Behavior of Reinforced Lightweight Concrete Two Way Slabs Strengthened With CFRP Sheets

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Abstract:

The principal objective of this paper is to investigation experimental and theoretical of flexural behavior of reinforced light weight concrete two-way slabs strengthened or repaired with externally bonded carbon fiber reinforced polymer (CFRP) sheets. The experimental work includes testing of eight reinforced concrete slab specimens with dimensions (1050mmx1050mmx600mm), five of these slabs were strengthened, three slabs were repaired with carbon fiber reinforced polymer (CFRP) strips and one specimen was tested without strengthening acts as reference slab (control) for comparing the performance of CFRP strengthened or repaired slabs. The experimental variables considered in the test program include the quantity and shape of CFRP sheets. All the reinforced concrete slab specimens were designed of the same dimensions and reinforced identically to fail in flexure. All slabs had been tested in simply supported conditions subjected to central concentrated load.The experimental results show that the ultimate loads are increased by about (7-45%) for the slabs strengthened with bonded CFRP sheets with respect to the unstrengthened reinforced concrete slab (control slab). Three-dimensional nonlinear finite element analysis has been used to conduct the numerical investigation of the general behavior of strengthened slabs. **ANSYS** (Version 13.0) computer software was used in this work. Eight-node brick elements (SOLID65) are used to represent the concrete and three dimensional shell elements (SHELL 41) are used to represent the CFRP strips in the finite element analysis model. Perfect bond between the concrete surface and the bonded CFRP sheets is assumed.

سلوك البلاطات الخرسانية الخفيفة الوزن المسلحة و المقواة بصفائح البوليمر المسلح بالألياف الكاربونية

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 (1050ملم طول، 1050ملم عرض، 600 ملم ارتفاع البلاطة) بالاضافة الى 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 أعتمادها في الجانب العملي هي كمية و شكل اشرطة الياف الكاربون البوليمرية المستخدمة في تقوية او تصليح هذه البلاطات.صممت

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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 (3D Shell 41) لتمثيل شرائط الياف الكاربون البوليمرية وتم إفتراض وجود ربط تام بين شرائط الياف الكاربون البوليميرية و سطح تماس البلاطة الخرسانية.

INTRODUCTION

The need to develop economic and efficient methods to upgrade, repair, or strengthen existing structures has received considerable attention. The motivation to strengthen 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 an attractive and may not be economically feasible to replace an outdated structure with a new one. In addition, traditional structural rehabilitation methods such as external post tensioning and bonded steel plates often suffer from inherent disadvantages ranging from difficult application procedures to lack of durability, leaving the growing repair and rehabilitation market in need of cost effective and efficient restoration techniques. Advances in the fields of plastics and composites have resulted in the development of high strength, fiber reinforced plastics (FRP) that offer great potential for light weight cost-effective retrofitting of concrete structures, including bridges. These high performance materials can be bonded to structural elements to increase the strength and stiffness of the structure with savings in application costs and improved durability over conventional methods. The old structure and the new bonded-on material create a new structural element that has a higher strength and stiffness than the original one [1].

Types of Slabs and Their Applications

Slabs are one of the most important parts of the structural construction. They are the members in which the thickness is small compared with the other dimensions and they sustain loads normal to their planes. Concrete slabs are widely used as floors not only in industrial and residential buildings but also as decks in bridges. Slabs may be supported on two opposite only, as shown in figure (1-a), in which case the structural action of the slab is essentially one-way, the loads being carried by the slab in the direction perpendicular to supporting beams. There may be beams on all four sides as shown in Fig.(1-b). On the other hand, one-way slab action may be obtained using intermediate beams, as shown in Fig.(1-c) [2].

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, a portion 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 [3]. 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 [4] . 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.(2-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.(2-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 [5]. 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 [4].

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) [6].

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 [7].

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 [8]. Some properties of the lightweight coarse aggregate of each type are given in Table (4).

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 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).

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 [9].

Mix Proportions of Lightweight Concrete (LWC)

Eight 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.

Details of Tested Slab

Eight simply supported slabs(with light weight concrete), (SLS) where (**S**: slab**,, L:** light weight concrete, **S**: strengthened with CFRP) first slab (**SL1**) was not strengthened with CFRP to serve as a reference slab(control slab), The remaining (7) slabs (**SLS2, SLS3, SLS4, SLS5, SLS6, SLS7, SLS8**) study how the form in which the CFRP strips are provided to the tension sides of the preloaded slabs are effect to the flexural behavior of strengthening slabs. The second concrete slab specimen.(**SLS2**) is provided with two perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region), each strip has a length of 1050mm, width of 100mm, and thickness of 0.131mm. The third concrete slab specimen (**SLS3**) is provided with four perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region) each strip has a length of 1050mm, width of 100mm, and thickness of 0.131mm. The fourth concrete slab specimen (**SLS4**) is provided with six perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region), each strip has a length of 1050mm, width of 100mm, and thickness of 0.131mm.

After all the strengthening specimens were tested, the best three pattern of gluing the CFRP sheet which give the highest increase in ultimate load comparing with control slab are selected in the repairing process, so the fifth concrete slab specimen (**SLS5**) was loaded to 57% of ultimate load and then is repaired with four perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region), each strip has a length of (1050mm), width of 100mm, and thickness of 0.131mm (similar to **SLS3** pattern).

The sixth concrete slab specimen (**SLS6**) was loaded to 68% of ultimate load and then is provided with six perpendicular strips of CFRP sheets gluing on the bottom face of the slab (maximum tension region), each strip has a length of 1050mm, width of 50mm, and thickness of 0.131mm (similar to **SLS4** pattern).

The seven & eight concrete slab specimen (**SLS7**&**SLS8**)study how the number of layers of CFRP affect the flexure behavior in which the CFRP strips are provided to the tension sides (similar to **SLS3 & SLS4** pattern)

External strengthening of specimens by CFRP sheets followed the procedure recommended by the manufacturer which is described below:

- First of all, the CFRP sheets were cut into the required lengths. Surface preparation of the CFRP followed with cleaning to remove any dust or other contaminants prior to installation.
- The two-parts comp. A (white) and comp. B (black) of adhesive (Sikadur-330) were mixed respectively with an electric mixer (here electric low speed drill was used) and mixed in 4: l proportion, until the color was a uniform gray, the adhesive paste then

was applied with a special tool to the concrete surface and the adhesive was also applied to the CFRP sheets.

- The strips were then placed on the concrete, epoxy to epoxy, and after the installation of strips, a ribbed roller was rolled in the direction of fibers to properly seat the sheets by exerting enough pressure so the epoxy was forced out on both sides of the strips.

- The adhesive was allowed to cure for at least 7 days before the slabs were tested. After completing the CFRP installation, two days before the testing date, all apparent concrete surface specimens were painted white to detect easily the crack propagation. Table (9) shows the description of the tested slabs, Fig.(3-1) from (a) to (c) shows the strengthening scheme of the (SLS) group tested slabs and Fig. (3-2) from (a) to (d) shows the tests slabs .

Test Set-up and Instruments:

Torsee's Universal Testing machine with a capacity of 2000 kN was used to apply the load. The slab was loaded from top at the mid-span. Load was applied in increments, with approximately fifteen load steps to failure. At each load increment, the total applied load on the slab, mid-span deflection, and crack width were measured. The cracks were plotted and marked. A test was terminated when the total load on the specimen started to drop off. The total time to failure in a test was approximately one hour.

Experimental Results:

1- Behavior of slab under loading and crack pattern:

External strengthening of RC slabs by CFRP sheets showed better enhancement in first cracking loads when compared with reference control slab SL1as shown in Table(10). However, the slab specimen SLS1 gives the minimum increasing ratio (6%) while the slab specimen SLS4 gives the maximum increasing ratio (31%) in first cracking loads. For the control slab, at early stages of loading, the deformations were initially within the elastic ranges (linear), and then the applied load was increased until the first crack became visible which was observed in the maximum moment region under the point load. As the load was increased further, several flexural cracks initiated in the tension face at intervals throughout the slab, gradually increased in number, became wider and moved upwards reaching the compression face of the slab.

As the load was increased further, a loss of stiffness occurred and one mode of failure appeared which can be classified as flexural failure in tension by yielding of the steel reinforcement followed by crushing of concrete.

The strengthened slabs also showed similar behavior, but when the load reached yielding of steel, the CFRP strips contributed mainly in resisting the loads and increased the stiffness of the concrete slabs up to failure. The failure was usually recorded due to debonding of CFRP sheets from bottom face of slabs specimens which was very suddenly and the only indication of such failure was few popping sounds before debonding happened. In repaired slabs (**SLS5** and **SLS6**), the failure was similar to strengthened slabs (**SLS3** and **SLS4**), this because of the flexural strength mainly attributed to CFRP. The comparison of **SLS7** and**SLS8** with **SLS3**and **SLS**4 it is interesting to note that when increasing the numbers of layers all this slabs fail at the same load levels. This means it is preferable to increase the amount of strengthen by increasing the number of CFRP rather than increasing the number of layers. Ragheed Fatehi [10] found that for a normal strength concrete strengthened with CFRP strips, an increase of (8% to 60%) with respect to the ultimate load of control slab is obtained, it can be concluded that effectiveness of CFRP with light weight concrete is less than normal strength concrete.

2- Load Versus Mid-Span Deflection Results

Seven reinforced concrete slabs were strengthened by CFRP strips to examine the effect of strengthening patterns on their behavior and ultimate load capacity. Experimental investigation on the behavior of load versus mid-span deflection curves for these slabs is presented in the Fig. (4). Obviously, it was noticed that the presence of CFRP sheets enhanced the behavior of strengthened and repaired slabs compared with the control slab by increasing the ultimate strength and reducing the ultimate central deflection.

3- Concrete Cracking

The slab control specimen SL1 was tested in order to have an unstrengthened slab to compare with CFRP strengthened and repaired slabs. The control slab behaved in an expected fashion under flexural loading. It was gradually loaded until the initiation of cracking. The appearance of flexural cracks was first at 12.2kN within the maximum moment region under the point load. Flexural cracks formed and widespread as loading proceeded throughout the slab. At a load of 17.3kN, the cracks reached the compression face of the slab. Failure of the control test specimen was by yielding of steel followed by crushing of the concrete at the compression zone at a load of 22.3kN,

For the first strengthened slabs specimens SLS2, the cracks pattern of this slab specimen first crack occurred at a load of 20kN, gradually the flexural cracks increased in intensity and widened. Cracks appeared at compression face at 24.2kN. Failure was observed at load 27kN by CFRP debonding (a separation at the interface between the substrate and the adherent material) due to propagation of diagonal flexural cracks at bottom face of the concrete slab. However, it was gained slightly increased in stiffness, restricted of cracks propagation and ultimate load from this pattern of strengthening.

For the second strengthened slabs specimens SLS3, Failure was observed at load 36kN by CFRP debonding due to propagation of diagonal flexural cracks at the bottom face of the concrete slab. The cracks pattern is of this slab specimen.

For the third strengthened slabs specimens SLS4, failure was observed at load 41kN by CFRP debonding due to propagation of diagonal flexural cracks at bottom face of the concrete slab. The cracks pattern is of this slab specimen.

The two repaired slabs designated as SLS5 and SLS6, these slabs were similar to slab SLS3 and SLS4 respectively in their strengthening patterns, the slabs were repaired by CFRP strips after loading to different percentages of ultimate load of the control slab SL1. These load levels were (57%) and (68%) of ultimate load of the control slab SL1 for SLS5 and SLS6 respectively. Failure was observed at load 35kN for SLS5 and 38 for SLS6 by CFRP debonding due to propagation of diagonal flexural cracks at bottom face of the concrete slab. The cracks pattern of this slab specimen.In repaired slabs, the failure was similar to strengthened slabs, this because of the flexural strength mainly attributed to CFRP.

For the seventh and eight strengthen slab SLS7and SLS8 strengthened with a two layer of CFRP strips installed on the tension bottom face of the reinforced (light weight) concrete slab. Failure was observed at load 36kN for SLS7 and 40 KN for

SLS8 by CFRP debonding due to propagation of diagonal flexural cracks at bottom face of the concrete slab.It is interesting to note that when increasing the numbers of layers all this slabs fail at the same load levels approximately.

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 [11], 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 [11].

Numerical Results

1-Loads at Failure

In general, the predicted ultimate load obtained by ANSYS-13 gives agreement with experimental result. In most of the slabs, the finite element ultimate load overestimated the experimental results by (3% - 9%).

There are several factors that may cause the higher stiffness in the finite element models. Microcracks produced by drying shrinkage and handling are presented in the concrete to some degrees. These would reduce the stiffness of the actual beams, while the finite element models do not include microcracks. Perfect bond between the concrete and steel reinforcing are assumed in the finite element analyses, but the assumption would not be true for the actual slabs. As bond slip occurs, the composite action between the concrete and steel reinforcing is lost.

2-Crack Patterns

In ANSYS computer program, the cracking or crushing types of fracture in concrete elements appear as circles at locations of these cracking or crushing, the shape of each crack and crush in concrete element is summarized as follows

1- Cracking is shown with a circle outline in the plane of the crack,
2- Crushing is shown with an octahedron outline.
3- If the crack has opened and then closed, the circle outline will have an X designation through it.

A cracking sign appears when a principal tensile stress exceeds the ultimate tensile strength of the concrete and appears perpendicular to the direction of the principal stress. The cracking sign appears perpendicular to the direction of the principal stress. To obtain good results from the Solid65 element, the use of a rectangular mesh is recommended. Therefore, the mesh was set up such that square or rectangular elements were created. The volume sweep command was used to mesh the steel plate and support. This properly sets the width and length of elements in the plates to be consistent with the elements and nodes in the concrete portions of the model. Fig.(5) shows the evolution of crack patterns in ANSYS program of load level (0.9 Pu). On the other hand, the variations in strain and stress in the Z directions for control slab (SL1) are shown in Figures (6)& (7).

Conclusions

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

1. 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 (7-45%) compared with the unstrengthened (control) and depends on the types of strengthen.
2. 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.
3. By comparison the result of this research with the result found by Ragheed Fatehi [9] it can be concluded that effectiveness of CFRP with light weight concrete is less than normal strength concrete and high strength concrete.
4. In all slab specimens strengthened with external CFRP sheets, the cracks pattern for flexural failure are similar. The appearance of flexural cracks was first within the maximum moment region under the central concentrated load, the cracks formed and widespread as loading proceeded throughout the slab move to the top face of the slab. The crack width continues to increase till the CFRP failed (Debonding of CFRP).
5. The types of strengthen by use different types of CFRP sheets as external strengthening in two direction in two- way slab has a significant effect on crack pattern and carrying capacity of slab.
6. The percentage of increase in the load carrying capacity of the repaired slab is almost similar to that of the corresponding strengthened slabs.
7. The increase number of layer of CFRP has unsignificant effect on crack pattern and carrying capacity of slab.

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

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

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

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

Table (3) Grading of fine aggtegate Iraqi specification No.45/1948

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

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

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

Table (5) Reinforcing steel properties.

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

*Assumed value

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

Type	Tensile Strength (MPa	Elongation at Failure (%)	Tensile modulus (GPa)	Thickness (mm)	Weight (g/m2)
Sika Wrap Hex-230C	3500	1.5	230	0.13	225

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

Type	Appearance	Density (kg/l) mixed	Mixing ratio by weight	Pot live (minute)	Tensile strength (MPa)	Flexural modulus (MPa)
Sikadu r-330	Com A: White Com B: Gray	1.31	A:B 4:1	15C:90min 35C:30min	30	3800

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

Type of coarse aggregate	Cement content (Kg/m^3)	Mix proportion	Water cement ratio	Slump (mm)	f'_c 7-day	f'_c 28-day
Crushed	430	1:1.52:3.52	0.46	30	19.52	27.32
thermostone			0.48	45	17.13	22.67

Table (9) shows the description of the tested slabs.

Slab No.	Details of strengthening
SL1	Reference slab (control slab) without strengthening
SLS2	Slab strengthened with one perpendicular strips of CFRP sheets gluing on the bottom face of the slab
SLS3	Slab strengthened with two perpendicular strips of CFRP sheets gluing on the bottom face of the slab
SLS4	Slab strengthened with three perpendicular strips of CFRP sheets gluing on the bottom face of the slab
SLS5	Slab retrofitting with CFRP strips, loading to 57% of the ultimate load (similar to **SLS3**pattern)
SLS6	Slab retrofitting with CFRP strips, loading to 68% of the ultimate load (similar to **SLS4**pattern)
SLS7	Slab strengthened with two layer CFRP,similar to **SLS3**pattern
SLS8	Slab strengthened with two layer CFRP,similar to **SLS4**pattern

Table (10) First cracking loads of the tested slabs

Specimen	First cracking load (kN)	Increase in cracking load(%)
SL1	12.2	N/A
SLS2	20.4	40
SLS3	23.6	48
SLS4	26.8	54
SLS5	21.2	42
SLS6	25.1	51
SLS7	24.2	49
SLS8	27.3	55

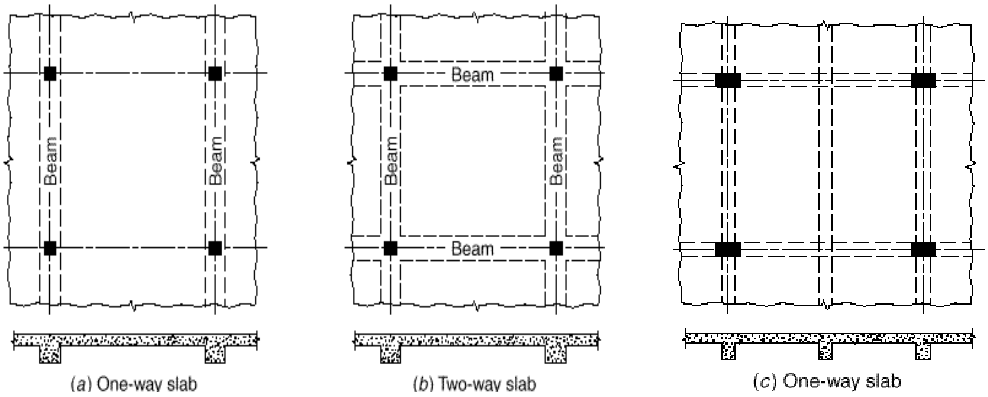
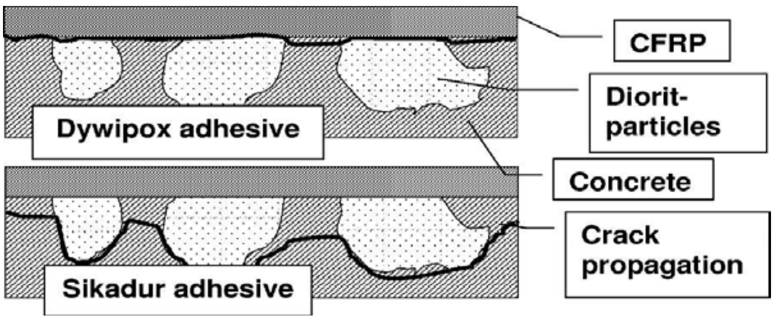
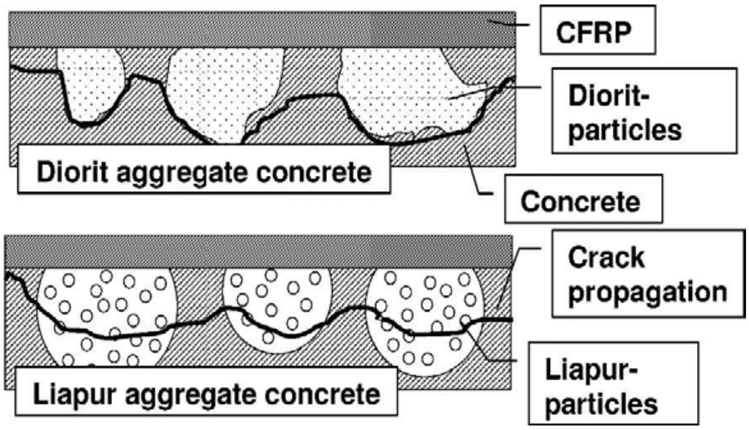


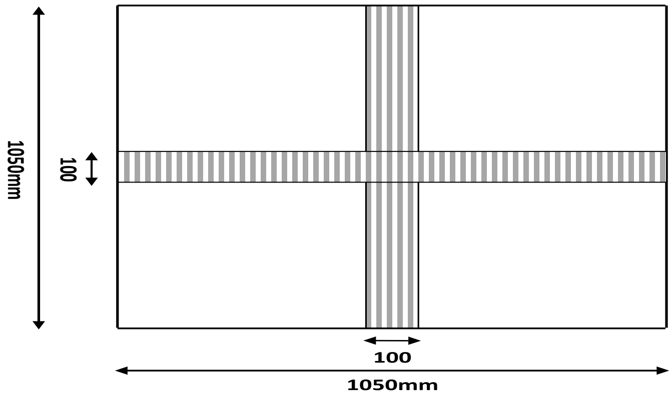
Figure (1): Several cases of one-way slab and two-way slab[1].



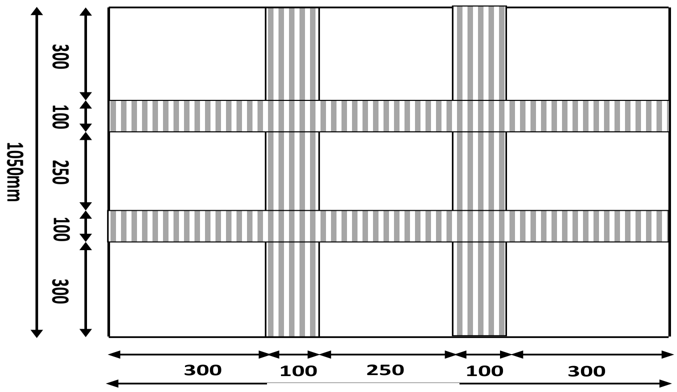
Figure(2-a) Difference in crack propagation for strong and weak aggregate types[3].



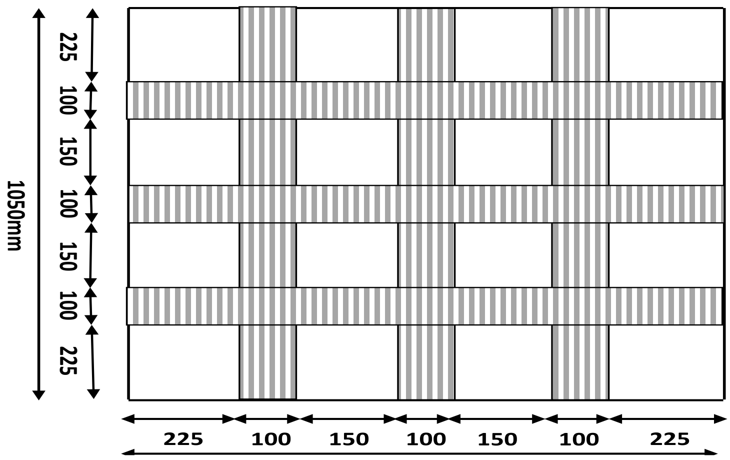
Figure(2-b) Difference in crack propagation for different bonding qualities[3].



A) Slab SLS2



B) SLS3

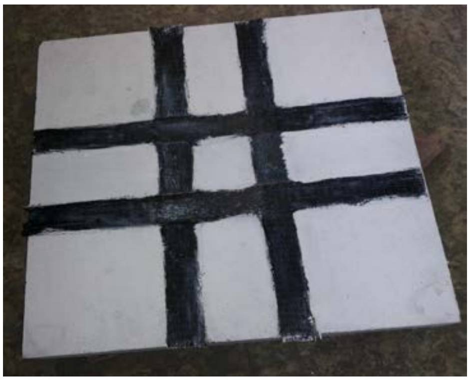


C)SLS4

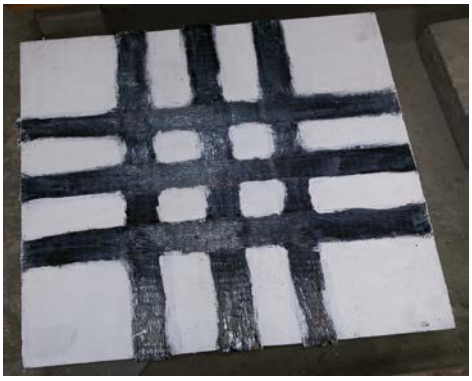
Figure(3-1)Schematic representation of CFRP strengthening Schemes

A)Bottom view of SL1

B)Bottom view of SLS2



C)Bottom view of SLS3



D)Bottom view of SLS4

Figure(3-2) Tests slabs

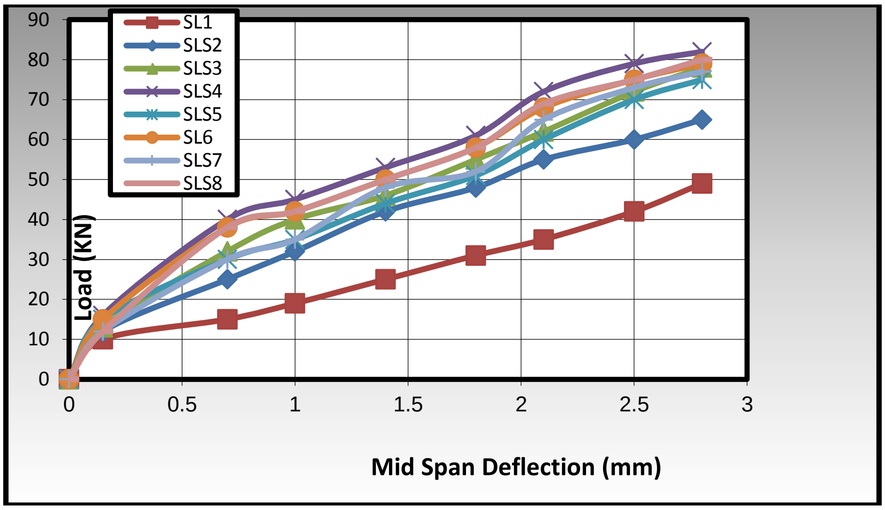


Figure (4) Load versus mid-span deflection

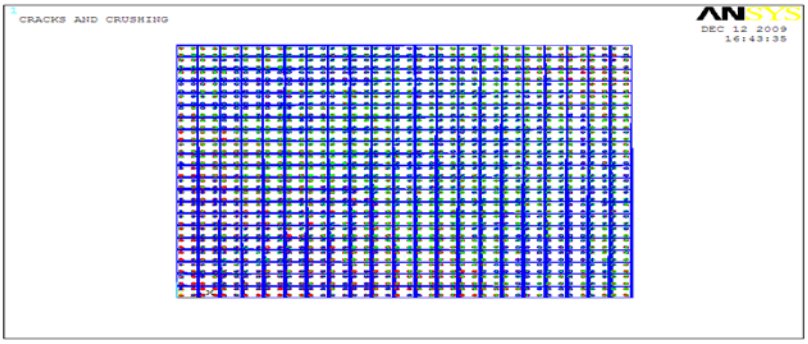


Figure.(5) Crack patterns for slab specimen (SL) (bottom view)

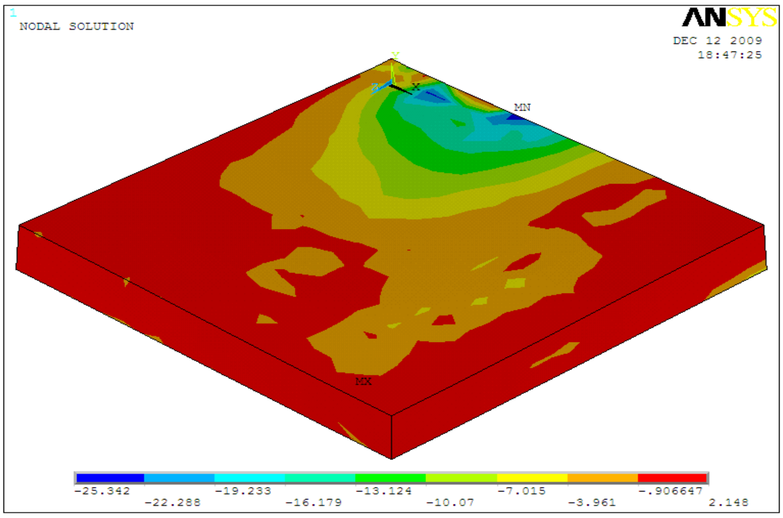


Figure (6)Variations in stress in X-direction for control slab (SL)

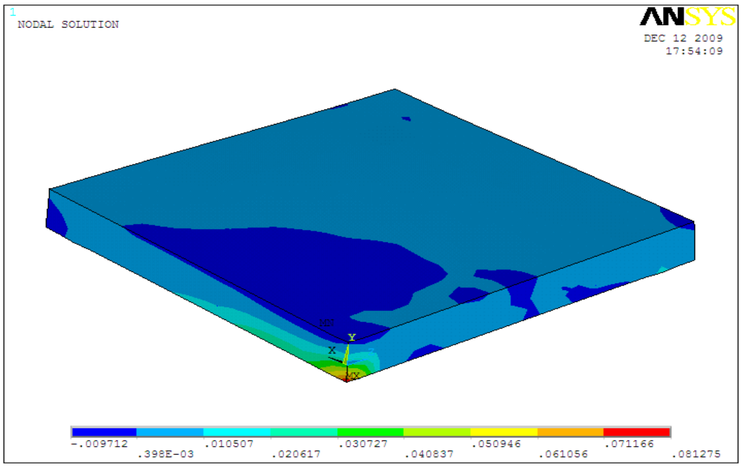


Figure (7)Variations in strain in Z-direction for control slab (LC)

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