

Behavior of Reinforced Concrete Columns Strengthened by GFRP with Different Steel Ratio

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ABSTRACT: The use of Fiber Reinforced Polymers (FRP) in strengthening of different Reinforced concrete elements is becoming one of the accepted solutions. This research studied the behavior of strengthened Reinforced concrete columns using locally available Glass Fiber Reinforced polymers (GFRP). The studied in this research are spacing between stirrups, parentage of main steel and number of GFRP layers. The experimental program includes testing of two main groups (A1 and A2).

Group A1 consists of three groups of RC columns (G1, G2 and G3), each group of **G** consists of four RC columns with main steel (4Ø6). The tested parameters were, the number of GFRP layers (one layer, or two layers), and stirrup spacing 500 mm, 300 mm, and 200 mm respectively.

Group A2 consists of three groups of RC columns (g1, g2 and g3), and each group of **g** consists of four RC columns with spacing between stirrups are 200mm. the main variable between each group is number of layer (without layer, one layer, two layers). For columns each group consists of variable ratio of main steel, the ratio of longitudinal reinforcement were [0% (without main steel), 0.785% (4Ø6), 1.09% (2Ø6 + 2Ø8), and 1.395% (4Ø8)].

All test specimens with overall length 1200mm, and square cross section 120x120 mm. All specimens were tested under centric vertical load. The effect of strengthening using (**GFRP**) on the mechanical properties of the columns will be investigated by comparing the obtained before and after strengthening.

KEYWORDS: Columns, GFRP, strengthened, stirrups, Reinforced Concrete, axial compression.

I. INTRODUCTION

Cracking and spalling of reinforced concrete (RC) columns often accompany the corrosion of internal steel reinforcements. The loss of cementation material, as well as the corrosion-induced reduction in cross-section areas of a steel reinforcement, leads to drastic reductions in the structural integrity and load-carrying capacity of column as supporting elements.

Until recently, the most common method of strengthening was RC columns by using reinforced steel jackets around circular sections. The use of a steel encasement to provide the lateral confinement to concrete in compression has been extensively studied and has been shown to be able to significantly increase the compression load-carrying capacity and deformation of the columns. However, the major disadvantages of using steel jackets are low resistance to corrosion, and high cost.

Fiber reinforced polymers (FRP), due to their high strength-to-weight and stiffness-to-weight ratios, large deformation capacity, corrosion resistance to environmental degradation, and tailor ability, presents an attractive option as an alternative and extremely efficient retrofitting technique in such cases through the use of composite jackets or wraps around a deteriorated column.[5]

CFRP sheets have been applied to increase the concrete confinement and loading resistance of reinforced concrete columns.[3]

The confinement effectiveness of externally bonded FRP jackets depends on different parameters, such as, the type of concrete, steel reinforcement, thickness of the FRP jackets i.e. „number of layers" and stiffness "type of FRP" and

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loading conditions. Also, the shape of the cross sections and sharp edges existing in the cross sections of columns can directly affect the confinement effectiveness of externally bonded concrete. The efficiency of FRP confinement is higher for circular than square sections. The mitigation of the effect of this shape i.e., with shape edges" is achieved by rounding the corners of rectangular sections with the effectiveness increasing

With the rounding radius, until a certain threshold is reached. The ultimate strength of the confined concrete is closely related to the failure strength of the FRP wraps. The GFRP strain at the rupture of the confined columns is usually lower than the ultimate strain obtained by tensile testing of the CFRP coupons.

II. EXPERIMENTAL PROGRAM

The experimental program included testing of two main groups (A1 and A2), each group consists of three groups of RC columns; each group contains typical four RC columns (medium scale specimens). All tested specimens with overall length 1200 mm, and dimensional 120x120 mm.

The tested parameters of group **A1** were the number of GFRP layers (one layer, or two layers), and stirrup spacing 500 mm, 300 mm, and 200 mm respectively. The main variables between each group in the main group **A2** is number of layer (without layer, one layer, two layers), the ratio of longitudinal reinforcement were [0% (without main steel), 0.785% (4Ø6), 1.09% (2Ø6 + 2Ø8), and 1.395% (4Ø8)].

The Reinforcement details of tested specimens are shown in Fig. (1) and Fig. (2) Specimens' were detailed reinforcement according to Egyptian code [2]. All specimens shared the same 28 days cube concrete compressive strength of 30 MPa "mix properties are shown in table (1)", the same steel grade 240 MPa proof strength.

In Groups (G1, g2), four specimens were retrofitted by using one layer of (GFRP) and another Groups (G2, g2), Four specimens were retrofitted by two layers of (GFRP), and in the Groups (G3, g3) contains four specimens were a control specimen, Specimens had been tested under vertical loading, as will be explained later.

Table (1): Concrete mix properties

Constituents	Contents(kg/m ³)	Proportions
Cement	325	1.00
Sand	600	1.85
Crushed stone grade(1)	600	1.85
Crushed stone grade(2)	600	1.85
Water	195	0.708

Compression test were conducted on 7 and 28 days and performed on standard cubes 15.8x 15.8 x15.8 cm. Table (2) shows the results of the test. Slump test is performed on fresh concrete according to ASTM C143 90a .Compressive strength tests are performed at age7 and 28 days respectively.

The main mechanical properties of steel reinforcement are shown in Table (3)

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Table (2): Recorded Cube strength results

Time days	After 7 days	After 28 days
Strength N/mm²	22.7	31.5

Table (3): Mechanical properties of reinforcing steel

Property	6mm
Yield strength (kg/mm ²)	31.8
Ultimate strength (kg/mm ²)	47.7
Elongation percent (%)	26.6

The technical data of GFRP and the mechanical properties of resins used are shown in table (4) and table (5) respectively.

Table (4): Technical data of GFRP.

Fiber type	E-Glass fibers
Fiber orientation	0:(unidirectional).The fabric is equipped with special weft fibers which prevent loosening of the roving (heat sat process)
Arial weight	430g/m ²
Fabric design thickness	0.17mm (based on total area of glass fibers)
Tensile strength of fibers	2250 N/mm ²
Tensile E- modulus of	70000 N/mm ²
Strain at failure of fibers	3.1 %
Fabric length per roll	>50m
Fabric width	300/600 mm
Shelf life	Unlimited
Packing	1 roll in card board box

Table (5): Mechanical properties of resins

Types of polyester	Glass content (%)	Tensile strength (MPa)	Tensile modulus (Gpa)	Elong (%)	Flexural strength (M P a)	Flexural modulus (Gpa)	Comp strength (Mpa)
Orthophthalic	40	150	5.5	1.7	220	6.9	–
Isophthalic	40	190	11.7	2.0	240	7.6	210
Vinyl ester	40	160	11.5	–	220	9.0	120

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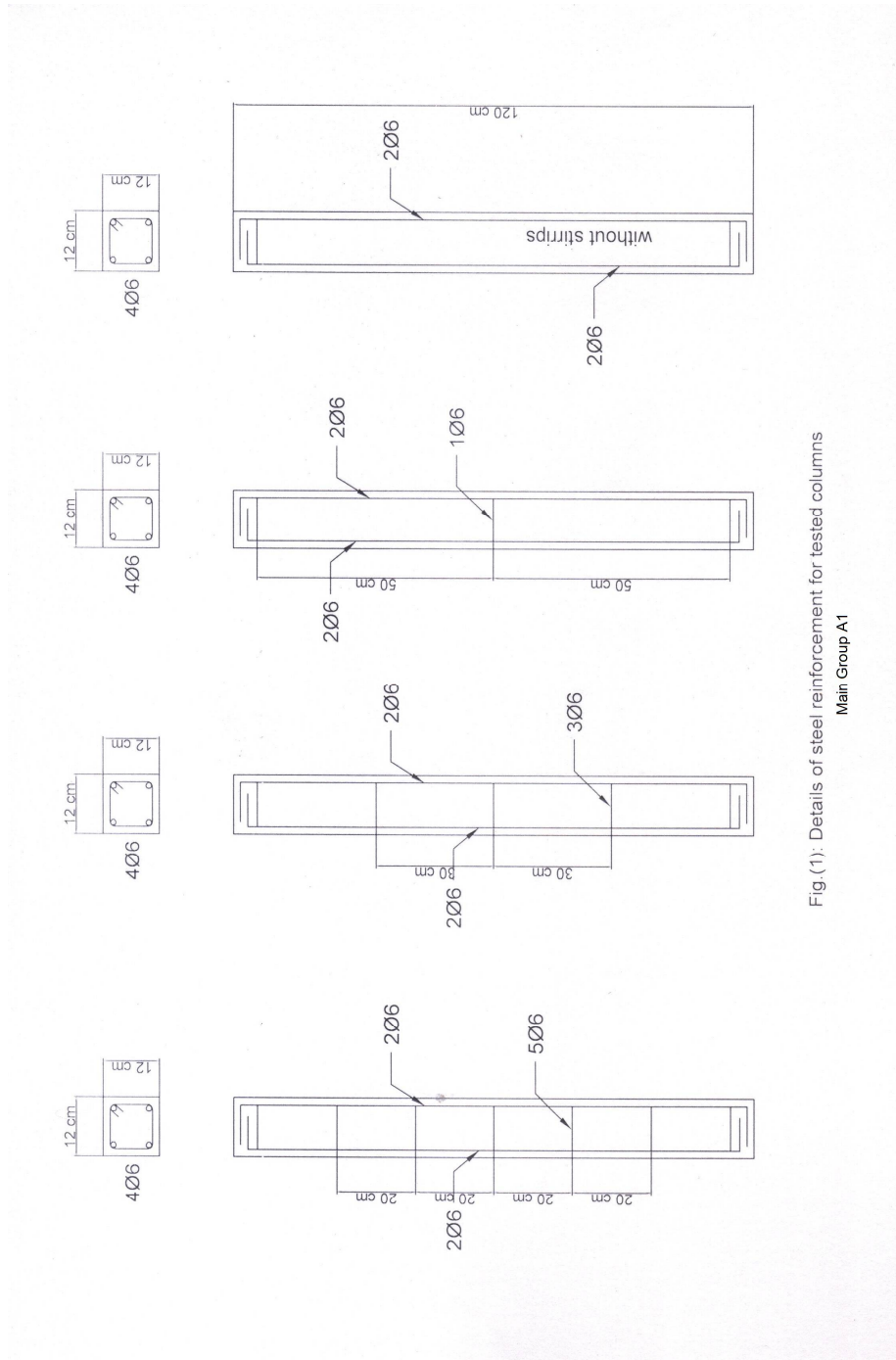


Fig.(1): Details of steel reinforcement for tested columns
Main Group A1

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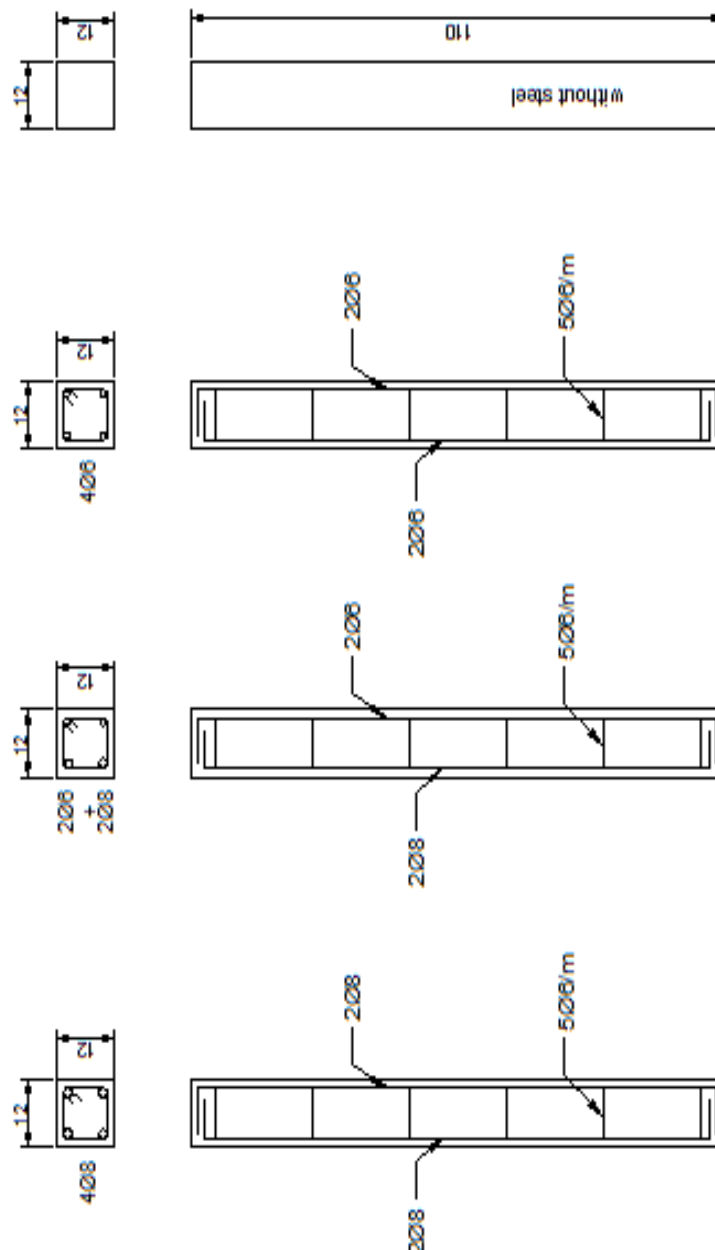


Fig.(2) : Details of test specimens of Main Group A2

III. STRENGTHENING PROCEDURE

1. Column surface was prepared by grinding, followed by compressed air to remove all loose particles and dust.
2. The resin matrix was prepared by mixing the resin and hardener.
3. An undercoat of resin was applied first to the column surface using a paint brush , taking care to fill in all voids.

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4. The GFRP wrap was applied through one circumference, pressing firmly down with a rag until the resin was squeezed out between the roving to remove all air bubbles.
5. As a covering layer an overcoat of resin was applied. This also served as an undercoat for the following layer.
6. Steps 4 and 5 were repeated for the following layers,
7. In all cases, the outside layer was extended by an overlap of 100 mm to ensure the development of full composite strength.

IV. LOADING SETUP AND TESTING PROCEDURE

All columns are tested to failure in uniaxial compression using compression static testing machine with 200 – tons capacity. The upper head was fitted with spherical seat. The end surface of the column was capped using non-shrink grout to ensure parallel and smooth surface. Care is taken to load the columns axially and to reduce any possible bending of the columns.

In order to force the failure in the tested region "middle third of the columns" , additional confinement is provided to the upper and lower 10cm sections by one layer of GFRP before testing for all columns.

V. EXPERIMENTAL RESULTS

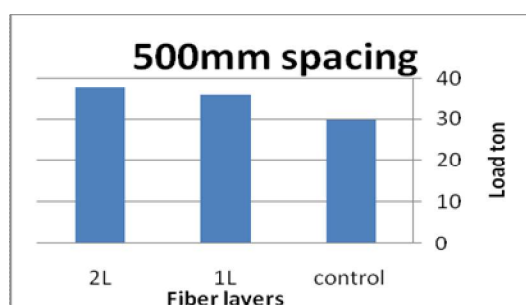
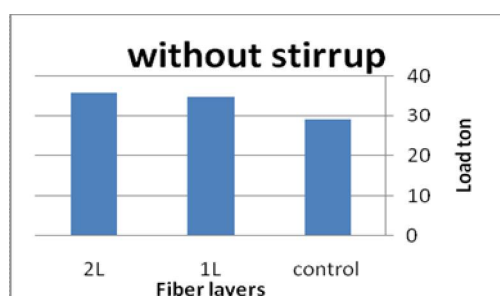
The specimens were tested gradually till failure load to provide necessary information required for defining the failure mechanism of each specimen, Table (6) and table (7) shows the recorded test results.

Table (6): Recorded test results of Group A1

Specimens	Spacing of Stirrups mm	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	without	29	35	36
Sp. 2	500	30	36	38
Sp. 3	300	33	39	43
Sp. 4	200	33	39	45

Table (7): Recorded test results of Group A2

Specimens	% of Main Steel	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	0%	28.5	34	39
Sp. 2	0.785%	32	39	45
Sp. 3	1.09%	33	41	48
Sp. 4	1.395%	35	45	51



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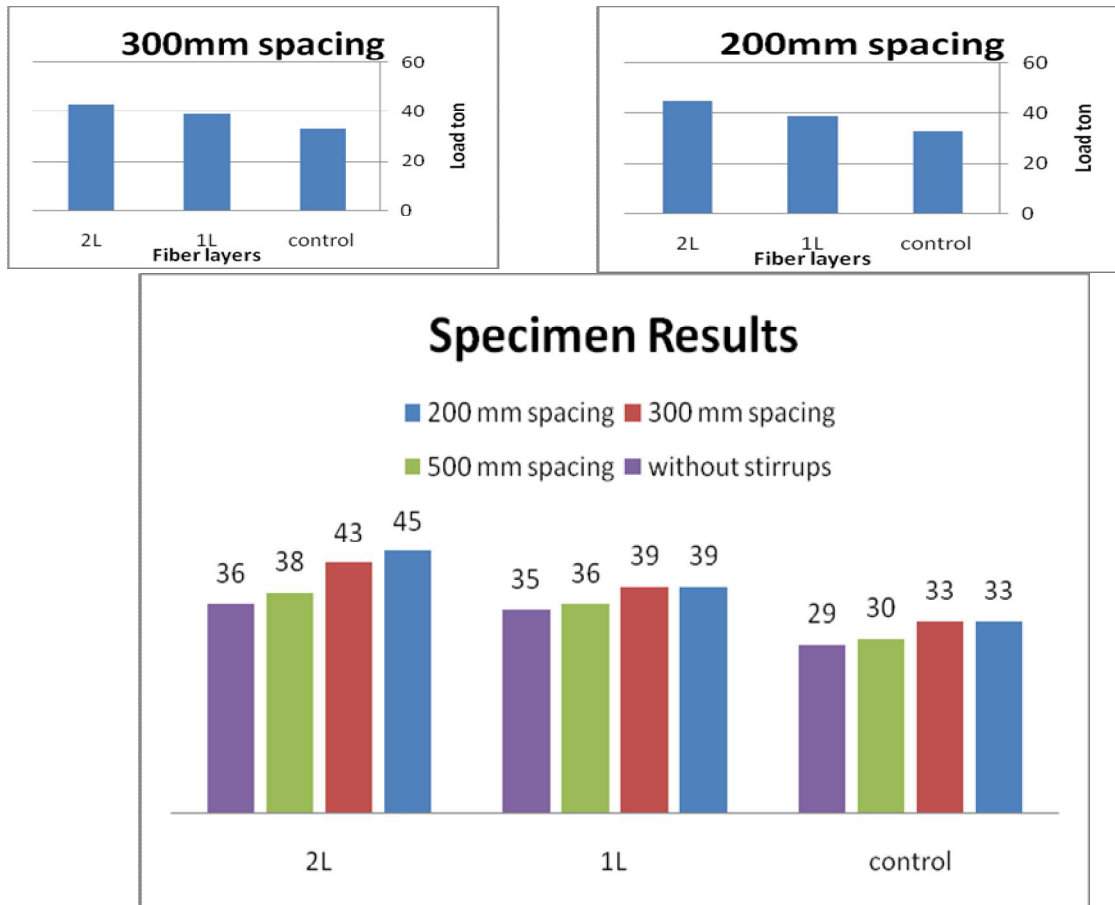
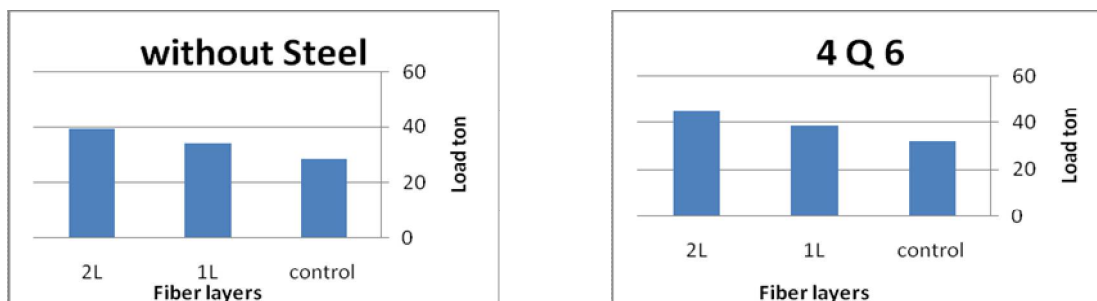


Fig.(3): comparison between test results
Group A1



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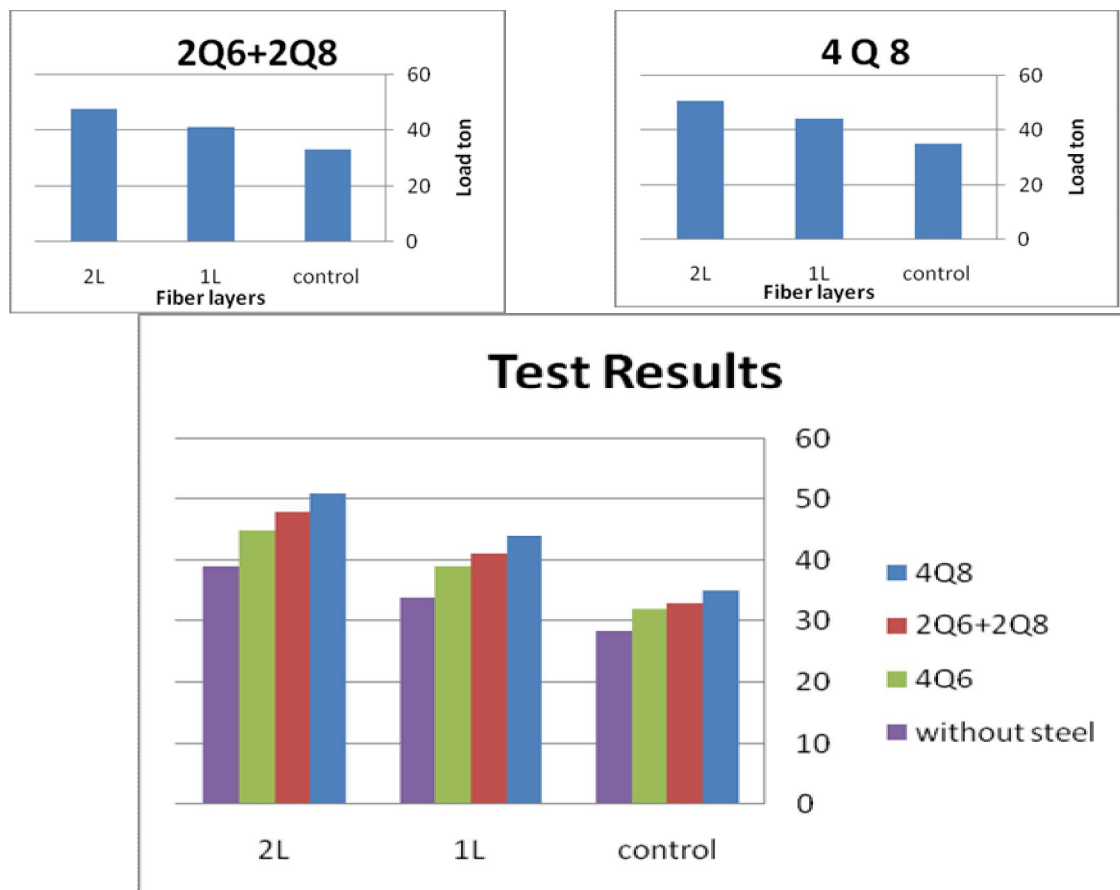


Fig.(4): comparison between test results
Group A2

Table (8): Percentage of gain strength in group A1

	No stirrup	500mm sp.	300mm sp.	200mm sp.
1 layer from non	20%	20%	18%	18%
2 layers from non	24%	27%	31%	36%
2 layers from one layer	3%	5%	10%	15%

Table (9): Percentage of gain strength in group A2

	0%	0.785%	1.09%	1.4%
1 layer from non	19.3%	21.9%	24.2%	28.6%
2 layers from non	36.8%	40.6%	45.5%	45.7%
2 layers from one layer	14.7%	9.8%	17.1%	13.3%

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VI. THEORETICAL ANALYSIS

The ultimate column strength was calculated theoretically by the using Egyptian code formula [2] as follow. The percentage of stirrups was not taken into consideration in the formula which means that, the calculated values were constant for all tested specimens as shown in table (10).

$$P_u = (2/3) f_{cuc} A_c + f_y A_{sc}$$

$$A_c = 120 \times 120 = 14400 \text{ mm}^2$$

$$f_y = 240 \text{ N/mm}^2$$

$$A_{sc} = \text{Zero}, 113 \text{ mm}^2, 157 \text{ mm}^2, 201 \text{ mm}^2$$

$$f_{cuc} = f_{cu} [2.25 (\sqrt{1 + 9.875 f_l / f_{cu}}) - 2.5 f_l / f_{cu} - 1.25]$$

$$f_{cu} = 30 \text{ N/mm}^2$$

$$f_l = k_e (\mu_f E_f \epsilon_{fe} / 2 \gamma_f)$$

$$\gamma_f = 1.3$$

$$\epsilon_{fe} = 0.75 \epsilon_{fu} \leq 0.004$$

$$E_f = 70000 \text{ N/mm}^2$$

$$\mu_f = 2 n t_f (b + t) / b t$$

$$b = t = 120 \text{ mm}$$

$$t_f = 0.17 \text{ mm}$$

$$n = 1, 2$$

$$k_e = 1 - \{ [(b - 2 r_c)^2 + (t - 2 r_c)^2] / [3 (b \times t)(1 - \mu_s)] \}$$

$$r_c = 10 \text{ mm}$$

$$\mu_s = 0\%, 0.785\%, 1.09\%, \text{ and } 1.395\%$$

Table (10): Theoretical results of Group A1

Specimens	Stirrup spacing's mm	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp.	-----	31.5	33.68	36.55

Table (11): Theoretical results of Group A2

Specimens	% of Main Steel	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	0%	28.8	30.05	32.93
Sp. 2	0.785%	32.4	33.64	36.52
Sp. 3	1.09%	33.8	35.04	37.92
Sp. 4	1.395%	35.2	36.44	39.32

VII. COMPARISON BETWEEN TH. AND EXP. RESULTS

Table (12): Comparison Results of Group A1

Specimens	Stirrup spacing's mm	Failure Load (ton) Control		Failure Load (ton) 1 Layer		Failure Load (ton) 2 Layer	
		Exp.	Th.	Exp.	Th.	Exp.	Th.
Sp. 1	-----	29	31.5	35	33.68	36	36.55
Sp. 2	500	30	31.5	36	33.68	38	36.55
Sp. 3	300	33	31.5	39	33.68	43	36.55
Sp. 4	200	33	31.5	39	33.68	45	36.55

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Table (13): Comparison Results of Group A2

Specimens	Stirrup spacing's mm	Failure Load (ton) Control		Failure Load (ton) 1 Layer		Failure Load (ton) 2 Layer	
		Exp.	Th.	Exp.	Th.	Exp.	Th.
Sp. 1	0 %	28.5	28.8	34	30.05	39	32.93
Sp. 2	0.785	32	32.4	39	33.64	45	36.52
Sp. 3	1.09%	33	33.8	41	35.04	48	37.92
Sp. 4	1.395%	35	35.2	45	36.44	51	39.32

VIII. CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

1. The use of GFRP for columns repair increases their strength even if there were no stirrups.
2. The effect of column GFRP reinforcement is rather limited in one layer.
3. Using of one layer increase the strength by overall 20%.
4. Using of two layers increase the strength by overall 35%.
5. The gain strength by using two layers over the one layer is 10%
6. A good agreement is obtained between experimental and theoretical studies.

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