Strengthening Of Short R.C. Columns By FRP Jackets

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Abstract:-Strengthening of R.C columns using the fiber reinforced polymers materials is the most important rehabilitation processes. This technique may view as an elective solution for the customary material for reinforcing of concrete structures. Experimental study is designed to test six specimens strengthen with FRP and compare with numerical results of specimens by a finite element models. The tested columns were categorized into two groups based on the column shape. The first contains three circular columns with 200 mm diameter and the second contains three square columns with200 mm length; control specimen, specimen partially strengthened by glass fiber reinforced polymers strip and specimen totally strengthened by glass fiber reinforced polymers sheet. Each column is 1000 mm high, 4ø12mm reinforcement, and ø6@200 mm stirrups. ABAQUS is used to make 18 specimens' numerical model. Both experimental and numerical analyses demonstrate that externally restricted FRP sheets are significant in improving the strength and ductility of the short concrete columns. A design equation is proposed to calculate the ultimate axial load for short concrete columns strengthening by GFRP total wrap.

Keywords-GFRP, ABAQUS, Short Reinforced Concrete Columns, Strengthening, Ductility

I. INTRODUCTION

Strengthening concrete structures restricted by FRP jackets was developed as alternates to traditional techniques like steel and concrete jackets. Many studies studied behavior of concrete structures restricted by FRP jackets. For example, Esfahani, et al. (2005) tested specimens strengthened with FRP wrap under axial compressive loading. The experimental programs include circular and square columns. The study concluded that the strength of columns with sharp square corners by utilizing FRP wrap is non-significant, while; the strength of circular columns increased by utilizing FRP wrap, and the square column with sharp corners exhibited a lower strength and ductility compared to those with rounded corners [2]. Chastre, C. et. al. (2010) presented monotonic axial behavior and modeling of RC circular columns obligated by CFRP. The experimental program included 25 reinforced concrete columns restricted by CFRP composites. Variables parameters of the columns were; the diameter of the columns, the type of material (plain or reinforced concrete), the steel hoop spacing of the RC columns and the number of CFRP layers. Predictive equations, based on the experimental analysis, were proposed to estimate the compressive strength of the confined concrete, the maximum axial load and the axial or the lateral failure strain of circular RC columns jacketed with CFRP. The conclusions of this study were the models with smaller diameter was significant of compression strength when compared with larger ones, the two different types of CFRP used reveal a good performance, the compressive strength of the concrete columns increased with increase in the number of plies of CFRP. Cui, C. et. Al. (2010) presented analytical model for circular normal-and high-strength concrete columns confined with FRP. The compressive concrete strength with a wide range of (25–110) MPa, was based on material properties, force equilibrium, and strain compatibility, and used FRP jacket. The conclusions of this study were very good to excellent agreements have been achieved between the analytical and experimental responses; the post peak behavior of the FRP-confined concrete was controlled by the section. Sangeetha, P. et al.(2010) presented the behavior concrete circular columns strengthened with GFRP wrap under uniaxial compression. The cross section of the concrete columns was diameter of150mm and height 300mm. The conclusions of this study were strength and ductility of the concrete column increased by using GFRP wrap, the compressive strength of the concrete columns increased with increase in the number of plies of GFRP, and the load carrying capacity of columns increased with increasing the period of curing. Silva, M.A.G. et al. (2011) presented behavior of square and circular columns strengthened with aramidic or carbon fibers. This study was performed on axially loaded RC columns, with and without jackets. The FRP tested were made either of carbon fibers reinforced polymers (CFRP) or aramidic (AFRP) wraps and the geometry of the specimens included square and circular cross-sections. The conclusions of this study were the improvement of appliedload capacity gained, either from jackets of AFRP, or CFRP was almost equal for cylindrical columns, columns of square section and sharp corners evidenced no improvement of capacity, nor ductility from being confined with CFRP jackets, columns of square section and sharp corners evidenced no improvement of capacity, nor ductility from being confined with AFRP jackets. Taghia, P. et al. (2013) presented behavior of confined circular reinforced concrete-CFRP sheets short columns under pure axial static load. ABAQUS/CAE software is used to analyze the circular reinforced concrete short column wrapped by CFRP and the

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finite element analysis results is compared to experimental results obtained from existing literature. The conclusions of this study were CFRP sheets were very effective in enhancing the applied strength and ductility of the concrete short columns, the increasing of number of CFRP sheets was more effective for ultimate strain and stress, the confinement effectiveness decreased when the column size is increased, and the lower concrete strength has a better performance respect to confinement behavior when the volumetric ratio is constant. Kabashi, N., et al. (2014) displayed behavior of confined reinforced square and circular columns strengthening by CFRP jackets under pure axial static load. The experimental program included 3 circular and 3 square columns with sharp corners. The square column specimens were tested in two different strengthening ways: full wrapped and stirrups wrapped. The circular column specimens were tested in one strengthening ways only (full wrapped). The tested specimens were wrapped using one layer of CFRP, but in analytical analyzing were presented also for more layers. The conclusions of this study were CFRP sheets were very effective in enhancing the axial strength and ductility of the concrete short circular columns, the main strengthening factor was rounded the edges so the results of strengthening fully and partially wrapped was similar. Cao Y. G., et al. (2016) presented unified stress-strain model with different cross-sectional concrete columns confined by FRP. The cross sections included circular, square, rectangular and elliptical concrete. In this study, unified stress-strain model with different cross sectional concrete columns confined by FRP was developed based on a database from the research already exists that included the behavior of circular, square, rectangular and elliptical concrete columns confined by FRP jackets. Using the database, the existing analytical models were evaluated. In the model calculations, the elliptical cross-section can be considered as a rectangular one with a special corner radius. A simple and accurate model of the equivalent corner radius ratio for elliptical columns was proposed. The conclusions of this study were the elliptical cross-section transformed to a rectangular cross-section using equivalent corner radius ratio (2re/b), and the proposed model has better performance of ultimate stress and strain compared to test data[10,11,12,13,14,15,16]. The objective of this research is to investigate the behavior of short reinforced concrete columns wrapped with FRP jackets.

II. EXPERIMENTAL PROGRAM

The experimental program studies the strengthening of short reinforced concrete columns with different cross sections by GFRP jackets. It consists of two groups according to the cross section; each of group is divided to control specimen, specimen wrapped by GFRP strips and specimen total wrapped by GFRP sheet. The two control specimens are tested to evaluate the material properties of the concrete and the longitudinal and transverse steel reinforcement. The variables of the experimental program are:

1) The cross section shapes.

a) Circular cross section with diameter 200mm.

b) Square cross section (200x200mm).

2) The strengthening technique.

a) Strips wrapped: GFRP strip width 10cm with clear spaces 8cm are installed for the total height of the column.

b) Total wrapped: GFRP sheets are used for the total height of the column.

Details of the specimens are described as shown in Table 1 and Figure 1-3.

Note: the first part means the cross section (Circular and Square), the second part means the strengthening technique (Control, Strips wrapped, and Total wrapped), and the last part means the FRP type (GFRP).

Table 1.Details of tested Specimens.

Columns	Dimension (mm2)	Fcu	RFT	Stirrups	RFT and Stirrup (%)	Strengthening Technique	GFRP (%)
CCG	Diameter 200	26.1 MPa	4ø12	5ø6/m`	1.368 and 0.254	Control	-
CSG						Strips wrapped	0.204
CTG						Total wrapped	0.34
SCG	200x200	26.1 MPa	4ø12	5ø6/m`	1.074 and 0.254	Control	-
SSG						Strips wrapped	0.204
STG						Total wrapped	0.34

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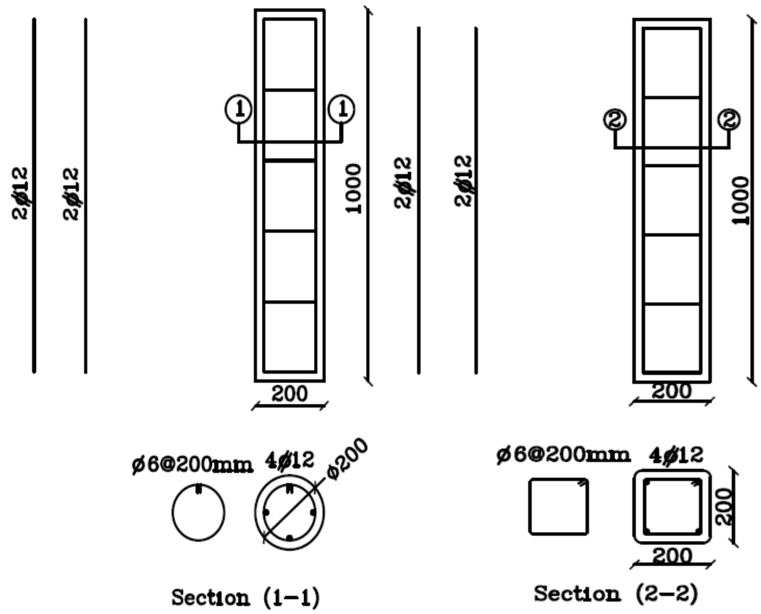


a) Circular b) Square

Figure 1.Details of different cross section.

Figure 2. Test set up and shape of failure of circular specimens.

Figure 3. Test setup and shape of failure of square specimens.

III. NUMERICAL ANALYSIS

3.1 Material modeling

The material properties are taken from the experimental study. The material properties, which concrete column, steel reinforcement and FRP sheets, are simulated using ABAQUS program[17].

3.1.1 Concrete column modeling

The behavior of concrete model represented as concrete damaged plasticity. This model considers the main two failure modes of the concrete are tensile cracking and compressive crushing (ABAQUS manual 6.13). The elastic parameters such as: Young's modulus of concrete and Poisson's ratio are inputted. A Poisson's ratio of concrete is 0.2. Concrete is modeled using a solid four-node element (C3D8R) with linear reduced Gauss integration points.

3.1.2 Steel reinforcement modeling

The behavior of the steel reinforcement represented as elastic-perfectly plastic. A Poisson's ratio for the steel reinforcement is 0.3.The transverse and longitudinal reinforcements are modeled with two-node truss (T3D2).

3.1.3 FRP sheets modeling

FRP sheets are modeled using lamina option available in ABAQUS to simulate the behavior of FRP in 3D. FRP sheets are modeled with four-node shell elements (S4R). The stress-strain relationship of the FRP sheets is linearly elastic up to failure. Sika Wrap Hex-430G is used. It is E-Glass fabric of 0.172 mm fiber thickness, 2300 MPa fiber tensile strength and the modulus of elasticity is 76000 MPa.

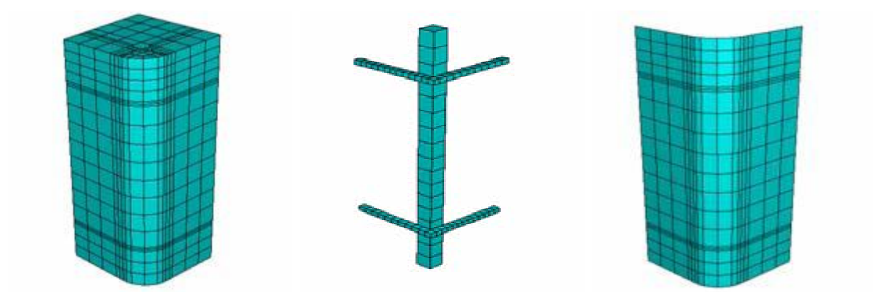
Sikadur-330 adhesive is used to bond external GFRP laminates to concrete surface. The flexural modulus, tensile modulus, tensile strength, and bond strength to concrete of resin are 3800,4500, 30, and 4 MPa, respectively.

3.2 Element modeling

The width and length of elements in the steel plates are set to be consistent with the elements and nodes in the concrete column model. A rectangular mesh is used to obtain good results. Therefore, the mesh is represented as a square or rectangular elements. The type of mesh selected for the concrete column and the loading plates is structured. The mesh element for concrete column is 3D solid which is called C3D8R. The meshing of the steel reinforcement is a special case compared to the volumes. The mesh element for the steel reinforcement is 2D truss which is called T3D2, and for FRP sheets are shell which are called S4RTable 2 and Figure 4.

Table 2.Element Types of Working Model.

Material Type	ABAQUS Element
Concrete	C3D8R
Steel Reinforcement	T3D2
FRP Sheets	S4R



(a) (b) (c)

Figure 4.Mesh of the parts of the reinforced concrete column (a) concrete, (b) steel reinforcement and (c) FRP jacket.

3.3 Bond between concrete column, reinforcement steel and FRP sheets

Tie (constrains) and surface to surface contact is used only to define the contact between concrete column and FRP sheet. Embedded region (constrains) is used only to define the contact between concrete column and steel reinforcement.

3.4 Load and boundary conditions

To ensure that the model acts the same way as the experimental model, boundary conditions need to be applied at supports and loading exist Figure 5.The support is modeled as fixed at bottom of the model. The loading is represented as axial deflection. The axial deflection is acted at the center of top steel plate of the model.

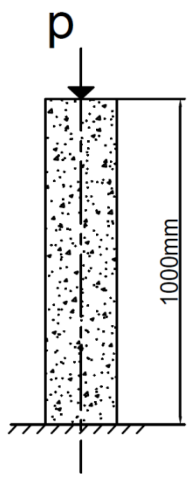
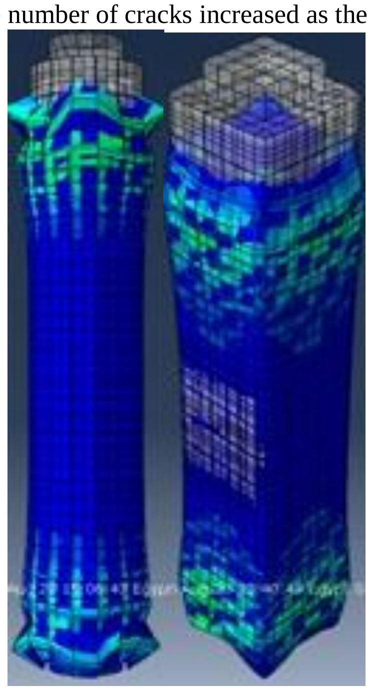


Figure 5.Boundary Condition at Bottom and Top Side.

3.5 Cracks Pattern

In all cases, the failure of the jacketed columns related directly to the rupture of the FRP jacket. The cracks appeared in the top and bottom of the columns, the number of cracks increased as the load increased Figure 6.



(a) (b)

Figure 6.Cracks Pattern at Ultimate Load for (a) Circular Models (b) Square Models.

IV. RESULTS AND DISCUSSION

4.1 Verification of the Nonlinear Finite Element Modeling

Numerical model by nonlinear finite element analysis program ABAQUS is used to verify the results of experimental program. Their results are compared to those obtained experimentally to check the validity of the finite element modeling as shown in Table 3, Figure 7-9. Then 18-specimens numerical model used to study the following parameters

1) Column cross-section shape

a) Circular cross section with 200-mm diameter; and b) Square cross section (200x200 mm).

2) Strengthening technique:

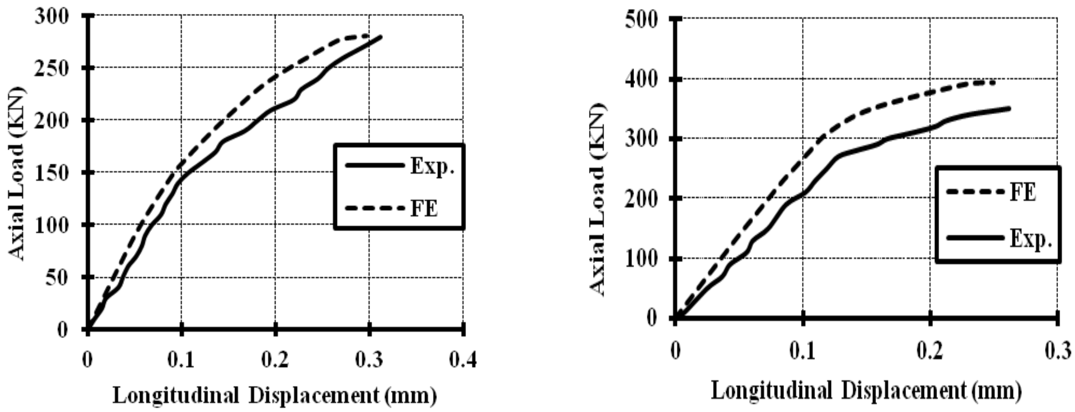
a) Wrapped strips by GFRP strip, and b) Total wrapped by GFRP sheet.

3) Characteristic strength of concrete

a) Fcu = 25 MPa, b) Fcu =35 MPa, and c) Fcu =45 MPa.

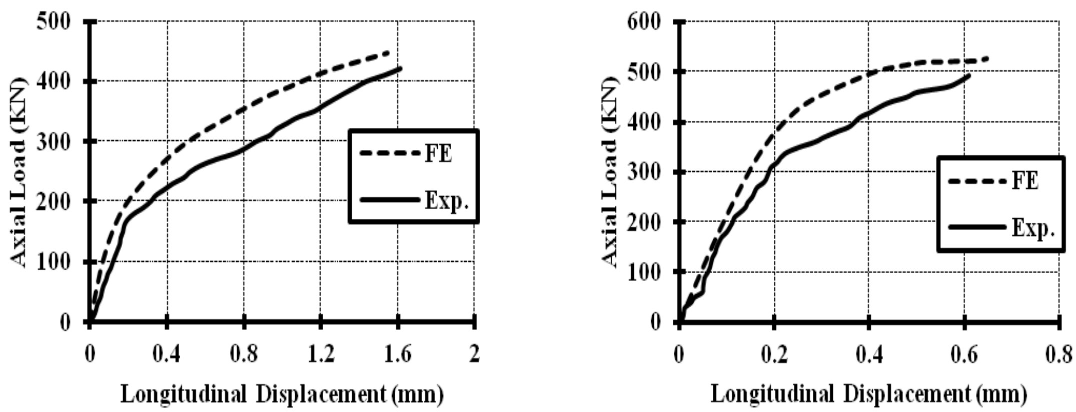
Table 3.Strain and Axial Load of Experimental and Finite Element Modes Results.

Experimental Models			Finite Element Models			Difference %	
Models	Pmax (KN)	Δ (mm)	Models	Pmax (KN)	Δ (mm)	Pmax%	Δ (mm)
CC	281	0.312	CC25	280.55	0.297	0.16	5.05
CSG	421	1.61	CSG25	447.47	1.546	6.29	4.14
CTG	470	1.754	CTG25	505.29	1.696	7.51	3.41
SC	350	0.262	SC25	393.98	0.25	12.56	4.96
SSG	493	0.61	SSG25	526.86	0.647	6.87	6.07
STG	541	1.44	STG25	546.86	1.4	1.27	2.78



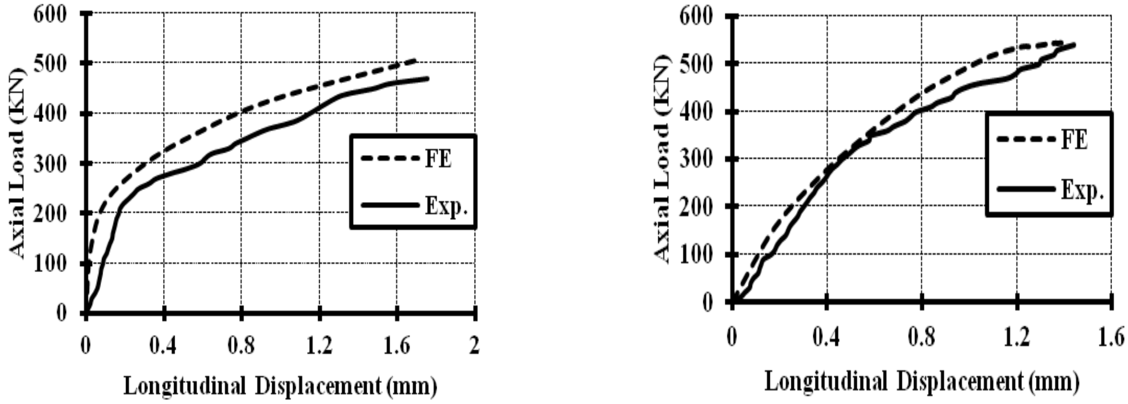
a. Circular models. b. Square models.

Figure 7. Load – Displacement of experimental & numerical results of control models



a. Circular models. b. Square models.

Figure 8. Load– Displacement of experimental & numerical results of specimens wrapped by GFRP strips



a. Circular models. b. Square models.

Figure 9. Load – Displacement of experimental & numerical results of specimens total wrapped by GFRP sheet

4.2 Numerical Results

4.2.1 Column cross-section shape

Table (4); for circular and square cross sections, GFRP strip wrapped models and Fcu=25 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 521% and 160% respectively for circular cross section and 237% and 134% respectively for square cross section. Figure 10 shows the comparison between ductility and applied load for circular and square, with GFRP strips wrapped models and Fcu=25 MPa. The circular with GFRP strips wrapped cross section is more significant than the square with GFRP strips wrapped cross section in ductility and applied load.

Table (4); for circular and square cross sections, GFRP total wrapped models and Fcu=25 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 571% and 180% respectively for circular cross section and 514% and 139% respectively for square cross section. Figure 11 shows the comparison between ductility and applied load for circular and square, with GFRP total wrapped models and Fcu = 25 MPa. The circular with GFRP total wrapped cross section is more significant than the square with GFRP total wrapped cross section in ductility and applied load.

Table (4); for circular and square cross sections, GFRP strip wrapped models and Fcu=35 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 432% and 134% respectively for circular cross section and 191% and 122% respectively for square cross section. Figure 12 shows the comparison between ductility and applied load for circular and square, with GFRP strips wrapped models and Fcu = 35 MPa. The circular with GFRP strips wrapped cross section is more significant than the square with GFRP strips wrapped cross section in ductility and applied load.

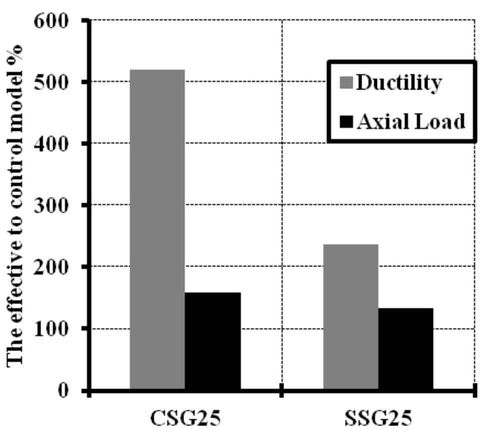
Table (4); for circular and square cross sections, GFRP total wrapped models and Fcu=35 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 457% and 147% respectively for circular cross section and 375% and 130% respectively for square cross section. Figure 13 shows the comparison between ductility and applied load for circular and square, with GFRP total wrapped models and Fcu = 35 MPa. The circular with GFRP total wrapped cross section is more significant than the square with GFRP total wrapped cross section in ductility and applied load.

Table (4); for circular and square cross sections, GFRP strip wrapped models and Fcu=45 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 394% and 125% respectively for circular cross section and 135% and 107% respectively for square cross section. Figure 14 shows the comparison betweenductility and applied load for circular and square, with GFRP strips wrapped models and Fcu = 45 MPa. The circular with GFRP strips wrapped cross section is more significant than the square with GFRP strips wrapped cross section in ductility and applied load.

Table (4); for circular and square cross sections, GFRP total wrapped models and Fcu=45 MPa, It is found that enhancement of ductility and applied load of tested models to control models is 446% and 141% respectively for circular cross section and 227% and 111% respectively for square cross section. Figure 15 shows the comparison between ductility and applied load for circular and square, with GFRP total wrapped models and Fcu = 45 MPa. The circular with GFRP total wrapped cross section is more significant than the square with GFRP total wrapped cross section in ductility and applied load.

Table 4.Strain and Axial Load Finite Element Models.

Models	Pmax(KN)	Δ (mm)	Strengthening Effect %		Failure Modes
			Axial Load	Ductility	
CC25	280.557	0.297	-	-	Compression Failure
CSG25	447.467	1.546	160	521	Rupture of GFRP Sheets
CTG25	505.297	1.696	180	571	Rupture of GFRP Sheets
CC35	475.495	0.406	-	-	Compression Failure
CSG35	638.764	1.752	134	432	Rupture of GFRP Sheets
CTG35	698.420	1.854	147	457	Rupture of GFRP Sheets
CC45	616.026	0.429	-	-	Compression Failure
CSG45	767.301	1.654	125	394	Rupture of GFRP Sheets
CTG45	867.468	1.875	141	446	Rupture of GFRP Sheets
SC25	393.980	0.25	-	-	Compression Failure
SSG25	526.860	0.647	134	237	Rupture of GFRP Sheets
STG25	546.865	1.4	139	514	Rupture of GFRP Sheets
SC35	622.540	0.429	-	-	Compression Failure
SSG35	759.268	0.817	122	191	Rupture of GFRP Sheets
STG35	806.74	1.61	130	375	Rupture of GFRP Sheets
SC45	943.401	0.728	-	-	Compression Failure
SSG45	1006.300	0.983	107	135	Rupture of GFRP Sheets
STG45	1047.700	1.637	111	227	Rupture of GFRP Sheets



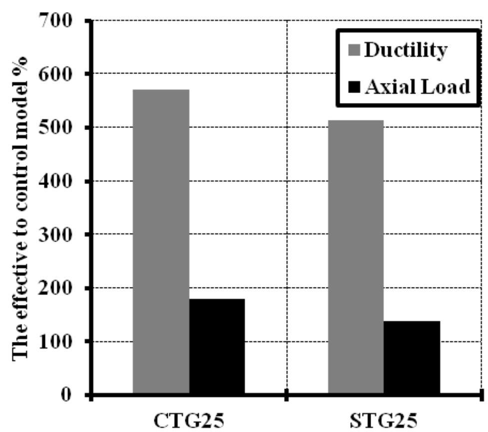
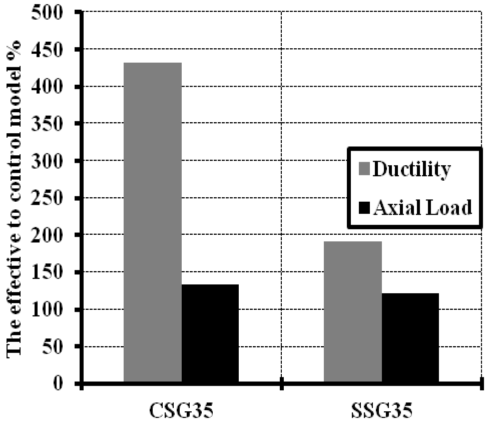


Figure 11. Cross section shapes of total wrapped models and Fcu= 25 MPa.

Figure 10. Cross section shapes with strips wrapped models and Fcu= 25 MPa.



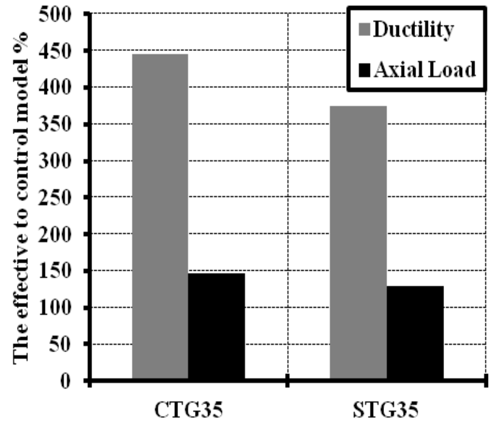
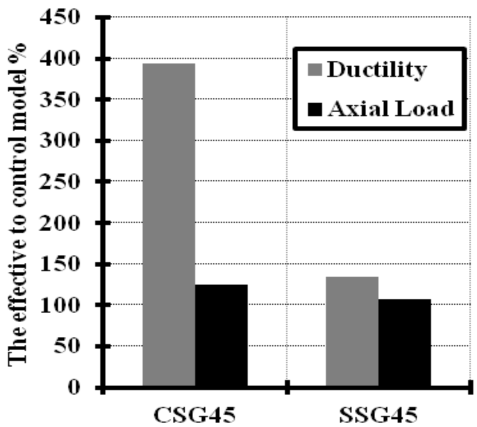


Figure 13. Cross section shapes of total wrapped models and Fcu= 35 MPa.

Figure 12. Cross section shapes with strips wrapped models and Fcu= 35 MPa.



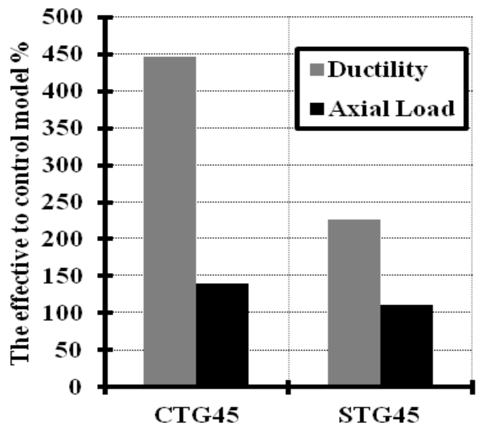


Figure 15. Cross section shapes of total wrapped models and Fcu= 45 MPa.

Figure 14. Cross section shapes with strips wrapped models and Fcu= 45 MPa

4.2.2 Strengthening technique

Table (4) and Figure 16 (a) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped circular cross sections with Fcu=25 MPa. It is found that applied load and ductility enhancement of tested models is 160% and 521% respectively for strips wrapped cross section, and 180% and 571% respectively for total wrapped cross section to control models.

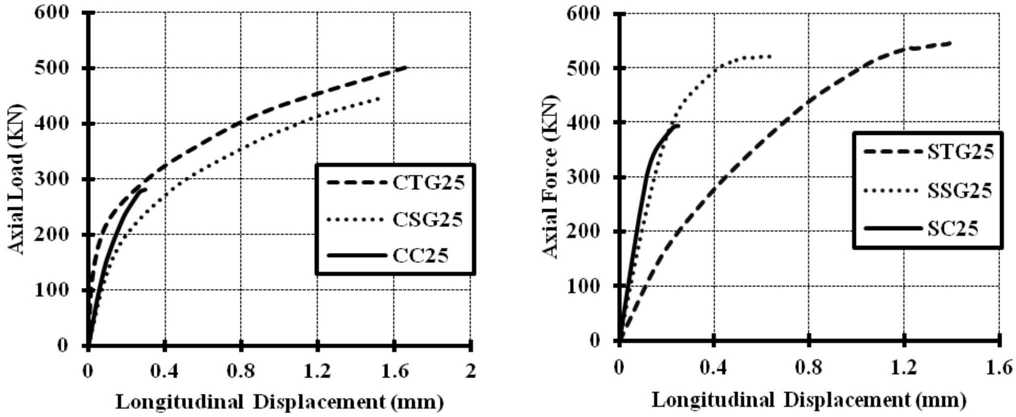
Table (4) and Figure 16 (b) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped square cross sections with Fcu=25 MPa. It is found that applied load and ductility enhancement of tested models is 134% and 237% respectively for strips wrapped cross section, and 139% and 514% respectively for total wrapped cross section to control models.

Total wrapped of circular and square cross sections is more significant than strips wrapped cross section in applied load and ductility as shown in Figure 16.

Table (4) and Figure 17 (a) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped circular cross sections with Fcu=35 MPa. It is found that applied load and ductility enhancement of tested models is 134% and 432% respectively for strips wrapped cross section, and 147% and 457% respectively for total wrapped cross section to control models. Table (4) and Figure 17 (b) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped square cross sections with Fcu=35 MPa. It is found that applied load and ductility enhancement of tested models is 122% and 191% respectively for strips wrapped cross section, and 130% and 375%

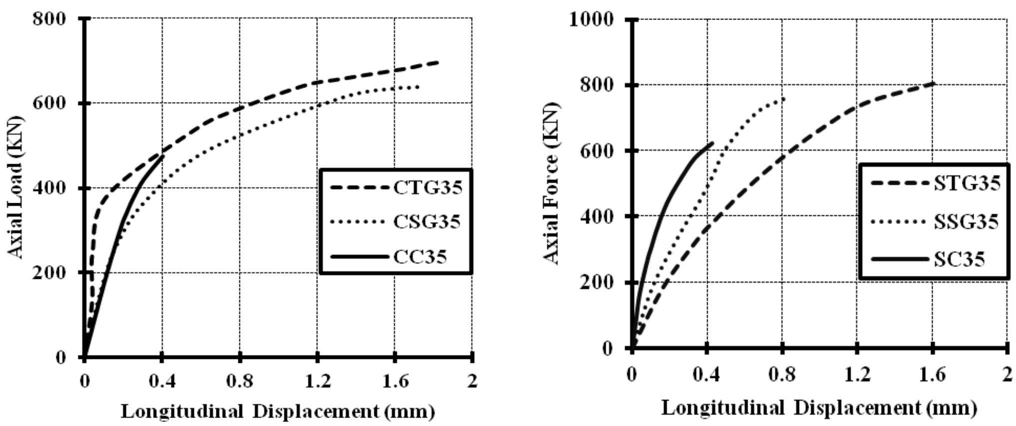
respectively for total wrapped cross section to control models. Total wrapped of circular and square cross sections is more significant than strips wrapped cross section in applied load and ductility as shown in Figure 17.

Table (4) and Figure 18 (a) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped circular cross sections with Fcu=45 MPa. It is found that applied load and ductility enhancement of tested models is 125% and 394% respectively for strips wrapped cross section, and 141% and 446% respectively for total wrapped cross section to control models. Table (4) and Figure 18 (b) shows the relationship between applied load and longitudinal displacement of control model, GFRP strips wrapped, and GFRP total wrapped square cross sections with Fcu=45 MPa.It is found that applied load and ductility enhancement of tested models is 107% and 135% respectively for strips wrapped cross section, and 111% and 227% respectively for total wrapped cross section to control models. Total wrapped of circular and square cross sections is more significant than strips wrapped cross section inapplied load and ductility as shown in Figure 18.



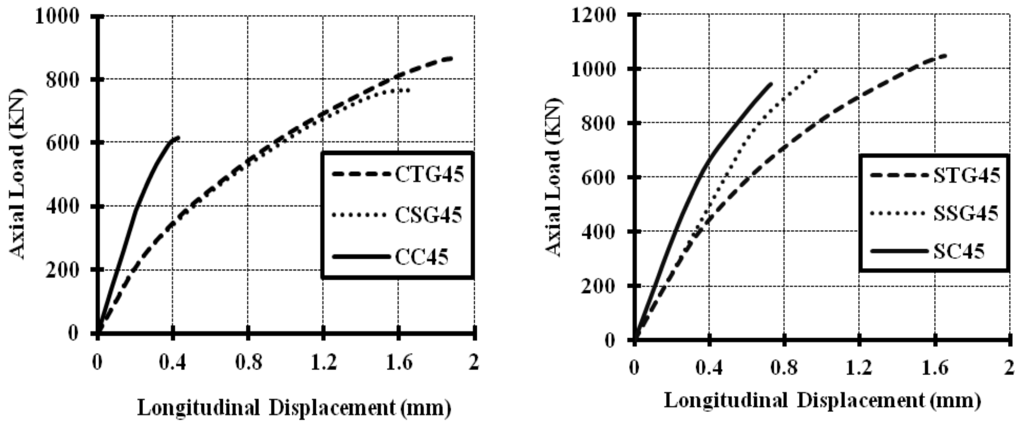
a. Strips wrapped models. b. Total wrapped models.

Figure 16. Cross section shapes with different wrapped models and Fcu= 25 MPa



a. Strips wrapped models. b. Total wrapped models.

Figure 17. Cross section shapes with different wrapped models and Fcu= 35 MPa



a. Strips wrapped models. b. Total wrapped models.

Figure 18. Cross section shapes with different wrapped models and Fcu= 45 MPa

4.2.3 Characteristic strength concrete

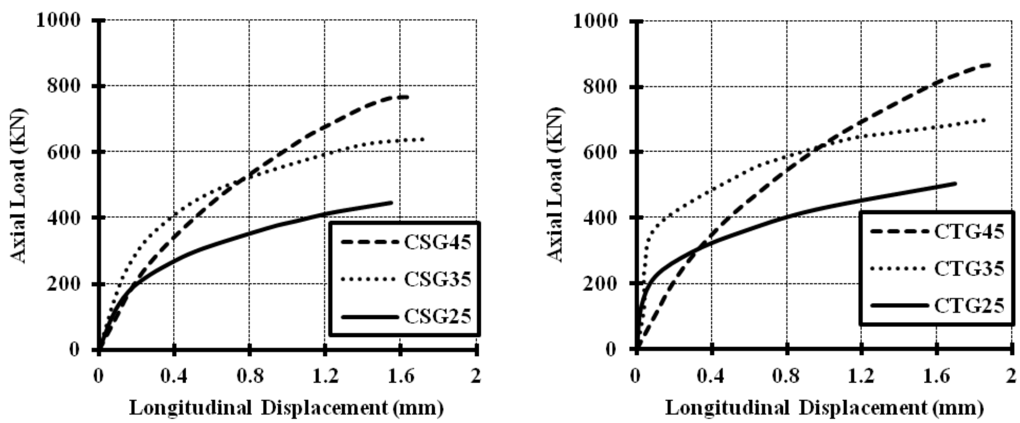
Table (4) and Figure 19 (a) shows the relationship between applied load and longitudinal displacement of GFRP strips wrapped circular cross sections with different Fcu. It is found thatapplied load and ductility enhancement of tested models is 160% and 521% respectively with Fcu=25 MPa, 134% and 432% respectively with Fcu=35MPa, and 125% and 394% respectively with Fcu =45 MPa to control models.

Table (4) and Figure 19 (b) shows the relationship between applied load and longitudinal displacement of GFRP total wrapped circular cross sections with different Fcu. It is found that applied load and ductility enhancement of tested models is 180% and 571% respectively with Fcu =25 MPa, 147% and 457% respectively with Fcu=35MPa, and 141% and 446% respectively with Fcu =45 MPa to control models.

Table (4) and Figure 20 (a) shows the relationship between applied load and longitudinal displacement of GFRP strips wrapped square cross sections with different Fcu. It is found that applied load and ductility enhancement of tested models is 134% and 237% respectively with Fcu =25 MPa, 122% and 191% respectively with Fcu=35MPa, and 107% and 135% respectively with Fcu =45 MPa to control models.

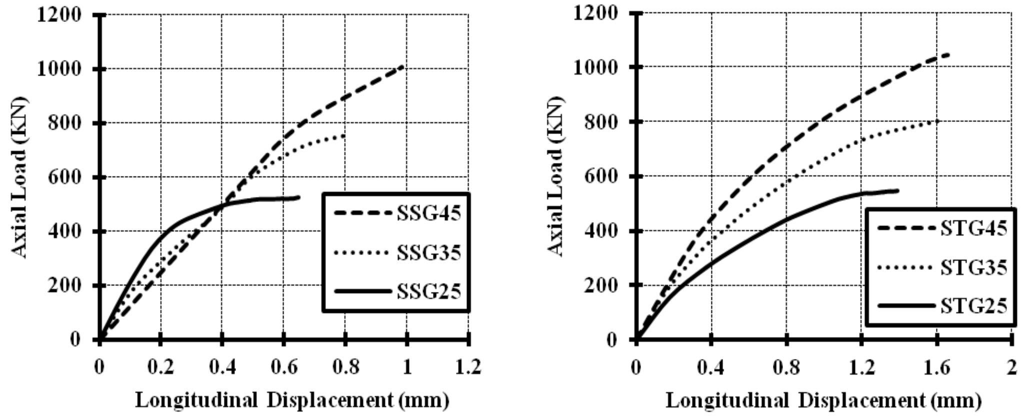
Table (4) and Figure 20 (b) shows the relationship between applied load and longitudinal displacement of GFRP total wrapped square cross sections with different Fcu. It is found that applied load and ductility enhancement of tested models is 139% and 514% respectively with Fcu =25 MPa, 130% and 375% respectively with Fcu=35MPa, and 111% and 227% respectively with Fcu =45 MPa to control models.

Enhancement of applied load and ductility is significant with the lower characteristic strength of concrete.



a. GFRP strips wrapped. b. GFRP Total wrapped.

Figure 19. Load- Displacement for different technique of GFRP wrapped and different Fcu.
For circular cross sections.



a. GFRP strips wrapped. b. GFRP Total wrapped.

Figure 20.Load-Displacement for different technique of GFRP wrapped and different Fcu.
For square cross sections.

V. A DESIGN OF AXIAL FRP STRENGTHENING SYSTEMS FOR SHORT CONCRETE COLUMNS

Ultimate axial load for short concrete columns with different cross section shapes strengthening by GFRP total wrap is determined by proposing equation and their results are compared with the results of ACI code[18], Egyptian code[19], and ABAQUS program[17] Table 5.

A proposed design equation to calculate the ultimate axial load for short concrete columns with square cross section strengthening by GFRP total wrap:

$$\boldsymbol{P_u = 0.4 * f_{cu} * A_g + 0.67 * f_y * A_s + 0.2 * \Psi * \varepsilon_f * E_f * t_f * p * n} \quad (1)$$

A proposed design equation to calculate the ultimate axial load for short concrete columns with circular cross section strengthening by GFRP total wrap:

$$\boldsymbol{P_u = 0.4 * f_{cu} * A_g + 0.67 * f_y * A_s + 0.25 * \varepsilon_f * E_f * t_f * p * n} \quad (2)$$

$$\boldsymbol{\Psi = 1 - \frac{(h-2r_c)^2+(b-2r_c)^2}{3A_c(1-\mu_s)}} \quad (3)$$

Where:

Ac	Concrete cross section area.	Pu	Ultimate axial load.
μs	longitudinal reinforcement ratio of the column section.	fcu	Characteristic compressive stress of concrete.
Ag	Net area of concrete cross section.	Ɛf	Ultimate rupture strain of the FRP.
H	Long dimension of column section.	Ef	Modulus of elasticity of FRP.
As	Area of longitudinal reinforcement in column.	tf	Nominal thickness of one ply of the FRP reinforcement.
Ψ	Confinement effectiveness coefficient.	p	Perimeter of column section.
fy	Yield strength of steel reinforcement.	n	Number of plies of FRP reinforcement.
rc	Radius of the edges of the section.	b	Short dimension of column section.

Table 5.Comparison between Proposed Equation and Different Codes for Different Cross Section Shapes with One Layer FRP.

Model	Pmax (KN)				Difference (proposed equation& codes)%		
	Proposed equation	ABAQUS	ACI code	Egyptian code	ABAQUS	ACI code	Egyptian code
CTG25	476.245	505.297	491.613	415.791	5.75	3.13	12.7

CTC25	524.611	545.136	547.7	457.440	3.77	4.22	12.8
CTG35	600.1	698.42	628.4722	524.6461	14.08	4.51	12.57
CTC35	648.465	735.154	684.557	568.002	11.79	5.27	12.41
CTG45	723.954	867.468	765.331	633.296	16.54	5.41	12.52
CTC45	772.319	887.078	821.416	677.674	12.97	5.98	12.25
STG25	532.819	546.865	550.364	478.417	2.64	3.29	11.14
STC25	559.453	583.650	578.475	510.304	4.33	3.4	9.05
STG35	689.636	806.74	723.646	615.841	16.98	4.93	11.98
STC35	716.27	831.108	751.758	648.521	16.03	4.95	10.45
STG45	846.453	1047.700	896.929	753.174	23.78	5.97	12.38
STC45	873.087	1075.700	925.04	786.315	23.21	5.95	11.04

VI. CONCLUSIONS

From the results of experiments and the numerical analysis of externally bonded FRP sheets; there are a significant enhancing in the normal strength and ductility of the short columns, and the following conclusions can be drawn.

1) Strengthening R.C columns with circular cross section and GFRP strips wrapped is more significant than the square cross section wrapped by GFRP strips in applied load and ductility. Where for circular cross sections, there values range (125:160) and (394:521) % to control model respectively, for square cross sections, there values range (107:134) and (135:237)% to control model respectively.

2) Strengthening R.C columns with circular cross section and GFRP total wrapped is more significant than the square cross section wrapped by GFRP total in applied load and ductility. Where for circular cross sections, there values range (141:180) and (446:571)% to control model respectively, for square cross sections, there values range (111:139) and (227:514)% to control model respectively.

3) Using GFRP strips wrapped different cross sections enhance of applied load and ductility is significant for the lower characteristic strength of concrete. Where for Fcu =25 MPa; there values range (134:160) and (237:521) % to control model respectively, for Fcu =35 MPa; there values range (122:134) and (191:432)% to control modelrespectively andfor Fcu =45 MPa; there values range (107:125) and (135:394)% to control model respectively.

4) Using GFRP total wrapped the enhancement of applied load and ductility is significant for the lower characteristic strength of concrete. Where for Fcu =25 MPa; there values range (139:180) and (514:571)% to control model respectively, for Fcu =35 MPa; there values range (130:147) and (375:457)% to control model respectively and for Fcu =45 MPa; there values rang (111:141) and (227:446)% to control model respectively.

5) For circular cross sections, the total wrapped cross section is more significant than the strips wrapped cross section in applied load and ductility. Where for the total wrapped cross section, there values range (141:180) and (446:571)% to control model respectively, for the strips wrapped cross section, there values range (125:160) and (394:521)% to control model respectively.

6) For square cross sections, the total wrapped cross section is more significant than the strips wrappedcross section in to applied load and ductility. Where for the total wrapped crosssection, there values range (111:139) and (227:514)% to control model respectively, for the strips wrapped cross section, there values range (107:134) and (135:237)% to control model respectively.

7) Ultimate axial load for short concrete columns strengthening by GFRP total wrap is determined by a proposing equation.

For square cross section:

$$\boldsymbol{P_u = 0.4 * f_{cu} * A_g + 0.67 * f_y * A_s + 0.2 * \Psi} * \varepsilon_{\boldsymbol{f}} * \boldsymbol{E_f * t_f * p * n} \quad (1)$$

For circular cross section:

$$\boldsymbol{P_u = 0.4 * f_{cu}} * A_g + 0.67 * f_y * A_s + 0.25 * \varepsilon_f * E_f * t_f * p * n \quad (2)$$

$$\Psi = 1 - \frac{(h-2r_c)^2+(b-2r_c)^2}{3A_c(1-\mu_s)} \quad (3)$$

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