Quest Journals
Journal of Architecture and Civil Engineering
Volume 7 ~ Issue 2 (2022) pp: 17-23
www.questjournals.org

Research Paper

Long Axially Concrete Columns Encased In Durable FRP Forms

Hamdy Mohamed
Department of Civil and Architectural Engineering, College of Engineering, Applied Science University (ASU), Kingdom of Bahrain.

ABSTRACT: *This paper presents the results of an experimental study carried out to investigate the axial behavior of reinforced concrete filled fiber-reinforced polymer (FRP) composite tubes (CFFT). The application of CFFT for different structural applications (piles, column, girder, bridge piers) has proved to be one of the more favorable systems. The FRP tubes benefits are in confinement, protective jackets, providing shear or/and flexural reinforcement and permanent formwork. Actually most of the experimental investigations which conducted to study the effect of different parameters on the behavior of the CFFT under compression load were on small dimension specimens (cylinders dimension). The axial load behaviors of short, medium and long height reinforced concrete filled GFRP circular tubes with steel bars were investigated. The aims of this study are to investigate the effect of the slenderness ratio on the confinement, axial stress-strain responses, axial and horizontal deformation, failure mode, and ultimate load capacity of the reinforced CFFT columns. The CFFT columns of different heights, 300, 600, 900, 1200 and 1500 mm have been evaluated under axial compression load. The internal diameter of the GFRP tubes used in this investigation was 152 mm, the tube thicknesses was 2.65 mm, the fiber orientation mainly in the hoop direction of ± 60 degree with respect to the longitudinal axes.*
KEYWORDS: Columns, Slender, FRP, Concrete, Durable, Tubes, Axial Load.

R*eceived 05 Feb, 2022;* ***R****evised 15 Feb, 2022;* ***A****ccepted 18 Feb, 2022 © The author(s) 2022.*
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I. INTRODUCTION

The application of composite materials has been propagated by the deterioration of the existed conventional concrete, steel, and timber structures (Karbhari et al. 2000; Karbhari 2004). The glass fibre-reinforced polymers tubes can play an important role in replacing transverse steel by providing ductility and strength for conventional columns. The use of composite materials in civil engineering application offers several advantages confinement, protective jackets, providing shear or/and flexural reinforcement and permanent formwork. A number of studies have been conducted to investigate many parameters for the FRP closed forms, particularly concrete filled FRP tubes CFFTs. Effect of column size, presences of internal reinforcements and direct or indirect loading on axial compression behavior of CFFT were studied (Zhu et at. 2005). The results indicate that, un-reinforced CFFT columns failed with local rupture of FRP tube, dowel action of steel bars enhances the ductility of the CFFT columns. A total of 42 concrete filled GFRP tube cylinders specimens were tested in uniaxial compression to investigate the dilation characteristics of the confined concrete (Mirmiran & Shahawy 1997a). It was concluded that, the dilation rate of CFFT reaches a maximum value which corresponds to a reversal in volumetric strain response. The dilation rate finally stabilizes at an ultimate value which is a function of the FPR tubes stiffness. Mirimiran et al. 2001 tested seven fixed-fixed long CFFTs with different slenderness ratios as a column under uniaxial compression. The CFFT columns were not internally reinforced. The study aimed to establish slenderness limits in CFFTs similar to those developed for conventional RC columns. It was concluded that increasing slenderness ratio from 11 to 36, the strength dropped rapidly; also the effect of column slenderness on its ductility is significantly more than its effect on the strength. Yuan & Mirmiran 2001 present an analytical and experimental study of the static buckling of thin-walled FRP tubes filled with concrete and bent in single curvature. The study shows that concrete-filled FRP tubes are much more susceptible to buckling than concrete columns with internal steel reinforcement. Also it was recommended that the current slenderness limit of 22 for steel-reinforced concrete columns bent in single curvature be reduced to 11 for concrete-filled FRP tubes.

II. RESEARCH METHODOLOGY

Concrete Proportion

All specimens were constructed from the same batch of the concrete using a ready mix concrete supplier. The concrete mixture was intended to provide 50 MPa a concrete compressive strength. The materials by kg per m3 for concrete mixture were 435 cements, 135 water, 1080 gravel (max aggregate size 14 mm), 680 sand, air content 0-4%, 212 ml /100Kg watering-reducing initial set retarder and 875 ml/100Kg super plasticizer - ADVA 140. Ten plain concrete cylinders (152 x 305 mm) were prepared at the time of casting of CFFT specimens. Five cylinders were tested at 28-days, and the second five cylinders were tested at the time of testing of the CFFT columns. The average concrete strength of all cylinders was found to be very close to 45 MPa.

GFRP Tubes

The internal diameter for all tubes is constant equal to 152 mm. The GFRP tubes are fabricated using filament winding technique; E-glass fibre and Epoxy resin are used for manufacturing these tubes. The GFRP tubes consist of three (±60°) layers oriented in the hoop direction with respect to the longitudinal axis of the tubes, the total thickness was 2.65 mm. The Young's modulus in the longitudinal and hoop direction was 8785 and 20690 MPa, respectively. The shear modulus and Poisson's ratio were 8836 MPa and 0.29, respectively. Also the ultimate hoop and axial tensile strength equal to 640 and 60 MPa.

Specimens

This paper investigates experimentally the behaviors of short, medium and long height CFFT columns, internally reinforced with steel bars. Test matrix and details of the CFFT columns are presented in Table 1. The aims of this study are to investigate the effect of the slenderness ratio on the confinement, axial stress-strain responses, axial and horizontal deformation, failure mode, and ultimate load capacity of the reinforced CFFT columns. Ten unconfined concrete cylinders and six confined CFFT columns were tested under uniaxial loads. The specimens are identified as shown in Table 1; the first number shows the Slenderness ratio (H/D) of the column ranged from 2 to 10. Where, H is the height of the CFFT columns equal to 305, 608, 912, 1216 and 1500 mm for the five specimens, D is the internal diameter of the tubes equal to 152 mm. The second number presents the height of the column by cm, see Figure 1.

Series No. 1 (C-2-30) presents two confined concrete cylinders proposed in the test matrix to obtain the ultimate confined concrete strength. Also, it is aimed to compare the ultimate strength values for the GFRP concrete cylinders with the following short, medium, long height CFFT columns constructed of the same type of concrete and GFRP tubes. The next four CFFT specimens from number two to five are made up from four different heights 608, 912, 1216 and 1500 mm. the variation in the heights were chosen to give slenderness ratio (H/D) equal to 4, 6, 8 and 10 for each height, respectively. The percentage of the GFRP reinforcement ratio (4t/D) is equal to 6.31, where t is the thickness of the GFRP tube. These specimens were internally reinforced with six deformed steel longitudinal bars 10 M with constant reinforcement ratio equal to 2.99 %. The bars were distributed uniformly inside the cross section of the GFRP tube.

The bars were welded at the top and the bottom of the height by two steel stirrups of 3.2 mm diameter, to fix the bars during casting. The distance between the bars and the tubes was 8 mm. a concrete cover of 10 mm was provided between the ends of the longitudinal steel bars and the top and bottom surfaces of the specimens to avoid the stress concentration at the steel bars area. The presence of the longitudinal reinforcement was used to increase the lateral flexural ductility of the specimens, at the induced transverse moment due to the lateral displacement of the columns, at the higher load levels. Especially for the existed GFRP tubes in this study which were fabricated from layers in the circumferential direction.

Two longitudinal steel rebar, 180 degrees apart were installed at mid height by two resistance electrical strain gages, before casting for each CFFT columns. Also two axial and two transverse electrical resistances strain gages were mounted 180 degree apart along the hoop direction for each specimen on the external surface of the GFRP tubes. Additional two pairs of the strain gages were also mounted at the quarter height level for the 1200 and 1500 mm height specimens. Strain gages of 6 mm length were used to obtain the strain distribution from the steel bars and the GFRP tubes surface, and strain gages 30 mm were bonded on the surface of the concrete cylinders.

Table 1. Details of CFFT columns.

Series No.	Specimen ID	Height (mm)	Slenderness ratio (H/D)	Internal steel bars	Failure load (kN)	No of specimen
Cylinder		305	Plain concrete		816	10
1	C-2-30	305	2	----	1585	2
2	C-4-60	608	4	6 No. 10	1741	1
3	C-6-90	912	6	6 No. 10	1595	1

4	C-8-120	1216	8	6 No. 10	1366	1
5	C-10-150	1500	10	6 No. 10	1203	1


Figure 1. GFRP tubes.

The axial displacement for each column was measured by two linear variable displacement transducers (LVDTs) 180 degrees apart along the hoop direction of the specimen. Moreover, to measure the horizontal displacement, which was expected for the 1200 and 1500 mm height columns, two LVDTs were placed horizontally of the mid-height of the column 90 degrees around the column. These LVDTs were used to measure the horizontal displacement of the column during the test. All the specimens were prepared before the test by a thin layer of the high strength sulfur capping on the top and bottom surfaces to insure the uniform stress distribution during the test. Finally, the specimens were tested using a 6,000 kN capacity FORNEY machine, where the CFFT column was setup vertically at the center of loading plates of the machine.

III. TEST RESULTS AND DISCUSSION

The ultimate confined concrete strength, final failure mode and ultimate load capacity were affected by the variation in the slenderness ratio of the CFFT columns. Specimens C-2-30 failed at an average ultimate axial load for the two specimens equal to 1585 kN. The failure occurred due to the rupture of the fibre in the hoop direction with brittle failure at the ultimate hoop stress resulting from the dilation of the concrete. The fracture of the GFRP tubes occurred along the total height of the cylinders started from top or bottom and extending to the opposite direction see Figure 3.

Specimen C-4-60 failed due to the rupture of the GFRP tube at the top end, continued to the third height of the specimen end accompanied by the crushing of concrete at ultimate load equal to 1741 kN. The failure of the CFFT columns No. 3 occurred due to buckling immediately followed by the rupture of the GFRP tube at 90 % of the ultimate failure load (1595 kN). For specimens C-8-120 and C-10-150 increasing the load up to 85% of the ultimate load, the horizontal displacement started and increased until buckling of a single curvature occurred without rupture of the GFRP tube. However the horizontal displacement approximately approached zero up to load level 85 % of the ultimate load.

The stress-strain curves for the confined and unconfined CFFT columns are shown in Figures 4. For all specimens, the results show that the stress-strain curve of the CFFT is bilinear shape with sharp softening in the transition zone above the stress level of the unconfined concrete strength. The stress-strain responses are similar such as in or as reported by (Teng & Lam 2002; Samaan et al. 1998; Mirmiran & Shahawy 1997b). The average ratios of confined concrete compressive strength to unconfined concrete strength for CFFT columns from specimen No. 1 to 5 were 1.9, 2.1, 1.9, 1.70 and 1.4, respectively.

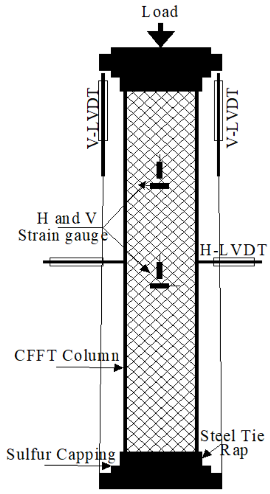

Figure 2. Test setup.

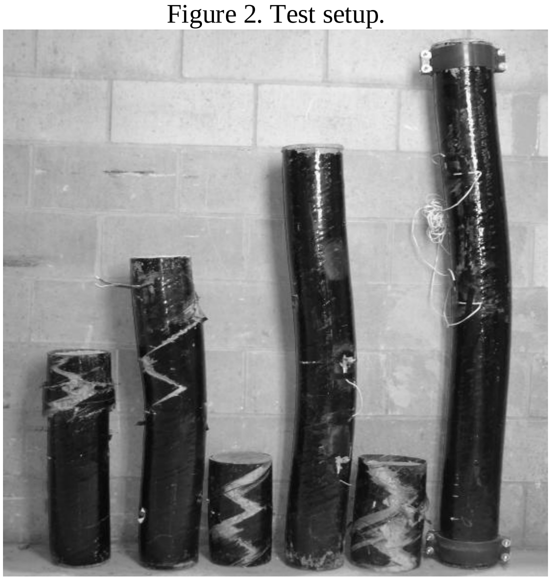

Figure 3. Different failure modes of the slender CFFT columns.

As shown in Figure 4, the strength of the confined concrete decreased with increasing the slenderness ratio of the CFFT columns. The maximum confinement strength was observed for specimen C-4-60 equal to 127.6 MPa, and the minimum confinement strength was observed for the specimen C-10-150 which equal to 66.25 MPa. However, specimen C-2-30 has lower slenderness ratio than C-4-60, but the increase in the concrete strength results from the presence of the longitudinal steel bars inside specimen C-4-60, which increases the ultimate load capacity of the column. Figure 5, presents the relationship between the ultimate load capacity and the slenderness ratio for all CFFT specimens. It is significantly clear that by increasing the slenderness ratio of the CFFT columns, the ultimate load capacity is decreased.

The axial displacement data for each specimen obtained by the two vertical LVDTs during the test were plotted against the axial load for each specimen. To study the effect of the slenderness ratio on the deformation of the CFFT columns, Load-axial and lateral displacement relationships for each specimen were plotted as shown in Figure 6 and 7, respectively. First, a linear response appeared prior to yielding of steel reinforcement. At 0.67 of the unconfined concrete strength, the specimen started to show nonlinear response with nominal residual displacements. For all specimens the maximum axial displacement increased up to failure.

The initial tangent modulus for different CFFT columns heights showed the similar behavior until yielding or softening stages as a linear response, However, the initial tangent modulus of the CFFT specimens of slenderness ratio equal to 8 and 10 showed lower values more than of the rest of the specimens. Actually, for specimens C-10-150 no enhancement in the ductility or in the strength was occurred after softening stage and the load decreased up to failure with a progressive increase in the lateral deformation. Figure 6 showed that by increasing the slenderness ratio of the CFFT, the maximum axial deformation increase and accompanied by a reduction in the ultimate load capacity.

Figure 7 showed the load-lateral deformation for specimens C-8-120 and C-10-150. It is clear that the lateral deformation resulted from the buckling instability progressively increased and cause the final mode of failure for these specimens with a permanent single curvature at the failure load.

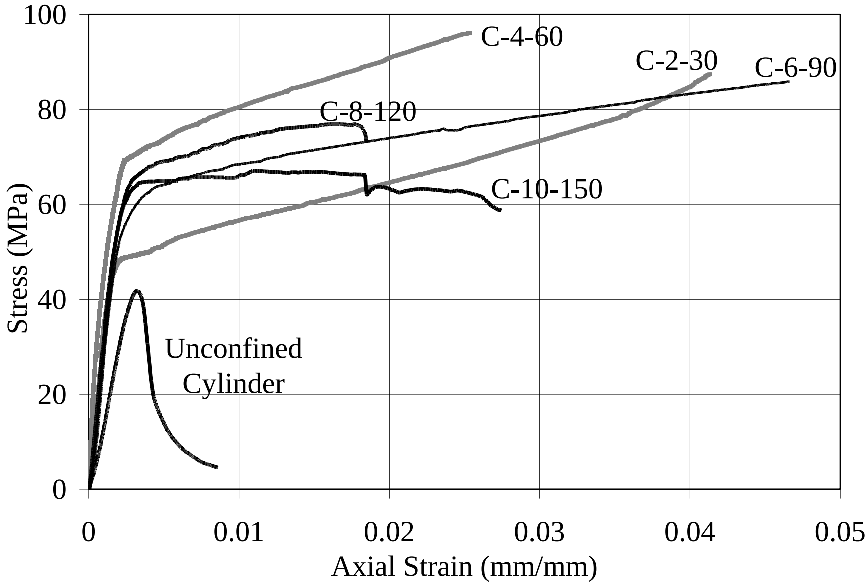

Figure 4. Stress-strain relationship.

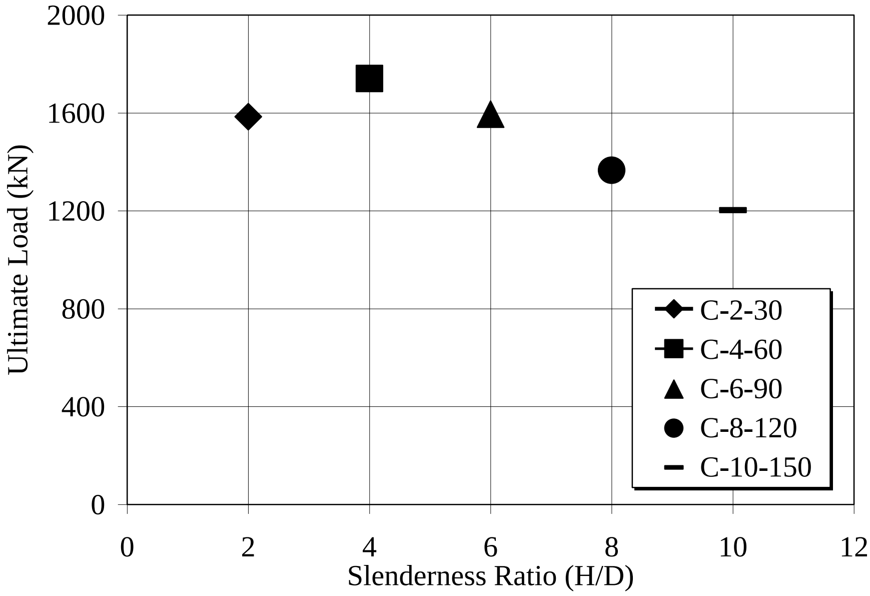

Figure 5. Load-slenderness ratio relationship.

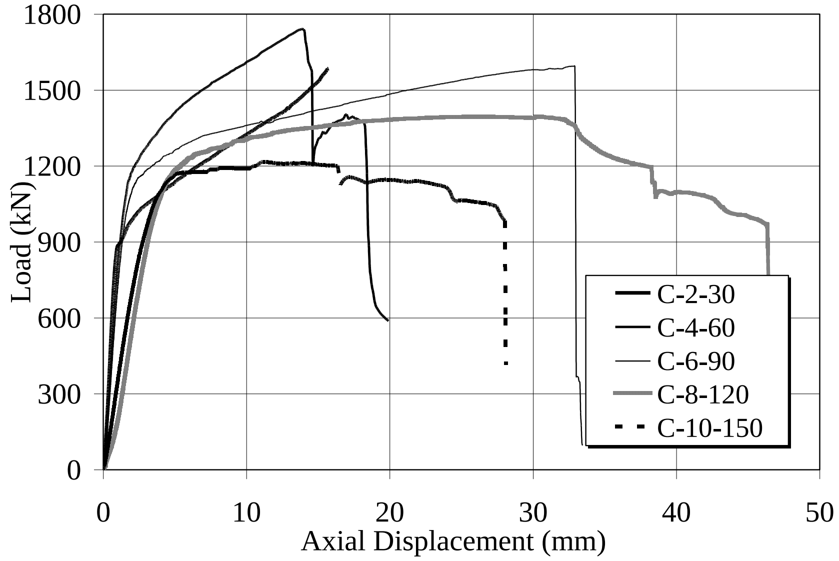

Figure 6. Load- axial deformation relationship.

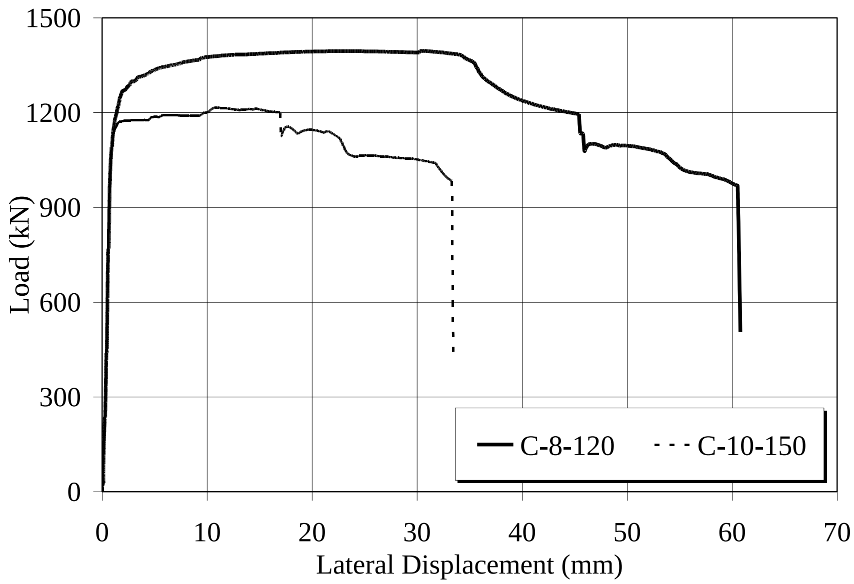

Figure 7. Load-lateral deformation relationship.

IV. CONCLUSION

In general, the behavior of the reinforced concrete filled GFRP tubes, the confinement, axial stress-strain responses, axial and horizontal deformation, failure mode, and ultimate load capacity were affected by the slenderness ratio. The behaviors of small, medium and long CFFT columns for different slenderness ratio under concentric axial loading were presented. The experimental results for 10 unconfined cylinders and 6 confined CFFT columns were investigated. The slenderness radios 2, 4, 6, 8 and 10 of the CFFT specimens were examined in the present study. The findings of this research can be summarized as follows: The confinement provided by the GFRP tubes improves both the load-carrying capacity and the ductility of the concrete columns. The final failure mode for CFFT is affected by the slenderness ratio, rupture of the GFRP tube for slenderness ratio equals to 2 and 4, buckling accompanied by rupture of the GFRP tube for specimens slenderness ratio equals to 6, and finally, buckling failure is the final mode for specimens slenderness ratio equal to 8 and 10 without rupture for the GFRP tube. The slenderness ratio of CFFT specimens does not affect the stress-strain responses or ductility but in general, reduces the ultimate capacity of the specimens due to the buckling of the columns. By increasing the slenderness ratio the ultimate load capacity of CFFT columns is reduced.

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