REPAIR OF PRE-LOADED R.C. COLUMNS USING EXTERNAL CFRP SHEETS AND EMBEDDED LONGITUDINAL STEEL REINFORCEMENT

ALAA M. MORSY* and EL-TONY M. EL-TONY**
*Construction & Building Engineering Department, College of Engineering & Technology, Arab Academy for Science, Technology and Maritime Transport, Egypt.
**Structural Engineering Department, Faculty of Engineering, Alexandria University, Egypt.
Email: alaamorsy@aast.edu and CEB_alex2010@yahoo.com

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ABSTRACT:

In the field application of fiber reinforced polymer (FRP) sheets to confining reinforced concrete (RC) columns for repairing or upgrading purposes, more or less, confinement is applied with the existence of preloading in the columns. This paper presents results of an experimental investigation on the behavior of axially preloaded short circular columns that have been repaired with carbon fiber-reinforced polymer (CFRP) wrapping. A total of six R.C. columns have been subjected to compression load up to three different loading levels (unloaded column “0% of ultimate load”, loaded until cracking load “85% of the ultimate load”, and loaded till failure 100% of ultimate load) then all the loaded column confined using CFRP wrap and subjected again to compression loading. Also a unique method has been presented in this paper for those three repaired columns using four reinforcing steel bars were embedded as near surface mounted with epoxy in grooves through the concrete cover then covered by the CFRP wrap, those additional longitudinal reinforcement could consider as replacement of any corroded existing reinforcement. The test results indicate that the existence of preloading stress put a slight positive effect on the capacity of confined columns. On the other hand, those columns with high preloading stress level “up to failure” have exhibited lower effect on the capacity of confined columns. This finding may seriously be considered for the columns that totally loaded column up to failure can attain its initial capacity without strengthening by repairing the spalled concrete parts it then wrapping it by one layer of CFRP. The presence of embedded steel reinforcement could help in increasing the carrying loading capacity of the columns especially in the totally loaded column before repairing with CFRP sheets.

INTROUDUCTION

Carbon fiber-reinforced polymer (CFRP) jackets have been extensively used to improve the performance of columns in terms of strength and ductility by providing adequate lateral confining pressure to the column. This confining pressure places the concrete in a tri-axial state of stress, altering the load-deformation characteristics of the concrete and enable concrete to sustain both higher axial load and ultimate axial strain[1, 2]. In case of a circular cross-section, the jacket exerts a uniform confining pressure resulting in a uniform tri-axial stress field. However in a non-circular cross section, the confinement results in a complex non-uniform tri-axial stress field, which generally results in a lower level of performance in comparison to circular cross sections[3].

Several studies have been conducted to investigate the axial behavior of concrete columns confined with CFRP jackets[1-13]. These studies have all indicated that CFRP jackets enhance the compressive strength and axial strain of confined concrete. Thus far, the main thrusts of research involving CFRP-jacketed columns aimed at characterize the behavior of columns with circular cross sections[4-8]. The results of such research have wide applicability, particularly with regard to circular bridge piers. However, the vast majority of all columns in buildings are square or rectangular columns. Therefore, their strengthening and rehabilitation need to be given attention to preserve the integrity of building infrastructure.

Another method for strengthening RC members with FRP is the Near surface mounting (NSM) technique, where grooves are cut in the concrete cover and FRP rods or thin plates referred to as strips are installed inside these grooves and bonded using an epoxy adhesive. These techniques were widely used specially in shear or flexural strengthening of beams[13-17].

The authors therefore suggest similar technique for strengthening RC columns, where grooves are cut through the column concrete cover and then steel bars are embedded in the grooves using grout or epoxy adhesive then the columns wrapped using CFRP sheets. This technique has the same advantage as the NSM technique in beams; in addition the embedment of the steel external reinforcement bars inside the columns will improve the carrying loading capacity of the column and compensate any corroded internal longitudinal reinforcement. The presence of the reinforcement inside the column may also improve ductility of the columns. On the other hand, few researches deal with the confining effect of preloaded columns with different percentage of loading capacities of the ultimate load[18], and the efficiency of CFRP wrapping in column repairing.

The details and results of a pilot test program that was undertaken to examine the feasibility of this technique and the effect of repairing preloaded columns are presented in the following sections

RESEARCH SIGNIFICANCE

The research aim to study two main parameters, first; the pre-loading effect on the efficiency of the CFRP wrapping in enhancing the R.C. column axial load capacity, then three columns specimens were tested under different loading level (0%, 85%, 100% of the ultimate failure column load) which indicate the control column without loading, the column load until the first cracks appear, and the totally failed column respectively. Second; the research investigates a unique method for strengthening using additional four longitudinal steel bars embedded in the concrete cover grooves similar to near-surface mounted method then covering it using wrapping by CFRP sheets.

EXPERIMENTAL DETAILS

Six specimens were tested in this program; all columns have been wrapped with one layer of CFRP sheets. Three specimens were tested without embedded longitudinal steel reinforcement and the other three specimens with the embedded longitudinal steel reinforcement. All the specimens tested under the three different loading levels. The following is a description of the specimens and the materials used.

Description of the columns

Six molds made of 6 mm PVC were constructed and used for casting the specimens vertically. Specimens were cast immediately after mixing in the moulds, and then compacted with the help of vibrating table. All specimens were exposed to identical curing conditions. The columns have circular cross section with 160 mm diameter and of total height 1000mm. Four steel bars of 8 mm diameter were used as longitudinal reinforcement, the transverse reinforcement were at spacing 120 mm with 6 mm diameter. While the top and bottom of the column having extra stirrups at spacing 50 mm to prevent failure due to stress concentration at both ends of column. Figure 1 shows the Longitudinal and cross section reinforcement detail of the experimental columns

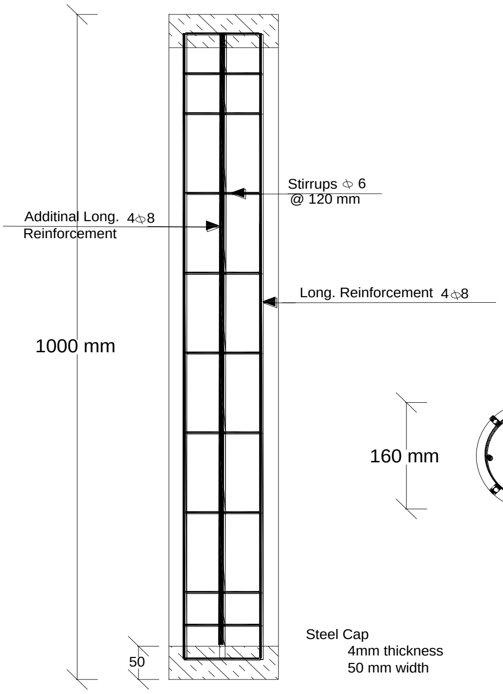

Figure 1. Longitudinal and cross section detail of the experimental columns.

The concrete cover was kept constant at 20 mm in all RC columns. As an attempt to prevent the occurrence of premature failure at the ends, the column ends were also capped with external steel cap of 4 mm thickness as shown in Fig. 2. This configuration forced general failure to occur within the test region. Also the steel cap served to stabilize the column during testing.

Figure 2. Confined Column with steel capping before loading

Strengthening Process

Preparation of the concrete substrate and application of CFRP materials were carried out in accordance with the guidelines for application to concrete that was provided by the material manufacturers. The surfaces of all columns to be wrapped are ground using mechanical metallic brush (grinding) to remove any dust or grease from concrete surface and to open the pore structure to make the epoxy primer penetrate through the concrete and ensure strong bond between the concrete and CFRP sheets. The prepared concrete surface is coated with a layer of epoxy-based primer using a short nap roller. CFRP sheet is then placed on concrete surface and pressed normally to the concrete surface using roller brush to remove air pockets from beneath the fiber sheets. A 100-mm overlap is necessary to provide sufficient anchorage in order to achieve the full tensile strength of the fiber sheet and prevent slip between layers. In all cases, the principal fibers were oriented perpendicular to the column axis.

Instrumentation and Load Application

Before assembling the reinforcing cages, electrical resistance strain gages were installed to measure the strain in both longitudinal embedded bars and lateral strain gauge on the CFRP at the mid height of the column and they were oriented in vertical and lateral directions to monitor the axial and lateral strains, respectively. In addition to the dial gauge to measure the vertical deformability of the column. Universal compression testing with 3000 kN capacity were used for testing. The loads were applied in small increments and the strains were recorded at a 50 kN-interval. The load control mode was followed throughout the program. Tests were conducted at the material laboratory of the structural engineering department in Alexandria University, figure (3) shows the test setup and instrumentation of the tested column

Figure 3. Test Setup and column instrumentation

Test specimens and preparation

Six identical column constructed as mentioned in the previous section were tested in this program. All columns have been strengthened using one layer or CFRP. The specimens divide into two groups according to the presence of embedded near surface mounted longitudinal reinforcement. The first group consists of three specimens were not reinforced using external near surface mounted steel bars, “Control C1” was a control specimen strengthened and testing without any preloading, the second specimen “C2” strengthened after loaded up to 80% of the ultimate load which correspond to the visual of first crack in the column, the third specimen “C3” strengthened after loaded up to failure load and repairing the column in the crushing part at the top of column using concrete with admixture for bonding the old concrete with the new repairing concrete after removing the loose concrete the spalled area was repaired using a fast-set non-shrink mortar as shown in figure (4).

Figure (4) repairing the top part of the loaded column (C3) before strengthening

The second group consists of three specimens reinforced using four external near surface mounted steel bars of diameter 8mm and steel grade of yielding strength 240 MPa and ultimate strength 360 MPa, the external reinforcement embedded inside groove in the column concrete cover and cover by cementitious grout material, as shown in figure (5), the forth column "C4" was a strengthened and testing without any preloading, the fifth specimen "C5" strengthened after loaded up to 80% of the ultimate load which correspond to the visual of first crack in the column, the six specimen "C6" strengthened after loaded up to failure load and repairing the column in the crushing part. Table 1 provides a summary of the details of the specimens used in this program.

Figure (5) embedding the external reinforcement into the column concrete cover

Table 1 Specimen specifications

Specimen	Specification
C1	Strengthened R.C. column with FRP, without internally embedded steel reinforcement and un-loaded
C2	Strengthened R.C. column with FRP, without internally embedded steel reinforcement and loaded till 80% failure load
C3	Strengthened R.C. column with FRP, without internally embedded steel reinforcement and loaded till full failure load after curing and repairing the crushed part
C4	Strengthened R.C. column with FRP, with internally embedded steel reinforcement and un-loaded
C5	Strengthened R.C. column with FRP, with internally embedded steel reinforcement and loaded till 80% failure load
C6	Strengthened R.C. column with FRP, with internally embedded steel reinforcement and loaded till full failure load after curing and repairing the crushed part

Material properties

The concrete used in these tests had strength of 30 MPa based on testing 150 mm cubes. The steel bars used for the longitudinal and stirrups reinforcement had nominal yield strength of 240 MPa respectively. Sikawrap 230 CFRP sheets manufactured by SIKA chemical company were used for column strengthening with 0.131 mm thickness. The mechanical properties of the used CFRP laminate and its epoxy are shown in the following table.

Table 2 Mechanical properties for CFRP laminate and it's adhesive

Material	Ultimate Tensile Strength (MPa)	Ultimate Strain	Elastic Modulus (MPa)	Density
CFRP laminate	4300	1.8%	238,000	1.76 g/cm3
Adhesive	30	---	4,500	1.31 kg/l

RESULTS AND DISSCUSSION

The test results of the six columns are listed in Table (3) that includes the ultimate load and the ultimate strain in CFRP sheets. Other collected data at various load stages is represented graphically. Observed crack patterns and mode of failure are discussed for each column.

Table (3) Failure and first crack loads

Specimen #	Failure load (ton)	FRP Ultimate strain	% increase/decrease over Un-loaded specimens	% increase / decrease over the specimen without external reinforcement
C1	102	0.0039	----	----
C2	108	0.0052	+ 5.8%	----
C3	60	0.0012	- 41.1%	----
C4	100	0.0004	----	-2.0%
C5	105	0.007	+ 5.0%	-2.7%
C6	80	0.0008	- 20%	33.3%

Overall behavior and failure modes

The failure of the columns in all cases was brittle an early noise due to concrete cracking was noticeable related to the micro cracking of concrete core was evident when the applied load approached 60 ton, This level may be corresponding to the unconfined strength of the column, indicating the start of stress transfer from the dilated concrete to the CFRP wrap. Prior to the failure, cracking noises were frequently heard. The failure was gradual, ending with a sudden and explosive noise.

The failure of the wrap initiated away from the overlap region at mid-height of the specimen and progressed to the top and bottom of the specimen. The sudden and explosive nature of the failure indicates the release of extraordinary amount of energy as a result of the uniform confining stress provided by the wrap. Inspection of the broken samples showed good contact between the wrap and the concrete indicating that no de-bonding took place at any stage throughout the loading process, and test was terminated due to the rupture of CFRP sheets. Figure (6) shows failure mode for all columns.

Figure (6) Failure modes for all columns

Comparing the failure loads for the tested columns as shown in figure (7), it can be found that there are very slight effect for preloading columns up to the cracking load (80% of the ultimate load) compared to the unloaded columns either the columns with or without embedded steel reinforcement. However this preloading level put a slight positive effect on the capacity of confined columns, these phenomena is clearly shown also in both columns with or without external embedded reinforcement.

On the other hand preloading the column up to failure load decrease its carrying loading capacity compared to the unloaded column by 41.1% and 20% for the columns without embedded steel reinforcement and with embedded steel reinforcement respectively, in spite of this decrease in the loading capacity the column keep the same capacity of the unconfined column without any strengthening, that is means that the totally failed/crushed column then repaired using one layer of CFRP sheets can attain its initial capacity before strengthening. Moreover the presence of embedded steel reinforcement could help in increasing the carrying loading capacity of the columns especially in the totally loaded column before repairing with CFRP sheets.

Also it is clearly shown that there no effect of presence embedded steel reinforcement in the unloaded columns or the columns loaded by 80% of the ultimate load, this may be related to the weak bond between the embedded steel reinforcement and the concrete. While it gives significant effect in the loaded columns up to failure over the same columns without embedded steel reinforcement by 33.3%

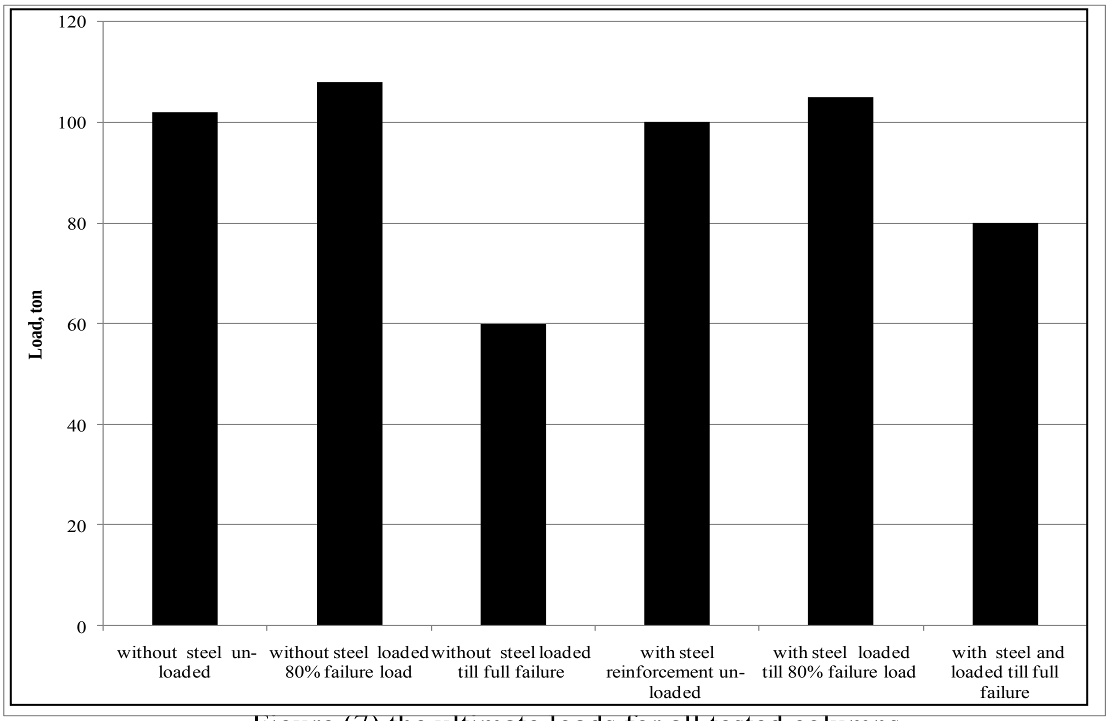

Figure (7) the ultimate loads for all tested columns.

Load-Deflection and Load-strain Relationships

The columns were tested using a load control universal testing machine. The transverse strain in CFRP sheets and the longitudinal strain in external near surface mounted steel bars were recorded using electrical strain gauges. The loads were applied continuously and recorded, along with the dial gauge and strain gauges readings using digital strain indicator. Application of the loads and the recording process continued until complete failure of the column occurred

The load versus transverse strain in CFRP sheets behavior of all the six tested specimens are shown in Figure (8).

It is clearly shown that the three columns (C1, C2, and C5) attain a large transverse strain up to 0.004, 0.005 and 0.007 mm/mm respectively compared to the other three columns (C3, C4 and C6) which indicate very low transverse strain 0.0012, 0.0004 and 0.0008 respectively. This implies that failure initiated at a location away from the location of strain gage, as all the strain gauge located at the mid height of the column while in specimens C3, C4, and C6 the failure occur at the upper third of the column height.

It should be reported herein that the maximum measured transverse strain in CFRP was found in column C5 was approximately 0.007 mm/mm, which corresponded to 38.8 % only of the reported ultimate strain of CFRP, that's confirmed that the rupture of CFRP away from the position of the strain gauge.

Also it is clearly shown that when comparing the stiffness for all columns, both preloaded columns up to failure exert lower stiffness than the unloaded column or preloaded up to 80% of the failure load; this may be related to the repairing process for those columns decrease the stiffness for the columns.

Also it can be stated obviously the column C1 has the largest stiffness as it is unloaded before testing compared to the loaded columns C2, and C3, and to ensure this behavior also the column C4 having large stiffness compared to C5, and C6. This indicates that the pre-loading the columns decrease the stiffness of the columns either having embedded steel reinforcement or without embedded steel reinforcement

Comparing the effect of embedded steel reinforcement the behavior of the two columns C2 and C5, which has the same preloading load (80%) and the same failure zone (mid-height) while C2 without embedded steel reinforcement and C5 with embedded steel reinforcement. It can be concluded that presence of embedded steel reinforcement lower the stiffness of the column and increase its ductility.

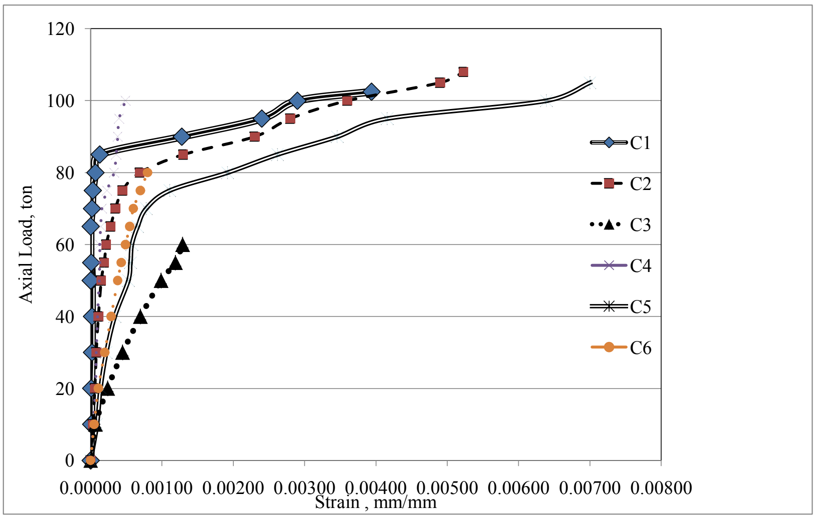

Figure 8 Load vs transverse strain in CFRP sheets for all specimens

Comparing the strain in longitudinal embedded steel reinforcement with the unloaded specimen C4 with the loaded specimen up to 80% of failure load C5, it clearly shown that the preloading effect decrease the strain in the longitudinal embedded steel reinforcement.

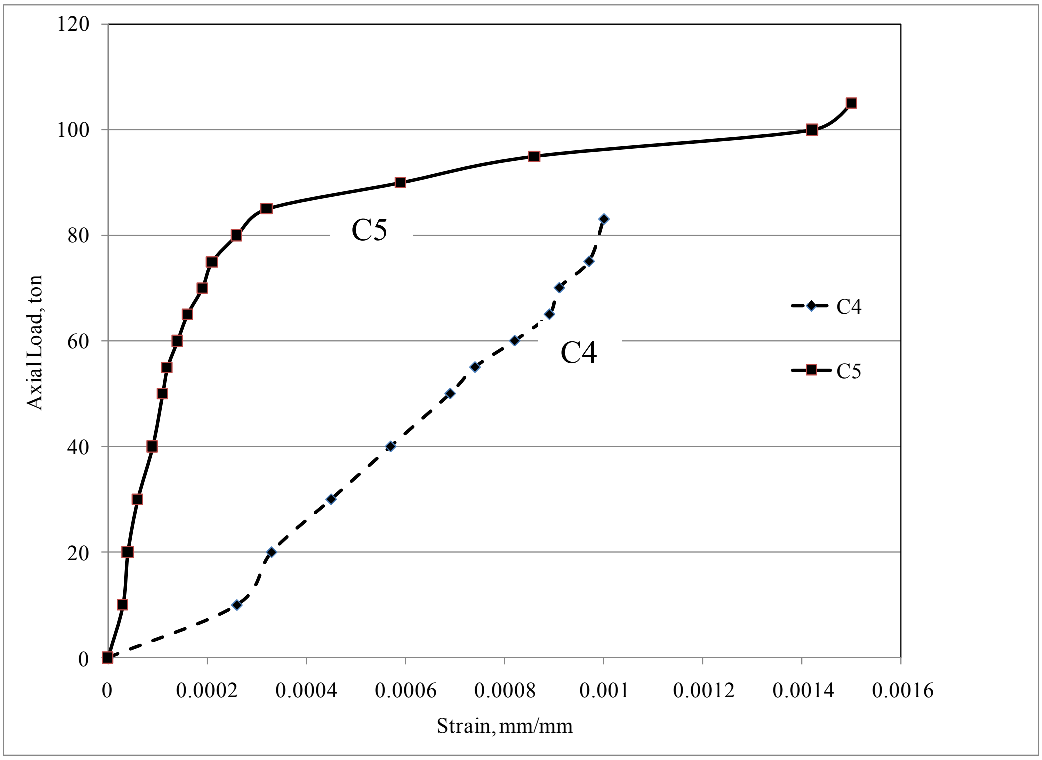

Figure 9 Load vs. longitudinal strain in external steel bars for specimen C4 and C5

CONCLUSIONS

This paper has presented the results of an experimental program investigating the effect of preloading on the confinement effect of columns repaired by CFRP sheets and also the effect of adding additional external steel reinforcement as near surface mounted in the behavior of repaired preloaded specimens. Based on the experimental results, and observations, the following conclusions can be stated:

1. There is a very slight effect for preloading strengthened columns up to the cracking load (80% of the ultimate load) compared to the unloaded strengthened columns either the columns with or without embedded steel reinforcement.
2. Preloading the column up to failure load decrease its carrying loading capacity compared to the unloaded column by 41.1% and 20% for the columns without embedded steel reinforcement and with embedded steel reinforcement respectively.
3. The totally loaded column up to failure can attain its initial capacity without strengthening by repairing the spalled concrete parts it then wrapping it by one layer of CFRP.
4. The presence of embedded steel reinforcement could help in increasing the carrying loading capacity of the columns especially in the totally loaded column before repairing with CFRP sheets.
5. The pre-loading the columns decrease the stiffness of the columns either having embedded steel reinforcement or without embedded steel reinforcement
6. The positions of both CFRP strain gauge and the CFRP failure zone have large effect for the value of transverse strain, as failure zone initiated at a location away from the location of strain gage.
7. Presence of embedded steel reinforcement lowers the stiffness of the columns and increases its ductility.

REFRENCES

[1] Chirs Cole and Abdeldelil Belarabi, "FRP Jacketed Reinforced Concrete Columns," *Center For Infra Structure Engineering Studies, Department of Civil Engineering, University of Missouri-Rolla, May 2001*

[2] Azadeh Parvin and Wei Wang, "Behavior Of FRP Jacketed Concrete Columns Under Eccentric Loading," *Journal of Composites for construction,* ASCE, Vol 5, No.8, August 2001, pp.146-152.

[3] Amir Mirmiran and Mohsen Shahawy, "Behavior of Concrete Columns Confined By Fiber Composites," *Journal of Structural Engineering, ASCE*, Vol. 123,No.5, May 1997, pp.583-590.

[4] Kaled Saleh, "New Aspects In Strengthening R.C. Columns With FRP " *Proceeding of Structural Composites For Infrastructure Applications Conference, Aswan, Egypt*, 2002.

[5] Abdelhady Hosny,Hamdy Shahin,Amr Abdelrahman and Tamer El-Afandy, " Uni-axial Tests on Rectangular Columns Strengthened With CFRP " *Proceeding of Structural Composites For Infrastructure Applications Conference, Aswan, Egypt*, 2002.

[6] Hatem Gith and Hanan Anwar, "Confinement Effect of Continuous GFRP wrapping On the Behavior of R.C. Columns" *Proceeding of Structural Composites For Infrastructure Applications Conference, Aswan, Egypt*, 2002.

[7] Said M.Allam and Tarek I.Ebeido, "Efficiency of CFRP Wrapping on R.C. Columns under Concentric and Eccentric Loading," *Alexandria Engineering Journal, Vol.41, 2002, No.3, 449-512*

[8] Yung C. Wang and Jose I. Restrepo, " Investigation of concentrically loaded reinforced concrete columns confined with Glass Fiber Reinforced Polymers jackets," *ACI Structural Journal*, May – June 2001, pp 337-385

[9] Omar Chaallal , Mohasen Shahawy and Munzer Hassan , " Performance of Axially Loaded Short Rectangular Columns Strengthened With Carbon Fiber-Reinforced Polymer Wrapping , "*Journal of Composites for construction, ASCE*, Vol 7,No.3, August 2003, pp.200-208.

[10] Pierre Rochette and Pierre Labossiere, " Axial Testing Of Rectangle Column Models Confined With Composites, "*Journal of Composites for construction, ASCE*, Vol 4,No.3, August 2000, pp.129-136.

[11] ACI Committee 318, "Building Code Requirements for Reinforced Concrete (ACI 318-02)," *American Concrete Institute, Farmington Hills, Michigan, 2002.*

[12] Saatcioglu, M., and Yalcin, C., "External Prestrssing Concrete Columns for Improved Seismic Shear Resistance," *ASCE Journal of Structural Engineering, Vol. 129, No. 8, 2003.*

[13] Alaa Morsy.et al, "Behavior of axially loaded columns strengthened with carbon fiber reinforced polymers," Fifth Alexandria international conference for structural and geotechnical engineering , December 2003.

[14] Rizzo, A & De Lorenzis, L. 2009. Behavior and capacity of RC beams strengthened in shear with NSM FRP reinforcement. Construction and Building Materials 23: 1555-1567.

[15] De Lorenzis L & Teng J.G. 2007. Near-surface mounted FRP reinforcement: an emerging technique for structural strengthening. Composites: Part B. 38(2):119–143.

[16] De Lorenzis L, Nanni A. 2001. Shear strengthening of reinforced concrete beams with NSM fiber-reinforced polymer rods. ACI Structural Journal. 98(1):60–68.

[17] Dias, S.J.E. & Barros, J.A.O. 2010. Performance of reinforced concrete T beams strengthened in shear with NSM CFRP laminates. Engineering Structures. 32: 373-384.

[18] Zheng He, et al "Seismic performance of preloaded R.C. columns confined with CFRP materials" 16th International Conference on Composite Structures, FEUP, Porto, 2011