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EFFECTIVENESS OF CONCRETE FILLED FRP TUBES UNDER AXIAL LOADING

HUIGYEONG KIM, T. G. SUNTHARAVADIVEL, and KAI DUAN

School of Engineering & Technology, Central Queensland University, Rockhampton, Australia

Concrete filled tube (CFT) has been widely used as an effective column structure because of the improved strength, ductility and stiffness as well as significantly reduced cost. Considerable studies have established that the improved performance of CFT columns results from the advantageous characteristics of both the tubes and concrete cores. It has been demonstrated that while the lateral confinement provided by the tube can improve the strength and ductility of the concrete, the concrete core will enhance the buckling strength of the tube. Currently, steels are the primary materials for the tubes because of their high strength and high stiffness. Over the past few years, fiber reinforcement polymer (FRP) has increasingly been used in structural application because of a number of its advantages over steels such as lightness, and reduced installing and maintenance costs among the other advantages. In line with this trend, a number of studies were reported on the use of FRP tubes in the CFT structures. This paper presents a brief state-of-art review of the application of FRP 'can' in structural engineering together with partial results from an experimental study of the behavior of a concrete filled FRP tubes under axial loading. The compressive strength of the FRP CFT and failure modes were obtained by varying the slenderness ratios of CFTs. The results are analyzed and discussed in terms of the effects of both slenderness ratio and lateral confinement due to the FRP tubes on the stress state and therefore, on failure mode and strength behavior.

Keywords: Fiber Reinforced Polymer (FRP), confinement ratio, Slenderness ratio, Strength, Structural failure.

1 INTRODUCTION

Over the past three decades or so, concrete-filled-tubes (CFTs) have been developed to an effective column structure, which takes advantage of the superior properties of both tube materials and concrete cores, and so far, the primary tube material for confining the concrete column has been steel, which has added significant advantages to the columns. Recently, fiber reinforcement polymer (FRP) has actively been investigated as potential tube material because of a number of its advantages over steels including high specific strength and stiffness as well as high corrosion resistance. It is particularly advantageous in some industries where portability is required to save time and budget. A number of studies have demonstrated that the use of FRP tube can significantly improve the strength of CFT columns (Bobadilla *et al.* 2013).

This paper presents preliminary results from an experimental study of CFT column with FRP as tube material at Central Queensland University. Details of the experimental program can be found elsewhere (Kim 2014). In total 12 specimens were prepared with various slenderness ratios and wall thicknesses. The experimental results and failure mode of the column are discussed with respect to the effects of specimen slenderness and FRP tube thickness.

2 LITERATURE REVIEW

The CFT columns have been utilized in recent years as a type of hybrid system for use in structures such as buildings and bridges (Xiao 2005). It is also economically beneficial to use CFTs in civil construction as opposed to structural steel. They are very useful where high axial loads and low moments are applied (O'Shea 2000) because most axial loads in the system are resisted by the concrete component which is much less expensive than the confinement material and is the most economical material for this purpose. In fact the confining tube plays two major roles in the column structure. First it will provide confining pressure to the concrete, which will increase the load carrying capacity of the column. Second it will serve as the formwork for the concrete. Therefore, it is used as the preferred supporting system in mining industry. Currently steels have been used as tube materials, which have significantly large weight, compare to FRP tubes with similar dimensions.

The concept of steel tubes being used as primarily transverse reinforcement for reinforced concrete (RC) columns was first proposed in the 1980s where the term 'tubed column' first appeared. This term was used to refer to the function of the steel confinement as that of the hoops in a RC column, resulting in the composite action between the steel and concrete being primarily in the transverse direction. It has effectively replaced wood cribbing and is the most common type of standing roof support in western mines today (Barczak 2005). However, because of the various limitations of steel tubes, researchers are looking for alternative systems that can replace the steel tubes. With FRP composites fast becoming accepted as a structural material, FRP tubes can effectively have been considered as a candidate to replace the steel tubes.

The basic principle behind CFT columns is simple. The enhancement in structural properties of these columns results from the composite action between the elements constituting them. Being confined by steel tube, some properties of the concrete core such as ductility will improve. Also the axial stress in the concrete core will increase while axial stress in the steel tube decreases. As the steel ratio increases, the confinement effect, ultimate capacity and ductility of the column are improved; on the other hand, increasing of the concrete strength results in decrease of the confinement effect and the ductility of the column (Diag 2011). The tube acts as both longitudinal and transverse reinforcement to the concrete while providing a passive confining pressure due to expansion of the concrete, as opposed to active confinement using other means such as pre-stressing. This results in the concrete core being under a triaxial state of stress.

The failure or yielding of concrete is defined as the stage where the volumetric strain of confined concrete starts to change from contraction to expansion. However, in tests conducted by Xiao (2000), the failure of FRP jacketed concrete was due to the onset of rupture in the FRP. Hajsadeghi (2011) also showed that failure of FRP-wrapped concrete occurred when the hoop rupture strength of the FRP composite was reached.

In addition, a number of analytical models have been developed to predict the stiffness, strength, ductility, deformation and failure mode of CFT columns. However the majority of these recently-developed models have been based upon the findings of Richart (1928) and Mander (1988), which both consider lateral confinement pressure to predict the strength of CFT columns.

While the use of FRP tube in the CFT system provides many advantages, most notably light weight, which helps in mining industry due to its portability over steel tubes, the FRP tube system also, has some limitations. In general the bonding between concrete and FRP is not as good as that of steel, which makes the two components (FRP tube and the concrete core) act independently during loading. Furthermore, properties of two materials make the analysis more complex compare with traditional steel tube system.

As available literature in this area is relatively limited, an experimental program was conducted in order to study the behavior of concrete filled FRP tubes, which is presented in this paper.

3 EXPERIMENTAL PROGRAM

A series of testing were conducted at the Central Queensland University, Australia to relate the aspect ratios (diameter-to-thickness, *D/t* and length-to-diameter *L/D*) with failure mode and ultimate capacity of concrete filled FRP tubes and investigate the behavior and the failure mode of concrete filled FRP tubes with high slenderness ratios.

3.1 Materials

All FRP tubes were manufactured by an external company and available commercially for structural purposes.

Concrete mix of 32 MPa strength and 80 mm slump with maximum aggregate size of 20 mm was used in the experiment. Properties of the concrete were tested according to Australian Standard AS1012. The compressive strengths of the concrete samples were found as 30 MPa for all samples except G1S11, G1S21, G1S22 and G1S31 for which it was 30.8 MPa.

3.2 Sample Preparation and Test Set-up

Total of 12 concrete filled FRP tube specimens were prepared with two different diameters and three different wall thicknesses. The length of specimens was kept as constant at 1200 mm to save the time with practical set-up and other requirements. The dimensions of the specimens are summarized in Table 1.

Table 1. Dimensions of Specimen.

Specimen	Inner diameter, *D* (mm)	Wall thickness, *t* (mm)	D/t ratio	L/D ratio
G1S11 & G1S12	101.7	3.5	29.1	11.8
G1S21 & G1S22	101.7	8.0	12.7	11.8
G1S31 & G1S32	101.7	9.5	10.7	11.8
G2S11 & G2S12	153.0	3.5	43.7	7.8
G2S21 & G2S22	153.0	8.0	19.1	7.8
G2S31 & G2S32	153.0	9.5	16.1	7.8

The FRP tubes were core filled with concrete mix and were allowed to cure under normal condition. Two sets of the strain gauges were attached at about 600 mm from the base of the tubes. All specimens were tested with concentric, axial loading under stroke (displacement) control at a rate of 1mm/min.

4 RESULTS AND DISCUSSION

The FRP CFT loading tests showed a clear variation in failure mode with the changing *L/D* ratios of the CFT specimens.

4.1 Ultimate Load Capacity

A typical of load-deflection curve measured on the sample G1S11 is shown in Figure 1 where it can be seen that initially, load increased linearly with displacement, and when the load reached about 180 kN, the buckling of the column became visible, which led to the sudden drop of the load.

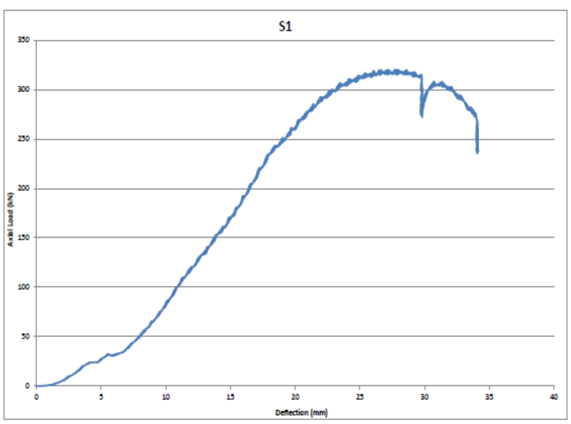

Figure 1. Load-deflection behavior of G1S11.

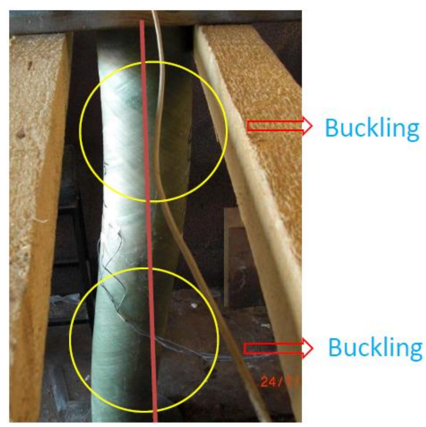

Figure 2. Buckling of G2S21.

All specimens exhibit similar behaviors and bucked at the middle. However, specimens G2S21 and G2S22 were also buckled closer to the top end as well (Figure 2). This could be attributed by slip/slide closer to the top end. The material properties, ultimate capacity and failure mode of each column are summarized in Table 2.

Table 2. Mechanical properties of FRP tubes.

Specimen	Properties of FRP Tube			Concrete Filled FRP Tube	
	Elastic Modulus (MPa)	**Ultimate Tensile Load (kg)**	**Stiffness (N/m/m)**	**Ultimate Stress (MPa)**	**Failure Mode**
G1S11	8,816	10,670	30,005	36.8	Buckling
G1S12	8,816	10,670	30,005	32.3	Buckling
G1S21	8,816	27,810	413,468	50.9	Buckling
G1S22	8,816	27,810	413,468	53.5	Buckling
G1S31	8,816	33,830	685,948	61.2	Buckling
G1S32	8,816	33,830	685,948	51.3	Buckling
G2S11	8,816	15,840	9,114	34.5	Buckling
G2S12	8,816	15,840	9,114	31.3	Buckling
G2S21	8,816	40,740	130,793	44.3	Buckling*
G2S22	8,816	40,740	130,793	45.8	Buckling**
G2S31	8,816	49,350	219,809	44.8	N/A**
G2S32	8,816	49,350	219,809	45.0	N/A***

* Failure occurred at the top part of the column.
** Buckling failure was observed, however loading was stopped due to safety reason (as ultimate load reached the allowable capacity of testing facility).
*** Loading was stopped due to safety reason (as ultimate load reached the allowable capacity of testing facility) – no conclusive failure mode was observed.

Figure 3. Change of texture of FRP column.

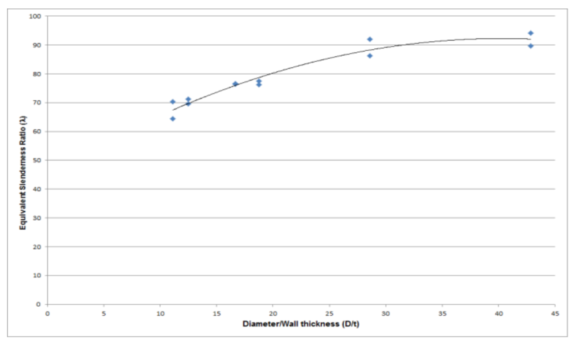

Figure 4. Measurement of deformation.

Some changes in the column were observed as shown in Figure 3 where specimen G1S11 is displayed. The FRP structure was stretched, which was noticed by the color changes in the middle part. However, no fracture in FRP tube was observed even at the end of the test. From about 180 kN load, the load increasing rate was decreased and column buckling become more visible at the middle of the column. Once it reached 320 kN load, the load starts to dropped. Then the loading was stopped and unloaded. Similar observations were made in the other samples except G2S21 and G2S22.

As expected, the results in Tables 1 and 2 show that the strength of composite columns increases as D/t ratio decrease. The experimental results, however, also show that the strength of FRP columns is reduced as the L/D radio (slenderness ratio) decreases, which contradicts the general believe that higher slenderness ratio causes buckling more easily, and therefore, lower strength. However, there was unexpected buckling observed during the testing with specimen G2S21 and G2S22, which may be caused by sliding effect during applying the load.

4.2 Failure Mode and Slenderness

All specimens failed on buckling while no fracture in FRP tube was observed. In the same time, the ultimate load decreased with the slenderness ratio. As it is a composite material with FRP and concrete, the equivalent slenderness ratio is calculated by considering the equivalent area of the cross section. The equivalent slenderness ratios have a good correlation with the *D/t* value of the column which can be seen in Figure 4.

5 CONCLUSION

The experimental results and analysis presented in this paper have demonstrated again the dominant influences of the diameter-to-wall thickness (*D/t*) ratio on the capacity of the CFT with FRP tubes, particularly when the buckling failure mechanism prevails.

For the purpose of investigating the slenderness effects on CFT column, an equivalent slenderness ratio is proposed. By comparing the proposed to the experimental results, it is found that the proposed equivalent slenderness ratio has a good correlation with the *D/t* ratio of the FRP tube. Furthermore, it was also noted that the thickness of FRP tube more sensitively effects on the strength of columns rather than diameter.

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