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Flexural Behavior of Repaired Reinforced Concrete Slabs with Different Typed of Concrete

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Keywords
LWC:-light weight concrete, NWC:- normal-strength concrete, HSC:-heig strength concrete , w/c:-water to cement ratio

ABSTRACT
Experimental study of the flexural behavior of repaired reinforced concrete two way slabs with epoxy injection study in this paper. Eleven simply supported reinforced concrete slabs are used, five of which are made with (NSC), four with (HSC) and two with (LWC). The slabs is repair by used epoxy injection method. The aim of repair method is to increase or at last restore flexural strength of these slabs and to monitor their post-repair load-deflection behavior. Investigate the behavior of reinforeced concrete two way slabs with difrent concrete compressive strength before and after repaired with epoxy injection is studied. Also, the efficiency of repaired after loading to the different level between (100%-66%) of the ultimate load obtained for control slab is investigated. The experimental results of repaired two way slabs indicate that; the repair method used is successful to restore or icrease the capacity of slabs; the lower-strength slabs is higher increase in capacity compered with other slabs; after retesting the crack repaired do not reopen, instead, new nearby cracks are developed. In repaired slabs the the structural behavior is similar to that of original slabs, however, a lower stiffness and greater ductility are observed .

مقاومة الانثناء للسقوف الخرسانية المصلحة وباستخدام انواع مختلفة من الخرسانة

الخلاصة
يقدم هذا العمل بحثاً عن خصائص مقاومة و تشوه السقوف الخرسانية المسلحة المصنوعة من الخرسانةذات الركام الاعتيادي و ذو المقاومة الاعتيادية و عالية المقاومة و الخرسانة المصنوعة من الركام خفيف الوزن و ذو المقاومة الاعتيادية ، الفاشلة مسبقا بالانثناء و المصلحة بوساطة حقن التشققات بالايبوكسي. تم استخدام احد عشرة من السقوف الخرسانية المسلحة ، خمس منها مصنوعة من خرسانة اعتيادية المقاومة و أربعة من خرسانة عالية المقاومة و اثنان من خرسانة خفيفة الوزن. استخدمت طريقة الحقن بالايبوكسي لاصلاح التشققات في السقوف الفاشلة بالانثناء و قد تم تنفيذها بعناية لملء التشققات بالايبوكسي و قد اثبتت الطريقة نجاحها. ان هدف الاصلاح هو استعادة او زيادة مقاومة الاثناء للعتبات و مراقبة سلوك الحمل – الهطول بعد الاصلاح ، كما تم بحث تأثير مقاومة انضغاط الخرسانة على سلوك و مقاومةالسقوف قبل و بعد الاصلاح ، كما تم مراقبة و مناقشة تشققات الانثناء و تطورها. كما تم مراقبة تاثير التصليح بعد تحميل السقوف الى مراحل مختلفة من (١٠٠%-٦٦%) من السقف الاساسي. ان اهم الاستنتاجات الرئيسية نجاح طريقة الاصلاح في زيادة او على الاقل استعادة الانثناء للعتبات حيث كانت الزيادة ملحوظة و بقيمة اعلى في العتبات الاقل مقاومة ، التشققات لم يعاد فتحها بعد الاصلاح بينما تشكلت تشققات جديدة قريبة. و بصورة عامة ، فان السلوك الانشائي للعتبات المصلحة كان مشابها لسلوك العتبات الاصلية مع صلادة اقل و مطيلية اعلى

الكلمات المفتاحية
(LWC) : -كونكريت خفيف الوزن،(NWC) :- كونكريت ذو مقاومة اعتيادية ، (HSC) : كونكريت عالي المقاومة ، (W/C) :-نسبة الماء الى الاسمنت

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Introduction

Incidence of failure, such as loading increases, fire damage, poor quality concrete, changes in design and repair deterioration that has taken place in reinforced concrete structures. Rehabilitation of old or damaged structures as an alternative to replacing them is an option that is gaining importance[1].

Causes of Failures and Defects

Failures and defects in concrete structures can be placed in five main categories[2] :

1. Structural deficiency resulting from such causes as, errors in construction, explosions and errors in design.

2.Fire damage; this often results in severe physical damage to the individual concrete members (floor slabs, beams, columns etc).

3.Deterioration due to poor quality concrete and the presence of chlorides in the concrete.

4.Chemical attack on the concrete .

5.Physical damage caused by the use to which the structure was put, such as the abrasion of a floor slab in a factory.

The scope of the rehabilitation project may vary from relatively minor remolding to the complete reconstruction of the structure, while the object of any repair is to bring concrete to the satisfactory condition of structural adequacy, durability, and appearance at a cost commensurate with the benefit to be derived[2].

Assessment of Damaged Reinforced Concrete Structures

The assessment of damaged structures is very important to decide whether the structure can be repaired or demolished. Befor the repaire prosess done, the cause of deterioration of concrete structures muste be evaluation. Evaluate the factors and cause contributing to deterioration and systematic field investigation this represent the first step in repair program[3].This evaluation may include a review of available design, structural instrumentation data, , destructive (core drilling) and nondestructive testing. Following the repair work, it is necessary to monitor the development of further deterioration to avoid hazards in the future[4].

High -strength Concrete

The term “High- strength concrete” is generally used for concrete with compressive strength 41 MPa or greater for (150*300mm) cylindrical specimens.[5]

Light- weight Concrete

The term “Light- weight concrete” is generally used for concrete of density lower than 2200 kg/ m3. The use of light-weight concrete is governed primarily by economic considerations. Light-weight concrete has been used usefully for many years for structural members in buildings and bridges. Lighter weight, which reducing in dead load and so reduces the costs of structures, this concrete is provides better sound and heat insulation than normal weight concrete. [6].

Experimental Work:

Materials

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

1-Cement

Falcon cement used in this study. Chemical and physical test results show in Tables(1) and (2).
They conform to Iraqi specification number(5/1984) [7].

Table (1): Chemical analysis of the cement .

Chemical analysis	**Percentage, by weight**	**Limit of I.Q.S No.5/1984**
(CaO)	60.83	
(SiO_2)	22.5	
(Al_2O_3)	5.36	
(Fe_2O_3)	4.4	
(MgO)	4.27	5.00 (Max.)
(SO_3)	2.30	2.80 (Max.)
(K_2O)	0.63	
(Na_2O)	0.29	
(L.O.I)	0.70	4.00 (Max.)
(I.R)	0.51	1.50 (Max.)
(L.S.F)	0.95	0.66-1.02
Main compounds (Bogues equations)		
C_3S	41.9	
C_2S	28.91	
C_3A	10.18	
C_2AF	9.35	

Table (2) :Physical properties of the used ordinary Portland cement, Iraqi specification number (5/1984) [7].

Physical property	**Test results**	**Limit of I.Q.S No. 5/1984**
Specific surface area (Blaine method), m^2/kg	310	230 (Min.)
Setting time (Vicat apparatus), hr:min Initial Final	 2:10 3:20	 00:45 (Min.) 10:00 (Max.)
Soundness (Autoclave expansion),%	0.31	0.8 (Max.)
Compressive strength (70.7mm cube), MPa 3-day 7-day	 19 29	 15 (Min.) 23 (Min.)

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

Coarse aggregate			Fine aggregate		
Sieve Size mm	Passing (%)	ASTM C33 limits	Sieve Size mm	Passing (%)	ASTM C33 limits
25	100	100	9.5	100	100
19	97	90-100	4.75	95.6	95-100
9.5	37	20-55	2.36	80.4	80-100
4.75	2	0-10	1.18	68.9	50-85
2.36	1	0-5	0.60	33.4	25-60
			0.30	9.7	5-30
			0.15	1.4	0-10

2-Fine & Coarse Aggregate (Sand)

A local natural coarse and fine aggregate from Zubair ,Basrah ,that meet the requirement of ASTM C33-03[8] were used. Table 3 presents the grading of fine and coarse aggregates. shown in Table(3). The sulfate content were within the limits of Iraqi specification No. 45/1984 [9].

3-Lightweight Coarse Aggregate

Crushed thermostone was used as lightweight coarse aggregate. Maximum size 20mm was used, the part of the excess fine was removed so as to satisfy the ASTM C-330 specification . Some properties of the lightweight coarse aggregate of each type are given in Table (4).

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

Test performed	Thermostone
Absorption%	17.4
Bulk specific gravity	2.11
Dry density (Kg/m^3)	442

4- Mixing Water

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

5-Steel Reinforcing Bars

Ukrainian deformed bars of 12mm diameter were used for the longitudinal reinforcement of slab.

Three tensile specimens were tested. Table (5) presented the properties of reinforcing bars

Table (5): Reinforcing steel propertie

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

***Assumed valu**

Mix Proportions of Concrete

For NSC,HSC and LWC the mix proportions are selected depending on several trial mixes.

1-NSC

Five slabs are made of NSC, and designated as S1,S2, S3 , S4 and S5. Mix proportions of these slab are show in Table (6). Maximum coarse aggregate size used for NSC slabs is 20mm.

2-HSC

Four slabs are made of HSC , and designated as S6,S7,S8,and S9. Mix proportions of these slabs are 1:1.35:1.71 by weight with water-cement ratio of 0.28 and amount of superplasticiser of 2 liters for each 100kg cement. Maximum coarse aggregate size used for HSC slabs is 14mm.See Table (6).

3-LWC

Two slabs are made of LWC, and designated as S10 and S11. Their mix proportions are 1:1:1.34 by weight with 0.31 water/cement ratio and amount of superplasticiser of 2 liters for each 100kg cement. Maximum coarse aggregate size used for LWC slabs is 20mm.See Table (6).

Table (6) :Concrete mix proportions

Slab designation	C:FA:CA (by weight)	w/c (by weight)	SP3 %of cement Wt.	Ave.f'_c (MPa) (28 days)
S1	1:1.5:3	0.6	—	22
S2	1:1.5:3	0.5	—	25
S3	1:1.5:3	0.5	—	28
S4	1:1.6:2.5	0.45	—	30
S5	1:1.6:2.5	0.4	—	٣٧
S6	1:1.35:1.71	0.28	2	66
S7	1:1.35:1.71	0.28	2	71
S8	1:1.35:1.71	0.28	2	72
S9	1:1.35:1.71	0.28	2	74
S10	1:1:1.34	0.31	2	27
S11	1:1:1.34	0.31	2	24

Preparation of Test Specimen

Mixing, Casting and Curing of the Specimens

Under laboratory conditions at Civil Engineering department-University of Al Basra, eleven two-way reinforced concrete slab specimens were cast and cured, also, two (200x100) mm standard cylinders and three (150X150X150)mm standard cubes were cast from the concrete for each slab specimens. The concrete was mixed in a horizontal rotary type mixer of 38.5 kg capacity and 19 rpm mixing speed. Casting and curing procedure for concrete is described below:

- Before casting concrete and before putting the grid of reinforcement, the cubes and the molds of specimens were treated with oil.
- For each specimen the steel grid placed in their correct position and the specified protection cover is checked.
- All the quantities were weighted and packed in a clean container before mixing.
- 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). After casting was completed smoothly finished the upper surface of concrete 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. Monitored and kept wet the burlap sacks until the fully twenty-eight days had past.
- Once the slabs were cured, the slabs were placed off to the side until they could be tested. The same procedure were performed on the concrete test cubes.

The steps of casting process of specimens are shown in Fig. (1).

Figure 1: The steps of casting process

Repair of Cracks in Failed slabs

The cracks in failed slabs are repair by epoxy injection.All slabs are designed to failed in flexural, the failure is huppen due to formation of flexural crack in the tension zone of the slab.The mjer and minor flexural cracks were repaired by the injection technique, while because of their difficulty in treating the hairline cracks are ignored them and insignificant effect.

Repair Procedure

In each failed slab the repair process in epoxy injection is done as followes:

1. After failure, cleand major and minor cracks from dust by a compressed air to ensure proper bond of the crack paste and good penetration of resin
2. The surface ports has an opening at the top are placed 10 – 15cm apart along considered crack
3.Fixed the surface ports by applying an epoxy.
4. Seal over the exposed cracks and surface ports by used epoxy paste. To prevent resin seepage 30mm paste is extend with 3mm thickness on either sides of crack .
5. Mixed two components of epoxy resin according to the manufacturer's instructions,(hardener: base) of (3:1) by volume.Theis two components of epoxy resin are mixed by using mechanical stirrer.
6. Injection process starts by usind mechanical injection gun. The epoxy injecte from the lowest port to the above port by using pumping, the injection continue until epoxy begins to flow from port above. The cap used to plugged the firest port.

7. The process of injection repeated until all crack has been completely filled with epoxy resin.
8. Provide a curing period to the injected epoxy about 24hours.
8. Remove the surface ports .

Fig.(2) shows the injection process. The injection process for all slabs is done successfully and easily for slabs loaded to100% of the ultimate load obtained for control slab. On the other hand, for slab loaded to the level of loading less than 100% of the ultimate load obtained for control slab, theis is takes relatively longer time.

Figure 2:Repair procedure

Details of Tested Slab

Eleven simply supported slabs with LWC, NSC and HSC,with (800mmx800mmx80mm) dimension and renforced with 12.5mm dimeter deformed steel bare in each way as shown in figure(3.1) and fig(3.2). Grope one normal strength concrete (S1,S2, S3, S4 and S5) study how the form in which the repair of epoxy injection are provided to the tension sides of the preloaded slabs are effect to the flexural behavior of slab, slab S1,S4and S5 with a w/c ratio of 0.6,0.45 and 0.4 respectively was repaired after loading to 100% of the ultimate load obtained for control slab. While slab S2 and S3 with the sime percinet of w/c ratio (0.5) was repaired after loading to 63.7% and 83.2% of the ultimate load obtained for control slab respectively. Grope two high strength concrete (S6,S7,S8 and S9) study how the form in which the repair of epoxy injection are provided to the tension sides of the preloaded slabs are effect to the flexural behavior of slab, slab S6 and S7 was repaired after loading to 100% and 42% of the ultimate load obtained for control slab respectively. While slab S8 and S9 was repaired after loading to 66.7% and 81.2% of the ultimate load obtained for control slab respectively. Grope three light weight concrete (S10 and S11) study how the form in which the repair of epoxy injection are provided to the tension sides of the preloaded slabs are effect to the flexural behavior of slab. Slab was repaired after loading the S10 to 100% and S11 to 74.3% of the ultimate load obtained for control slab. The aime of difference on the number of slabs are to investicate the effects of repaire process for different load levels and w/c ratios.

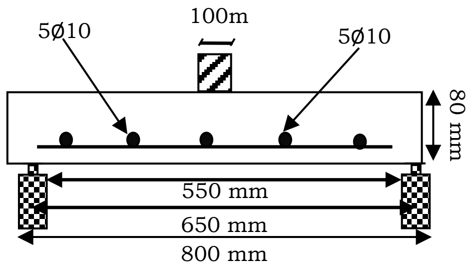

Figure 3.1: Cross section of laboratory

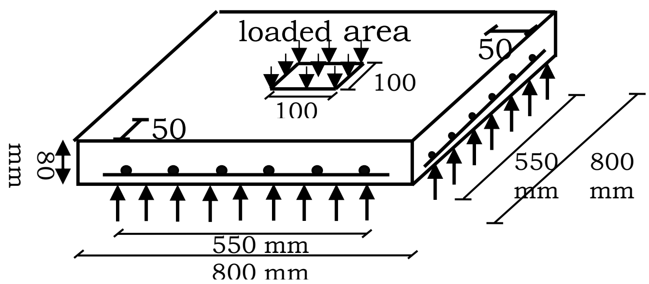

Figure 3.2 :Geometry of laboratory specimens

Experimental Results:

1- Behavior of slab under loading and crack pattern:

The behavior of repaired slabs is similar to the original slabs. The failure in theis slabs are characterized by flexural cracking. For the control slab, the deformations were initially linear at the early stages of loading, then when the applied load was continoue to increased the firest crack appere and became visible in the maximum moment region. Several flexural cracks initiated in the tension face as the load was further increased. The failure of slab occur due to the further increasing in the load and the flexural cracks gradually increased in number, became wider and moved upwards reaching the compression face of the slab

The flexural cracking load is defined as the load at wich the flexural cracks first formed (Fc). For all types of slabs the ratios of flexural cracking load for the repaired slabs (Fcr) to original slabs (Fco) are found between0.87 to 1.16

The flexural ultimate load is defined as the load at wich the failure occurs (Fu).The ratio of th flexural ultimate load for the repaired slab to the flexural ultimate load for the original slab(Fur / Fuo) varies between 0.85 to 1.14 for all types of slabs.

For both original and repaired slabs the ultimate loads , flexural cracking loads and their corresponding ratios are present in Table (7). The above results indicate that the original flexural strength restored by repaired slabs.

In both original and repaired slabs more than one flexural crack has developed, the failure will cause by one of them. In this study, the “major flexural crack” is indicate to failure crack in the original slabs others are called “minor flexural cracks”.

Repair of epoxy injection of RC slabs showed better enhancement in first cracking loads when compared with reference control slab as shown in Table(7). However, the maximum increasing ratio (21%) in flexural ultimate loads gives by slab specimen S10 while the minimum increasing ratio (5%) gives by the slab specimen S3.

For the repair of epoxy injection of reinforced concrete slabs, after testing the repaired slab the flexural cracks(major and minor) do not reopen in all slabs except slab S8 & S9 , approximately with the sam sequence and formation as the major flexural cracks in the original slabs the new flexural cracks developed to couse a slab failure. The new flexural crack is developed adjacent to the repaired major crack in slabs S4, near the repaired major crack in S1&S5 and away from the repaired major crack at other slab S2. In all slabs near the repaired minor flexural crack a new minor flexural crack is developed. See Figs.(4.1) to (4.5).

2- Deformation Results

Table(8) and Figs.(5.1) to (5.11) show the load-deflection behavior of the original and repaired slab, the behavior of theis two slabs is nearly similar. For original slabs the maximum deflections and deflections at flexural cracking loads are less than corresponding deflections of repaired slabs, also a greater ductility and lower stiffness of the repaired slabs compared with the original slabs is show in theis figures, becouse the difference in stiffness between a repaired and original slab. Deference in

3- Deference in Behavior of NSC, HSC and LWC slabs:-

3-1 Normal-Strength Concrete Slab

This group consists of five slabs designated as S1, S2 , S3 , S4 and S5

3-1-1 Repairing Process

The repairing process is done for all slabs after failure. For slabs S1,S4 and S5, the injection process is done successfully and easy compered with other slabs, because the cracks width in these slabs are wide enough, there for the injected resin is easy penetration. On the other hand, for slab S2 and S3, because of the small width of the flexural crack the injection process is done with some difficulty and take longer time. The small flexural crack width make the the penetration of injected resin into the crack is difficulty

3-1-2Behavior of Repaired slabs

After repaired major and minor flexural cracks in all tested slabs, these cracks do not reopen. The failure in repaired slabs were happen due to developed new flexural cracks, theis cracks as the same formation and sequence as the major flexural cracks in the original slabs. Near or adjacent to the repaired major crack the new flexural cracksis developed. See Figs.(4.1) to (4.3).

3-1-3 Flexural Strength Results

For repaired slabs the flexural cracking loads are equal to or greater than those for original slabs. 0.97, 0.98, 1.12, 1.14 and 1.18 respectively are the ratios of the flexural cracking loads for repaired to original slabs (F_{cr} / F_{co}).

For repaired slabs the flexural ultimate loads are equal to or greater than those for original slabs. 0.98, 1.14, 1.05, 0.95 and 1.00 respectively are the ratios of the flexural ultimate loads for repaired to original slabs (F_{ur} / F_{uo}).

3-1-4Deformation Results

Table(8) and Figs.(5.1) to (5.5) show the load-deflection behavior of original and repaired slab, the behavior of theis two slabs is nearly similar. For original slabs the maximum.

Table (7) :Flexural cracking and ultimate loads for the tested slabs

Beam	f'_c (MPa)	Original slab		Repaired slab		Ratio	Ratio
		F_{co} (kN)	F_{uo} (kN)	F_{cr} (kN)	F_{ur} (kN)	F_{cr} / F_{co}	F_{ur} / F_{uo}
S1*	22	26	44	25.22	43.12	0.97	0.98
S2*	25	32	47	31.36	53.58	0.98	1.14
S3*	28	30	45	33.6	47.25	1.12	1.05
S4*	30	36	62	41.04	58.9	1.14	0.95
S5*	35	32	59	37.76	59	1.18	1.00
S6#	66	46	82	41.86	75.44	0.91	0.92
S7#	71	42	79	36.54	68.73	0.87	0.87
S8#	72	44	76	46.64	64.60	1.06	0.85
S9#	74	41	64	37.72	60.16	0.92	0.94
S10†	27	36	49	41.76	50.96	1.16	1.21
S11†	24	30	52	25.8	45.76	0.97	0.95

*NSC, #HSC,+LWC

Table (8): flexural cracking and maximum deflections for the tested slabs

Slab	f'_c (MPa)	Original slab		Repaired slab	
		$D_{c,o}$ (mm)	$D_{max,o}$ (mm)	$D_{c,r}$ (mm)	$D_{max,r}$ (mm)
S1*	22	1.278	3.73	2.960	4.85
S2*	25	1.828	4.21	2.860	5.53
S3*	28	1.076	4.31	1.928	6.12
S4*	30	2.725	4.71	2.900	5.7
S5*	35	2.635	4.32	3.182	4.61
S6$^{\#}$	66	1.310	4.50	2.140	5.30
S7$^{\#}$	71	1.700	4.30	2.350	5.70
S8$^{\#}$	72	1.475	3.72	2.382	4.72
2.942	74	1.675	4.10	2.942	4.82
S10†	27	2.270	5.30	3.320	6.30
S11†	24	2.736	4.21	2.632	4.62

deflections and deflections at flexural cracking loads are less than corresponding deflections of repaired slabs, also a greater ductility and lower stiffness of repaired slabs compared with original slabs is show in theis figures, as may be expected. This may be attributed to the hair line cracks, which presence in the repaired slab, and the difference in stiffness of original slab and stiffness of repaired slab.

3.2 High-strength Concrete slabs

This group consists of four slabs designated as S6, S7 , S8 and S9.

3-2-1Repairing Process

The repairing process is done fore all slabs after failure. For slabs S6 and S7, the injection process is done successfully and easy compered with other slabs, because the cracks width in these slabs are wide enough there for the injected resin is easy penetration. On the other hand, for slab S8 and S9, the injection process is done with longer time and some difficulty , because the width of flexural crack is relatively small, the epoxy resin penetration became difficulte and limated to penetrate into the crack this will happen in slab loaded to level of load leas than 100% of the ultimate load obtained for control slab.

3-2-2Behavior of Repaired Slabs

After repaired major and minor flexural cracks in all tested slabs, these cracks do not reopen in slabs S6 and S9. The failure in repaired slabs were happen due to developed new flexural cracks, theis cracks as the same formation and sequence as the flexural cracks in the original slabs.Near or adjacent to the repaired major crack the new flexural is developed in slab S6. The repaired major flexural cracks in the repaired slabs S8 and S9 are reopened, as shown in Figs.(4.4).

Figure 4.1:Slab (S1) after repairing and retesting

Figure 4.2 : Slab (S2) after repairing and retesting

Figure 4.3 : Slab (S4) after repairing and retesting

Figure 4.4 : Slab (S6) after repairing and retesting

Figure 4.5 : Slab (S11) after repairing and retesting

Flexural Strength Results

For repaired slabs the flexural cracking loads are equal to or less than those for original slabs. 0.91, 0.87, 1.06 and 0.92 respectively are the ratios of the flexural cracking loads for repaired slabs to original slabs (Fcr / Fco).

The flexural ultimate loads for the repaired slabs S6, S7, S8 and S9 are less than those for the original slabs. 0.92, 0.87,0.85 and 0.94 respectively are the ratios of flexural ultimate loads for repaired slabs to original slabs (Fur / Fuo). The flexural capacity of the slabs S6, S7,S8 and S9 are restoring and increasing by using the repair processes.

The major flexural cracks for HSC differs from case of NSC slabs, theis cracks may reopen and cause failure.

The above results indicate fact that the compressive strength of HSC slabs is approximately similar to the compressive strength of epoxy used in repaired slabs and reopening of cracks may occur.See Fig.(5.6)-(5.9) and Table (7).

This investigation indicates that after repairing NSC slabs the increase in flexural capacity is relatively heigher than that for repairing HSC slabs. See and Table (7).

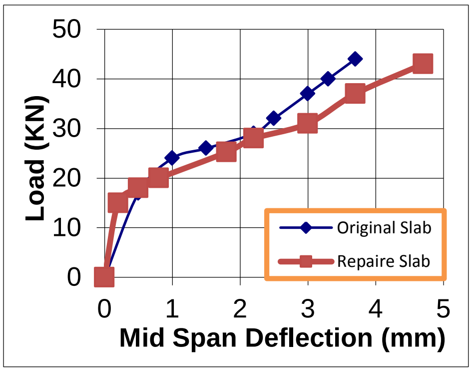

Figure 5.1: Load versus mid-span deflection (S1)

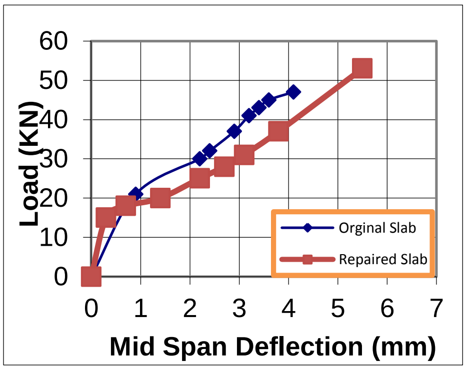

Figure 5.2:Load versus mid-span deflection (S2)

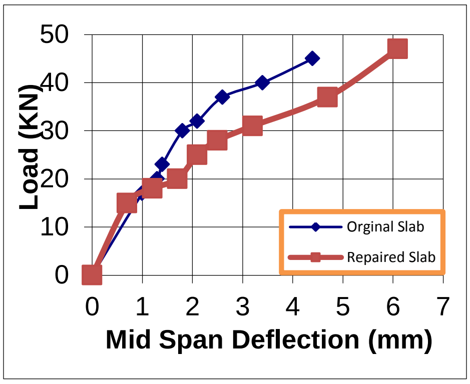

Figure 5.3: Load versus mid-span deflection (S3)

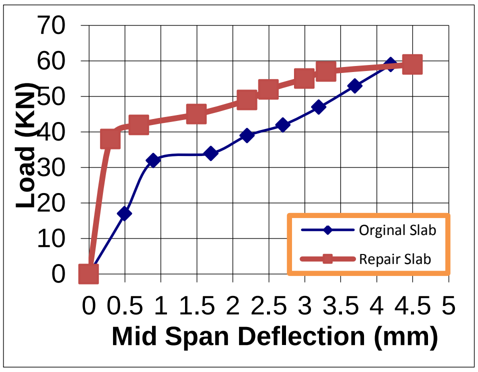

Figure 5.5: Load versus mid-span deflection (S5)

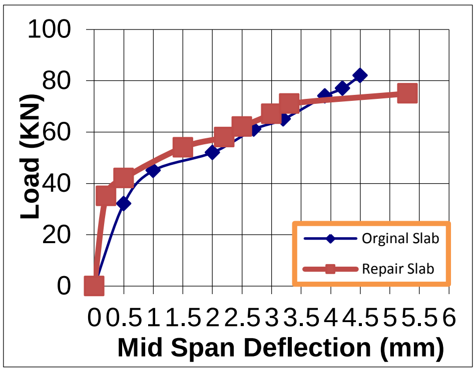

Figure 5.6:Load versus mid-span deflection (S6)

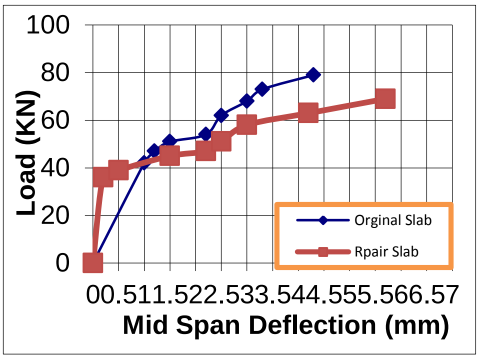

Figure 5.7: Load versus mid-span deflection (S7)

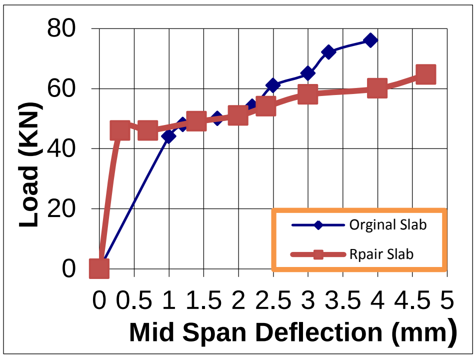

Figure 5.8: Load versus mid-span deflection (S8)

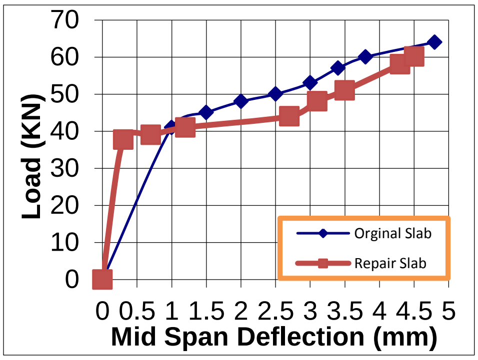

Figure 5.9: Load versus mid-span deflection (S9)

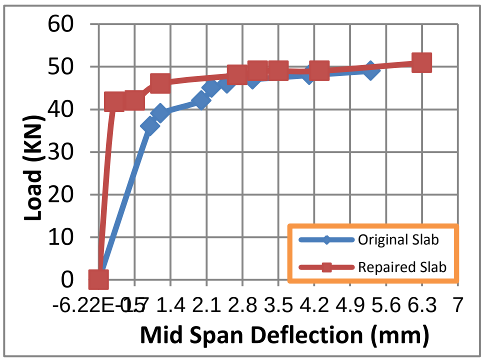

Figure 5.10:Load versus mid-span deflection (S10)

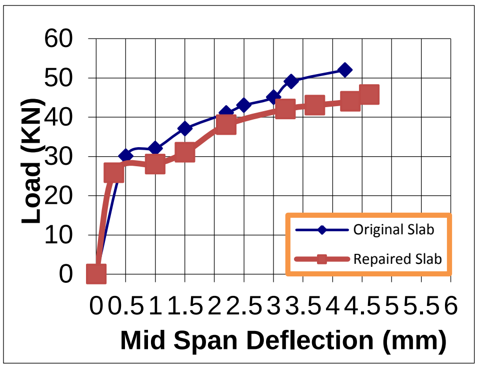

Figure 5.11:Load versus mid-span deflection (S11)

3-2-4 Deformation Results

Figs.(5.6) to (5.9) show the load-deflection behavior of the original and repaired slab, the behavior of theis two slabs is nearly similar. For original slabs, the deflections at flexural cracking loads are less than corresponding deflections of repaired slabs. The maximum deflections of the repaired slabs S6, S7 and S8 are greater than the maximum deflections of the original slabs. For slab S9 , the maximum deflection of the repaired slab is lower than the maximum deflection of the original slab.A lower stiffness and greater ductility of the repaired slabs compared with original slabs is show in theis figures, as may be expected. This may be attributed to the hair line cracks, which presence in the repaired slab, and difference in stiffness of original slab and stiffness of repaired slab.

Figs.(5.6) to (5.9), show that up to pre-failure stage the ductility increase and reduction in stiffness for original and repaired HSC slabs are more noticeable than those for NSC slabs.

This study indicates that after repairing NSC slabs the increase in maximum deflections is relatively heigher than that for HSC slabs at failer stage. This due to fact that the HSC slabs more brittle failure compered with NSC slabs.

3-3Light-weight Concrete Slabs

This group consists of two slabs designated as S10 and S11.

3-3-1Repairing Process

The repairing process is done fore all slabs after failure. The process of epoxy resin injection is done easily and successfully for the major flexural cracks of the two slabs and the minor flexural crack of slab S10 because the cracks width in these slabs are wide enough there for the injected resin is easy penetration.

For the minor diagonal crack in slab S11, the injection process is done with longer time and some difficulty ,becouse the width of flexural crack is relatively small, the epoxy resin penetration became difficulte and limated to penetrate into the crack, this will happen in slab loaded to level of load leas than 100% of the ultimate load obtained for control slab.

3-3-2Behavior of Repaired Slabs

After repaired major and minor flexural cracks in slab S10, these cracks do not reopen, failure in theis slab was happen due to developed new flexural cracks, theis cracks as the same sequence and formation as the flexural cracks in the original slab. In slabs S11 the major flexural crack do not reopen, failure in theis slab was happen due to reopening of the repaired minor crack as a result of incomplete penetration of the epoxy resin into the fine flexural crack. Near the repaired major flexural cracks a new flexural ceacks were developed in the two slabs ,Figs.(3.5).

3-3-3Flexural Strength Results

For the repaired slab S10 the flexural cracking load is greater than that for the original slab. The ratio of the flexural cracking load for the repaired slab to the original slab (Fcr / Fco) is 1.16.

For repaired slab S10 the flexural ultimate load is greater than those for original slab. 1.21 is the ratios of the flexural ultimate loads for repaired slab S10 to original slab (Fur / Fuo).

The repair process increasing and restoring the flexural capacity of the slab S10.
For repaired slab S11 the flexural cracking load is lower than those for original slab. 0.97 is the ratios of the flexural cracking loads for repaired slab S11 to original slabs (Fcr / Fco). The flexural ultimate load for the repaired slab S11 is less than those for the original slab. 0.98 is the ratios of the flexural ultimate loads for repaired slabs to original slabs (Fur / Fuo).
The repaired slab S11 exhibited the same behavior as the repaired slab S10 until the repaired minor crack reopened which caused an early failure before the repaired slab develops its full capacity which may exceeds the original slab capacity (as in slab S10).
This investigation indicate that the flexural capacity of the LWC slabs after repair increase greater than that for NSC and HSC slabs, see Table (7).

3-3-4 Deformation Results
Figs.(5.9) to (5.11) show the load-deflection behavior of the original and repaired slab, the behavior of theis two slabs is nearly similar. For repaired slab S10 the deflections at flexural cracking loads is greater than the corresponding deflections of the original slabs. The maximum deflections of the repaired slabs S10 is greater than the maximum deflections of the original slab. For slab S11 , deflections at flexural cracking loads and the maximum deflection of the repaired slab is lower than the deflection of the original slab.A greater ductility and lower stiffness of repaired slabs compared with original slabs is show in theis figures, as may be expected. This may be attributed to the hair line cracks, which presence in the repaired slab, and difference in stiffness of original slab and stiffness of repaired slab.
Figs.(5.9) to (5.11), show that up to pre-failure stage the ductility increase and reduction in stiffness for original and repaired LWC slabs are less than those for HSC and NSC slabs. At failure, increase in maximum deflection in repaired slabs records its highest value in slab S10 which is made of LWC among all NSCand HSC slabs ,Table (8).

Conclusions

1. The strength and deformation characterestics of light-weight concrete slabs are, in general, similar to those of normal concrete slabs but they exhibit a more ductile behavior than normal concrete slabs.

2. The flexural capacity of the slabs is increase or at least restor by using the epoxy resin .

3. For lower-strength (normal and light-weight) concrete repaired slabs the increase in flexural capacity is relatively higher than the higher-strength concrete repaired slabs.

4. Greater ductility and lower stiffness for repaired slabs compared with the original slabs.

5. For HSC concrete slab the increase in ductility and the reduction in stiffness after repair are more noticeable compered with NSC and LWC concrete slabs, while at failure, in the repaired slabs the increase in maximum deflections for HSC slabs is lower than for NSC and for LWC slabs.

6. The repaired major flexural cracks in lower-strength (normal and light-weight)concrete slabs do not reopen.

7. The repaired major flexural crack reopens in some higher-strength concrete slabs because the compressive strength of adjacent concrete and injected resin has approximately similar.

8. Repair of reinforced concrete slabs using epoxy resin injection method is successful in increasing flexural capacity of the slabs after repair of all level of loading, and the level of loading is effected only to the widths of the crack.

9. The crack injection process is done easily and successfully for the range of cracks width from 0.5 to 1.0 mm and for cracks width more than 1.0mm becam more easier. For crack widths less than 0.5 mm(for slab loaded to level of load less than 100%), the process is done with some difficulty **,**the epoxy resin penetration became difficulte and limated to penetrated into the crack because of the relatively small width of flexural crack.

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