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COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS FOR REINFORCED CONCRETE BEAM STRENGTHENED WITH FRP STRIPS

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ملخص البحث:

اصبح مجال تدعيم المنشأت الخرسانية في اللأونة الأخيرة من أكثر المجلات الهندسية تطورا وطلبا في السوق الهندسية في العالم أجمع، حيث ان اكبر مميزاته هي اعادة هيكلة وتوزيع الاحمال المعرضة لها المنشأت الخرسانية واجبار العناصر الانشائية علي تحمل اوزان اكثر من التي صممت من اجلها لعدة اغراض مختلفة، وعلي ذلك تم تنفيذ برنامج عملي علي عدد 3 كمرات خرسانية واستخدام نظام التدعيم بشرائح الكاربون فايبر حيث تعد الياف الكاربون فايبر من احدث واجود الخامات المستخدمة في تنفيذ عمليات تدعيم المنشأت الخرسانية،

1 Abstract :

This paper summarizes the experiments that were carried out to verify the performance of reinforced concrete beams reinforced with (EB) technology using FRP strips. The beams were subjected to three-point loaded testing. In addition, the ultimate shear loads were predicted, as per Egyptian code guidelines, and compared with the experimental results. Finally, a set of recommendations was drawn based on the results of this study and the available literature.

2 INTRODUCTION

Due to its lower ratios of stiffness to weight and strength to weight, as well as due to its lower susceptibility to abrasion, externally bonded fiber-reinforced polymer (FRP) has become an alternative to other conventional reinforcing technologies. In recent years, the real applications of this technology have increased, and it has become a market booster. It has been presented in several papers that the use of fiber-reinforced polymers (FRP) has been a very successful reinforcing method for shear failures in reinforced concrete beams, however, 'debonding' is still one of the major shortcomings when using this method of strengthening.

According to [1-2], the final shear strength of beams externally strengthened in shear by FRP strips can be obtained as the sum of the contribution of different components: concrete, transverse steel and FRP external reinforcement. However, the interaction between all the above components is not clear enough. To increase the capacity of existing

RC beams and delay the debonding process by externally bonding, more efforts have been made to enhance the interfacial bond by exploring various materials, configurations, and wrapping techniques.

3 State of the art review

A lot of factors can play a role in determining the overall strength of CFRP materials. Some of these factors are not related to the properties of the materials alone, but rather the location and method of application. These factors include, but are not limited to: shear span-to-depth ratio, different CFRP layouts and configurations, internal shear reinforcement, multiple layers of CFRP material, and strain distribution across the critical crack.

AbdelhakBousselham, OmarChaallal (2005) [5] studied the effect of transverse steel and shear span on the performance of RC beams strengthened in shear with CFRP. The parameters they used were: CFRP ratio, transverse steel reinforcement ratio, and the type of beam (deep-slender). They concluded from these studies that: the gain in shear capacity was significant in lender beams whereas it was very modest in deep beam. The increase of CFRP thickness (1layer-2layer) achieved an additional gain in capacity for slender specimens, particularly those pertaining to series (S0 “no stirrups “). In deep specimens no noticeable gain was achieved. The additional of internal transverse steel resulted in a significant decrease of the gain in the slender specimens. However, in deep beams the addition of transverse steel had no effect on the shear resistance. The CFRP strains were higher in the specimens strengthened with one layer of CERP compared to two layers. Also, these strains tended to be greater in the slender specimens. The additional of the CFRP eased the transverse steel. Concrete attained a significant level of stain, particularly in the specimens with transverse steel. In addition, the CFRP seem to have helped the concrete to undergo higher strains.

Ernesto Grande, Imbimbo Maura (2009) [6] made an Experimental program to study the effect of transverse steel on the response of RC beams strengthened in shear by FRP. Stirrups spacing and the strengthening configuration were the parameters studied in this research.

They deduced from this experimental program that: the FRP shear resisting action is generally smaller in beams with closer stirrups. And, with specific reference to steel stirrups, it has been observed that the stirrups yield only in the specimens with 400 and 300 mm spacing and not in those with 200 mm spacing.

According to [7] Eva Oller, Mireia Pujol (2019), the FRP sheets are not effective if they are not anchored, since a premature debonding takes place. The FRP strengthening system modifies the strut orientation affecting the contribution of the transverse steel reinforcement. In the case of beams without anchorages, where a premature sheet de bonding was observed, the modification of strut orientation might be the reasons of a lower ultimate shear force for some strengthened beams in comparison to the control beam. Once the FRP sheets debond, if the transverse steel has not yielded, the beam can increase its shear strength capacity, because the further increment of shear force is carried out by the internal stirrups. But if the stirrups are already yielded, a shear failure occurs just after the FRP debonding. A huge dispersion is observed when applying the different existing formulations to predict the FRP contribution to the experimental program. It is not clear enough if the guidelines predict the maximum FRP contribution or the FRP contribution at failure.

[8]Zhang and Hsu (2005) investigated a study on the effect of fiber direction for strengthening FRP shear. The results showed that with the fibers directed at 90° to the longitudinal axis of the beam, there was a 60% increase in the shear capacity over the control beam, but with the fibers at 45° directed to the longitudinal axis of the beam there was an 80% increase in the shear capacity over the control beam. Therefore, this demonstrates that directing the fibers at 45° to the longitudinal axis of the beam is beneficial for the strengthening effect.

An experimental program was studied by [9]Bukhari et al. (2010) analyzing the effectiveness of shear strengthening for various configurations. Therefore, orientating the fibres of the FRP at 45° to the longitudinal axis of the beam provides superior strengthening over conventional vertical FRP sheets. The only disadvantage of inclined FRP wraps is that they cannot accommodate substantial load reversal.

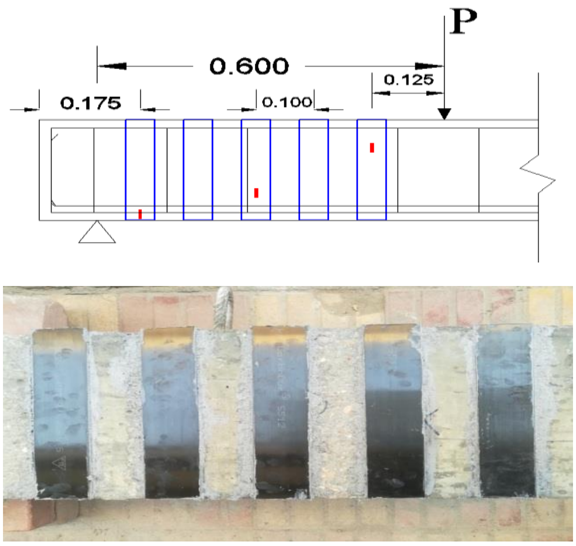

Figure 1: Details of tested specimen

Ref [10]Weiwen Li, Christopher K.Y. Leung (2017) concluded that the FRP strips are most effective for medium shear span-depth ratio, followed by high shear span-depth ratios, and are least effective for low shear span-depth ratio. The FRP strips are most effective for medium shear span/depth ratios, followed by high shear span/depth ratios, and are least effective for low shear span/depth ratios. For U-wrapping FRP configurations, the predicted FRP shear contributions from five design guidelines (ACI, FIB, JSCE, GB and CSA) are all strongly affected by the shear span/depth ratio, especially for deep beams.

3 Experimental program

3.1 Test matrix

The test matrix was prepared and tested to assess the enhancement in the shear capacity of slender beams using EB CFRP strips. Three specimens were tested in this program; one strengthened by EB-CFRP strips , one specimen kept without strengthening and without stirrups as a reference and the last specimen kept without strengthening but with stirrups as a reference also. Table 1 shows the details of the tested specimens and the strengthening technique. All specimens measured 150 mm wide by 250 mm deep and 2400 mm long. The flexural and compression reinforcement and the shear reinforcement were shown in Table 1. All the specimens were single point loaded with a span of 2200 mm and the load was applied at a distance of 600 mm from the left support where maximum shear occurs at this point. All specimens were designed to fail due to shear. CFRP strips were vertically strengthen on both sides of the web of the beam with 50 mm wide (W_f) and 1.2 mm thick with variable length (d_f) for shear strengthening as indicated in table 1. Figure 1 shows the details of the tested specimens.

Table 1: Details of tested specimens

Beam	Dimensions (b*h*L) (mm)	Stirrups	Reinforced steel	S_f (mm)	W_f (mm)	d_f (mm)
B1(R)	150*250*2400	____	4Ø16	____	____	____
B2(RS)	150*250*2400	7Ø6/m	4Ø16	____	____	____
B3(epoxy)	150*250*2400	7Ø6/m	4Ø16	100	50	250

Where: R refers to beam without stirrups and without strengthening, RS refers to beam with stirrups but without any strengthening, S_f = spacing between the CFRP strips, d_f = the length of the CFRP strip.

Concrete material: Mixes of the concrete were conducted in the concrete station and reached the cubic compressive strength to 60 N/mm^2 after 28 days with a maximum aggregate size of 20 mm and 10mm. Also adding three types of additives used in concrete mixing were R859, RH1 200 and ICE 1 to improve the properties and workability of concrete.

Steel reinforcement: The main longitudinal steel used in this experimental program was high-tensile steel (40/60) of 10, 16 mm diameter, and the stirrups were mild steel and the diameter was 6mm. The clear concrete cover was maintained to be 20 mm to the outside of stirrups for all reinforced specimens.

Fiber: Carbon fiber laminates (S512) produced by SIKA Carbodur was used in this investigation. The manufacturer's data of the fiber used in this experimental program is shown in Table 2 (a & b).

Adhesive material: the used adhesive material was Sikadur-30. This adhesive material is two components (A&B) adhesive and repair mortar.

3.2 Installation of strengthening CFRP strips

The method of strengthening the specimen was performed in the following steps:

(a) Carefully markings have been made on the beams to locate the CFRP strips as designed.
(b) Surface scratching: to obtain a perfect bond, the marked locations surface were ground by a rotary hammer drill and manually hammer to expose the coarse aggregates.
(c) The epoxy adhesive was mixed well and applied to the marked locations and holes.
(d) The CFRP strips were installed on the marked locations and removing the residual epoxy.
(e) The final shape of strengthened beam.

Figure 2: test setup and instrument

3.3 Test Setup and Instrumentations

A hydraulic jack with 1000 KN capacity was used to test all specimens, and it is manually operated by an oil pump. An electrical load cell with accuracy 0.1 KN connected to a digital load indicator was used to measure the applied vertical loads. The deflection of the beam was recorded using three electric dial gauges LVDT. One LVDT is located under the load, the second at a third of the loaded distance from the left-side beam support, and the last at a third of the loaded distance from the right-side beam support, located at the bottom face of the beam. At each overload, cracks were marked and the readings were recorded for all LVDT strains. Strains in the main steel, the stirrup, strain at the concrete surfaces, and CFRP strips are measured. The load cell, LVDT's and strain gauges were connected to a data acquisition system to record their measurements Each tested specimen is loaded up till failure.. The test setup and the instrumentation are shown in Figure 2.

4 Experimental Results

4.1 Loads at failure for all specimens

The maximum loads and the deflection are recorded for each specimen. Table 2 lists the load capacity (P_u), the deflection underneath point load of specimen at ultimate load (δ_u), and the load at first cracking (p_{cr}) respectively for all specimens

Table 2: results data for all specimens

beams	P_U (KN)	P_{cr} (KN)	δ_u (mm)	load increase (KN)	% increase in load	Stirrup strain (μЄ)	Mode of failue
B1-R	95.3	34.8	8.02	NA	NA	NA	S
B2-RS	127.2	38.17	8.58	NA	NA	2663	S
B3-epoxy	159.97	25.21	10.6	32.77	25.7626	2464	D+S

Where: S is for ‘‘shear’’, D + S is for ‘‘combined debonding and shear.’’

4.2 Cracks pattern and mode of failure

For specimens B1-R and B2-RS, there were two phases after first flexural cracking, the first phase is the cracking formation phase in which new shear cracks occur, and the second phase is the stabilizing cracking phase in which only the shear cracks. For specimen B3-epoxy, it was noticed that the failure mode was combined with shear cracks and strip debonding for the bottom as indicated below in figure 3.

Figure 3: cracks pattern for all specimens

4.3 Results data & Load-deflection relationship

Figure 4 indicates the load–deflection curves for the two specimens (B1-RS, B2-epoxy) and the reference one (the beam with stirrups (RS)). The deflection was recorded at each increase in the load until the maximum load was reached at which the deflections δu were determined.

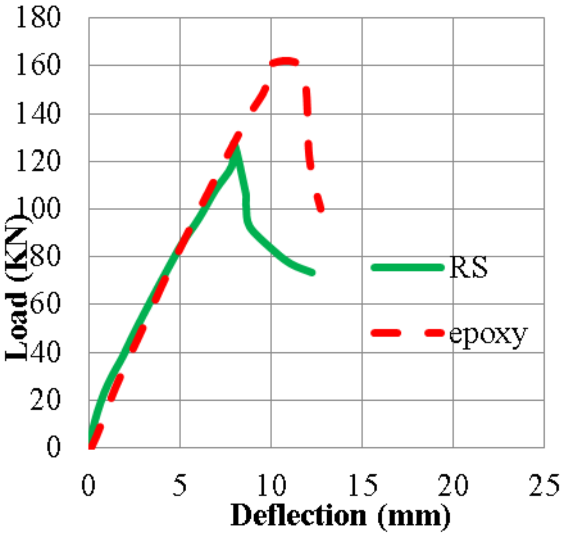

Figure 4: load-deflection curves

4.4 Load-Strain Relations

The load-strain of main steel, stirrups, concrete, and CFRP strip curves are shown in Figure 5

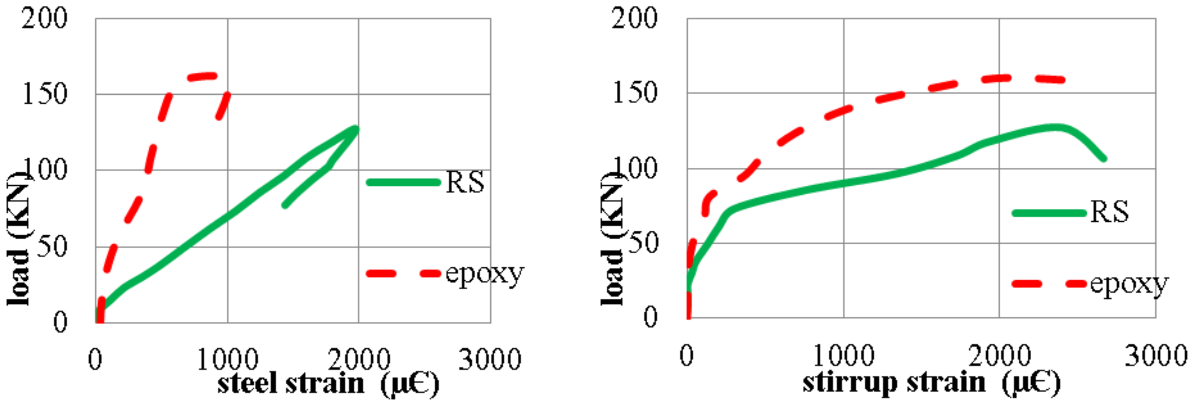

Figure 5: load-strain relationships

5 Comparison between experimental and theoretical results

Table 3, 4 and 5 indicates the expected failure load of the specimens by applying the equatios in the Egyptian code (ECP 203-2017). And, table 6 shows the comparison between the experimental and theoretical results.

Table 3: calculate of fiber shear stress

specimen	h (mm)	L_e	d_f (mm)	k_2	k_v	ϵ_{ef}	S_f (mm)	b_w (mm)	q_{fu} (N/mm^2)
B3(epoxy)	250	19.399	250	0.845	0.117	0.00202	100	152.4	2.9889

Table 4: calculate of shear failure load

specimen	q_{fu} (N/mm^2)	$q_{fu\ max}$ (N/mm^2)	q_{sti} (N/mm^2)	q_{cu} (N/mm^2)	Q_u (N/mm^2)	Q_u (KN)	p_s (KN)
B3 (epoxy)	2.9889	4.4272	0.64686	1.859032	4.565321	136.9596	192.9009

Table 5: calculate of moment failure load

specimen	b (mm)	d (mm)	As (mm^2)	A_f (mm^2)	Mu (KN.m)	Pm (KN)
All specimens	150	200	804.249	120	54.0455	117.49

Where: A_f= area of fiber used in shear direction, Pm = moment failure load.

Table 6: Summary of experimental and theoretical results

specimen	Theoretical failure load (KN)	Experimental failure load (KN)
B1-R		95.3
B2-RS	66.607316	127.2
B3-epoxy	192.900885	159.97

6 Conclusion and Recommendation

Based on this study, the following conclusions were drawn:

1. Using externally bonded (EB) strengthened technique with full length and spacing 100 mm (B_7-epoxy) increased the failure load by 26% over that of the un-strengthened beam (B_2-RS).
2. The initial stiffness of the two specimens is approximately equal.
3. The ductility of the B3-epoxy specimen is larger than B2-RS, so we can say that the EB strengthening technology provides an increase in ductility improvement.

4. At the same loading, the strain of steel in the tested specimen B2-RS was higher than B3-epoxy.
5. At the same loading, the stirrup strain in the RS specimen was higher than the specimen B3-epoxy. This is consistent with the theory that increasing the strengthening technique decreasing the stirrups effect.
6. For Beam RS specimen, the experimental value was increased by about 91% times than the theoretical value
7. For Beam epoxy specimen, the experimental value decreased by about 17% times than the theoretical value.

7 - Rererences

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