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Abstract

This paper reports the result of an experimental investigation on the behaviour of Glass Fibre Reinforced Polymer (GFRP) tube reinforced concrete columns under axial compression. The GFRP tube was placed into the concrete to provide reinforcement both in the longitudinal and transverse directions. In this study, a total of 8 columns with 150 mm diameter and 300 mm height were cast and tested under axial compression. The columns were divided into four groups and each group contains two identical columns. The first group had two columns of plain concrete, and the remaining three groups were reinforced with solid, axially perforated and diagonally perforated GFRP tubes, respectively. The test results showed that for columns reinforced with solid GFRP tube, both the load-carrying capacity and the ductility capacity improved significantly. However, for axially perforated FRP tube reinforced columns, the load-carrying capacity increased only slightly. For diagonally perforated GFRP tube reinforced columns, the ductility capacity improved notably, but the increase was less than the increase in the solid GFRP tube reinforced columns.

Keywords

behaviour, reinforced, columns, tube, gfrp, concrete, compression, axial, under

Disciplines

Engineering | Science and Technology Studies

Publication Details

Wang, W., Sheikh, M. Neaz., Hadi, M. N. S. & Lyons, B. (2014). Behaviour of GFRP tube reinforced concrete columns under axial compression. 7th International Conference on FRP Composites in Civil Engineering (CICE 2014) (pp. 1-6). United States: International Institute for FRP in Construction.

BEHAVIOUR OF GFRP TUBE REINFORCED CONCRETE COLUMNS UNDER AXIAL COMPRESSION

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ABSTRACT: This paper reports the result of an experimental investigation on the behaviour of Glass Fibre Reinforced Polymer (GFRP) tube reinforced concrete columns under axial compression. The GFRP tube was placed into the concrete to provide reinforcement both in the longitudinal and transverse directions. In this study, a total of 8 columns with 150 mm diameter and 300 mm height were cast and tested under axial compression. The columns were divided into four groups and each group contains two identical columns. The first group had two columns of plain concrete, and the remaining three groups were reinforced with solid, axially perforated and diagonally perforated GFRP tubes, respectively. The test results showed that for columns reinforced with solid GFRP tube, both the load-carrying capacity and the ductility capacity improved significantly. However, for axially perforated GFRP tube reinforced columns, the load-carrying capacity increased only slightly. For diagonally perforated GFRP tube reinforced columns, the ductility capacity improved notably, but the increase was less than the increase in the solid GFRP tube reinforced columns.

1. Introduction

Steel bar has been traditionally used as reinforcement in the construction of Reinforced Concrete (RC) structural members. However, corrosion of steel bar has been the major cause of deterioration of RC members, which compromises the serviceability of the structure. On the other hand, fiber reinforced polymer composite materials have been recently used as reinforcement due to their high strength to weight ratio and corrosion resistance. The application of Glass Fibre Reinforced Polymer (GFRP) tube to strengthen concrete columns has recently been investigated (Mirmiran, et al., 1998; Fam and Rizkalla, 2001; Fam and Rizkalla, 2002; Fam, et al., 2005; Shao and Mirmiran, 2005). The GFRP tube acts as structural formwork during construction and confines lateral expansion of the concrete under axial and flexural load. Besides, GFRP tube has the potential to increase the service life of the structure and reduce maintenance, repair and replacement costs. Therefore, GFRP tube can substitute steel reinforcement in RC members, especially in bridge piers and marine piles.

Although GFRP tube can be a viable alternative to traditional steel reinforcement, it presents significantly different design challenges. The main challenges of the use of GFRP tubes as reinforcement for columns include (1) column externally reinforced with GFRP tube behaves in a brittle manner and fails without prior warning; and (2) the susceptibility of the tube to be damaged in fire or under impact loading limiting the application of GFRP tube in architectural construction (Ji, et al., 2008).

To address these challenges, a new form of GFRP tube confined concrete columns is proposed in this paper. The GFRP tube has been placed into the concrete, which is distinctly different from previous studies. The challenges can be addressed as (1) the bonding strength is increased due to increased interface between GFRP tube and concrete, (2) the spalling of concrete cover can be used as an indication of eminent failure due to the rupture of GFRP tube, and (3) the fire performance and impact resistance of the columns are improved as the concrete cover protects the GFRP tube. In this paper, the strength and the ductility capacity of concrete columns reinforced with perforated and solid GFRP tubes have been investigated.

2. Experimental Programme

The experimental programme was carried out at the High Bay Laboratory of the University of Wollongong. All materials were provided by local suppliers.

2.1. Design of Experiments

A total of eight circular columns were cast and tested. The columns were 150 mm in diameter and 300 mm in height. Concrete clear cover was 30 mm on the sides and 20 mm at the top and bottom. Four groups of columns were tested. Each group contains two identical columns. Group REF columns were used as reference columns which contain no reinforcement (Table 1). Group ST columns were internally reinforced with solid GFRP tube. Columns in Group APT and Group DPT were internally reinforced with perforated GFRP tubes. APT specifies the columns reinforced with axially perforated GFRP tubes and DPT specifies the columns reinforced with diagonally perforated GFRP tubes. GFRP tubes were 6 mm thick with 77 mm inner diameter. Each tube was 260 mm long. 25 mm diameter circular holes were drilled in the GFRP tubes. Two different perforation patterns (APT and DPT) were created in the tubes. Four rows of holes were drilled in each tube. The rows were symmetrically distributed along the tube circumference. The clear spacing between holes was 40 mm. 16 holes were drilled in axially perforated tubes and 14 holes were drilled in diagonally perforated tubes. Fig. 1 shows the elevation and cross-section of reinforced column specimens and Fig. 2 shows the GFRP tubes with different configurations.

Table 1 – Test Matrix

Specimen	Description	Reinforcement
REF	Plain concrete columns	None
ST	GFRP tube reinforced concrete columns	Solid GFRP tube
APT		Axially perforated GFRP tube
DPT		Diagonally perforated GFRP tube

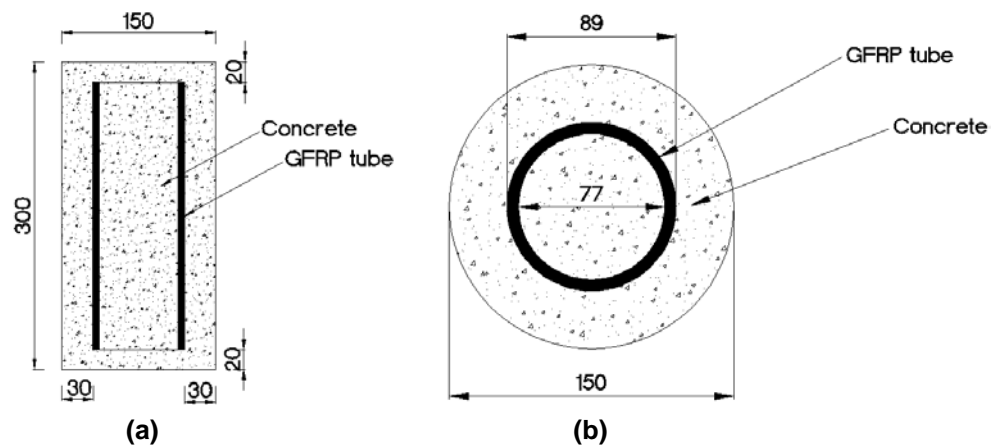


Fig. 1 – Reinforced column specimen: (a) elevation and (b) cross-section (dimensions are in mm)



Fig. 2 – GFRP Tubes (solid tube, axially perforated tube, and diagonally perforated tube)

2.2. Preparation of Columns

The moulds were made of PVC pipes with inner diameter of 150 mm and height of 300 mm. Before concrete casting, the GFRP tubes were placed into the mould first. Three tiny holes were drilled within the base as well as at the bottom of GFRP tube. The holes were 10 mm long. Afterwards, three 40 mm long thin steel wires were inserted into the tube and the base to support the GFRP tube to maintain 20 mm concrete cover both at the top and at the bottom of the specimen. After curing of concrete, the steel wires were removed from the concrete columns. Moreover, four steel wires were aligned symmetrically around the top end of GFRP tube to ensure 30 mm cover on the sides of the specimen. The steel wires were removed after two thirds of the concrete had been cast. Each mould was stabilized vertically by three galvanized steel straps and two hose clips. Fig. 3 shows the layout of GFRP tubes in the moulds.



Fig. 3 – Layout of GFRP tubes: (a) 20 mm cover at bottom and (b) 30 mm cover on the sides

Normal strength concrete was used. The maximum size of the coarse aggregate was 10 mm. Concrete was mixed and cast in accordance with Standards Australia (AS 1012.2, 1994 and AS 1012.3.1, 2000). After casting, a wet hessian was placed over the columns to prevent moisture loss. All the columns were watered during weekdays until the test date. To prevent premature failure, the top and the bottom of the columns were strengthened by two layers of Carbon Fibre Reinforced Polymer (CFRP) sheets. 70 mm overlapping was applied. The columns were then capped at the top end with high strength plaster to ensure uniform load application. Fig. 4 shows the GFRP tube reinforced concrete column specimens.



Fig. 4 – GFRP tube reinforced concrete column specimens

2.3. Preliminary Tests

Concrete slump test was conducted according to Standards Australia (AS 1012.3.1, 1998). The concrete had a slump of 80 mm. Concrete cylinders with 100 mm diameter and 200 mm height were tested for

compressive strength at 7 and 28 days. The average compressive strengths at 7 and 28 days were 26 MPa and 35 MPa, respectively.

The properties of GFRP tube were determined from tube compression test. Three groups of GFRP tubes were tested under axial compression. Table 2 shows the ultimate load and the axial deflection at ultimate load for GFRP tubes. For the solid GFRP tube, the average ultimate compression strength was 400 MPa and the corresponding strain was 0.014. The average elastic modulus was 36.5 GPa.

Table 2 – Results of tube compression test

Tube types	ST	APT	DPT
Ultimate load (kN)	624	375	337
Axial deflection at ultimate load (mm)	3.59	3.58	2.98

2.4. Test Setup

All columns were tested using the Denison testing machine, which has an ultimate compressive load capacity of 5000 kN. Axial displacements of the columns were measured using LVDT (Micro-Measurement LDC1000A). All the tests were displacement controlled. The loading rate was set to 0.5 mm/min. All columns were tested until failure. The load and displacement data were collected using an electronic data-logger attached to the testing machine.

3. Results of Experimental Programme

3.1. Load-Axial Deflection Behaviour

Fig. 5 shows the load-axial deflection behaviour of the tested columns. It can be seen that all columns showed similar behaviour before yielding. Afterwards, columns reinforced with GFRP tubes showed decrease in the strength with increase in the deflection. This behaviour is attributed to the spalling of concrete clear cover. It is noted the concrete clear cover was 30 mm at the sides and hence significant decrease in the strength of the columns was expected. Afterwards, the strength of the column was increased with the increase in deflection because of the confining effect of GFRP tube. Finally, all the columns failed due to the rupture of the GFRP tube. It is evident from Fig. 5 that several fluctuations in the applied load of the columns occurred before failure.

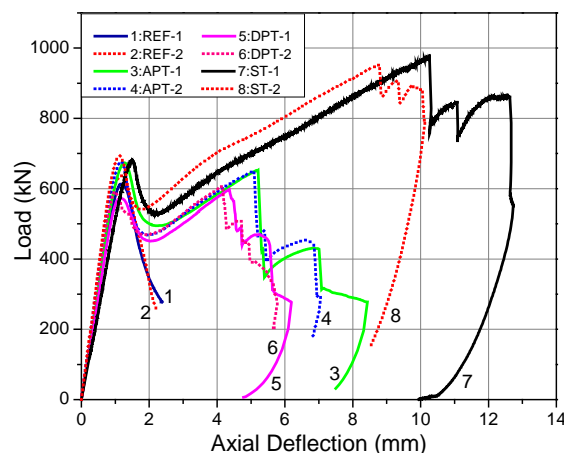


Fig. 5 – Load-Axial Deflection Diagram

Fig. 6 shows the failure modes observed in GFRP tube reinforced concrete columns. The failure modes observed depended largely on the perforation pattern of GFRP tubes. The columns in Group ST failed because of the rupture of GFRP tube at the longitudinal direction and in-plane shear. For columns in Group APT, rupture was observed between two neighbouring holes aligned in the transverse direction. For columns in Group DPT, rupture was observed at the middle of three neighbouring holes aligned in transverse direction.

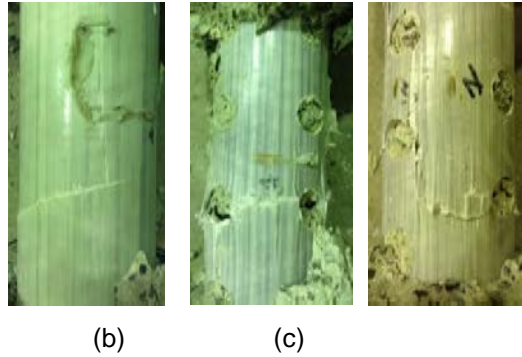


Fig. 6 – Failure Modes: (a) ST (b) APT (C) DPT

3.2. Summary of Test Results

Table 3 summarises the test results of all columns. The yield load and ultimate load as well as the corresponding deflections were recorded. Here the ductility capacity was calculated as the ratio of axial deflection at ultimate load and axial deflection at yield load. It is noted that ductility capacity is an important parameter for the design of structural members under seismic loadings (Sheikh, et al., 2010; Hadi and Schmidt, 2002). It can be seen that Group ST columns showed significant increase in both ductility and load-carrying capacity. For columns in Group APT, the yield load and the ultimate load increased but less significantly compared to Group ST columns. The ductility of Group DPT columns improved notably but less than that of Group ST columns. It is evident that Group APT columns showed better performance in improving the load-carrying capacity while the Group DPT columns were more effective in increasing the ductility capacity.

Table 3. Summary of Test Results

Specimen	Yield load (kN)	Axial deflection at yield load, D_y (mm)	Ultimate load (kN)	Axial deflection at ultimate load, D_u (mm)	Ductility D_u/D_y
REF-1	613	1.18	613	1.18	1.00
REF-2	637	1.19	637	1.19	1.00
ST-1	680	1.59	975	10.34	6.50
ST-2	694	1.19	953	8.84	7.43
APT-1	674	1.32	674	1.32	1.00
APT-2	677	1.26	677	1.26	1.00
DPT-1	573	1.26	598	4.45	3.53
DPT-2	592	1.04	607	4.22	4.06

4. Discussion

- (1) The columns tested in this study had diameter of 150 mm with concrete clear cover of 30 mm. The inner diameter of the GFRP tube was 77 mm. Hence, as expected, significant drop in the load-carrying capacity of columns was observed after the spalling of concrete cover. The increase in the load-carrying capacity of the columns together with the improvement in the ultimate deflection of the columns was evident afterwards.
- (2) The use of perforated tubes is mainly to investigate the integration of the concrete core and concrete clear cover, which was not investigated before. The success of integration of the concrete core and concrete cover may result in increasing use of FRP tubes in concrete columns. It was observed that the strength of the perforated GFRP tube reinforced concrete columns was less than that of solid GFRP tube reinforced concrete columns because of the perforation pattern (mainly hole diameter) used in this study. Therefore, the effect of perforation patterns (e.g., hole diameter, number of holes, and the distance between holes) should be further investigated.
- (3) The failure modes of the GFRP tube reinforced concrete columns is dominated by the rupture of the GFRP tube around the hole area. Therefore, some measures should be taken to protect the areas

around the holes from rupture to further increase the strength of the columns.

5. Conclusions

Based on the experimental investigation of this study, the following conclusions can be drawn:

- (1) Group ST columns achieved the highest load-carrying capacity and ductility capacity among the groups of columns tested in this study. Group APT columns showed slight increase in load-carrying capacity but did not improve the ductility capacity. The ductility capacity of Group DPT columns improved notably; however, the increase was less than the ductility capacity of Group ST columns.
- (2) The use of GFRP tube as internal reinforcement can avoid the corrosion problem and increase bonding strength between GFRP tube and concrete. The concrete cover not only protects the tube from fire and impact, but also indicates eminent rupture of GFRP tube. Moreover, the GFRP tube only reinforces the concrete core, thus the tube size is relatively small, which means less in material cost.
- (3) Finally, it can be concluded that using GFRP tubes can be a viable option for reinforcement of columns.

6. Acknowledgments

The authors acknowledge the contributions of Mr. Ritchie Mclean (technical officer) and Mr. Fernando Escribano (senior technical officer), especially for their help in carrying out the experiments. The authors thank Wagners Australia for providing GFRP tubes. Also, the first author would like to acknowledge the University of Wollongong and the China Scholarship Council for supporting his PhD scholarship.

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