NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 3, ISSUE 12, Dec.-2016

USE OF FRP COMPOSITES FOR STRENGTHENING OF RCC COLUMNS

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ABSTRACT

Fibre Reinforced Polymer (FRP) wrapping of Reinforced Concrete (RC) columns, as a rapidly growing strengthening technique, requires appropriate design methods. However, the current available design guides are based on models, in their majority semi-empirical, and calibrated with small-scale plain concrete specimens. These models might not be reliable in predicting the strength and ductility enhancement sought through FRP confinement in RC columns with geometric and material properties as found in practice. The percentage of strength enhancement is variable for different shapes and sizes of FRP wrapped columns.

In the present study, an experimental investigation will be carried out to study the effect of slenderness ratio on circular shaped reinforced concrete columns confined with carbon fibre reinforced polymer (CFRP) sheets. Total 24 number of reinforced concrete columns of same diameter but different lengths was cast and will be subjected to axial compression. In which 12 specimens are control specimens and remaining are confined with one layer of CFRP sheet. The effect of slenderness ratio on strength enhancement and ductility of CFRP confined reinforced concrete column subjected to axial compression is to be studied.

INTRODUCTION

It is well known that compressively loaded concrete members under confinement exhibit ductile behavior with considerable plastic hardening, unlike unconfined concrete, which shows quasi-brittle or strain softening behavior. This improved behavior has led to the use of fiber-reinforced polymer (FRP) wraps as confinement for concrete columns. The wraps are also comparatively lightweight, not susceptible to corrosion, and have high chemical resistance to environmental effects. Fiber Reinforced Polymer (FRP) materials have been widely applied in construction and structural rehabilitation due to their high strength, stiffness-to-weight ratio, high corrosion resistance, the ability to form and to shape to the existing structure, and the application process which is relatively fast and easy. Concrete has found its use in nearly all types of civil constructions. As the world's need for housing, industry and transportation increases, the consumption of structural concrete is expected to increase correspondingly. The widespread deterioration of structural concrete due to several factors has created a critical need for cost effective and durable materials with advanced technologies for use in rehabilitation and retrofit. One of the most promising avenues, which have been recently explored, is to use Fiber Reinforced Polymer Composite (FRPC) for civil engineering applications. FRP could be very effective in rehabilitation and retrofitting of deteriorating structures as well as new constructions.

1.1 NEED TO STRENGTHEN RCC COLUMNS:

There arises a need to strengthen RCC columns of an existing structure by various techniques due to following reasons:

- Inclination of the column is more than allowable
- Load on column is increased due to either increasing number of floors or due to mistakes in design
- The compressive strength of concrete or the type and % steel isn't according to codal requirements.
- The settlement of the foundations is more than allowable

1.2 ADVANTAGES OF FRP OVER TRADITIONAL TECHNIQUES

1. Corrosion proof
2. Easy in transportation, can be easily rolled
3. Higher UTS and young's modulus
4. High fatigue resistance
5. Light weight. Hence, very high strength to weight ratio
6. Joints can be easily avoided as they are available in desired length.

METHODOLOGY FOR FIBER WRAPPING OF COLUMNS

2.1 GRINDING AND SURFACE PREPARATION

For round columns sharp corners are negligible except junctions. For square columns apart from the grinding the plane surface it is also necessary to remove all the sharp corners with grinder and form at least a minimum of 20 mm radius for smooth functioning. For surfaces with unevenness putty is used to make is even.

Figure1: Surface grinded and prepared for fiber wrapping

2.2 MARKING AND DRILLING

The center of column width is marked and drilled at points to the depth of 50-60mm to put anchors.

2.3 PRIMER COATING

After making sure that all water has evaporated and moisture is minimal a primer coat is applied to make surface very smooth epoxy application and fiber adhesion. It takes some hours for primer to cure depending on the ambient conditions. It is important to alienate the concrete from the fiber- wrap system so that moisture and other impurities may not affect the process. It also makes the surface very smooth so that the epoxy sticks to the surface nicely and there is no loosening, or layer formation that might make the process less effective.

Figure 1: Surface Primer applied on the column

2.4 EPOXY COATING AND WRAPPING OF FIBER

After Primer coating the surface is perfect for epoxy application. There are two techniques employed for wrapping fiber.

- The 2- component epoxy adhesive is mixed properly in required proportion and is applied throughout the surface where fiber is to be put. Immediately after epoxy application fiber is wrapped around the column or as per the design proposed. After which a second coat of epoxy is applied.
- It is also sometimes pre- wetted with epoxy with the help of wet-layup machine and then applied to the surface of application. The fabric is checked again for any air bubbles trapped and roller is rolled over wherever required, which is important as it hampers in functioning of the fiber wrap.

Figure 2: Cutting and applying of fiber sheet on the column

2.5 ANCHORING AND SAND SPRINKLING

A second coat of epoxy is then applied over which anchors are put into the previously drilled holes so that it holds the ends of fiber wrap and does not allow it to peel off. After which sand sprinkles and a minimum layer of 12mm thickness of polymer modified mortar covering is done. This is done to enhance the life of fiber wrap system. Now the whole system is safe and active.

Figure 3: Final look of column after plastering

EXPERIMENTATION

Experimental Procedure

Test Matrix and Materials

The experimental program implement in this study was divided into two groups: Group A and Group B. The specimens in Group A consisted of nine small-scale plain concrete cylinders with dimensions of 150 mm in diameter and 300 mm in height. These specimens were divided into three categories: Category I consisted of three plain concrete cylinders, Category II consisted of three CFRP wrapped cylinders, and Category III consisted of three SFRP wrapped cylinders. Three specimens from each category were tested for repeatability purposes. The specimens in Group B consisted of three large-scale plain concrete columns with dimensions of 300 mm in diameter and 1200 mm in height. One column was left unwrapped to act as the control specimen, the second column was wrapped with CFRP sheets, and the third column was wrapped with SFRP sheets.

The concrete mix contained a water/cement ratio of 0.4, maximum aggregate size of 20 mm, and 1 % air content. The maximum 28-day compressive strength of the concrete from Group A and Group B was 40 MPa and 37.8 MPa, respectively, with a standard deviation of 1.3 MPa and 9.3 MPa, respectively.

Specimen Preparation and Test Set-up

The specimens in Group A were cast in standard cylindrical moulds (150×300mm), whereas the specimens in Group B were cast in sonotube fiber-forms (300×1200mm). All the specimens were left to cure for at least 7 days before strengthening with the FRP sheets.

Group A specimens had an overlap length of 100 mm as suggested by the manufacturer [15]. However, Group B specimens had a larger overlap length of 250 mm due to their larger dimension. The suggested overlap length satisfies the minimum overlap length of 150 mm provided by ISIS Canada [17].

A uniaxial compression loading was applied to the cylinders at a loading rate of 10 KN/sec using a 2 MN hydraulic testing machine until failure, whereas the large-scale columns were tested using a 9 MN hydraulic testing machine at a loading rate of 120 KN/min.

Table 1. Summary of Group A and Group B compression test results.

G[A]	C	ID	COMPRESSIVE STRENGTH (MPa)		AXIAL STRAIN (με)		HOOP STRAIN (με)		DUCTILITY (MN-mm/mm)	
			Max[c].	Avg. [Std. Dev.][d]	Max.	Avg. [Std. Dev]	Max.	Avg. [Std. Dev]	Total	Average
A	I	CT-1	44	42	3000	2200	380	380	1500	1000
		CT-2	40		1200		360		516	
		CT-3	42		2300		400		1100	
	II	CFRP-1	54	58	7700	4300	15000	9800	4700	4100
		CFRP-2	58		2800		7500		3500	
		CFRP-3	61		2500		7100		4200	
	III	SFRP-1	100	97	16000	16600	15000	14300	21300	31400
		SFRP-2	95		NA*		16000		51400	
		SFRP-3	95		17000		12000		21500	
B	I	CT	37	-	640	-	390	-	870	-
	II	CFRP	51	-	2000	-	550	-	5700	-
	II	SFRP	63	-	5000	-	4900	-	1700	-

G[A] = Group, C = Category, Max[C]. = Maximum, Avg. [Std. Dev.][d] = Average [Standard Deviation], and NA*= Not Applicable [Strain Gauge Damage].

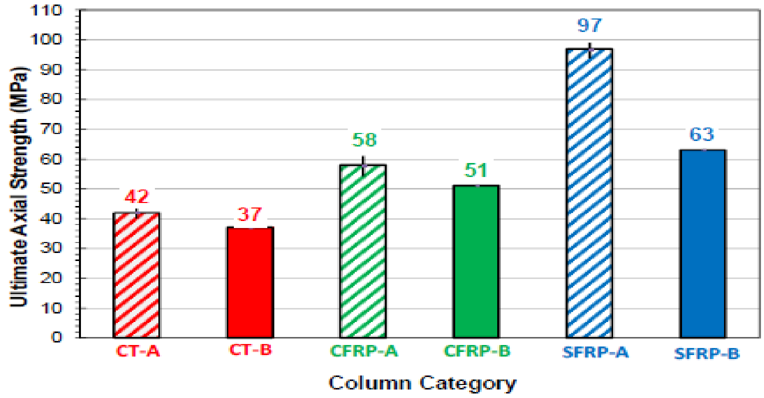

Figure 1. Ultimate axial strength of Group A and Group B specimens

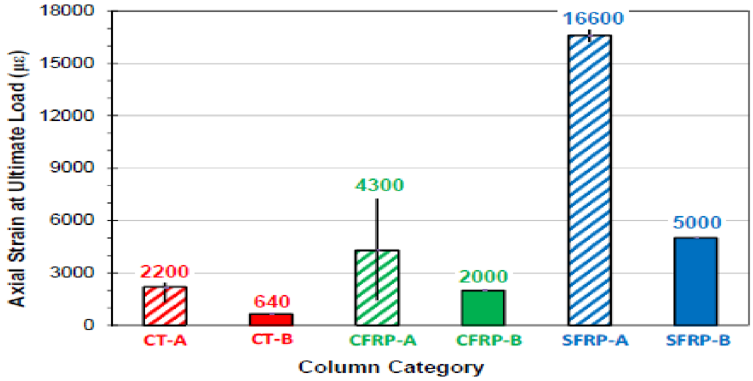

Figure 2. Axial strain of Group A and Group B specimens

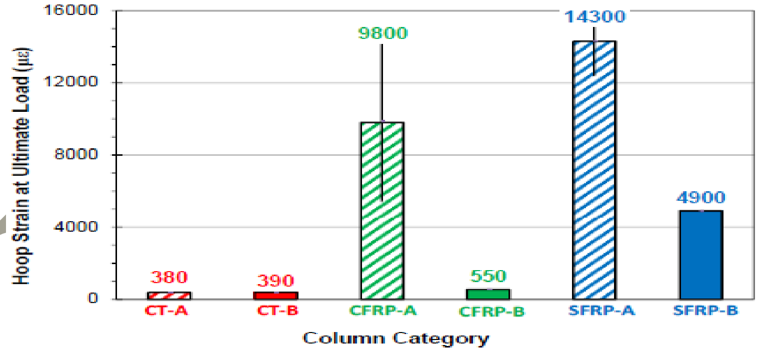

Figure 3. Hoop strain of Group A and Group B specimens

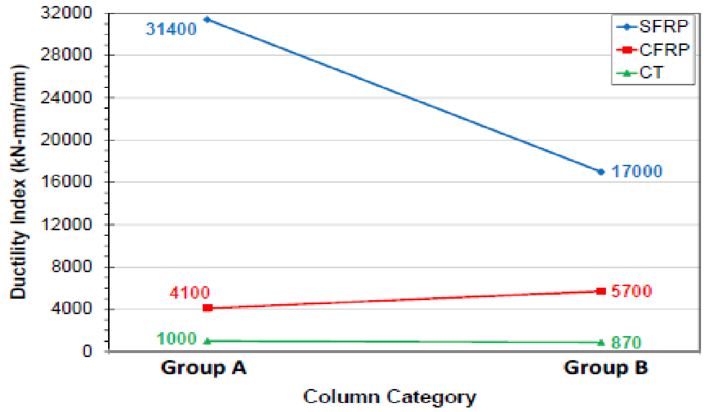

Figure 4. Ductility of Group A and Group B specimens

The small specimens are mainly affected by the restraining influence of the end bearing plates, which leads to non-homogeneities and produce results not representative of the larger columns [19]. It is always expected that greater confinement pressure is provided by smaller specimens. In order to understand the reasoning of this statement, the confinement pressure exerted by the wrapped
FRP sheets for the circular columns provided by the ACI Committee 440.2R [20] is presented as follows:

$$f_l = \frac{2E_{ju} n t_j \varepsilon_{fe}}{D}$$

Where
l f is the confinement pressure
ju E is the modulus of elasticity of the FRP sheet
n is the number of layers
j t is the thickness of the FRP sheet
fe
ε is the effective strain in the FRP sheet
Dis the diameter of the circular confined specimen it can be clearly seen that as the size of the column increases, the maximum confinement pressure provided by a given thickness of the FRP wrap reduces. Since the confinement pressure is decreased, the strength and strain enhancement of the larger columns is expected to decrease as presented

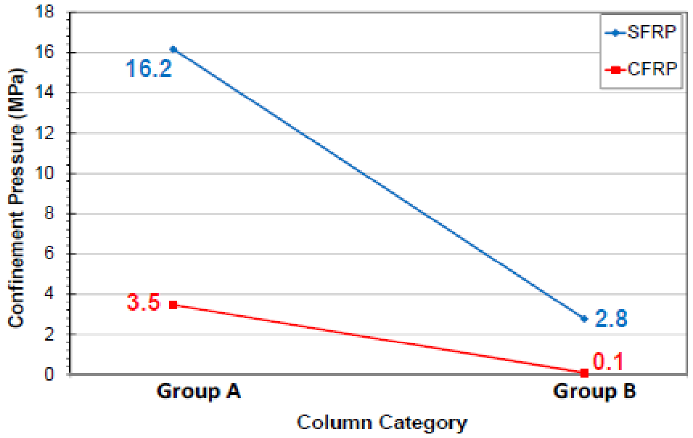

Figure 5. Confinement Pressure of Group I and Group II columns

CONCLUSIONS

1. Increasing the size of the specimens significantly affects the ultimate axial strength, axial strain, and hoop strain of CFRP and SFRP wrapped columns, when compared to small-scale specimens.
2. The ductility parameter of the unwrapped and the CFRP wrapped specimens are insignificantly altered by the size effect. However, increasing the size of the SFRP wrapped column significantly affected the ductility parameter when compared to the small-scale SFRP wrapped cylinders.
3. For a given thickness of the CFRP and the SFRP wrap, increasing the size of the specimen decreases the confinement pressure imposed on the specimen.

ISSN: 2394-3696
VOLUME 3, ISSUE 12, Dec.-2016

REFERENCES

Experimental investigations on FRPC confined concrete columns have seen a significantly carried out since early 90s. From the exhaustive body of literature available, a review of some of the notable research applications is presented in this section related with present work.

1) Amir Mirmiran *et. al.*, (1997) *tested fifty four concrete filled FRP tubes in uniaxial compression under displacement control mode to study the dilation characteristics of confined concrete. A dilation rate is defined as the rate of change of lateral strains with respect to axial strains.*
2) Amir Mirmiran *et. al.*, (1998*) studied the effect of only three column parameters such as shape, length and bond on FRP-confined concrete. A total of twelve square and thirty cylindrical specimens were tested to investigate the effect of shape under uniaxial compression test.*
3) Omar Chaallal *et. al.*, (2000) *presented results of a comprehensive experimental investigation on the behavior of axially loaded short rectangular columns strengthened with CFRP wrap. The study concluded that the maximum gain in strength for lower grade of concrete was more as compared to higher grade of concrete.*
4) Reza Esfahani *et. al.*, (2005) *presented the results of a study on the axial compressive strength FEM Analysis of concrete columns strengthen by FRP sheet Page 23 of square and circular columns strengthened with FRP wrap. The corners of the square columns were rounded off and their confined compressive strength was compared with the square columns having sharp corners. The experimental part of the study included testing 6 reinforced concrete columns in two series. The first series comprised three similar circular reinforced concrete columns strengthened with FRP wrap. The second series consisted of three similar square columns, two with sharp corners, and the other with rounded corners. Axial load and displacement of columns were recorded during tests using a displacement control test set up*
5) Marwan N. Yousef *et. al.*, (2006) *studied factors such as ultimate stress, rupture strain, jacket parameters, and cross-sectional geometry affecting the stress–strain behavior of FRP- confined concrete. Such parameters were analyzed statistically based on the experimental data and equations theoretically prediction of behavior.*