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Experiment Investigation of Behavior of Preloaded Thick One –Way Slabs Repaired by NSM CFRP Plate

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Abstract

Five slab specimens, including two reference specimens, without strengthening and three specimens strengthened with CFRP plate were tested to examine the utilizing carbon fiber polymer NSM method in damaged slabs repairing. Examinations were made by comparing the behavior of specimens without damaged to that of preloaded up to 60% from the flexural load capacity of the reference slab. CFRP strips length is the parameter which is studied in this current work.

After the preloading portion of the experimental tests, slabs with CFRP plate showed fewer cracks than the reference slabs. However, the pattern of the cracks for the slabs has similar behavior. The effect of added CFRP strips length on the mid span deflection was obvious, where the deflection increased by around (59.9, 39.4, and 27.1%) for S3, S4, and S5 concerning the specimen S2. This repair system is able to upgrade and improve the flexural performance of damaged reinforced concrete slabs

Keywords:CFRP, preloaded , repairing, thick One –Way Slabs.

1. INTRODUCTION

Near Surface mounted (NSM) technique of carbon fiber reinforced polymer (CFRP) has become an efficient method for repairing damaged concrete structures all over the word. An important issue in the repairing of damaged concrete structures using NSM is to design against de-bonding failures. This adhesive parameter is crucial on the load transfer action of the bonding technique, since the shear stresses transferring between the composite strip and concrete block is depends on bonding agent, in both ultimate and service loads. Pre-loading circumstances had an impact on the investigational outcomes. Appearance of Cracks has negative effects for bonding agent as well as the performance of structural members result from pre-loading stresses. Cracking is one of the common failures monitored in all structural members. For the purpose of restoring the flexural capacity of the damaged members, repairing or strengthening is required{1}{2}{3}{4}{5}{6}

{7}looked at the performance of one-way reinforced concrete (RC)specimens that were repaired by (CFRP). Three parameters were studied: the amount of steel, the amount of pre-loading, and the length of the CFRP plate. Specimens repaired with CFRP that was preloaded and pre-cracked had fewer cracks than those that were preloaded without repairing. By adding CFRP plates the cracks behave can be greatly improved. Different techniques could be used to repair and strengthen pre-loaded slabs, Ferro-cement layers, steel plates, and FRP plates. It was found that CFRP strips is the most powerful technique among all aforementioned {8}{9}

The amount of preloading percentage had no effect on the crack pattern as well as deflection of the repaired slabs, which all reached the same maximum deflections [10]

[11] investigated the behavior of pre-cracking RC slabs repaired by NSM CFRP laminates using stiff and flexible adhesives. Two variables were examined during the loading process, pre-cracking slabs and the type of glue. Using a flexible adhesive gave 80 percent of failurecapacity that could be obtained with a hard adhesive. The slabs were stable even though they had been pre-damaged

In this study, the research reported an experimental investigation on the preloaded thick one way reinforced concrete slabs. CFRP NSM technique was employed to repair the damaged slabs. Cracks pattern, load capacity, and mode of failure are presented and discussed. Energy absorption capacity and Ductility factor is calculated from the test data

2. PLAN OF EXPERIMENTATION

2.1. Testing Specimens and Material

The experimented work comprised slabs casting, pre-loading, strengthening, and testing slabs to failure. The slab dimension is 1200 X 600 X 200 mm. they were designed according to ACI 318-14 design code [12].The longitudinal steel rebar was 5ϕ10, the temperature and shrinkage steel rebar was 8 ϕ10 in the lateral direction, as in Fig (1). Two un-strengthened slabs and three strengthen slabs by NSM CFRP plate (thickness 1.2 mm) were tested under two-line loads. All specimens except the first one (S1) were tested under a preload protocol equal to 60% of the ultimate load of slab S1 (0.6*455=267kN) to get a damaged ratio of 60%. The experimental program was designed to examine the flexural repair improvement for the damaged reinforced concrete one-way slabs. The second one (S2) was un-strengthened while the other three slabs were repaired with NSM CFRP strip, as shown in table (1). The results were discussed with three main divisions to comprehend of the performance of preloaded RC one-way. These are;

- Cracks pattern, load capacity, and mode of failure.
- Load-deflection behavior.
- Ductility factor.

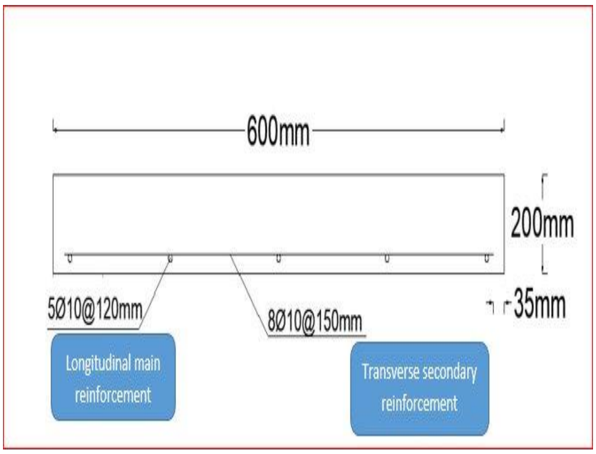

Fig (1) Structural details of test specimen

Table 1. specimens details

symbol	Pre-loading %	Strengthening material	CFRP strip length (mm)	CFRP strip width(mm)
S1	----	---	---	---
S2	60	---	---	---
S3	60	CFRP plate	1000	30
S4	60	CFRP plate	800	30
S5	60	CFRP plate	600	30

The concrete material properties are illustrated in Table (2). Table (3) presents the mix proportions to produce 1 m3 of the concrete. The target strength was 35 MPa, and measured strength was 37 MPa.Tensile test results of steel bars are presented in Table (4). Specimens were casted in three layers and set using vibrator to get an acceptable compaction. Slabs were de-moulded after 36 hours and immersion in a water tank for the remaining 28 days. Then, slabs were moved to civil engineering lab for ten days prior testing.

Table 2. Mix proportion of concrete

Property	Experimental	ACI318M (2014)
Compressive strength (f'c) (MPa)	37.865	-
Splitting tensile strength (f 'ct) (MPa)	3.78	3.09 ($0.5\sqrt{f'c}$)
Modulus of rupture (f r) (MPa)	6.8	3.83 ($0.62\sqrt{f'c}$)
Modulus of elasticity (Ec) (MPa)	-	29010.8 ($4700\sqrt{fc'}$) 29926.2 (Wc1.50.043$\sqrt{fc'}$)

Table 3. properties of mix design

Target compressive strength (MPa)	Measured compressive strength (MPa)	Water-cement ratio	Cement (kg/m^3)	Sand (Kg/m^3)	Coarse aggregate (kg/m^3)	Super. % by wt. of cement
35	37	450	450	580	1078	3.5

Table 4. Tensile test results of steel bars

Property	Test results
Nominal steel bar DIA. (mm)	10
Actual steel bar DIA. (mm)	10.06
f_y (MPa)	524
f_u (Mpa)	650
E_c (Mpa)	200000

Carbon fiber plate SikaCarboDur S1012 was used with elastic modulus was 160 Gpa and tensile strength 2800 Mpa. The structural adhesive paste used Sikadur-30 Lp. This adhesive material consists of two parts; epoxy resin (white) color and hardener (black) color. These two parts were mixed with 3:1 ratio. The procedure of CFRP installation was that grooves with (1.2 mm) width and (30mm) depth were cut after 28 days of concrete curing by using diamond cutter in concrete sides then the grooves were washed and cleaned by compressed air to remove all dust. CFRP plate was cut in a proper dimension before installation. The two parts of adhesive past were mixed in a proper amount until grey color was appeared. Mixing time is about 3 min inside with temperature 35° C. According to the manufacturer's instructions. Epoxy adhesive were put inside the groove and CFRP plate was inserted inside the groove and extra adhesive amount had been removed. By using spatula, the surface was smoothed. Adhesive was permissible 7days in air before testing for curing. All specimens were painted before testing in order to follow the cracking path. Fig2 explain the installation procedure. Table 4 & 5 shows the mechanical properties of CFRP and epoxy resin, respectively.

Fig 2: Steps of strengthening by CFRP plate

Properties	Sika CarboDur S1012
Tensile strength (MPa)	2800
E- modulus (GPa)	160
Strain at break (min.) %	1.69
Width (mm)	(15-30)
Thickness (mm)	1.2

Table 5.mechanical properties of CFRP

Table 6. mechanical properties of epoxy resin

Properties at 7days and 25°c	**Sikadur-30 Lp**
Tensile strength (MPa)	12-15
E-Modulus (MPa)	10000
Compressive strength (MPa)	>85
Bond strength	> 4
Mixing ratio	1B:3A

2.2 Experimental Setup

five simply supported slab specimens were tested at the Civil Engineering Lab., Al-Nahrain University by using a2000 kN capacity hydraulic universal testing machine. The tests were conducted, as in the fig 3. At first, the slabs were supported along their short sides by solid steel support with the clear span 1100 mm. Stiffened steel plates with breadth (50 mm) were put over the supports and under load actuator to distribute loads over the concrete's surface[13].I-section (steel beam) was installed above the slab with length (500 mm) and depth (200 mm) to apply the two-line loads as shown in Fig4. The mid span deflection is measured by applying the dial-gages at bottom face of slab.

Fig 3: hydraulic testing machine

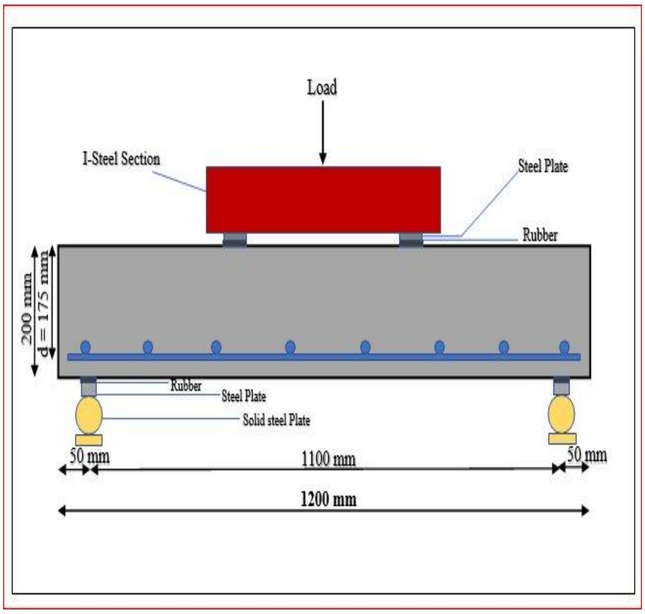

Fig 4: Test setup and instrument

3. EXPERIMENTAL RESULTS

3.1 Cracks pattern, load capacity, and mode of failure

The experimental results concerning the loads at cracking and the loads at failure are listed in Table 6. It is noticed that the first flexural crack occurred at the different applied load (98-128 kN) for all specimens, with different cracking load / ultimate load (**Pcr** / **Pu**) percent as shown in Table 6. It was concluded that the cracking load is the same for the un-strengthened slabs S1 (control slab) and S2 (slab with a preload 60% of ultimate load), while ultimate load for S2 was decreased by 19.6 % concerning S1.

The percent of the decrease in cracking load of slabs S4, and S5, was 18.3, 1.7 respectively, concerning slab S2, while the percent of the increase in cracking load of slab S3 was 7% concerning slab S2. the percent of the increase in ultimate load of slab S3, S4, and S5 were 18.5, 8.8, and 7.9% respectively, concerning slab S2.

Increase the added CFRP strips length has a minor influence on the **Pcr** / **Pu** percent, where this percent was 29.5, 24.6, and 30 for slabs S3, S4, and S5 respectively, flexural cracks initiated in the mid span of tension side of the specimen (max. moment value) when tensile stresses in concrete bottom fiber exceeded the concrete modulus of rupture. Then cracks developed slowly to slab edges parallel to the support's direction. Then, cracks were extended to the both sides of specimen. Crack pattern for specimens is shown in figs. (5) to (9). It was obvious that tension cracks are almost comparable as well as there are no cracks were observed near slab's ends. Also, it was clear thatcrack pattern for the slabs has similar behavior.

Table 7. Cracking loads and Ultimate Loads of Monotonic load test.

Specimens	Description	Width of CFRP strip (mm)	Area of CFRP strip (mm^2)	Max. Load (**Pu**) (**kN**)	Load at first crack (**P** cr) (**kN**)	% of the change in Cracking Load concerning Ref. S2	**Pcr** / **Pu** (%)	% of the change in Ultimate Load concerning Ref. S2
S1	Control slab	-	-	455.16	120	100	26.4	+24
S2	without strengthening	-	-	366.03	120	Ref.	32.8	Ref.
S3	Strengthened with (2*1000mm)	30	72	433.59	128	+7	29.5	+18.5
S4	Strengthened with (2*800mm)	30	72	398.39	98	-18.3	24.6	+8.8
S5	Strengthened with (2*600mm)	30	72	394.98	118	-1.7	30	+7.9

Fig 5 Cracks Pattern for Tension and Front Side of (S1).

Fig 6 Cracks Pattern for Tension and Front Side of (S2).

Fig 7 Cracks Pattern for Tension and Front Side of (S3).

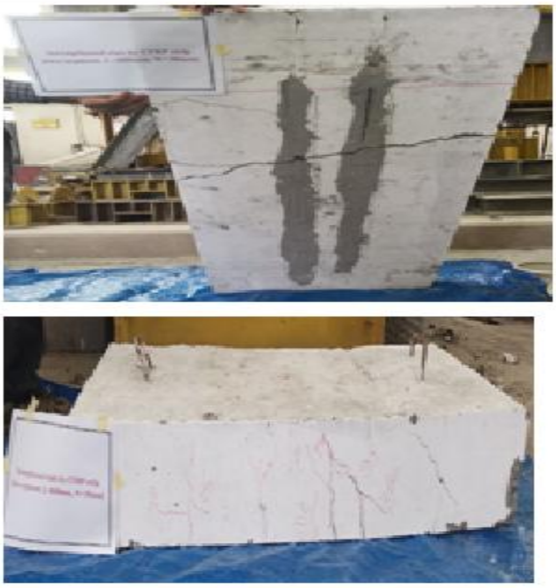

Fig 8 Cracks Pattern for Tension and Front Side of (S4).

Fig 9 Cracks Pattern for Tension and Front Side of (S5).

Table 7 shows the cracking width at ultimate load. The percent of the increase in ultimate crack width was 3.6% for specimens S1 concerning specimen S2. The percent of the decrease in ultimate crack width was 14.3, 7.1, and 10.7 % for specimens S3, S4, and S5, respectively, concerning specimen S2. Adding FRP strip has a considerable influence on the stiffness of slabs, the increase of adding FRP strips area increased the stiffness of slabs which leads to a decrease in the cracking width.

Table 8. Cracking at Ultimate Load of Monotonic load test.

Specimens	Ultimate crack width, (mm)	decreasing in Ultimate crack width, (%)
S1	1.45	+3.6
S2	1.4	Ref.
S3	1.2	-14.3
S4	1.3	-7.1
S5	1.25	-10.7

3.2 Load-deflection results

Each load incrementationof tested specimens, deflection at the mid-span was obtained.Deflectionswere discussed at service and failure load. Tan KH. Zhao H. {14}showed that load at service state is ranged (70-75%) of failure load. The service load was considered to be 70% of failure loads for each specimen while the loads at failure were considered the peak recorded loads, see Table 8

In general, when the load is applied gradually, at first stage, deflection will increase at a constant rate (elastic region), then after (generation and development of cracks) the deflection increases at a faster rate and continues to increase until longitudinal steel rebar yielding.

Fig 10 shows a comparison of load-deflection behavior between the two un-strengthened slabs, the reference slab (S1) and the un-strengthened slab with a preload to 60% of the failure load of the control specimens (S2). This figure shows that both slabs have the same stiffness in the elastic region while after that the stiffness of S2 is weaker, in other words, the deflection of S2 is less than S1 at the same load level, this is because that S2 had the preload, despite that both slabs are similar. Also, the ultimate load of S2 was 80.4% of S1. The central deflection of S2 decreased by about 29.3, and 39.4% concerning the specimen S1 at service and ultimate load respectively, as shown in table 8

Table 9.Slab's deflections at mid-span

Specimens	Ultimate-load (kN)	Service-load (kN)	Def. at service-load (mm)	Decrease ratio (def. at service-load)	Def at failure-load- (mm)	Decrease ratio (def. at failure-load)
S1	455.16	318.6	12.16	Ref.	19.63	Ref.
S2	366.03	256.2	8.6	29.3	11.9	39.4

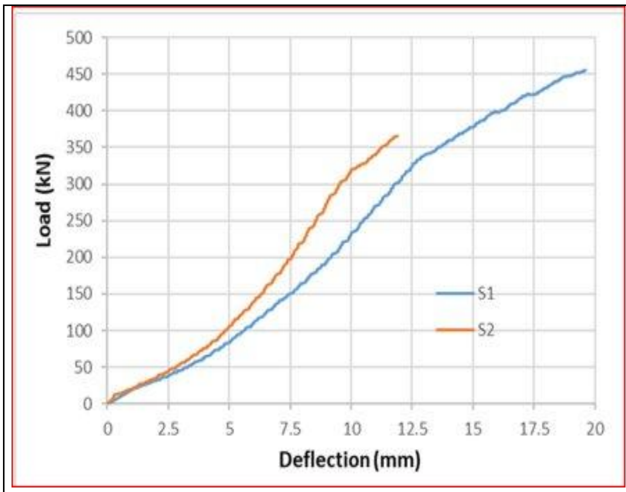

Fig 10: A comparison of load-deflection behavior between S1 and S2.

The effect of added CFRP strips length on recorded load-deflection behavior is illustrated in Fig. (11) and table 9. The results for specimens S3, S4, and S5 are compared with S2 (the control specimen without CFRP). From load-deflection curves, it is clear that the four slabs have the same stiffness in the elastic region while after yielding of tension reinforcement the increase of added CFRP strips length is directly proportional to slab stiffness. However, the effect of added CFRP strips length was obvious, where deflection increased of (26.3, 16.2, and 12.09%) for S3, S4, and S5 concerning the specimen S2. While the effect of added CFRP strips length on the deflection at ultimate load is more effective, where the deflection increased by almost (59.9, 39.4, and 27.1%) for S3, S4, and S5 concerning the specimen S2. As shown in table 9.

The energy absorption of a one-way slab is calculated area below load deflection curve[15].The energy absorption up to the slabs strength is the most appropriate indication of flexural response to seismic. From the outcomes in Table 9 and fig. 11, it is clear that the absorbed energy increased with the increase in added FRP strips length.

Table 10. Effect of added CFRP strip length on deflections at mid-span of slabs at service loads and ultimate loads

Specimens	Description	Def. at serviceload (mm)	increaseratio (def. at service-load)	Def at failure load-(mm)	Increase ratio (def. at failureload)
S2	without strengthening	8.6	Ref.	11.9	Ref.
S3	Strengthened with (2*1000mm)	10.86	26.3	19.03	59.9

S4	Strengthened with (2*800mm)	9.99	16.2	16.59	39.4
S5	Strengthened with (2*600mm)	9.64	12.09	15.12	27.1

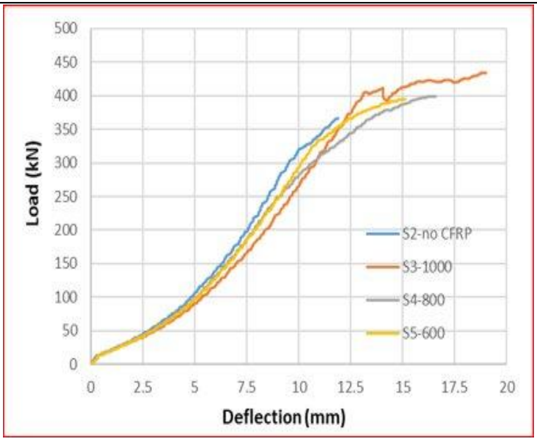

Fig 11: Effect of added CFRP strips length on load-deflection behavior at mid-span.

3.3 Ductility factor

The ductility factor represents the structural member's capacity to withstand significant deformation. Fig (12) illustrates the influence of adding FRP strips length on the ductility factor of slabs. Ductility factor was given in Table (10) for all specimens

Table 11. Ductility Factor for Slabs

Specimens	Load at yielding (kN)	Def.at yielding (mm)	Def. at failure (mm)	Ductility factor
S1	345	13.42	19.63	1.463
S2	320	10	11.9	1.19
S3	404	13.28	19.03	1.433
S4	355	13	16.59	1.276
S5	334	11	15.12	1.375
Ductility Factor = Ultimate Deflection / Yield Deflection				

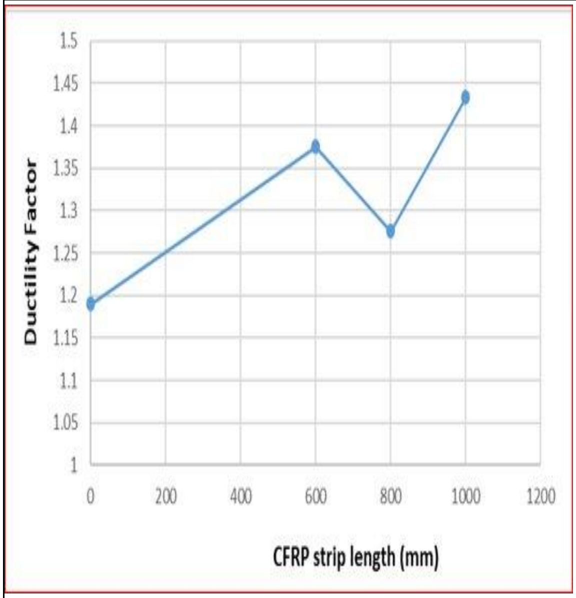

Fig (12): Effect of the added length of CFRP on ductility factor.

4.CONCLUSIONS

•The cracking load is the same for the unstrengthened slabs S1 (control slab) and S2 (slab with a preload equal to 60% of the ultimate load of slab S1), while the ultimate load for S2 was decreased by 19.6 % concerning S1

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•The percent of the decrease in cracking load of slabs S4, S5, and S6 was 18.3, 1.7, and 20% respectively, concerning slab S2, while the percent of the increase in cracking load of slab S3 was 7% concerning slab S2.

•The percent of the decrease in ultimate load of slab S6 was 24.5% concerning slab S2, while the percent of the increase in ultimate load of slab S3, S4, and S5 were 18.5, 8.8, and 7.9% respectively, concerning slab S2.

•Increase the length of added CFRP strips has a minor influence on **Pcr** / **Pu** percent, where this percent was 29.5, 24.6, and 30 for slabs S3, S4, and S5 respectively, while the distribution of added CFRP strips was more effective.

• For all specimens, the first flexural crack initiated in the mid span of the slab (maximum moment) when tensile stresses in concrete bottom fiber exceeded the concrete modulus of rupture. Then cracks developed slowly towards slab edges parallel to the support's direction.

• Percentage of the increase in ultimate crack width was 3.6% for specimens S1 concerning specimen S2. The percent of the decrease in ultimate crack width was 14.3, 7.1 and 10.7 % for specimens S3, S4, and S5, respectively, concerning specimen S2. Adding FRP strips have a noticeable influence on slabs stiffness, the increase adding FRP strips area increased the stiffness of slabs which leads to a decrease in the cracking width.

5. ACKNOWLEDGMENT

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7. BIOGRAPHIES

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