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

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ABSTRACT

Concrete columns have an important function in the structural concept of many structures. Often, these columns are vulnerable to exceptional loads (such as impact, explosion or seismic loads) , load increase (increasing use or change of function of structures, etc.) and degradation (corrosion of steel reinforcement, alkali silica reaction , etc.). On the other hand, confinement of concrete is an efficient technique to enhance the structural behavior of concrete members primarily subjected to compression .Structural repair and rehabilitation of reinforced concrete structures is becoming an increasing important option for all deteriorated / damaged structures to restore, enhance the load bearing capacity and increase the life span of the structure. The strengthening of concrete structures with externally bonded reinforcement is generally done using either steel plates or FRP laminates. The main disadvantages of using steel plates are steel corrosion in the adhesion zone, heavy weight and excessive size of single plates. With the development of technology , the use of high- strength concrete members has proved most popular in terms of economy, superior strength , stiffness, and durability. With the increase of concrete strength, the ultimate strength of the columns increases, but a relatively more brittle failure occurs. The lack of ductility of high strength concrete results in sudden failure without warning, which is a serious drawback. [1] .The application of FRP in the construction industry can eliminate some unwanted properties of high strength concrete , such as its brittle behavior [2,3]. To study the behavior of normal and high strength circular R.C.columns confined with CFRP under statically load, tests on columns wrapped with FRP have been executed. The efficiency of externally bonded CFRP of circular R.C.columnsis declared and evaluated .

Keywords: Carbon Fiber Reinforced Polymer (CFRP) ,strengthening**,** efficiency**,** reinforced short 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].

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2. Previous works

2.1. Egyptian code for FRP (Code 208 version 2005):

Egyptian Code for FRP [4] presents the following equations for the strength of confined concrete columns:

The ultimate strength of section of concrete confined with FRP and subject to axially load .

** $P_u=0.35 f_{cuc} A_c + 0.67 f_y A_{sc}$ for columns having hoop stirrups (1)

** Pu=0.4fcucAc +0.76 fyAsc for columns having spiral stirrups (2)

A_c= the net area of cross- section A_{sc}= the total area of longitudinal reinforcement.
f_y= the specified yield strength of reinforcement. f_{cuc} = the compressive strength of confined concrete,f_{cuc} is obtained according the following equation:

$$f_{cuc} = f_{cu}\left[2.25\sqrt{1+9.875\frac{f_l}{f_{cu}}} - 2.5\frac{f_l}{f_{cu}} - 1.25\right] \quad (3)$$

f_{cu} =characteristic strength of concrete ,f_l =the lateral pressure is calculated according to the shape and strengthening system of cross- section as follow:

2.1.1.For circular columns

2.1.1.1For full wrapping circular columns:

$$f_l = \frac{\mu_f E_f \varepsilon_{ef}}{2\gamma_f} \quad (4)$$

E_f = the modulus of elasticity of FRP. μ_f =the percentage of confinement in full wrapping case where

$$\mu_f = \frac{4nt_f}{D}$$

n = the number of layers of FRP, t_f = the thickness of the FRP for one layer .

D = diameter of circular column .$\gamma_f$the reduction strength factor for FRP and equals (1.3) . ε_{ef}=the effective strain of FRP = 1.6%.

2.1.1.2. For partial wrapping circular columns

$$\mu_f = \frac{4b_f nt_f}{SD}$$

μ_f= the percentage of confinement in partial wrapping case

k_{e1}= $\left(1-\frac{(S-b_f)}{2D}\right)^2$ where k_{e1} =confinement effectiveness coefficient in partial wrapping case < 1.00 ,b_f= width of the bounded CFRP, S = centre to centre spacing of the CFRP, D, n, t_f= as mentioned before.

3. Experimental program

The aim of this paper is to demonstrate the effect of grade of concrete and strengthening technique that affecting the efficiency of externally bonded (CFRP) strengthening circular reinforced concrete columns axially loaded.

3.1. Test specimens

Twelve normal and high strength reinforced concrete columns with circular shape of cross-sections were constructed to study the various parameters for short reinforced concrete columns under axial static centric load, as shown in **Table(1)**.All R.C. columns have constantpercentage of longitudinal and lateral reinforcement, H/D ratio was kept constant and equals 6, where H is the height of columns and D is the diameter,grade of concrete was ***C200***, ***C400*** and ***C600***.

$\mu = (As / Ac) \times 100$ and $\mu` = (V_{st} / V_c) \times 100$ Where

$\mu_f = \dfrac{4 \times b_f \times n \times t_f}{S \times D}$ 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 oflateral 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, see ***Fig. (1)*** **.**

Table1.
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	Grade of concrete kg/ cm^2
Ac 1-0	Shape and size of cross – section , µ%, µf, μ^- %, H/D ratio	Grade of concrete , strengthening system	Circular	D= 22.57 cm	6Φ12 (1.7 %)	1 Ø 6 @ 14.18 cm (0.35 %)	-	-	135.42 cm	***C 200***
Ac 1-1							1 layer, 5 strips b_f= 14 cm	0.14 %		
Ac 1-2							2 layers , 5 strips b_f= 14 cm	0.28 %		
Ac 1-3							Full wrapping 1 layer	0.23 %		
Ac 2-0							-	-		***C 400***
Ac 2-1							1 layer, 5 strips b_f= 14 cm	0.14 %		
Ac 2-2							2 layers , 5 strips b_f= 14 cm	0.28 %		
Ac 2-3							Full wrapping 1 layer	0.23 %		
Ac 3-0							-	-		***C 600***
Ac 3-1							1 layer, 5 strips b_f= 14 cm	0.14 %		
Ac 3-2							2 layers , 5 strips b_f= 14 cm	0.28 %		
Ac3-3							Full wrapping 1 layer	0.23 %		

3.2. Materials and concrete mix proportion

3.2.1. Concrete

The columns were made from different types of concrete strength, therefore three concrete mix design were done to produce normal and high cube strength of about 200 , 400 and 600 kg / cm^2 after 28 days which are named *C 200* , *C 400* and *C 600* respectively. The constituent materials were as follows:

- Ordinary Portland Cement (Assiut cement) was used throughout the program for making concrete, the cement content was 300 to 500 kg /m^3 and water - cement ratio was defined to be ranged between 0.29 to 0.60 to have a slump of 60 to 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 for grade of concrete*C 200* . Also. the coarse aggregate was crushedbasalt of 20 mm maximum nominal size, fineness modulus of 6.43 , specific gravity of 2.60 and unit weight of 1.55 t/m^3 for grade of strength *C 400* and *C 600* .
- No additives were incorporated in concrete for *C 200* .
- Plasticizer and supper Plasticizer admixture are used for *C 400*, *C 600* respectively . Silica fume[5] added for both C400 and C 600 . Drinking water used for mixing concrete.

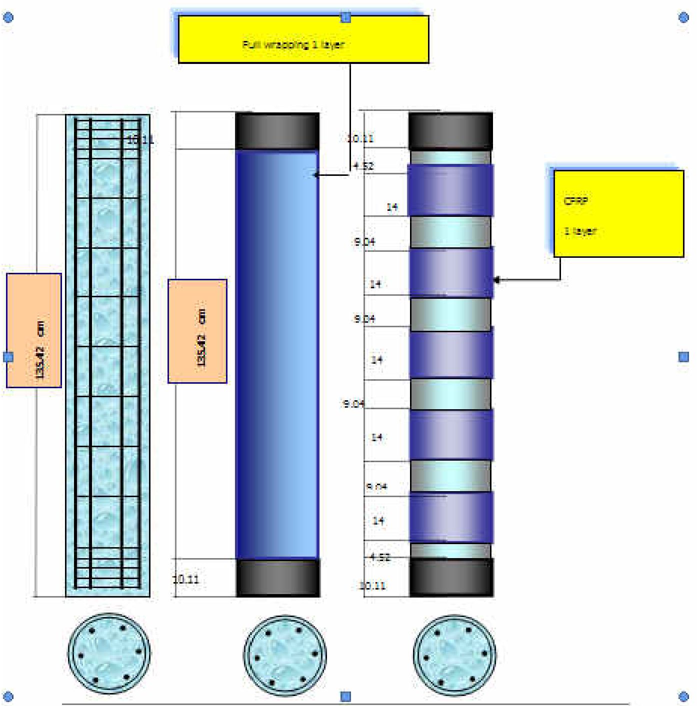


Fig. 1. R.C. columns - circular sections D=22.57 cm (C200,C400 and C600 kg/cm^2)

3.2.2. 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**	**C 400**	**C 600**
Cement (type / weight)	OPC / 300	OPC / 400	OPC / 500
Coarse aggregate (type / weight)	R / 1174	C / 1144	C / 1050
Fine aggregate (type / weight)	R / 718	R / 671	R / 671
Silica fume	_	45	80
Plasticizer	_	7.00	12.5
Water	180	144	150
Ratio water/ cement (W/C)	0.60	0.36	0.30

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

Table 3.
Mechanical properties of CFRP [6]

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

4. Test results

4.1. With respect to failure mode of tested columns:

During tests two failure mechanisms of failure were observed from the following Photos**:**

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

This mechanism was due to shear failure, in non-strengthened columns which is referred as control concrete 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 (*Ac1-0),(Ac 2-0)*and *(Ac 3-0)*as shown in the following photos .

The second mechanism (FM 2):

This mechanism was observed in case of strengthened columns with a number of CFRP strips of one layer or two layers and one ply full wrapping *(Ac1-1), (Ac 2-1)(Ac 3-1),(Ac 1-2), (Ac 2-2) , (Ac 3-2) , (Ac1-3), (Ac2-3)*and *(Ac3-3)*as shown in the following photos .

Failure mode,the first mechanism, (Ac 1-0), (Ac 2-0) and (Ac 3-0)
(unconfined circular R.C. columns)(FM 1)

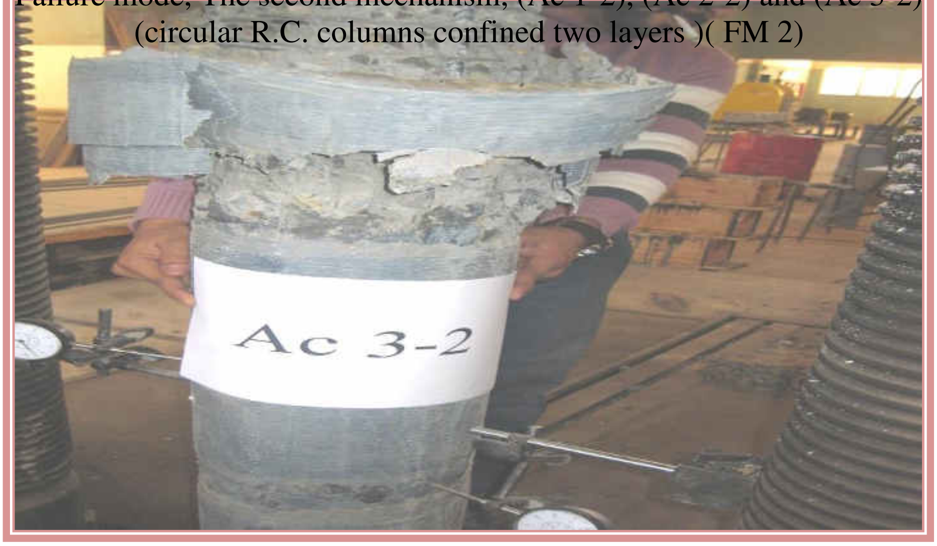

Ac ١-١


Ac 2-1


Ac 3-1

Failure mode,the second mechanism, (Ac 1-1), (Ac 2-1) and (Ac 3-1)
(circular R.C. columns confined one layer)(FM 2)

Failure mode, The second mechanism, (Ac 1-2), (Ac 2-2) and (Ac 3-2)
(circular R.C. columns confined two layers)(FM 2)




Ac 3-3

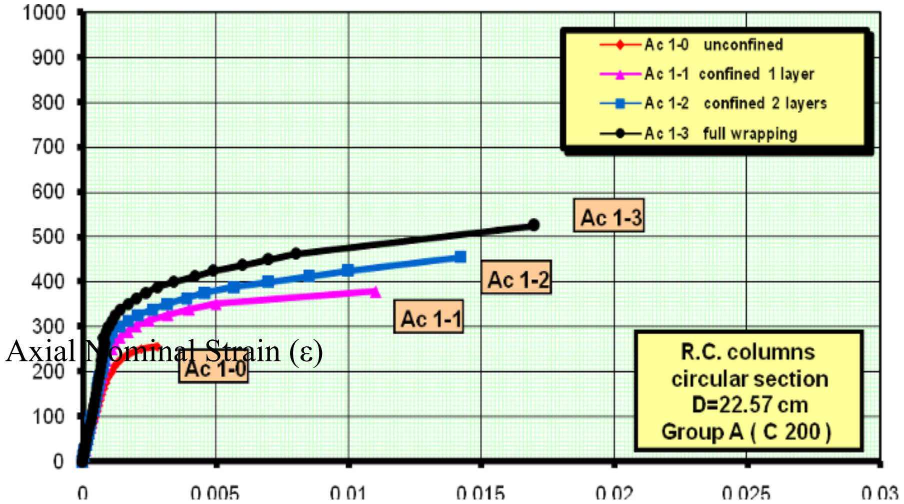
Failure mode, The second mechanism, (Ac 1-3), (Ac 2-3) and (Ac 3-3)
(circular R.C. columns confined one ply full wrapping)(FM 2)

4.2. With respect to the axial nominal stress - axial nominal strainrelationship of tested columns

The axial nominal stress defined by the applied load over the gross area = P/A (kg / cm^2), the axial nominal strain define by the change in height (deformation) over the overall height of the column $\varepsilon = \Delta/\lambda$ (cm / cm) for all tested columns are evaluated during the testing of each column up to failure. *Fig. (2)*to *Fig. (4)*show the relationship between the axial nominal stress and axial nominal strain for all tested circular of R.C. columns. Based on these relationships the values of max.load, the max. nominal stress, the max. nominal strain , modulus of elasticity as well as the modulus of toughness for all tested columns are evaluated tabulated in *Table (4)* .

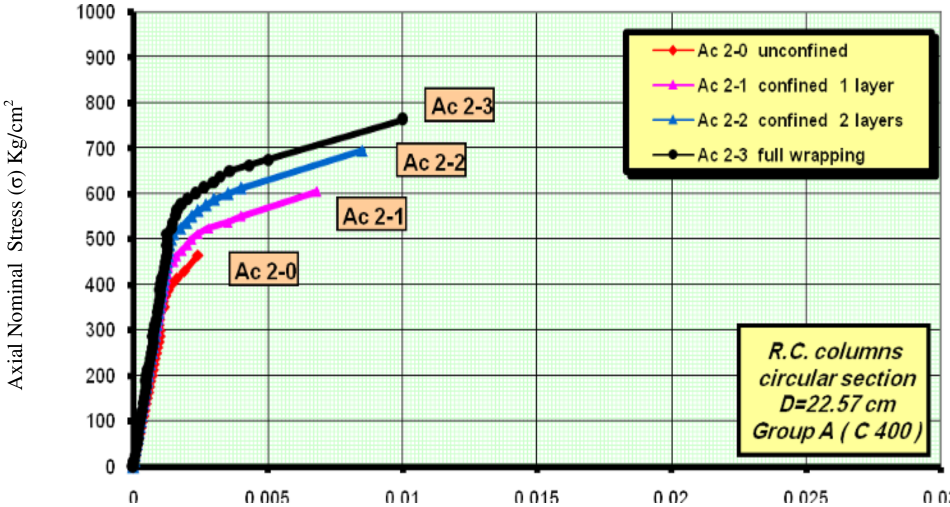
The values of the maximum axial nominal stress, maximum axial nominal strain, as well as the strength , ductility, stiffness and absorbed energy efficiencies are given in *Table (4)* for circular reinforced concrete columns sections unconfined and confined with one layer , two layers (partial wrapping) and confined with one lay full wrapping having grade of concrete (C 200, C 400 and C600) .Also, the values of initial modulus of elasticity, as well as modulus of toughness of such columns are included .

Axial Nominal Stress (σ) Kg/cm^2



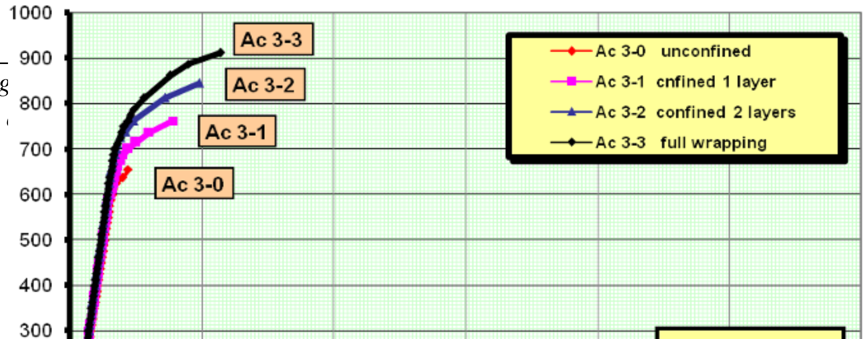
Axial Nominal Strain (ε)

Fig. 2. Relation between axial nominal stress and axial nominal strain for unconfined and confined circular R.C. columns (Group A - C 200)



Axial Nominal Strain (ε)

Fig. 3. Relation between axial nominal stress and axial nominal strainfor unconfined and confined circular R.C. columns (Group A - C 400)



Axial Nominal Stress (σ) Kg/cm^2

Axial Nominal Strain (ε)

Fig. 4. Relation between axial nominal stress and axial nominal strain for unconfined and confined circular R.C. columns (Group A - C 600)

Table 4.
The values of max.axial nominal stresses and max nominal strains, as well as the different values of efficiencies for circular reinforced concrete columns

olumn designation	Maximum axial load (Pu) ton	Max. axial nominal stress (σ) Kg / cm^2	Max. axial nominal strain (ε_c)	% Increase of max. axial nominal stress (ζ1)	% Increase of max. axial nominal strain (ζ2)	Initial modulus of Elasticity (E) Kg / cm^2	% Increase of modulus of elasticity (ζ3)	Modulus of toughness (M. T) Kg / cm^2	% Increase modulus of toughness (ζ4)	Grade of concrete kg/ cm^2
Ac 1-0	102	255	0.0028	-	-	2.20×10^5	-	0.5105	-	**200**
Ac 1-1	151	377.5	0.011	48.03	292.85	2.65×10^5	20.45	3.5672	598.76	
Ac 1-2	182	455	0.0142	78.43	407.14	3.10×10^5	40.90	5.3742	952.73	
Ac 1-3	210	525	0.0170	105.88	507.14	3.35×10^5	52.27	7.4686	1362.99	
Ac 2-0	186	465	0.0024	-	-	3.15×10^5	-	0.7257	-	**400**
Ac 2-1	242	605	0.0068	30.10	183.33	3.55×10^5	12.69	3.2762	351.45	
Ac 2-2	278	695	0.0085	49.46	254.16	3.92×10^5	24.44	4.7738	557.82	
Ac 2-3	305	762.5	0.010	63.97	316.67	4.20×10^5	33.33	6.6206	812.30	
Ac 3-0	262	655	0.0022	-	-	3.80×10^5	-	0.8655	-	**600**
Ac 3-1	305	762.5	0.0039	16.41	77.27	4.08×10^5	7.36	2.1206	145.01	
Ac 3-2	338	845	0.0049	29.00	122.72	4.32×10^5	13.68	3.0527	252.70	

olumn designation	Maximum axial load (Pu) ton	Max. axial nominal stress (σ) Kg / cm^2	Max. axial nominal strain (ε_ℓ)	% Increase of max. axial nominal stress (ζ1)	% Increase of max. axial nominal strain (ζ2)	Initial modulus of Elasticity (E) Kg / cm^2	% Increase of modulus of elasticity (ζ3)	Modulus of toughness (M. T) Kg / cm^2	% Increase modulus of toughness (ζ4)	Grade of concrete kg/ cm^2
Ac 3-3	365	912.5	0.0057	39.31	159.09	4.50×10^5	18.42	4.2655	391.79	

5. 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 (ζ_2) which is represented by the percentage of increase of axial nominal strain .
- Stiffness efficiency (ζ_3) 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.

The calculated values of different efficiencies ζ_1, ζ_2 , ζ_3 and ζ_4 are included also in Table 4.

Based on the obtained test results and data given in table (4), it is obvious that the strength and deformation capacities of short R.C. circular columns subjected to axial static loading depends on both grade of concrete as well as the system of the externally strengthening technique.The effect of these parameters is declared through the following items :

5.1 From point of view of strength

Fig. 5. shows the relations between the strength efficiency (ζ1) against grade of concrete of circular reinforce concrete columns (**C**).

These relations indicate that the efficiency (ζ1) decreases by the increase of grade of concrete of circular columns kg/cm^2 , the relations can be best represented as follow:

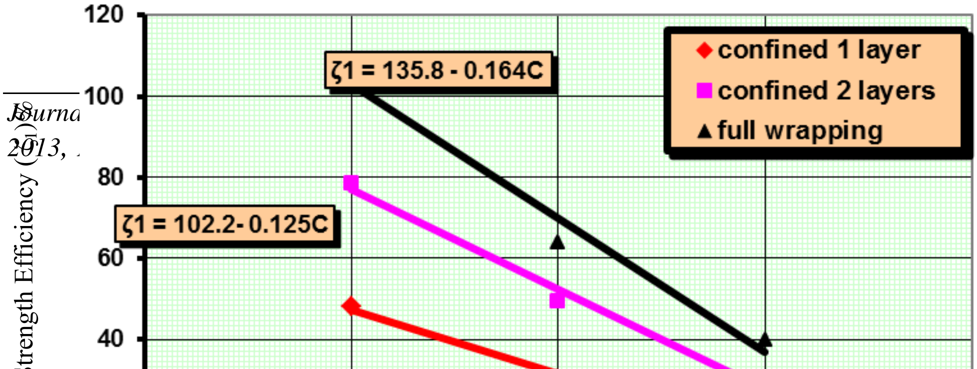
$\zeta_1 = 63.13 - 0.079\ C$ (for circular R.C. columns confined 1 layer) (5)

$\zeta_1 = 102.2 - 0.125\ C$ (for circular R.C. columns confined 2 layers) (6)

$\zeta_1 = 135.80 - 0.164\ C$ (for circular R.C. columns full wrapping) (7)

The rate of decrease mainly depends on the technique used in wrapping.

From the above equations, it is seen that the value of (ζ1) vanishes when (C) equal ≅ 800, ≅ 820 kg/cm^2 and ≅ 820 kg/cm^2 for R.C. circular columns confined with one layer , two layers and full wrapping respectively . This means that confinement of R.C. columns is not beneficial for grades of concrete greater than 800 kg/cm^2 for circular R.C. columns.



Grade of Concrete (C) kg/cm^2

Fig. 5. Relation between efficiency (ζ1) and grade of concrete for circular R.C columns

5.2.From point of view of strain

Regarding the ductility coefficient (ζ2), ***Fig. 6*** shows the relations between its value against grade of concrete for confined with one layer, two layers and full wrapping R.C. circular columns. The relations can best fitted by the following equations:

ζ_2 =400.00 – 0.539 C (for circular R.C. columns confined 1 layer) (8)

ζ_2= 545.70 – 0.711 C (for circular R.C. columns confined 2 layers) (9)

ζ_2 = 675.60 – 0.870 C (for circular R.C. columns full wrapping) (10)

From the above equations, it is obvious that the ductility coefficient (ζ2) decreases with the increase of grade of concrete and vanishes when (C) equals $\cong$ 745, $\cong$ 770 and $\cong$ 780 kg/cm^2 for circular R.C. columns confined with one layer, two layers and full wrapping respectively . Again the confinement is not beneficial for grades of concrete beyond (C) $\cong$ 750 kg/cm^2 for circular R.C. columns.

5.3.From Point of View of Stiffness

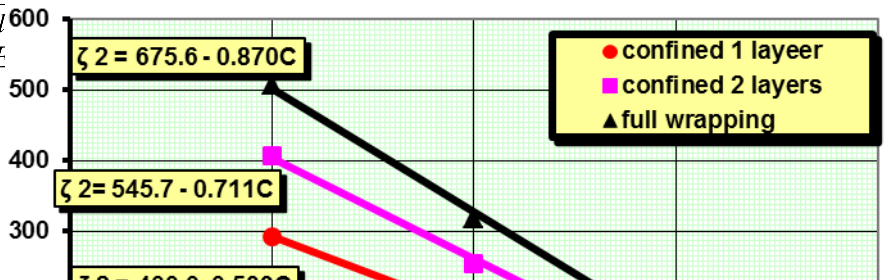
Concerning thestiffness efficiency,***Fig. 7*** shows the relations between (ζ3) values and the grade of concrete for confined R.C. circular columns. These relations can be written by the following equations:

ζ_3 = 29.61 – 0.380C (for circular R.C. confined 1 layer) (11)

ζ_3 = 53.56 – 0.068C (for circular R.C. confined 2 layers) (12)

ζ_3= 68.52 – 0.084C (for circular R.C. confined full wrapping) (13)

From the above equations, it is seen that the value of (ζ3) vanishes when grade of concrete is equal 780 $\cong$ 785 and $\cong$ 815 kg/cm^2 for circular R.C. concrete columns confined with one layer, two layers and full wrapping respectively . This means that



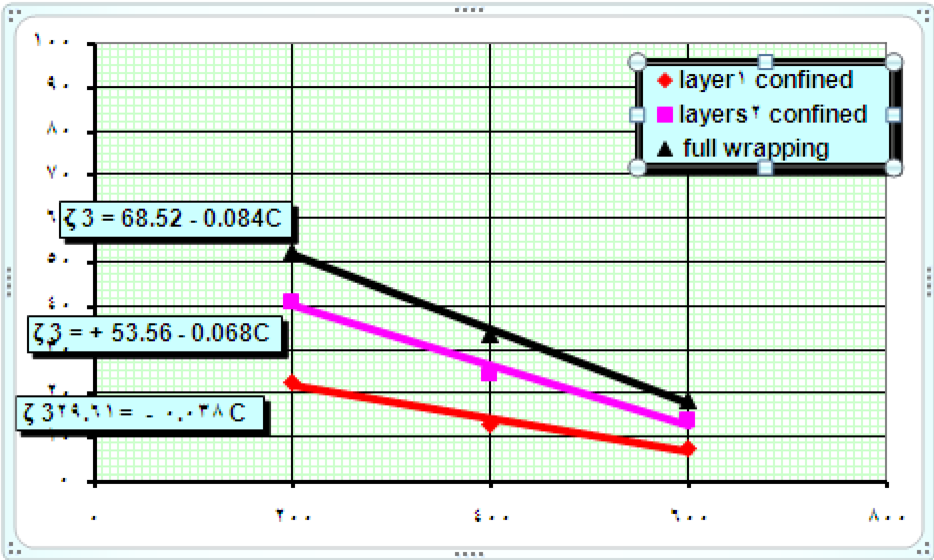
confinement of R.C. columns is not beneficial for grades of concrete greater than 800 kg/cm^2 for circular R.C. columns.

Ductility Efficiency

Grade of Concrete (C) kg/cm^2

Fig. 6. Relation of efficiency (ζ2) and grade of concrete for circular R.C columns

Stiffness Efficiency (ζ3)%



Grade of Concrete (C) kg/c m^2

Fig. 7. Relation between efficiency (ζ3) and grade of concrete for circular R.C columns

5.4. From point ofview of total absorbed energy

Fig. 8. shows how these efficiencies (ζ4), decrease with the increase of grade of concrete (C), it can be represented by the following equations:

ζ_4 = 818.8- 1.134 C (for circular R.C. columns confined 1 layer) (14)

ζ_4 = 1278.0 – 1.750 C (for circular R.C. columns confined 2 layers) (15)

ζ_4 = 1821.0 – 2. 418 C (for circular R.C. columns confined full wrapping) (16)

From the above equations, it is seen that the value of (ζ4) vanishes when grade of concrete(C) is equal ≅ 725, ≅ 730 and ≅ 755 kg/cm^2 for circular R.C. columns confined with one layer, two layers and full wrapping. Again the confinement is not beneficial beyond for grades of concrete (C) ≅ 725 kg/cm^2 for circular R.C. columns.

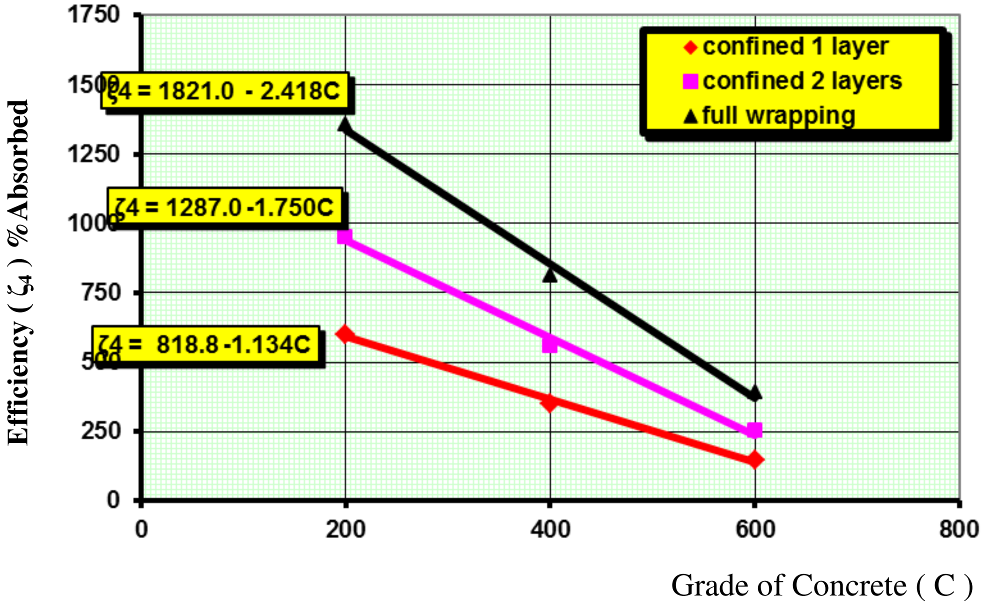


Fig. 8. Relation between efficiency (ζ4) and grade of concrete for circular R.C columns

Table 5 presents a summary for the evaluated values of strength efficiency, ductility efficiency, stiffness efficiency and absorbed energy efficiency for tested circular R.C columns with different grades of concrete .

Table 6shows the percent of average decrease of efficiencies for circular reinforced concrete columns confined with CFRP one layer (partial wrapping) , two layers (partial wrapping) and full wrapping (one ply) for ***C 400*** and ***C 600*** comparing with that of ***C200*** for , see ***Figs (5) to (8).***

6. Theoretical approach and mathematical modelling

6.1. Load carrying capacity of axial of R.C. strengthened short columns

The obtained experimental results showed that the load carrying capacity of R.C. columns confined with wrapped CFRP sheet improved considerably in comparison with 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 and grade of concrete. 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.(18).* Consequently, to predict the load carrying capacity ofaxial R.C. columns strengthened externally by means of wrapped CFRP sheets, it should predict both the confining pressure $f_l$due to externally wrapped sheets [7].

Table 5.
Comparison for all efficiencies of circular reinforced concrete columns with different grades of concrete and strengthening system.

(C) grade of concrete	Column designation	CFRP system	% strength efficiency (ζ1)	% of decreases (ζ1)	%ductility efficiency (ζ2)	% of decreases (ζ2)	% stiffness efficiency (ζ3)	% of decreases (ζ3)	% modulus of toghness (ζ4)	% of decreases (ζ4)	% of average decrease of efficiencies
200*	**Ac 1-1**	One layer	48.03	-	292.85	-	20.45	-	598.76	-	**-**
400	**Ac 2-1**		30.10	37.33	183.33	37.39	12.69	37.94	351.45	41.30	**38.49**
600	**Ac 3-1**		16.41	65.83	77.27	73.61	7.35	64.05	145.01	75.78	**69.81**
200*	**Ac 1-2**	Two layers	78.43	-	407.14	-	40.90	-	952.73	-	**-**
400	**Ac 2-2**		49.46	36.90	254.16	37.57	24.44	40.24	557.82	41.45	**39.04**
600	**Ac 3-2**		29.00	63.02	122.72	69.85	13.68	66.55	252.70	73.47	**68.22**
200*	**Ac 1-3**	Full wrapping	105.88	-	507.14	-	52.27	-	1362.99	-	**-**
400	**Ac 2-3**		63.97	39.58	316.67	37.55	33.33	36.23	812.30	40.42	**36.45**
600	**Ac 3-3**		39.31	62.87	159.09	68.62	18.42	64.75	391.79	71.26	**66.87**

* *efficiencies for C 200 confined with CFRP as a control*

Table 6.
The percentof average decrease of efficiencies for circular R.C. columns (C 200 as a control)

Grade of concrete (kg/cm^2)	% ofdecrease of efficiencies			% of average decrease of efficiencies
	Case of one layer (partially wrapping)	Case of two layers (partially wrapping)	Case of full wrapping (one ply)	
400	**38.49**	**39.04**	**36.45**	**38**
600	**69.81**	**68.22**	**66.87**	**68**

$$P_{\max,s} = f'_{cc}\, A_c + f_s\, A_s \qquad (17)$$

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 $P_{max,s.}$

6.1.1. Equivalent Confinement Pressure

6.1.1.1. Case for a circular R.C. column confined with a fully wrapped

For a circular short column confined with a fully wrapped CFRP sheet, the lateral confining pressure f_l exerted on the concrete core is assumed a uniform one and calculated according to *Eq.(19)* by assuming uniform tension in the CFRP sheet, see *Fig.(9).*

$$f_l = \frac{2 f_f\, n\, t_f}{D} = 0.5\, \rho_f\, f_f \qquad (18)$$

where,

in which $\rho_f = \frac{A_f}{A_c} = \frac{\pi D n t_f}{\pi D^2/4} = \frac{4\, n\, t_f}{D}$ f_f is the stress in the CFRP sheet, ρ*f* is the ratio of the volume of wrapped reinforcement A_f to the volume of confined concrete core A_c per unit length for a fully wrapped columns, *n* is the number of CFRP plies, t_f is the thickness of the CFRP sheet, and *D* is the diameter of the circular column.

6.1.1.2. Case for a circular r.c. column confined with a partly wrapped :

If the concrete is partially wrapped, less efficiency is obtained as both confined and unconfined zones existed. In this case, the effective lateral confining pressure is obtained according to ***Eq.(20)*** by introducing a confinement effectiveness coefficient ke1 ≤ 1.0. The effectiveness coefficient is obtained by considering that the transverse pressure from the confining system is only effective on that part of the concrete where the confining pressure has fully developed due to arching action, which is assumed as a parabola with an initial slope of 45°**[8],** see ***(Fig. 9).*** As a result, at the midway between two successive wrapped CFRP strips, the area of effectively confined concrete core A_e is obtained through ***Eq.(21).*** Consequently, the confinement effectiveness coefficient ke is obtained by considering the ratio *(A_e /A_c),* where A_c is the difference between the gross cross-sectional area A_g and the area of longitudinal steel A_s *:(A_c = A_g - A_s).*

$$f_l = 0.5\, k_{e1}\, \rho_f\, f_f \qquad (19)$$

$$k_{e1} = \frac{A_e}{A_c} = \frac{\frac{\Pi}{4}\left(D - \frac{s'}{2}\right)^2}{A_g - A_s} = \frac{\left(1 - \frac{s'}{2D}\right)^2}{1 - \rho_{sg}} \qquad (20)$$

where, $\rho_f = \dfrac{A_f \pi D}{(\pi D^2 / 4) \times s} = \dfrac{4 b_f \, n \, t_f}{D s}$

in which b_f is the width of the CFRP strips, s is spacing between center to center of the CFRP strips ($s = b_f$ in case of fully wrapping), ($s' = s - b_f$) is the clear spacing between two successive wrapped CFRP strips, ρ_{sg} is the reinforcement ratio of the longitudinal steel reinforcement with respect to the gross cross-sectional area *(*$= A_s / A_g$*)*.

6.2. 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. 10).***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,

$$f_{cc}' = f_{co}\left[2.254\sqrt{1.0 + 7.94\frac{f_l}{f_{co}}} - 2.0\frac{f_l}{f_{co}} - 1.254\right] \qquad (21)$$

where $f_{co}$is unconfined concrete strength .

6.3 Analytical verification:

Saadatmanesh et al model , *Eq. (21),*presents thepredictload carrying capacity of the tested columns (P_{pr}) according to *Eq. (19)*for circular reinforced concrete columns full wrapping and*Eq. (20)* for circular reinforced concrete columns partially wrapping , compared with the corresponding experimental results are tabulated in *Table (7).*

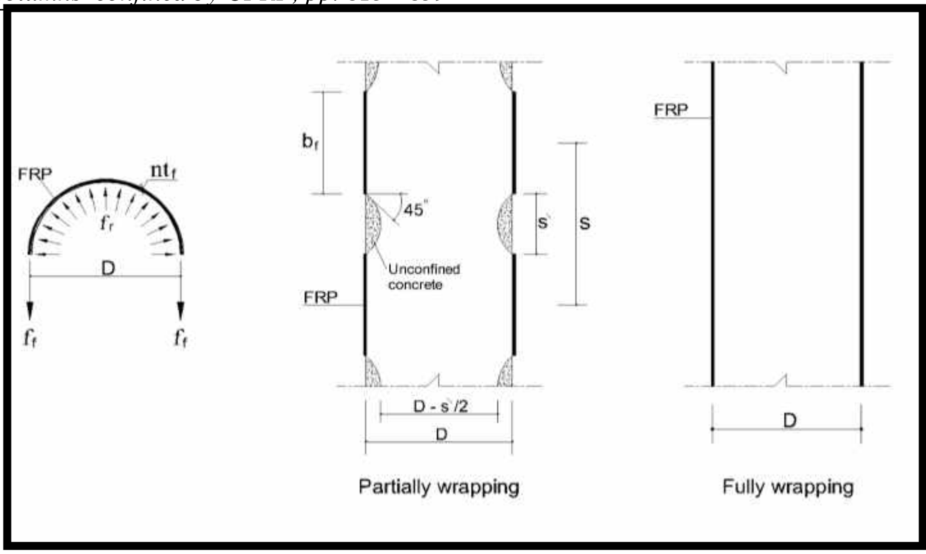


Fig. 9. Confining pressure exerted by wrapping FRP sheet on a circular column [9]

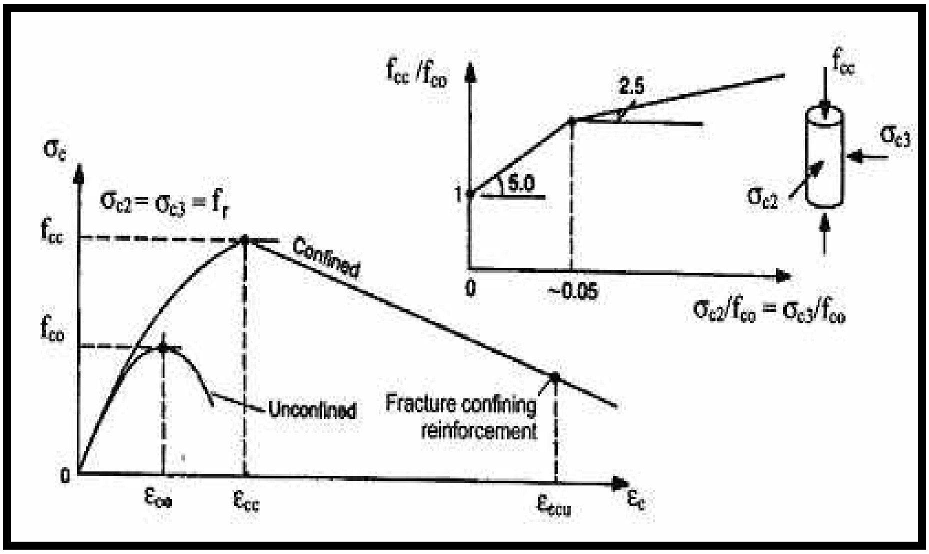


Fig. 10. Model for confined concrete (constant confining action) [11].

Table 7.
Experimental and predicted results for circular R.C .columns

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)	$P_{pr.c}$/ $P_{pr.u}$		
Ac 1-0	102	255	-	-	104.1	-	0.979	
Ac 1-1	151	377.5	1.48	309.38	148.0	1.42	1.020	**200**
Ac 1-2	182	455	1.78	398.57	179.9	1.72	1.011	
Ac 1-3	210	525	2.05	427.19	195.0	1.87	1.076	
Ac 2-0	186	465	-	-	184.1	-	1.010	
Ac 2-1	242	605	1.30	520.28	232.2	1.26	1.042	**400**
Ac 2-2	278	695	1.49	619.66	271.9	1.47	1.022	
Ac 2-3	305	762.5	1.63	669.89	292.0	1.58	1.044	
Ac 3-0	262	655	-	-	264.1	-	0.992	
Ac 3-1	305	762.5	1.16	724.45	313.8	1.18	0.971	**600**
Ac 3-2	338	845	1.29	832.98	357.2	1.35	0.946	
Ac 3-3	365	912.5	1.39	889.58	379.9	1.43	0.960	

Throughout *Fig. 11* and *Table 7, it* is obvious that the calculated results according to the proposed model concerning the load carrying capacity of the strengthened columns achieved a considerable approach to the actual values (experimental results) particularly for *C 200* and *C400* ,the ratio of obtained experimentally to that the predicted maximum load of the strengthened columns by Saadatmaneshexpression*($P_{max .exp}$/ $P_{pr.}$)* ranged between 1.011 and 1.076 , while it ranged between 0.946 and 0.971 for *C 600.*

7. Conclusions

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

7.1 General conclusions

These items present general conclusions and remark concerning the CFRP technique for strengthening columns specially axial short circular columns as follows:

1. Using CFRP technique in strengthening is generally preferable due to the easy procedure to apply for the concrete columns with very high efficiency of adhesive material.
2. CFRP sheets can be used as an alternative solution for strengthening technique instead of steel bars dueto its outstanding advantages especially, the high resistance of corrosion, the very light weight and the negligible thickness.

3. Using CFRP sheets changes the mode of failure for the most of the tested columns due to the high increase in the shearing capacity of the cross section.
4. Behavior of concrete column is significantly improved due to confinement provided by CFRP.

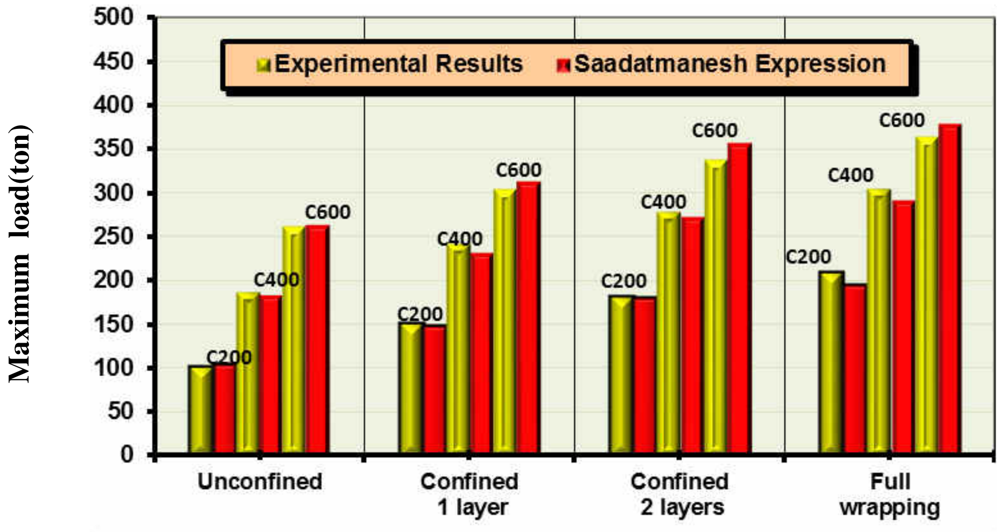


Fig. 11. Predicted maximum load in comparison with that obtained experimentally

7.2 With respect to grade of concrete and strengthening system:

1. As a general rule , as the strengthening system increases, the axial nominal stress, the axial nominal strain, the modulus of elasticity and the modulus of toughness are increased for confined one layer , two layers and full wrapping reinforced concrete columns than that for unconfined for both normal and high strength.
2. For reinforced concrete columns circular section confined with CFRP, the strength efficiency, ductility efficiency, stiffness efficiency and the absorbed energy efficiency are higher for normal strength concrete than that for high strength concrete at the same level of strengthening system.
3. For reinforced concrete columns of circular sections, the strength efficiency , the ductility efficiency, the stiffness efficiency and the absorbed energy efficiency are higher for confined full wrapping (one lay) than that confined two layers (partial wrapping), also all efficiencies of confined two layers (partial wrapping) are higher than that confined one layer (partial wrapping) .
4. For circular reinforced concrete columns, the strength efficiency vanishes when grade of concrete (C) is higher than 800 kg / cm^2 disregarding the strengthening system .

5. For circular reinforced concrete columns, the ductility efficiency vanishes when grade of concrete (C) is higher than 750 kg / cm^2disregarding the strengthening system.
6. For circular reinforced concrete columns, the stiffness efficiency vanishes when grade of concrete (C) is higher than 800 kg / cm^2 disregarding the strengthening system.
7. For circular reinforced concrete columns, the absorbed energy efficiency vanishes when grade of concrete (C) is higher than 725 kg / cm^2disregarding the strengthening system.
8. For circular reinforced concrete columns confined with CFRP (one layer , two layers and full wrapping) , the efficiencies decrease with mean percent 38% for *C400* and 68 % for *C600* comparing with that *C200.*

8. References

[1] S. R. Razvi and M. Saatcioglue , (1994) ; Strength and Deformability of Confined High Strength Columns, ACI Structural Journal , 91, pp. 678-687.

[2] J.H Li and M. N. S Hadi, (2003) ; Behavior of Externally Confined High Strength Columns under Eccentric Loading , Composite Structure, 62, pp. 145-153.

[3] www.yahoo.com, http://tesching .ust.hk/~civil 111/chapter5.pdf, pp. 55- 57.

[4] Egyptian Code for FRP ; (Code 208 Version 2005), Chapter 2 and Chapter 3.

[5] Malhotra V. M. and Garette C. G. (1982); Silica Fume Concrete : Properties, Application and Limitations, Proceeding of Annual meeting of Institute of Concrete Technology, Fulmer Grange, Slough, England, PP. 1-23.

[6] SIKA (2001); SikaCarbdur system. P.C.26: Specifications for Structural Strengthening with SIKA, CARBODUR System.

[7] Omar A. Farghal and Abd El-RahmanMegahid : Behavior of Axially Loaded Circular R.C. Column Confined with Wrapping Sheet ,Journal of Engineering Sciences , Assiut University, Egypt, Vol. 34, No. 4, pp 1027-1047, July 2006.

[8] CEN (1995); Adhesive Determination of Tensile Lap-Shear Strength of Rigid-to-Rigid bonded assemblies, EN 1465: 1995, Comeit´ Europeen de Normalisation (CEN), Brussels, Belgium, 12pp.

[9] CEB (2001); CEB-FIP Model Code 2000, Design Code – Externally Bonded FRP Reinforcement for R.C. Structures.

[10] CEB (1993); CEB-FIP Model Code 1990 Design Code, Comite Euro- international du Beton, Lausanne, Switzerland, Tomas Telford, 437 pp.

[11] Mander. J. B, Priestly. M. J. N, and Park. R., (1988); Theoretical Stress –Strain Model for Confined Concrete." Journal of Structural Engineering , ASCF., V.114, No. 8.Aug. 1988,PP-1804-1826.

[12] Saadatmanesh, H., Ehsani, M.R. and Li, M. W. (1994); Strength and Ductility of Concrete Columns Externally Reinforced with Fiber Composite Straps. ACI Structural Journal , July-August (1994), PP. 434-447 .

بعض العوامل التي تؤثر على السلوك الإستاتيكي للأعمدة الخرسانية المسلحة العادية والعالية المقاومة والدائرية المقطعة والمحاطة بألياف الكربون

ملخص:

في هذا البحث تم عمل دراسة معملية لبيان تأثير بعض العوامل على السلوك الإستاتيكي للأعمدة الخرسانية المسلحة الدائرية المقطع والمحاطة برقائق الألياف الكربونية البوليمرية Carbon Fiber Reinforced Polymer Sheets الملصوقة عرضيا وجزئيا (Partial Wrapping) سواء كانت طبقة واحدة) ($\mu_f = 0.14\%$ أو طبقتين) ($\mu_f = 0.28\%$ على سطح الأعمدة الخرسانية في صورة كانات خارجية موزعة على طول العمود وكذلك إحاطة كلية (Full Wrapping) خارجية بكامل طول ومحيط العمود طبقة واحدة)($\mu_f = 0.23\%$ وذلك تحت تأثير حمل مركزي في ضوء تغير رتبة الخرسانة (C 200 و C 400 و C 600) . تم دراسة كفاءة رقائق الألياف الكربونية البوليمرية المستخدمة وذلك من وجهة نظر كل من (المقاومة Strength- الممطولية Ductility- الصلابة Stiffness - المتانة Absorbed energy) لعدد 12 عمود دائري قطر 22.57 سم . 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 فى 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 الآتي :-

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

1. في الأعمدة الخرسانية المسلحة الدائرية المقطع ساهمت رقائق الألياف الكربونية في زيادة كل من المقاومة و الممطولية ومعاير المرونة ومعاير المتانة بصورة ملحوظة وواضحة للأعمدة ذات رتبة خرسانة تقليدية normal (strength) عن مثيلتها ذات رتبة خرسانة عالية (high strength) وبمعنى آخر فان كفاءة رقائق الألياف الكربونية تتناسب عكسياً مع زيادة رتبة الخرسانة.
2. مع زيادة عدد طبقات التقوية في حالة التقوية جزئياً (Partial wrapping) برقائق الألياف الكربونية للأعمدة الخرسانية المسلحة الدائرية تبين أن هناك زيادة ملحوظة لكل من المقاومة و الممطولية ومعاير المتانة وزيادة طفيفة لمعاير المرونة.
3. في الأعمدة الخرسانية الدائرية المقطع ساهمت رقائق الألياف الكربونية للأعمدة المحاطة كلياً بطبقة واحدة (التي تغطي كامل مسطح العمود Full wrapping) في تحسين كل من المقاومة و الممطولية ومعاير المتانة ومعاير المرونة بصورة ملحوظة عن مثيلاتها في الأعمدة المحاطة جزئياً(Partial wrapping) سواء طبقة واحدة(One layer) من الألياف الكربونية أو طبقتين(Two layers) .
4. نظرا لزيادة معاير المتانة الواضح خصوصاً لرتبة الخرسانة التقليدية C 200 و(C 400Normalstrength) في الأعمدة الخرسانية الدائرية المقطع المحاطة فإن أسلوب التقويات باستخدام رقائق الألياف الكربونية يكون أكثر فائدة وتأثيراً في المنشئات المعرضة لأحمال ديناميكية مثل الزلازل والرياح والأحمال المتكررة .
5. النتائج التي تم الحصول عليها بتطبيق النموذج الرياضي Saadatmanesh Expression أثبتت تقارب كبير للنتائج المقابلة التي تم الحصول عليه معملياً لرتبة الخرسانة التقليديةC 200 و Normal) C 400strength) وتراوحت هذه النتائج (Pmax .exp/ Ppr.) ما بين (107.6% : 101.0 %) بينما قلت هذه النسبة لرتبة الخرسانة عالية المقاومة (C 600high strength) وتراوحت ما بين (97.1 % .: 94.6 %)