Behavior of the Concrete Columns Reinforced with the Carbon Polymer Fibers under Centric Loads

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Abstract: Present development trends incline on the strengthening structures, especially concrete columns with cross sections of different shapes, towards the behavior and comparison of significant difference. The use of FRP materials in the field of civil engineering offers several advantages in comparison to the materials traditionally employed, such as better durability, excellent mechanical properties, etc. Fiber-reinforced polymers (FRP) have emerged as an alternative solution for strengthening and retrofitting structures, especially in existing structures. In attempt to increase strength and ductility of reinforced concrete (RC) load bearing elements through confining systems, the FRP membranes have become a familiar solution. Extensive studies (experimental, finite element modeling and analytical modeling) were carried out on the analysis of confining effect in case of centric loaded RC columns. This paper investigates the prospect of reinforcing deficient rectangular columns and circle columns with carbon fiber-reinforced polymer (CFRP) jackets, in preparing the five series for both cases. Currently, the study of RC columns confined with composite materials will be focused in centric apply loads, because the non-centric apply loads are relatively new and limited. FRP confinement systems are less effective under non centric loading compared to centric loading. Experimental program on testing the performance of centric loaded RC columns externally strengthened with CFRP membranes was carried out and is presented in this paper.
Keywords: column; concrete; ductility; fibers; strengthening; confinement; etc.

1. Introduction

Many studies which concerned about strengthening of existing reinforced concrete columns, especially in seismic regions changed the aspect of different use of structures, this aspect have focused on providing additional confinement to the core concrete elements by means of external reinforcement. From the studies that have been conducted over the past several years, the advantages of using FRP materials have become more apparent. Reinforcement or strengthening aspect can be achieved in a column by wrapping the column with cross sections of different shapes using fiber reinforced polymer.

Due to the increase in the ultimate compressive strain, the ductility capacity and energy absorption capacity are also considerably improved, always in comparing the different shape cross sections of columns. In all different case studies, the results will be compared with non-reinforced samples.

Different types of reinforcement and different shape cross sections result with optimizations and orientations toward the benefits. The methodology of applying the CFRP, such wrapping was in accordance with technical specifications of materials [1].

2. Test Setup and testing procedures of concrete samples

The samples are prepared for two types of columns: Circular (10x40) cm and Rectangular (10x10x40)cm cross section in general such more present in practical engineering works, presented in Fig1.a and1.b [12].

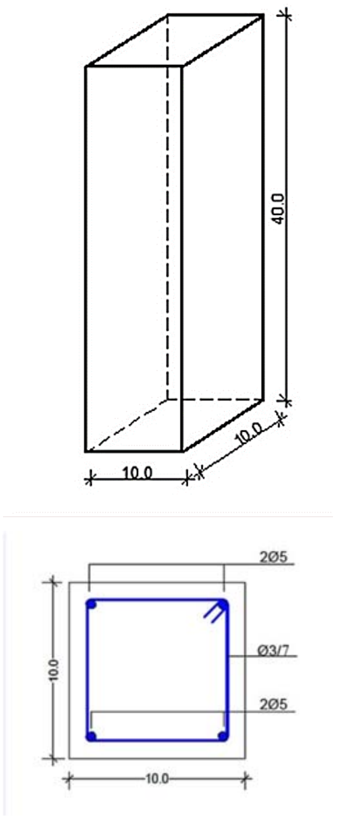

Fig.1.a. Rectangular cross section

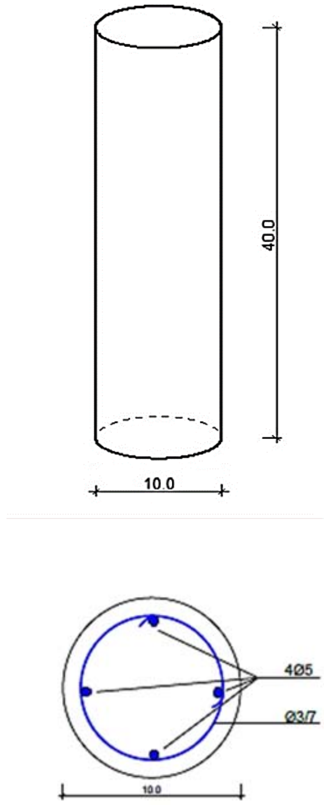

Fig.1.b. Circular cross section

2.1 Materials Properties

The concrete mix design for all the specimens is approved according to the EN-206-1, presented in Table 1.

Table 1. Materials and properties of materials

Material	Mass(kg/m^3)	Concrete properties
Cement/CEM II 42.5	340	Compressive Strength(fc'=38.5)N/mm^2
water	180	Slump=150 mm
Coarse aggregate	780	W/C =0.53
Fine aggregate	1080	Max. Aggregate size-16 mm
Chemical additives	1.5	Air entrant 3.5 %

The CFRP, used for strengthening are from producer, MAPEI-Italy, with properties presented in Table 2.

Table 2. Materials and properties of CFRP

Description	MAPEWRAP C QUADRI-AX 760/48
Mass (gr/m^2)	760
Density(gr/cm^3)	1.79
Thickness (mm)	0.106
Tensile strength (N/mm^2)	>4800
Tensile modulus of Elasticity (GPa)	230
Elongation (%)	2.1

2.2 Test Specimens

To determine the effect of CFRP wrapped on columns, we used the samples with cross sections of different shapes: three circular and six rectangular columns were manufactured and tested in laboratory [3].

The geometric dimensions of samples and reinforcement details are presented in Figures 1.a and 1.b. In all cases they were the same, only the wrapping is changed (full or partial wrapped). In order to obtain a reasonable mean value of the results, the rectangular column specimens were analyzed in two different strengthening (wrapped) ways: full wrapped and partially wrapped (in spacing similar with stirrups and width 5-6 cm). The analyzing specimens were wrapped using one layer of CFRP, but in analytical analyzing are presented also for more layers, as it requested. All the geometrical and mechanical properties of CFRP are presented in Table 2.

3. Testing procedure

The columns were axially loaded measuring the apply load continuously with rate of the load 500 kPa/sec and also measuring the displacement control using the LVDT during the experiments. The preparing test samples are presented in Table 3 with specifications for each series of samples.

Table 3. Series and details of test specimens

Series/type	Shape cross sections	wrapped	Number of layers
A	rectangular	fully	one
B	rectangular	Partially wrapped/spacing like stirrups; width 5-6cm	one
C	rectangular	Non strengthening/ plain samples	no
D	circle	Fully wrapped	one
E	Circle	Non strengthening/ plain samples	no

The first column (circle–Series D) was loaded continuously until failure and measurement of the displacement was done in the same procedure. Displacement and load were recorded throughout the entire tests, Figure 2.

The rectangular columns (Series A and B) are also tested in the same way and in same conditions, Figure 3 and Figure 4.

The plain samples (non-strengthening samples) (Series C and E) in both cases are tested using the same procedures. [10].

4. Analyzing testing results observation

4.1 Circle Specimens

Specimen D (fully wrapped circle specimens): Failure was sudden. It was observed through a crack which formed approximately 150mm from the top of the columns. The CFRP appeared to have burst due to the pressure or strain caused by the load. [8] (Richard D. Iacobucci, Shamim A. Sheikh, and OguzhanBayrak), [10] (R.Aliu, 2014)

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

4.2 Square Specimens (fully wrapped)

Specimen A (fully wrapped): The columns showed warning signs of failure and cracked approximately in the middle of the column but at one side through edge. There were visual signals of failure such as particle debris, but not only in layer of CFRP.

Fig.3. Test set up and shape of failure of rectangular (fully wrapped) specimens

4.3 Rectangular specimens (partially/stirrups wrapped)

Specimen B (wrapped/ spacing like stirrups; width 5-6cm): The columns showed warning signs of failure and cracked approximately in the middle of the column but in all of surfaces. There were visual signals of failure such as totally debris in concrete structure. (Fig. 4); [4].

Fig.4. Test set up and shape of failure of rectangular (partially wrapped) specimens

Presentation of the all results is on the Table 4, with short descriptions in the failure analyses.

Table 4. Short descriptions of Series of Samples

Series/type	Shape cross sections	Wrapped CFRP	Failure short descriptions
A	rectangular	Fully	Warning signs of failure and cracked approximately middle of the column but in one side through edge/fig.3.
B	rectangular	Partially wrapped/spacing like stirrups; width 5-6cm	Warning signs of failure and cracked approximately in middle of the column but in all of surfaces/fig 4
C	rectangular	Non strengthening/ plain samples	Usually failure –middle of the span of column with brittle failure
D	circle	Fully wrapped	crack which formed approximately 150mm from the top of the columns., fig.2
E	Circle	Non strengthening/ plain samples	Usually failure –middle of the span of column with brittle failure

5. Analyzing and comparing the results

To be able to determine the confining effect of CFRP wrap on the behavior of reinforced concrete columns, the axial compressive strength of concrete columns without CFRP wrap are calculated. [7] (*Sung-Chul Chun; Hyung-Chul Park*).

$$N_{Rcc,d} = \frac{1}{\gamma_{Rd}} A_c \cdot f_{ccd} + A_{sl} \cdot f_{yd} \tag{1}$$

A_c -Concrete cross section area; A_s - area of steel reinforcement; f_{ccd} -strength of strengthening concrete

In our case study we used the different cross section, and the factor of cross section is presented in formula (3)

$$k_\alpha = \frac{1}{1+(\tan\alpha_f)^2} = \frac{1}{1(\tan 90)^2} = 0 \qquad (2)$$

Analytical calculations for different cross sections specimens are presented in Table 5.

Table 5. Analytical Calculated strength for different cross sections/after strengthening

Shape Cross section	rectangular	circle
Axial Strength $\mathbf{N_{Rcc,d}}$(kN)	**175.7**	**418.0**
Shear Strength $\mathbf{V_{Rd,f}}$ (kN)	**14.0**	**3.4**

Comparing the results of all tested specimens, including also the plain samples which are presented in Table 6.

Table 6. Compare the all tested sample for different shape cross sections

Series	Sample	Cross section	Dim a x b(cm)	High (cm)	Type of wrapped	Compression force (kN)	Compressive strength (N/mm²)
A	1	Rect.	10x10	40	Fully wrapped	331.81	33.18
	2	Rect.	10x10	40	Fully wrapped	361.20	36.12
	3	Rect.	10x10	40	Fully wrapped	368.29	36.83
B	1	Rect.	10x10	40	Partially/ stirrups	318.14	31.81
	2	Rect.	10x10	40	Partially/ stirrups	328.35	32.84
	3	Rect.	10x10	40	Partially/ stirrups	369.91	36.99
C	1	Rect.	10x10	40	Non strength.	261.75	26.18
	2	Rect.	10x10	40	Non strength	288.61	28.86
	3	Rect.	10x10	40	Non strength	278.45	27.85
D	1	circle	d=10	40	Fully wrapped	555.13	70.72
	2	circle	d=10	40	Fully wrapped	590.81	75.26
	3	circle	d=10	40	Fully wrapped	518.11	66.00
E	1	circle	d=10	40	Non strength	221.58	28.23
	2	circle	d=10	40	Non strength	231.25	29.46
	3	circle	d=10	40	Non strength	236.13	30.08

The analysis of all cases in this paper is presented in graphical form, using the charts in Fig.5 and Fig.6.

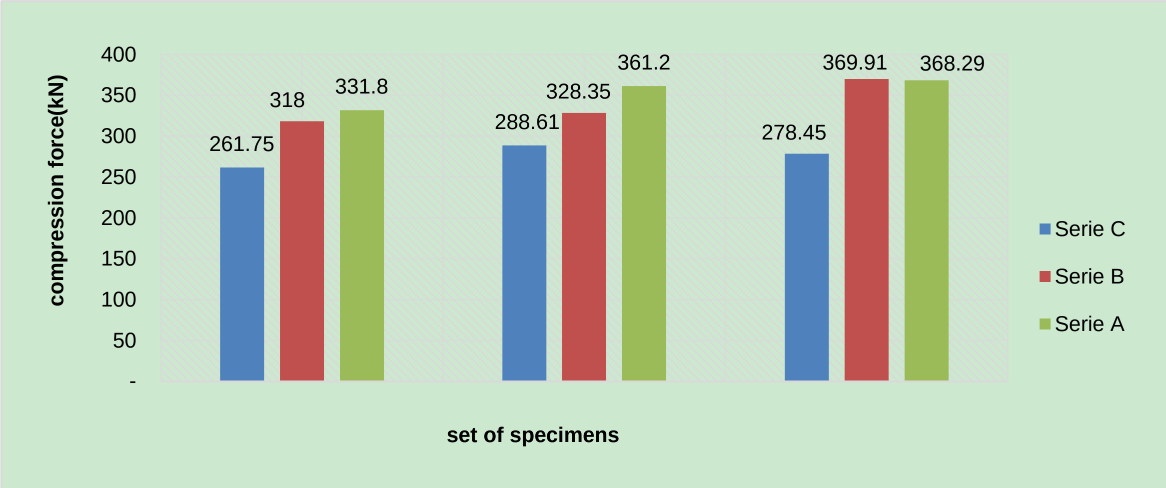

Fig.5. Comparison the different series of rectangular shape cross section columns

Comparison between the test results of wrapped shape rectangular cross section columns with the calculated value express not present significant changes between series A(fully wrapped) and B (Partially/stirrups) and very slightly increasing compare with series C (non-strengthening), presented in Fig 5. However, if the corners of the square columns are rounded appropriately, the ductility of columns will increase considerably.

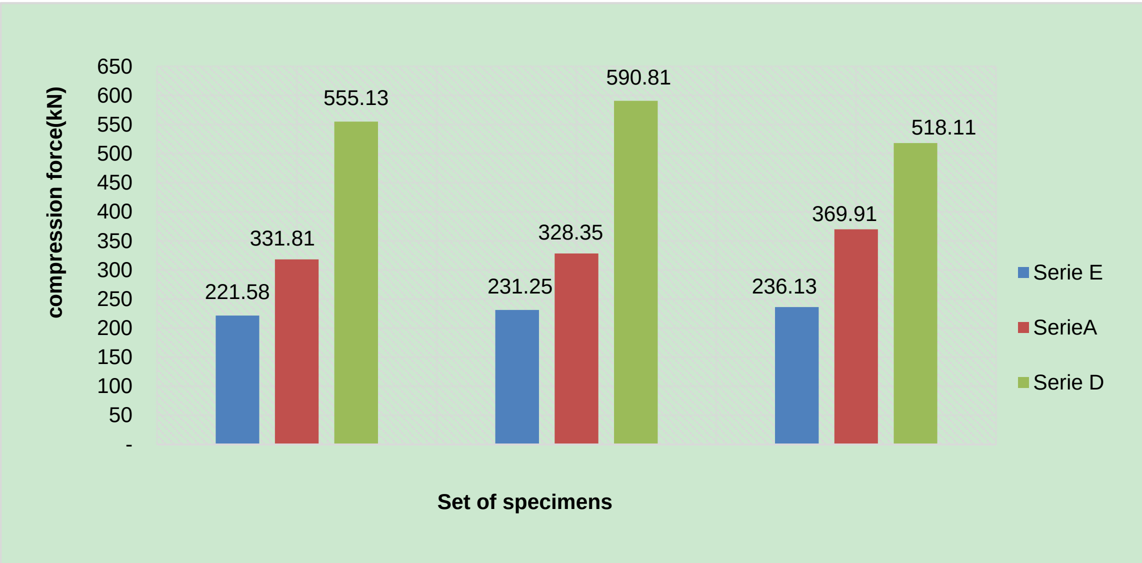

Fig.6. Comparison the different series of circle shape cross sections columns

Comparison between the test results of wrapped circle columns shows that the CFRP wrap can increase the axial strength of circular columns significantly. The wrapping method and the shape cross sections in this case is more acceptable. Especially the over wrapped and shape without edges is the indicator factor for increasing the compressive strength comparing with rectangular shape cross section. The ductility of circle columns is improved because the absorption energy inside the wrapped is higher, based also on the properties of CFRP. Comparing with series A, there is a significant increase in the axial loads. (Comparing the Series A and D, Fig.6) [6]; [9].

6. Conclusions

The effect of the CFRP wrap on the axial strength of reinforced concrete columns was analyzed and it was the aim of this paper. The study included testing of two types of shape cross sections columns in five series. The output evaluation results consist on following conclusions:

1) Applied the strengthening of circle columns is more effective in the directions of increasing the axial loads and in same time achieving the more ductile element.

2) Then applied the strengthening with fully wrapped and partially wrapped/stirrups wrapped in increasing the compressive strengthening factors is very slightly and it is limited, based on the failure mode and maximum bearing capacity of concrete columns.

3) The partially wrapped/stirrups wrapped is more applicable in elements or positions, and it is because the shear force has the maximum values.

4) The recent proposed equations presented for the wrapped circle columns can be used to predict the axial strength of CFRP wrapped circle columns. However, their proposed equations for rectangular columns overestimate the axial strength of CFRP wrapped columns unless the edges of the rectangular columns are rounded appropriately.

References

[1]L.C.Hollaway,M.K. Chryssanthopoulos and S.S.J.Moy , Advance Polymer Composite for Structural applications in constructions , ACIC 2004.

[2]Jin-GuangTeng, BEng, PhD, FHKIE. Behavior, Design and Monitoring of Concrete Structures Strengthened with Fibre-Reinforced Polymer (FRP) Composites Kong Polytechnic UniversityKatarina GAJDOSOVA, Juraj BILCIK**,** Slender rectangular concrete columns strengthened by cfrp confinement and nsmr; Slovak University of Technology

[3]PezhmanTaghia and Suhaimi Abu Bakar; Mechanical Behaviour of Confined Reinforced Concrete-CFRP Short Column- Based on Finite Element Analysis, World Applied Sciences Journal 24 (7): 960-970, 2013

[4]RiadBenzaid and Habib-AbdelhakMesbah: Circular and Square Concrete Columns ExternallyConfined by CFRP Composite: Experimental Investigation and Effective Strength Models, 2013

[5]M. Reza Esfahani, M. Reza Kianoush, axial compressive strength of reinforced concrete columns wrapped with fibre reinforced polymers (FRP), 2005

[6]Faella, C., Realfonzo, R., Rizzano, G. Experimental Behaviour of R/C Columns Confined by FRP; fib-2006, Italy

[7]Sung-Chul Chun; Hyung-Chul Park; load carrying capacity and ductility of RC columns confined by carbon fiber reinforced polymers;

[8]Richard D. Iacobucci, Shamim A. Sheikh, and OguzhanBayrak; Retrofit of Square Concrete Columns with Carbon Fiber-Reinforced Polymer for Seismic Resistance;ACI Structural Journal, December 2003

[9]Dr. SujeevaSetunge; Review of strengthening techniques using externally bonded fiber reinforced polymer composites,report 2002

[10]R.Aliu; Analyse and calculation of bearing capacity of RC Columns strengthening with CFRP; master thesis, Prishtina, 2014

[11]N.Kabashi, R.Basha, C. Krasniqi, V. Nushi Strengthening the Concrete Columns Wrapped With Fiber Reinforced Polymers , 2014 International Conference on Civil Engineering, Energy and Environment, Hong Kong

[12]N.Kabashi, C.Krasniqi, A.Muriqi; Flexure behavior the concrete beams reinforcement with polymermaterials;Journal:Materials, Science and Engineering/Advance Materials Research2014 / Volume 687 / pp.472-479