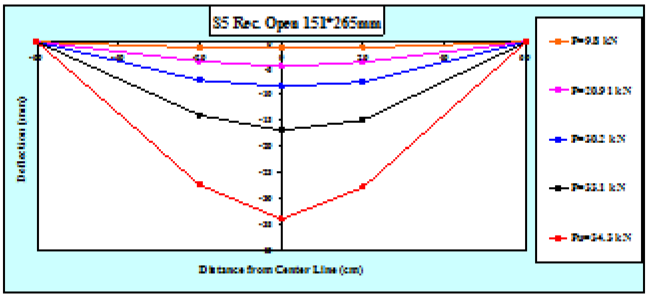


Figure 16: Deflection profile for specimen S5

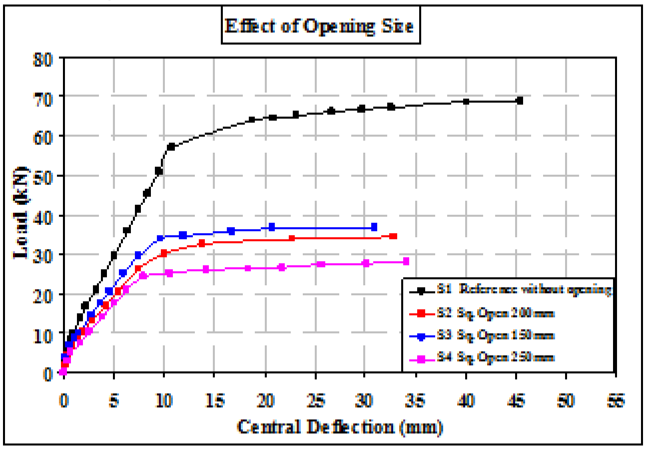


Figure 21: Effect of opening size on load-deflection curve

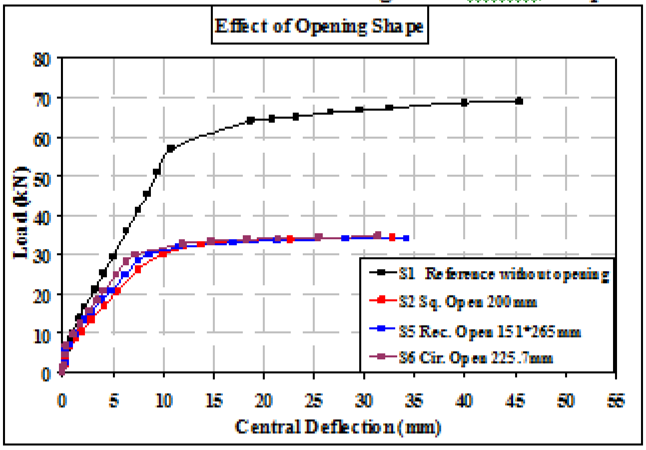


Figure 22: Effect of opening shape on load-deflection curve

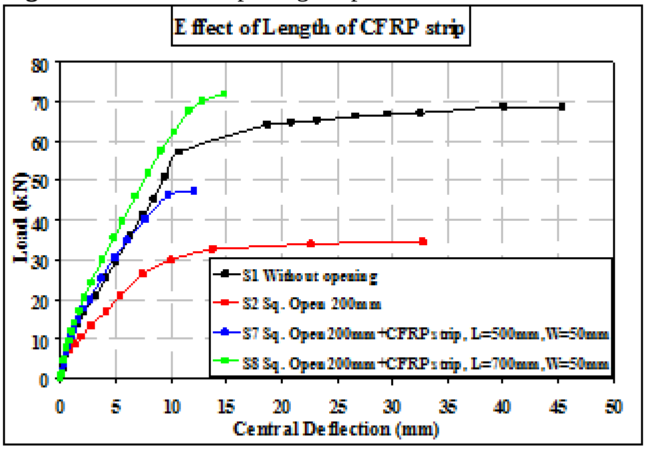


Figure 23: Effect of length of CFRP strip on load-deflection curve

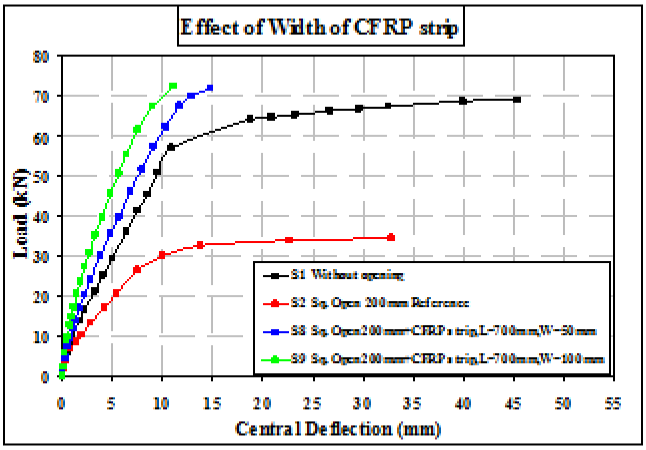


Figure 24: Effect of width of CFRP strip on load-deflection curve

When the force–displacement graphs are analyzed, it's seen that from Figure (21), when introducing opening in reinforced concrete slab with deferent size (150mm, 200mm and 250mm) which represent opening ratio (4.2%, 7.4% and 11.6%) in specimens (S3, S2 and S4) the ultimate load capacity will decrease by about (46.37%, 50.0% and 59.01%) respectively in comparison with reference slab without opening (S1), also seen that the service deflection will increase at increasing opening size, this is due to decreasing in amount of concrete and reinforcement steel at opening region causing decrease in second moment of cross sectional area and reducing in stiffness of member therefore the ultimate load will decrease and service deflection will increase. Table (6) shows the ultimate load capacity and corresponding decreasing or increasing in ultimate load for all slabs.

Table 6: Ultimate load capacity of specimens

Specimen	Ultimate load, P_u (kN)	% $\frac{Pu}{Pu\ Referenc}$	% Decreasing or Increasing in (P_u)
S1	68.8	Reference	Reference
S2	34.4	50.00	-50.00
S3	36.9	53.63	-46.37
S4	28.2	40.99	-59.01
S5	34.3	49.85	-50.15
S6	34.7	50.44	-49.56
S7	47.4	68.90	-31.10
S8	71.8	104.36	+4.36
S9	72.3	105.09	+5.09

Can be seen that from Table (6) and Figure (22), for specimens (S2, S5 and S6), which have same catting or opening ratio (7.4%) with deferent opening shape (square, rectangle and circle), these specimens have approximately same ultimate load capacity (about 50% from reference slab S1) and approximately same behavior (same load-deflection behavior), this is because of the same amount of concrete and reinforcement steel are cutting in critical region (region of maximum moment).

Strengthening the reinforced concrete slab with square opening (200mm) using CFRP strip (with different length and width of CFRP strip) are shown in Figures (23 and 24) and Table (7), It can be seen that at increasing the length of CFRP strip strengthening from (500 mm to 700mm) in specimens (S7 and S8), the ultimate load capacity will increase and the service deflection (deflection at 70% of reference ultimate load) will decrease, the percentage of increased ultimate load are (37.79% and 108.72%) and the percentage of decreased deflection are (47.28% and 58.31%) respectively. And at increasing the width of CFRP strip from (50mm to 100 mm) in specimens (S8 and S9), the percentage of increase in ultimate load are (108.72% and 110.17%) and the percentage of decreased in service deflection are (58.31% and 72.66%) respectively. This is due to increasing the stiffness of member at using CFRP strip causing increasing in ultimate load and reduction in service deflection.

Table 7: Enhancement in ultimate load and deflection due to strengthening by CFRP strip

Specimen	Ultimate load P_u (kN)	Ultimate deflection Δ_u (mm)	Δ@70% of P_u^* (mm)	% increase in P_u	% decrease in Δ@70% of P_u
S2	34.4	32.80	6.62	Reference	Reference
S7	47.4	12.10	3.49	37.79	47.28
S8	71.8	14.83	2.76	108.72	58.31
S9	72.3	11.00	1.81	110.17	72.66

*Deflection at 70% of ultimate load of reference slab S2

5.2 Concrete Compressive Strain

The strains in the concrete at compression face of the tested slabs have been measured by strain gauge along the length of slab at center line. Figure (9-a) shows the position of strain gauge. From Figures (25) to (28), it can be seen that the concrete compressive strain is small at the elastic stage as loading is applied, and then it increases after the first crack when loading is continued. Positive values in the diagrams refer to compression strain.

As shown in Figure (25), test results show that, in introducing opening in reinforced concrete slabs with opening ratio of (4.2%, 7.4% and 11.6%) in specimens (S3, S2 and S4) respectively, the concrete compressive strain at service stage will increase gradually over that of the reference slab specimen without opening (S1) due to reduced concrete volumes in compression zone due to the opening.

From Figure (26) can be seen that at service stage the concrete compressive strain will increase at approximately same value due to same volume of cutting concrete (7.4%) in these specimens (S2, S5 and S6).

From Table (8) and Figures (27) and (28), it can be seen that when strengthening the RC slab with opening by CFRP strip in specimens (S7, S8 and S9) the concrete compressive strain (at 70% of ultimate reference slab load) will reduced by about (36.83%, 48.14% and 55.57%) respectively, because of contribution of strengthening CFRP strip in increase the restrained and increase the stiffness of member at this region.

Table 8: Enhancement of concrete compressive strain due to strengthening by CFRP strip

Specimen	Ultimate strain ε_u (mm/mm)	ε@70% of P_u^* (mm/mm)	% Decrease in ε@70% of P_u
S2	0.004056	0.001078	Reference
S7	0.001400	0.000681	36.83
S8	0.001767	0.000559	48.14
S9	0.001650	0.000479	55.57

* Strain at 70% of ultimate load of reference slab S2

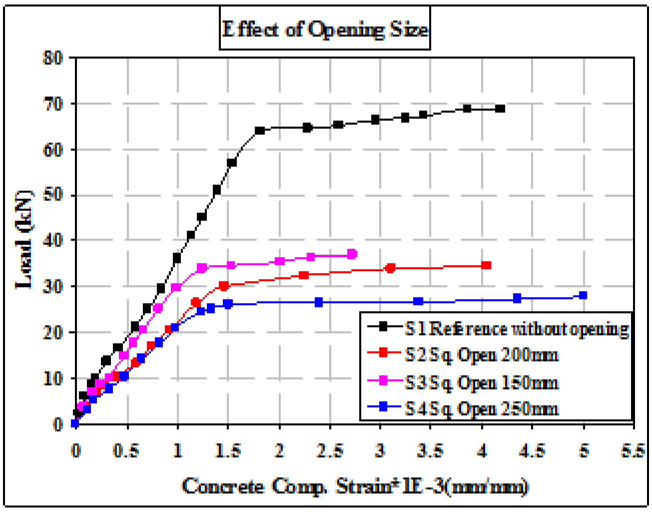


Figure 25: Effect of opening size on load-concrete compressive strain curve

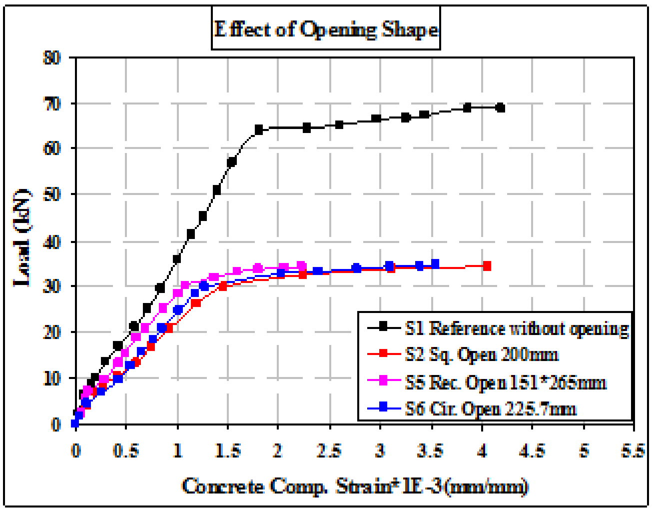


Figure 26: Effect of opening shape on load-concrete compressive strain curve

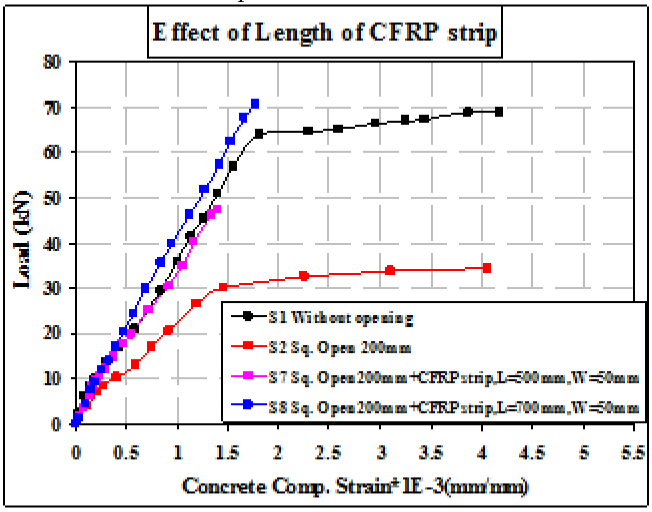


Figure 27: Effect of length of CFRP strip on load-concrete compressive strain curve

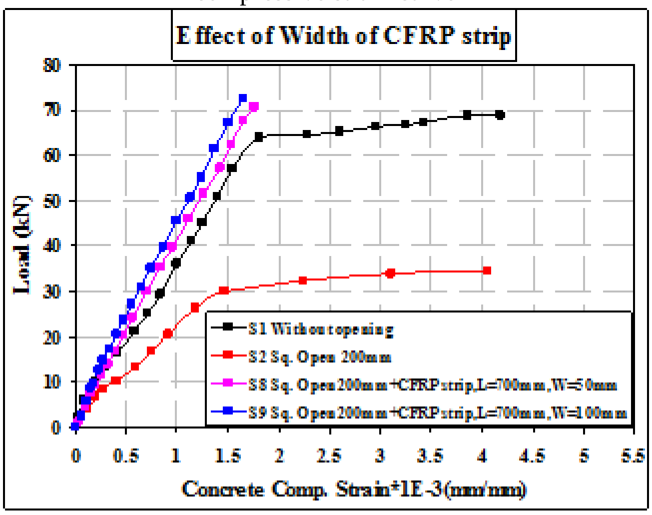


Figure 28: Effect of width of CFRP strip on load-concrete compressive strain curve

5.3 Crack Patterns of the Tested Slabs

For reference slab without opening (S1), specimens without strengthening (S2, S3, S4, S5 and S6), and slab specimens that have 50mm CFRP strip strengthening (S7 and S8), the first crack appeared transversally at the center of the slab on the tension face. Increasing the load, these cracks widened, increased in number and extend to top face of slab in compression zone. At ultimate load, the specimens (S1, S2, S3, S4, S5 and S6) showed flexural failure mode with flexural cracks, but specimens (S7 and S8) showed flexural-shear failure mode with flexural-shear cracks. Also the specimen (S9) which has 100mm CFRP strip width, the first crack appears at maximum shear zone (between the support and load point) and at increasing the load this shear crack widened and at ultimate load this specimen shows shear failure mode with flexural-shear cracks. The test results of first cracking loads of slabs are presented in Table (9) and Figures (29) to (32). When load is applied to these slab specimens, the first crack is formed at (14.39%, 20.06%, 19.78%, 18.44%, 20.70%, 19.60%, 25.95%, 18.11% and 37.76%) of the ultimate load of slabs specimens (S1, S2, S3, S4, S5, S6, S7, S8 and S9), respectively.

It is noted that from Table (9), the specimens (S3, S2 and S4) which have opening ratio of (4.2%, 7.4% and 11.6%) gave a decrease in the first cracking load in comparison with reference slab specimen without opening (S1) by about (26.3%, 30.3% and 47.5%), respectively. This is due to the reduction of the concrete volumes in tension zone due to the opening, also can be seen that from Figures (29) that the crack width at service stage will be increased at increased the opening ratio. And from Figure (30) can be seen that the constant decreased in crack width at specimens (S2, S5 and S6) which have deferent shape of (square, rectangle and circle) because of constant volume of cutting concrete (7.4%).

Enhancement the crack load and crack width due to strengthening by CFRP strip is shown in Table (10) and Figures (31) and (32). Figures (33) to (41) illustrate crack patterns for all slabs.

Table 9: Cracking load of specimens

Specimen	Crack load P_{cr}(kN)	Ultimate load, P_u (kN)	% $\frac{Pcr}{Pu}$	% Decrease or Increase in cracking load
S1	9.9	68.8	14.39	Reference
S2	6.9	34.4	20.06	-30.3
S3	7.3	36.9	19.78	-26.3
S4	5.2	28.2	18.44	-47.5
S5	7.1	34.3	20.70	-28.3
S6	6.8	34.7	19.60	-31.3
S7	12.3	47.4	25.95	+24.24
S8	13.0	71.8	18.11	+31.31
S9	27.3	72.3	37.76	+175.76

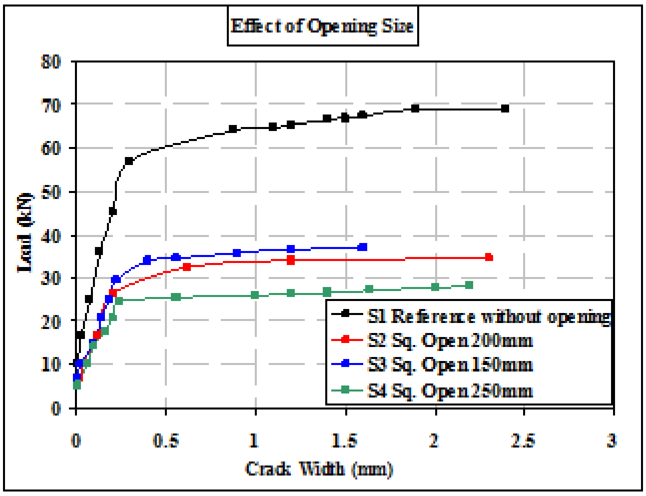


Figure 29: Effect of opening size on load-crack width curve

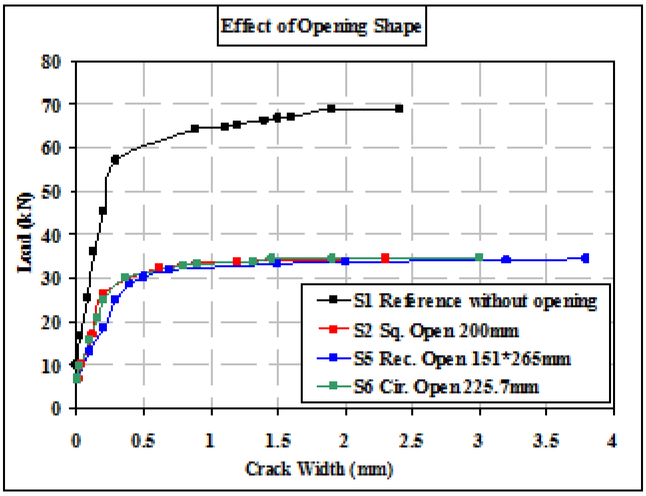


Figure 30: Effect of opening shape on load-crack width curve

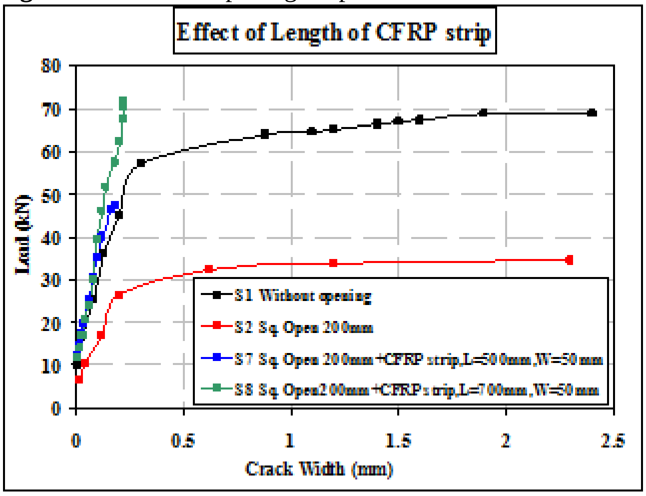


Figure 31: Effect of length of CFRP strip on load- crack width curve

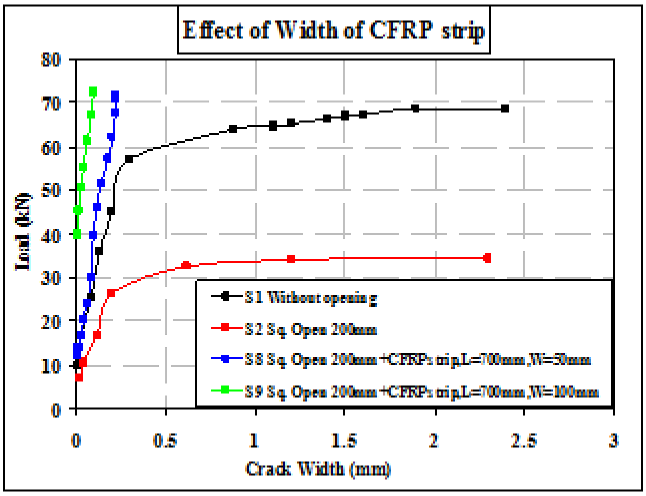


Figure 32: Effect of width of CFRP strip on load- crack width curve

Table 10: Enhancement of crack load and crack width due to strengthening by CFRP strip

Specimen	Crack load (kN)	% Increase in crack load	Ultimate crack width w_u(mm)	(w@70% of P_u)*(mm)	% Decrease in (w@70% of P_u)
S2	6.9	Reference	2.30	0.180	Reference
S7	12.3	78.26	0.18	0.059	67.22
S8	13.0	88.41	0.22	0.055	69.44
S9	27.3	295.65	0.10	0.0 (No crack)	100

***** crack width at 70% of ultimate load of reference slab S2

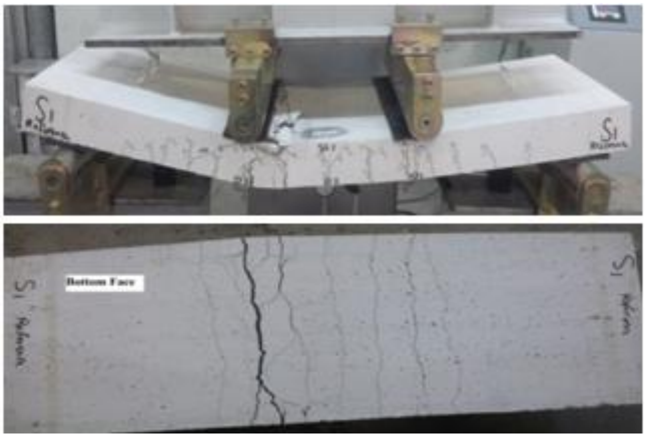


Figure 33: Crack pattern of specimen S1 (without opening)

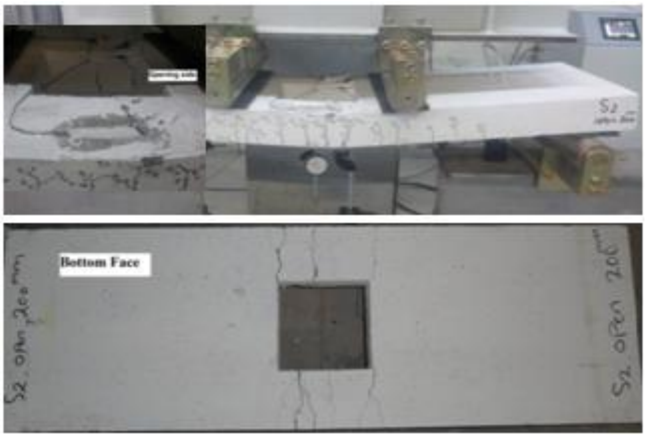


Figure 34: Crack pattern of specimen S2

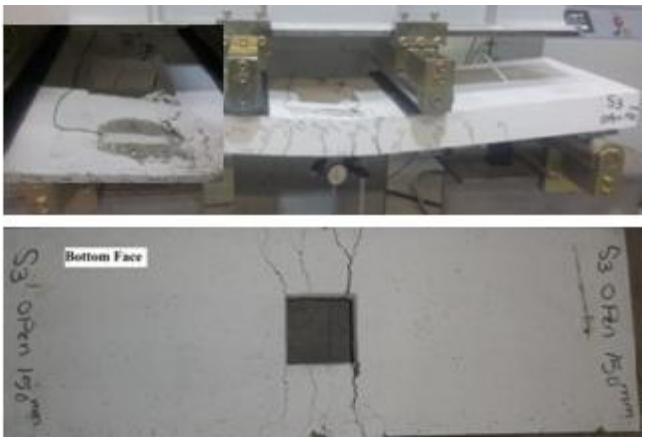


Figure 35: Crack pattern of specimen S3

Figure 36: Crack pattern of specimen S4

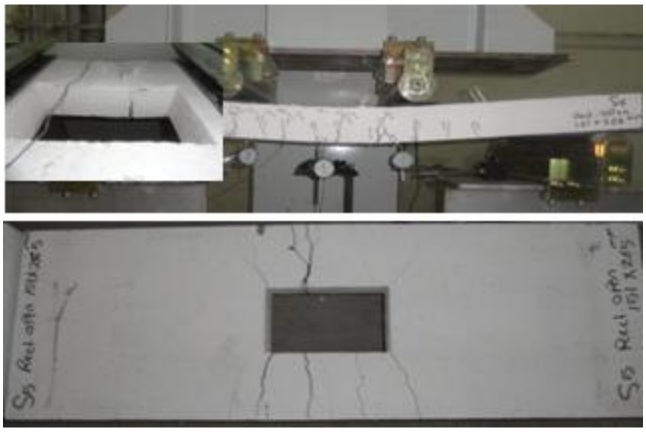


Figure 37: Crack pattern of specimen S5

Figure 38: Crack pattern of specimen S6

Figure 39: Crack pattern for S7

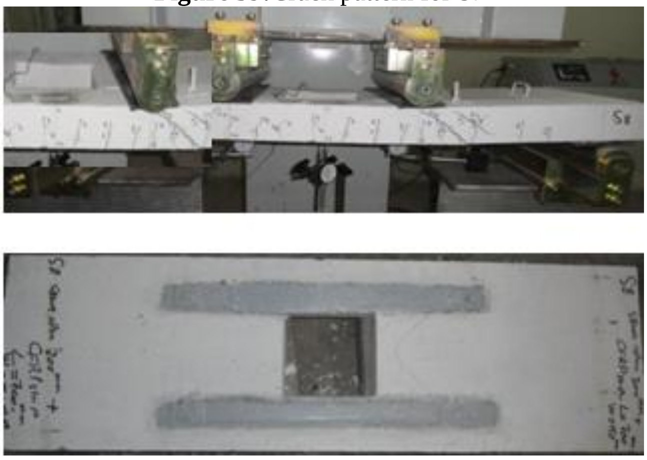


Figure 40: Crack pattern of specimen S8

Figure 41: Crack pattern of specimen S9

6. Conclusions

The scope of this study is to investigate the effects of strengthening one way reinforced concrete slabs with opening by using CFRP strips. Size of the openings, shape of the openings, length of CFRP strip, and width of CFRP strip are the main parameters that are researched. Totally nine slabs are constructed and tested. One of these specimens is chosen as a reference, and after testing completed results is used for the comparisons. Some comments are made about the specimens such as crack load, ultimate load, service deflection, ultimate deflection, concrete compressive strain, crack width, crack pattern and failure mode by using the results that are obtained from tests. Results obtained from the conducted study are summarized below:

1. The ultimate load capacity of reinforced concrete slabs with opening ratio of (4.2%, 7.4% and 11.6%) are less than of reinforced concrete one way slabs without opening by about (46.37%, 50.0% and 59.01%) respectively.
2. The service deflection, concrete compressive strain and crack width of reinforced concrete slabs with opening are greater than of reinforced concrete one way slabs without opening.
3. The ultimate load capacity of reinforced concrete slabs with opening ratio of (7.4%) and have different shape of (square, rectangle and circle) are less than of reinforced concrete one way slabs without opening by about (50.00%, 50.15% and 49.56%) respectively.
4. The end anchors for CFRP strip prevented the de-bonding of both ends of the strips till the CFRP strips ruptured around the mid-span of the slab. They enabled the CFRP strips to utilize their full tensile capacity resulted in the full restoration of the flexural capacity of the slabs strengthened with CFRP strips in the tension side.
5. The strengthening of reinforced concrete one way slab with opening by CFRP strips, with two stripsof length are (500mm and 700mm) which represent (2.5 and 3.5 times opening side) and constant strip width of 50mm (0.25 side), gave an increase in ultimate load capacity by about (37.79% and 108.72%), an decrease in service deflection by about (47.28% and 58.31%), an decrease in concrete compressive strain by about (36.83% and 48.14%), an increase in crack load by about (78.26% and 88.41%) and an decrease in crack width by about (67.22% and 69.44%), respectively.
6. The strengthening of reinforced concrete one way slab with opening by CFRP strips, with two stripsof width are (100mm) which represent (0.5 times opening side) and length of 700mm (3.5 side), gave an increase in ultimate load capacity by about (110.17%), an decrease in service deflection by about (72.66%), an decrease in concrete compressive strain by about (55.57%), an increase in crack load by about (295.65%) and an decrease in crack width by about (100%), respectively.

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