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مجلة المثنى للعلوم الهندسية

PUNCHING SHEAR RESISTANCE OF LIGHTWEIGHT CONCRETE TWO WAY SLABS STRENGTHENED WITH CFRP STRIPS

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ABSTRACT

The aim of this study is to investigate the experimental behavior of reinforced concrete light weight concrete two-way slabs stiffened by CFRP strips to punching load and compare the results with the finite element model results. The experimental program includes testing a total of 14 slabs (800 x 800 x 70) and (800 x800 x 90) mm. The slabs are divided into two groups; each group consists of seven slabs. In each group of seven slabs, one slab was left without strengthening as a reference slab, while each slab of the remaining six slabs has a different CFRP distribution. The effect thickness of slabs and shape of the CFRP distribution on the punching shear strength of slabs are studied. All slabs in this study are designed to fail in punching shear. During the test, the slabs are simply supported on all four edges and loaded centrally by a (75 x 75) mm column. Load deflection curves, cracking patterns and effect of variables on the test results are discussed. Experimental results showed that, the CFRP strengthening increased the ultimate punching load of the slabs by (9-26) %, also the first cracking load increased by (38-141) %. The strengthened slabs showed less deflection during loading by about 24% compared to the non- strengthened slabs. Increasing the slab depth gives changes to the slabs punching strength. The slabs are modeled by three dimension finite elements and non-linearly analyzed by the ANSYS program where the concrete is represented by the eight nodes solid element (solid 65) and the CFRP strips are represented by (3D shell 41) with a perfect bond between the CFRP and concrete slabs. Finite elements results showed a comparable results to laboratory tested slabs and the difference is not more 12% in ultimate load.

سلوك البلاطات الخرسانية الخفيفة الوزن المسلحة والمقواة بصفائح البوليمر المسلح بالألياف الكربونية

الكلمات المفتاحية

البولمرية، الطابوقية

الخلاصة

ان الغرض من هذا البحث هو تقديم دراسة عملية و نظرية لسلوك الانحناء للبلاطات الخرسانية المسلحة ذات الاتجاهين والمقواة او المعاد تصليحها بالبوليمر المدعم بالياف الكاربون (CFRP). يتضمن الجزء العملي من هذا البحث فحص ثمانية نماذج لبلاطات خرسانية مسلحة مختبرياً بابعاد) 1050 ملم طول، 1050 ملم عرض، 600 ملم ارتفاع البلاطة (بالإضافة إلى سلسلة من الفحوصات على المواد الانشائية المستخدمة .خمسة من هذه البلاطات الخرسانية المسلحة تم تقويتها وثلاثة من هذه البلاطات تم اعادة تصليحها باستخدام اشرطة الياف الكاربون البوليميرية(CFRP) وبلاطة خرسانية مسلحة واحدة تم فحصها بدون أي تقوية واعتبرت كنموذج اساس لغرض المقارنة مع النماذج المقواة او المعاد تصليحها. ان المتغيرات الاساسية التي جرى اعتمادها في الجانب العملي هي كمية و شكل اشرطة الياف الكاربون البوليمرية المستخدمة في تقوية او تصليح هذه البلاطات .صممت جميع البلاطات الخرسانية المستخدمة في هذا البحث بنفس الابعاد وتم تسليحها بشكل يضمن فشلها بالانحناء، تم فحص جميع البلاطات في فضاء بسيط الاسناد وبتسليط حمل مركز في منتصف هذه البلاطات .أظهرت النتائج العملية التي تم الحصول عليها من النتائج المختبرية أن عملية تقوية البلاطات الخرسانية باستخدام الياف الكاربون البوليمرية ادت الى زيادة في قيمة التحمل الاقصى للانحناء للبلاطات (Ultimate Loads) يصل مقدارها بين) 7-45 %(مقارنة بالبلاطات الخرسانية غير المقواة باستخدام الياف الكاربون البوليمرية. تم أستعمال التحليل اللاخطي بواسطة العناصر المحددة (Finite Elements) ثلاثية الأبعاد كوسيلة عددية للدراسة والتحري عن سلوك وتصرف هذه البلاطات باستخدام البرنامج (ANSYS الاصدار الثالث عشر(حيث تم في هذا البرنامج تمثيل الاجزاء الخرسانية باستخدام العناصر الطابوقية ذات الثمانية عقد (Solid 65) بينما تم استخدام العناصر القشرية ثلاثية الابعاد) D Shell 413) لتمثيل شرائط الياف الكاربون البوليمرية وتم إفتراض وجود ربط تام بين شرائط الياف الكاربون البوليميرية و سطح تماس , البلاطة الخرسانية

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Introduction

Reinforced concrete flat slabs are chosen by architects and engineers because they provide an elegant form of construction. In addition, they simplify and speed up site operation, allow easy and flexible partitioning of space and reduce the overall height of building **[1]**. A flat slab is a reinforced concrete floor which is usually with or without drops, supported generally without beams or girders **[2]**,Fig.(1.1)**[3]**.It acts as a plate and is divided into column strips and middle strips. The steel reinforcement runs continuously in both directions in order to bring its load directly to the supporting columns. Such slabs are usually under-reinforced. Therefore, their rotational capacity is high **[4]**. One of the major problems in such slabs is the punching shear failure at the connection between the slab and the column. Punching shear failure takes place when a plug of concrete is pushed out from the slab immediately above the column **[5]**. Punching shear failure of slabs is usually sudden and leads to progressive failure of flat plate structures. Therefore, caution is needed in the design of slabs and attention should be given to avoid the sudden failure condition. The catastrophic nature of the failure exhibited at the connection between the slab and the column has taken engineers attention. This area, Fig.(1.2), becomes the most critical area as far as the strength of flat slabs is concerned due to the concentration of high bending moments and shear forces**[6]**. Fig.(1.3) shows a typical punching shear failure in Piper's Row Car Park, Wolverhampton, UK, 1997 (built in 1965).

Figure1.1: Flat Plate Construction [3].

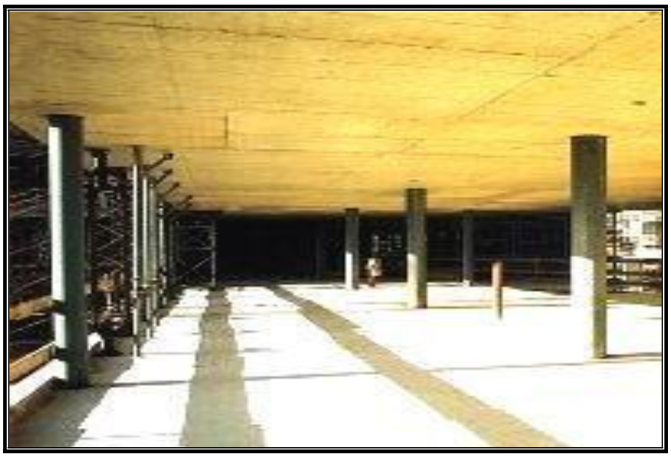


Figure1.2: Punching Failure Surfaces of Flat Slab [6].

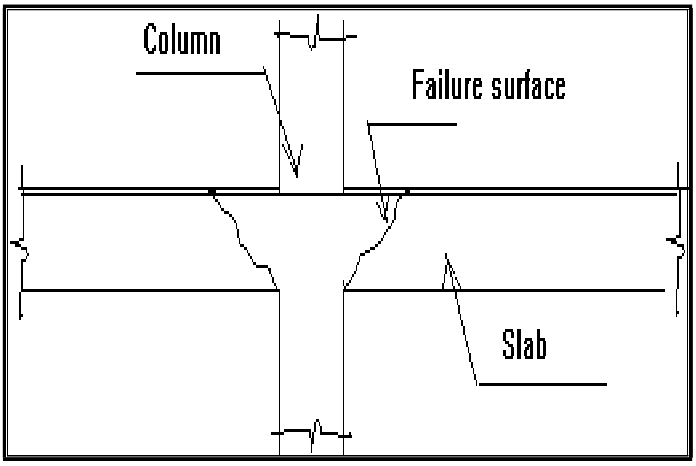


Figure.(1.3) Punching Sheer Failure in piper's Row Car Park wolverhampton, UK , 1997 (built in 1965) .

Fiber Reinforced Polymers (FRP)

The need to develop economic and efficient methods to upgrade, or strengthen existing structures has received a considerable attention recently. The motivation to strengthen and repair an existing structure typically comes from changes in design, loading increases and a desire to repair deterioration that has taken place over the years of use. In such circumstances, there are two possible solutions which are to demolish and rebuild or carry out a program of strengthening, the first solution is not attractive and may not be economically feasible to replace an outdated structure with a new one.

Advances in the fields of plastics and composites have resulted in the development of high strength, (FRP). This FRP is fast becoming the preferred choice in the strengthening and rehabilitation of existing structures, it has been used to strengthen and repair concrete members such as columns, slabs, beams and girders in structures such as bridges, parking, decks, and buildings. Depending on the member type, the objective of strengthening may be one or a combination of several of the following [7]:

1. To increase axial, flexural or shear load capacities.
2. To increase stiffness for reduced deflections under service and design loads.
3. To increase the remaining fatigue life , and
4. To increase durability against environmental effects.

The term composite often refers to a material composed of two or more distinct parts working together. Often one of the parts is harder and stronger, while the other is more of a force transferring material. FRP is an abbreviation of fiber reinforced polymers and is a composite of fibers and adhesive, see Fig.(2).

The materials FRP holds many advantages over other materials in civil engineering, it has very high stiffness to weight ratio and high strength to weight ratio, light weight, the material exhibits excellent fatigue properties, non-magnetic properties, corrosion resistance, and is generally resistant to chemicals. Fiber Reinforced Polymer, FRP, is a composite material consisting of fibers and a polymer matrix.

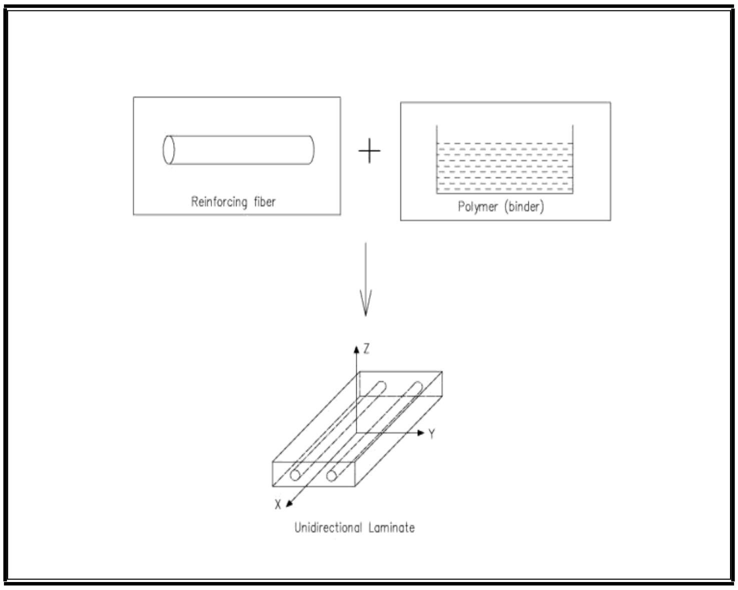


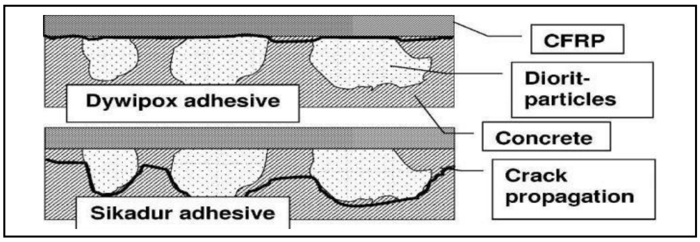
Figure2 Schematic of FRP Composites [9].

Structural Light weight concrete and uses

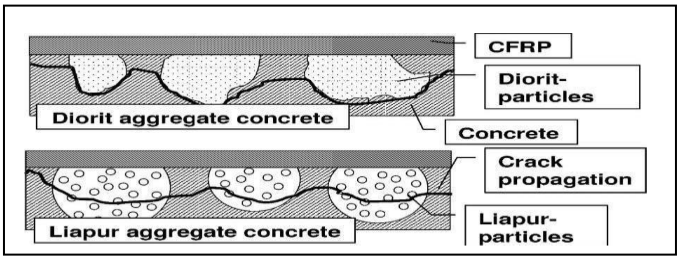
Structural light weight concrete has an in –place density(unit weight) on the order of (1440 to 1840kg/m3) compared to normal weight concrete with a density in the range of (2240 to 2400 kg/m3). For structural applications the concrete strength should be greater than (17.0 MPa). The concrete mixture is made with a lightweight coarse aggregate. In some cases apportion or the entire fine aggregate may be lightweight product. Lightweight aggregates used in structural lightweight concrete are typically expanded shale, clay or slate materials that have been fired in a rotary kiln to develop a porous structure. Other products such as air -cooled blast furnace slag are also used. There are other classes of non-structural lightweight concretes with lower density made with other aggregate materials and higher air voids in the cement paste matrix, such as in cellular concrete. These are typically used for their insulation properties [8]. The primary use of structural lightweight concrete is to reduce the dead load of a concrete structure, which then allows the structural designer to reduce the size of columns, footings and other load bearing elements. Structural lightweight concrete mixtures can be designed to achieve similar strengths as normal weight concrete. Lightweight concrete can be manufactured with a combination of fine and coarse lightweight aggregates or coarse lightweight aggregate and normal weight fine aggregate. Complete replacement of normal weight fine aggregate with a lightweight aggregate will decrease the concrete density by approximately (160 kg/m3).

Influence of Concrete Structure on Interfacial Fracture between Concrete and CFRP

One of the crucial issues in the use of fiber reinforced polymers for civil engineering applications is the interfacial bonding between the different materials used. As a load transfer from the concrete to the composite components occurs via shear stresses in the interfacial region, studies of the interfacial bond quality should concentrate on load situations in which primarily shear stresses are induced. The bound capacity is considered to be strongly dependent on the material properties(normal weight, light weight, heavy weight concrete) , compressive strength of the concrete, tensile strength of the concrete itself, size and content of aggregate. It is obvious, that the weak aggregate breaks, when a critical load is transferred into it. In the case of strong particles, this effect does not appear. Fig.(3-a) explains this tendency briefly, when a comparison is mad between the "heavy" concrete, filled with granite (Diorit) particles and" light weight" concrete, filled with vopourtone (Liapur). The effects of different interfacial bond qualities between composite-adhesive and con-crete on the fracture path is described in Fig.(3-b), Offering sufficient adhesive strength, the concrete fails at the mortar-aggregate interface. If this minimum bonding strength is not reached by the adhesive, the reinforced concrete fails at the aggregate-adhesive interface, resulting in a smooth fractured surface. Theoretical analysis indicate that the shear stress distribution along the FRP/concrete interface at ultimate debonding failure is usually dominated by the frictional part, where cracking has already occurred in concrete, and aggregate interlocking is leading to residual stress. Brittle debonding has particularly been observed at laminate ends, due to high concentration of shear stresses at discontinuities, where shear crack in the concrete are likely to develop. Thus, it is necessary to study and understand the behavior of CFRP strengthened reinforced concrete members, including those failures[9].



Figure(3-a) Difference in crack propagation for strong and weak aggregate types[3].



Figure(3-b) Difference in crack propagation for different bonding qualities[3].

Experimental Work:

Materials

The slabs consisted of several materials: cement, fine aggregate, coarse aggregate, water, reinforcing steel, and CFRP. The property of each material was described separately to study the behavior of specimens.

1-Cement

Ordinary Portland cement was manufactured by falcon Cement, used in this study. The physical analysis and chemical test results for the used cement are given in Tables(1) and (2) respectively. They conform to the Iraqi specification number (5/1984) [10].

Table (1) Chemical analysis and main compounds of the used ordinary Portland cement , Iraqi specification number (5/1984) [6].

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Limit of I.Q.S No.5/1984	Percentage, by weight	Chemical analysis
	62.83	(CaO)
	20.5	(SiO_2)
	6.36	(Al_2O_3)
	3.4	(Fe_2O_3)
5.00 (Max.)	4.47	(MgO)
2.80 (Max.)	2.00	(SO_3)
	0.61	(K_2O)
	0.23	(Na_2O)
4.00 (Max.)	0.73	(L.O.I)
1.50 (Max.)	0.58	(I.R)
0.66-1.02	0.91	(L.S.F)
Main compounds (Bogues equations)		
	40.9	C_3S
	27.91	C_2S
	11.18	C_3A
	10.35	C_2AF

Table (2) Physical properties of the used ordinary Portland cement, Iraqi specification number (5/1984) [6].

Limit of I.Q.S No. 5/1984	Test results	Physical property
230 (Min.)	312	Specific surface area (Blaine method), m^2/kg
00:45 (Min.) 10:00 (Max.)	2:20 3:30	Setting time (Vicat apparatus), hr:min Initial Final
0.8 (Max.)	0.31	Soundness (Autoclave expansion),%
15 (Min.) 23 (Min.)	17 26	Compressive strength (70.7mm cube), MPa 3-day 7-day

2-Fine Aggregate (Sand)

Natural sand from Zubair area in Basrah was used as fine aggregate for concrete mixes in this study. The fine aggregate was sieved at sieve size (4.75mm) to separate the aggregate particle of diameter greater than (4.75mm). The sand was then washed and cleaned with water several times, later it was spread out and left to dry in air, after which it was ready for use. The grading test results of the fine aggregate is shown in Table(3) The obtained results indicated that the fine aggregate grading and the sulfate content were within the limits of Iraqi specification No. 45/1984 [11].

Table(3) Grading of fine aggregate Iraqi specification No. 45/1984 [7].

No.	Sieve size	Passing (%) fine aggregate	Passing (%) Iraqi specification 45/1984 for zone No.(1)
1	4.75 mm	97.76	90-100
2	2.36 mm	81.41	60-95
3	1.18 mm	63.91	30-70
4	600 µm	32.43	15-34
5	300 µm	9.73	5-20
6	150 µm	0.45	0-10

3-Lightweight Coarse Aggregate

In this study one type of lightweight coarse aggregate used crushed thermostone. The shape of crushed lightweight coarse aggregate was normally in angular with adequate amount of elongated of and flaky particles. The maximum size of 20mm was used, the part of the excess fine was removed so as to satisfy the ASTM C-330 specification [12]. Some properties of the lightweight coarse aggregate of each type are given in Table (4).

Table(4) Physical properties of lightweight coarse aggregate [8].

Thermostone	Test performed
18.4	Absorption (SSD)
2.18	Bulk specific gravity (SSD)
450	Dry density (Kg/m^3)

4-Mixing Water

Ordinary tap water was used for mixing and curing for concrete mix of this study .

5-Steel Reinforcing Bars

Ukrainian deformed bars of 12mm@120mm diameter were used for the longitudinal reinforcement of slab. Three tensile specimens of each size of bars were tested. The properties of reinforcing bars are presented in Table (5) and shown

Table (5) Reinforcing steel properties.

Ultimate Strength (MPa)	Yield stress (MPa)	Modulus of Elasticity* (MPa)	Bar size
656	540	200000	Ø12.5mm

*Assumed value

6-Carbon Fiber Reinforced polymer (CFRP) strips

Carbon fiber fabric laminate of type Sika Wrap Hex-230C and epoxy based impregnating resin of type Sikadur-330 have been used to externally strengthen the reinforced concrete slabs. The properties of carbon fiber and epoxy resin are presented in Table (6) and Table (7) respectively[13].

Table (6) Properties of carbon fiber strips[9].

Weight (g/m^2)	Thickness (mm)	Tensile modulus (GPa)	longation at Failure (%)	Tensile Strength (MPa)	Type
225	0.13	230	1.5	3500	Sika Wrap Hex-230C

Table (7) Properties of epoxy resin[9].

Flexural modulus (MPa)	ensile trength h MPa)	Pot live (minute)	Mixing atio by weight	Density (kg/l) mixed	Appearance	Type
3800	30	15C :90 min	A:B 4:1	1.31	Com A: White Com B: Gray	Sikadur-330

Mix Proportions of Lightweight Concrete(LWC)

Fourteen slabs are made of LWC. The calculated mix proportion should be checked by mixing trial mixes. Concrete in all slabs were made with natural sand as fine aggregate and use crushed thermostone as coarse aggregate. The coarse aggregate was washed dried to remove dust. The water-cement ratio was changed to cover a wide range of strength and workability. The selected mixes and the corresponding water-cement ratio are presented in Table (8). The trial maxi number two (Water cement ratio 0.48) is used for the concrete casting the concrete beams.

Table (8) The mix proportions of the ingredients by dry weights for(LWC) for one cube concrete .

f′c 28-day Mpa	f′c 7-day Mpa	Slump (mm)	Water cement ratio	Mix proportion	Cement content (Kg)	pe of coarse aggregate
27. 32 22.	19.5 2 17.1	30 45	0.46 0.48	1:1.52:3. 52	430	**Crushed thermostone**

Preparation of Test Specimen Mixing, Casting and Curingof the Specimens

Fourteen two-way slab specimens were cast and cured under laboratory conditions at the Civil Engineering department of the University of Al Basra also, three standard cubes (100X100X100)mm and two standard cylinders (200x100) mm were cast from the concrete for each two slab specimens. The concrete was mixed in a horizontal rotary type mixer of 38.5 kg capacity and 19 rpm mixing speed. The concrete casting and curing procedure is described below:

- ❖ The molds of specimens, cubes and cylinders were treated with oil befo re putting the reinforcement grid or casting the concrete.
- ❖ Steel grid for each specimen placed in their correct position and the specified protection cover is checked.
- ❖ Before mixing, all the quantities were weighted and packed in a clean container.
- ❖ Prior to starting rotation of the mixer add the coarse aggregate and some of the mixing water. Start the mixer, then add the fine aggregate, cement, and water with mixing running. Mix the concrete, after all ingredients are in the mixer, for 3 min. followed by a 3 min rest, followed by 2 min final mixing.
- ❖ After the mixing process was completed, Concrete was poured in the molds in two layers, and each layer was compacted manually using a standard metal rod with diameter of 16 mm by divide the slab surface area to a fictitious grid (25 stroke for each 100mmX100mm). The upper surface of concrete was smoothly finished after casting was completed using hand trowel.
- ❖ After casting , the molds were left in the laboratory for about 24 hours, then the specimens were removed from their molds. The burlap sacks were placed over the slabs and wetted down. The burlap sacks were monitored and kept wet until the fully twenty-eight days had past.
- ❖ Once the slabs were cured, the slabs were placed off to the side until they cou ld be tested. The same procedure were performed on the concrete test cubes and cylinders.

The steps of casting process and curing of specimens are shown in Figure (4).

Preparation of Concrete Surface and Installation of CFRP Sheets

The most crucial part of any strengthening application is the bond between the FRP and the surface to which the FRP is bonded. Proper bond ensures that the force carried by the structural member is transferred effectively to the FRP [49]. Before the CFRP sheet is applied to the soffit of the slabs, the surfaces of the concrete are grinded using an electrical hand grinder to expose the aggregate and to obtain a clean sound surface, free of all contaminants such as cement laitance, and dirt see Fig.(4)

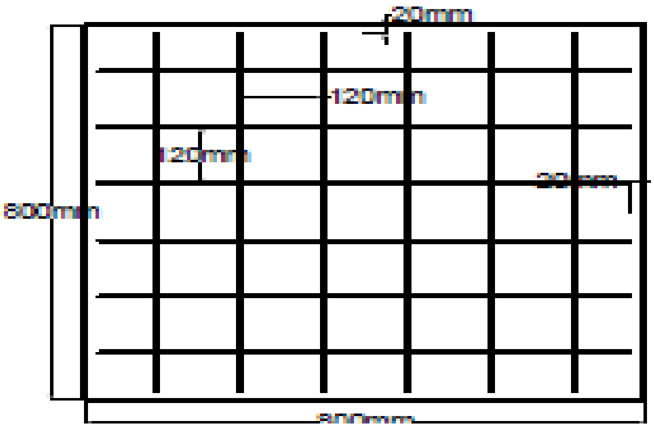
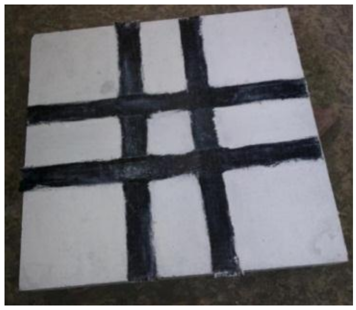
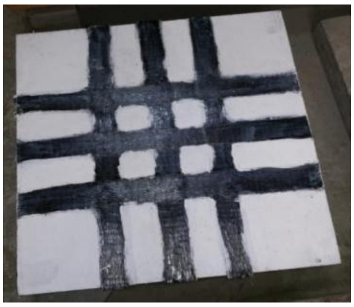


Figure 4: Distribution of Reinforcement Bars



SLS2&SLS9 **SLS3&SLS10**



SLS4&SLS11

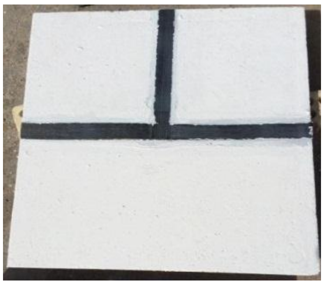
Figure 5: Practical Steps to Grinded Surface

Details of Tested Slab

Fourteen simply supported slabs(with light weight concrete), (SLS) where (S: slab,, L: light weight concrete, S: strengthened with CFRP) first group consists of seven slabs of (800 x 800 x 70)mm slab (SL1) was not strengthened with CFRP to serve as a reference slab(control slab), the remaining (6) slabs (SLS2, SLS3, SLS4, SLS5, SLS6,SL7) study how the form in which the CFRP strips are provided to the tension sides of the preloaded slabs are effect to the punching load behavior of strengthening slabs. The second group consists of seven slabs of (800 x 800 x 90)mm slab (SL8) was not strengthened with CFRP to serve as a reference slab(control slab), the remaining (6) slabs (SLS9, SLS10, SLS11, SLS12, SLS13,SL14) study how the form in which the CFRP strips are provided to the tension sides of the preloaded slabs are effect to the punching load behavior of strengthening slabs. The concrete slab specimen.(SLS2&SLS9) is provided with two perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region). The concrete slab specimen (SLS3&SLS10) is provided with four perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region). The concrete slab specimen (SLS4&SLS11) is provided with six perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region),. The concrete slab specimen (SLS5&SLS12) is provided with Plus strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region). The concrete slab specimen (SLS6&SLS13) is provided with (Plus & cross) strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region),. The concrete slab specimen (SLS7&SLS14) is provided with Tea strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region). Each strip has a length of 80mm, width of 50mm, and thickness of 0.131mm. The shapes and specification of the tested slabs groups are given in Fig.(5) & Table (9).

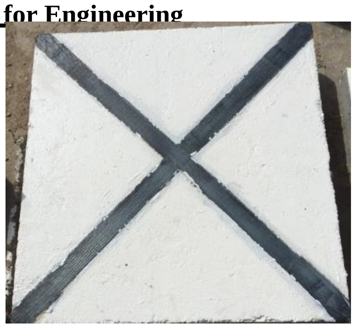
Table (9) Classifications of Slabs

Form of CFRP strips	No. of CFRP strips	*Batch type*	Depth of slabs (mm)	Groups
Nil	*Nil*	SLS1	70	Group one
two perpendicular	2	SLS2		
Four perpendicular	4	SLS3		
Six perpendicular	6	SLS4		
plus	2	SLS5		
Plus & cross	6	SLS6		
Tea	2	SLS7		
Nil	Nil	SLS8	90	Group two
two perpendicular	2	SLS9		
Four perpendicular	4	SLS10		
Six perpendicular	6	SLS11		
plus	2	SLS12		
Plus & cross	6	SLS13		
Tea	2	SLS14		



SLS5&SLS12

SLS6&SLS13



SLS7&SLS14

Figure 6: Samples Shape in Each Group

Experimental Results:

1- General Behavior of Slabs Under Loading

The general behavior (crack pattern and failure mechanism) of (14) slabs are all nearly identical, when the load is applied to the slab specimen, the first visible crack (bending cracks) is observed at the tension face of the tested slab at load level equal to (15 – 30.7)% of ultimate load as shown in Table (10). In all slabs, cracking on the tensile face began near the center and radiated towards the edges (semi- random phenomena). As the load is increased the cracking migrates to the opposite face. At higher loads, the already formed cracks get widened while new cracks started to form. The new formed cracks are roughly circular or elliptical in shape and occurred in the tension surface of the slab. Failure of the slab occurred when the cone of failure radiating outward from the point of load application pushed up through the slab body (brittle failure with limited warning). At failure, the slab is no longer capable of taking additional load.

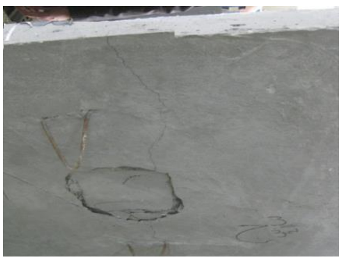
Table (10) Deflection Characteristics at First Crack and Ultimate Loads of

P(CFRP)/P(control) %	Deflection at Pu (mm)	Deflection at Pcr (mm)	Ultimate load, Pu. (kN)	irst cracking oad, Pcr. (kN)	Slab
0	7.18	0.3	71.3	11	SLS1
18.32	7.15	0.47	84.3	17.5	SLS2
16.87	8.17	0.71	83.3	25	SLS3
17.75	6.12	0.54	83.9	33	SLS4
21.85	5.63	0.34	86.8	25	SLS5
26.32	5.43	0.49	90.0	28	SLS6
16.47	5.21	0.62	83.0	36	SLS7
0	6.2	0.69	79.5	16	SLS8
12.34	6.87	0.43	89.2	21	SLS9
9.52	6.53	0.56	87.0	28	SLS10
10.36	5.57	0.7	87.7	35.5	SLS11
21.85	6.21	0.58	90.8	34.9	SLS12
17.61	6.34	0.69	93.4	40.8	SLS13
11.36			88.5		SLS14

2- Effect of the Configuration of CFRP on Ultimate Load

Figure (7) shows the increase in ultimate punching resistance of the slabs compared to the control slab. The average increase of the ultimate punching resistances is not constant and varies from 9% to 26% as shown in Table (9).

As in all models, the failure in the CFRP strengthening happened in the bond of CFRP with the concrete, this explains the high results of slab SLS6 among the other models as it has the greatest bonded area. The effect of CFRP stripe in grope one is more effective than grope two, this can be behavior of slab under loading and crack pattern, it is clear in Fig.(7).



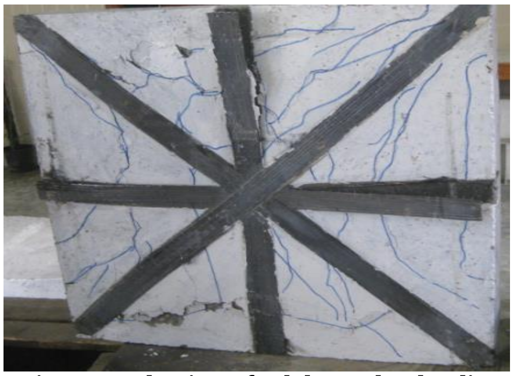
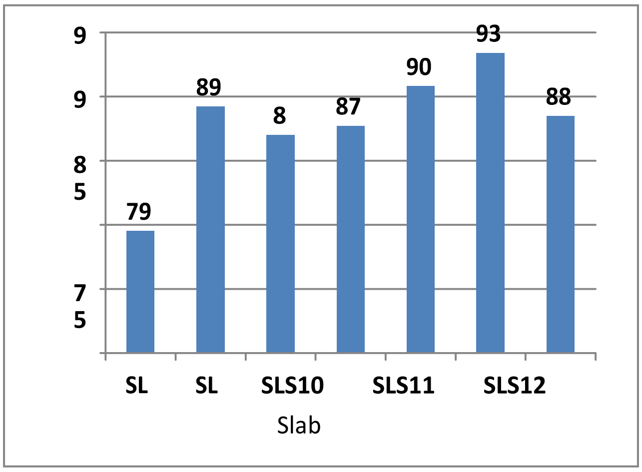


Figure7:Behavior of slab under loading & Crack

2- Effect of CFRP Strengthening on Load-Deflection Behavior of Slabs

Figures (8) and (9) show the load deflection relation of all groups of slabs. The deflection is measured at the center of slabs. In all these figures, each single curve in any figure consists of two parts; the first part is for the uncracked slab and up to the initiation of the first crack, then the second part which represents the cracked slab and up to failure. The first part of the curves is approximately a straight line with a high slope angle with the x-axes. It is very clear from these curves that the strengthened slabs have higher limit for the first cracking load and higher slope. Slab SLS6 has the highest values among the other slab however; it is not the slab with the higher ultimate resistance. This means that the distribution of the CFRP sheets for slab SLS6 is better in reducing cracks and improving elastic behavior of the slab. The second part of the curves is also approximately a straight line; these lines are mainly parallel in all models and the difference between them is in the starting point which is relating to the first part. This means less effect of CFRP laminates on the slabs after the slabs are cracked



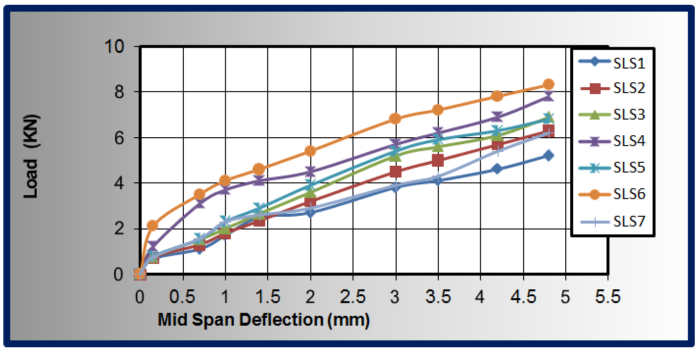


Figure 8: Comparison of Load - Central Deflection Curves of Group One

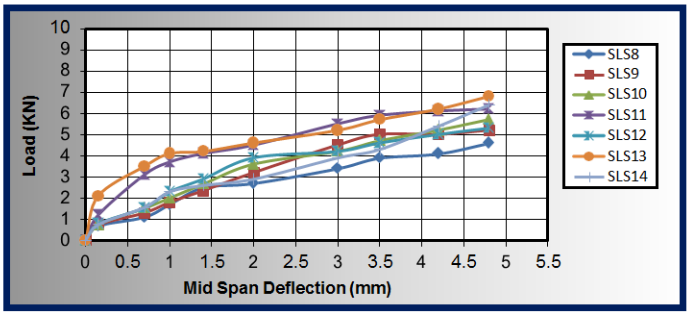


Figure 9: Comparison of Load - Central Deflection Curves of Group two

Numerical Applications

A nonlinear finite element analysis has been carried out to analyze the concrete slab , which are reinforced by CFRP strips tested in this study. The analysis is performed by using ANSYS computer program (Version 13).

In this section, verification is done in order to check the validity and accuracy of the finite element procedure. The ability of the constitutive finite element analysis method to simulate the behavior of this type of members is demonstrated through the analysis of the tested slabs.

SHELL41 Element Description

SHELL41 is a 3-D element having membrane (in-plane) stiffness but no bending (out-of-plane) stiffness. It is intended for shell structures where bending of the elements is of secondary importance. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions. This element has variable thickness, stress stiffening, large deflection, and a cloth option [14], This element is used to simulate CFRP shear for all slabs.

SOLD65 Element Description

SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete, while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations of the nodes in x, y, and z-directions. Up to three different rebar specifications may be defined. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebars are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. This 8-node brick element is used, in this study, to simulate the behavior of concrete (i.e. plain concrete). The element is defined by eight nodes and by the isotropic material properties [14].

Numerical Results

1- First Cracking Load

Table (10) shows the numerical results that are related to the first cracking load. It can be observed that the first cracking load in strengthened slabs increases for strengthened slabs when compared with the corresponding unstrengthened control slabs.

The first cracking load obtained from the numerical results showed good agreement with experimental data recorded with difference ranging from 1 to 11 percent.

In control slab in group one-the appearance of shear cracks was first at 12.51 kN in ANSYS analysis within the mid span, as shown in Fig.(11).

Table (11) Finite Element First Cracking

$P_{Num.}$ / $P_{Exp.}$	Numerical cracking Load (kN)	Experimental cracking Load (kN)	Slab
1.137	12.51	11	SLS1
1.16	20.3	17.5	SLS2
1.05	26.25	25	SLS3
1.073	35.41	33	SLS4
1.126	28.15	25	SLS5
1.112	31.14	28	SLS6
1.01	36.36	36	SLS7
1.14	49.02	43	SLS8
1.25	20	16	SLS9
1.15	24.15	21	SLS10
1.1	30.8	28	SLS11
1.034	36.71	35.5	SLS12
1.039	36.26	34.9	SLS13
1.085	44.27	40.8	SLS14

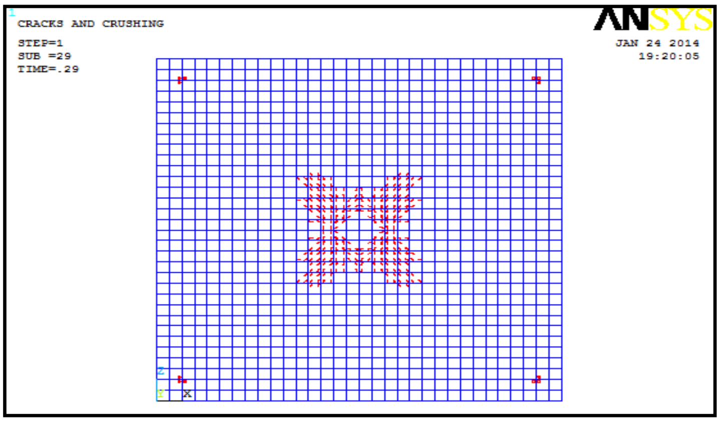


Figure 10: Shear Crack of Slab (A) in Group One

2-Cracking Patterns

The cracking behavior of same slab specimen is discussed in the following to compare between ANSYS-13 and experimental results: Fig.(11) show the crack patterns for slabs in group one. The circular crack was appearing clearly in slabs, especially at slabs of lower height, with a lot of cracking under load

3-Concrete Strain Distribution

The distribution of concrete strains along the two axes (x, z) is in tension face of the tested slab specimens .The concrete strain distribution for each slab. The same numerical result can be seen in Fig. (12). In addition to that, the presence of CFRP laminates at the bottom tension zone surface reduced the concrete strains, and this reduction was reflected to strains in the bottom tension steel bar reinforcement (i.e., reducing the tension steel bar strains), and that means increasing the tension strength and some tensile stresses were carried by CFRP laminates.

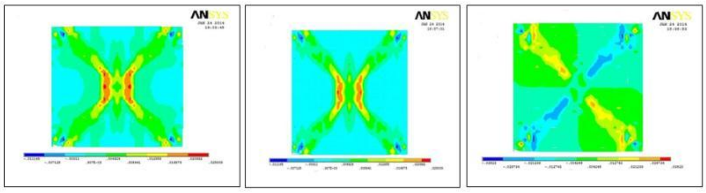


Figure 12: Concrete Strain Distribution in X- Direction of Slab (C) in Group One at ultimate load

Conclusions

Based on the overall results obtained from the experimental work and the finite element analysis for the externally strengthened reinforced concrete slabs by CFRP strips, the following conclusions can be drawn as follows:

- The externally strengthened reinforced concrete two-way slabs with bonded CFRP sheets show a significant increase in ultimate loads and the capacity of the slabs, this increase is about (9-26)% compared with the unstrengthened (control) slab.
- The external CFRP strips attached to the tension faces of reinforced concrete slabs increase the stiffness of the slabs at all stages of loading, and consequently reduces the deflection at corresponding loads, the decrease in maximum deflection is about (14-24.3) % compared with the unstrengthened (control) slab.
- The use of CFRP sheets as external strengthening has a significant effect on crack pattern of the reinforced concrete two-way slabs by delaying the crack appearance and reducing the crack width, the increase in cracking loads is about (28-141)% compared with the unstrengthened (control) slab.
- It is observed from the three points mentioned above that the presence of CFRP strips improves the structural behavior of the reinforced concrete two-way slabs but this enhancement is largely effected by the location, quantity, shape and dimensions of

CFRP strips provided for these slabs.

- The three-dimensional finite element model used in the present study is able to simulate the strengthened reinforced concrete two-way slabs with CFRP strips. The cracking loads, crack patterns, and ultimate loads predicted are very close to those measured during the experimental testing.
- The percentage of increase in the load carrying capacity of thin slabs is more effective in deep slabs.
- By comparison the result of this research with the result found by Hameed K. Maro [15] it can be concluded that effectiveness of CFRP with light weight concrete is similar than normal strength concrete and high strength concrete.
- The percentage of increase in the load carrying capacity and crack pattern of (Plus & cross) strengthen pattern represent the past shape from all the pattern used.
- The finite element model (ANSYS-13) used in the present work is able to simulate the behavior of externally strengthened reinforced concrete slabs strengthened with CFRP strips. The numerical ultimate loads are in good agreement with those obtained from experimental work. In most of the slabs, the finite element ultimate load overestimated the experimental results by (3%
- 9%).

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