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Compressive behaviour of large rupture strain FRP-confined concrete-encased steel columns

L. Huang [a], S.S. Zhang [b,*], T. Yu [a,*], Z.Y. Wang [c,d]

[a] School of Civil, Mining & Environmental Engineering, Faculty of Engineering & Information Sciences, University of Wollongong, Australia
[b] School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, China
[c] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin, China
[d] School of Civil Engineering, Harbin Institute of Technology, Harbin, China

HIGHLIGHTS

- An experimental study on large rupture strain FRP-confined concrete-encased steel columns (FCSCs) was conducted.
- The ultimate axial strain of the tested FCSCs was up to 11%.
- The encased steel section can provide additional confinement to the concrete in FCSCs.

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ABSTRACT

Fibre-reinforced polymer (FRP)-confined concrete-encased steel columns (FCSCs) have emerged as a new form of hybrid columns. An FCSC consists of an outer FRP tube, an inner steel section, and concrete filled in between. The concept of FCSCs not only provides a durable and ductile structural form for new construction, but also can be practiced as an effective method for the retrofitting/strengthening of existing steel columns. This paper presents the first ever study on FCSCs with a large rupture strain (LRS) FRP tube [i.e., polyethylene terephthalate (PET) FRP tube]. A total of 12 circular specimens (six FCSCs and six FRP-confined concrete columns) were tested, with the main test variable being the thickness of the PET FRP tube. The test results showed that the buckling of the encased steel section can be well prevented by the constraint from the surrounding FRP-confined concrete even when the axial deformation is large. On the other hand, the encased steel section can provide additional confinement to the concrete in FCSCs, leading to excellent structural performance of the columns in terms of both axial strength and deformation capacity.

1. Introduction

Fibre-reinforced polymer (FRP) composites have attracted increasing research attention and practical applications in civil engineering due to their many advantages, such as the high strength-to-weight ratio and excellent corrosion resistance. One of the most popular applications of FRP is as an external confining device for reinforced concrete (RC) columns. Extensive studies have been conducted in the past two decades on FRP-confined columns, including experimental studies [1–3], numerical studies [4,5], and analytical studies [6,7]. On the other hand, H-section steel columns have been widely used in steel structures. It has been well known that premature buckling failure of H-section steel columns can significantly affect their load-carrying capacity [8], while corrosion is a big concern for steel structures in harsh environments.

Against this background, a new type of hybrid columns, termed as FRP-confined concrete-encased steel columns (FCSCs), have emerged recently [3,9]. An FCSC consists of an outer FRP tube, an inner steel section, and concrete filled in between. In an FCSC, the FRP tube not only serves as a protection skin to improve the durability of the column, but also provides confinement to the concrete core and the steel section to enhance the axial strength and deformation capacity of the column. The concept of FCSCs was first explored by Liu et al. [9] as a retrofitting technology for deficient steel columns. It is also very attractive for new construction: the outer FRP tube can serve as in-situ permanent formwork and the concentrically encased steel column facilitates the connection with beams and foundations.

* Corresponding authors.
E-mail addresses: shishun@hust.edu.cn (S.S. Zhang), taoy@uow.edu.au (T. Yu).

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A number of studies have been conducted on FCSCs [3,9–13]. Liu et al. [9] conducted the first study on FCSCs. In their tests, the H-section steel columns were notched in the mid-region to simulate the loss of steel section due to corrosion. Linde et al. [13] also conducted compression tests on circular FCSCs to investigate the efficiency of using FRP-confined concrete for the retrofit of deficient steel columns. Karimi et al. [10,11] investigated the behaviour of circular and rectangular FCSCs. In their tests on rectangular FCSCs, the steel H-sections were firstly wrapped with a layer of resin saturated glass fibre sheet to avoid possible galvanic corrosion and then wrapped with a single layer or multiple layers of resin saturated carbon fibre sheets. Concrete was then poured into the space between the so-formed FRP tube and the steel section to form FCSCs. Furthermore, Zakaib and Fam [12] conducted an experimental study on the flexural behaviour of FCSCs. In their tests, pre-fabricated FRP tubes with a considerable longitudinal stiffness were used. Most recently, the authors' group [3] conducted eccentric compression tests on circular FCSCs and developed analytical models based on section analysis to predict the compressive behaviour of FCSCs.

The existing studies on FCSCs have been limited to the use of conventional FRPs such as carbon FRP (CFRP) and glass FRP (GFRP) with a rupture strain of less than 3%. The use of large rupture strain (LRS) FRP composites [e.g., polyethylene terephthalate (PET) FRP composites] in FCSCs has not yet been studied. PET FRP composites possess a rupture strain of over 7% [14,15] and have been used as a confining material by previous researchers [14,16–18]. As the ultimate state of FCSCs is controlled by the hoop rupture of FRP tube, the use of LRS FRP as the outer tube may significantly improve the deformation capacity of FCSCs, which is particularly important for applications in seismic regions.

Against this background, this paper presents results from an experimental program on FCSCs with a PET FRP tube. Comparisons between the test results and predictions of existing stress-strain models for FRP-confined concrete are also presented.

2. Experimental program

2.1. Test specimens

In total, 12 specimens were prepared and tested under axial concentric compression, including six circular PET FRP-confined concrete-encased steel columns (FCSCs) and six circular PET FRP-confined concrete columns (FCCCs). All the FCSCs and FCCCs were short columns with a nominal diameter (i.e., the diameter of the concrete core) of 208 mm and a height of 500 mm. The encased steel H-sections in the FCSCs all had the same height of 500 mm and were cut from the same piece of steel H-section which had a total length of 6000 mm. As prefabricated PET FRP tubes were not available to the authors, resin-saturated PET fibre sheets were wrapped on hardened concrete cylinders with an overlapping zone of 150 mm to form the FRP tubes for the specimens. Existing studies [19–20] have shown that there is little difference in the behavior of concrete confined by a prefabricated FRP tube and that confined by an wet-layup FRP jacket with the same circumferential stiffness. To be accurate, hereafter, the term "FRP jacket" is used other than the term "FRP tube" for the external skin of the specimens. The details of all the specimens are summarized in Table 1, while the dimensions of the encased steel H-sections are shown in Fig. 1. As shown in Table 1, the thickness of FRP jacket was the main test variable and three different thicknesses were used for both FCSCs and FCCCs, leading to a total of six different cross-sectional configurations. For each cross-sectional configuration, two nominally identical specimens were prepared and tested. For ease of reference, each specimen is given a name, which starts with four letters to indicate the type of the specimen (i.e., FCSC or FCCC), followed by an Arabic numeral (i.e., 2, 3 or 4) to indicate the number of layers of fibre sheets used for the FRP jacket, and then a Roman numeral (i.e., I or II) to differentiate two nominally identical specimens. For example, FCSC-3-I refer to the first of the two FCSC specimens that were confined with an FRP jacket made of a 3-ply PET fibre sheet.

Table 1
Details of Specimens.

Specimen	FRP tube (Number of plies)	Dimensions of steel sections (mm)			
		Flange width	Web width	Flange thickness	Web thickness
FCSC-2-I, II	2	100	139	6.8	6.1
FCSC-3-I, II	3				
FCSC-4-I, II	4				
FCCC-2-I, II	2	N/A			
FCCC-3-I, II	3				
FCCC-4-I, II	4				

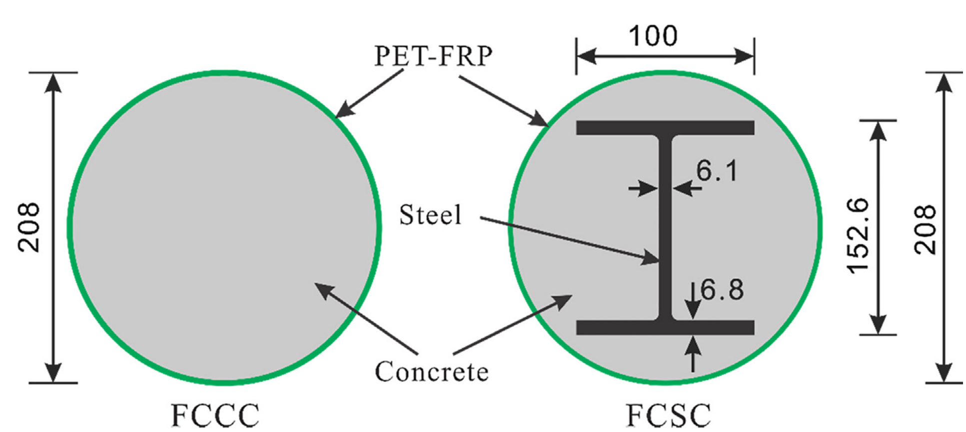

Fig. 1. Cross-sectional configurations and dimensions (mm).