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Experimental Study of Self Compacting RC Slabs with Opening Strengthening with Carbon Fiber Laminated and Steel Fiber

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Abstract:

Introducing openings in existing reinforced concrete slabs can severely weaken the slabs due to the cut out of both concrete and reinforcing steel. There are several traditional approaches to strengthen slabs with openings; however. these approaches can be cumbersome, expensive, and may require significant usable floor area. This paper reports field tests on the use of Carbon Fiber Reinforced Polymers (CFRP) strengthening and steel fiber to restore the load capacity of the slab after having openings cut out in the positive moment region.
Eight slabs (450*450*40) mm were casting to evaluate the ability of the CFRP strengthening and steel fiber to restore the load capacity of the slab,made of self compacting concrete, after introducing the openings. Two different strengthening techniques were investigated to determine the most effective system for strengthening. The two different strengthening techniques are the use of externally bonded CFRP strips, and add steel fiber 1% by volume fraction. Test results showed that the two strengthening techniques increased the load-carrying capacities of the slabs with openings. The CFRP is more effective than the steel fiber technique. Use of CFRP enable the slabs to restore its full load capacity and increased it by 30%, also the steel fiber hence enabled the slab to restore its full capacity and increased it by 20 %.CFRP and steel fiber redused the cracks at the inside faces of opening and also CFRP prevint it at the inside cornrs.

الخلاصة:

من المعروف ان احداث الفتحات في البلاطات الخرسانية المسلحة يضعف بشدة البلاطات بسبب حدوث استقطاع في الخرسانة وحديد التسليح .هناك العديد من الطرق التقليدية لتقوية البلاطات المسلحة التي فيها فتحات ،على اية حال،هذه الطرق ممكن ان تكون مربكة ،مكلفة وتحتاج الى ان تشغل مساحة من الارضية. هذا البحث يبين فحوصات عملية لأستخدام شرائح الياف الكاربون البوليمرية والالياف الحديدية لتقوية البلاطات واسترجاع قدرة التحمل للبلاطات

الخرسانية المسلحة التي فيها فتحات في منطقة العزم الموجب. تم صب ثمانية بلاطات بأبعاد (٤٥٠*٤٥٠*٤٠) ملم لتقييم قدرة شرائح الياف الكاربون البوليمرية والياف الحديد في تقوية البلاطات مع وجود الفتحات ،تم استخدام طريقتان مختلفتان للتقوية والهدف هو لتحديد الطريقة الاكثر فعالية. الطريقتان هي استخدام شرائح الياف الكاربون البوليمرية الخارجية واستخدام الياف الحديد في الصب بنسبة ١ % نسبة للحجم . نتائج الفحوصات اظهرت ان الطريقتين تزيدان من قدرة التحمل للبلاطات ذات الفتحات . حيث اظهرت النتائج ان شرائح الكاربون اكثر فعالية من الياف الحديد حيث يمنح البلاطة القدرة على التحمل الكاملة بزيادة مقدارها ٣٠ % وكذلك الياف الحديد تزيد من قدرة التحمل بمقدار ٢٠ %. كما تقلل شرائح الكاربون والياف الحديد من حدوث التشققات في الوجوه الداخلية للفتحات اضافة الى ذلك فأن شرائح الكاربون قللت ظهور الشقوق في الزوايا الداخلية للفتحات.

1. Introduction:

Openings in slabs are usually required for plumbing, fire protection pipes, heat and ventilation ducts and air conditioning. Larger openings that could amount to the elimination of a large area within a slab panel are sometimes required for stairs and elevators shafts. For newly constructed slabs, the locations and sizes of the required openings are usually predetermined in the early stages of design and accommodated accordingly [(1)].

The ACI 318 Building Code permits openings of any size in any new slab system, provided that an analysis is performed that demonstrates that both strength and serviceability requirements are satisfied (ACI 318-02 13.4.1) [(2)]. The analysis for slabs containing openings could be complex and time consuming, as an alternative the ACI 318 Code gives guidelines and limitations for opening location and size. If the designer satisfies those requirements the analysis could be waived.

Modifications to an existing structure, although not frequent, occur in almost every structure. New slab openings or penetrations in an existing concrete building are easily accommodated in the majority of instances. However, the analysis required, and the remedies are typically more involved than similar openings in a new slab. [(1)]

Hence, problem becomes more complex when openings are planned to be made in existing slab, the most common way to substitute additional steel reinforcement is to apply CFRP strengthening before cutting a hole [(3)].

In this paper the comparison between CFRP strengthening for opening assumed to be in existing slab (casted without opening reinforcement) just like cut with a saw after casting ,and adding steel fiber (1%by volume) to the concrete of a new slab designed with opening reinforcement,but without additional steel reinforcement.

Reinforced concrete structures often require strengthening or repair at some point during their design lifetime. The requirement for strengthening can arise for a variety of reasons, including a need for upgrading the load-carrying capacity, a necessity to make changes in the structure or a need to solve problems that have occurred during construction. When dealing with RC slabs, post-construction installation of escalators, elevators or utilities such as air conditioning, heating or wiring ducts are often required. In these cases, holes in slabs become one of the most common problems encountered.

2. Structural Design of Reinforced Concrete Slab with Openings.

The design of RC slab with opening is not clearly stated in BS 8110 [(4)]. The American Concrete Institute, ACI 318[(2)] provides more guidelines for opening size in different location for flat slabs. Figure 1 illustrates the suggested opening sizes and location on a new flat slab. The flat slab is divided into column and middle strips in two perpendicular directions. The opening with any size is permitted in the area where middle strip intersects. For the opening in the area interesting column strips, the allowable opening size is 1/8 the width of column strip in either span. For opening involved in the area intersecting one column and one middle strip, the maximum opening size is where only 1/4 of the slab reinforcement in either strip may be interrupted. In order to apply the ACI 318 guidelines, the total number of reinforcement for slab without opening on both directions must be maintained. Hence, the reinforcement interrupted on the opening must be replaced on each side of the openings [(2)]. Both ACI 318[(2)] and BS 8110[(4)] share the same idea where all the opening must not be encroach on the column head or drop especially at the edge of column where the shear in the slab is the highest.

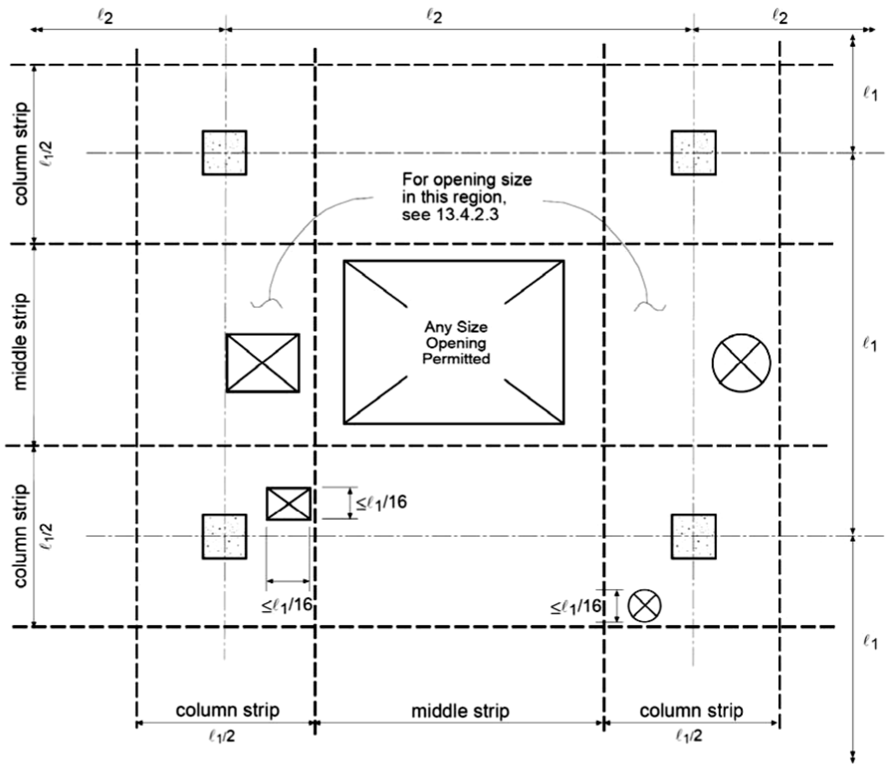


Figure 1: Suggested opening size and location in flat slabs[(5)]

3. Openings in Existing Slabs:

Cutting openings in existing slabs should be approached with caution and avoided if Possible [3]. When cutting opening in existing slabs the effect on the slab structural integrity must be evaluated. For existing slabs it is advisable to analyze the slab first for excess capacity and possible moment redistribution before deciding on the sizes and locations of the openings.

Small openings in existing slabs are usually cored to the required diameter. Large openings are cut with a circular saw or concrete chain saws with plunge cutting capabilities. When using circular saw, circular cores can be made at the corners of the required opening first and connected by saw cutting to avoid cutting longer slot at the top than the bottom of the slab.


(505 Fifth Avenue, NYC – Courtesy: Rosenwasser / Grossman, NYC)

Figure (2) large opening in flat slab floor

4.Self Compacting Concrete.

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Concrete that requires little vibration or compaction has been used in Europe since the early 1970s but self-compacting concrete was not developed until the late 1980’s in Japan. In

Europe it was probably first used in civil works for transportation networks in Sweden in the mid1990's [6].

Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and structures.

The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration.

The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction[5].

5. Experimental Program

The experimental program consists of testing eight slabs. All slabs were casting from self compacting concrete divided into two group self 30 and self 30/S according to add steel fiber or not , S1, S2, S3, Sc2 and Sc3 without steel fiber, Ss1, Ss2, Ss3 with steel fiber (1% by volume fraction). According to opening S1 and Ss1 without opening ,S2,Ss2and Sc2 with opening 75*75mm at 75mm from the center of slab and ,S3,Ss3 and Sc3 with opening 75*150 mm at 75mm from the center of slab, slabs Sc2 and Sc3 strengthening with CFRP, the details are shown in Table (1). Three cubes of 150*150*150 mm were casting with each group, the mix proportions and the compressive strength are shown in Table(2).

Table (1) Detailes of slabs

Slab name	Ratio of steel fiber % by volume fraction	Opening size (mm*mm)	Mix Notation
S1	0	_	Self 30
S2	0	75*75	Self 30
S3	0	75*150	Self 30
Ss1	1	_	Self 30/S
Ss2	1	75*75	Self 30/S
Ss3	1	75*150	Self 30/S
Sc2	0	75*75	Self 30
Sc3	0	75*150	Self 30

Table (2) Mix proportions

Mix Notation	Cement Kg/m^3	LSP Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Water L/m^3	Superplasti-cizer L/m^3	Steel Fiber (%by the total volume)	Compressive Strength Mpa
Self 30	367	195	841	791	183	4	0	30
Self 30/S	367	195	841	791	183	12	1	32

5.1 Material

5.1.1 Cement

Ordinary Portland cement (type 1) according to ASTM C150-89 produced by Taasloja cement factor was used throughout this study. The chemical and physical properties of this cement are shown in Table (3) and (4), which comply with Iraq Standard Specification I.Q.S. No.5, 1984 requirements[6].

Table (3) Physical properties of Taasloja cement

Property		Result	Iraqi Specification Limits I.O.S 5/1984
Fineness by air permeability method (Blaine)		3015	Not less than 2300 cm^2/gm
Initial Setting time		170 min	Not less than 45min.
Final Setting time		4.167 hr	Not more than 10hrs.
Soundness (Autoclave method)			Not more than 0.8 %
Compressive Strength	3-day age	30	Not less than 15MPa
	7-day age	42	Not less than 23MPa

Table (4) chemical analysis and compound composition of Taasloja cement

Oxides	Content %	Iraqi Specification Limits I.Q.S 5/1984
CaO	63.46	60 -67 %
SiO_2	19.94	17- 25 %
AL_2O_3	4.67	3.0-8.0 %
MgO	2.86	5 % max.
Fe_2O_3	3.29	0.5- 6.0
SO_3	2.30	2.8 % max.
L.O.I	3.32	4 % max.
Insoluble Residue	0.72	1.5 % max.
L.S.F.	0.97	0.66-1.02
Compound Composition		
C_3S	39.28	
C_2S	32.63	
C_3A	11.98	
C_4AF	8.00	

5.1.2 Fine Aggregate

The grading, particle shapes and the amount of fine aggregate are important factors in the production of self-compacting concrete as well as conventional concrete. Natural sand from Al-Ukhaider region is used. Table (5) shows the grading of the fine aggregate and the limits of the Iraqi specification No.45/1984(7).

5.1.3 Coarse Aggregate

The coarse aggregate conforms to the Iraqi specification No.45/1984 [7] gravel of maximum size of 10 mm from Al-Niba'ee region is used. Table (6) shows the grading of this aggregate after sieving on 14mm**.**

Table (5) Grading of Fine Aggregate.

Sieve Size (mm)	% Passing by Weigh	
	%Fine Aggregate Passing	IOS 45/1984 Limits
10	100	100
4.75	93.40	90-100
2.36	85.40	75-100
1.18	75.60	55-90
0.6	41.70	35-59
0.3	9.10	8-30
0.15	0.04	0-10

Table (6) Grading of Coarse Aggregate.

Sieve Size mm	% Passing	
	%Coarse Aggregate	IOS 45/1984 Limits
12.5	100	100
9.5	98	85-100
4.75	25	10-30
2.36	3	0-10
1.18	0.5	0-5

5.1.4 Water Ordinary potable water is used without any additives.

5.1.5 Superplasticizer

For the production of the self-compacting concrete and high strength conventional concrete, superplasticizer (high water reducing agent HWRA) based on polycarboxylic ether is used. One of a new generation of copolymer-based superplasticizer designed for the production of self-compacting concrete is the Glenium 51. The typical properties of Glenium 51 are shown in Table (7).

Table (7) Typical Properties of Glenium 51.

Form	Viscous Liquid
Colour	Light Brown
Relative Density	1.1 @ 20 ^{0}C
pH	6.6
Viscosity	128+/-30 cps @ 20 ^{0}C
Transport	Not Classified as Dangerous
Labeling	No Hazard Label Required

Glenium 51 is free of chlorides and complies with ASTM C494, type A and type F. It is compatible with all Portland cements that meet the recognized international standards.

5.1.6 Limestone Powder (L.S.P.)

In this work, crushed limestone brought from local market is used and the fineness of the gained material is (3100 cm^2/gm).
The limestone powder passing sieve No. 0.075mm is used in this work. The chemical composition of the limestone powder is shown in Table (8).

Table (8) Chemical Analysis of the Limestone Powder.

Oxide	Content %
CaO	56.10
SiO_2	1.38
Fe_2O_3	0.12
Al_2O_3	0.72
MgO	0.13
SO_3	0.21
L.O.I	4.56

All chemical tests are performed by the National Center for Construction Laboratory and Researches.

5.1.7 Steel Reinforcement

welded wire fabric mesh was used as flexural reinforcement placed in the tension face of the slab. The yield strength was determined from tensile test was 387 N/mm^2 .
The wire were 6 mm in diameter at 100 mm c/c spacing each way. A clear cover of 10 mm was provided below the mesh. Figure (3) showes the reinforcement detailes of slabs.

1.without opening

*2. (75*75) mm opening*

*3.(75*150)mmopening*

Figure (3) The reinforcement detailes of slabs

5.1.8 Carbon Fiber Fabric Strengthening System (CFRP)

The SikaWrap 230C/45 is an externally applied strengthening or repairing system for structural members made of reinforced concrete, masonry or timber. This system was supplied by (Sika near East s. a. I. Beirut - Lebanon). The following information related to this system is summarized as follows:

5.1.8.1 System Components

Carbon fiber fabric SikaWrap 230C/45 and epoxy based impregnating resin Sikadur-330 are shown in Fig. (4) the technical data of them shown in Tables (9 and 10).

Figure (4) CFRP and Epoxy

Table (9) SikaWrap 230C/45 (Carbon Fiber Fabric) (*)

Fiber type	High strength carbon fibers
Fiber orientation	0° (unidirectional). The fabric is equipped with special weft fibers which prevent loosening of the roving (heatset process).
Areal weight	230+_10 g/m^2
Fabric design thickness	0.1 mm (based on total area of carbon fibers)
Tensile strength of fibers	4300 MPa
Tensile E – modulus of fibers	234 GPa
Elongation at break	1.8 %
Fabric length/roll	≥ 50 m
Fabric width	300/600 mm

(*) Provided by the manufacturer

Table (10) Sikadur-330 (Impregnating Resin) (*)

Appearance	Comp. a: white Comp. b: grey
Density	1.31 kg/l (mixed)
Mixing ratio	A : B = 4 : 1 by weight
Open time	30 min (at + 35°C)
Viscosity	Pasty, not flowable
Application temperature	+ 15°C to + 35°C (ambient and substrate)
Tensile strength	25 MPa (cured 7 days at +23°C)
Flexural E-modulus	3800 MPa (cured 7 days at +23°C)

(*) Provided by the manufacturer

5.1.8.2 Carbon Fiber Design

The amount of CFRP used to strengthen slab SQ3 was computed under the premise that the loss of steel reinforcement caused by the cutout would be replaced by an equivalent amount of FRP according to the following simple relationship (transformed section) [8]:

$$\frac{E_s\, A_s^{lost}}{E_f\, A_f} = 1 \qquad (1)$$

The amount of steel reinforcement lost is equivalent to:

$$A_s^{lost} = N \times A = 56.6\ mm^2 \qquad (2)$$

Where (N=2) is the number of steel bars which have been cut (for slab with opening 75*75 mm). Substituting into eq. (1.1) we can compute the equivalent area of CFRP:

$$A_f = \frac{E_s}{E_f} \times A_s^{lost} = 48.37\ mm^2 \qquad (3)$$

Since each ply has a nominal width bf = 300 mm, the necessary overall thickness of CFRP laminate is given by:

$$T_{total} = \frac{A_f}{b_f} = 0.1612\ mm \qquad (4)$$

Given that thickness of one ply, t'=0.1 mm, the total number of plies required is:

$$n' = \frac{T_{total}}{t'} = \frac{0.161}{0.1} = 1.61 \text{ plies} \qquad (5)$$

A total of 2 plies were applied: one was placed on one side of the cutout and one on the other side in each direction.

For slab with opening 75*150 mm the number of steel bars which have been cut (N=3) in this case A_s^{lost} = 84.85 mm^2 from eq. (2) ,and A_f = 72.52 mm^2 from eq.(3).

The T_{total} = 0.241mm,this need 2.41 plies .A total of 3 plies were applied : one was placed on the short side of opening and two on the long side in each direction (see Figure 5).

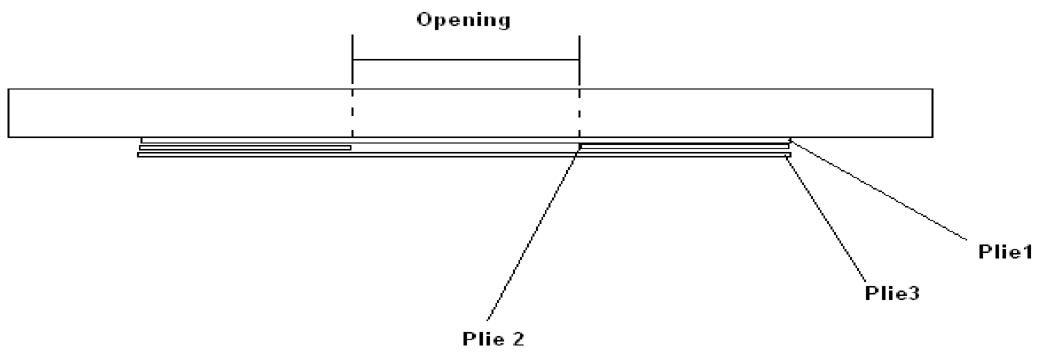


Figure (5) The CFRP plies applied

5.1.9 Steel Fibers

Commercially available high strength steel, end hooked, steel fibers (1000 MPa) are added in the desired volume percentage 1% by volume. Dramix® ZC 50/50 type end hooked steel fibers manufactured by Bekaert Corporation which is of Belgium origin are used in this study, as shown in Figure (6). The steel fibers have a length of 50 mm and a diameter of 0.5 mm with aspect ratio of 100 and density of 7850 kg/m^3. The fiber details and dimensions are presented in Figure (7).

Figure (6) Hooked Steel Fiber

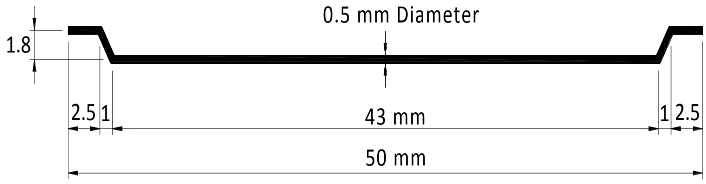


Figure (7) Steel fiber dimensions

5.2 Specimen Preparation.

Wooden moulds with clear dimensions of 450 x 450 x 40mm. The opening was made by using two wooden form with the size [75 mm×75 mm×40mm] for S2,Ss2and Sc2, and [75 mm×150 mm×40mm] for S3, Ss3 and Sc3, the forms were fixed in their correct positions using bolts. The bolts can be easily removed to take off the wooden cubes from the mold after casting. The wooden forms were covered with a paper and wide tape and oiled before casting, to prevent bonding between the wooden forms and the concrete Figure (3) shows the reinforcement details and the wooden moulds.

Loading from MFL SYSTEM of hydraulic universal testing machine type EPP 300, as shown in Figure (8), with maximum capacity of 3000 kN was applied in rate of 2 kN/min continued up to failure, under the plate of machine a sand bag used to distributing the load on the slab as a uniform distributed load. Deflection was recorded in each loading stage.

igure (8): Specimen Preparation and Set – up of Test Machine

6. Results and Discussions

The results recorded during the experiments are presented and compared. The aim is to judge the used methods of strengthening considering the deflections and the load capacity. Strengthened and the control slabs with an opening should have similar deflections and higher or an equal load capacity as the homogeneous slab. Furthermore, the results obtained from the tests of the slabs with opening show how the holes were decreasing the load capacity, so that strengthening is needed. In the diagrams presented below symbols of the slabs are used, which are explained in Table(1).

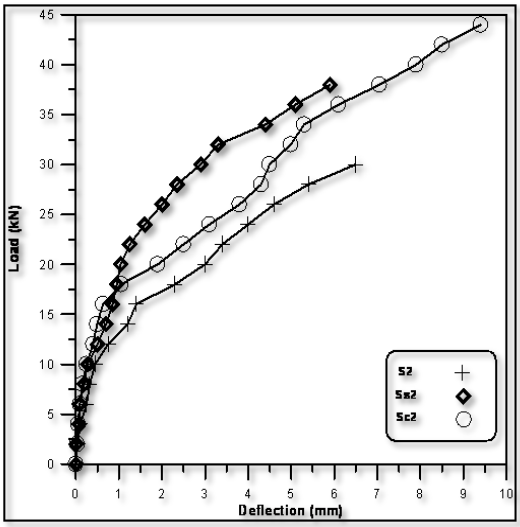
6.1 Deflections

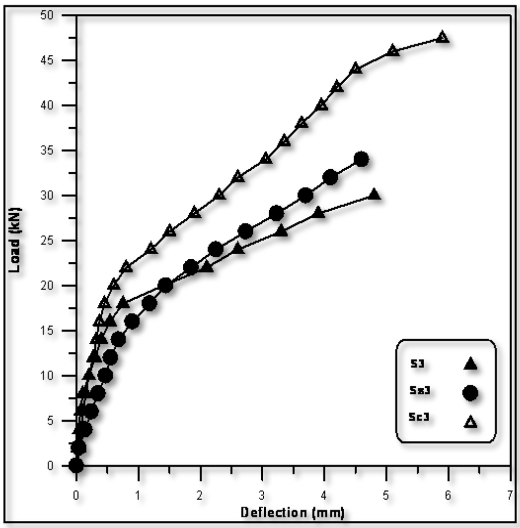
The deflections presented in this study were measured at the center of slabs, these results represent the largest possible displacement of homogeneous slabs and for slabs with opening at the same location, and hence it's the nearest point to the opening that the deflection can be measured on it.

The magnitude of the deflection is very important in the discussion of the load carrying capacity of the slabs. Considering the diagrams in Figures (9 and 10) it can be concluded , that the proposed method of using the steel fiber in slab with small opening Ss2 show more stiff behavior than use it in slab with large opening Ss3 ,and when comparative are made between (S_2 and S_3) and (Ss_2 and Ss_3) respectively the increasing of load capacity in slab Ss_2 was more than that in Ss_3..

Much better results given by the strengthening with CFRP strips, slabs show more ductile behavior and load capacity increased by 46.67% and 55.7% for Sc2 and Sc3 as compared with S2 and S3.

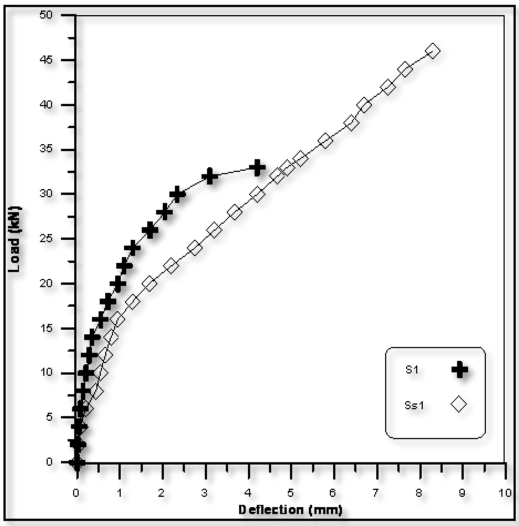
For the solid slabs S1 and Ss1 the effect of the steel fiber was very clear, Figure (11) shows the comparative between S1 and Ss1, the load capacity increased by 37.87% when steel fiber added, the behavior of S1 was more stiff at the first stage then become more softener and then failure occurred at 33 kN, while the slab Ss1 contineu to failure at 45.4 kN.





Figure(9)   ***Figure(10)***

Figures (12,13 and 14) show comparatives in load _deflection relationships for each group. Figure (12) shows the effect of opening in normal concrete slab, the effect of opening very clear on the load capacity and the maximum deflection occurs for slab with square opening. Figure(13) for slabs with steel fiber, the worst case of opening effect was for slab with rectangular opening. Figure (14) shows the effect of carbon strengthing,the behavior was like that in Figure (12) the square opening reduced the load capacity and increased the maximum deflection.



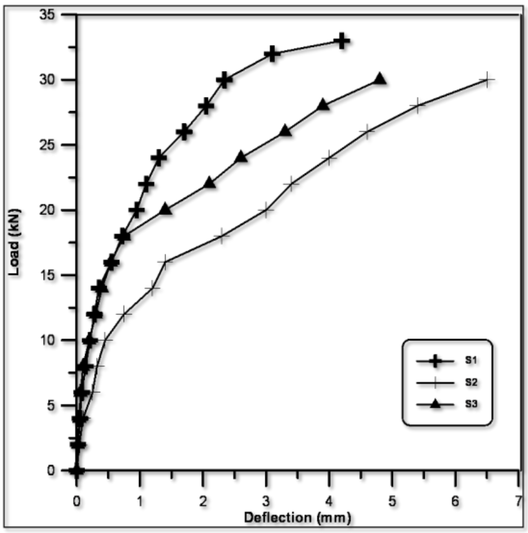
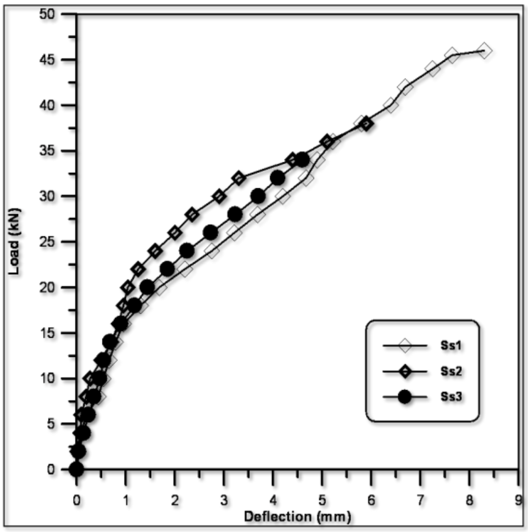
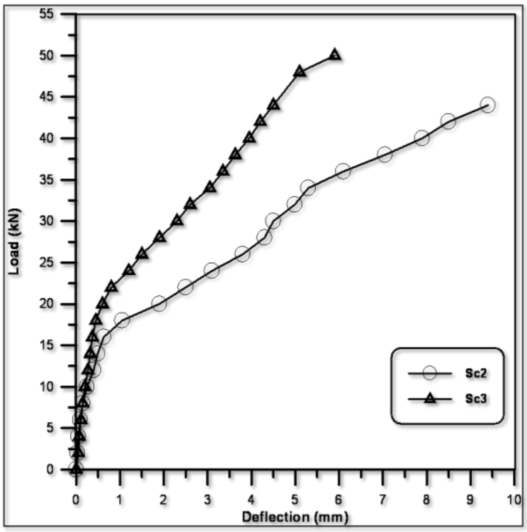


Figure (11)   ***Figure (12)***





Figure(13) *Figure (14)*

6.2 Mode of failure and Cracks Pattern

In general, all slabs failed under pure bending. In slabs Sc2 and Sc3 the failure was caused by sudden pull-off the CFRP system at the end of one laminate. First cracks began at 9.5 kN for solid slab S1, for S2 at 7 kN, and for S3 at 6.5 kN its obviously clear that the opening effect and waked the slab from the first stage of loading, Table (11) shows the first cracks loads for all slabs, the effect of the strengthening methods on these loads very clear, specially using of CFRPstrips the values of load increased more than adding the steel fiber. Flexural cracks started either at the center of the slab (in slabs without opening) or along the edges of the cutouts (in slabs with opening) developing perpendicular to the adjacent line of support. Under increasing load, these cracks developed diagonally towards the four support corners, symmetrically located across the entire tension face (see Figure (15)).

This pattern was repeated in all slabs and occurred more evidently at high levels of load. At slabs (Sc2 and Sc3) debonding of the laminates started from flexural cracks at the maximum bending moment region around the hole, and particularly in the area where the two perpendicular strips overlapped on the diagonal . At failure, the entire concrete cover was pulled off suddenly (see Figure (16)).

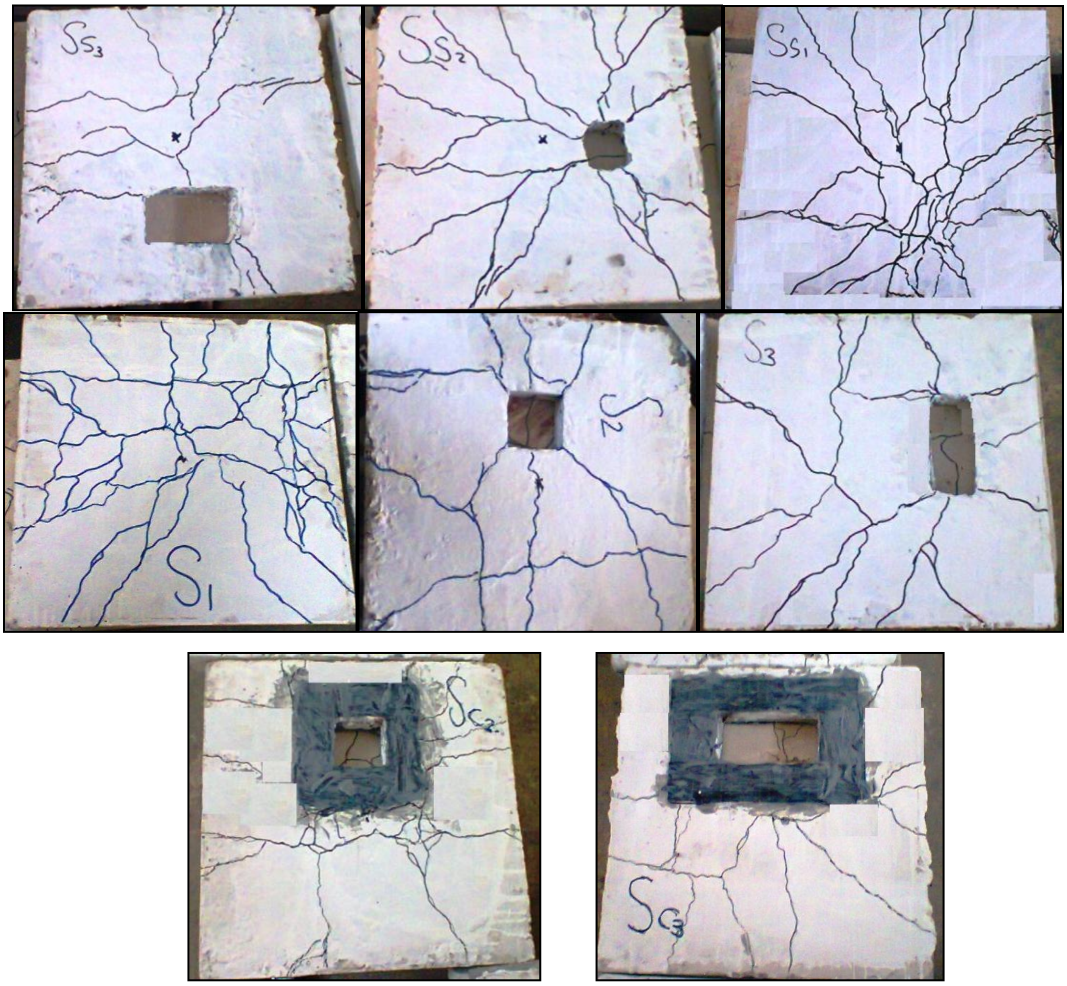


Figure (15) Slabs crack pattern.

Cracks inside the cutout also noticed ,for S2 and S3 the cracks started at the inside corners of opening and also appeared at the inside faces of opening ,for Ss2 nd Ss3 the same case occures,but less than that at S2 and S3. For Sc2 and Sc3 few cracks appeared at the inside faces of opening,but disappeared at the inside corners,this pointed to the additional strength for opening corners provided by using CFRP see Figure (17).

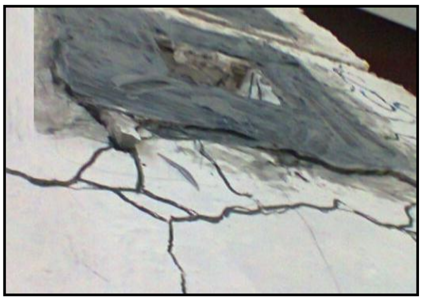


Figure (16)

Figure (17)

Table (11) Load and Deflection Characteristics at First Crack and Ultimate Loads of Slabs

Slab Name	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	$\% \frac{F.C.L}{U.L}$	Deflection at first crack (mm)	Deflection at ultimate load (mm)
S_1	9.5	33	28.7	1.6	4.2
S_2	7	30	23.3	2.8	6.5
S_3	6.5	30.5	21.3	0.7	4.8
Ss_1	11	45.5	18.68	4.5	8.5
Ss_2	10	38	26.31	2.7	5.9
Ss_3	6	33.5	17.91	2.4	4.6
Sc_2	9	44	20.45	1.8	9.4
Sc_3	8	47.5	16.84	1.5	5.9

7.Conclusions

1. The two strengthining methods (CFRP strips and steel fiber adding)enable the slabs to restore its full load capacity and increased it higher than these for solid slabs.
2. The use of CFRP strips is more effective than the steel fiber .
3. Use of steel fiber increased the load capacity by 26.67% and 9.83% for small and large opening respectively.
4. CFRP increased the load capacity by 46.67% and 55.7% for small and large opening respectively.
5. CFRP and steel fiber reduced the cracks at the inside faces of the opening while CFRP prevint it at the inside corners of opening.

8. Referenses:

1. Mota,M.C. and Kamara M." **Floor Openings in Two-Way Slabs**" , Concrete International Journal, Vol.28,07, July 2006,pp33_36.
2. ACI committee 318,2008,''**Building Code Requirements For Structural Concrete** (ACI 318M08), American Concrete Insitute, Formington Hills,MI 4731.

3. Newman, Alexander, "**Structural Renovation of Buildings - Methods, Details, and Design Examples,** "McGraw-Hill, New York, 2001, 693p.
4. BS 8110-1 (1997), "**Structural use of concrete part1: Code of practice for design and construction**", British Standards Institution, London, 163p.
5. "**The European Guidelines for Self-Compacting Concrete Specification, Production and Use**", May, 2005.

٦. المواصفات العراقية رقم ٥ لسنة ١٩٨٤ "**السمنت البورتلاندي**، **الجهاز المركزي للتقييس والسيطرة النوعية**" بغداد ١٩٨٤، ص ٨.

٧. المواصفات العراقية رقم ٤٥ لسنة ١٩٨٤ "**ركام المصادر الطبيعية المستعملة في الخرسانة والبناء**"، بغداد ١٩٨٤، ص (٥-٢٠).

8. Casadi,p.,I bell T.,Nanni A.,''**Experimental Results of Two Way Slabs with Opening Strengthened with CFRP Laminates**'', Advancing with Composites, Plast 2003, pp239_253 ,2003.