1-1-2015

Confining concrete cover of GFRP tube reinforced concrete columns with polymer grids

Weiqiang Wang
University of Wollongong, ww674@uowmail.edu.au

M Neaz Sheikh
University of Wollongong, msheikh@uow.edu.au

Muhammad N. S Hadi
University of Wollongong, mhadi@uow.edu.au

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Abstract

This study presents the results of an experimental investigation on the behaviour of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns under axial compression. The polymer grids were embedded into the concrete cover of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns to reduce the spalling of concrete cover. A total of four column specimens were prepared and tested under axial compression. The columns were 150 mm in diameter and 300 mm in height. The first column was the reference column without any reinforcement. The second column was reinforced with GFRP tube without cover confinement. For the third and fourth GFRP tube reinforced concrete columns, concrete cover was confined with one layer and two layers of polymer grids, respectively. The test results show that FRP tube reinforced concrete columns can obtain much higher strength and ductility than reference column. Confining the concrete cover by polymer grids can effectively reduce the spalling of concrete cover.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Wang, W., Sheikh, M. Neaz. & Hadi, M. N. S. (2015). Confining concrete cover of GFRP tube reinforced concrete columns with polymer grids. In Z. Wu, G. Wu & X. Wang (Eds.), Joint Conference of the 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12) & the 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015) (pp. 1-6).

The 12th International Symposium on Fiber Reinforced Polymers for Reinforced Concrete Structures (FRPRCS-12)
& The 5th Asia-Pacific Conference on Fiber Reinforced Polymers in Structures (APFIS-2015)
Joint Conference, 14-16 December 2015, Nanjing, China

CONFINING CONCRETE COVER OF GFRP TUBE REINFORCED CONCRETE COLUMNS WITH POLYMER GRIDS

Weiqiang WANG [1,*], M. Neaz SHEIKH [2] and Muhammad N. S. HADI [3]

[1] School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
Email: ww674@uowmail.edu.au

[2] School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
Email: msheikh@uow.edu.au

[3] School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia
Email: mhadi@uow.edu.au

Keywords: GFRP tube, Concrete columns, Cover, Polymer grids, Strength, Ductility

ABSTRACT

This study presents the results of an experimental investigation on the behaviour of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns under axial compression. The polymer grids were embedded into the concrete cover of glass fibre reinforced polymer (GFRP) tube reinforced concrete columns to reduce the spalling of concrete cover. A total of four column specimens were prepared and tested under axial compression. The columns were 150 mm in diameter and 300 mm in height. The first column was the reference column without any reinforcement. The second column was reinforced with GFRP tube without cover confinement. For the third and fourth GFRP tube reinforced concrete columns, concrete cover was confined with one layer and two layers of polymer grids, respectively. The test results show that FRP tube reinforced concrete columns can obtain much higher strength and ductility than reference column. Confining the concrete cover by polymer grids can effectively reduce the spalling of concrete cover.

1 INTRODUCTION

A new type of composite column named FRP tube reinforced concrete (FTRC) column was recently proposed by the authors [1,2]. In FTRC column, the FRP tube is placed into the concrete column to provide reinforcement in both longitudinal and transverse directions. Compared to traditional concrete-filled FRP tubes (CFFTs), this new composite column is expected to achieve the following advantages: (1) the concrete cover can prevent the FRP tube from exposure of high temperature; (2) the concrete cover can avoid the adverse influence of freeze-thaw cycles and ultraviolet radiation on the FRP tube; and (3) the spalling of concrete cover can serve as a suitable indication before the brittle failure of concrete columns. Previous studies showed that FTRC columns can obtain considerable strength and ductility capacity under axial compression. FTRC column was found to be more competitive than other types of concrete columns especially in harsh environments that can lead to performance deterioration of steel reinforced concrete columns and concrete columns externally confined with FRP composites [1,2].

Despite many advantages, FTRC column is susceptible to premature spalling of concrete cover because the concrete core and concrete cover is separated by the FRP tube [1]. Since the concrete cover is essential to protect the FRP tube form extreme conditions [3], it is necessary to reduce the premature spalling of concrete cover. Hadi and Hua [4] used polymer grid to reduce the cover spalling of steel reinforced concrete columns. The polymer grid was placed between the concrete surface and the primary confinement reinforcement and was used as a secondary confinement of steel RC columns. The test results indicated that by applying polymer grid as the secondary confinement in the steel RC columns, the spalling of concrete cover could be effectively reduced by limiting the progression of cracks. Most of the concrete cover was remained onto the RC columns until failure. Moreover, considerable increases in strength and ductility was obtained.

In this research, an experimental program was carried out to investigate the use of polymer grid to reduce the cover spalling of FTRC column. Polymer grid was placed between the concrete surface and FRP tube, as shown in Figure 1. A total of four columns were cast and tested under axial compression. The axial load-axial deformation behaviour of FTRC columns was investigated. The failure modes, strength and ductility capacities were studied as well.

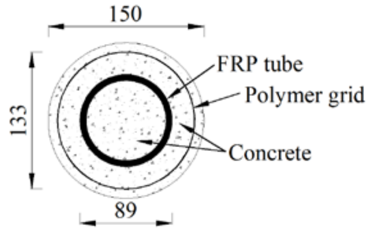


Figure 1 Cross-section of FTRC column

2 EXPERIMENTAL PROGRAM

The experimental program was conducted at the High Bay Civil Engineering Laboratory of the University of Wollongong, Australia.

2.1 Materials

Glass FRP (GFRP) tubes manufactured by Wagners CFT [5] were chosen to confine the concrete core of FRP tube reinforced concrete (FTRC) columns. The GFRP tubes were 6 mm thick with 77 mm inner diameter. The mechanical properties of GFRP tubes provided by the manufacturers are listed in Table 1.

Table 1 Mechanical properties of GFRP tubes [5].

Ultimate Tensile Strength (MPa)		Ultimate Compressive Strength (MPa)		Modulus of Elasticity (GPa)	
Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse
650	41	550	104	35.4	12.9

Polymer grid was chosen as the confinement material of the concrete cover of FTRC columns. The polymer grid was square in shape (36 × 36 mm) and was manufactured from polypropylene by Polyfabrics Australia Pty Ltd [6]. In order to provide confinement to the concrete cover, the polymer grid was formed into tubular shape (e.g., tubular polymer grid) and then held with plastic ties (Figure 2). The diameter of tubular polymer grid was 133 mm. The polymer grid was overlapped at an approximate length of 70 mm to ensure that the polymer grid would not be loosened or slid and to provide uniform confinement to the concrete cover.

Figure 2 Tubular polymer grids

Normal strength concrete with a design compressive strength of 32 MPa was used for casting of concrete columns. The maximum size of the coarse aggregate for concrete was 10 mm.

2.2 Test matrix

A total of four concrete columns with 150 mm in diameter and 300 mm in height were cast and tested under axial compression. One plain concrete column and three FTRC columns were tested in this study. For FTRC columns, the diameter of concrete core was 77 mm. The diameter of tubular polymer grid was 133 mm and the clear concrete cover (outside the polymer grid) was 10 mm on the sides. The clear concrete cover was 20 mm at the top and bottom of the column. Details of the test matrix are presented in Table 2. The labelling of concrete columns has been carried out as: "P" is used to identify plain concrete column; "FTRC" indicates FRP tube reinforced concrete (FTRC) columns; "0" indicates that no confinement was provided to the concrete cover of FTRC column, "1" indicates that the concrete cover was confined with one layer of polymer grid, and "2" indicates that the concrete cover was confined with two layers of polymer grids. For example, column FTRC-1 indicates that FTRC column for which the concrete cover was confined with one layer of polymer grid.

Table 2 Test matrix.

Specimen	Concrete core confinement	Concrete cover confinement
P	--	--
FTRC-0	GFRP tube	--
FTRC-1	GFRP tube	1 layer of polymer grid
FTRC-2	GFRP tube	2 layers of polymer grids

2.3 Preparation of concrete columns

For FTRC columns, GFRP tube and tubular polymer grid were placed into the mould before the casting of concrete. In order to ensure a 20 mm concrete cover at the top and bottom of the columns, three tiny holes were drilled into the timber base as well as at the bottom of GFRP tubes. The holes were 10 mm in depth. Afterwards, three 40 mm long thin steel wires were inserted into the holes to support the GFRP tubes and to maintain 20 mm concrete cover. The steel wires were removed from the concrete columns after curing of concrete. To ensure that the GFRP tube was in the middle of the mould, four thin steel wires were aligned symmetrically around the top end of GFRP tube [1]. The steel wires were removed after the casting of two thirds of the concrete. Concrete was mixed and cast according to AS 1012.9-1999 [7] and AS 1012.8.1-2000 [8]. All the concrete columns were watered during weekdays until the test date.

2.4 Preliminary tests

Concrete cylinders with 100 mm in diameter and 200 mm in height were tested for compressive strength at 28 days. The average compressive strength at 28 days was 35 MPa.

The properties of GFRP tubes were determined by tube axial compression test [1,9]. The average ultimate axial compressive strength was 400 MPa and the corresponding axial strain was 0.014 mm/mm. The axial elastic modulus was 33 GPa, which was close to the value provided by the manufacturer (35.4 GPa).

Tensile properties of the polymer grid were determined by testing polymer grid strands using the Instron 8033 machine, as shown in Fig. 3 (a). Each end of the polymer grid strands was embedded in steel clamps (Fig. 3 (b)). The two steel plates were then tightened towards each other in order to fix the polymer grid. The average ultimate tensile load per strand was approximately 1.30 kN. The average tensile strength was approximately 430 MPa with an elastic modulus of 6.5 GPa.

(a) Tensile test set up (b) Testing Clamps

Figure 3 Polymer grid tensile test

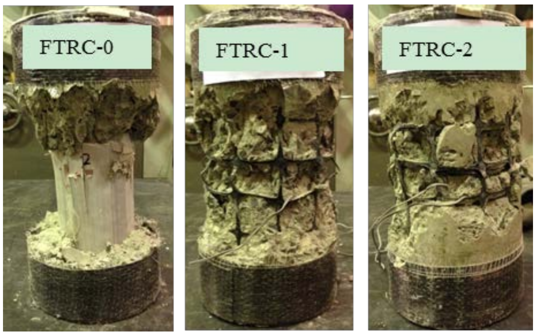
2.5 Instrumentation and test procedure

The Denison 5000 kN testing machine in the High Bay laboratory at University of Wollongong was used for testing all the columns. Before testing, all the columns were capped at the top end with high strength plaster to ensure uniform load application. An additional layer of CFRP was wrapped at both ends of the columns to prevent premature damage at the ends. The columns were placed vertically on the steel plate. Axial deformations were measured using two Linear Variable Differential Transducers (LVDTs), which were mounted at the corners between the loading plate and supporting steel plate. The deformation readings from the two LVDTs were averaged to obtain representative result. The load and deformation data were recorded using an electronic data-logger connected to a computer for every two seconds. The displacement controlled tests were carried out at a rate of 0.3 mm/min. All the columns were tested until failure.

3 EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Failure modes

Figure 4 shows the failure modes of tested columns. For FRP tube reinforced concrete (FTRC) columns, the concrete cover began to spall off when the unconfined concrete compressive strength was approached. Nevertheless, the columns still carried substantial amount of axial load up to a much higher axial deformation. The FTRC columns failed due to the longitudinal rupture of GFRP tubes, which was accompanied by a loud noise. For Column FTRC-0, most of the concrete cover spalled off (Figure 4 (a)) since no confinement was provided to the concrete cover. For Columns FTRC-1 and FTRC-2, the spalling of concrete cover was effectively controlled because of the confinement provided by the polymer grids (Figure 4 (b), (c)). This observation indicates that polymer grid is very effective in reducing the premature spalling of concrete cover of FTRC columns.



(a) FTRC-0 (b) FTRC-1 (c) FTRC-2

Figure 4 Failure modes of tested columns

3.2 Axial load-axial deformation behaviour

Figure 5 shows the axial load-axial deformation behaviour of columns. It can be seen that, up to yield load, all columns showed similar behaviour, i.e., axial load increased with the increase in axial deformation. Afterwards, for Column P, the axial load decreased significantly and finally lost all the strength with a small increase in axial deformation. For Column FTRC-0, a considerable decrease in the axial load with increase in the axial deformation was observed after the yield load. This behaviour is attributed to the spalling of concrete cover. For Columns FTRC-1 and FTRC-2, the yield loads were less than those of Column FTRC-0, and no significant decrease in axial load was observed after the yield load. It can be explained that the existence of polymer grid interrupted the consistency of the concrete cover, which may adversely influence the casting quality of concrete cover and resulted in a reduced yield load. Afterwards, the axial load of the FTRC columns was increased with increase in the axial deformation because of the activation of confinement effect provided by GFRP tubes as well as the axial load carried by the GFRP tubes. Eventually, all the FTRC columns failed due to the rupture of the GFRP tubes. It is noted that by using polymer grid as confinement of concrete cover, the load carrying capacity of FTRC columns was increased, although the increase was not significant.

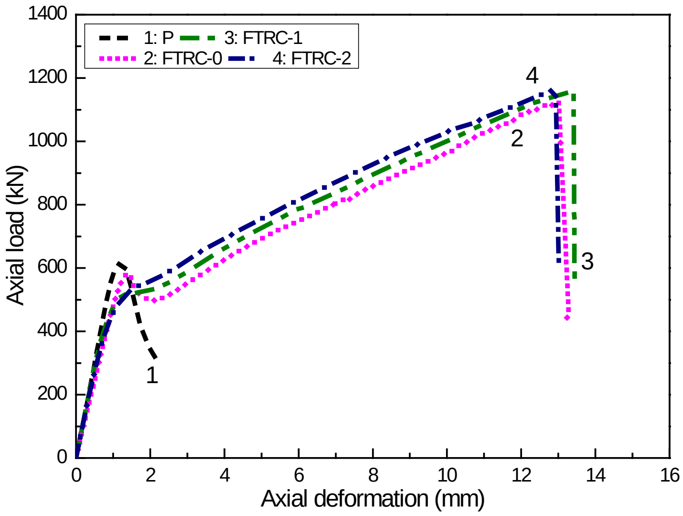


Figure 5 Axial load-axial deformation behaviour of all columns

Table 3 summarizes the test results of all concrete columns. The yield load, the ultimate load as well as the corresponding axial deformations have been presented. For plain concrete column, the ductility can be calculated as the ratio of the axial deformation at the 85% post-ultimate load divided by the axial deformation at the yield load. While for FTRC columns, the ductility can be calculated as the ratio of the axial deformation at ultimate load divided by the axial deformation at the yield load. In this study, the definition of yield load suggested by Pessiki and Pieroni [12] was adopted. For FTRC columns, the ultimate load was defined as the load at the failure of FRP. It can be seen from Table 3 that FTRC columns show significant increase in both the ultimate load and the ductility compared to plain concrete column. By applying polymer grid, the ultimate load has been increased only slightly, while the ductility has not been increased since the failure of concrete columns was dominated by the rupture of GFRP tubes.

Table 3 Summary of test results

Specimen	Yield load (kN)	Axial deformation at yield load δ_y (mm)	Ultimate load (kN)	Axial deformation at ultimate load δ_u (mm)	Ductility μ
P	567	0.90	613	1.18	1.74
FTRC-0	563	1.21	1124	13.01	10.75
FTRC-1	492	1.07	1159	13.41	12.53
FTRC-2	486	1.12	1166	12.93	11.54

4 CONCLUSIONS

FRP tube reinforced concrete (FTRC) columns are effective in improving the strength and ductility under axial compression. The FRP tube not only provides confinement to the concrete core but also carries axial load. The polymer grids confine the concrete cover and reduce the cover spalling. The application of polymer grids has only minimum effect on the strength improvement of FTRC columns.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of technical officers Messrs Ritchie Mclean, Alan Grant and Fernando Escribano for their help in carrying out the experiments. The authors also thank Wagners CFT for providing GFRP tubes. The first author acknowledges the China Scholarship Council and the University of Wollongong for supporting his PhD scholarship.

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