SOME PARAMETERS AFFECTING THE STATIC BEHAVIOR OF NORMAL STRENGTH RECTANGULAR R.C. SHORT COLUMNS CONFINED BY CFRP

Abdel Rahman Megahid [1], Omar Ahmed Farghal [2] and Mahmoud Mohamed El-Taher [3, *]

[1, 2] Staff in Civil Eng. Department, faculty of Engineering, Assuit University, Assuit , EGYPT
3 Consulting Engineer , Luxor , EGYPT

Received 3 December 2012; accepted 30 December 2012

ABSTRACT

Changing social needs, upgrading of design standards, increasing safety requirements and deterioration are some of the reasons that make the existing reinforced concrete structure (such as bridges and buildings) need to be strengthened or repaired . Over the past several years, there has been a concerned research efforts to explore the strengthening effect of Carbon Fiber Reinforced Polymer (CFRP) laminates applied to reinforced concrete columns under centric loading . So, the main objective of this work is to identify the main parameters affecting the mechanical behavior of confined rectangular R.C. columns such as the confinement level and rectangularity ratio (t/b ratio) . The efficiency of externally bonded CFRP of rectangular R.C. columns is declared and evaluated . [1,2,3].

Keywords: Carbon Fiber Reinforced Polymer (CFRP) , strengthening, efficiency, rectangular R.C. columns.

1. Introduction

Fiber reinforcement polymer (FRP) materials are composites which consist of organic or inorganic fibers embedded in matrix, the matrix sometimes referred to as binder, is a polymer resin, often with some fillers and additives of various natures. Externally bonded FRP reinforcement can be regarded as a system of FRP and a bonding agent to glue the FRP to the structure. Fiber reinforcement polymer (FRP) , are used as Carbon Fiber (CF), Armid Fiber (AF) and Glass Fiber (GF) [4].

2. Experimental program

The aim of this paper is to demonstrate the effect of main parameters that affecting the efficiency of externally bonded (CFRP) strengthening reinforced concrete axially load short normal strength concrete columns namely :

1- Strengthening system 2- Rectangularity of cross-section

* Corresponding author.
Civil Engineering Department, Faculty of Engineering, Assiut University, Assuit , EGYPT

2.1. Test specimens

Nine rectangular R.C. columns with different rectangularity of cross-sections were constructed to study the various parameters for short reinforced concrete columns under axial static centric load. The details and the data of tested columns are listed in ***Table (1)*** . All R.C. columns have constant percentage of longitudinal and lateral reinforcement. , H/D ratio was kept constant and equals 6, where H is height of columns and D is the smallest dimension of cross-section.

Table 1
Details and data of tested columns

Col. designation	Constants	Parameter	Shape	Cross-section dim.	Longit. steel (μ %)	Lateral steel (μ^{-} %)	Strengthening System	% of Confin. μf %	H cm	(t/b)	Grade of concrete kg/ cm ^{2}
Bs 1-0	H/D ratio , grade of concrete Shape of cross – section , μ%, μf, μ^{-} %	Strengthening system, Rectangularity	Rectangular	20 x 20 cm	6Φ12 (1.7 %)	μ^{-} = (0.35 %)	-	-	120	1.00	***C 200***
Cr 1-0				16 x 25 cm			-	-	96	1.56	
Gr 1-0				12.5 x 32 cm			-	-	75	2.56	
Bs 1-1				20 x 20 cm			1 layer,5 strips b_f= 11 cm	0.14 %	120	1.00	
Cr 1-1				16 x 25 cm			1 layer, strips b_f= 8 cm	0.14 %	96	1.56	
Gr 1-1				12.5 x 32 cm			1 layer, 5 strips b_f= 5.5 cm	0.14 %	75	2.56	
Bs 1-2				20 x 20 cm			2 layers,5 strips b_f= 11 cm	0.28 %	120	1.00	
Cr 1-2				16 x 25 cm			2 layers,5 strips b_f= 8 cm	0.28 %	96	1.56	

Col. designation	Constants	Parameter	Shape	Cross-section dim.	Longit. steel (μ %)	Lateral steel (μ` %)	Strengthening System	% of Confin. μf %	H cm	(t/b)	Grade of concrete kg/ cm²
Gr 1-2				12.5 x 32 cm			2 layers,5 strips b_f = 5.5 cm	0.28 %	75	2.56	

$\mu = (A_s / A_c) \times 100$ and $\mu` = (V_{st} / Vc) \times 100$ Where

$$\frac{(b+t)\times 2\times b_f \times t_f \times n}{b\times t\times S}$$ (for square and rectangular cross-sections) `

Where, μ = percentage of longitudinal steel reinforcement, $\mu`$ = the percentage of lateral steel (stirrups), μ_f= the percentage of confinement, A_s =cross-sectional area of longitudinal steel reinforcement, A_c = cross-sectional area of concrete, V_{st} = volume of lateral steel reinforcement, V_C = volume of concrete, b_f = total width of the bounded CFRP , t_f = CFRP thickness, n = number of layer of CFRP, b ,t = dimension of column cross-section and S = centre to centre spacing of the CFRP.(for examples see ***Fig. (1)*** .

2.2. Materials and concrete mix proportion :

2.2.1. Concrete:

All columns were made from concrete having the same strength, therefore concrete mix design was done to produce cube strength of about 200 kg / cm^2 after 28 days. The constituent materials were as follows:

- Ordinary Portland Cement (Assiut cement) was used throughout the program for making concrete, the cement content was 300 kg /m^3 and water - cement ratio was 0.60 to have a slump of 100 mm.
- The fine aggregate used was natural siliceous sand with a fineness modulus of 2.60 , specific gravity of 2.55 and unit weight of 1.70 t/m^3.
- The coarse aggregate was natural gravel of 20 mm maximum nominal size, fineness modulus of 6.61 , specific gravity of 2.65 and unit weight of 1.58 t/m^3 . Drinking water used for mixing concrete **.**

2-2-2 Steel reinforcement:

High tensile steel deformed bars of grade 36/52 and diameter 12 mm was used as longitudinal steel, while mild steel plain bars of grade 24/35 and diameter 6 mm was used as lateral steel in all RC columns.

Table 2
Concrete mix proportions

Composition (kg / m^3)	**C 200**
Cement (type / weight)	OPC / 300
Coarse aggregate (type / weight)	R / 1174
Fine aggregate (type / weight)	R / 718
Water	180
Ratio water/ cement (W/C)	0.60

The external reinforcement was a CFFRP sheet **[6]** , the mechanical properties of CFRP are listed in Table (3*)*

Table 3
Mechanical properties of CFRP [4, 9,10,11,16]

Modulus of Elasticity (kg / cm^2)	Tensile strength kg / cm^2)(	Ultimate strain	Thickness (mm)	Weight of CFRP (g/m^2)
2380000	43000	1.8 %	0.131	230 ± 10

3. Test results

3.1. With respect to failure mode of tested columns:

During tests, two failure mechanisms of failure were observed as follows:

<u>The first mechanism (FM 1):</u>

This mechanism was due to shear failure, in non-strengthened columns . The non-strengthened columns failed because of the combination of two brittle mechanisms; steel reinforcement compressive bars buckling and concrete cover spalling. Failure was governed by shear failure between the medium third to the upper or lower third for all columns. This mechanism was observed in case of reference columns ***(Bs1-0), (Cr1-0)*** and ***(Gr1-0) ,*** see the following photos

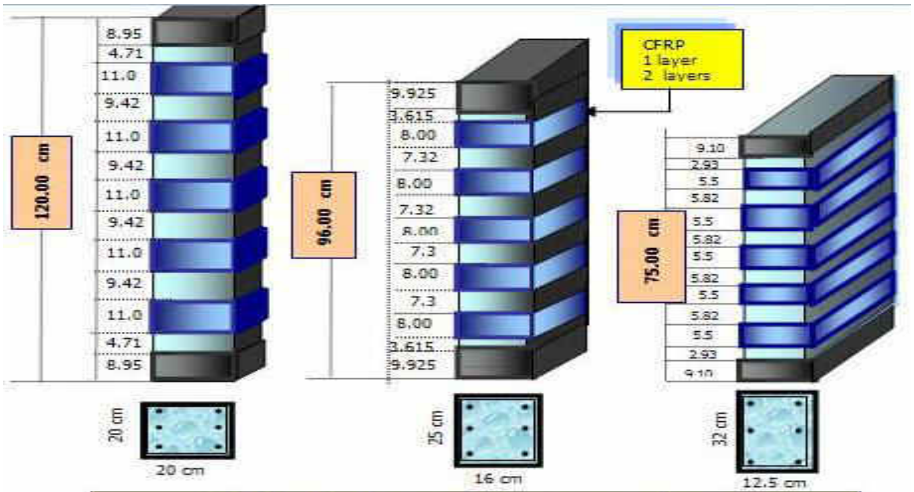

Fig. 1 Reinforced concrete columns - rectangular section

Failure mode, (unconfined rectangular R.C. columns) (FM 1)

The second mechanism (FM 2):

This mechanism was observed in case of strengthened columns with a number of CFRP strips of one layer and two layers (***Bs1-1), (Cr 1-1), (Gr1 -1), (Bs1-2), (Cr 1-2), (Cr 2-2)*** and ***(Gr 1-2),*** see the following photos .


Gr 1-1


Bs 1-2

Failure mode, R.C. columns confined one and two layers) (FM 2)

3.2. With respect to the axial nominal stress - axial nominal strain relationship of tested columns :

For all tested columns, the axial nominal stress and the axial nominal strain are evaluated during the testing of each column up to failure . ***Fig. (2)*** and ***Fig. (3)*** show the relationships between the axial nominal stress and axial nominal strain for tested of R.C. columns. Also, the values of max. axial load , the max. axial stress, the max. strain , modulus of elasticity , the modulus of toughness, as well as the strength , ductility, stiffness and absorbed energy efficiencies are tabulated in ***Table (4)*** .

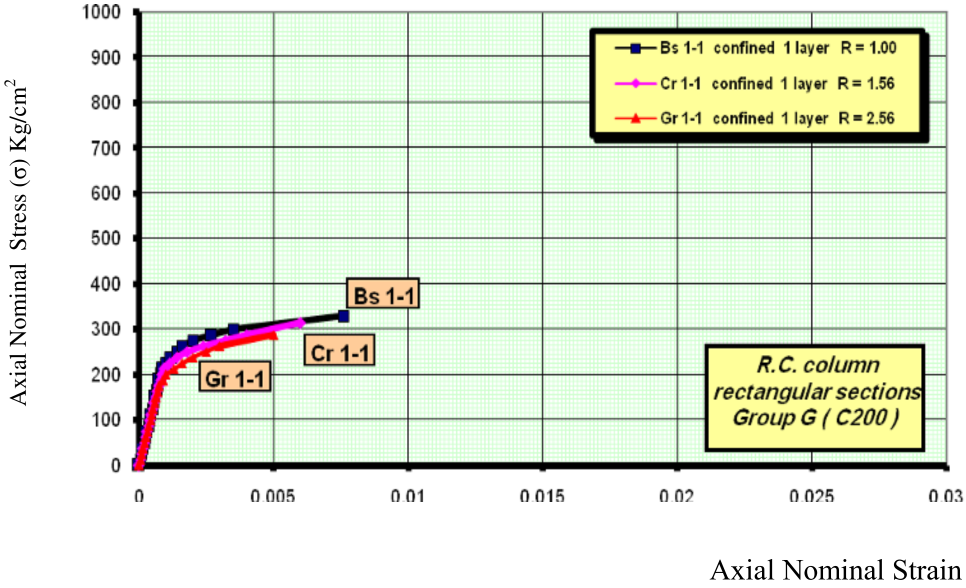

Fig. 2. Relation between axial nominal stress and axial nominal strain for different rectangularity of rectangular R. C. columns confined 1 layer (Group G -C 200)

4. Analysis and discussions of test results

The efficiencies are evaluated by calculating the following items for the strengthened columns compared with that without strengthening :

-Strength efficiency *(ζ_1)* which is represented by the percentage of increase of axial nominal stress .

- Ductility efficiency (ζ2) which is represented by the percentage of increase of axial nominal strain .

- Stiffness efficiency (ζ3) which is represented by the percentage of increase of modulus of elasticity.

- Absorbed energy efficiency *(ζ_4)* measured by the percentage of increase of the modulus of toughness .

One of the main parameters affecting the behavior of static normal strength of the externally bonded (CFRP) strengthening R.C. columns as well as the above efficiencies is the rectangularity ratio (t/b) of cross section . This effect is declared through the following items :

- From point of view of strength (strength coefficient $\zeta 1$) :

Fig. 4. shows the relations between ($\zeta 1$)value against (t/b) ratio for all cases confined R.C. rectangular columns, the relations can be best represent by the following equations :

$\zeta_1 = 41.57 - 9.782$ (t/b) ....(1) (for rect. R.C. columns confined 1 layer)

$\zeta_1 = 61.42 - 13.57$ (t/b) ... .(2) (for rect. R.C. columns confined 2 layers)

From the above equations , the value of ($\zeta 1$) equal zero when (t/b) ratio equal $\cong$ 4.20, $\cong$ 4.50 for R.C. columns confined with one layer and two layers respectively . This means that the strength efficiency increases in strength due to confinement with two layers than that one layer when (t/b) ratio and grade of concrete are constant. Also, the strength efficiency decreases when (t/b) ratio is increased .

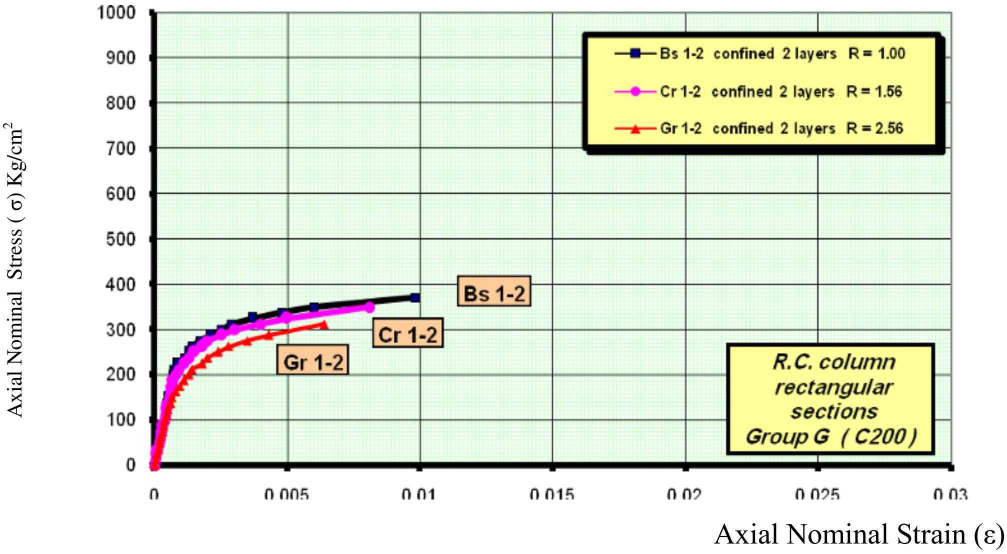

Fig. 3. Relation between axial nominal stress and axial nominal strain for different rectangularity of rectangular R. C. columns confined two layers (Group G - C 200)

Table 4

The values of max. nominal stresses and max. nominal strains and different values of efficiencies for different rectangularity of rectangular R.C. columns

Group	Column designation	Maximum axial load (Pu) ton	Max. axial nominal stress (σ) Kg /	Max. axial nominal strain (ε_ℓ)	% Increase of max. axial nominal stress (ζ1)	% Increase of max. axial nominal strain (ζ2)	modulus of Elasticity (E) Kg /	% Increase of modulus of elasticity (ζ3)	Modulus of toughness (M. T.)	% Increase modulus of toughness (ζ4)	Grade of concrete
G	**Bs 1-0**	100	250	0.0028	-	-	2.19×10^5	-	0.5068	-	200
	Cr 1-0	100	250	0.00275	-	-	2.18×10^5	-	0.4960	-	
	Gr 1-0	98	245	0.0027	-	-	2.18×10^5	-	0.4471	-	
	Bs 1-1	132	330	0.0076	32.00	171.42	2.55×10^5	16.43	2.0996	314.28	
	Cr 1-1	126	315	0.0060	26.00	118.18	2.42×10^5	11.00	1.5035	203.12	
	Gr 1-1	115	287.5	0.005	17.30	85.18	2.35×10^5	7.79	1.1464	156.40	
	Bs 1-2	148	370	0.0098	48.00	250.00	2.72×10^5	24.20	3.0607	503.92	
	Cr 1-2	140	350	0.0081	40.00	194.54	2.65×10^5	21.55	2.2639	357.52	
	Gr 1-2	125	312.5	0.0064	27.55	137.03	2.45×10^5	12.36	1.6136	260.94	

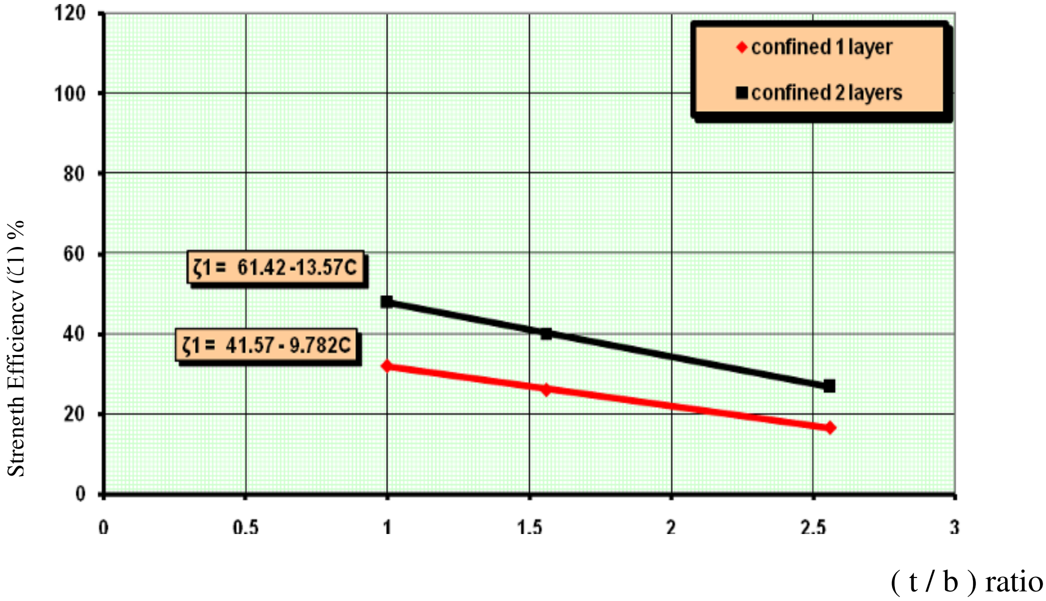

Fig. 4. Relation between efficiency(ζ1) and rectangularity (t / b) ratio

- From point of view of strain (ductility coefficient ζ2):

Fig. 5. shows the relations between (ζ2)value against (t/b) ratio for all cases confined reinforced concrete rectangular columns, these relations can be best represent by the following equations :

$\zeta_2 = 214.80 - 52.66\ (t/b)$ ………...(3) (for rect. R.C. columns confined 1 layer)

$\zeta_2 = 314.40 - 70.66\ (t/b)$ ………...(4) (for rect. R.C. concrete confined 2 layers)

The value of (ζ2) equal zero when (t/b) ratio equal ≅ 4.10 and ≅ 4.40 for R.C. columns confined with one layer and two layers respectively. This means that the ductility efficiency increases in strength due to confinement with two layers than that one layer when (t/b) ratio and grade of concrete are constant . Also, the ductility efficiency decreases when (t/b) ratio is increased.

From point of view of stiffness (stiffness efficiency ζ3):

The relation between (ζ3) and (t/b) ratio for confined with one layer and two layers reinforced concrete rectangular columns, ***Fig. 6*** , the relations can be best represent by the following equations :

$\zeta_3 = 20.72 - 5.265(t/b)$ ……….. (5) (for rect. R.C. columns confined 1 layer)

$\zeta_3 = 32.64 - 7.777\ (t/b)$ ……….. (6) (for rect. R.C. columns confined 2 layers)

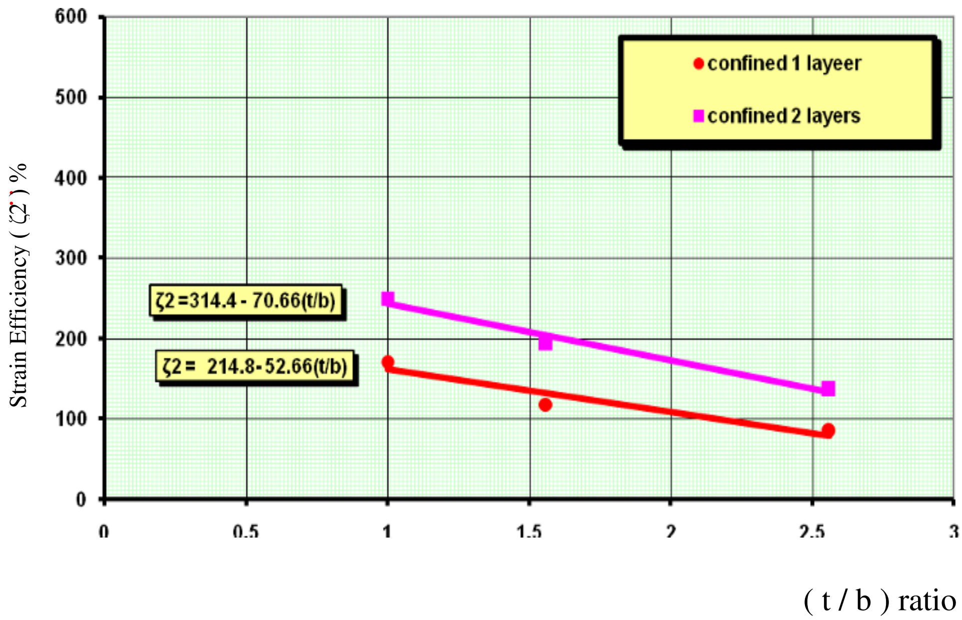

Fig. 5. Relation between efficiency(ζ2) and rectangularity (t / b) ratio

The value of (ζ_3) equals zero when (t/b) ratio is equal $\cong$ 3.95 and $\cong$ 4.20 for R.C. columns confined with one layer and two layers respectively, This means that the stiffness efficiency of rectangular R.C. columns increases when the confinement level is increased for constant rectangularity and grade of concrete . At the same time, the stiffness efficiency decreases when (t/b) ratio is increased .

From point of view of total absorbed energy (modulus of toughnessζ_4):

From ***Fig.*** *7*, the values of the efficiency (ζ_4) measured by modulus of toughness, decreases with the increases of (t/b) ratio, these relations can be best represent by the following equations :

$\zeta_4 = 386.4 - 94.80\ (t/b)$ ………….(7) (for rect. R.C. columns confined 1 layer)

$\zeta_4 = 628.0 - 148.80\ (t/b)$ ………..(8) (for rect. R.C. columns confined 2 layers)

The value of (ζ_4) equals zero when (t/b) ratio equal $\cong$ 4.10 and $\cong$ 4.20 for R.C. columns confined with one layer and two layers respectively . This means that the modulus of toughness efficiency of rectangular R.C. columns increased when the confinement level increase for constant rectangularity and grade of concrete . Also, the modulus of toughness efficiency decreases when (t/b) ratio is increased .

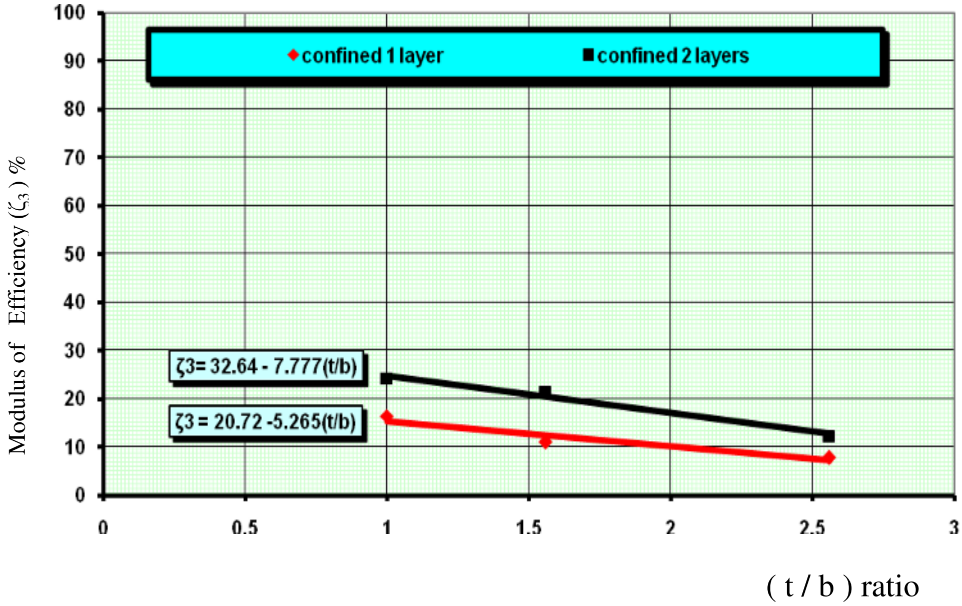

Fig. 6. Relation between efficiency(ζ3) and rectangularity (t / b) ratio

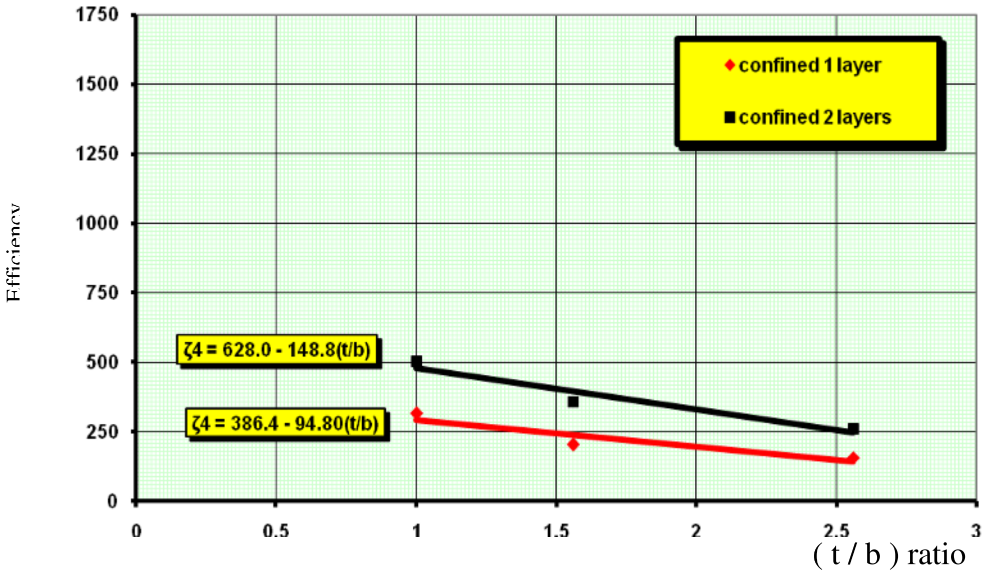

Fig. 7. Relation between efficiency(ζ4) and rectangularity (t / b) ratio

Table 5
Comparison for all efficiencies of different Rectangularity (t/ b)ratio

(t/ b) Rectangularity	Column designation	CFRP system	% strength efficiency (ζ1)	% of decreases (ζ1)	% ductility efficiency (ζ2)	% of decreases (ζ2)	% stiffness efficiency (ζ3)	% of decreases (ζ3)	% modulus of toughness (ζ4)	% of decreases (ζ4)	% of average decrease of efficiencies
***1.00**	**Bs 1-1**	One layer	32.00	-	171.42	-	16.43	-	314.28	-	-
1.56	**Cr 1-1**		26.00	18.75	118.18	31.05	11.00	33.04	203.12	35.36	***29.55***
2.56	**Gr 1-1**		17.30	45.93	85.18	50.30	7.79	52.58	156.40	50.23	***49.68***
***1.00**	**Bs 1-2**	Two layers	48.00	-	250.00	-	24.20	-	503.92	-	-
1.56	**Cr 1-2**		40.00	16.66	194.54	22.18	21.55	10.95	357.5	29.05	***19.71***
2.56	**Gr 1-2**		27.55	42.60	137.03	45.18	12.36	48.92	260.94	48.21	***46.22***

* Rectangularity (t/ b) = 1.00 as a control

Table 6. explains the percent of average decrease of efficiencies for different rectangularity of rectangular reinforced concrete columns confined with CFRP one layer (partial wrapping) and two layers (partial wrapping) comparing with that have rectangularity (t/b) = 1 . Also ***, Table (7)*** presents the average of max. (t/b) when the average of efficiencies are vanishing for both confined one layer and confined two layers. Based on this table , it is recommended that the ratio of (t/b) should not exceed 4.00 in order to provide a beneficial effect by strengthening the rectangular R.C. short columns by CFRP either one layer or two layers partial wrapping.

5. Theoretical approach and mathematical modelling

5.1. Load carrying capacity of R.C. strengthened columns

The obtained experimental results showed that the load carrying capacity of R.C. columns confined with wrapped CFRP sheet considerably improved in comparison with that of the corresponding reference columns. So that the load carrying capacity of strengthened columns is affected by the confined concrete strength f_{cc} which it is affected by the degree of confinement. As a result, and similar to the unstrengthened R.C. columns, the load carrying capacity of strengthened columns P_{max} can be obtained according to ***Eq.(9).*** Consequently, to predict the load carrying capacity of R.C. columns strengthened externally by means of wrapped CFRP sheets, it should predict both the confining pressure fl due to externally wrapped sheets **[5,6]** .

Table 6
The percent of average decrease of efficiencies for rectangular R.C. columns with different rectangularity

(t/ b) Rectangularit y	one layer (partially wrapping)	two layers (partially wrapping)	% of average decrease of efficiencies
1.56	**29.55**	**19.71**	**25**
2.56	**49.68**	**46.22**	**48**

(Rectangularity = 1.00 as a control)

Table 7
The max. of (t/b) ratio of rectangular reinforced concrete columns when efficiencies are vanishing

(C) **Grade of concrete**	CFRP system	*Max. (t/b) ratio when* (ζ1=0)	*Max. (t/b) ratio when* (ζ2=0)	*Max. (t/b) ratio when* (ζ3=0)	*Max. (t/b) ratio when* (ζ4=0)	*Average max. (t/b)*
200	One layer	4.20	4.10	3.95	4.10	***4.10***
	Two layers	4.50	4.40	4.20	4.20	***4.30***

$$P_{\max,s} = f_{cc}{}' A_c + f_s A_s \tag{9}$$

where A_c is area of concrete cross-section, $f_{cc}{}'$ is confined concrete strength, A_s is area of longitudinal reinforcement and f_s *is* the stress of longitudinal reinforcement corresponding to the maximum load of strengthened column P_{max}.

5.2. Equivalent Confinement Pressure :

5.2.1 For Rectangular R.C. Column Confined with a Fully Wrapped :

For a rectangular section wrapped with FRP ***Fig. (8),*** and with corners rounded with a radius rc the parabolic arching action **[4,6,7,8,9,10,11]** is again assumed for the concrete core where the confining pressure is fully developed. For the concrete core is fully confined, a large part of the cross- section remains unconfined. In this case, the effective lateral confining pressure is obtained according to ***Eq.(10)*** by introducing a confinement effectiveness coefficient $k_{e2} \leq 1.0$.

$$f_l = 0.5\ k_{e2} \rho_f f_f \tag{10}$$

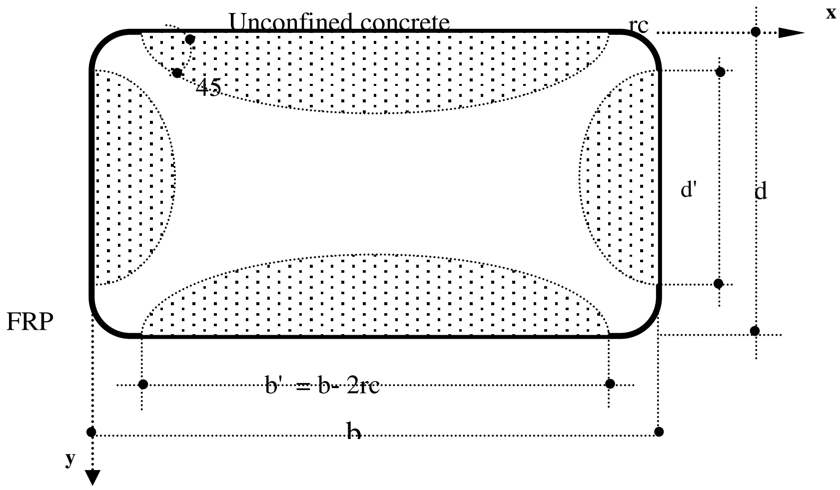

Fig. 8. Effectively confined for non-circular sections

Taking the sum of the different parabolas, the total plan area of unconfined concrete is obtained as:

$$A_u = \sum_{i=1}^{4} \frac{(w_i')^2}{6} \qquad = \frac{b'^2 + d'^2}{3} \tag{11}$$

Where w_i', is the clear distance between the rounded corners. Considering the ratio (Ac –Au) / Ac, the confinement effectiveness coefficient Ke2 is given by:

$$K_{e2} = 1 - \frac{b'^2 + d'^2}{3A_g(1-\rho_{sg})} \tag{12}$$

The lateral confining pressures induced by the FRP wrapping reinforcement on a square or rectangular cross-section are given as:

$$\sigma_{\lambda x} = K_{confx}\varepsilon_f \quad with\ K_{confx} = \rho_{fx} K_e E_f \tag{13}$$

$$\sigma_{\lambda y} = K_{confy}\varepsilon_f \quad with\ K_{confy} = \rho_{fy} K_e E_f \tag{14}$$

Where the ratios ρ_{fx} and ρ_{fy} represent the quantities of transverse confining reinforcement in the x and y direction and are given by:

$$\rho_{fx} = \frac{2b_f t}{sd} \quad and \quad \rho_{fy} = \frac{2b_f t}{sb} \tag{15}$$

5.2.2. For Rectangular R.C. Column Confined with a Partly Wrapped :

If the concrete is partly wrapped, less efficiency is obtained as both confined and unconfined zones existed, see ***Fig. 8.*** In this case, the effective lateral confining pressure is obtained according to ***Eq.(16)*** by introducing a confinement effectiveness coefficient $k_{e3} \leq 1.0$.

$$f_l = 0.5\ k_{e2} k_{e3} \rho_f f_f \tag{16}$$

Where

$$K_{e2} = 1 - \frac{b'^2 + d'^2}{3A_g(1-\rho_{sg})} \tag{17}$$

For rectangular columns confined partly wrapped, the partially wrapping coefficient K_{e3} can be calculated as follows **[6]:**

$$k_{e3} = \frac{A_e}{A_c} = \frac{\left(1 - \frac{s'}{2(t-2r_c)}\right)\left(1 - \frac{s'}{2(b-2r_c)}\right)}{1-\rho_{sg}} \tag{18}$$

5.3. Confined Concrete Strength:

Various models for confinement of concrete have been developed, primarily for steel wrapping reinforcement [**10,11].** These models basically provide an equivalent uniaxial stress-strain relationship for confined concrete, see ***(Fig. 9).*** These models assume a constant confining pressure, and in reality confinement action increases as the concrete expands. For steel transverse reinforcement, the assumption of the constant confining pressure is somewhat realistic when the stress level is in yielding stage. On the contrary, FRP reinforcement behaves linear elastically up to failure and the inward radial pressure (confining pressure) increases as the concrete expands laterally. Regardless of the complete stress-strain response of the FRP reinforcement, on the basis of both models assuming a constant confining pressure **[10,11]** and the model of FRP confined concrete suggested by **Saadatmanesh et al [12],** the confined concrete strength f_{cc}' was derived directly from the maximum effective confining pressure f_l with,

$$f'_{cc} = f_{co}\left[2.254\sqrt{1.0+7.94\frac{f_l}{f_{co}}} - 2.0\frac{f_l}{f_{co}} - 1.254\right] \tag{19}$$

where f_{co} is unconfined concrete strength

5.3.1. Analytical verification

Saadatmanesh et al model , ***Eq. (19),*** presents the predict load carrying capacity of the tested columns (P_{pr}) according to ***Eq. (10)*** for rectangular reinforced concrete columns full wrapping and ***Eq. (16)*** for rectangular R.C columns partially wrapping , compared with the corresponding experimental results are registered in ***Table (8).***

With respect to the varying rectangularity for rectangular R.C. columns ***Fig. 10*** and ***Table 8,*** demonstrate the ratio of the obtained experimentally to that the predicted maximum load of the strengthened columns by **Saadatmanesh expression** *($P_{max.exp}$/ $P_{pr.}$)* ranged between 0.979 and 1.070 .

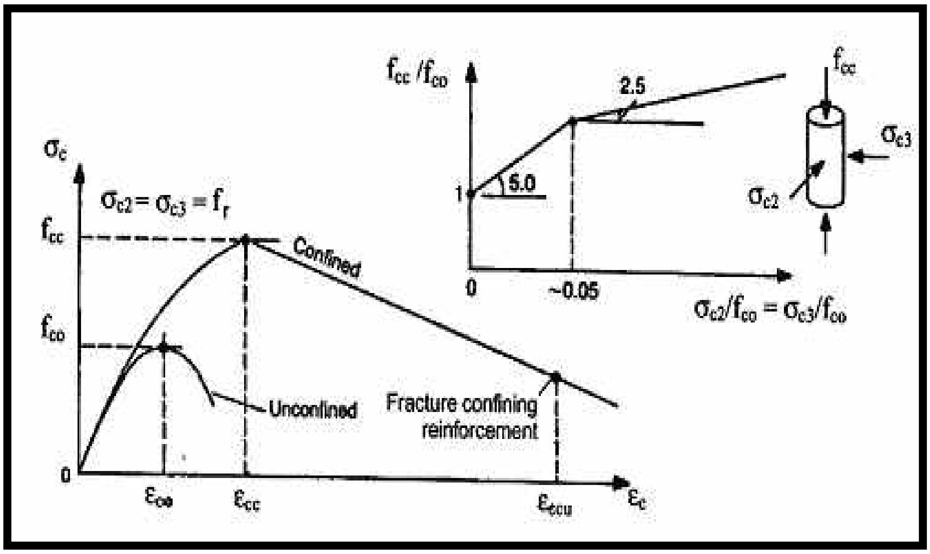

Fig. 9. Model for confined concrete (constant confining action) [11].

Table 8
Experimental and predicted results for tested R.C . columns with varying rectangularity

Column No.	Experimental Results			Saadatmanesh Expression Results			$P_{max\ -exp}$ / P_{pr}	Grade of concrete kg/ cm ^{2}
	$P_{max\ -exp}$ ton	f_{cc} kg/cm^2	$P_{max.c}$/ $P_{max.u}$	f_{cc}' kg/cm^2	$P_{pr.}$ ton	$P_{pr.c}$/ $P_{pr.u}$		
Bs 1-0	100	250	-	-	104.1	-	0.961	**200**
Cr 1-0	100	250	-	-	104.1	-	0.961	
Gr 1-0	98	248	-	-	104.1	-	0.941	
Bs 1-1	132	330	1.32	252.83	125.3	1.20	1.070	
Cr 1-1	126	315	1.26	252.56	125.2	1.20	1.006	
Gr 1-1	115	287.5	1.17	226.04	114.6	1.10	1.003	
Bs 1-2	148	370	1.48	297.40	143.1	1.37	1.034	
Cr 1-2	140	350	1.40	296.93	142.9	1.37	0.979	
Gr 1-2	125	312.5	1.27	249.85	124.1	1.19	1.007	

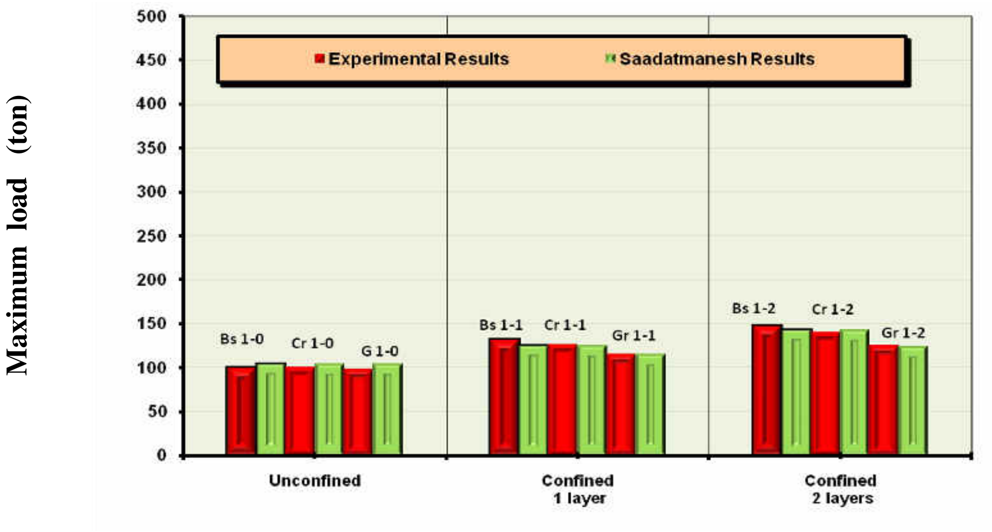

Fig. 10. Predicted maximum load in comparison with that obtained experimentally

6 . Conclusions

Based on the obtained experimental results the following conclusions can be drown out :

1- For rectangular section reinforced concrete columns, the strength efficiency , the ductility efficiency, the stiffness efficiency and the absorbed energy efficiency are higher for confined of both one layer and two layers than that for unconfined columns.

2- The rectangularity (t/b) ratio , for unconfined R.C. columns has no significant effect on strength efficiency , ductility efficiency, stiffness efficiency and the absorbed energy efficiency, meanwhile the rectangularity (t/b) ratio has a significant effect on all efficiencies for confined concrete columns.

3- As a general rule , for rectangular section reinforced concrete columns as the rectangularity (t/b) increases, the axial nominal stress, the axial nominal strain, the modulus of elasticity and the modulus of toughness are increased by the confined one layer and two layers are decreased .

4- For confined R.C. columns, strength efficiency , ductility efficiency, stiffness efficiency and the absorbed energy efficiency decreases as (t/b) ratio increases. However, for square R.C. columns confined with CFRP where rectangularity (t/b) = 1.00 , all the efficiencies are slightly higher comparing with that rectangular R.C. columns having rectangularity (t/b) = 1.56 for two reasons namely : a) although the volume of CFRP was constant , but the free spacing between strips are less for rectangular sections than that for square sections . b) the rectangularity for rectangular section (t/b) ratio was 1.56 and it is not large enough than that for square sections .

5- For rectangular R.C. columns confined with CFRP , the percentage of average of efficiencies decreases with 25 % and 48 % for rectangularity (t/b) = 1.56 and 2.56 respectively than that have rectangularity (t/b) = 1.00

6- For rectangular R.C. columns confined with CFRP partial wrapping, the max. of (t/b) ratio was 4.00 when the average of efficiencies are vanishing.

7- The predicted results concerning the load carrying capacity of rectangular R.C. columns strengthened with wrapping CFRP sheets obtained according to the proposed modified mathematical model showed a considerable approach to the results obtained experimentally where the ratio of obtained experimentally to that the predicted maximum load of the strengthened columns by **Saadatmanesh expression** $(P_{max\ .exp} / P_{pr.})$ ranged between 0.979 and 1.070 .

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بعض العوامل التي تؤثر على السلوك الإستاتيكي للأعمدة الخرسانية المسلحة القصيرة المستطيلة المقطع والمحاطة بألياف الكربون

ملخص:

في هذا البحث تم عمل دراسة معملية لبيان تأثير بعض العوامل على السلوك الإستاتيكي للأعمدة الخرسانية المسلحة المستطيلة المقطع والمحاطة برقائق الألياف الكربونية البوليمرية Carbon Fiber Reinforced Polymer Sheets الملصوقة عرضيا وجزئيا (Partial Wrapping) سواء كانت طبقة واحدة (μ_f = 0.14%) أو طبقتين (μ_f = 0.28%) على سطح الأعمدة الخرسانية في صورة كانات خارجية موزعة على طول العمود وذلك تحت تأثير حمل مركزي في ضوء تغير نسبة أبعاد المقطع (t/b ratio) لرتبة خرسانة عادية C 200 . تم دراسة كفاءة رقائق الألياف الكربونية البوليمرية المستخدمة وذلك من وجهة نظر كل من (المقاومة Strength- الممطولية Ductility- الصلابة Stiffness - المتانة Absorbed energy) لعدد 9 أعمدة مستطيلة المقطع ذات قطاعات متغيرة (20×20 و 16× 25 و 12.5 ×32 سم) مع ثبات مساحة المقطع وتساوي $400\ cm^2$ وكانت نسبة H/D ثابتة لجميع الأعمدة المختبرة حيث H ارتفاع العمود و D البعد الصغر لقطاع العمود . كذلك تم مقارنة نتائج أقصى حمل محوري تم الحصول عليه بالمعمل بالنموذج الرياضي Saadatmanesh Expression الذي يعتمد أساساً على التنبؤ بمقاومة الخرسانة تحت تأثير الإجهادات العرضية (Lateral Stresses) المتولدة عن شرائح ألياف الكربون البوليمرية المحزمة للعمود. هذه الإجهادات العرضية تعتمد أساسا على الإجهاد الفعال المتولد في تلك الشرائح. هناك عدد قليل من النماذج الرياضية التجريبية المقترحة للتنبؤ بالإجهاد الفعال المتولد في التسليح العرضي الخارجي (شرائح ألياف الكربون البوليمرية) و لكن النتائج المتوقعة بتطبيق هذه النماذج التجريبية لا تتوافق كلية مع النتائج المنطقية التي أثبتتها النتائج المعملية التي تم الحصول عليها من خلال هذا العمل. و النتائج الغير دقيقة التي أمكن الحصول عليها باستخدام النماذج التجريبية المتاحة تعزى إلى أنه تم تجاهل بيانات معينة عند استنباط تلك المعادلات التجريبية (على سبيل المثال رتبة الخرسانة) ، وبتحليل النتائج التي تم الحصول عليها معمليا أمكن استنتاج آلاتي :-

- بصورة عامة في الأعمدة الخرسانية المسلحة المستطيلة المقطع (المحاطة برقائق الألياف الكربونية) ساهمت رقائق الألياف الكربونية في زيادة كل من المقاومة و الممطولية ومعاير المرونة ومعاير المتانة بصورة ملحوظة عن مثيلتها الغير محاطة .

- مع زيادة عدد طبقات التقوية برقائق الألياف الكربونية للأعمدة الخرسانية المسلحة المستطيلة الشكل تبين أن هناك زيادة ملحوظة لكل من المقاومة و الممطولية ومعاير المتانة وزيادة نسبياً لمعاير المرونة .

- تقاربت كفاءة التقوية برقائق الألياف الكربونية للأعمدة الخرسانية المسلحة المستطيلة ذات نسبة أبعاد المقطع (t/b ratio = 1.56) من العمود المربع حيث نسبة أبعاد المقطع (t/b ratio = 1.00) على الرغم من ثبات حجم التقوية بالألياف الكربونية وذلك لسببين رئيسيين هما :

  1- تقارب المسافات البينية لرقائق الألياف الكربونية التي في صورة كانات خارجية .

  2- نسبة أبعاد المقطع صغيرة نسبياً .

- لنسبة أبعاد المقطع المستطيل (t/b) ratio تأثير واضح على كفاءة رقائق الألياف الكربونية , حيث أن كفاءة رقائق الألياف الكربونية تتناسب عكسياً مع زيادة النسبة . وأيضا كلما زادت نسبة أبعاد المقطع تقل كفاءة رقائق الألياف الكربونية بصورة أكثر وضوحاً.

- نظرا لزيادة معاير المتانة الواضح في الأعمدة المحاطة فإن أسلوب التقويات باستخدام رقائق الألياف الكربونية يكون أكثر فائدة وتأثيراً في المنشئات المعرضة لأحمال ديناميكية مثل الزلازل والرياح والأحمال المتكررة .

- النتائج التي تم الحصول عليها بتطبيق النموذج الرياضي أثبتت تقارب كبير للنتائج المقابلة التي تم الحصول عليه معملياً لرتبة الخرسانة التقليدية C 200 (Normal strength) وتراوحت هذه النتائج ($P_{max.exp}$ / $P_{pr.}$) ما بين (97.9 % : 107.6 %)