

University of Wollongong
Research Online

Faculty of Engineering and Information
Sciences - Papers: Part B

Faculty of Engineering and Information
Sciences

2016

Concrete-encased steel columns confined with large rupture strain FRP composites: axial compression tests

Le Huang

University of Wollongong, lh794@uowmail.edu.au

Shi Shun Zhang

University of Wollongong, shishun@uow.edu.au

Tao Yu

University of Wollongong, taoy@uow.edu.au

Zhenyu Wang

Harbin Institute of Technology, zhenyuwang@hit.edu.cn

Follow this and additional works at: <https://ro.uow.edu.au/eispapers1>



Part of the [Engineering Commons](#), and the [Science and Technology Studies Commons](#)

Recommended Citation

Huang, Le; Zhang, Shi Shun; Yu, Tao; and Wang, Zhenyu, "Concrete-encased steel columns confined with large rupture strain FRP composites: axial compression tests" (2016). *Faculty of Engineering and Information Sciences - Papers: Part B*. 134.

<https://ro.uow.edu.au/eispapers1/134>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Concrete-encased steel columns confined with large rupture strain FRP composites: axial compression tests

Abstract

Fibre Reinforced (FRP)-confined concrete-encased steel composite columns (FCSCs) are an emerging form of hybrid columns. The idea of a combined use of FRP-confined concrete and an encased steel section not only offers a durable and ductile structural form for new construction, but also can be practiced as an efficient method to retrofit/strengthen deteriorated steel columns. This paper presents a series of axial compression tests on concrete-encased steel columns confined with Large Rupture Strain (LRS) FRP composites, namely, Polyethylene Terephthalate (PET) FRP composites. A total of 12 circular specimens, including 6 FCSCs and 6 FRP-confined concrete circular columns (FCCCs) were tested, with the main test variables being the thickness of the FRP tube. The test results showed that FCSCs with PET FRP possessed excellent performance in terms of both axial strength and ductility.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Huang, L., Zhang, S. S., Yu, T. & Wang, Z. Y. (2016). Concrete-encased steel columns confined with large rupture strain FRP composites: axial compression tests. In H. Hao & C. Zhang (Eds.), *Mechanics of Structures and Materials: Advancements and Challenges: Proceedings of the 24th Australian Conference on the Mechanics of Structures and Materials (ACMSM24)* (pp. 1725-1730). Leiden, The Netherlands: CRC Press/Balkema.

Concrete-encased steel columns confined with large rupture strain FRP composites: axial compression tests

L. Huang, S. S. Zhang & T. Yu

School of Civil, Mining & Environmental Engineering, Faculty of Engineering & Information Sciences, University of Wollongong, Australia.

Z. Y. Wang

Professor, ^aKey Lab of Structures Dynamic Behavior and Control of the Ministry of Education (Harbin Institute of Technology), ^bSchool of Civil Engineering, Harbin Institute of Technology, Harbin, China.

ABSTRACT: Fibre reinforced polymer (FRP)-confined concrete-encased steel composite columns (FCSCs) are an emerging form of hybrid columns. The idea of a combined use of FRP-confined concrete and an encased steel section not only offers a durable and ductile structural form for new construction, but also can be practiced as an efficient method to retrofit/strengthen deteriorated steel columns. This paper presents a series of axial compression tests on concrete-encased steel columns confined with large rupture strain (LRS) FRP composites, namely, polyethylene terephthalate (PET) FRP composites. A total of 12 circular specimens, including 6 FCSCs and 6 FRP-confined concrete circular columns (FCCCs) were tested, with the main test variables being the thickness of the FRP tube. The test results showed that FCSCs with PET FRP possessed excellent performance in terms of both axial strength and ductility.

1 INSTRUCTIONS

Fibre reinforced polymer (FRP)-confined concrete-encased steel composite columns (FCSCs) are an emerging form of hybrid columns. An FCSC consists of an outer FRP tube, an encased steel section and concrete filled in between (Figure 1). The main advantages of FCSCs include: (1) excellent corrosion resistance, (2) excellent energy-dissipation capacity, and (3) ease for construction. FCSCs can be easily used in new structures since the outer FRP tube can serve as in-situ and permanent formwork and the concentrically encased steel column facilitates the connection between FCSCs and other structural members. In addition, the concept of FCSCs can be adopted as a retrofitting technology for deteriorated steel columns (e.g. Liu et al. 2005).

The concept of FCSCs was first proposed by Liu et al. (2005) as a retrofit technology for deficient steel columns. Liu et al. (2005) tested 5 FCSCs specimens in which the FRP wraps were pre-fabricated by bonding several slotted FRP tubes together in an onion-skin pattern and the embedded steel sections were notched to simulate the loss of steel section due to corrosion. Karimi et al. (2010, 2011b) tested 10 circular FCSCs under axial compression in which pre-fabricated FRP tubes were used. Karimi et al. (2011a, 2012) tested 11 rectangular FCSCs under axial compression where the FRP tubes were formed by wrapping saturated FRP sheets directly around the existing steel columns via wet-layup method. Zakaib and Fam (2012) conducted an experimental study on the flexural performance of FCSCs which contain pre-fabricated FRP tubes with a considerable longitudinal stiffness. While the above-mentioned

experimental studies demonstrated the excellent structural behavior of FCSCs, the limited studies do not allow the interactions between the three components (i.e. the encased steel section, the confined concrete and the outer FRP tube) to be thoroughly examined. In addition, the existing studies are generally limited to conventional FRPs (e.g. carbon FRPs and glass FRPs). The use of large rupture strain (LRS) FRP composites [e.g., polyethylene terephthalate (PET) FRP composites] in FCSCs has not yet been investigated. PET FRP is made from waste plastic bottles or bags and the manufacturing cost for PET-FRP is usually much lower than that for conventional FRPs. PET-FRPs is thus an economic and green material. Furthermore, PET FRP composites were reported to have a rupture strain of over 7% (Dai et al. 2011) and thus could significantly improve the ductility of FCSCs.

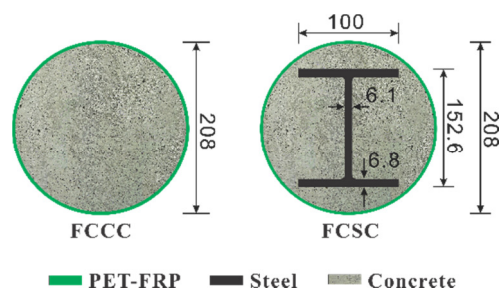


Figure 1. Cross-sections of FCCCs and FCSCs

To develop an in-depth understanding of the structural behavior of FCSCs, a total of 12 specimens, including 6 FCSCs and 6 FRP-confined concrete columns (FCCCs), were tested under concentric axial compression. To enhance the deformation

capacity and ductility of the specimens, PET FRPs were used to fabricate the FRP tubes for the FCSCs and the FCCCs in the present study. The test results are presented in this paper, based on which the behavior of FCSCs and FCCCs is compared.

2 EXPERIMENTAL PROGRAM

2.1 Test specimens

A total 12 columns (i.e., 6 FCSCs and 6 FCCCs) were tested under concentric axial compression in the present study. In addition, one bare steel I-section column (SC) was also compressed concentrically to determine its compression behavior. The FCSCs and FCCCs had the same nominal diameter (i.e. inner diameter of the FRP tube) of 208 mm and the same height of 500 mm. The SC had the same dimensions and material properties as those used in FCSCs. The cross-sectional dimensions of the tested specimens are shown in Figure 1.

Three different thicknesses of FRP tubes (i.e. 2 plies, 3 plies and 4 plies) were used for both FCSCs and FCCCs, while other parameters of the columns were the same. For each FRP thickness, two nominally identical specimens were prepared for both FCSCs and FCCCs, leading to a total of 6 specimens for each type of column.

The specimens are named as follows: the first four or two letters (i.e. FCSC, FCCC or SC) are used to indicate the type of the specimen. These letters are then followed by an Arabic numeral (i.e. 2, 3 or 4) to indicate the number of plies of FRP sheets. The last Roman numeral (i.e., I or II) is used to identify two nominally identical specimens. For example, FCSC-3-I is the first of the two FCSC specimens confined with 3 plies of PET FRP sheets and SC represents the steel I-section column.

2.2 Material properties

Ready-mix concrete was used in the present study and the average compressive strength of concrete obtained from three plain concrete cylinders of 150 mm x 300 mm during the test period was 28.4 MPa; the strain corresponding to the peak stress was 0.0025.

Tensile tests were conducted on 4 steel coupons following the test standard BS 18 (1987). Two of the steel coupons were longitudinally cut from the flange and the other 2 from the web of the same piece of steel I-section column. The obtained tensile behaviors of all the four coupons were quite similar to each other with the average yield stress and tensile strength being 328.6 MPa and 483.7 MPa respectively. The elastic modulus of steel was found to be 198.7 GPa from the coupon tests.

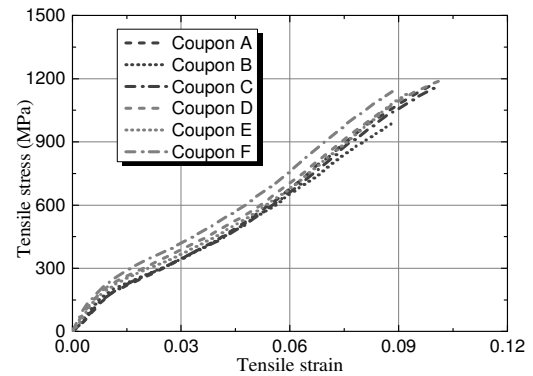


Figure 2. Coupon test results for PET-FRP.

Tensile tests on 6 coupons were also conducted to determine the material properties of PET FRP following the standard ASTM-3039 (2008). The test region of the FRP coupons had a width of 25 mm and a length of 250 mm. The tensile stress-strain curves are shown in Figure 2, in which the tensile stresses were calculated by using the nominal thickness of PET FRP sheets (i.e., 0.819 mm per ply as specified by the manufacturer). As can be seen from Figure 2, the tensile stress-strain curves of PET FRP are slightly nonlinear, and the tensile strength and ultimate strain averaged from the 6 coupons were 1141.5 MPa and 0.0981 respectively.

2.3 Test set-up and instrumentation.

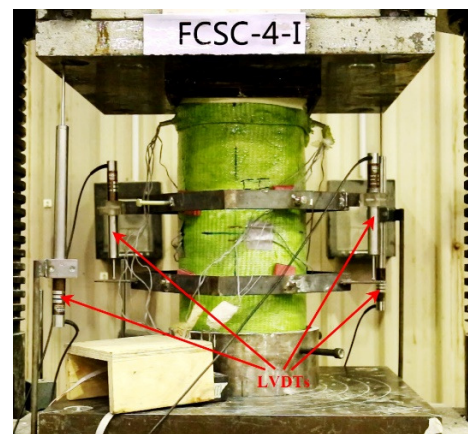


Figure 3. Test set-up

Four strain gauges with a gauge length of 20 mm were evenly applied on the surface of FRP tube along its hoop direction. For the steel I-section in FCSCs, a number of axial strain gauges with a gauge length of 10 mm were applied at the mid-height. Two linear variable displacement transducers (LVDTs) were used to measure the overall axial shortening of the column while another two LVDTs were used to measure the shortening of the middle 150 mm segment of the column. The test set-up and the layout of the LVDTs are shown in Figure 3. All the specimens were tested using a Denison Compression Testing Machine with a load capacity of 500 ton and the loading rate was 0.6 mm per minute.

3 FAILURE MODES

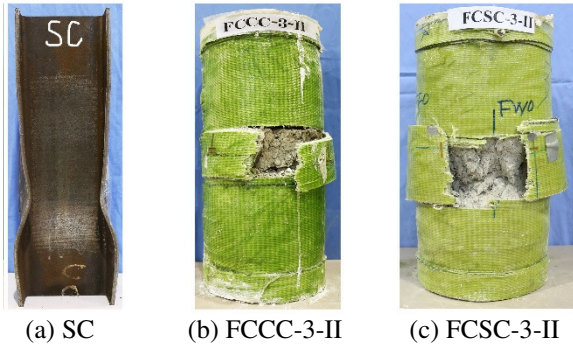


Figure 4. Typical failure modes of SC, FCCCs and FCSCs.

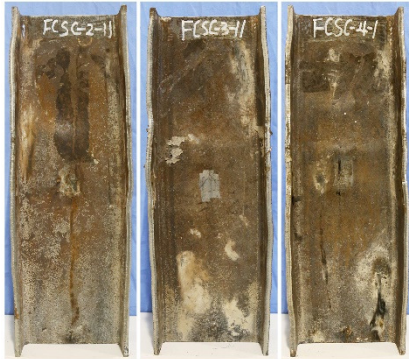


Figure 5. Deformed shape of the encased steel I-section in FCSCs.

For the steel I-section column (i.e. SC), severe local buckling was observed in both the web and flanges, as shown in Figure 4a.

The FCCCs all failed by the rupture of the outer PET FRP tubes near the mid-height of the specimens, and the typical failure mode of FCCCs is shown in Figure 4b. A loud noise was heard at the explosive rupture of the PET FRP tube.

The failure of FCSCs was also caused by the explosive rupture of the PET FRP tube, as shown in Figure 4c. The encased steel I-sections taken out from the column after test are shown in Figure 5, which shows that the deformed shapes of the encased steel I-section are quite different from that of the bare steel I-section column (SC) tested under axial compression (Figure 4a). The severe bulking of the SC did not happen in the encased steel I-sections in FCSCs due to the restraint from the surrounding concrete.

4 AXIAL LOAD-SHORTENING CURVES

4.1 Axial load-shortening behavior of FCCCs

Figure 6 shows the axial load-shortening curves of all FCCCs. It can be seen from Figure 6 that the axial load-shortening curves of FCCCs with PET FRP have two ascending branches connected by a smooth transition region. The ultimate axial load and shortening of the specimens increase with the thickness of the PET FRP tube. It should be noted that the second ascending branches of the axial load-

shortening curves of FCCCs are slightly curved downward (i.e., the slope shows a gradual increase), which is different from that observed in FCCCs with conventional FRPs (e.g. glass FRP and carbon FRP).

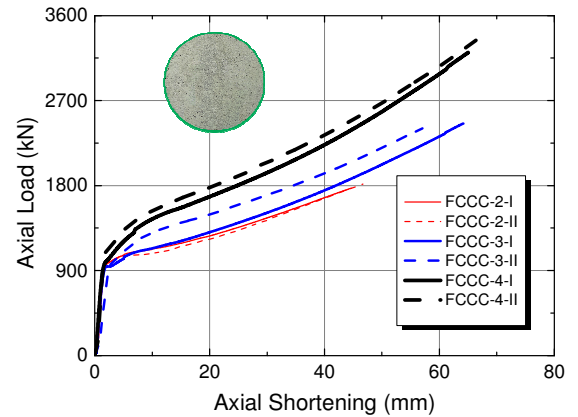


Figure 6. Axial load-shortening curves of FCCCs

4.2 Axial load-shortening behavior of FCSCs

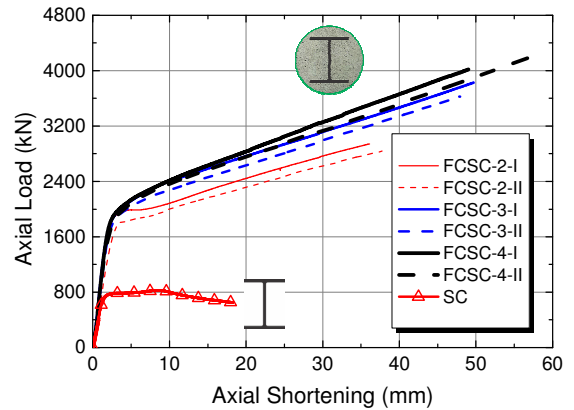


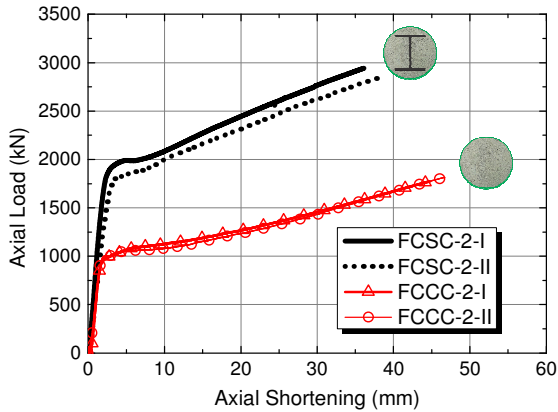
Figure 7. Axial load-shortening curves of FCSCs and SC

The axial load-shortening curves of all 6 FCSCs are shown in Figure 7, where the curve of the SC specimen is also plotted for comparison. Similar to FCCCs, the axial load-shortening curves of FCSCs also have two ascending branches connected by a nearly smooth transition region. The ultimate axial load and shortening of the specimens also increase with the thickness of the PET FRP tube.

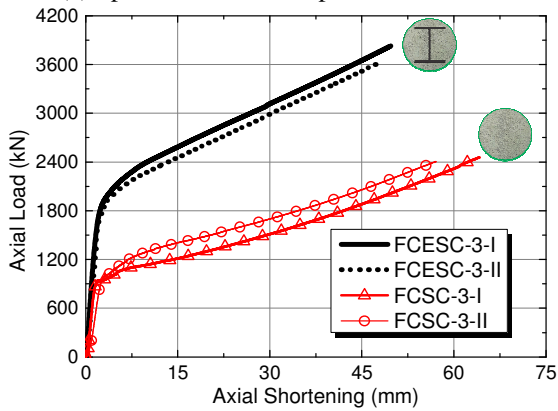
4.3 Comparison between FCCCs and FCSCs

Figure 8 shows a comparison of the axial load-shortening curves between FCCCs and FCSCs. It can be seen from Figure 8 that the load-carrying capacity of FCSCs is significantly larger than that of the FCCCs with the same thickness of the PET FRP tube. This is not surprising due to the existence of a steel I-section in the FCSCs. The local buckling of the steel I-section in FCSCs is effectively constrained by the concrete which is confined by PET FRP, thus a higher and reliable axial contribution from the steel I-section can be obtained. It is interesting to note in Figure 8 that the difference in the

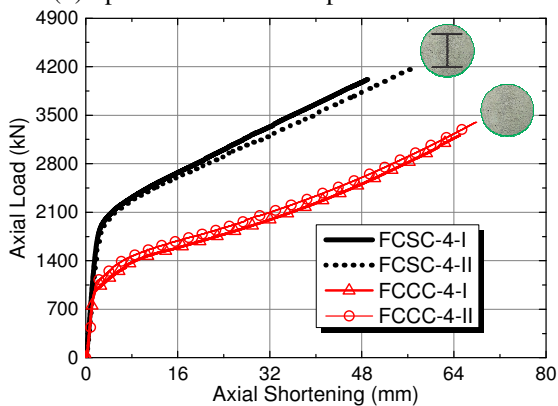
ultimate axial load between FCCCs and the corresponding FCSCs are considerably larger than the ultimate axial load of the steel I-section (i.e., around 800 kN as shown in Figure 7). This phenomenon suggests that the existence of steel I-section in FCSCs may have led to additional strength enhancement of the concrete by providing additional confinement.



(a) Specimens with two plies of PET FRP



(b) Specimens with three plies of PET FRP



(c) Specimens with four plies of PET FRP

Figure 8. Comparison between FCSCs and FCCCs

5 CONCLUSIONS

This paper has presented results from a series of axial compression tests on concrete-encased steel columns confined with a PET FRP tube which has a large rupture strain. Based on the test results, the following conclusions can be made:

- 1) The FCSCs and FCCCs with large rupture strain FRP (i.e., PET FRP) exhibited excellent per-

formance in terms of axial load capacity and axial deformation capacity/ductility;

- 2) The local buckling of the encased steel I-section in FCSCs is effectively constrained by the concrete which is confined by the FRP tube, leading to a higher and reliable axial contribution from the encased steel I-section.
- 3) Compared with FCCCs, the encased steel I-section in FCSCs may provide additional confinement to the concrete, leading to further enhanced strength of the confined concrete.

ACKNOWLEDGMENT

The authors are grateful for the financial supports received from the Australian Research Council through a *Discovery Early Career Researcher Award* (Project ID: DE140101349) for the third author.

6 REFERENCES

- ASTM D3039/D3039M-08. (2008). *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*, American Society for Testing and Materials (ASTM), Philadelphia, USA.
- BS 18. (1987). *Tensile testing of metals (including aerospace materials)*. London, UK: British Standards Institution.
- Dai, J.G., Bai, Y.L. and Teng, J.G. (2011). "Behavior and modeling of concrete confined with FRP composites of large deformability." *Journal of Composites for Construction*, 15(6), 963-973.
- Karimi, K., El-Dakhkhni, W.W. and Tait, M.J. (2010). "Performance enhancement of steel columns using concrete-filled composite jackets," *Journal of Performance of Constructed Facilities*, 25(3), 189-201.
- Karimi, K., Tait, M.J. and El-Dakhkhni, W.W. (2011a). *Testing and modeling of a novel FRP-encased steel-concrete composite column*. *Composite Structures*, 93(5), 1463-1473.
- Karimi, K., El-Dakhkhni, W.W. and Tait, M.J. (2011b). Behavior of slender steel-concrete composite columns wrapped with FRP jackets," *Journal of Performance of Constructed Facilities*, 26(5), 590-599.
- Karimi, K., Tait, M.J. and El-Dakhkhni, W.W. (2012). "Influence of slenderness on the behavior of a FRP-encased steel-concrete composite column," *Journal of Composites for Construction*, 16(1), 100-109.
- Liu, X., Nanni, A. and Silva, P.F. (2005). "Rehabilitation of compression steel members using FRP pipes filled with non-expansive and expansive light-weight concrete," *Advances in Structural Engineering*, 8(2), 129-142.
- Zakaib, S. and Fam, A. (2012). "Flexural performance and moment connection of concrete-filled GFRP tube-encased steel I-sections," *Journal of Composites for Construction*, ASCE, 16(5), 604-613.