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Study of Shear Strengthening of Reinforced Concrete Beams Using Embedded Bars and CFRP

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ABSTRACT

A new technique for shear strengthening of reinforced concrete (RC) elements is the embedded through section (ETS). This technique calls for holes to be drilled through the beam section, and then bars of steel are introduced into these holes, bonded with adhesives or fixed mechanically. This research presents an experimental and analytical study for shear strengthening of reinforced concrete beams. The main objective of the research is to study the different methods for shear strengthening by using ETS technique (bond and mechanical) and the use of this technique on beams early strengthened with CFRP sheets. An experimental program including fourteen test specimens was conducted. The beams were classified into four groups to draw the necessary conclusion for the study parameters (strengthening method for ETS, inclination of ETS, loading history, CFRP sheets). The effects of the selected parameters on the beam shear capacity are presented in form of cracking, and failure load comparisons. The analytical results from (Eurocode and ACI code) and the gained shear capacity were compared to those obtained from experiments. Based on the above study, recommendations for shear strengthening using ETS and CFRP composites were drawn.

Keywords: shear strengthening, reinforced concrete beams, ETS steel bars, ETS technique, CFRP sheets.

1. Introduction

In last decades, the strengthening of existing structures to assure or increasing its structural safety became a challenging problem for civil engineers. As a result for the need of strengthening, several methods were introduced such as increasing concrete dimensions, adding additional reinforcements, using steel plates, CFRP laminates and newly using embedded through section technique (ETS) [1,2]. The strengthening of concrete element using FRP composites appears to be feasible way of increasing capacity and stiffness; because of its high resistance to corrosion, strength to weight ratio and fatigue resistance. The most popular techniques based on the use of FRP reinforcements are the externally bonded reinforcement (EBR) and the near surface mounted (NSM). The available experimental research showed that NSM is more effective than EBR for both the flexural [3,4,5] and shear strengthening [6,7]. The NSM method utilizing fiber fortified polymer (FRP) bars is currently an entrenched method for the reinforced concrete strengthening structures. As a result of using NSM FRP, beams with this scheme showed significantly increased the final load and shear capacity [8]. The openings through beams are a source of potential weakness [9]. Externally epoxy-bonded steel strips plate or FRP strips was used at the openings. The result was Drilling an opening of an existing beam may seriously incorporated shear failure at opening zone, the strengthened beams around the opening incorporated a flexural failure at mid-span zone, provided that the continuity of strengthening, the continuous steel plate around the opening is more effective than strips FRP, And the use of near surface mounted (NSM) for continues steel plate is an effective technique to enhance the shear capacity of the opening RC beams [9]. An alternative approach for the shear strengthening of RC beams, denominated as (ETS) technique [10,11], was recently studied by group of researchers. According to this technique, steel or FRP bars are inserted into holes and bonded with an epoxy adhesive. The ETS technique can also be extended for the punching shear strengthening of concrete slab [12, 13]. High increase of shear capacity has been accrued [10,14]. The tests were carried out to study the effectiveness of the ETS technique using vertical CFRP bars by comparing the efficiency of the ETS, EBR and NSM techniques on beams [11]. These tests showed that the ETS technique provided the highest efficiency. The deeply embedded ETS technique improves bond performance between the strengthening system and the surrounding concrete much more than previous FRP-based strengthening techniques [15,16,17,18]. The previous research work in the available literature investigated the effect of using CFRP laminates or ETS technique on increasing shear

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capacity of concrete beams; but the use of CFRP and ETS together in strengthening of concrete element needs further research.

2. Experimental Program

2.1Test Beams

The experimental program consists of four series A, B, C, and D. The typical cross section of beams was 120*250 mm, with a total length 1700 mm and a shear span of 600 mm as shown in Figure 1. The longitudinal tension steel of beams consists of two steel bars 22 mm diameter (Φ22 mm) with 513 MPa yield strength. The longitudinal compressive steel reinforcement was two steel bars of 16 mm diameter (Φ16 mm) with 490 MPa yield strength. The shear reinforcement consists of closed mild steel stirrups with yield strength of 350MPa. Shear reinforcement was arranged variably along the beam span. The first zone, 600 mm from support, was reinforced by stirrup Φ6 mm at 150 mm spacing. The second zone was reinforced by stirrups Φ6 mm at 80 mm spacing, that configuration was used to prevent failure in this zone. The concrete clear cover for the top, bottom and lateral faces of the beams was 15 mm.

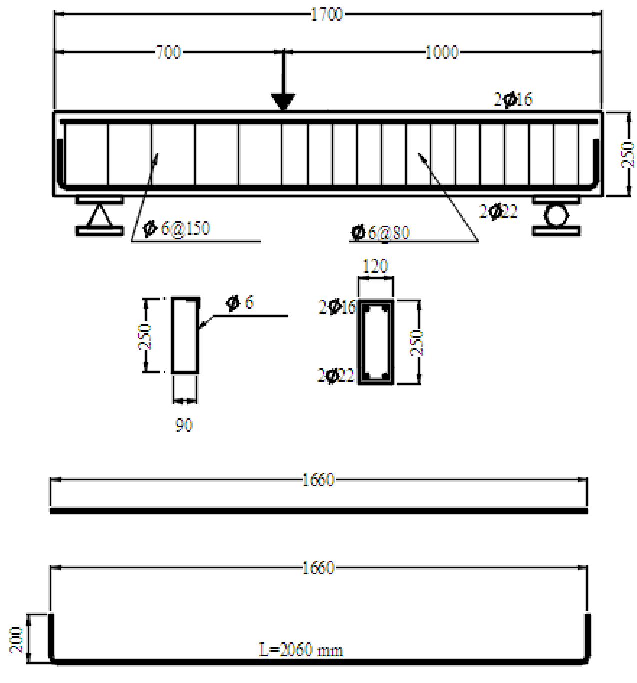


Figure 1: Typical beam reinforcement details (all dimensions are in mm).

2.2 Group parameters of test beams

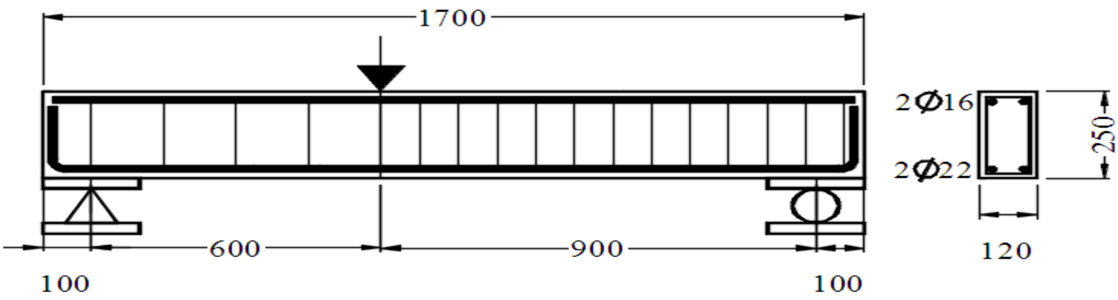
The tested beams divided into four groups A, B, C and D. Group (A) studies the effect of strengthening scheme on the structural behavior and shear capacity of test beams without loading history. Group (B) studies the effect of loading history on the structural behavior and shear capacity of test beams. Group (C) studies the effect of erecting type (mechanical anchorage). Group (D) studies the efficiency of using ETS strengthening schemes for early rehabilitated beams using CFRP.

Group A consisted of four beams as Control, E-90-B, E-45-B and F-90-B. The main object of this group was to study the effect of strengthening scheme on the structural behavior and shear capacity of test beams without loading history. Group B consisted of four beams Control-L, E-90-B-L, E-45-B-L, and F-90-B-L. The beams of this group such as the beams for group A, but the difference is that beams of group B were preloaded beams (35 % of total load). The main object of this group was to study the effect of loading history on the structural behavior and shear capacity of test beams. Group C consisted of four beams E-90-M, E-45-M, E-90-M-L and E-45-M-L, the main object of this group was to study the effect of erecting type (mechanical anchorage). Group D consisted of two beams E-90-F-B-L and E-90-F-M-L. Beams of this group were strengthened with ETS technique and CFRP sheets. The main object of this group was to study the efficiency of using ETS strengthening schemes for early rehabilitated beams using CFRP. Table (1) shows the Summary and designation of tested beams. Figures (2 to 4) show the typical elevation and cross-section of the test beams. Erecting type and loading history configuration for groups A, B, C, and D were presented in Tables 2, 3, 4, and 5 respectively.

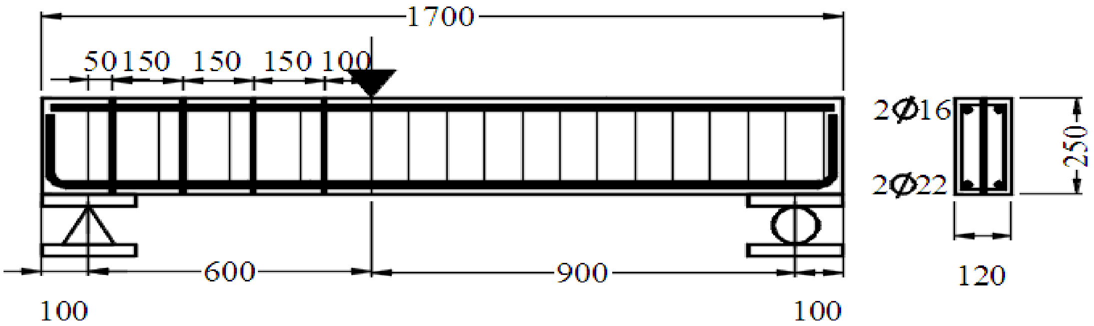
Table 1: Summary and designation of test beams

Group	Designation	Strengthening scheme
A	Control	Reference beam
	E-90-B	Vertical ETS at 90° with spacing 150mm
	E-45-B	Inclined ETS at 45° with spacing 150mm
	F-90-B	CFRP strips with spacing 100mm
B	Control-L	Reference pre-loading beam
	E-90-B-L	Vertical ETS at 90° with spacing 150mm
	E-45-B-L	Inclined ETS at 45° with spacing 150mm
	F-90-B-L	CFRP strips with spacing 100mm
C	E-90-M	Vertical ETS at 90° with spacing 150mm
	E-45-M	Inclined ETS at 45° with spacing 150mm
	E-90-M-L	Vertical ETS at 90° with spacing 150mm
	E-45-M-L	Inclined ETS at 45° with spacing 150mm
D	E-90-F-B-L	CFRP then vertical ETS-150
	E-90-F-M-L	CFRP then vertical ETS-150

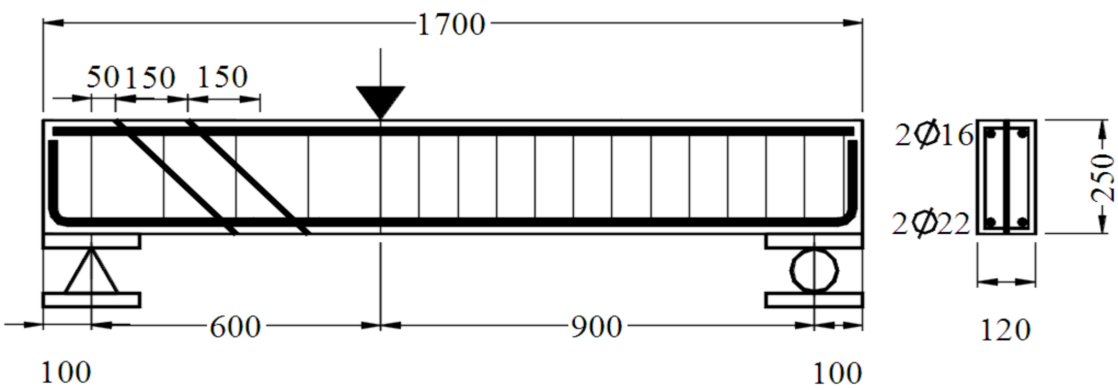
Control



E-90-B



E-45-B



F-90-B

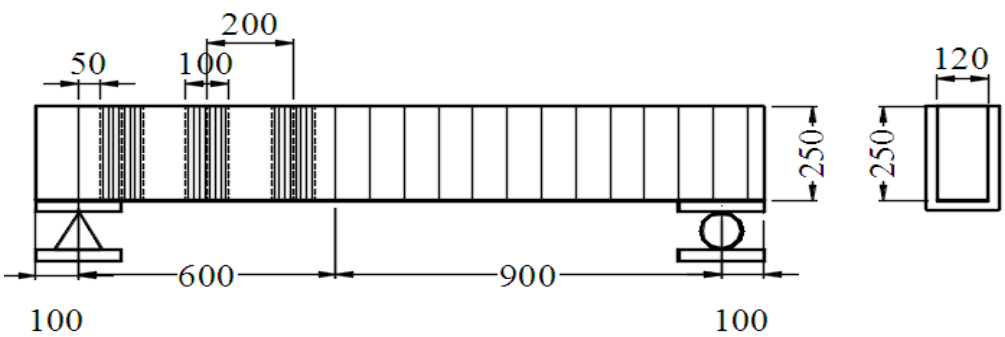
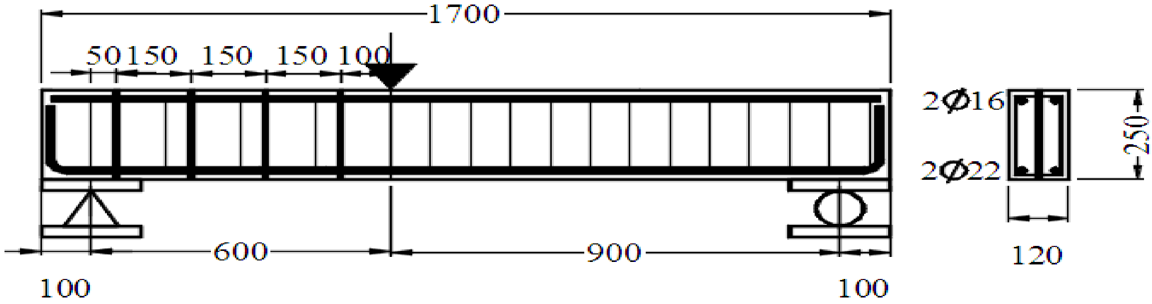
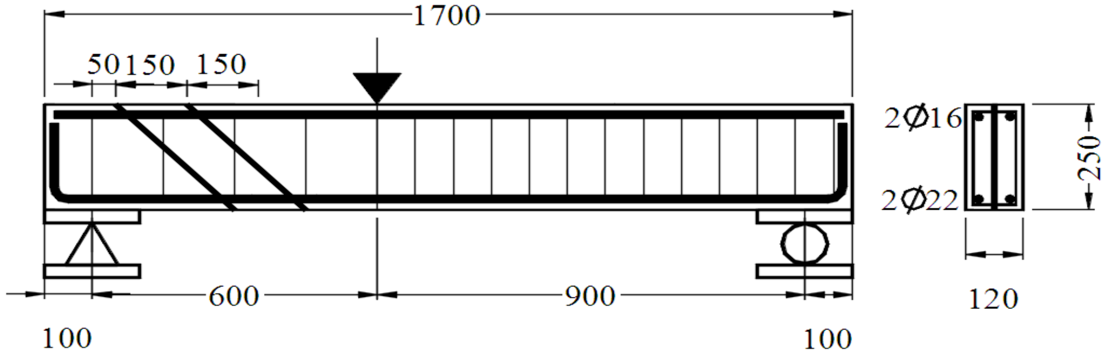


Figure 2: The strengthening schemes for beams in groups (A and B).

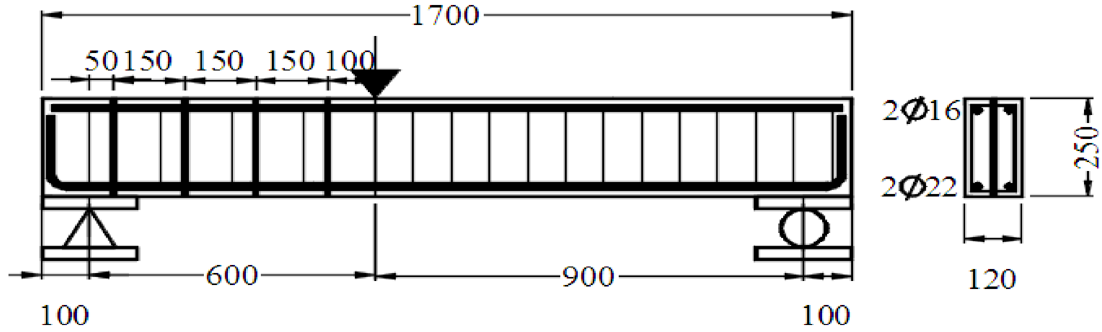
E-90-M



E-45-M



E-90-M-L



E-45-M-L

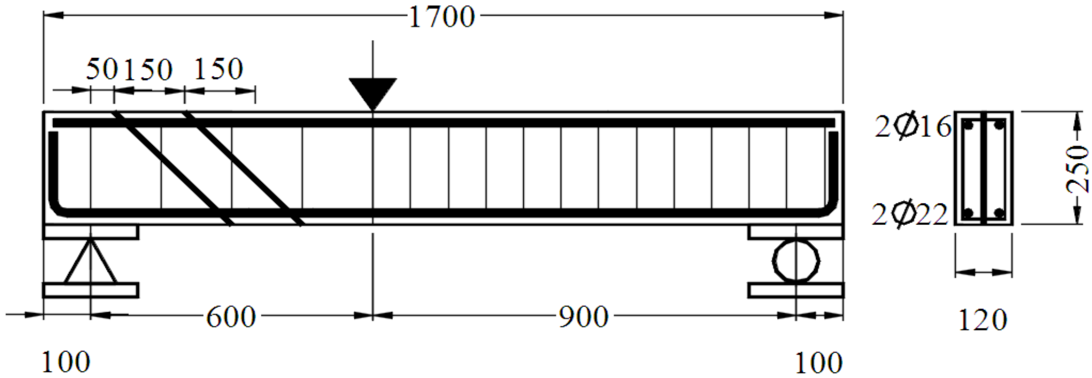


Figure 3: The strengthening schemes for beams in group C.

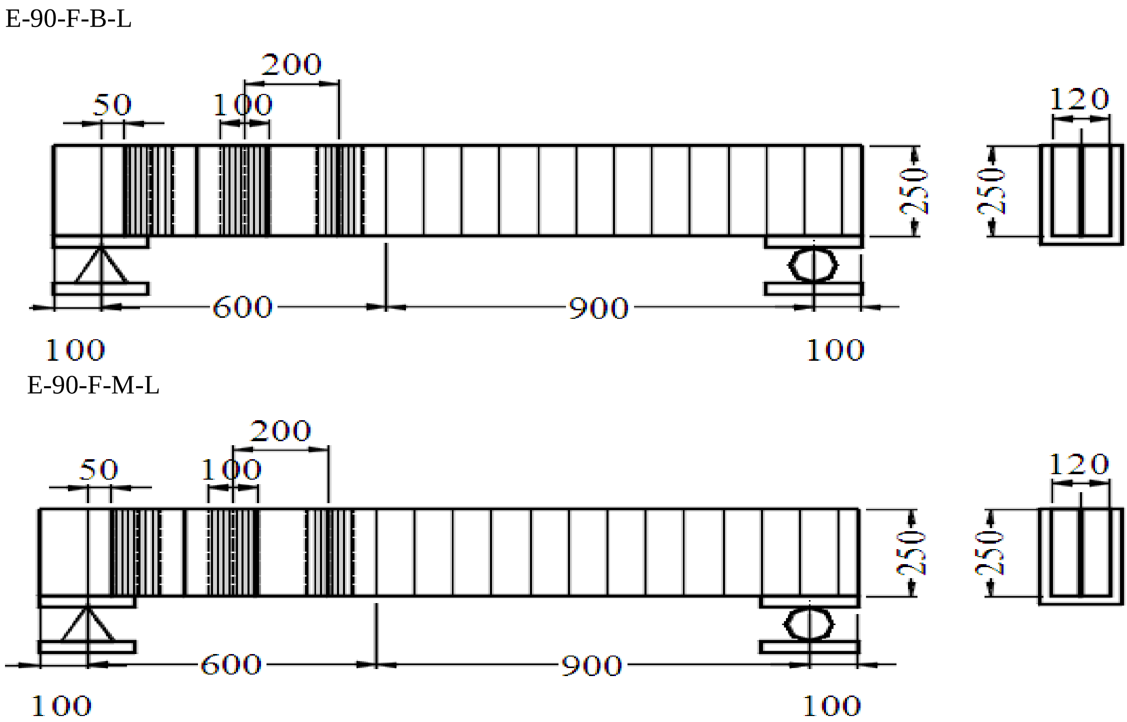


Figure 4: The strengthening schemes for beams in group D.

Table 2: Erecting type and loading history configuration for group A.

Group	Designation	Configuration and Strengthening Scheme	
		Erection Type	**Loading History**
A	Control	-----	No
	E-90-B	bonded	No
	E-45-B	bonded	No
	F-90-B	bonded	No

Table 3: Erecting type and loading history configuration for group B.

Group	Designation	Configuration and Strengthening Scheme	
		Erection Type	**Loading History**
B	Control-L	-----	Yes
	E-90-B-L	bonded	Yes
	E-45-B-L	bonded	Yes
	F-90-B-L	bonded	Yes

Table 4: Erecting type and loading history configuration for group C.

Group	Designation	Configuration and Strengthening Scheme	
		Erection Type	**Loading History**
C	E-90-M	Mechanical	No
	E-45-M	Mechanical	No
	E-90-M-L	Mechanical	Yes
	E-45-M-L	Mechanical	Yes

Table 5: Erecting type and loading history configuration for group D.

Group	Designation	Configuration and Strengthening Scheme	
		Erection Type	**Loading History**
D	E-90-F-B-L	bonded	Yes
	E-90-F-M-L	Mechanical	Yes

2.3Properties of Materials

Materials used in construction of test beams are concrete, reinforcing steel, and CFRP. Each material was studied separately to acquire the properties that will later help in the analytical investigation of test beams. Table (6) summarizes the mechanical properties for the materials used in construction of test beams.

Table 6: Material Properties for Concrete, Steel, and CFRP sheets

1. Concrete			
Average Cubic Strength (MPa)		37	
2. Reinforcing Steel			
Bar Diameter (mm)	Yield Strength (MPa)	Tensile Strength (MPa)	%Elongation
6	350	380	22
10	400	425.4	22
16	490	610	32
22	513	680	22
3. CFRP Sheets			
Thickness (mm)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Ultimate Strain
0.125*	4000*	240*	0.02*

* Obtained from CFRP material data sheet [19].

2.4Strengthening of Test Beams

2.4.1Concrete Beam Preparation for (ETS)

The main steps of the ETS strengthening technique are shown in Figure 5. These steps are: (1) preparation of steel bars used either in bonded ETS or mechanical anchorage ETS Figure 5- a and b respectively. (2) holes of 14 mm diameter for ETS steel bars were drilled through the center of the beam up to bottom ; during the drilling process, the concrete dust was aspirated using a vacuum system Figure 5-c; (3) the holes were cleaned with compressed air Figure 5-d ; (4) the epoxy resin, which was prepared according to the recommendations of the supplier, was slowly poured into the holes ; (5) the steel bars, which were previously cut in the desired length and cleaned, were slowly introduced into the holes removing the resin (KEMAPOXY 165) excess Figure 5-e ; for mechanical anchorage the steel bars were introduced into the holes and tied it with washer and nut Figure 5-f. The test bar will be cut later during working stage of the beam (for bonded bars). Mechanical grove 2 cm inside the beam just to maintain the ETS is to be constructed in concrete (for mechanically anchored bars).

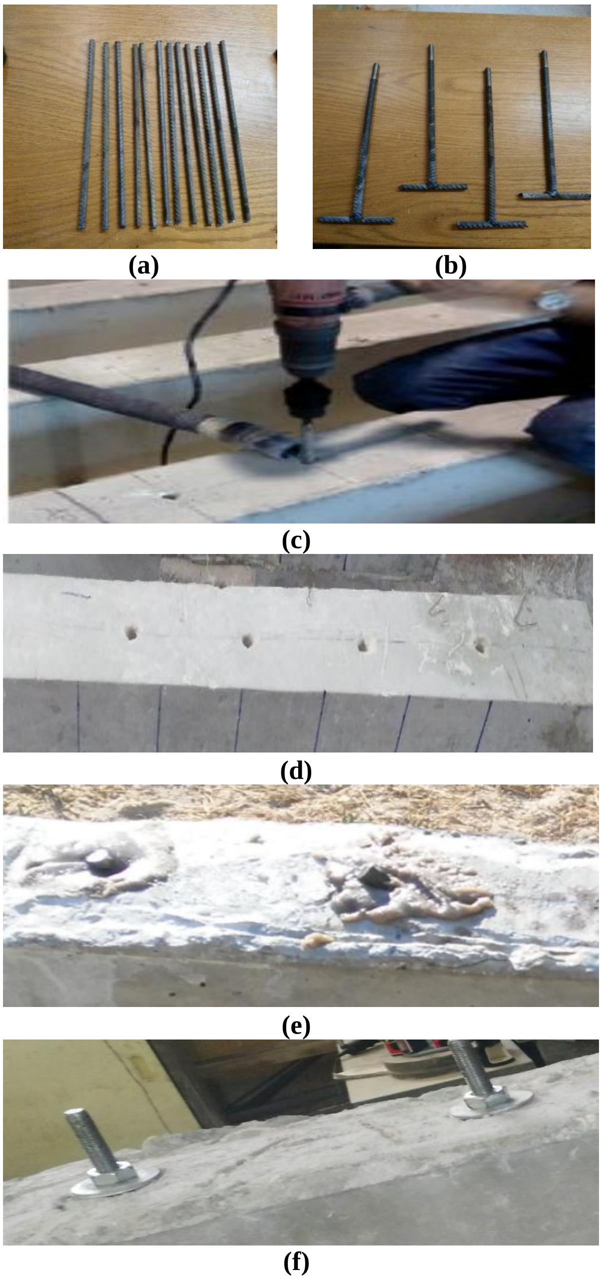


Figure 5: Strengthening procedures for the ETS `

2.4.2Beam Surface Preparation for (FRP)

It was necessary to have a leveled concrete surface to serve as a bonding plain for the CFRP. Also, the surface should be independent from all unwanted particles such as dust or lubricants. To achieve this, a hand-held grinder was used to remove the surface layer on the two sides and the top of beams. This also helped by exposing a large portion of aggregate that would be beneficial in bonding with the CFRP. The preparation was completed by blowing the specimen with compressed air using electrical blower machine to remove any excess particles. The specimens were then covered until the CFRP was applied. Figure 6 shows the concrete surface preparation.

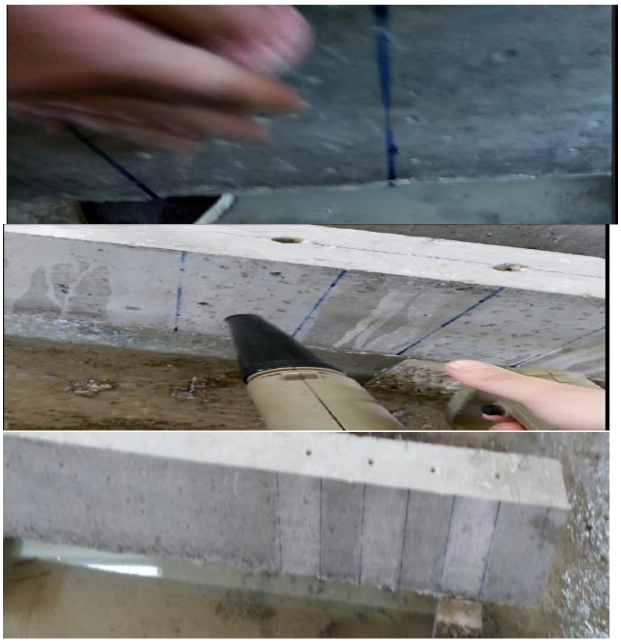


Figure 6: Strengthening procedures for the CFRP sheets.

2.4.3 Bonding the CFRP Sheets

After the beam surface was prepared, the beam surface was impregnated by hand with adhesive, the CFRP sheet was rolled onto the beam side. Each CFRP sheet was heavily rolled to ensure that the air voids were nearly removed, each beam was allowed to cure in air for at least 24 hours. Figure 7 shows application of CFRP sheet.

Figure 7: Application of CFRP strips.

2.5Test Setup

The beams were tested in Faculty of Engineering Concrete Laboratory, Port Said University. The beam was then placed and adjusted into position on the machine. A roller and hinged supports were provided along a span of 1700 mm. Dial deflectometers with an accuracy of 0.01 mm were arranged to measure the deflections at the 200,600 and 1000 mm form the beam support, Figure 8 show the location of deflectometers.

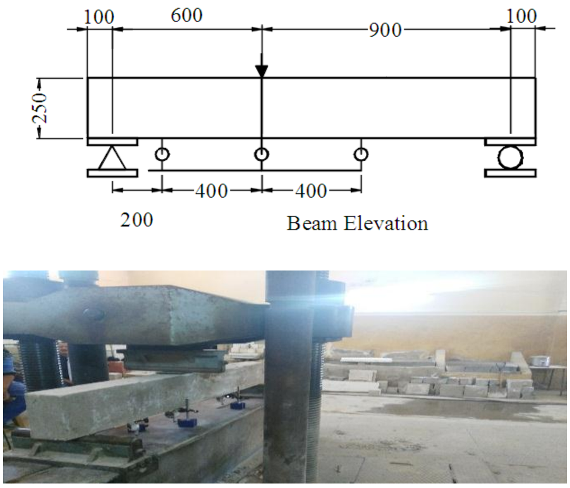


Figure 8: Test setup and location of deflectometers.

3. Results and discussion

3.1Crack patterns and Failure mode

Figures (9 to 12) show the crack patterns and failure modes of all tested beams. In the control beam, the first noticed inclined crack was formed at F = 70 KN. By increasing the load, additional cracks appeared and extended from support. Due to failure in the shear region, the beam was finally failed at load of 144 KN. The crack patterns for all strengthened beams were similar to those of control beam, but the crack width was decreased, the first crack appeared far away from strengthened zone, the cracks inclination decreased from the beam axis and also the number of cracks decreased.

Control

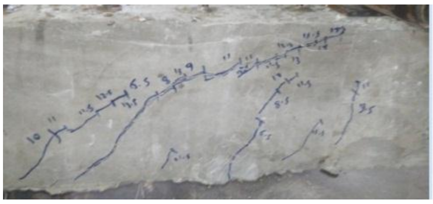
E-90-B

E-45-B

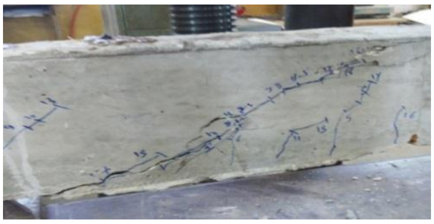
F-90-B

Figure 9: Final crack patterns for group A

Control-L



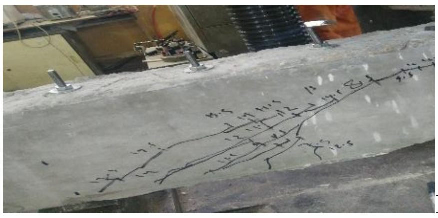
E-90-B-L



E-45-B-L

F-90-B-L

Figure 10: Final crack patterns for group B.



E-90-M

E-45-M

E-90-M-L

E-45-M-L

Figure 11: Final crack patterns for group C

E-90-F-B-L

E-90-F-M-L

Figure 12: Final crack patterns for group D.

The beams strengthened with CFRP sheets failure process was started by CFRP sheets debonding. The debonding process started at the crack intersection with the CFRP sheets. At higher load levels CFRP strips was completely deboned from concrete surface. Approaching failure, a sudden separation occurred. Referring to beams strengthened with ETS techniques, it was noticed that the beams failed due to the bond failure at the bar/adhesive interface.

3.2 Load deflection response

Figures 13-17 show the load versus deflection plots for different beams in the experimental work. The load deflection plot in the first segment for different test beams was almost the same. Referring to beams in different groups, the strengthened beams showed more stiffness than control one in all loading stages except the preloading specimens. The load deflection plots show that the shear strengthening not affected greatly the stiffness of the test beams, this small effect can be referred to the low participation of shear stiffness in the overall stiffness of beams.

Referring to Figure 13, the beam strengthened with inclined ETS, without loading history, showed higher overall stiffness than other beams in the same group. The previously load beams, having load history, also showed more stiffness, but this increase in stiffness appeared in the final loading history, Figure 14.

In Figure 15, the preloaded beams strengthened with mechanical anchorage showed lower stiffness than normal case of loading. The beam strengthened with bonded ETS bars and CFRP sheets showed higher stiffness than beam strengthened with mechanical ETS bars and CFRP sheets, Figure 16.

In Figure 17, the beams strengthened with mechanical anchorage showed lower stiffness than bonded ones.

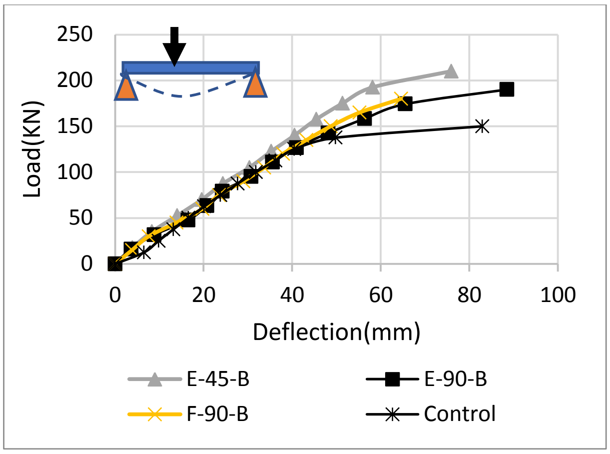


Figure 13: Load vs. deflection at the loaded section for group A**.**

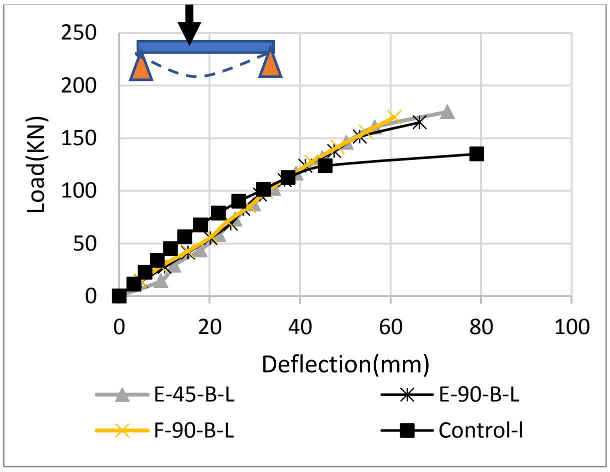


Figure 14: Load vs. deflection at the loaded section for group B**.**

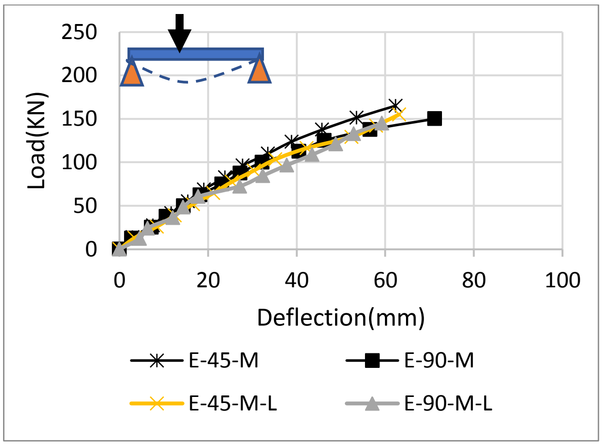


Figure 15: Load vs. deflection at the loaded section for group C**.**

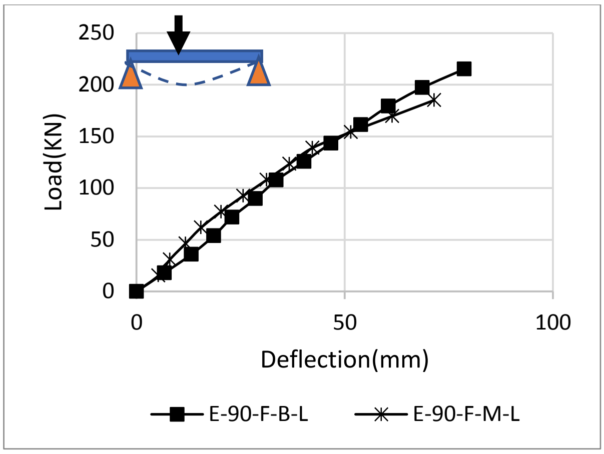


Figure 16: Load vs. deflection at the loaded section for group D**.**

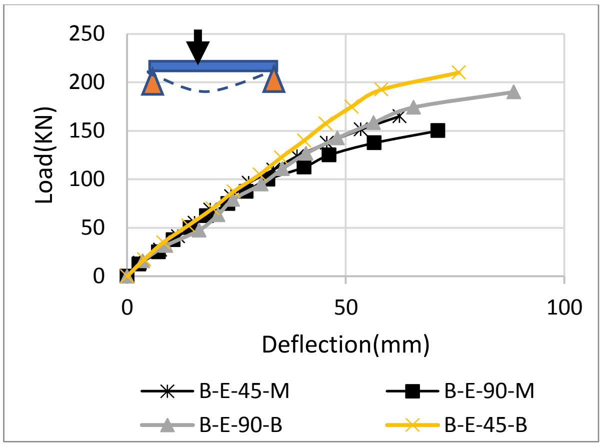


Figure 17: Load vs. deflection at the loaded section (Effect of anchorage system).

3.3 Shear carrying capacity

The main results of the experimental tests are presented in Table (7), where F is the maximum load attained by the beams and U_L is the displacement in the loaded section at F.

Table 7: Experimental results of group A, B, C and D

Beam	F_{max} KN)	U_{Lmax} mm)	$\Delta F/F_{control}$ %	V_{max} (KN)	ΔV (KN)
		Group A			
Control	144	65.45	-----	86.4	-----
E-90-B	184	88.47	27.8%	110.4	24
E-45-B	210	75.9	45.8%	126	39.6
F-90-B	181	64.6	25.7%	108.6	22.2
		Group B			
Control-L	134	79	-----	80.4	-----
E-90-B-L	169	66.4	26.12%	101.4	21
E-45-B-L	175	72.5	30.6%	105	24.6
F-90-B-L	171	60.77	27.6%	102.6	22.2
		Group C			

B-E-90-M	150	71.14	4.2%	90	3.6
E-45-M	165	62.3	14.6%	99	12.6
E-90-M-L	145	59.23	8.2%	87	6.6
E-45-M-L	155	63.12	15.7%	93	12.6
Group D					
E-90-F-B-L	216	78.72	61.2%	129.6	49.2
E-90-F-M-L	190	71.5	41.8%	114	33.6

The strengthening efficiency of the ETS technique can be evaluated by considering the $\Delta F/F_{control}$ ratio, where $F_{control}$ is the maximum load of the reference beam, and $\Delta F = F_{max} - F_{control}$ is the increase of maximum load provided by different strengthening technique. Table 7 also includes the maximum shear force $V_{max} = 0.6\ F_{max}$ applied in the shear span, Figure 1, and the shear contribution provided by the ETS arrangement, $\Delta V = V_{max} - V_{control}$. From the results shown in Table 7, it can be noticed that:

1. The ETS technique increased the shear strength of beams from 24% to 39.6%.
2. The use of ETS bars with CFRP sheets increased the shear strength of beams by 49.2%.
3. The beams without loading history achieved good results than preloaded beams by 24.6% to 39.6%.
4. As a result of using bond method, beams with this scheme showed more shear strength than those with mechanical anchorage method by 12.6% to 39.6%.

3.3.1 Effect of the inclined of ETS

Figure 18 shows the effect of the inclination of ETS bars on shear strength. The shear contribution is evaluated by considering the $\Delta F/F_{control}$ ratio (Table 7). Referring to Figure 14, the inclined ETS bars were much more effective than vertical ones. The higher effectiveness of ETS inclined bars is justified by the larger total resisting bond length of the ETS bars and by more effective orientation of these bars since they cross the shear crack plane almost orthogonally. For ETS-B, and in terms of $\Delta F/F_{control}$ the inclined ETS bars were 1.65, 1.17, 3.48, and 1.91 times more effective than vertical bars, ETS-B-L, ETS-M and ETS-M-L, respectively.

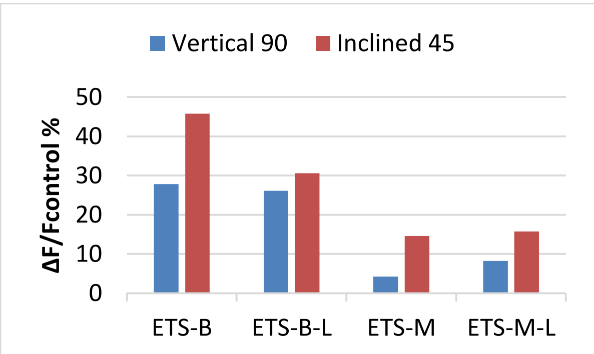


Figure 18: Effect of the inclination of ETS bars.

3.3.2 Effect of loading history

Figure 19 shows the effect of loading history on shear strengthening, evaluated by considering the $\Delta F/F_{Ref}$ ratio (Table 7). The preloaded beams showed lesser shear strengthening effectiveness than normal case loading. In terms of $\Delta F/F_{control}$ the normal case loading beams were about 1.1, 1.5, 1.95, and 1.1 times more effective than preloaded beams in ETS-90-B, ETS-45-B, ETS-90-M, and ETS-45-M, respectively.

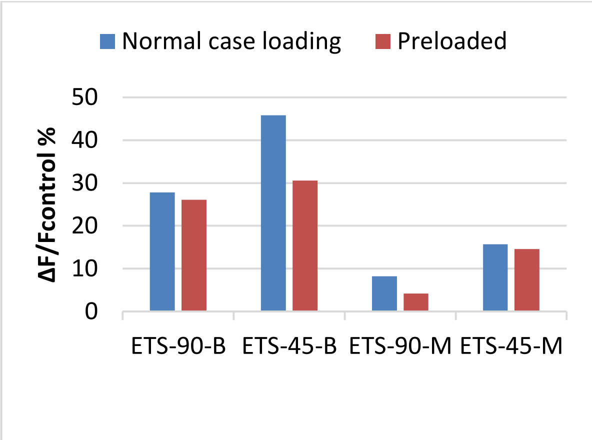


Figure 19: Effect of loading history

3.3.3 Effect of anchorage system

Figure 20 shows the effect of anchorage techniques on shear strength of test beams, evaluated by considering the $\Delta F/F_{control}$ ratio (Table 7). As a result of using mechanical anchorage, beams with this scheme showed less effectiveness than bonded ones. In terms of $\Delta F/F_{control}$ the bonded method were 6.6, 3.14, 3.18, and 1.95 times more effective than mechanical method in B-90-ETS, B-45-ETS, B-90-ETS-L, and B-45-ETS-L, respectively.

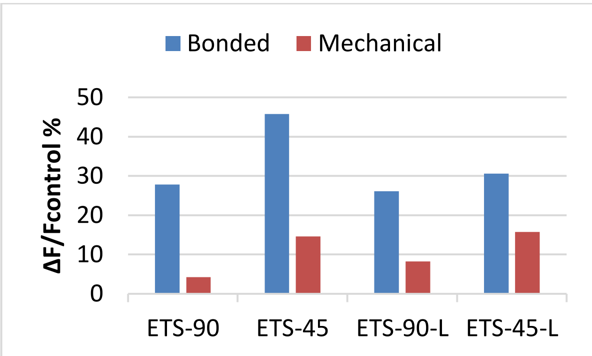


Figure 20: Effect of anchorage system.

4.Comparison between Experimental and Code Equations

The experimental results of the nominal shear capacity (contribution of concrete, stirrups, CFRP, and ETS) were compared to those calculated using a different codes, such as ACI committee and Eurocode2. Tables 8, 9, and 10 provide the comparison results for test beams of different groups. Referring to these tables, the experimental results of the test beams agree to an acceptable degree with the predicted values using different codes. But some beams were higher than to those from experimental tests, this difference may be due to the bonded between concrete and beams strengthened with CFRP sheets and ETS bars. Moreover, some beams predictions using codes equations were lower than those from experimental tests, this difference may be referred to the neglected effect of preloading stage and the force induced in bars due to mechanical anchored in code calculations. The used shear contribution equations from ACI and Eurocode are listed in the appendix of current paper.

Table 8: Experimental results of group A, B, C and D.

Beam	**Experimental**		
	V_c+V_s(KN)	V_f(KN)	V_{exp}(KN)
Group A			
Control	86.4	----	86.4
E-90-B	86.4	24	110.4
E-45-B	86.4	39.6	126
F-90-B	86.4	22.2	108.6
Group B			
Control-L	80.4	-----	80.4
E-90-B-L	80.4	21	101.4
E-45-B-L	80.4	24.6	105
F-90-B-L	80.4	22.2	102.6
Group C			
E-90-M	86.4	3.6	90
E-45-M	86.4	12.6	99
E-90-M-L	80.4	6.6	87
E-45-M-L	80.4	12.6	93
Group D			
E-90-F-B-L	80.4	49.2	129.6
E-90-F-M-L	80.4	33.6	114

Referring to Tables (8, 9, and 10) respectively, ACI and Eurocode have predicted a shear resistance lower than the one registered experimentally.

Table 9: Analytical results using ACI [20,21]

Beam	**Analytical (ACI)**				
	V_c KN	V_s KN	V_f KN	V_n KN	$V_{exp.}$ /Vn
Group A					
Control	33.8	29.4	-----	63.22	1.37
E-90-B	33.8	29.4	42.03	105.25	1.05
E-45-B	33.8	29.4	59.45	122.67	1.03
F-90-B	33.8	29.4	35.6	98.9	1.10
Group B					
Control-L	33.8	29.4	-----	63.22	1.27
E-90-B-L	33.8	29.4	42.0	105.2	0.96
E-45-B-L	33.8	29.4	59.45	122.67	0.86
F-90-B-L	33.8	29.4	35.6	98.9	1.04
Group C					
E-90-M	33.8	29.4	42.0	105.2	0.86
E-45-M	33.8	29.4	59.4	122.6	0.81
E-90-M-L	33.8	29.4	42.0	105.2	0.83
E-45-M-L	33.8	29.4	59.4	122.6	0.8
Group D					
E-90-F-B-L	33.8	29.4	77.7	137	0.95
E-90-F-M-L	33.8	29.4	77.7	137	0.83

Table 10: Analytical results by Eurocode 2 [22]

Beam	**Analytical (Eurocode 2)**				
	$V_{Rd,c}$ KN	$V_{Rd,s}$ KN	$V_{Rd,f}$ KN	V_{Rd} KN	V_{exp}. /V_{Rd}
Group A					
Control	29.61	26.6	-----	56.11	1.54
E-90-B	29.61	26.6	37.83	93.94	1.18
E-45-B	29.61	26.6	53.5	109.61	1.15
F-90-B	29.61	26.6	48.2	104.3	1.04
Group B					
Control-L	29.61	26.6	-----	56.11	1.43
E-90-B-L	29.61	26.6	37.83	93.94	1.08
E-45-B-L	29.61	26.6	53.5	109.61	0.96
F-90-B-L	29.61	26.6	48.2	104.3	1.01
Group C					
E-90-M	29.61	26.6	37.83	93.94	0.96
E-45-M	29.61	26.6	53.5	109.61	0.903
E-90-M-L	29.61	26.6	37.83	93.94	0.93
E-45-M-L	29.61	26.6	53.5	109.61	0.85
Group D					
E-90-F-B-L	29.61	26.6	86.03	142.1	0.91
E-90-F-M-L	29.61	26.6	86.03	142.1	0.80

5.Conclusions

Based on the experimental program and analytical predictions for test beams examined in this research, the following points may be concluded:

*Results showed that using ETS bars for shear strengthening for reinforced concrete beams is more effective than using CFRP sheets because of good contact with the surrounding concrete.
*The inclined ETS bars were much more effective than vertical ones. Using the ETS technique, the occurrence of brittle shear failure in RC beams can be avoided.
*Both bonded and mechanically anchored ETS are affected by pre-loading process due to the loss of concrete shear contribution.
* Providing previously CFRP strengthened beams with ETS bars results in an increase in their shear strength.

*The preloading process reduces the shear strength of beams and must be taken into considerations during shear capacity predications using code equations.
* The capability of the ACI and Eurocode 2 design guidelines to evaluate the shear resistance of the tested beams was appraised using the experimental results. A good agreement between the experimental and analytical values was obtained, mainly when using the ACI 318 approach.

6.Appendix

ACI code equations. [19,20]

$$\phi v_n = \left(v_c + v_s + \Psi_F v_f\right) \quad (1)$$

$$v_S = \frac{A_v * f_{yt} * d}{S} \quad (2)$$

$$v_F = \frac{A_F * f_{yt} * d}{s_F} \quad (3)$$

$$v_f = \frac{A_F * F_{yt} * (\sin\alpha + \cos\alpha)^* d}{s_F} \quad (4)$$

V_n= the nominal shear strength.
V_c is the contributions from the concrete

$V_c = 0.23\sqrt{f_c'} * b_{w^*} d$

where, F_C' is the concrete compressive strength, b_w is the web width, and d is the distance from the extreme compression fiber of the cross section to the centroid of the longitudinal reinforcement.

where V_s is the contributions from the steel stirrups, A_v is the cross-sectional area of steel stirrups of spacing s and f_{yt} is the yield stress of the steel stirrup.

V_f is the contributions from ETS bars, A_f is the cross-sectional area of the ETS bars of spacing S_f and f_{yt} is the yield stress of the ETS bar. α is the angle between the inclined bar and the axis of the of the beam.

ψ_f= reduction factor applied to the contribution of the shear strengthening system (0.95).

Ø= the strength reduction factor required by ACI 318 [10] (0.85).

Eur**o**code equations. [21]

$$V_{Rd} = V_{Rd,c} + V_{Rd,s} + V_{Rd,f} \quad (5)$$

$$V_{Rd.c} = \left\{\left\{c_{Rd.c} k\left(100 p_1 f_{ck} + k_1 \sigma_{cp}\right)^1 / 3\right\} * b_\omega * d \quad (6)$$

$$v_{Rd.s} = \frac{A_{s\omega}}{s} * z * f_{ywd} * \cot\theta \quad (7)$$

$$V_{Rd.F} = \frac{A_{sf}}{s_F} z f_{ywd} (\cot\theta + \cot\alpha)\sin\alpha \quad (8)$$

where, V_{Rd} is the nominal shear strength, $V_{Rd,c}$ is The contribution of the concrete, and f_{ck} = the characteristic value of concrete compressive strength.

$k = 1 + \sqrt{200/d} \leq 2$ (width d in mm).

$\rho_l = A_{sl}/b_w.d$, A_{sl} the cross-sectional area of the tensile reinforcement.

$C_{Rd,c} = 0.18/\gamma_c$, where γ_c is the partial safety factor for concrete.

σ_{cP}= the stress because of the axial load.
k1 = 0.15 (recommended value).

$V_{Rd,s}$ = the contributions from the steel stirrups.

where, A is the cross-sectional area of the shear reinforcement; S is the spacing of the stirrups; z is the lever arm (z = 0.9 d); f_{ywd} is the design value of the yield stress of the shear reinforcement; Ɵ is the angle of the inclined struts ($1 \leq \cot\theta \leq 2 \cdot 5$); α is the angle between the inclined bars and the axis of the beam.

$V_{Rd,f}$ = The contribution of the ETS bars.

where A_{sf} and f_{ywd} is the cross-sectional area and the design value of the yield stress of a ETS bar, and S_f is the spacing of ETS bars.

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العنوان

دراسة تقوية القص للكمرات الخرسانية المسلحة باستخدام التدعيم المخترق للقطاع والبوليمرات الكربونية المسلحة بالالياف

الملخص

صلب تسليح المخترق للقطاع الخرسانى هو واحدة من التقنيات الحديثة لتدعيم الكمرات الخرسانية المسلحة فى القص. هذه التقنية تتم بعمل ثقوب خلال الكمرة، ثم يتم ادخال اسياخ الحديد فى هذه الثقوب. بعد ذلك يتم الربط بالمواد اللاصقة او تثبتها ميكانيكيا. يقدم هذا البحث دراسة معملية ونظرية لتدعيم الكمرات الخرسانية المسلحة فى القص. الهدف الرئيسى من البحث هو دراسة الطرق المختلفة لتدعيم القص باستخام صلب التسليح المخترق للقطاع الخرسانى واستخدام هذه التقنية على الكمرات التى تم تقويتها سابقا بالبوليمرات الكربونية المسلحة بالالياف. وقد تم تنفيذ برنامج عملي مكون من اربعة عشر عينة من الكمرات الخرسانية المسلحة. وتم تقسيم الكمرات الى اربع مجموعات طبقا للمتغيرات المدروسة وذلك بغرض دراسة تأثير هذه المتغيرات على مقاومة الكمرات الخرسانية المقواه في القص. تم مقارنة النتائج النظرية من الكود الاوروبى والكود الامريكى بمثيلاتها المعملية. بناء على الدراسة المعملية والدراسة النظرية تم استخلاص الاستنتاجات والتوصيات الخاصة بتقوية الكمرات الخرسانية في القص باستخدام البوليمرات المسلحة بالألياف وصلب التسليح المخترق للقطاع الخرسانى.