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Effect of BFRP Post Tensioning System on Hybrid Reinforced Concrete Slab

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Abstract— This paper represents the effect of post tensioning system on reinforced concrete slab. Three slabs were tested to ensure the system capacity of post tensioning by two techniques. The first specimen is a reference slab reinforced with traditional steel bars system, the second one is cast with an embedded duct (two holes) in slab to install post tensioning basalt fiber reinforced polymer bars (BFRP). Finally, the last one as first specimen but enhanced with external post tensioning BFRP bars. These systems have a fixed level of post tensioning 10% of bar stress. Cast slabs with a rectangular cross-section of 500 mm width, 120 mm depth and an overall span of 3000 mm and were tested under the effect of pure bending moment. The results showed a conservative achievement for post tensioning RC slabs with 10% level of stress.

Index Terms— Post tensioning, RC Slabs, Basalt FRP, Hybrid Reinforcement, RC Slab, Strengthening, Embeded Bars

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1 Introduction

It is known that, the pre-stressed precast slab system with either steel bars or FRP bars has many advantages over ordinary reinforced concrete, such as a reduced construction period, use of long-span one-way slab systems, increase load capacity, and reduce the number and width of cracks. Many researchers have studied the behavior of precast and post-tensioned concrete slabs, and the different types of reinforcement, **E. Brunesi et.al, 2015**, has carried out a modeling approach, based on nonlinear fracture mechanisms, and was proposed to predict the shear response of precast prestressed hollow core (PPHC) slabs. Numerical observations were discussed to investigate the failure mode of the units analyzed and to depict behavioral changes as consequence of geometrical variations in their cross-section shape.

A post-tensioning method using externally un-bonded steel rods was applied by **Swoo-Heon Leeet.al., 2018**, to pre-damage reinforced concrete beams for flexural strengthening. Nine simply-supported beams, three reference beams and six post-tensioned beams were subjected to three-point bending. The design parameters observed in that study were the amount of tension reinforcements and the diameters of the external rod. A V-shaped profile with a deviator at the bottom of the mid-span was applied to the pre-damaged beams, and a post-tensioning force was added to overcome the low load resistance and deflection already incurred in the pre-loading state. Specimens were tested under the effect of flexural and it's noted that, external post-tensioning was highly effective in strengthening the RC beams because the strengthened test specimens generally exhibited stable load–deflection behavior after reaching the maximum load, without a rapid decrease in strength and the rehabilitation or reinforcement of the beams using external unbonded post-tensioning steel rods resulted in enhancements exceeding 28% and 40% in stiffness and strength, respectively. Furthermore, the external post-tensioning was effective in controlling the crack width and re-establishing the service load deflections of the RC beams. This method reduced the crack widths or closed the cracks and resulted in a stiffer load–deflection behavior.

Martin Noel et.al., 2011, presented an experimental investigation on the effects of pre-stressing on the flexural behavior of GFRP-reinforced SCC slabs. A total of six SCC slab strips were constructed and tested up to failure. Each slab had a length of 5000 mm and a width of 600 mm. The height of each slab was 300 mm except for one which had a reduced depth of 250 mm. The area of passive tensile reinforcement in the 300 mm-height slabs was kept constant as each slab contained six No. 16 (#5) GFRP bars in the bottom longitudinal direction, except for the control slab which contained six 15M steel reinforcing bars. Based on the results of this experimental, it's noted that, the GFRP-reinforced concrete slabs displayed higher strength compared with the control slab reinforced with conventional normal-strength steel reinforcement bars with a similar reinforcement ratio. CFRP-post-tensioned slabs displayed significantly greater cracking loads and post-cracking stiffness compared to similar non-pre-stressed GFRP-reinforced slabs, with increases of approximately 150% and 40%, respectively. Pre-stressing significantly reduced crack widths compared with non-pre-stressed slabs. The slabs were uncracked at service loads and crack widths were reduced by more than 50% at an applied load of 100 KN.

Martin Noe1 and Khaled Soudki, 2011, showed an evaluation of FRP post-tensioned slab bridge strips. Five slabs had a height of 300 mm, while a sixth slab was constructed with a reduced depth of 250 mm in order to evaluate whether post-tensioned CFRP tendons can be used effectively to minimize the slab thickness. Three of the slabs did not contain any pre-stressing tendons. These include the control slab, S, and two GFRP-RC slabs, G1and G1ST. An additional three slabs each contained two No. 13 CFRP pre-stressing tendons at a distance of 75 mm from the bottom concrete surface. They concluded that, slabs containing pre-stressed CFRP tendons displayed much lower deflections for the given service load than those which did not, CFRP pre-stressed slabs also displayed similar or better serviceability than the steel RC control slab and Post tensioning techniques significantly reduced crack widths in the members by more than 75% at service loads.

Gouda Ghanem et.al., 2016, studied the flexural behavior of strengthened RC beams using external post-tensioning technique under the effect of cyclic loads. The behavior of RC beams in different levels of cracks was studied. The experimental study included using of prestressing steel bars and GFRP bars and the effect of different percentage of shear reinforcement was taken into consideration. Based on the test results, the conclusions are drawn as follow, the post-tensioning techniques enhanced the performance of cracked beams can restore and enhance their capacities. At cracking load level equal 50% of ultimate load of non-strengthened beam, the ultimate load of strengthened beams with steel prestressing bars were more than ultimate load of non-strengthened beam by 7%. The post-tensioning technique using prestressing GFRP bars recovered the value of ultimate load of non-strengthened beam then gained ultimate capacity load over that of non-strengthened beam by a range of 5 to 21%. The percentage of increasing load capacity depends on level of stress in prestressing bars, by increasing level of stress, the percentage of ultimate load increased. Increasing shear reinforcement (stirrups) showed a little significant effect on the behavior of studied beams. The value of ultimate load of studied beams differs in the range of 3%. This percentage was too small to be effective but during testing of theses beams, by increasing shear reinforcements (stirrups), the crack width reduced for studied beams in the maximum shear zone. The cracking load level for strengthened beams has a significant effect on ultimate load of studied beams. The beams strengthened with external GFRP prestressing bars at cracking load level equal zero% of ultimate load of non-strengthened beam, gave ultimate load more than beams strengthened at cracking load level equal 50% of ultimate load of non-strengthened beam by 23%. It was also noted that, beams strengthened at cracking load level equal zero% of ultimate load of non-strengthened beam, gave ultimate load more than non-strengthened beam by 36%. These calculated percentages were collected at the same prestressing level.

2 Experimental Program

Three reinforced concrete slabs with a rectangular cross-section of 500 mm width, 120 mm depth and an overall span of 3000 mm were tested under the effect of pure bending moment. **Figure.1**. show the test setup for specimens. The main core of this study was the investigation of flexural strength and serviceability of RC slabs reinforced/strengthened with BFRP. S1 was reinforced with traditional steel reinforcement bars but S2 was reinforced with BFRP bars and S3 as the same of S1 but strengthened externally with BFRP bars (Hybrid). **Table 1**, shows the details of tested slabs.

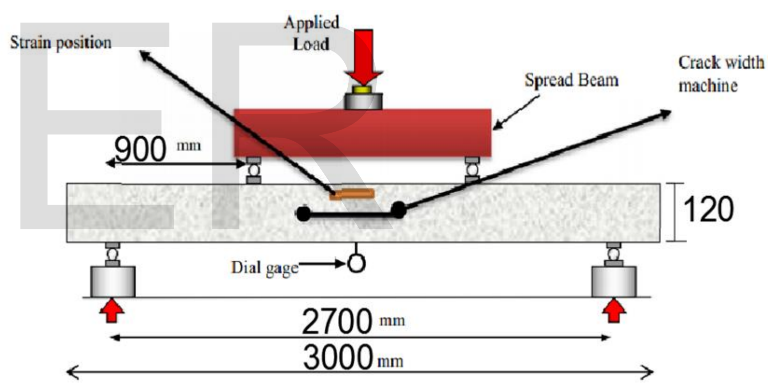

Figure 1: Test Setup

Table 1: Details of Tested Slabs

Slab No.	F)$_{cu}$ N/mm^2	Dimensions (mm) Span x width x thickness	As (mm^2)	A$_f$ (mm^2)	Pre-stressing Technique
S1	35	3000x500x120	3Φ10	-	-
S2	35		-	3Φ10	Internally
S3	35		3Φ10	2Φ10	External

Coarse aggregate is a natural crushed stone of size 20 mm was used in this study for normal strength concrete, from Attaka quarry in Egypt. It was tested according to **E.S.S: 1109/2002**, **Egyptian Standards for Natural Aggregate**. It has specific gravity, volume weight and fineness modulus of 2.58, 16.6 KN/m^3 and 6.68, respectively. Fine aggregate is a natural sand obtained from pyramid quarry in Egypt. It was tested according to **E.S.S: 1109/2002**, **Egyptian Standards for Natural Aggregate**. It has specific gravity, volume weight and fineness modulus of 2.65, 16.8 KN/m^3 and 2.53, respectively. Sand was washed and dried in open area before used. Very fine sand was excluded from the mixture by using fine sieve (No. 200). **Table 2** and **3** shows the results of sieve analysis of coarse and fine aggregate, respectively. Portland cement (El Suez Cement) with CEMI 42.5 N was used in the concrete mix. Testing of cement was carried out according to **E.S.S. 4756-1-2013** and its appendages. Physical and mechanical properties of the used cement are given in **Table 4**. The results of the testes show that the physical and mechanical properties of cement comply with **E.S.S. 4756-1-2013**.

Table 2: Sieve Analysis of Coarse Aggregate

Sieve Size (mm)	40	20	10	5
Passing %	100	98.8	32.5	0.6

Table 3: Sieve Analysis of Fine Aggregate

Sieve Size (mm)	5	2.5	1.25	0.63	0.31	0.16
Passing %	100	95.4	85.39	54.25	10	1.9

Table 4: Physical and Mechanical Properties of Cement

Property		Results	Specifications Limits
Soundness (mm)		4	**Not more than 10 mm**
Fineness of Cement (cm^2/gram)		3190	-
Specific Gravity		3.15	-
Setting Time (minutes)	**Initial**	170	**Not less than 60 Minutes**
	Final	220	-
Compressive Strength (N/mm^2)	**2 days**	22.7	**Not less than 10 N/mm^2**
	7 days	33.9	-

Drinking water was used for mixing and curing of concrete. A concrete mix was designed according to **BS: 5328** to produce concrete of cubic strength of 35 MPa after twenty-eight days. The mix proportions by weight were as follows in **Table 5**. BFRP bars of 3000 mm length and 10mm diameter were used in reinforced concrete slabs. The BFRP bars were manufactured by pultrusion of basalt continuous and thermosetting polyester resin. The tensile testing for three sample of ribbed BFRP bars with 550 mm length were done by installing bar into filled steel tubes with an epoxy material (**Sikadur 31CF component-A**) at its ends. Steel tubes of length 200 mm and 3 mm thickness were used. The specimens were kept more than 7 days before testing to allow curing. The mechanical properties obtained from the tensile test according to the specification of **ACI: 318-14**. Tensile strength, tensile modulus and elongation % are reported in **Table 6**. The used longitudinal steel reinforcement was 10 mm diameter and was tested according to **E.S.S:262/2015, Egyptian Standards for Steel Reinforcement**. Both proof and ultimate strengths for selected diameter is listed in **Table 7**.

Table 5: Proportion of Concrete Ingredients

(F_{cu}) (MPa)	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (Liter/m^3)
35	450	608.7	1126	202

Table 6: Mechanical properties of BFRP Bars.

Type	Diameter (mm)	Tensile strength (MPa)	Tensile modulus of elasticity (GPa)	Elongation %
BFRP Bars	10	835	55.70	1.5

Table 7: Mechanical properties of used steel

Steel Type	Diameter (mm)		Proof Strength (Fy) MPa	Ultimate Strength (Fu) MPa	Elongation %
	Nominal/Actual diameter				
H.T.S	10	10.07	481	608	20.45

3 Fabrication of Slabs

The tested concrete slabs were cast in wood form. Pieces of steel bars spacers were used to hold the longitudinal reinforcement in its position. The concrete was mixed in the laboratory using a mixer. After casting, concrete was compacted mechanically using a 25 mm diameter electric vibrator. Control specimens including three cylinders of 150 mm diameter and 300 mm height and three cubes of 150x150x150 mm were cast from each batch. The forms were removed one day after casting. Each slab and the corresponding control specimens were cured and tested in the same day just after 28 days from casting. The deflection at mid-span was measured by means of dial gauges with an accuracy of 0.01 mm. The dial gauge was fixed on the bottom surface at mid-span of the tested slab to achieve an accurate measurement. The induced strains in bottom basalt FRP, steel bars at mid-span were measured by means of electrical strain gauges. These strain gauges had a 350 Ohms resistance, 2.04 gauges' factor and a length of 15 mm. The strain gauges were attached to the bottom surface of reinforcement at mid span for longitudinal reinforcement and at a distance 600 mm from edge of slab.

4 Testing of Slabs

All slabs were tested at the age of 28 days. The test setup for tested slabs is shown in **Photo 1**. The load was applied at the two points of span of the tested beam using a rigid steel rod. The initial reading of the dial gauge was first recorded. The load was applied in increments. Each increment was about 5 KN. The load was maintained constant between two successive increments for about 2 minutes, to enable recording of the different reading, and observing the initiated cracks.

Photo 1: Test Setup of Slabs

5 Test Results

All specimens were tested to failure and the crack damages were observed. For all test specimens, different load measurements were captured at all stages of testing, the results include load-deflection and load-concrete strain an augmented understanding of the behavior. Discussions of all test results are provided here. This analysis and discussion aimed to study the effect of different parameters on flexural behavior and deformation of the tested slabs. **Table 8**, shows the test results for tested specimens.

Table 8: Test Results for slabs

Tested Slab	Cracking load P_{cr} (KN)	Δ_{cr} (mm)	Yielding load P_y (KN)	Δ_y (mm)	Ultimate Load P_{ult} (KN)	Δ_{ult} (mm)	Pcr / Pult
S1	**6.02**	**5.71**	**35.07**	**48.12**	**35.00**	**53.02**	**17.20%**
S2	**7.06**	**7.53**	**-**	**-**	**23.84**	**81.05**	**29.61%**
S3	**8.09**	**5.56**	**33.05**	**36.18**	**37.50**	**57.07**	**21.57%**

6 Load –Mid-span Deflection Response of Slabs

From **Figure 2**, the relationship between the applied load and the measured mid-span deflection for slabs obvious passed through two phases. The initial part of the curves was linear for all slabs until first crack at load level of 6.02, 7.06 and 8.09KN for S1, S2 and S3, respectively. The second phase was non-linear for all slab and started with first crack level and achieved low young's modulus for tested specimens. It can be seen, that the deflection at failure in slabs S1 which was reinforced with traditional steel bars (3Φ10 steel) slightly smaller than that in slabs S2, S3 due to higher young's modulus for steel bars but slab S2 which were internally reinforced with BFRP bars was slightly larger than that in slab S3 which were externally strengthened with BFRP bars and internally reinforced with steel bars. Hybrid slab S3 showed larger strength than slab S2 and S1. Slab S2 recorded low ultimate strength and higher mid-span deflection than S3 and S1 due to low young's modulus for BFRP bars. The ultimate load of slab S3 more than slab S1 by 7%, which mean approximately the same and prove that the level of stress 10% not the best choice for prestressing systems. The ultimate load for slab S2 less than slabs S1 and S3 due to the larger stiffness of slabs S1 and S3 caused by increase of the steel reinforcement area.

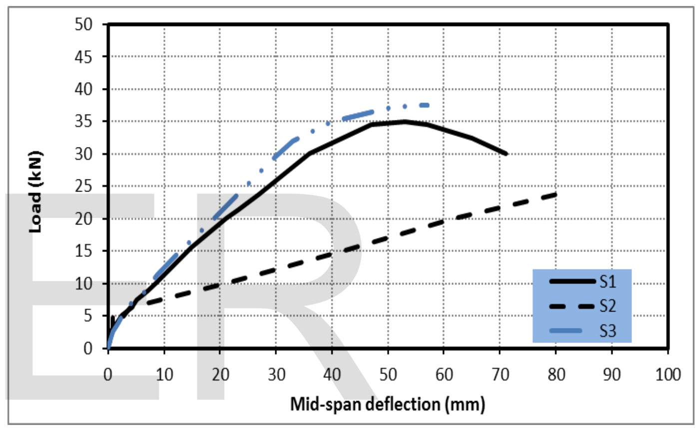

Figure 2: Load Deflection Curve for tested Specimens

From **Figure 3,** In first stage of loading (elastic-stage) there are linear relation between load and strain till proof load then the relation after elastic stage were nonlinear plastic-stage till failure. Finally, after specimen's failure the deflection increased when the applied load decreases. The tensile strain in the main longitudinal reinforcement (steel and Basalt FRP bars) was measured for the different slabs tested under static load condition, the measured values were plotted against the applied load from zero loading up to failure as shown in **Figure 3**. It is obvious that, for basalt FRP reinforced concrete slab S2, the tensile strain increased after the first crack up to about 45% of the ultimate load in comparison to S1. This means that the deformation of BFRP concrete slabs increase quickly after cracking. Also, it can be seen that the steel reached to yield strain, while the BFRP don't ruptured because FRP generally have no plastic range.

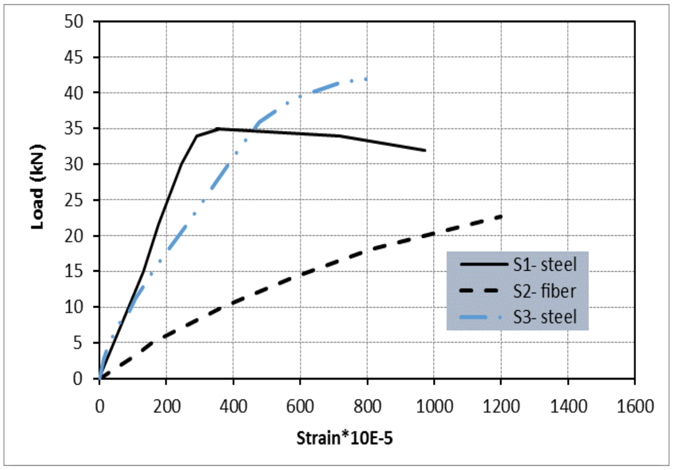

Figure 3: Strain Curve for tested Specimens

7 Crack Patterns and Failure Modes

The slabs were observed visually until the first crack appeared. Cracks starting and spreading for different tested slabs and observed visually for all slabs, it was noticed that the cracks in both sides were approximately similar. The cracks were first start at the bottom side in the flexural moment zone at low load level. The observed first crack was extending up to a point higher than half of the slab thickness. As the load increased, the cracks widened and propagated upward. Later, new cracks were created along the bottom of the slab and these cracks propagated towards the point of load application. A number according to the corresponding load value marked the cracks, which appeared at each load increment. At the end of each test, the crack pattern was sketched and the height of cracks, number of cracks, the cracks spacing and the length of the major cracks were marked. The slope of the major inclined crack at failure with a horizontal line is shown on the crack patterns. **Photo 2. (a), (b) and (c)**, shows crack pattern for tested specimens.

Photo 2: Crack Pattern for different Specimens

Conclusions

The effect of static loading on serviceability conditions and the flexural behavior of concrete slabs reinforced with BFRP bars, hybrid reinforcements (steel and BFRP bars) and, steel reinforcement (A_s) were experimentally investigated. Based on the results obtained. The following conclusions can be drawn:

-The BFRP bars exhibited a linear elastic behavior up to failure with a modulus of elasticity less than that of steel reinforcement.

-Using hybrid FRP is effective in improving the ultimate strength and stiffness of a strengthened slab than using steel reinforcement only.

-The ultimate load capacity increased with increasing the reinforcement ratio.

-Load deflection response due to static loading shows a greater reduction in stiffness in the case of BFRP reinforced slabs than the conventional slab. The slab reinforced with hybrid FRP slabs have larger deflection compared to the conventional slab.

-The conventional slab shows an increase in curvature prior to collapse indicating the typical ductile mode of failure where yielding of reinforcement followed by the crushing of concrete in compression. Whereas in the case of hybrid slabs, there is no yielding of reinforcements the concrete fails in the compression zone.

-Slab reinforced with hybrid bars gives fewer cracking loads compared with slabs reinforced with steel bars only.

- 10% post tensioning level of stress gives no significant enhancement in flexural behavior for tested slabs.

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