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Effect of GFRP Wraps on HSC Columns Strengthened with GFRP with Different Steel Ratio

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***Abstract*— Experimental investigation was conducted to study the pure compression and ductility behavior of high-strength concrete (HSC) columns strengthened with glass fiber reinforced polymers (GFRP) having different stirrup spacing and different main steel ratio.**

A total of twenty four columns were tested. The variables of this research are spacing of main stirrups, percentage of main steel and number of layers of (GFRP). The experimental program includes testing of two main groups (G1 and G2).

Group G1 consists of three groups of columns (H1,H2 and H3), each group consists of four columns (medium scale specimens), all specimens with overall length 1200mm, columns are square with a dimensional 120 mm and main steel (4Ø6).The considered parameters were the number of layers (1-without layer, 2-one layer, 3-two layers). Variable stirrup spacing, the spacing of stirrup reinforcement was [1) without stirrups, 2) 500 mm, 3) 300 mm, 4) and 200 mm].

Group G2 consists of three groups of RC columns (C1, C2 and C3), and each group 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)].

Four columns without GFRP were assigned as control columns in each main group and the rest were strengthened using GFRP sheets. In this study, different wrap configurations and the effect of different numbers of GFRP plies. Investigation into ductility using two different concepts showed enhancement in the behavior of strengthened columns with GFRP. The experimental results were compared with the results from analytical methods.

***Index Terms*— Columns, GFRP, strengthened, stirrups.**

I. INTRODUCTION

Deterioration of reinforced concrete structures, due either to corrosion of the reinforcement bars or to the continual upgrading of service loads (for example, increase in the traffic load on abridge) has resulted in a large number of structures requiring repairing or strengthening.

Various methods are available to repair or strengthen such structures. External bonding of composite materials to deficient or damaged reinforced concrete structures is one type of strengthening methods. Because GFRP materials are non-corrosive, non-magnetic, resistant to various types of chemicals, high in strength, and lightweight, they are increasingly being used for external reinforcement of existing concrete structures.

There is limited information on strengthening members with fiber-reinforced-polymers (FRP) in the literature and all of them have been carried out on strengthening of normal strength concrete columns. The lack of experimental and analytical studies in this field led to the present study on the Ductility behavior of reinforced concrete columns repaired with GFRP sheets.

II. TEST PROGRAM

The experimental program included testing of two main groups each group consists of three Groups; each group contains typical four HSC columns.

The reinforcement details of the tested specimens are shown in Fig. (1) and Fig. (2), the details of specimens' reinforcement were according to Egyptian code.

The compressive strength of the used concrete was about 75 N/mm2. The steel used was grade 37 normal mild bars. In each main groups, groups (H1 and C1), Four specimens were retrofitted by using one layer of (GFRP) and another groups (H2 and C2), Four specimens were retrofitted by two layers of (GFRP) , and the third groups (H3 and C3) contains four specimens were a control specimen. They had been tested under vertical loading, as will be explained later. High-strength concrete is used for the tested specimens. The concrete mix is designed to achieve a target compressive strength of 75N/mm2 after 28 days. The mix proportions are given in table (1).

Table (1): Concrete mix properties

Constituents	Contents(kg/m3)	Proportions
Cement	520	1.00
Sand	545	1.048
Crushed dolomite grade(1)	550	1.058
Crushed stone grade(2)	550	1.58
Super plasticizer	6.6	0.0127
Silica fume	14.85	0.0286
Water	198	0.381

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

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mechanical properties of reinforced steel are shown in Table (3).

Table (2): Recorded Cube strength results

Time days	After 7 days	After 28 days
Strength N/mm2	38.9	75.4

Table (3): Mechanical properties of reinforcing steel

Property	6mm
Yield strength (kg/mm2)	31.8
Ultimate strength (kg/mm2)	47.7
Elongation percent (%)	26.6

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/m2
Fabric design thickness	0.17mm (based on total area of glass fibers)
Tensile strength of fibers	2250 N/mm2
Tensile E- modulus of	70000 N/mm2
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

Comp streng th (Mpa)	Flexu ral modul us (Gpa)	Flexu ral streng th (M P a)	Elong (%)	Tensil e modul us (Gpa)	Tensile strength (MPa)	Glass conte nt (%)	Types of polyeste r
_	6.9	220	1.7	5.5	150	40	Orthoph thalic
210	7.6	240	2	11.7	190	40	Isophtha lic
120	9	220	_	11.5	160	40	Vinyl ester

III. STRENGTHINING PROCEDURE

1. The 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.
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 and5 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.

Loading setup and Testing Procedure

All columns are tasted to failure in uniaxial compression using compression testing machine with 200 –tons capacity. The upper head was fitted with spherical seat. The end surface of the columns is capped using non-shrink grout to ensure parallel and smooth surfaces. 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 G FRP before testing for all columns.

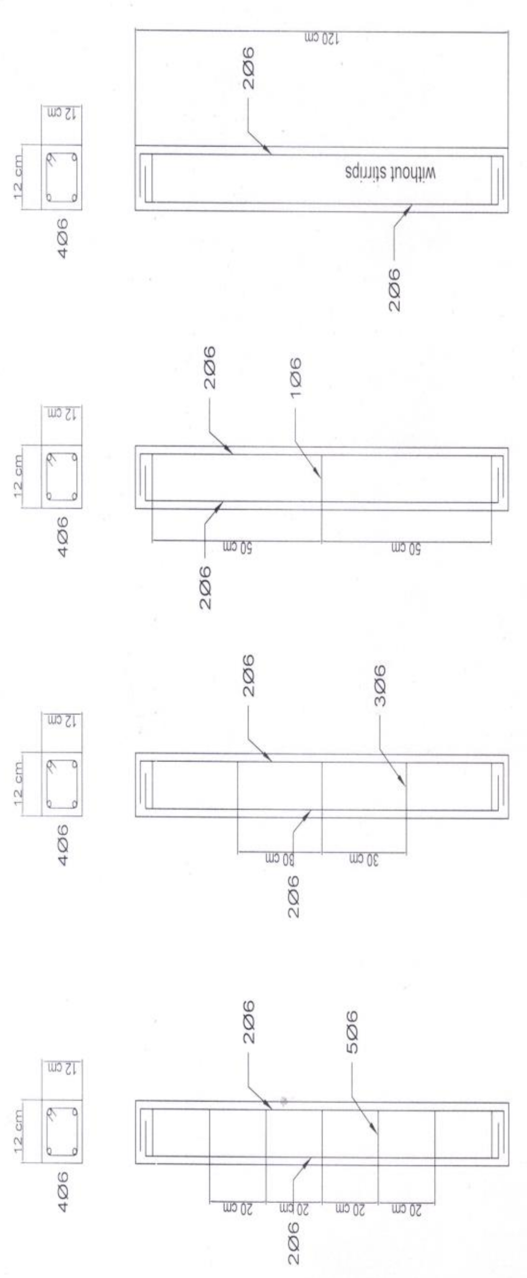

Fig.(1): Details of steel reinforcement for tested columns
Main Group G1

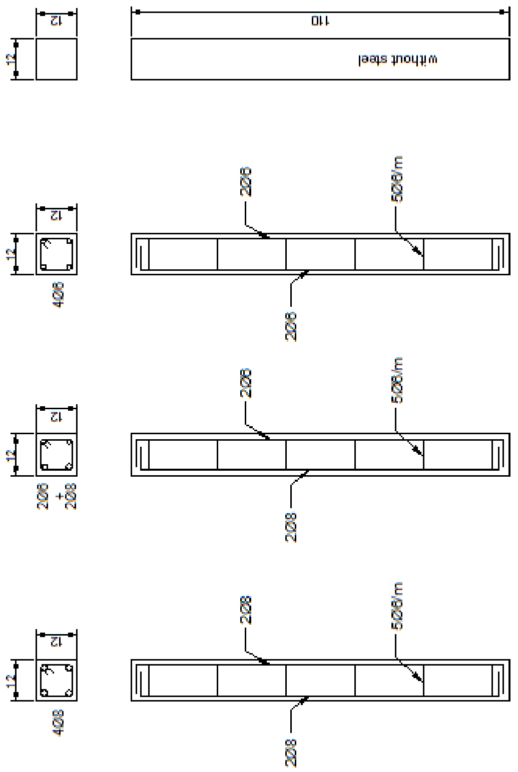

Fig.(2): Details of test specimens of Main Group G2

IV. EXPERIMENTAL RESULTS

After the peak of each cycle, the specimens was tested gradually till failure load to provide necessary information required for defining the failure mechanism of each specimen, Fig. (3,4) show the mode of failure of same specimens. Table (6,7) shows the recorded test results.

Fig. (3): Control

Fig. (4): Two layers specimen

Table (6): Recorded test results of group G1

Specimens	Spacing of Stirrups mm	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	without	48	53	67
Sp. 2	500	50	54	74
Sp. 3	300	51	59	75
Sp. 4	200	53	64	78

Table (7): Recorded test results of group G2

Specimens	% of Main Steel	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	0%	46	53	69
Sp. 2	0.785 %	49	55	72
Sp. 3	1.09 %	52	56	74
Sp. 4	1.395 %	53	61	78

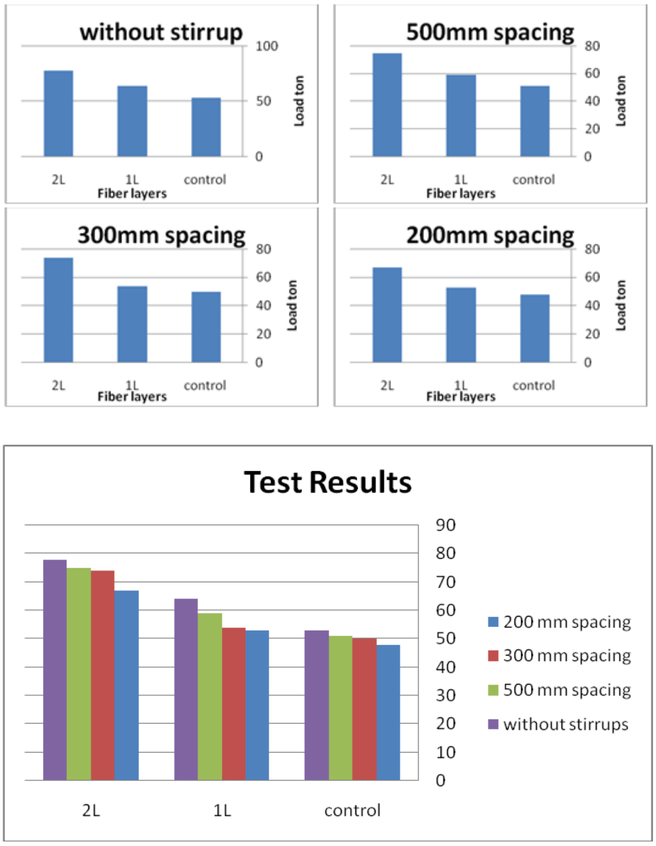

Fig.(5): charts of test results of group G1

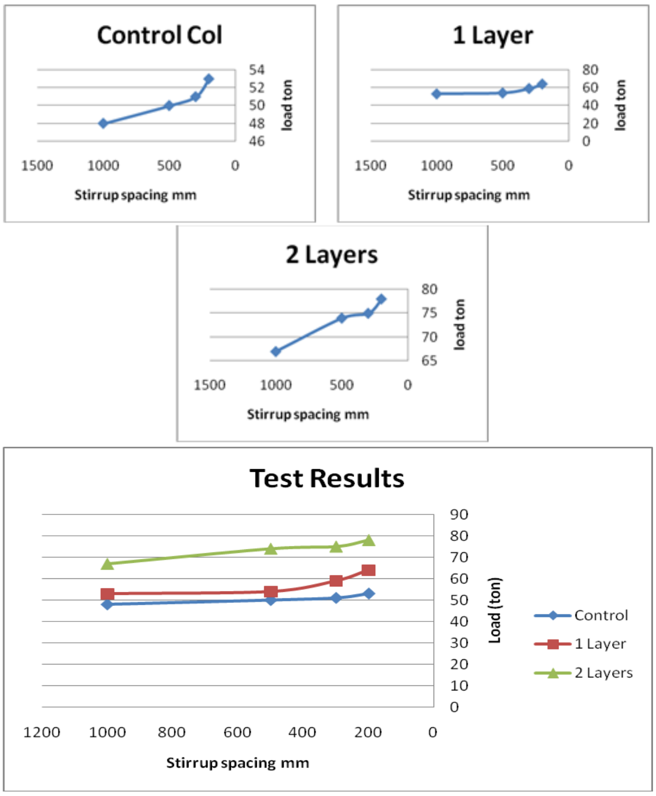

Fig.(6): comparison between tested specimens in group G1

Table (8): Percentage of gain strength in group G1

	No stirrup	500mm sp.	300m m 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%

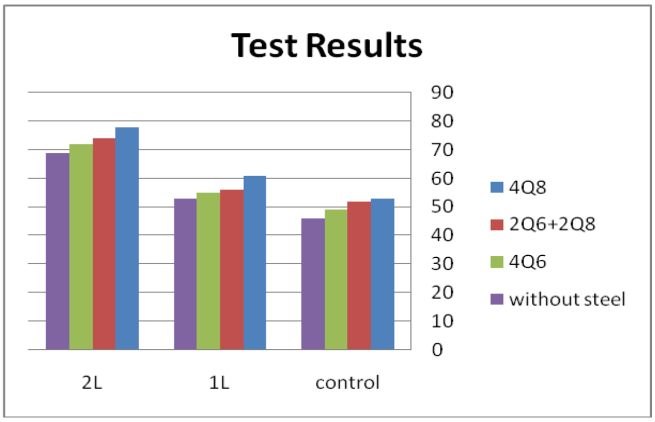

Fig.(7): Recorded test results in group G2

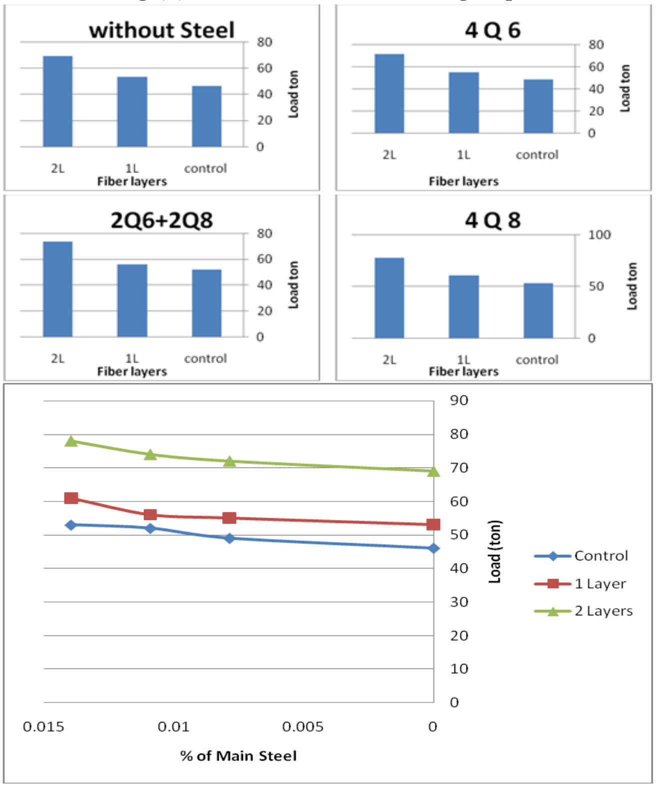

Fig. (8): Comparison between tested specimens in Group G2

Table (9): Percentage of gain strength in group G2

	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%

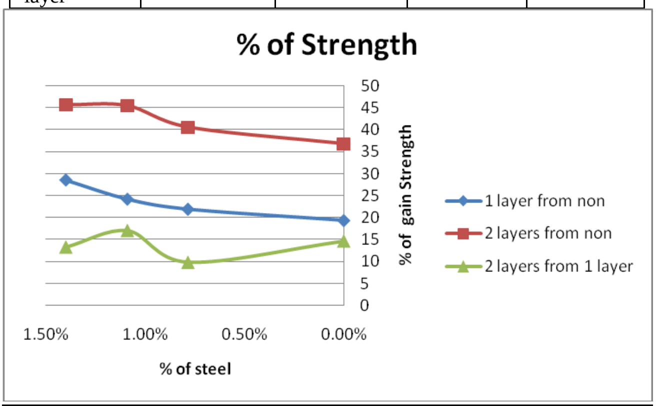

Fig. (9): percentage of gain strength of group G2

V. THEORETICAL ANALYSIS

The equation of calculating ultimate load of columns in ordinary concrete is not compatible with HSC because of brittleness of HSC, so we suggest equation

$Pu = 0.44\ fcuc\ Ac + fy\ Asc$

The percentage of stirrups was not taken into consideration in formula which means that, the calculated values were constant for all specimens as shown in table (10).

The factor 0.44 instead of 0.67 is suggested by trials and checked by applied this equation to all tested specimens of HSC. The factor 0.44 instead of 0.67 is suggested by trials and checked by applied this equation to all tested specimens of HSC.

Ac = 120 x 120 = 14400 mm2
Fy = 240 N/mm2
Asc = Zero , 113 mm2 , 157 mm2 , 201 mm2
$fcuc = fcu\ [2.25\ (\sqrt{1 + 9.875\ f1/fcu}) – 2.5\ f1/fcu – 1.25]$
fcu = 75 N/mm2
$f1 = ke\ (\ \mu f\ Ef\ \varepsilon fe / 2\ \gamma f\ )$
$\gamma f = 1.3$
$\varepsilon fe = 0.75\ \varepsilon fu \leq 0.004$
Ef = 70000 N/mm2
$\mu f = 2\ n\ tf\ (b + t) / b\ t$
b = t = 120 mm
tf = 0.17mm
n = 1 , 2
$ke = 1 – \{[(b – 2\ rc)^2 + (t-2\ rc)^2] / [3\ (b \times t)(1- \mu s)]\}$
rc = 10 mm
μs = 0% , 0.785% , 1.09% , and 1.395%

Table (10): Theoretical results of group G1

Specimens	Stirrup spacing's mm	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp.	-----	51.08	53.14	57.89

Table (11): Theoretical results of group G2

Specimens	% of Main Steel	Failure Load (ton) Control	Failure Load (ton) 1 Layer	Failure Load (ton) 2 Layer
Sp. 1	0%	47.52	49.58	54.33
Sp. 2	0.785%	51.08	53.14	57.89
Sp. 3	1.09%	52,48	54.54	59.29
Sp. 4	1.395%	53.85	55.91	60.66

COMPARISON BETWEEN TH. AND EXP. RESULTS

Table (12): Comparison Results of group G1

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	-----	48	51.08	53	53.14	67	57.89
Sp. 2	500	50	51.08	54	53.14	74	57.89
Sp. 3	300	51	51.08	59	53.14	75	57.89
Sp. 4	200	53	51.08	64	53.14	78	57.89

Table (13): Comparison Results of group G2

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%	46	47.52	53	49.58	69	54.33
Sp. 2	0.785	49	51.08	55	53.14	72	57.89
Sp. 3	1.09%	52	52,48	56	54.54	74	59.29
Sp. 4	1.40%	53	53.85	61	55.91	78	60.66

VI. CONCLUSIONS

1. Using of FRP for columns repair increase their strength even if there are no stirrups.
2. The effect of column FRP 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 30%.
5. The gain strength by using two layers addition the one layer is 10%
6. Theoretical analysis is compatible with experimental results.

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