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Abstract

This study investigated the behaviour of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns under eccentric loading. A total of four reinforced concrete columns with 240 mm in diameter and 800 mm in height were cast and tested under concentric or eccentric loading conditions. The first column was the reference column which was reinforced with steel helix and longitudinal steel bars, and the other three identical columns were reinforced with GFRP tubes. The cover thickness was 28 mm on the sides and 20 mm at the top and bottom ends. All the columns were made from normal strength concrete (compressive strength of 35 MPa). The reference column was subjected to concentric loading. For the other three GFRP tube reinforced concrete columns, one column was subjected to concentric loading, while the other two columns were subjected to eccentric loading with eccentricities of 25 mm and 50 mm. It has been shown that GFRP tube reinforced concrete column obtained higher load carrying capacity than steel reinforced concrete column under concentric loading. Eccentric loadings dramatically reduced the load carrying capacity of GFRP tube reinforced concrete columns.

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BEHAVIOUR OF GFRP TUBE REINFORCED CONCRETE COLUMNS UNDER ECCENTRIC LOADING

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Keywords: GFRP tube, Columns, Eccentric loading, Load carrying capacity

ABSTRACT

This study investigated the behaviour of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns under eccentric loading. A total of four reinforced concrete columns with 240 mm in diameter and 800 mm in height were cast and tested under concentric or eccentric loading conditions. The first column was the reference column which was reinforced with steel helix and longitudinal steel bars, and the other three identical columns were reinforced with GFRP tubes. The cover thickness was 28 mm on the sides and 20 mm at the top and bottom ends. All the columns were made from normal strength concrete (compressive strength of 35 MPa). The reference column was subjected to concentric loading. For the other three GFRP tube reinforced concrete columns, one column was subjected to concentric loading, while the other two columns were subjected to eccentric loading with eccentricities of 25 mm and 50 mm. It has been shown that GFRP tube reinforced concrete column obtained higher load carrying capacity than steel reinforced concrete column under concentric loading. Eccentric loadings dramatically reduced the load carrying capacity of GFRP tube reinforced concrete columns.

1 INTRODUCTION

In recent years, the use of FRP tube in the form of concrete-filled FRP tubes (CFFTs) for the construction of new concrete columns has been widely studied. The FRP tube can provide passive confinement to the concrete core, which can lead to increase in the strength and ductility of columns. In spite of many advantages, the CFFTs may experience significant performance deterioration when the columns are subject to harsh environments such as freeze-thaw cycles, ultraviolet radiation, high temperature, or combined effects [1]. Moreover, due to the linear elastic properties of FRP tubes, the CFFTs always fail in a brittle manner without prior warning. Due to the above limitations, the applications of CFFTs have been narrowed.

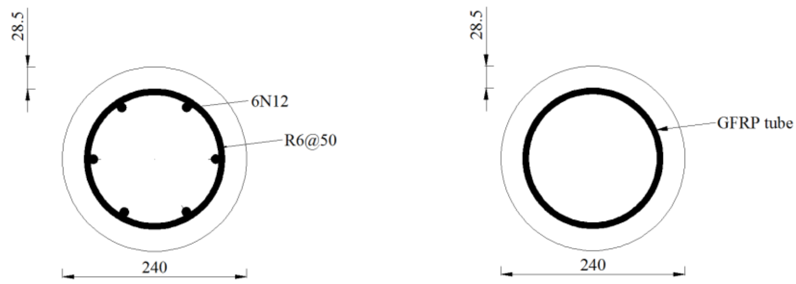
In order to solve the apparent disadvantages of the CFFTs, a new composite column named FRP tube reinforced concrete (FTRC) columns has been proposed by the authors [2]. This composite column consists of an inner concrete-filled FRP tube and a concrete cover. Compared to CFFTs, the performance of FTRC column under freeze-thaw cycles, ultraviolet radiation, and high temperature can be significantly improved because of the presence of concrete cover. Also, the spalling of concrete cover can be used as a suitable indication before sudden failure. Previous studies showed that FTRC columns can obtain a considerable strength and ductility under axial compression [2,3]. Even though the behaviour of FTRC columns under axial compression has been investigated previously, the performance of FTRC columns under eccentric axial loading has not been investigated yet. However, it is common that concrete columns are always subjected to a combination of axial load and bending moment, and the confinement effectiveness of FRP composites in eccentrically loaded concrete columns is much less than that of concentrically loaded concrete columns [4]. Therefore, it is necessary to investigate the behaviour of FTRC columns under eccentric axial loading.

2 EXPERIMENTAL PROGRAM

An experimental program was conducted at the High Bay Civil Engineering Laboratory of the University of Wollongong, Australia, to investigate the behaviour of full-scale FRP tube reinforced concrete (FTRC) columns under concentric and eccentric loadings.

2.1 Design of Experiment

A total of four columns with a length of 800 mm and a diameter of 240 mm were cast and tested under concentric and eccentric loadings. The cover thickness was 28 mm on the sides and 20 mm at the top and bottom ends. The first column (REF) was a steel reinforced concrete column which was designed in accordance with AS 3600 [5]. The reinforcement consisted of 6N12 bars (12 mm deformed bars with a nominal tensile strength of 500 MPa) as longitudinal bars and R10 bars (10 mm plain bars with a nominal tensile strength of 250 MPa) as transverse reinforcement in the form of helix with a pitch of 50 mm. The other three columns were GFRP tube reinforced concrete (FTRC) columns. The GFRP tubes were supplied by Exel Composites Australia [6] and had an inner diameter of 167 mm. The thickness of the tubes was 8 mm. The reference column was subjected to concentric loading. One of the three FRTC columns was subjected to concentric loading, and the other two were subjected to eccentric loading with eccentricities of 25 mm and 50 mm. Figure 1 shows the cross-sections of the tested columns.



(a) REF (b) FTRC-0, FTRC-25, and FTRC-50

Figure 1 Cross-sections of columns (all units are in mm).

The notation of the columns consists of two parts: the first part is REF or FTRC, which indicates the types of columns (REF indicates column reinforced with steel helixes and steel bars and FTRC indicates columns reinforced with GFRP tubes). The second part is either 0, 25, or 50, which indicates the loading conditions (0 indicates concentric loading; 25 indicates eccentric loading with 25 mm eccentricity; and 50 indicates eccentric loading with 50 mm eccentricity). Table 1 shows the detailed test matrix.

Table 1 Test Matrix.

Column	Internal Reinforcement	Test Modes
REF-0	6N12 and R10@50 mm	Concentric
FTRC-0	GFRP tube	Concentric
FTRC-25	GFRP tube	Eccentric, e=25 mm
FTRC-50	GFRP tube	Eccentric, e=50 mm

2.2 Preparation of Columns

The N12 and R10 steel bars were provided by a local supplier. The N12 steel bars were cut into lengths of 760 mm to ensure a concrete cover of 20 mm at the top and bottom of the columns. The R10 steel bars were outsourced to a local steel fabrication company to manufacture steel helix with 50 mm pitch and 183 mm outer diameter. Afterwards, the six N12 steel bars were fixed to the steel helix using steel wire to form the reinforcement cage for column REF-0.

The GFRP tubes used in this study were manufactured by Exel Composites Australia based in Boronia, Victoria, Australia [6]. The GFRP tubes were pultruded tubes made from vinyl ester resin systems with E-glass fibre. GFRP tubes were cut into 760 mm in length to provide reinforcement for Columns FTRC-0, FTRC-25, and FTRC-50. The mechanical properties of GFRP tubes provided by the manufacturers are listed in Table 2.

Table 2 Mechanical properties of GFRP tubes [6].

Ultimate Tensile Strength (MPa)		Ultimate Compressive Strength (MPa)		Modulus of Elasticity (GPa)	
Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
450	50	450	80	30	10

The moulds for casting of columns were made of PVC pipe with an inner diameter of 240 mm. Before pouring of the concrete, all the moulds were aligned vertically by a formwork made from timber. The formwork was vertically fixed to a base and tied together laterally with timber. Moreover, the bottom ends of the PVC moulds were evenly greased with Vaseline to prevent the leakage of water from the concrete.

The concrete was supplied by a local concrete provider. The nominal compressive strength was 32 MPa and the maximum aggregate size was 10 mm. Before casting of concrete, the concrete was delivered to the High Bay Civil Engineering Laboratory at the University of Wollongong. The steel reinforcement cages and the GFRP tubes were placed into the moulds first, and then the concrete was cast according to AS 1012.8.1 [7]. After casting, all the concrete columns were covered with wet burlap with plastic sheets on top to prevent moisture loss and allow continual hydration of the cement. All the columns were watered during the weekdays until the test date.

Compressive tests of concrete cylinders at 28 days showed that the average compressive strength of the concrete was 35 MPa. Three specimens of N12 deformed bars and R10 plain bars (250 mm length) were tested in accordance with AS 1391 [8]. The test results revealed that the average tensile strengths of N12 and R10 steel bars were 440 MPa and 400 MPa, respectively.

2.3 Instrumentation and Test Procedure

The Denison 5,000 kN testing machine was used for testing all the columns. The columns were capped with high-strength plaster at both ends to ensure uniform load distribution between the loading heads and the columns. The first loading head was placed on the flat steel plate and the column was then seated vertically upon it. Calibration was then performed to ensure that the columns were placed at the centre of the testing machine. After the calibration, the second loading head was then placed onto the top of the columns. Axial deformations were measured using two Linear Variable Differential Transducers (LVDTs), which were mounted diagonally at opposite corners between the loading plate and supporting steel plate. The deformation readings from the two LVDTs were then averaged to obtain representative results.

For eccentrically loaded columns, the loading was applied to the columns by an especially designed loading heads. Detailed description of the loading system could be found in Yazici and Hadi [9]. In order to measure the lateral deflection for the eccentrically loaded columns, a laser triangulation device was set up at mid-height of the column and connected to the data logger as well. All the tests were conducted as deformation controlled with a rate of 0.3 mm/min.

3 EXPERIMENTAL RESULTS

The failure modes are shown in Figure 2. Column REF-0 failed gradually due to cover spalling and the buckling of longitudinal steel bars (Figure 2 (a)). Column FTRC-0 failed suddenly due to the rupture of GFRP tube with a loud noise, and almost all the concrete cover spalled off at the time of failure (Figure 2 (b)). For Columns FTRC-25 and FTRC-50, the columns failed due to the rupture of GFRP tubes at the compression region, and a loud noise was heard as well. No rupture was observed onto the GFRP tube in the tension region for Columns FTRC-25 and FTRC-50. It is noted that for Columns FTRC-25 and FTRC-50, even though the concrete cover at the compression region was spalled off, the concrete cover remained onto the surface of GFRP tubes at the tension region (Figure 2 (c), (d)). However, severe cracks were observed on the concrete cover at the tension region, which indicates that the concrete cover already lost the capacity to carry load on the tension region.

(a) REF-0 (b) FTRC-0 (c) FTRC-25 (d) FTRC-50

Figure 2 Failure modes of tested columns

Figure 3 shows the axial load-axial deformation behaviour of Columns REF-0 and FTRC-0. Similar behaviour can be observed before the yielding of columns. After the yield loads were reached, both columns experienced load reductions due to the spalling of cover concrete. A continuous decrease of axial load was observed for Column REF-0. While for Column FTRC-0, the axial load began to increase again since the confinement provided by the GFPR tube to the concrete core was activated as well as the increased axial load carried by the GFRP tube. Even though higher ultimate load can be observed for Column FTRC-0, the deformation capacity was significantly less than that of steel reinforced concrete Column REF-0 [10,11].

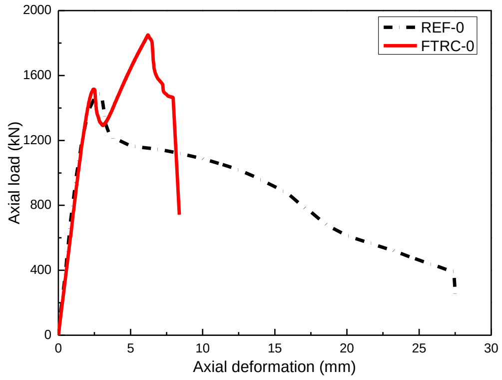


Figure 3 Behaviour of Columns REF-0 and FTRC-0 under loading

Figure 4 shows the behaviour of Columns FTRC-0, FTRC-25, and FTRC-50 under loading. It is evident that with the increase of eccentricity, the load carrying capacity of FTRC columns decreased significantly. This phenomenon was mainly attributed to the existence of strain gradient. Moreover, the lateral deflections of Columns FTRC-25 and FTRC-50 were less than those of corresponding axial deformations. This is due to the high axial stiffness of GFRP tube which may prevent the lateral deflection of columns.

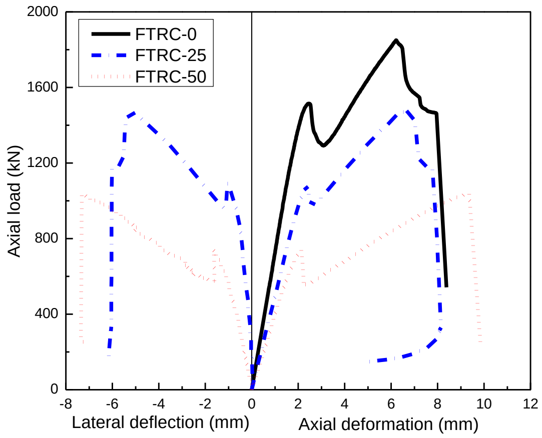


Figure 4 Behaviour of Columns FTRC-0, FTRC-25, and FTRC-50 under loading

Table 3 summarizes the test results of all concrete columns. The yield load, the ultimate load as well as the corresponding axial deformations and lateral deflections have been presented. It can be seen from Table 3 that for Columns FTRC-25 and FTRC-50, the axial deformations at ultimate axial loads were higher than the axial deformations at ultimate loads for Column FTRC-0. This is because with the increase of eccentricity, the expansion of concrete core is less significant. Therefore, the hoop tensile rupture of GFRP tube can occur with a higher axial strain. Moreover, the lateral deflections of FTRC columns increased with the increase of eccentricities.

Table 3 Summary of test results.

Column	Yield load (kN)	Axial deformation at yield load (mm)	Ultimate load (kN)	Axial deformation at ultimate load (mm)	Lateral deflection at ultimate load (mm)
REF-0	1486	2.83	1486	2.83	--
FTRC-0	1515	2.47	1850	6.21	--
FTRC-25	1091	2.40	1474	6.70	5.14
FTRC-50	741	2.29	1038	9.36	7.31

4 CONCLUSIONS

FRP tube reinforced concrete (FTRC) columns (FTRC-0) can obtain a higher load carrying capacity than steel reinforced concrete column (REF-0) under axial compression. The deformation capacity is less than that of steel reinforced concrete column (REF-0).

The load carrying capacity of FTRC columns decreased significantly when the columns were subjected to eccentric axial loading, which is mainly due to the existence of strain gradient. The load carrying capacity of FTRC columns decreased continuously with the increase of eccentricity.

For eccentrically loaded FTRC columns (FTRC-25 and FTRC-50), the axial deformation at ultimate load was higher than that of concentrically loaded FTRC columns (FTRC-0). This is mainly attributed to the lower tensile properties of GFRP tubes, which may lead to premature tensile rupture of GFRP tubes under concentric loading.

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REFERENCES

[1] M.F. Green, L.A. Bisby, A.Z. Fam, V.K.R. Kodur. FRP confined concrete columns: Behaviour under extreme conditions. Cement and Concrete Composites, 2006, 28:928-937.

[2] M.N.S. Hadi, W. Wang, M.N. Sheikh. Axial compressive behaviour of GFRP tube reinforced concrete columns. Construction and Building Materials, 2015, 81:198-207.

[3] W. Wang, M.N. Sheikh, M.N.S. Hadi. Behaviour of GFRP tube reinforced concrete columns under axial compression. Proceedings of the Seventh International Conference on FRP Composites in Civil Engineering (CICE 2014), August 20-22, 2014, Vancouver, Canada.

[4] M.N.S. Hadi. Behaviour of FRP wrapped normal strength concrete columns under eccentric loading. Composite Structures, 2006,72:503-511.

[5] AS 3600-2009. Concrete structures. Standards Australia Limited, NSW; 2009.

[6] Exel Composites Australia. 991 Mountain Highway, Boronia, Melbourne, VIC Australia. http://www.exelcomposites.com.au/ (Accessed on March 2015).

[7] AS 1012. 8.1-2000. Methods of testing concrete: Method of making and curing concrete - Compression and indirect tensile test specimens. Standards Australia Limited, NSW; 2000.

[8] AS 1391-2007. Metallic materials-tensile testing at ambient temperature. Standards Australia Limited, NSW; 2007.

[9] V. Yazici, M.N.S. Hadi. Axial load-bending moment diagrams of carbon FRP wrapped hollow core reinforced concrete columns. Journal of Composites for Construction, 2009, 13(4):262-268.

[10] M.N. Sheikh, H.H. Tsang, T.J. McCarthy, N.T.K. Lam. Yield curvature for seismic design of circular reinforced concrete columns. Magazine of Concrete Research, 2010, 62 (10):741–748.

[11] M.N. Sheikh, F. Légeron. Performance based seismic assessment of bridges designed according to canadian highway bridge design code. Canadian Journal of Civil Engineering, 2014, 41(9): 777-787.