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Performance of New Strengthening Technique for Square Reinforced Concrete Columns with Innovative CFRP Confinements

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Abstract-This paper presents results of an experimental study for the strengthening of the weakened columns because of the insufficiencies of interior steel confinement. A newly strengthening method technique is utilized small-scale reinforced concrete square columns using CFRP sheets. Diverse parameters were studied including the volumetric percentage of lateral reinforcement confinement, method of strengthening, the number of external CFRP confinement, and the longitudinal CFRP layers thickness (2, 3, and 4 number). Under axial compression loading test, thirty columns having the measurements of (200x200 mm) in the cross area and 700 mm height were studied. The peak load, the relating strain, and ductility were determined and compared. The results proved that CFRP improved the square columns in terms of axial strength and ductility; however, the enhancement for square columns by a new technique of strengthening was prominent as that for tradition strengthening method. Innovative equations were suggested to expect the strength of CFRP-confined concrete of the cross section square and compared with experimental results. The suggested equation approves the accuracy and adequacy of the test result.

***Index*-Rectangular Column; Confinement; CFRP; Stress–strain relationship; Compression Test; Compressive Strength; Ductility Improvement.**

I. INTRODUCTION

In latest years, the existing columns are in the retrofitting and a necessary requirement. The improvement of a dependable and fee technique for strengthening the present columns has been considered as a requirement. Steel jacketing and confining procedures have been used broadly [1] and are shared applies in numerous countries for the strengthening of reinforced concrete columns, or due to failings in the columns themselves, old or unplanned harm [2–6]. In spite of the fact that steel jacketing is additional effective than confining, because the latter results found in addition to the structures self-weight, both procedures are work serious and sometimes hard to purpose on site in addition to their humble confrontation to climate settings [7]. However, feebleness to corrosion and the moderate strength-to-weight ratio of steel jackets made their utilization unfavorable. In this manner, the scan for another repairing material that can conquer every one of the downsides of conventional fortifying materials has never been halted.

CFRP have supplanted steel as the favored process for outer fortified support for a few reasons; simple using, high quality to weight proportion, and great resistance to erosion [8,9], however, greatest research studies concentrated on confinement productivity of reinforced concrete columns [10,11, and 12]. The strengthening of reinforced concrete columns with (CFRP) is enhanced [27]. The strength and ductility were observed to be expanded perpetually utilizing these FRP, of the strengthened columns [26]. Both the investigational and theoretical studies on the conduct of concrete confined discovered that the strength, stiffness, and ductility were observed to be expanded constantly utilizing these CFRP, of the strengthened columns. The searches study on the conduct of concrete confined with CFRP established the stress-strain behaviors for CFRP-confined concrete, mainly the circular columns below axial load. It was obvious in light of the theoretical and experimental, that, the FRP control of a circular column was more prominent than that contrasted with the square column. In the event of a square column, the effectiveness of FRP containment was less in light of the fact that, the stresses were concentrated at the corners and the dynamic area of the restricted segment by FRP was low.

A large portion of the columns is square in cross section as these are simple to fabricate by traditional square and rectangular formwork compared to circular columns. In any case, early researchers showed that the FRP containment for square or rectangular columns with sharp corners gave almost downgrade in enrichment limit in their load capacity. In any case, researchers [13, 14 and 15] exhibited that the FRP confinement for square columns provided very insignificant enrichment in their ultimate load; therefore, investigating a newly strengthening technique for enhancing the load capacity of involving construction errors square column became an objective of this study.

A. *Confinement vision*

Confinement is for the most part under compression, with the point of improving their ultimate load or, in instances of seismic up degree, or to build their flexibility. FRP, as uniqueness with steel, applies a steady confining pressure subsequent to yielding and has a flexible conduct till failure and accordingly applies its latent restricting activity on a member under axial loads differently as for steel. It has been seen that, at a specific estimation of concrete strain, the steel begins yielding starting there it applies a steady confining pressure, yet though, the FRP applies an expanding confining pressure. Utilizing composite schemes as confining reinforcement for concrete, the concrete tensile stresses are exchanged to FRP.

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The most extreme productivity of confining utilizing FRP materials is accomplished as columns with round cross-section by the way that the full section of the column is included into the confinement impact and the confining pressure is consistently circulated on the columns cross section. Yet, in the event of columns with a non-circular cross-section, just a piece of it is subjected to the restricting impact, and that part is known as the confined area.

In view of rectangular sections, the restriction can be given rectangular-formed outer wrapping, with corners adjusted before application [16]. The rectangular confining scheme is less skilled as the confinement activity for the most part situated at the corners and a significant jacket should be utilized between corners to control sidelong enlargement and column bar buckling. Fig. 1.demonstrates the confinement impact at corners. In the case of square columns, the constrained can be given with square- molded external wrapping, with longitudinal confinement for the part situated between the corners and was insignificant with wrapping.

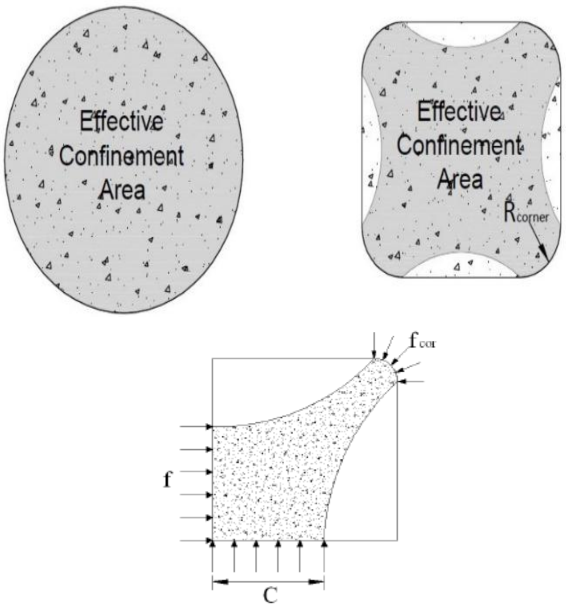

Fig 1: Effective confinement areas in circular and square columns.

II. RESEARCH SIGNIFICANCE

This research is the first that experimentally investigated the adequacy and possibility of the recently created method utilizing CFRP as restricting material to strengthen un-confinement concrete columns area, which is not affected by the external wrapping. The effects of different factors, such as, the volumetric percentage of lateral reinforcement confinement, method of strengthening, the number of external horizontal CFRP confinement, and thickness of the CFRP longitudinal (number of layers), that affect the effectiveness of CFRP confinement are examined.

III. EXPERIMENTAL PROGRAM

The experimental study consisted of 13 square columns reinforced with a different volumetric ratio (Vs) of lateral steel confinement (horizontal stirrups), a method of strengthening, the number of external CFRP confinement, and the longitudinal CFRP layers number (2, 3, and 4). The columns specimens were 200 mm x200 mm in section and 700 mm in length with longitudinal reinforcement 4 Φ 10 mm in corners with yielding stress and tensile strength 490 and 656 Mpa, respectively. The control specimens consisted of three square reinforced columns C2, C3, and C4 with volumetric ratio (Vs) = 0.144% (horizontal closed stirrups 2 Φ 6 mm), (Vs) = 0.216% (horizontal closed stirrups 3 Φ 6 mm) and (Vs) = 0.288% (horizontal closed stirrups 4 Φ 6 mm respectively without strengthening, The mechanical properties of the steel reinforcing bars are presented in Table I.

Table I : Average mechanical properties of steel bars.

Bar Diameter (mm)	6	10
Yield Stress (MPa)	403	490
Tensile Strength (MPa)	573	656
Ultimate Strain (%)	28	16

The strengthening specimens are wrapped with two layers of CFRP (breadth = 50 mm) and divided into three groups: Group (I) includes specimen C2 with 4 horizontal CFRP laminate (two layers) only and with horizontal (4 horizontal CFRP laminate (two layers) and longitudinal CFRP laminate two layers (breadth = 100 mm) at the four sides of the specimens (S4H/C2) and (S4H2L/C2) respectively. Group (II) includes specimen C3 with 3 horizontal CFRP laminate and with addition longitudinal CFRP laminate 2, 3, and 4 layers at the four sides of the specimens. Group (III) includes specimen C3 with 4 horizontal CFRP laminate and with addition longitudinal CFRP laminate 2, 3, and 4 layers at the four sides of the specimens. Table II and Fig. 2 explain the study experimental program and the different schemes of strengthening.

A. Materials

The cylindrical compressive strength of the concrete that used in the study was 26.5 Mpa. The thickness of CFRP fabrics (SikaWrap-230C) is 0.131 mm per layer were utilized. The elastic modulus, tensile strength, and elongation for CFRP equal 238 Gpa, 4300 Mpa, and 1.8 %, respectively.

The saturation resin for the applied fiber is a two unit; thixotropic epoxy based saturating sap/cement (Sikadur-330) with thickness 1.3 kg/l, with elastic modulus and tensile strength equal 4500 Mpa and 30 Mpa respectively.

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Table II: Specimens details.

Groups	Specimens ID	No. of Stirrups	(Vs) %	Strength scheme	
				A	B
Control Spec.	C2	2 Φ 6	0.144	Without strengthening	
	C3	3 Φ 6	0.216	Without strengthening	
	C4	4 Φ 6	0.288	Without strengthening	
I	S4H/C2	2 Φ 6	0.144	4	-
	S4H2L/C2	2 Φ 6	0.144	4	2
II	S3H/C3	3 Φ 6	0.216	3	-
	S3H2L/C3	3 Φ 6	0.216	3	2
	S3H3L/C3	3 Φ 6	0.216	3	3
	S3H4L/C3	3 Φ 6	0.216	3	4
III	S4H/C3	3 Φ 6	0.288	4	-
	S4H2L/C3	3Φ 6	0.288	4	2
	S4H3L/C3	3 Φ 6	0.288	4	3
	S4H4L/C3	3 Φ 6	0.288	4	4

A= No. of horizontal wrapped with two layers CFRP of 50 mm width

B= No. of longitudinal CFRP of 100mm width

IV. INSTRUMENTATION

The columns were tested in compression testing machine. Thin layers of covering were used at the top and bottom surfaces of columns to certify the uniform distribution of loading. Columns were tested under axial compression load and documented their deformation using mechanical demec gages fixed on the surface. The axial deformations and strains were recorded during the testing. The ultimate loads were recorded and their corresponding strains were calculated. Load deformation relationship was obtained from the curve plotted in the chart recorder of the machine. Fig. 3 Show the specimen in the testing machine.

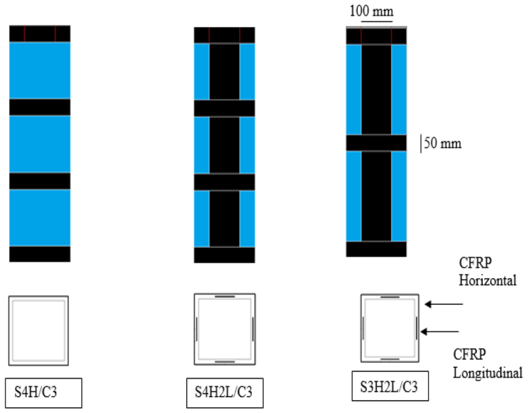

Fig. 2: Schemes of strengthening system for testing column.

Fig. 3: Test setup and instrumentation.

V. EXPERIMENTAL RESULTS

Table III displays the ultimate load, the maximum axial deformation, the maximum strain, and energy absorption for the control specimens and different groups. Figs. 4 delineate the columns failure modes. Fig. (5-8) demonstrate the load-axial

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displacement curves for control specimens and the three groups of the column specimens. Fig. (9–12) show the increments in ultimate load, and the corresponding strain for column specimens. The tabulated and showed results Fig. (4–12) and Table III are analyzed and discussed.

Table III: Test results for column specimens.

.Groups	Specimens ID	(V_s) %	Ultimate load		Axial deformation		Maximum strain	Energy absorption	
			Kn	± %	mm	± %		KN.mm	± %
Control Spec.	C2	0.144	400	- 31	6.98	+ 50.43	0.00544	1396	+ 86
	C3	0.216	580	-	6.23	+ 34.2	0.02051	2125	+ 41
	C4	0.288	580	-	4.64	-	0.01765	1508	-
I	S4H/C2	0.144	540	- 6.89	6.5	+ 40	0.0250	2015	+ 33.6
	S4H2L/C2	0.144	620	+ 6.89	8.36	+ 80	0.0079	3553	+ 135
II	S3H/C3	0.216	600	+ 3.44	9.9	+ 113	0.01188	3019.5	+ 100
	S3H2L/C3	0.216	620	+ 6.89	10.5	+ 126	0.00772	3307	+ 119
	S3H3L/C3	0.216	700	+ 20.7	11.7	+ 152	0.00808	4270.5	+ 183
	S3H4L/C3	0.216	760	+ 31.0	6.82	+ 47	0.011	2337.5	+ 55
III	S4H/C3	0.288	650	+ 12.1	5.2	+ 12	0.0198	1768	+ 17
	S4H2L/C3	0.288	720	+ 24.1	6.24	+ 34	0.01291	2464.8	+ 63
	S4H3L/C3	0.288	747	+ 28.8	5.91	+ 27	0.01692	2334.5	+ 54
	S4H4L/C3	0.288	722	+ 24.5	5.76	+ 24	0.0156	2304	+ 52

±% indicates the percentage of increment in value relative to that of the specimen C4.

A. Cracks and pattern failure

The failure mechanism of the control columns was of a sudden type, vertical and horizontal cracks started to spread and widen as the load is increased for the control specimens C3 and C4. The cover was separated from the core of specimen. At the peak load, buckling of longitudinal bars was dominant and exhibited significant plastic deformation. It is worth to note that, the control specimen C2 has a volumetric ratio (V_s) less than the requirements according to Egyptian code, for specimen C2, rough fine cracks started during increasing the load with sudden and brittle splitting failure occurred at the peak load. This could have been due to the losses of confinement. The failure mechanism for the wrapped columns was associated with internal noise which, in turn, was associated with localized deboning of the fibers. For the groupI, the mode of failure for column specimens was enhanced and crushing of concrete core plus buckling of longitudinal reinforcement bars were dominated as shown in Fig. 4. The confining of CFRP layer number limited the concrete core crushing and reduced the vertical bars buckling, the number of longitudinal CFRP layers increased this phenomenon as shown in Fig. 4. The stress concentration occurred due to the effect of the testing machine, the failure specimens (S4H4L/C3 and S4H2L/C3) start was bursting of concrete near column ends.

B. Ultimate load

For group I, due to the low volumetric ratio (Vs = 0.144%) for specimen C2, The failure occurred at an ultimate load of 400 Kn, with losses in load capacity 31 % with respect to the specimen C4. Results indicated that external horizontal strengthening CFRP for specimen (S4H/C2), is failed to reach the ultimate load similar to the specimen C4 because of that the restricting activity is, for the most part, constrained at the corners, producing a confining pressure not adequate to overcome the consequence of concrete collapse, the percentage of ultimate load losses was 6.89%. For specimen (S4H2L/C2) as an additional longitudinal CFRP (two layers) along the column height for each face, the ultimate load is increased 6.89 % over specimen C4, the longitudinal CFRP is performing as external reinforcement and resist the tensile stress that occurred due the lateral deformation between the external horizontal confinement of CFRP.

For group II, the volumetric ratio (Vs = 0.218%) is heavy closely satisfied the requirement Egyptian code, and the failure for specimen C3 occurred at an ultimate load of 580 Kn, similar to the specimen C4. The increment in the ultimate load arises for all strengthening specimen C3, the percentage of increase oscillates according to the strengthening method. The ultimate load of the specimen

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(S3H/C3) is increased 3.44% over specimen C4. By addition external longitudinal CFRP along the column specimen, the percentage of increase in the ultimate load is significant, the ultimate load for specimen (S3H2L/C3) is increased 6.89 % over specimen C4, as the number of longitudinal layers increased, the ultimate load is increased, for specimens (S3H3L/C3) and (S3H4L/C3), the ultimate load is increased 20.7% and 31 % over specimen C4 respectively.

For group III, with volumetric ratio (Vs = 0.288%) similar to group II, The increase in the ultimate load carrying capacity is more significant due to the increment of horizontal confinement CFRP number, the ultimate load for specimens (S4H/C3), (S4H2L/C3), (S4H3L/C3), and (S4H4L/C3) is increased 12.1%, 24.1%, 28.8% and 24.5% over specimen C4 respectively. It is precious to note that the increment of ultimate load carrying capacity for specimen (S4H4L/C3) is less than specimen (S3H4L/C3), due to the stress concentration at the edge of the column and rupture of warping CFRP during the testing. For comparison, the strengthening for a column with three horizontal wrapping CFRP and longitudinal three-layers is more effective in increasing the ultimate load than that column strengthening by only four horizontal wrapping CFRP.

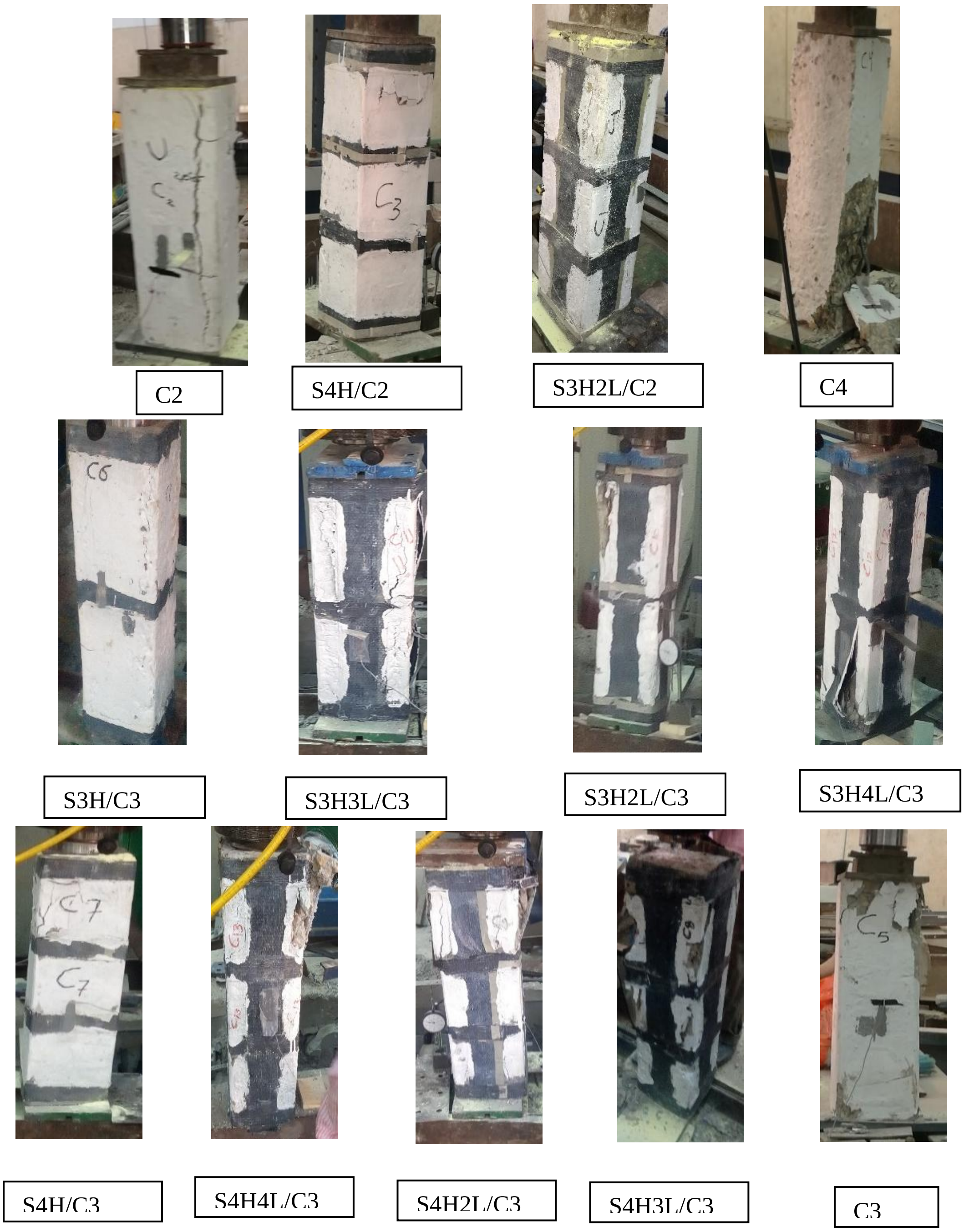

Fig. 4: Failure of column specimens.

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C. Axial deflection

At failure, the control specimen C2 exhibited higher axial deflection 6.98 mm. due to the losses of confinement. As the internally reinforced confinement increased, the axial deflection decreased, the control specimen C3 demonstrated axial deflection 6.23 mm. at the ultimate load and less than reference specimen C4 (4.64 mm.). Due to the losses of confinement, the percentage of increase in axial deflection are 50.43%, and 34% for the control C2, and C3 specimens with respect to reference specimen C4. Therefore, the strengthening for the group I is more significant in reducing axial deformation, the axial deformation is increased by 40%, and 80 % for specimens S4H/C2, and S4H2L/C2 respectively with respect to specimen C4. The strengthening along the column height addition is slightly the impact of increasing the axial deformation.

The axial deformation increment for group II column specimens is much higher than those for group III. In group II, the increments were 113%, 126%, 152% and 47 % for S3H/C3, S3H2L/C3, S3H3L/C3 and S3H4L/C3 respectively, with respect to specimen C4. For group III, the axial deformation increased by 12%, 34%, 27% and 24% for S4H/C3, S4H2L/C3, S4H3L/C3 and S4H4L/C3, respectively with respect to specimen C4. It can be noticed that the wrapping CFRP number has a significant effect in reducing the axial deformation, the values of axial deformation for S4H/C3, S4H2L/C3, S4H3L/C3 and S4H4L/C3 is reduced by 47%, 40 %, 49% and 15 % for column specimens with respect to S3H/C3, S3H2L/C3, S3H3L/C3 and S3H4L/C3 respectively.

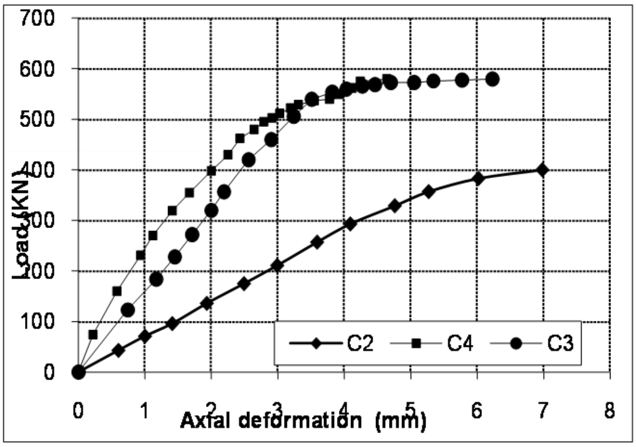

Fig. 5: load-axial displacement curves for control specimens.

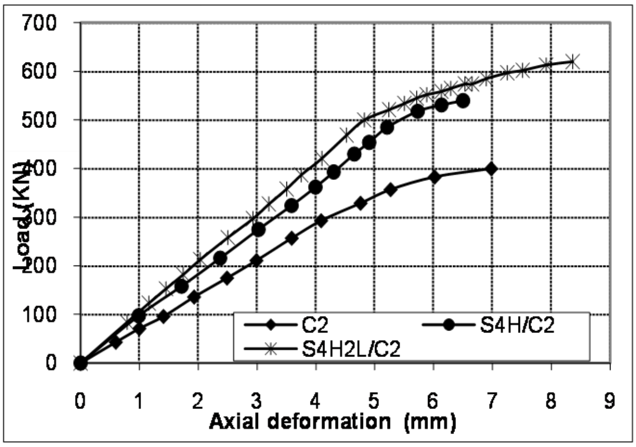

Fig. 6: load-axial displacement curves for Group I.

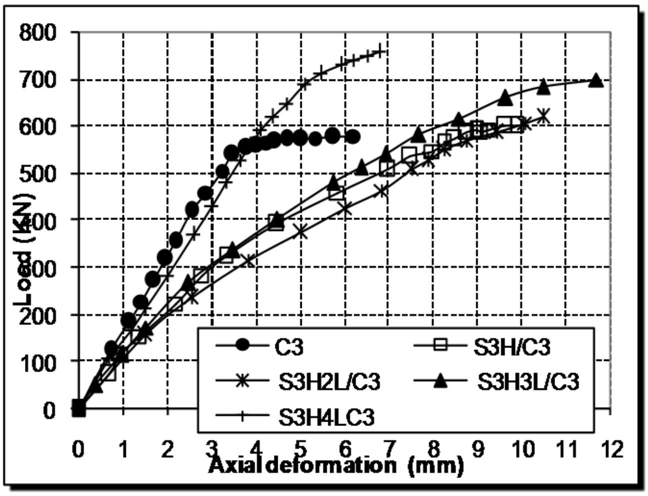

Fig. 7: load-axial displacement curves for Group II.

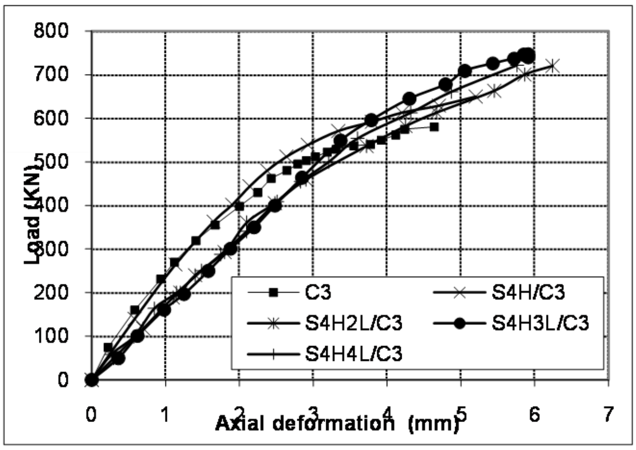

Fig. 8: load-axial displacement curves for Group III.

D. Strain

Tables 3 shows that higher decrease in volumetric ratio brings about the smaller increment in strain, the maximum strain for specimen C2, C3 and C4 reached to 0.544%, 2.05%, and 1.765% respectively. The results reported in Fig. 9 to 12 show that the axial load-strain relationship for the columns with and without strengthening with CFRP are slight differences at the initial stage of testing, the development of the concrete core in the horizontal direction made the CFRP more dynamic in opposing the pivotal compressive forces by

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building constrain confining pressure. For group I, the maximum strain of the specimens wrapped by equivalent two CFRP layers with four horizontal wrapped (S4H/C2) reached to 2.50%, the strain of strengthening specimen with horizontal and longitudinal CFRP (S4H2L/C2) reached to 0. 79%. For group II, the specimen (S3H/C3) reached a higher maximum strain 1.118% while, it is less than the reference specimen C4 at ultimate load, the strengthening in longitudinal of column reduced the strain. The results show that the maximum strains of strengthening specimens S3H2L/C3, S3H3L/C3 and S3H4L/C3 reached 0.772%, 0.808%, 1.1% respectively.

Although Specimens strain for group III is similar compared to that of Specimens for group II in behavior, at the point when a CFRP restricted concrete column is vigorously limited, its compressive strength and strain are fundamentally higher than those of the less confined, the strains are increased as the number of wrapped increased, the maximum strains of strengthening specimens S4H/C3, S4H2L/C3, S4H3L/C3 and S4H4L/C3 reached 1.98%, 1.29%, 1. 69% and 1.56% respectively.

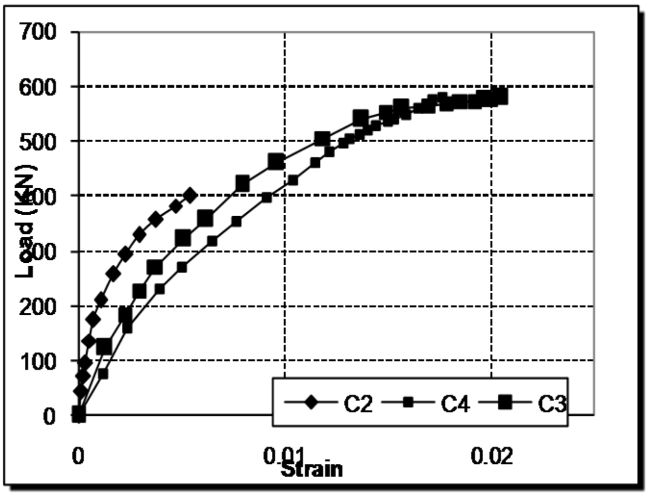

Fig. 9: load-strain concrete surface curves for control spec.

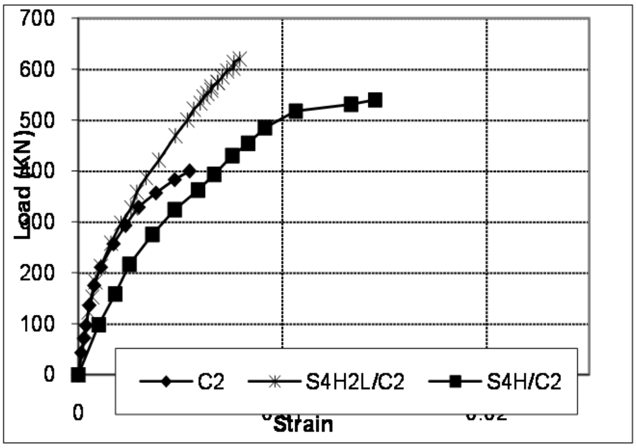

Fig. 10: load-strain concrete surface curves forGroup I.

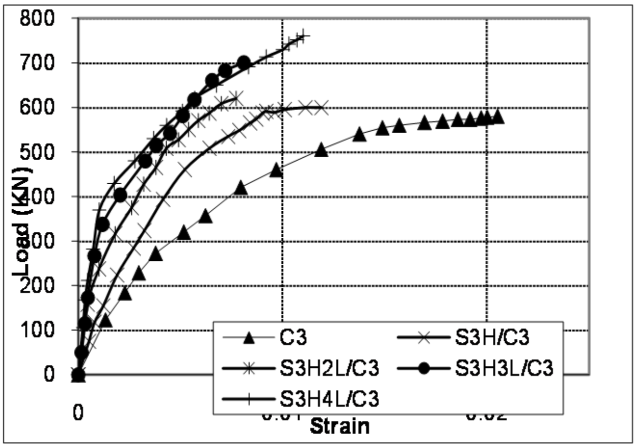

Fig. 11: load-strain concrete surface curves for Group II.

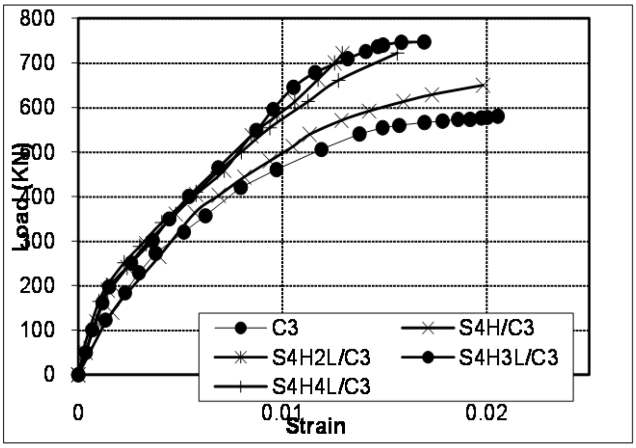

Fig. 12: load-strain concrete surface curves for Group III.

E. Ductility

The ductility uncovers the capacity of a structural member to show large deformation without failure. In any case, there is no hard control for the meaning of ductility, the load-axial displacement, given in Fig. 7 and 8, demonstrate that the strengthening with CFRP has enhanced ductility over those of the control C3. The average increment in ductility is 6% and 13% for group II and group III respectively with respect to their control specimen C3.

F. Energy absorption

The energy absorption was assessed by ascertaining the area under load-axial deformation curve for each column specimen. The increment in energy absorption of horizontal strengthening wrapped was highest 33. 6%, 100%, 17% for column specimens (S4H/C2), (S3H/C3), and (S4H/C3) respectively to those of column specimen C4. The energy absorption was increased with addition longitudinal strengthening and decreased as the number of horizontal strengthening wrapped increased. The energy absorption of the columns for (S4H2L/C2), (S3H2L/C3), (S3H3L/C3), and (S3H3L/C3) was found to be higher than that column

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specimen C4, by 135%, 119%, 183%, and 55% respectively. For group III, the energy absorption of columns (S4H2L/C3), (S4H3L/C3), and (S4H4L/C3) was increased by 63%, 54%, and 52% respectively with respect to C4.

VI. MODEL OF FRP-CONFINED CONCRETE

The confinement of concrete by FRP have been presented in different models. Most of these models were prepared on plain concrete. An extensive segment of the present quality models for FRP restricted limited concrete expected the idea of [17], in which the confined concrete strength presents in the form at failure:

$$f'cc = f'co + k_1 f_l \quad (1)$$

Where $f'cc$ and $f'co$ are the compressive strength ofconcrete for confined and the unconfined respectively, f_l istheconfining lateral pressure and can be expected using Equation (2) for the square section, k_1 is the confinement factor and equal 4.1 for steel-confined concrete [17].

$$fl = 2t_{fyp} E_{fyp} \varepsilon_{up} / 1.414b \quad (2)$$

However, numerous studies discovered that models withsteel-confined concrete arenot- preservationist and cannot be used for FRP-confined concrete. Numerous of strength modeling have been submitted for FRP-confined concrete which engagement Equation (1) with changed value for k_1 [18, 19and 20]. Most of these models used a constant value for $k1$ (between2 and 3.5) demonstrating that the relationship between the strength of confined concrete $f'cc$ and the lateral confining pressure fl is linear[21, 22-23].Another researcherindicated $k1$ in the nonlinear formula in terms of $f_l / f'co$ or f_l[18, 19].

ForFRP-confined concrete, the FRP material tensile strength was not stretched at FRPrupture[25],the ratio of the tensile strain FRP at rupture in the square column(ε_{hrup})to the ultimate strain from FRP in tensile tests(ε_{fu})is defined as the effective FRP strain coefficient η.

$$fl = 2t_{fyp} E_{fyp} \varepsilon h_{rup} / 1.414b = 2t_{fyp} E_{fyp} \eta \varepsilon f_u / 1.414b \quad (3)$$

$$\eta = \varepsilon h_{rup} / \varepsilon_{fu} \quad (4)$$

Where E_{fyp} is the modulus of elasticity for the FRP, εf_u is the ultimate strain of FRP, t_{fyp} is the total thickness of the FRP, b is the concrete column breadth.

Type of bond, geometry, the thicknessof FRP jacket, and type of resin effect onthe (η) coefficient. FRP strain coefficient (η) was 68 % for square column according tothe experimental results.

For square section, the powerful sidelong restricting pressure can be characterized as a component of the shape using a constraint viability coefficient ke, for the determination of the effectiveness factor ke it can be expected that for the square area, there is a diminishment in the productively limited of confined of core that can be accepted like with the case of concrete core bound by transverse steel stirrups [24], as a moment degree parabola with an initial tangent slope of 45°. For a square section wrapped with FRP (Fig. 1), the parabolic arching action is in charge of the concrete core improvement the confining pressure, an expansive piece of the cross-section stays unconfined. In light of this perception, it is conceivable to get the region of unconfined concrete Au, as takes after:

$$Au = 4 (b^2 / 6) = 2 b^2 / 3 \quad (5)$$

The coefficient ke can be defined as the ratio of the area of confinement Ae to the total concrete area constrained by the FRP jacket, Ac, as follows:

$$k_e = A_e / A_c = (A_c - A_u) / A_c = 1 - A_u / (A_g - A_s) =$$
$$1 - A_u / (A_g (1 - \rho sc)) \quad (6)$$

Where Ag is the total area of column section, and ρsc is theratio of longitudinal steel to the totalarea of column section. ke is consequently indicated by for square section:

$$ke = 1 - 2b^2 / (3 A_g (1 - \rho sc)) \quad (7)$$

Depend on the equation suggested [17] for equally confined concrete, the proposed display utilizes a comparative approach with a few alterations, mulling over the FRP strain and the effective of confinement. The compressive strength of a square FRP-confined concrete column is suggested to be a basic adjustment of Equation (8) by the presentation of a coefficient meant ke. In this way,

$$f'cc / f'co = 1 + k_1 k_e f_l / f'co \quad (8)$$

The coefficient $k1$ and ke were suggested for uniformly confined concrete 1.60, and 0.36 respectively depending on the tested columns results. Lastly, the equation recommended for the confined concrete strength is:

$$f'cc = f'co + 0.58 f_l \quad (9)$$

A. Proposed Equation

A simple equation is proposed to expect the peak strength of CFRP -confined concrete of different volumetric ratio and number of horizontal confinement with CFRP-based on regression of experimental results reported in Table 3. The equation (8) depends on the lateral confining pressure is constant along the column height, so for the column, which is confined by CFRP strip, the equation (8) is modified, and the equation suggested for the confined concrete strength is:

$$f'cc / f'co = 1 + k1 k_e f_l (n b_{hf} / h) / f'co \quad (10)$$

Where n is the number of horizontal strip CFRP along the column height, b_{hf} is the width of the CFRP in the horizontal direction, h is the total height of the column.

Figs 13, 14 and 15 show the relation between actual longitudinal confinement ratio (t_f b_f /b) and f 'ccL /f 'cc ratio for the test series of square short columns for different volumetric ratio 0.144%, 0.216%, and 0.288% with two, three, and four horizontal confinement with CFRP respectively. Where f 'ccL and f 'cc are the compressive

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strength of confined longitudinal and the confined horizontal concrete respectively, tf is the total thickness of the CFRP in the longitudinal direction, bf is the width of the CFRP in the longitudinal direction.

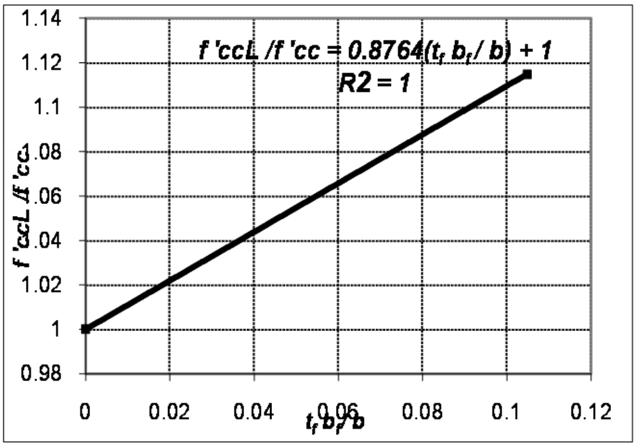

Fig. 13: Strengthening ratio vs. longitudinal confinement ratio for group I.

The proposed equation for the confined concrete strength with volumetric ratio 0.144% is:

$f'cc_L=[f'co+\ k1\ k_e fl\ (n\ b_{hf}/h)]\ +0.8764\ \ [f'co+ k1\ k_e fl\ (n\ b_{hf}/h)][t_f\ b_f/b]$ (11)

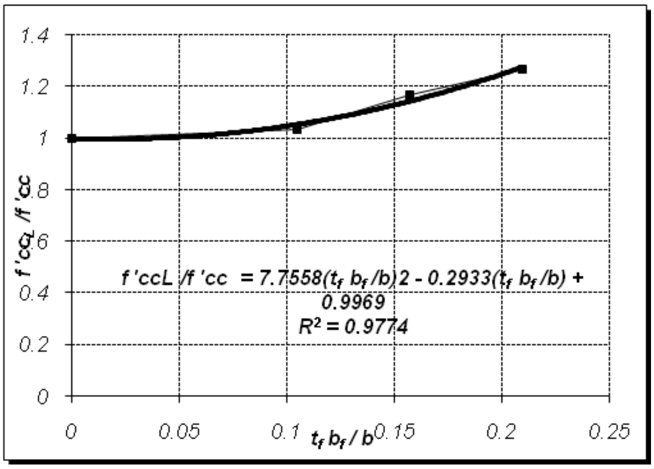

Fig. 14: Strengthening ratio vs. longitudinal confinement ratio for group II.

The proposed equation for the confined concrete strength with volumetric ratio 0.216% is:

$f'ccL=[f'co+\ k1\ k_e\ fl\ (n\ bhf/h)][\ 7.7558(t_f\ b_f/b)2 - 0.2933(tf\ bf/b) + 0.9969](12)$

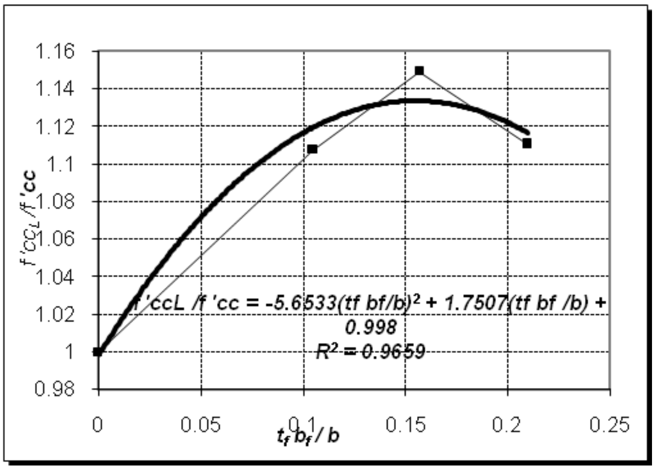

Fig. 15: Strengthening ratio vs. longitudinal confinement ratio for group III.

The proposed equation for the confined concrete strength with volumetric ratio 0.216% is:

$f'cc_L = [f'co +\ k1\ k_e\ fl\ (n\ b_{hf}/h)][-5.6533(t_f\ b_f/b)^2 + 1.7507(t_f\ b_f/b) + 0.998]$ (13)

Table IV presents the ultimate load of the strengthening specimens according to experimental results and proposed equations for the groups I, II and III. The proposed equations presented good forecasts against the experimental records, including extreme inaccuracies of 18.6%.

Table IV: Results for column according to experimental results, and proposed equations.

. Groups	Specimens ID	(V_s) %	Ultimate load experimental	Ultimate load using proposed equation (10)		Ultimate load using proposed equations(11), (12) and (13)	
			Kn	Kn	%	KN	%
Control Spec.	C2	0.144	400	-	-	-	-
	C3	0.216	580	-	-	-	-
	C4	0.288	580	-	-	-	-
I	S4H/C2	0.144	540	452.6	16.2	452.6	16.2
	S4H2L/C2	0.144	620	-	-	504.6	18.6
II	S3H/C3	0.216	600	619.7	3.3	617.8	2.9

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	S3H2L/C3	0.216	620	-	-	676.4	9
	S3H3L/C3	0.216	700	-	-	743.2	6.2
	S3H4L/C3	0.216	760	-	-	871.5	14.7
III	S4H/C3	0.288	650	632.6	2.7	631	2.9
	S4H2L/C3	0.288	720	-	-	713	0.9
	S4H3L/C3	0.288	747	-	-	709	5
	S4H4L/C3	0.288	722	-	-	676	6.3

VII. CONCLUSION

This paper presents a study for strengthening square short RC columns with lateral confinement and longitudinal using CFRP. Built on the results the following conclusions can be drawn:

1. The external Wrapping column specimen having volumetric steel ratio of ties 0.144% with four horizontal CFRP laminate is not sufficient as a confinement in increasing the ultimate load similar to the load capacity short column having volumetric steel ratio of ties 0.288%, which is satisfied the Egyptian code.
2. Adding longitudinal CFRP (two layers) with four horizontal CFRP laminate for square short RC columns having volumetric steel ratio of ties 0.144% increases the ultimate load with 6.89 % with respect to ashortcolumn having volumetric steel ratio of ties 0.288%.
3. Wrapping the column three horizontal CFRP laminate with longitudinal CFRP (one or two layers) is not significant in increasing the ultimate load, the ultimate load increase by 20.7% and 31 % for three and four longitudinal CFRP respectively.
4. The strengthening for a column with three horizontal wrapping CFRP and longitudinal three-layer is more effective in increasing the ultimate load than that column strengthening by only four horizontal wrapping CFRP.
5. RC column specimens confined with external ties and longitudinal CFRPexhibits more plastic deformation and more ductile compared to specimens confined with only external CFRP ties only.
6. The energy absorption was increased with addition longitudinal strengthening and decreased as the number of horizontal strengthening wrapped increased.
7. As the lateral wrapping CFRP confinement increased, the axial deformation decreased and the strain increased.
8. Innovative equations were suggested to expect the strength of FRP-confined concrete of the cross section square for both strengthening in horizontal and longitudinal direction

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