Journal of University of Duhok, Vol.23, No.2 (Pure and Eng. Sciences),Pp 720-730, 2020 (Special Issue)
3rd international conference on recent innovations in engineering (ICRIE) Duhok, September 9-10-2020

BEHAVIOR OF SQUARE REINFORCED CONCRETE COLUMNS STRENGTHENED BY DIFFERENT LAYERS OF GLASS FRP SHEETS

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(Accepted for Publication: December 8, 2020)

ABSTRACT

The behavior of reinforced square concrete columns strengthened by specific layers of glass fiber reinforced polymer (FRP) sheets were investigated through an experiment by testing of thirteen variety of concrete columns that were axially loaded at their ends. The most variable thought of during this study were the quantity or number of layers of glass fiber reinforcement polymer sheets and also the effect of confinement techniques (fully wrapped, strip ties and spiral sheets). The test values were compared with the proposed equation of ACI 440.2R-02, for samples strengthened by one layer of GFRP sheet can upgrade the load carrying capacity of columns in numerous ways of strengthening (fully wrapped, strip ties and spirally) by 25.5%, 6.7% and 29.5% respectively compared to the control (unstrengthen) column. Be that as a result of it would, for columns strengthen by 2 layers of GFRP sheets (fully wrapped, strip ties and spirally) the load carrying capacity increases by 36.5%, 19.6% and 29.8% respectively. While, for 3 layers of strengthen sample the percent of enhancement in the load carrying capacity increases by 38.2%, 20.1% and 30.7% respectively. Finally, the load carrying capacity increases by 43.2%, 29.2% and 33.2% for different confinement techniques (fully wrapped, strip ties and spiral sheets) respectively if they are strengthened by 4 layers of GFRP sheets.

KEYWORDS: Glass fiber reinforcement polymer (FRP) sheets; GFRP layer; Square columns; Confinement.

1. INTRODUCTION

The process of using fiber-reinforced polymer (FRP) composites is becoming one of the preferred methods in structural engineering, and the properties of reinforced concrete columns enhanced through FRP has become a topic of interest for researchers all around the world. This recent popularity can be attributed to certain competitive properties of FRP composites like a high resistance against corrosion and ease of transportation due to their light weight. In addition, these materials have been becoming more affordable as the fabric cost of FRP composites had a declining trend for a certain period of time, which makes them ever more popular as a result.

In their study, Abdulrahman et al. (2020) experimented on a small number of columns with different shapes (square section samples with 135 mm sides, and circular samples with 150 mm diameter) where they loaded them at underpins and arranged them in a structure that would support a temporary structure held over steel plates. Some of these columns were reinforced using carbon fiber polymer sheets, while others were reinforced using glass fiber polymer sheets. To prevent buckling due to any potential uneven load, the columns were coiled with steel ties that span their whole height.

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Performing the structural load test by increasing the weight of the temporary structure, the researchers have found out that carbon FRP sheets provided greater increase in terms of load capacity for both circular and square-section column types, compared to the glass FRP sheets. The ratio of increase in loading capacity due to FRP reinforcement was found to be higher in circular columns, compared to their square-section counterparts. The researchers attribute this difference to the strain within circular columns being comparatively higher than that of the square-section columns under load. The researchers have also reported that the ductility factors of the reinforced columns also changed, and the greatest change occurred in the circular columns reinforced with glass FRP sheets[1].

In their study, Raval and Dave (2013) have performed a series of similar tests on reinforced concrete columns of different shapes (circular, square-section, and rectangular) with equal cross-sectional areas. The researchers first prepared a total of 15 RC columns for each shape, and separated them into two groups as control and test (with 9 and 6 pieces in each group, respectively). The strengthening of the test group columns was performed by wrapping them with GFRP (20 mm corner radius). The test group columns were then subjected to axial compression and the strain on their structure was measured. The results have shown that GFRP reinforcement provided significant increase in loading capacity while having a minimal impact on the column size. The GFRP wrapping also made the columns fail through brittle destruction instead of debonding, where circular columns simply exploded under load (but the wrapping kept the debris within) and the square columns gave way through the corners where they had greater stress. In rectangular columns, however, the stress area shifted from the corners to the sides. GFRP columns failed in an unstable fashion, but the contact between GFRP wrapping and the columns themselves were evident in damaged columns[2].

One study investigated the improving of pressing RCC columns qualify substituted with framework of GFRP which placed in the route of used axial load (Sudhakar & Partheeban, 2017). Those columns of reinforced concrete designed and placed beneath the axil load. Applying Fe 456 grade steel and M20 concrete grade, the researchers examined nine columns with size of 800 mm x 150 mm x 150 mm. By four steel bar every column reinforced for reinforcing latitude and reinforcing longitude respectively 8 mm and 12 mm diameter. Three columns reinforced by double layered GFRP, three columns reinforced by one GFRP layer, as well as three columns as a control is planned. Their conclusion showed RCC columns that covered by one GFRP layer, in comparing with columns of control 15.31% expanded. In comparing to columns of control, there was 31.35% strength increase of two layers GFRP converted column. In comparing with columns of control, there was 53.5% decrease in deviation of one-layer GFRP covered column and 64.68% in double layer GFRP covered column.

Kumutha et al. (2007) performed a study where they inspected the behavior of GFRP-strengthened rectangular columns under axial loads. The researchers used three different column edge proportions (sides being “a” and “b”, with an a/b ratio of 1.0, 1.25, and 1.66, respectively). GFRP wrapping was also performed in three different volumes (wrapping the columns with 1, 2, and 3 layers of GFRP sheets, respectively). The specimens were then subjected to axial loads until they failed, and the point at which they failed was recorded. The results clearly indicated that GFRP application greatly increased the compressive strength of the columns, and the confinement success increased as the number of GFRP layers increased. The increase in ductility was reflected as increased loading capacity, but the increase was more prominent in the columns with a/b ratio of 1.0 (square section columns), and got smaller as the a/b ratio increased. The results of the experiments in this study are indicative of a linear connection between the lateral confining pressure increase provided with GFRP and the increased quality (ductile and load properties) of columns[4].

A. N. Nayak, R. B. Swain, G. N. Prajapati and S. Swetapadma (2014) Examined the behavior of square R. C. columns of measure 750 × 150 × 150 mm retrofitted with Glass fiber reinforced polymer (GFRP) sheets. One column without GFRP and four columns complete wrapped with one, two, three and four layers of GFRP sheets have been tried for axial loading. The failure axial loads and failure modes of the columns have moreover been observed. Examined increment within the quality of retrofitted columns with regard to the column without GFRP in arrange to investigate the ideal utilize of GFRP for strengthening the R.C. columns. And proposed, an explanatory demonstrate of RC column retrofitted with externally bonded FRP. The test ultimate load carrying capacity of columns is additionally compared with that of the respective columns predicted from the present analytical model and literature. Comes about drawn that the strength has been upgraded up to 36% with retrofitting of as it were 3 layers of GFRP sheets. The axial strength of RC column retrofitted with GFRP sheets increments with increase in number of layer at first up to certain number of layer, at that point decreases with advance increment in number of layer of GFRP sheets. Subsequently, the greatest strength can be gotten with as it were ideal number of layers of GFRP sheets. Moreover, the failure mode changes with increment in number of layers of GFRP sheets beyond optimum number from tearing of GFRP sheets and splitting of concrete within the beat portion of column due to lateral pressure to smashing of concrete and tearing of GFRP sheets within the bottom portion of column due to bearing pressure[5].

Vasumathi et al. (2014) investigated the structural behaviors of reinforced concrete columns strengthened with external FRP sheets, in particular focusing on the applicability of CFRP materials in strip structure in enhancing fiber-reinforced RC columns. The CFRP strips were arranged in two different mesh compositions (one with 20 mm wide gap between strips, and the with 30 mm gap wide). Different columns were then strengthened using one, two, or three layers of CFRP material in one of the arranged mesh formations. The results show that such an application of CFRP strips were capable of preventing any lateral extension of the RC blocks, resulting in an overall increase in column stiffness. On average, columns were found to have an increase in axial deformation resistance of 198.87% and a total 91.75% increase in overall strength, compared to reference columns. 20 mm gap strip formation was found to have increased effect, compared to the 30 mm strip formation. The increase in ductile resistance was also found to increase as the number of CFRP layers increased[6].

2. EXPERIMENTAL WORK

2.1 Materials

The concrete mixes prepared as part of this study were prepared using ordinary Portland cement (in accordance with ASTM C150), fine aggregate (Sand, natural; in accordance with ASTM C33), coarse aggregate (gravel, natural; largest grain 9.5mm; in accordance with ASTM C33), water (tap water), E-Glass fiber polymer (GFRP) sheets (unilateral, with 1.016mm thickness for each layer, modulus of elasticity 26 GPa ,Tensile strength 612 MPa) and deformed

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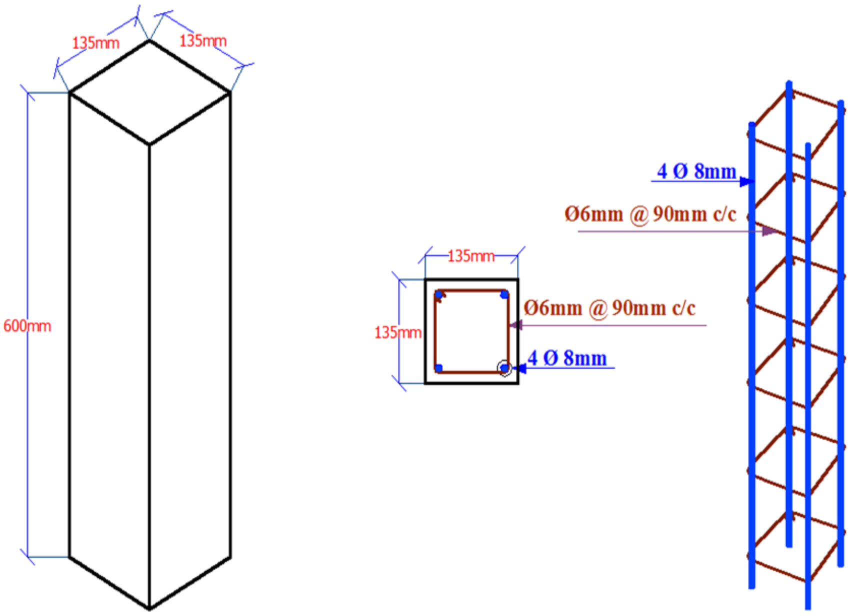
steel bars (ø8mm) to provide longitudinal support for the columns, and (ø6mm) steel bars used as ties for the support columns. The properties of the reinforcing steel used are given in Table 1.

Table (1): Details of steel Reinforcement

Diameter of steel (mm)	Yield strength fy (MPa)	Ultimate Strength fu (MPa)
6	480	600
8	430	630

2.2 Properties of the Columns

A total of 13 columns were prepared as part of the experimental section of the study, and the properties of these columns can be seen in Fig. 1. All of the columns are in square-section shape, and all have 135 mm long edges on all four sides. The columns were cast in 600 mm height, which were then fitted with steel plates at each end to prevent any uneven load point damage. These columns were then strengthened using different formations of FRP sheets and strips. Any central deflection occurring in the columns were detected using dial gauges, and the strain on the central fibers were measured using strain gauges. Fig. 1. Provides in-depth presentation regarding the geometric layout of the columns and reinforcement sheets.



a. Cross-Section Details of columns

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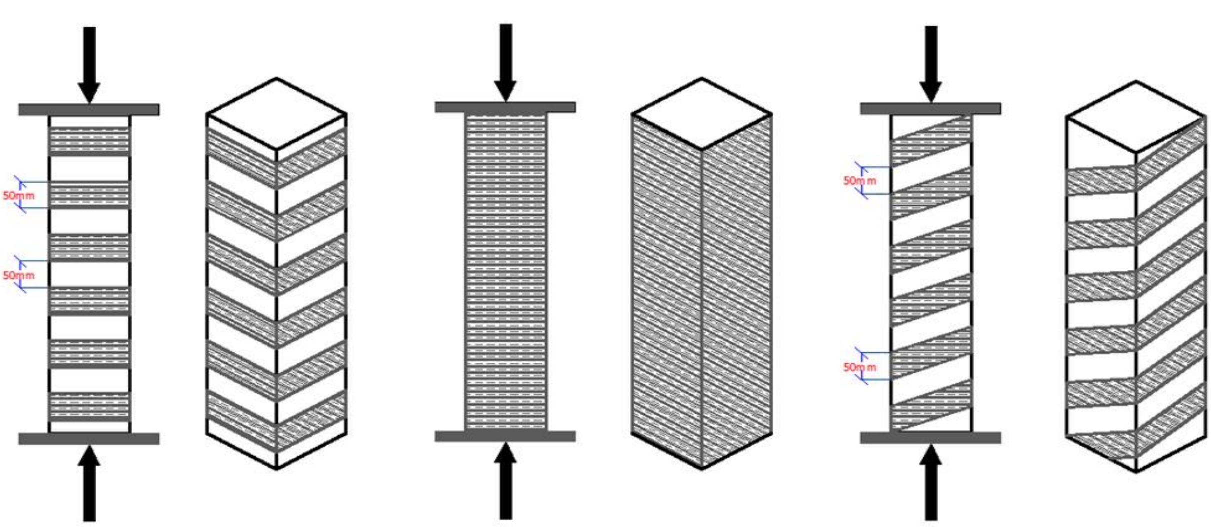

b. Details of the columns with confinements

Fig. (1): Details of the columns

2.3 Column classification

As can be seen in Table 2, the columns used in tests were grouped in four different categories. While each group has the same cross section and height, different number of FRP materials and application methods were used on them. The details for these groups are as follows:

Group1 consists of 4 square columns. one column was not strengthened, the second column was fully strengthened using GFRP sheets, third column was strengthened using GFRP strips, and the fourth column was strengthened using the GFRP strips in a spiraling mesh formation. Group 2 consists of a total of 3 samples. One sample was strengthened using two layers of GFRP sheets, the second was strengthened using two layers of strip mesh, and the third was strengthened using two layers of spiraling GFRP mesh formation. Group 3 consists of 3 columns, and the only difference with the Group 2 columns is that they have another layer of GFRP material (1 x triple GFRP sheet, 1 x triple GFRP strip mesh, 1 x triple spiraling GFRP strip mesh). Group 4, is the same with Group 3, except another layer was added on top of the existing setups (1 x quadruple GFRP sheet, 1 x quadruple GFRP strip mesh, 1 x quadruple spiraling GFRP strip mesh).

Table (2): Details of the tested columns

Group Name	Specimen Abb.	Specimen Condition	Compressive Strength of Concrete f'c (Mpa)	FRP sheet ratio ρ_f
G1	UCC	UnStrengthened Control Specimen	30	0
	GF1	Strengthened with **one layer GFRP** Sheets Fully Wrapped		0.03010
	GT1	Strengthened with **one layer GFRP** Sheets with Strip Ties		0.01505
	GS1	Strengthened with **one layer GFRP** Sheets Spirally		0.01505
G2	GF2	Strengthened with **two layer GFRP** Sheets Fully Wrapped	30	0.06021
	GT2	Strengthened with **two layer GFRP** Sheets with Strip Ties		0.03010
	GS2	Strengthened with **two layer GFRP** Sheets Spirally		0.03010
G3	GF3	Strengthened with **three layer GFRP** Sheets Fully Wrapped	30	0.09031

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	GT3	Strengthened with **three layer GFRP** Sheets with Strip Ties		0.04516
	GS3	Strengthened with **three layer GFRP** Sheets Spirally		0.04516
G4	GF4	Strengthened with **four layer GFRP** Sheets Fully Wrapped	30	0.12041
	GT4	Strengthened with **four layer GFRP** Sheets with Strip Ties		0.06021
	GS4	Strengthened with **four layer GFRP** Sheets Spirally		0.06021

3. RESULTS AND DISCUSSION

3.1 Load deflection

Fig. 2 represents the load deflection curves for the column samples at their central cores. These curves provide useful information regarding how a column is expected to behave under load. Any column that has not been confined (ie. strengthened with an outside layer/mesh) goes through two steps as the load on top of it increases: The initial step consists of a linear slope phase and lasts as long as there are no cracks on the column. As soon as a crack occurs, however, the second step starts where the slope suddenly changes as the crack quickly carries the column to failure. Any column strengthened using FRP sheets or mesh, however, gains an additional step following the initial two, as the column has to go through an additional phase until its outer enhancements also give way to the load.

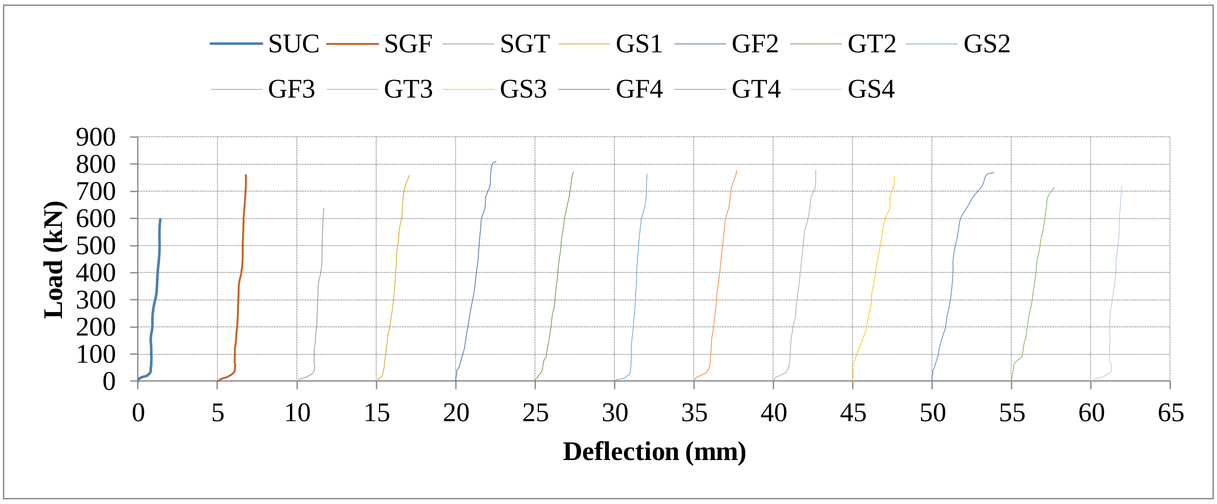

Fig. (2): Load-deflection curves for columns

3.2 Modes of Failure

Figure 3 represents a collection of different failure patterns for different types of GFRP-strengthened columns. As can be seen, all of the columns –with the exception of the sample that wasn't strengthened- reached failure with a rupture of the GFRP material where the hoop tension reached critical at some point. The column without GFRP strengthening can be seen to have cracked more violently, compared to its strengthened counterparts, as the concrete was crushed and the cracks reached both sides of the column.

Even a single layer of GFRP was found to result in greatly enhanced axial load resistance, compared to the sample with no strengthening. The cracks that occurred during the load were accompanied by snapping sounds. The fully-wrapped sample failed through the cracks that were close to one of its ends, where the GFRP material was also deformed and ruptured (Fig. 3). Some amount of debonding was also observed in various columns with fully wrapped GFRP sheets.

The failures that occurred in columns with mesh or spiral mesh GFRP strengthening occurred in the gaps between the GFRP strips. Interestingly, the orientations of the cracks were almost universally parallel to the GFRP strip orientation.

The columns with 2 or 3 GFRP sheets seem

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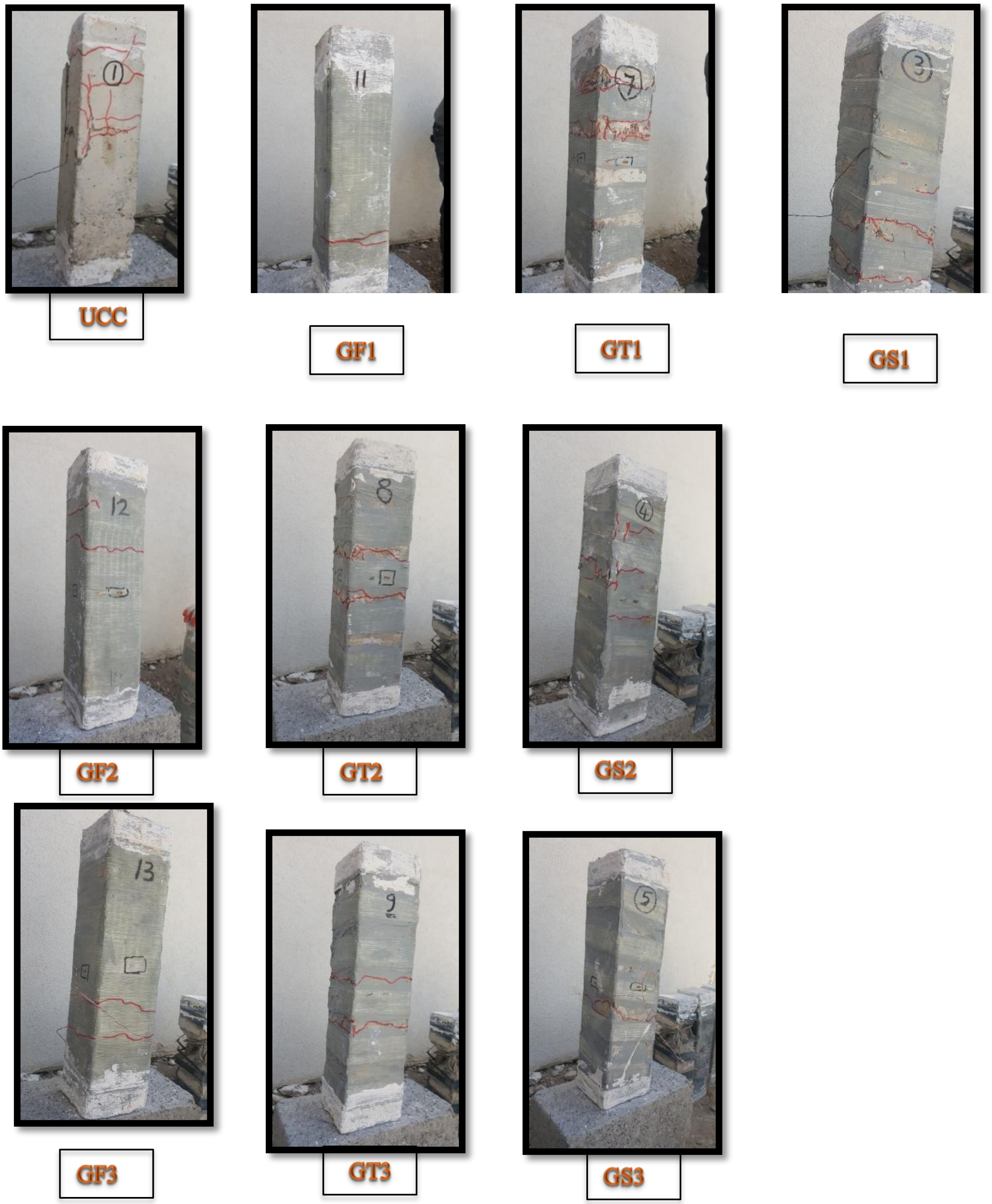
to have similar crack patterns to their counterparts with only one layer of GFRP, but the loading point at which the cracks occurred was much higher.



UCC GF1 GT1 GS1

GF2 GT2 GS2

GF3 GT3 GS3

Fig. (3): Crack Pattern and Mode of Failures

3.3 Load capacity of the sample columns

Fig. 4. Represents the data regarding the load capacity of the samples, and Table 3 shows failure strain values of the samples and FRP materials.

3.3.1 Effects of different strengthening methods

A total of three different strengthening

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methods were used as part of this study, which were full wrapping, strip meshing, and spiral strip meshing. The changes in load capacity of the strengthened columns compared to their non-strengthened counterpart are explained below:

- For a single GFRP sheets used in wrap, mesh, and spiral mesh formation, the load capacity (Pu) of the sample columns have increased by 25.46%, 6.70% and 29.48 %, respectively.
- For double GFRP sheets used in wrap, mesh, and spiral mesh formation, the load capacity (Pu) of the sample columns have increased by 36.52%, 19.60% and 29.82 %, respectively.
- For triple GFRP sheets used in wrap, mesh, and spiral mesh formation, the load capacity (Pu) of the sample columns have increased by 38.19%, 20.10% and 30.65 %, respectively.
- For quadruple GFRP sheets used in wrap, mesh, and spiral mesh formation, the load capacity (Pu) of the sample columns have increased by 43.22%, 29.15% and 33.17 %, respectively.

These results show that the greatest increase in load capacity was achieved through full-wrap application of GFRP material, while the strip mesh formation yielded the smallest amount of increase.

3.3.2 Effects of different number of GFRP layers

The samples in this study were applied one, two, three, or four layers of GFRP material, and the changes that happened in carrying capacity of the columns for these applications are clarified shown below:

For the full-wrap application, going from a single layer up to two, three, and four layers of GFRP sheets results in a relative load capacity increase of 8.81%, 10.15% and 14.15%, respectively.

- For the strip mesh formation application, going from a single layer up to two, three, and four layers of GFRP strips results in a relative load capacity increase of 12.09%, 12.56% and 21.04%, respectively.
- For the spiral strip mesh formation application, going from a single layer up to two, three, and four layers of GFRP strips results in a relative load capacity increase of 0.26%, 0.26% and 2.85% respectively.

These results show that increasing the number of GFRP material layers results in increased load capacity. In strip mesh formation, increasing the number of layers from 2 to 3 seems to have minimal effect, while the spiral strip formation seems to have very little gain in terms of load capacity, even when going from a single layer to four layers.

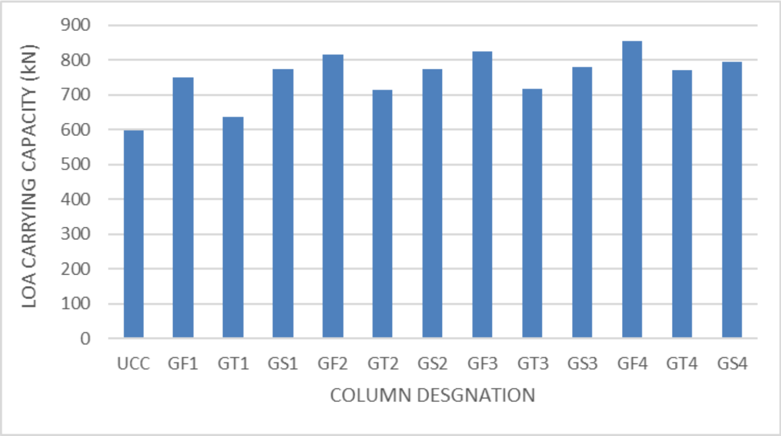

Fig. (4): Load carrying capacity of specimens

3.4 Strain points for FRP sheets

As expected, the application of GFRP materials in total wrap or in strip formation greatly increases the axial deformation resistance of the columns, thanks to the additional restraining effect that improves the bending stress endurance of the samples. Table 3 shows failure strain points for FRP sheets. Examining

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this table, it is evident that the maximum strains achieved for single-layer full-wrap, strip mesh, and spiral strip mesh GFRP applications were 0.01813, 0.02054, and 0.02370, respectively. The maximum strains achieved for double-layer full-wrap, strip mesh, and spiral strip mesh GFRP applications were 0.01808, 0.02135 and 0.01788, respectively. For the triple-layer full-wrap, strip mesh, and spiral strip mesh GFRP applications, the maximum strain points achieved were 0.01425, 0.01738, and 0.02236, respectively. Finally, the maximum strains achieved for quadruple-layer full-wrap, strip mesh, and spiral strip mesh GFRP applications were 0.01756, 0.02728, and 0.02587, respectively.

Table (3): Strains of GFRP sheets at failure load

No.	Samples Abb.	Load of Failure (kN)	Strain at failure of GFRP
1	UCC	597	-
2	GF1	749	0.01813
3	GT1	637	0.02054
4	GS1	773	0.02370
5	GF2	815	0.01808
6	GT2	714	0.02135
7	GS2	775	0.01788
8	GF3	825	0.01425
9	GT3	717	0.01738
10	GS3	780	0.02236
11	GF4	855	0.01756
12	GT4	771	0.02728
13	GS4	795	0.02587

3.5 Comparison of the Findings with the Proposed Equation of ACI 440.2R-02

The results obtained as part of the experimental section of this study were compared with the proposed ACI equations (ACI 440.2R-02 for confined specimens, ACI 318 for unconfined specimens). Table 4 shows comparison of these values, and it is evident that the ACI equation is more conservative in terms of predicting the failure point for the load, where the Pexp/Pcal is greater than 1. The only exception is for three layers GF3, GT3 and four layer GFRP application of GF4, GT4 and GS4. Figure 5 shows the experimental and equation-prediction values on the same chart, and it is evident here that the lower bound accuracy of the equation is higher, indicating that the equation has an acceptable performance in predicting the properties of one or two layer GFRP sheet applications.

Table (4): Experimental and theoretical failure load

No.	Sample Abb.	Experimental failure load, Pexp, (kN)	Theoretical failure load, Pcal, (kN)	P_{exp}/P_{cal}
1	UCC	597	469.31	1.27
2	GF1	749	661.21	1.13

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3	GT1	637	565.97	1.13
4	GS1	773	565.97	1.37
5	GF2	815	812.87	1.00
6	GT2	714	661.21	1.08
7	GS2	775	661.21	1.17
8	GF3	825	931.38	0.89
9	GT3	717	742.26	0.97
10	GS3	780	742.26	1.05
11	GF4	855	1028.05	0.83
12	GT4	771	812.87	0.95
13	GS4	795	812.87	0.98

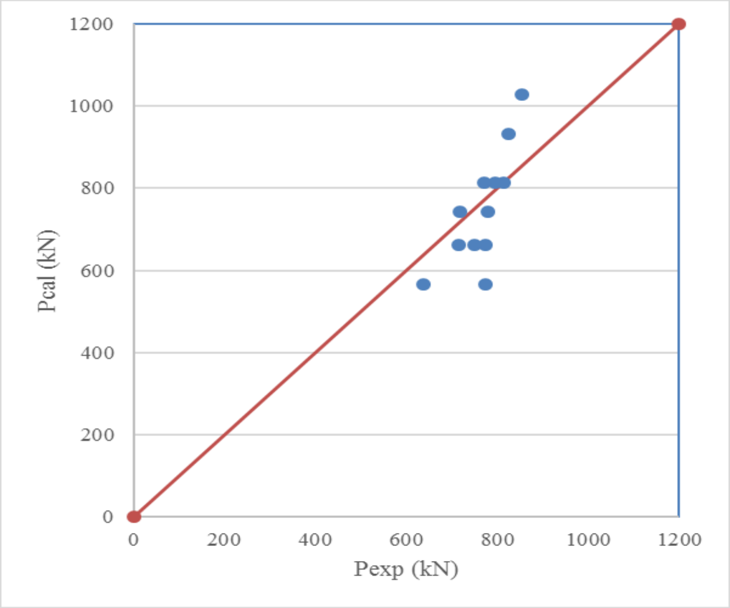

Fig. (5): Experimental and calculated loads

4. CONCLUSIONS

In this study tested square columns under compression load, confined by various layers of GFRP and different method of confinement the following conclusions can be concluded:

1- It is interesting to note that by one layer of GFRP sheet will enhancement the load carrying capacity of columns in different methods of Strengthening (fully warped, strip ties and spirally) by 25.5%, 6.7% and 29.5% respectively compared to the reference column. However, for two layers of Strengthen of GFRP sheets the load capacity increasing for Strengthen (fully warped, strip ties and spirally) by 36.5%, 19.6% and 29.8% respectively. While, for three layers of Strengthen the load carrying capacity increasing by 38.2%, 20.1% and 30.7% respectively. Finally, for four layers of Strengthen the load carrying capacity increasing by 43.2%, 29.2% and 33.2% respectively.

2-The results pointed that the percentage of increase in load carrying capacity increased by increasing number of layers for (fully wrapped) by 8.81%, 10.15% and 14.15% for two, three and four layers respectively compared with one layer columns.

3-It can be concluded by increasing the number of layers for fully wrapped the load carrying capacity increases. The load carrying capacity increases for column strengthened by four-layer strip ties while same load carrying capacity

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obtained for two and three layers. No significant rate of increase obtained by increasing number of layers from one to 4 layers for spiral method of Strengthening.

4-The ACI 440.2R-02 equation for strengthened columns can predict the ultimate load safely for square columns strengthened by one and two layer of GFRP sheets, while the percentage of Pexp/Pcal less than 1 for three and four layers, which mean that ACI 440.2R-02 equation isn't conservative for more than three layers.

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