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Effect of Pre-Compression Ratio on the Flexural Behavior of Two Way Bonded Post Tensioned Slabs Pre-Strengthened with External CFRP Strips

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Abstract: This paper introduces experimental study concerning of the effect of pre-compression ratio on the flexural behavior of two-way bonded post tensioned slabs pre-strengthened with external CFRP strips. In order to evaluate the strength improvement offered by attaching the CFRP strips, three post-tensioned, simply supported concrete slabs were checked in the laboratory. One of each was a control specimen and two were strengthened using CFRP strip. The specimen failure resulted either by concrete crushing and/or by rupture of the CFRP. A 62.18 %, 58.2 %, and 37.8 % improvement in ductility, initial stiffness, and deflection compared to control specimens was provided by the post-tensioned concrete slab with bonded tendons and strengthened with CFRP strips with a pre-compression ratio of 1mpa. On the other side, the ultimate load was increased by the post-tensioned concrete slab with a pre-compression ratio of 2mpa and reinforced with CFRP strips and deflection by 27.1%, 43.2% and a decrease in ductility and initial stiffness by 18.36%, 41.8%, respectively when compared to strengthen slab with CFRP strips that had 1mpa pre-compression ratio.
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1. Introduction

There are extra benefits of post-tensioned concrete slabs, such as rapid construction, reduced total member depth and low materials. Moreover, Post-tensioned concrete slabs with good Post-tensioned show no deflect and few cracks under loads. Although there are many benefits of post-tensioned concrete slabs, their efficiency remains uncertain, and the actions of bidirectional slabs are more difficult to assess than those of one-way slabs [1].

Since the mid-1980s, externally bonded FRP systems were used to reinforce and retrofit existing concrete structures worldwide.

FRP systems have been developed in Europe as alternatives to steel plate bonding. It was shown that bonding steel plates to the tension zones of concrete members with adhesive resins was a viable technique to increase their flexural strengths (Fleming and King 1967). To strengthen many bridges and buildings, this technique has been used around the world. Researchers have been looking at FRP materials as an alternative to steel because steel plates can corrode, contributing to a deterioration of the bond between steel and concrete, and because they are hard install, install, needing the use of heavy machinery. As early as 1978, experimental work in Germany using FRP materials for retrofitting concrete structures was documented (Wolf and Miessler 1989). Research in Switzerland contributed to the first implementations of externally bonded FRP systems for flexural reinforcement of strengthened concrete bridges (Meier 1987; Rostasy 1987) [2-3]. Depending on how they are delivered to the site and installed, FRP system forms can be classified. Based on the appropriate transfer of structural loads and the ease and simplicity of application, the FRP system and its type should be chosen. The common types of the FRP system appropriate for reinforcing structural members are: Wet layup systems, Prepreg systems, Pre-cured systems and Near-surface-mounted (NSM) systems.

For post tension member, however, there is a multitude of acceptable designs; each arrived at based on the entry values that a designer assumes. Each of the designs while satisfying the requirements of serviceability and safety, can have a different amount of prestressing. In general case, for a post-tensioned member, a designer must make at least two entry assumption, before initiating a design. The two-assumptions are:

Average precompression (prestressing force (P/A)).

Tendon profile Where: P/A = (Post tensioning force) / (strip width x gross depth)

1. BS8110 [3]: Experience shows that for the pre-compression to be effective, it should be at least 0.7MPa in each direction.

2. ACI318-14[4]: A minimum average effective pre-stress of 125/145=0.862≈ 0.9 N/mm2 on the slab.

3. ECP 203-2018[5]: The pre-compression to be effective it should be at least 0.9MPa in each direction for each tendon at its slab section.

Although many works adopted FRP in strengthen RC members, there has been little study on reinforcing CFRP materials for pre-stressed concrete slabs. Some field applications have been used to repair existing pre-stressed concrete using CFRP, but few full-scale samples were checked to failure [6] the flexural conduct of pre-stressed concrete bridge one-way slabs reinforced with different CFRP systems was examined by Hassan and Rizkalla [7]. The aim of this paper is to present the results of experiment study concerning of strengthening of bonded post-tensioned two-way with different pre-compression ratio concrete slabs using external fiber reinforced polymer (CFRP) strips.

2. The Experimental Program

2.1 Details of specimens

To evaluate the strength improvement offered by attaching the CFRP strips, three post-tensioned, simply supported concrete slabs were checked in the laboratory. One of each was bonded control (BN) and others were bonded to CFRP strips (BS1) and (BS2). Studied and monitored parameters were ultimate load, deflection behavior, ductility index, failure mode and cracking pattern [8-9].

The slabs were square with 2360 mm side length, a supported span of 2000 mm, and a depth of 150 mm and supported with four square columns with 200mm side length and 200 mm height, as shown in Fig. (1).CFRP strip locations are taken as shown at the locations of critical flexural trends. In Table 1, a summary of the designation and test parameters of the specimen is provided.

The three half-scale simply supported slab specimens were tested to failure. The posttensioned slabs were designed according to Post-Tensioning Manual 6th edition (2006) [10], the Concrete Society Technical Report (TR43) (2005) [11], American Concrete Institute (ACI-318) (2014) [4], Egyptian Code of Practice for Reinforced Concrete Construction (ECP 203-2018) [5] and Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R) [12].

The investigated main parameters included: number of tendons in X-direction, Number of tendons in Y-direction, and pre-compression ratio. In addition to the pre-stressing steel, each specimen was reinforced with four 10 mm in diameter steel bars that were required as minimum bonded reinforcement above columns in both X and Y directions, in accordance with the ACI Building code (318-17) [2]. In order to simulate actual slab design and construction, no shear reinforcement was provided in the specimens.

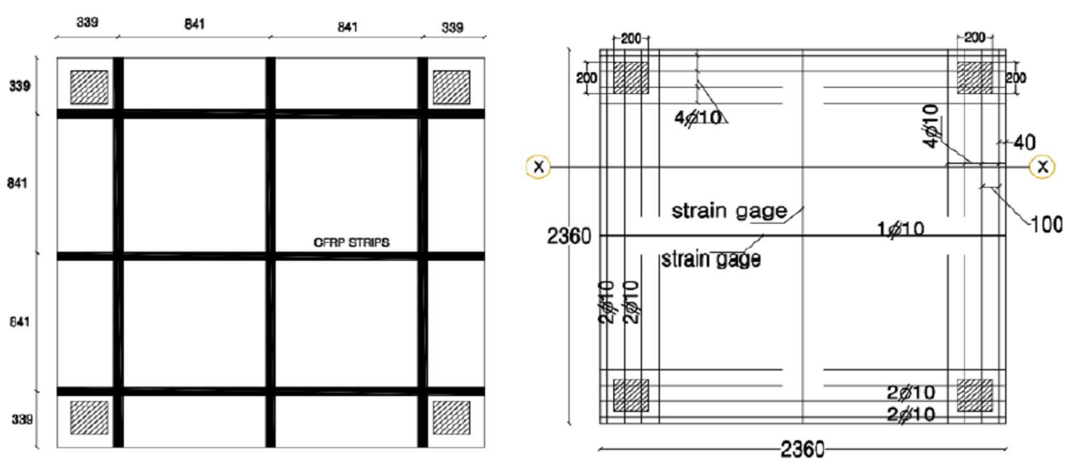


Fig. (1): Specimen Dimension, reinforcement, and CFRP Strips Locations

As shown in Fig. (2), tendon profile, chair distribution and considering the tendon curvature as a second-degree parabola, the heights of the chairs were interpolated. Each tendon goes through live and dead anchorages that were similar. The general layout of bonded posttensioned two-way concrete slabs is shown in Figures 3, 4.

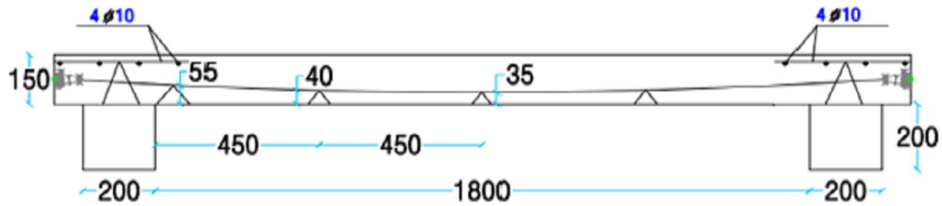
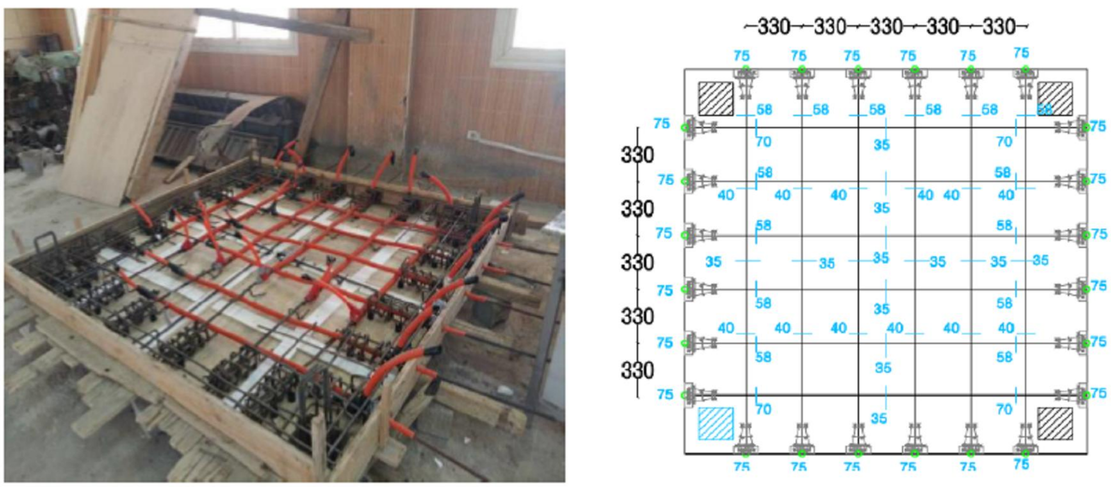
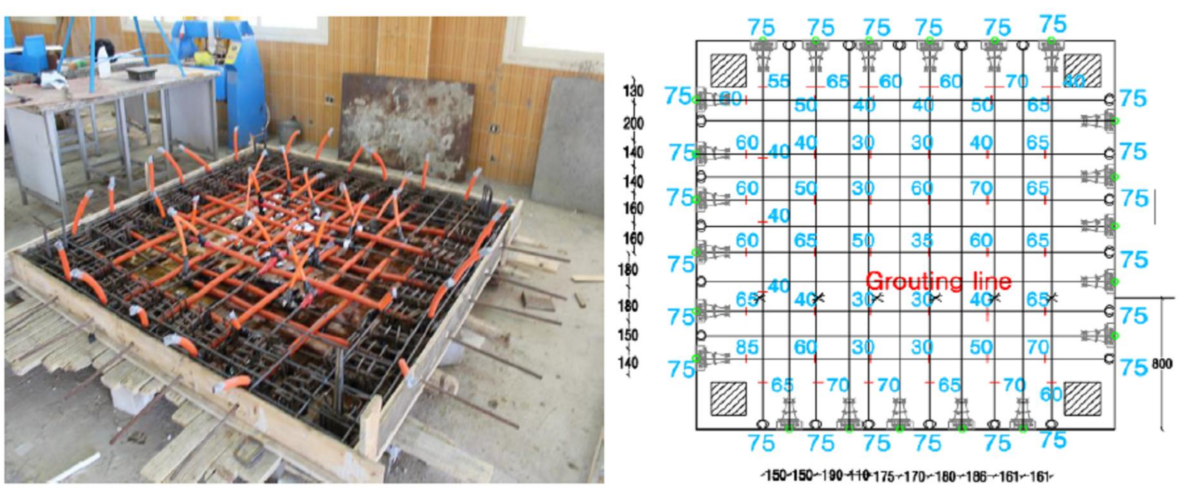


Fig. (2): Chair Distribution and tendon profile for slabs (sec x-x) [All Dimension in mm].



(a) Bonded Tendon Slab (1mpa) (b) Tendon Layout and Distribution

Fig. (3): Tendon Distribution for Bonded (1mpa), All Dimension in mm



(a) Bonded Tendon Slab (2mpa) (b) Tendon Layout and Distribution.

Fig. (4): Tendon Distribution for Bonded slab (2mpa), All Dimension in mm.

Table 1: Summary of Test Specimens Types.

Notation	Specimen types	Test Parameters		
		Type of pre-stressing	No.of tendon in(X-and Y-direction)	pre-compression ratio in(X-and Y-direction)
BN	Bonded Control Slab	bonded	6	1MPa
BS1	Bonded Slab with CFRP Strips	bonded	6	1MPa
BS2	Bonded Slab with CFRP Strips	bonded	12	2MPa

2.2 Material Properties

2.2.1 Concrete Properties

The concrete mix was designed the coarse aggregate: sand: cement proportions by weight were 0.47:0.35:0.18, with a ratio of water to cement of 0.3. The specified 28-day cylinder concrete compressive strength was expected to be 32MPa. Nine cylinders were taken alongside the specimens in order to test the compressive strengths after 7, 28 and at test days respectively. Strengths were recorded as the average of three specimens of each, As shown in Fig. (5).

Fig. (5): Casting and testing standard cylinder of concrete.

2.2.2 Carbon Fiber Reinforced Polymer (CFRP) Strips Properties

Unidirectional carbon fiber reinforced polymer (CFRP) strips were used for FRP strengthening and supplied by Haining Anjie Composite Material. The thickness of the fiber reinforcement per ply (tf) was 1.4mm, the ultimate tensile strength (ffu) was 2,400 N/mm2, the rupture strain (εfu) was 0.015 mm/mm, the modulus of elasticity of FRP laminates (Ef) was 159,400 MP and the width was 50 mm. CFRP strips extended until the face of the support and were applied in accordance with the manufacturer recommendation at the tension face of the slab specimens.

2.2.3 Tendon Characteristics.

The tendon was a mono strand with onion end and duct with vent. The pre-stressing steel was tested and gave a design ultimate tensile strength of 1860 MPa (Grade 270), as shown in Fig. (6). Each slab had six longitudinal tendons and six transverse tendons, the tendon nominal diameter was15.24 mm and the area was150 mm^2, that supplied by Strand for Trading & Construction S.A.E.

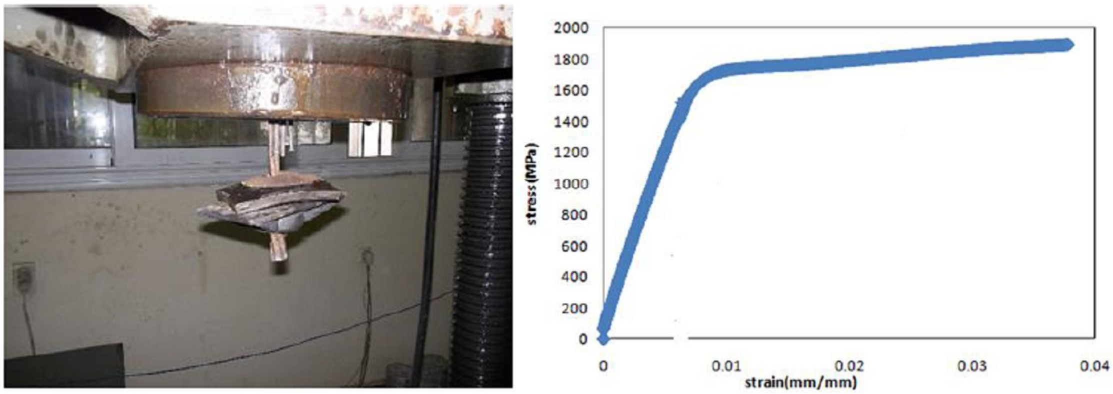


Fig. (6): Bonded Tendon Test.

2.3 Loading of Specimens.

The specimens were loaded comparable to the middle of the span with four concentrated area loads applied symmetrically and separated by a distance equal to 1/6 the span length to simulate as closely as possible the moment diagram produced using uniformly applied load. As shown in Fig. (7). the load was statically applied at a rate of roughly 2 kn/min. At midspan, electrically bonded resistance (EBR) strain gauges were connected to the FRP strip and two EBR strain gauges were directly attached at mid-span to the concrete on the top of the slab. For the deflection measurement of all slab samples, linear variable displacement transducers (LVDTS) were used. A data acquisition system recorded loading, deflection, and strain measurements. The crack patterns were also noticed at each load stage.

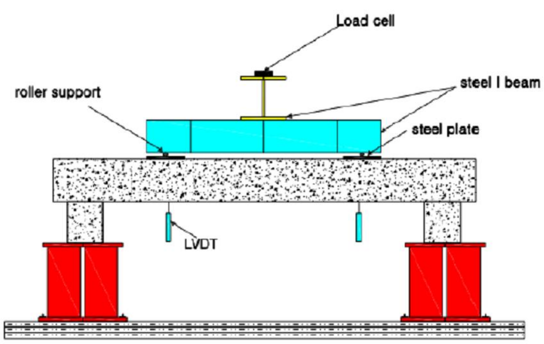


Fig. (7): Test setup

3. Results and Discussions

3.1 Failure Modes and Crack pattern

It is observed that the first crack has occurred near column. As the load increased, successive cracks were formed also at nearby the flexure zones. It was found that cracks in the shear span region have also occurred by increasing the load.

3.1.1 Control Specimens Failure

Bonded control slab (BN) failed due to a combination of pre-stressing steel yielding and a concrete crushing at a load of 464 kn and a deflection of 22.0 mm, with the first crack load 180 KN near column. The load further increases the cracks increase in number and width. Near ultimate, diagonal flexural cracks modes were observed and extended towards the loading area and formed a compression fan, as shown in Fig. (8). The curvature of control slab at failure cause the flexural cracks to bifurcate, or fork, near the compression zone. Crushing have happened at top surface at middle span and increase in crack width at bottom surface at load level 502KN.

3.1.2 FRP Specimens Failure

BS1 slab, it was observed that the first crack propagates near column line at load level 150 KN, as shown in Fig. (9), Loading was gradually increased cracks had regular distributed at bottom surface until load level 200 KN cracks started to appear in slap side. The load further increased the cracks increased in number and width that lead to intermediate crack debonding at load level 460KN at extend to strip edge give rise rupture in CFRP strip at load level 480KN. Near ultimate, diagonal flexural cracks modes were observed and extended towards the loading area and formed a compression fan.

BS2 slab, it was observed that the first crack propagates near column line at load level 170 KN, as shown in Fig. (9), Loading was gradually increased cracks had more regular and widespread distributed at bottom surface until load level 250 KN cracks started to appear in slap side. The load further increases the cracks increase in number and width that lead to intermediate crack debonding at load level 500 KN at extend to strip edge give rise rupture in CFRP strip at load level 610KN. Near ultimate, diagonal flexural cracks modes were observed and extended towards the loading area and formed a compression fan.

Fig. (8): Pattern of Crack, Concrete Crushing For BN

Fig. (9): Pattern of Crack, Debonding of FRP for BS1.

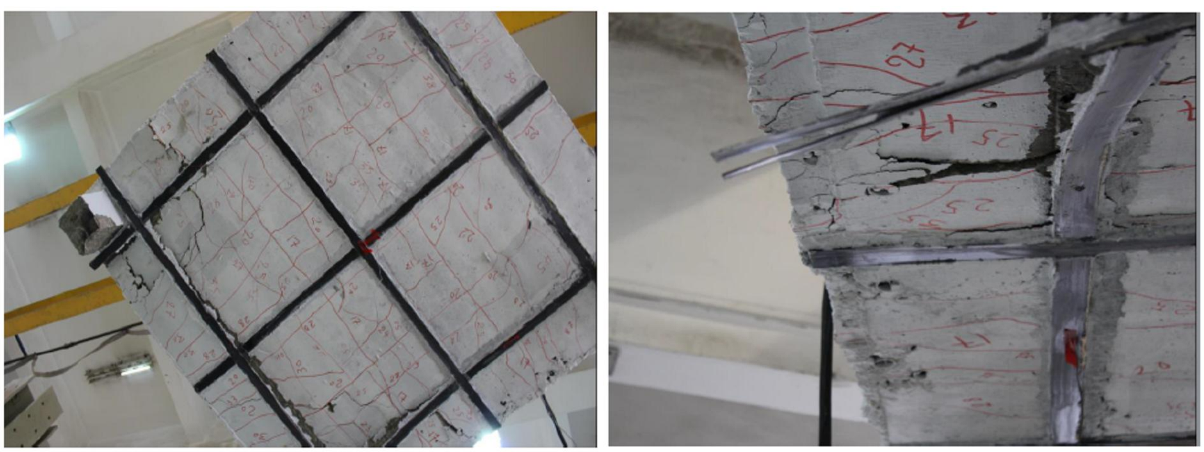


Fig. (10): Concrete Crushing, Debonding and Rupture of FRP for BS2.

3.2 Load-Deflection Relationships

The load-deflection behavior of all tested beam specimens is presented in Fig. (11). From the results, it is indicated that FRP strengthened slabs significantly improved both the ductility and the corresponding deflection. The test result in terms of applied load deflection at cracking, ultimate state, and the modes of failure are shown in Table 2 and Table 3.

Table 2: Loads and Deflections Results of the Tested Slabs

specimens	P_{CR}	Δ_{CR}	P_U	Δ_U	Δ_{MAX}	%strain FRP
BN	179.4	3.22	502	27	44	---
BS1	149.6	10.57	480	25	58	34%
BS2	169.17	4.31	610.37	35.89	48	34%

Table 3: Failure modes

specimens	FRP rupture	concrete cover separation	crushing of concrete	plate end interfacial debonding	intermediate crack induced interfacial debonding	shear failure
BN	N/A	N/A	observed	N/A	N/A	N/A
BS1	N/A	observed	observed	observed	observed	N/A
BS2	observed	observed	observed	observed	observed	N/A

3.3 Ductility Index:

A significant parameter to be regarded in a structure to reflect the structural lifetime is the ductility index. It can be characterized as its ability, prior to failure, to withstand inelastic deformation without loss of load carrying capacity. It is possible to acquire the deflection ductility index as the ratio of the mid-span deflection at the ultimate load to the mid-span deflection at the yield load. The index of ductility was computed for BS1 and BS2 tested slabs a maximum increase for BS1 slab was 62.18% and BS2 slab about 22.5% was obtained as shown in Figure11.

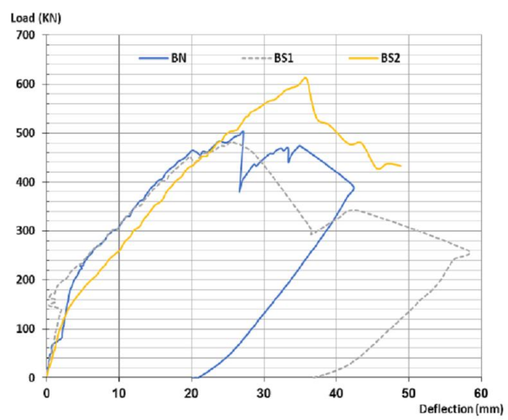


Fig. (11): Load - Deflection Curve for Bonded slabs with pre-compression ratio 1mpa and 2mpa.

3.4 Stiffness:

The initial stiffness of the strengthened bonded slab with CFRP strips BS1 slab was higher than the control slab BN and the strengthened bonded slab with CFRP strips BS2 slab with 36%, 42% respectively. The post cracking was considerably equal for the strengthened slab compared to the control and the strengthened bonded slab with CFRP strips BS1, as shown in Table 4.

Table 4: Initial Stiffness & post cracking stiffness

Specimens	Ki: initial stiffness	Ku: post cracking stiffness
BN	55.7	13.4
BS1	88	12
BS2	51.2	14.6

3.5 FRP Strips Efficiency

From Fig. (12), it is concluded that the effect of increasing pre-compression ratio on the behavior of CFRP strips had no significant effect of the value of maximum strain which can be carried by the strips before deponding. The maximum strain for BS1and BS2 is 34% of ultimate strain.

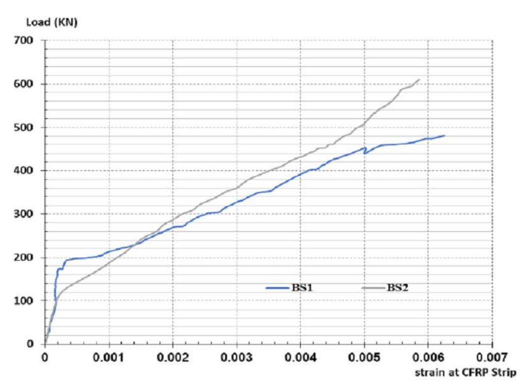


Fig. (12): Strain at CFRP strips for Bonded slabs with pre-compression ratio 1mpa and 2mpa.

Conclusion

To evaluate the strength improvement offered by the attachment of the CFRP strips, three post-tensioned, simply supported concrete slabs were checked in the laboratory. First slab was control with 1mpa pre-compression ratio and two were strengthened with CFRP strips with different pre-compression ratio 1mpa and 2mpa. The parameters studied and monitored were ultimate load, ductility, deflection, mode of failure and patterns of cracking. The following conclusions can be reached based on the experimental program and the analysis of the test outcomes:

1. The failure modes of the slab specimens were concrete crushing, FRP rupture and/or FRP debonding regardless of pre-compression ratio.

2. Strengthening using FRP materials is very effective in increasing the ductility index of bonded post tensioned concrete slabs as ductility was increased by 62.18% when compare to control one with pre-compression 1mpa.

3. The initial stiffness of the bonded strengthened slab BS1 was 36% compare to the control bonded BN with pre-compression 1mpa.

4. The initial stiffness of the bonded strengthened slab BS1 was 42% compare to the strengthened bonded slab with CFRP strips BS2 slab.

5. The increase in ductility due to FRP strengthening result a significant increase in the deformation capacity when compare to control one about 37.88% with precompression 1mpa.

6. The increase in pre-compression ratio from 1mpa to 2mpa had an increase in ultimate load and deflection by 27.1%,43.2% and a decrease in ductility and initial stiffness by 18.36%, 42%.

7. The strain in the FRP reinforcement is 34% of the specified manufactured rupture strain for bonded strengthened slabs BS1 and BS2.

References

1. Min S. K. (2017), et.al," Analytical Model for Deflections of Bonded Post tensioned Concrete Slabs", Article ID 3037946, 7 pages.
2. A. M.M. Ismail (2011), "behavior of statically determinate prestressed concrete beams subject to fire ", PHD thesis, in shams university.
3. BS 8110-1(1997),"Part 1: Code of practice for design and construction".
4. ACI (2015.), "Building code requirements for structural concrete (ACI 318M-14) and commentary (ACI318RM-14)". American Concrete Institute, Farmington Hills, Michigan.
5. ECP203(2018), "Egyptian code for design and implementation of concrete structures",.
6. Schiebel S, Parretti R, Nanni A (2001)" Repair and Strengthening of Impacted PC Girders on Bridge A4845." Missouri Department of Transportation, Report RDT01-017/RI01-016.
7. Hassan T, Rizkalla S (2002). "Flexural Strengthening of Prestressed Bridge Slabs with FRP Systems". PCI J,47.
8. Uksun K., Thomas H.-K. K., and Pinaki R. C. (2010)," Rehabilitation of Unbonded Post - Tensioned Slabs with Different Boundary Conditions", pti journal, v8, No2, December.
9. Fatima. E, M. Harajli (2012), "Strengthening of Unbonded Post-Tensioned Concrete Slabs Using External Frp Composites", Conference Paper · June.
10. Post-Tensioning Institute (2006). "Post-Tensioning Manual (6th edition)".
11. Post-Tensioning Institute. Technical report no.43(,2005), "Post-Tensioned concrete design handbook "(2nd Edition).
12. ACI Committee 440, ACI 440.2R-08(2017), "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures", American Concrete Institute, P.O. Box 9094, Farmington Hills, Michigan, 48331.
13. Owen A. R. (2006)" Behavior of Frp Repair/Strengthening Systems for Prestressed Concrete", Doctor Of Philosophy, North Carolina State University.
14. Usama A. E., Hesham M. (2004)" Fiber-Reinforced Polymer Strengthening of Two-Way Slabs", Aci Structural Journal, 101-S64.

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