Thin-Walled Structures 106 (2016) 1–8

Contents lists available at ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws

Short communication

Study on steel reinforced concrete-filled GFRP tubular column under compression

Bing Xue, Jian Gong *

College of Civil Engineering, Henan Polytechnic University, Jiaozuo City, Henan Province 454000, People's Republic of China

ARTICLE INFO

Article history:
Received 3 October 2015
Received in revised form
7 April 2016
Accepted 25 April 2016

Keywords:
Concrete filled FRP tubular column
Test
Numerical analysis
Steel section

ABSTRACT

The Steel reinforced concrete-filled fiber reinforced polymer (FRP) tubular column is proposed as a new form of composite column to obtain higher mechanical performance. This paper presents experimental and numerical studies of axially loaded steel reinforced concrete-filled GFRP tubular columns. Ten steel reinforced concrete-filled GFRP tubular columns and two concrete filled GFRP tubular columns are tested. The specimens fail by the rupture of the GFRP tubes under hoop tension and only outward buckling can be observed because of the presence of the concrete core and steel section. Also, the crushed concrete core and buckling of steel section could be observed after removing of the FRP tube. The results indicate steel reinforced concrete-filled GFRP tubular columns have higher specimen stiffness, strength and deformability than concrete filled GFRP tubular columns. A parametric study, including steel ratio and concrete strength, is also carried out.

1. Introduction

Over the past decade, fiber reinforced polymer (FRP) composites have become increasingly more popular as a confining material for concrete columns, both in the retrofitting of existing reinforced concrete columns with an FRP jacket and in the use of concrete-filled FRP tubes as structural members in new construction. In these composite columns, the external FRP jackets or tubes can provide a permanent formwork and confinement for the concrete to enhance the compressive strength of the concrete. And the columns are also highly durable because the outer FRP tubes have high corrosion resistance in harsh conditions.

A great number of studies have been devoted to evaluate the behavior of concrete filled-FRP tubes (CFFT) [1–5]. One of the most important issues in civil engineering applications is the safety implications of using FRP materials. In order to avoid catastrophic failure of an entire structure, it is desired to dissipate energy by post-elastic deformations. However, FRP materials are generally known for their linear elastic response to failure. These CFFT columns without internal steel reinforcement are not feasible for practices. Zhuo et al. [6] found that FRP alone would be hard to develop plastic hinge in a column or pile. Yamakawa et al. [7] also considered that the FRP was incapable of producing a nonlinear ductile response when the concrete filled FRP tube is under seismic conditions. Some studies reported that unidirectional FRP may exhibit severe nonlinearity based on a sophisticated design [8], however, it was too complex and difficult for practice. Therefore, internal steel reinforcement is necessary for such a composite column. Seible et al. [9] carried out a feasibility study of carbon CFFT columns under simulated seismic actions. Test results on three 40% scale models of a prototype circular bridge column showed significant ductility for the CFFT members with steel reinforcement, whereas the system without any steel bars suffered from premature failure. While CFFT systems with steel reinforcement have desirable properties, their practical applications are not easy. It is inconvenient to pour and vibrate concrete in FRP tubes with reinforcing cages, which can lead to inferior quality of the concrete core. Steel reinforced concrete (SRC) structural members are widely used due to their advantages in term of high seismic resistance and high sectional strength. However, they are vulnerable to corrosion.

A new form of composite columns therefore is proposed to overcome the existing disadvantages of concrete filled FRP tubes and it consists of a steel reinforced concrete inside, an FRP tube outside, as shown in Fig. 1. The new column is an attempt to combine the advantages of the SRC column and the concrete filled FRP tubular column, so as to achieve a high performance structural member.

A series of experimental and analytical works are being carried out on steel reinforced concrete-filled GFRP tubular columns in Henan Polytechnic University. In this contribution, the compression test of the composite columns are conducted firstly and then the behaviors of axially loaded composite columns are simulated by the finite element program ABAQUS.

* Corresponding author.
E-mail address: gongjianh1982@163.com (J. Gong).

http://dx.doi.org/10.1016/j.tws.2016.04.023
0263-8231/

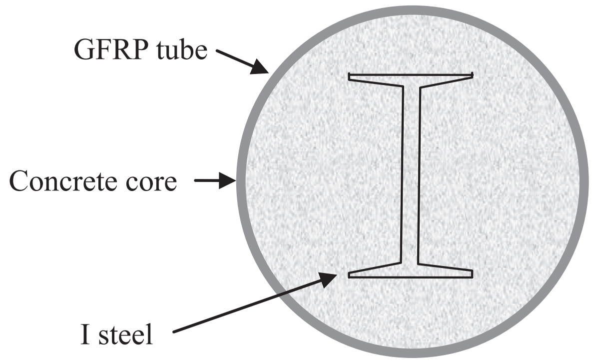

Fig. 1. Sketch of cross section of steel reinforced concrete-filled GFRP tube.

Table 1
Mix proportion of concrete.

Concrete type	Mix component kg/m^3					Mix ratio (cement to aggregates)
	Cement	Sand	Lime stone	Water	Additional high-range water reducer	
I	429	536	1250	185	–	0.42
II	432	558	1242	168	4.32	0.39

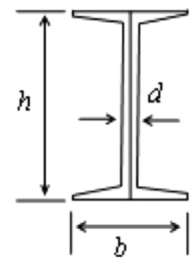

Table 2
Geometrical parameters for I steel.

Steel type	h /mm	b /mm	d /mm
1	50	74	4.0
2	63	80	5.0

2. Experimental program

2.1. Materials

The common Portland cement, crushed lime stone, natural sand and water were used to prepare the concrete. The concrete mixes proportions are shown in Table 1. The nominal maximum coarse aggregate size was 10.0 mm. The 28-day cube compressive strengths for these two types of concretes were 39.5 and 51.6 MPa, respectively.

The GFRP tubes were manufactured using a two-axis filament winding machine. Angle of glass fiber with the hoop direction is 55°. Three types of GFRP tubes with same inner diameter of 100 mm and different tube thicknesses of 4, 5 and 6 mm were used. The material parameters for FRP materials are summarized in Table 2.

Two types of the hot rolled Q235 I steel are used in this test. The geometrical parameters for the steels are indicated in Fig. 2 and listed in Table 3.

2.2. Fabrication of the test specimens

The FRP tube and I steel were cut and machined to the required length. The I steel was weld by two U steel. Any deposit of dusts and oil on the faces of I steel was wiped off by dry cloth. Before casting of the concrete mix, one end of the FRP tube was capped using a plastic sheet. I steel is placed at the center of the tube, as shown in Fig. 3, and then the concrete mix is poured. The other ends of the specimens are sealed by epoxy to prevent moisture loss during curing. All the specimens cured for 28 days in a standard wet curing room with a relative humidity of 100%. Two specimen groups, A1 and A2, are designed according to the cube strength of the concrete core. There are six test specimens in each specimen groups. In each specimen group, one specimen without steel section is made for comparison purpose. All the specimens have the same length of 300 mm. The details about these test specimens are listed in Table 4. It should be noted that the parameter of steel ratio is defined as following:

$$\alpha = A_s/A_c \tag{1}$$

where A_s and A_c are cross-sectional area of core concrete and cross-sectional area of I steel, respectively.

2.3. Instrumentation and test

In order to gain an in-depth understanding of the composite structural behavior, strain gages were used to obtain local strain distributions. Strain gages were used for each test specimen. The strain gages were mounted at the middle height of I steels and FRP tubes. Fig. 4 shows the strain gage locations. Two displacement transducers were symmetrically attached on the FRP tube at the top end to measure the axial displacement. Two steel bearing plates are used between specimen ends and test machine, as shown in Fig. 5.

The load was applied in small increments of 2 kN until failure occurred. Each load interval was maintained for about 2–3 min. At each load increment the strain readings and the displacement measurements were recorded.

3. Test results

3.1. Failure mode

All test specimens failed by the rupture of the GFRP tubes under hoop tension. The typical failure modes are presented in Fig. 6. For all test specimens, GFRP tubes are only outward buckling because the presence of the concrete core and steel section prevents the occurrence of inward bucking. Only one dominant crack formed and developed during the failure process for each specimen. The GFRP tube is removed after test, and the failure of concrete core and steel section are presented in Fig. 7. The crushed concrete core and buckling of steel section can be observed.

3.2. Load-displacement curve

For better understanding of the axial loaded performance of the steel reinforced concrete-filled GFRP tubular column, the typical load-displacement curve is presented in Fig. 8. The curve can generally divided into three stages: the elastic stage (OA), elastic-plastic stage (AB) and plastic stage (rest of curve).

During the elastic stage, no obvious deformation or evens can be observed. After a linear response up to about 50–60% of the failure load, some white lines can be seen from outer face of the