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Mechanical behavior of ECC-encased CFST columns subjected to eccentric loading

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ABSTRACT

To increase the durability and fire resistance of concrete filled steel tube (CFST) columns, engineered cementitious composite (ECC)-encased CFST columns were proposed in this paper. Seven ECC-encased CFST columns with different parameters were tested, the parameters examined included eccentricity ratio, stirrup reinforcement ratio, longitudinal reinforcement ratio and thickness of inner steel tube. The results of the experimental study indicate that the proposed composite column exhibited both superior ductility and high strength under different eccentricity. Three typical failure modes can be observed depending on different eccentricity ratios, which were compression-controlled failure mode, balanced failure mode and tension-controlled failure mode. The thickness of steel tube had significant effects on both load carrying capacity and ductility of ECC-encased CFST columns. The longitudinal reinforcement could enhance the rigidity and loading carrying capacity of ECC-encased CFST columns, and the stirrup could improve the ductility of the composite column. Finally, the failure processes for typical columns were also investigated based on the strain analysis.

1. Introduction

Concrete filled steel tube (CFST) columns have gained increasing attention over the last decades. A large amount of studies have been carried out on the performance of CFST columns under static and dynamic loading previously [1–4]. It has been found that CFST columns have better structural performance than steel reinforced concrete (RC) columns in terms of ductility and load carrying capacity. However, despite its structural advantages, the outer steel tube of CFST is susceptible to corrosion especially under chloride environment. It has been found that corrosion caused significantly deterioration to the compressive and flexural strength of CFST column [5,6]. Moreover, the fire resistance of CFST column has been a concern as the outer steel tube nearly loses its strength at 600 °C. It was also found that the post-fire load carrying capacities of CFST columns can be 50% lower than those at ambient temperature without fire exposure [7].

In order to increase the durability and fire resistance of CFST column, the CFST composite columns have been proposed and investigated, such like fiber reinforced polymer (FRP) encased-CFST column and concrete-encased CFST column. The FRP encased-CFST column consists of inner CFST and externally wrapped FRP sheet, which has various structural benefits compared with normal CFST column, such as higher corrosion and impact resistance [8,9]. However, the fire resistance of FRP encased-CFST column is questionable, since FRP materials may suffer melting, delamination, deformation and debonding when exposed to fire [10,11]. The concrete-encased CFST column is a conjunction of inner CFST component and outer RC component. The addition of the outer RC layer is believed to improve the corrosion resistance, fire resistance, and buckling resistance of inner CFST column [12–14]. However, it was also noticed that the outer concrete was easily crushed while the inner CFST was still in the elastic-plastic stage. This is due to the lack of deformation compatibility between the outer RC component and the inner CFST component, since the outer RC component is brittle while the inner CFST component is ductile. Moreover, since the outer concrete is brittle and easily-crushed, the long-term durability of concrete-encased CFST columns becomes a major concern especially for those exposed to severe environment such as marine or freezing-thawing environments.

In order to improve the durability and fire resistance of CFST composite column, the engineered cementitious composite (ECC) encased-CFST column was proposed in this paper. Fig. 1 shows the typical cross section of ECC-encased CFST column, which includes an inner CFST component and an outer reinforced ECC component. ECC is a kind of fiber reinforced cementitious material which features high tensile strain and superior crack control capacity. The tensile strain capacity for ECC is in the range of 2–7% which is several hundred times that of conventional concrete. After reaching such strain level, the crack width can still be controlled below 60 μm [15]. Also, ECC has a similar

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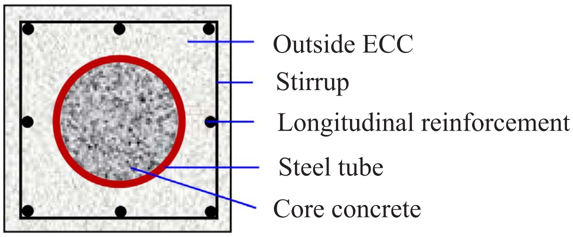

Fig. 1. Typical cross section of ECC-encased CFST column.

compressive strength with normal concrete, but has a higher ductility as well as lager strain at reaching its compressive strength [16]. Moreover, ECC's crack control and self-healing ability lead to its superior durability under various mechanical and environmental loading conditions such as freeze thawing [17] and chloride exposure [18]. It has also been observed that the mechanical performance of fire-deteriorated ECC material is better than that of conventional concrete and no explosive spoiling occurred in ECC specimens [19], since PVA fiber could introduce additional channels for vaporized moisture in ECC to escape without creating high internal pressure in the material [20]. Due to its unique properties, ECC material has been successfully applied to structural members such as beams [21], columns [22], slabs [23] and beam-column connections [24].

In this study, seven ECC-encased CFST columns with different eccentricity ratios and component parameters were tested. The effects of longitudinal reinforcement ratio, stirrup ratio and the thickness of steel tube on the mechanical behavior of ECC-encased CFST were studied. The mechanical behavior and failure mechanism of typical ECC-encased CFST columns were also investigated.

2. Experimental programs

2.1. Test specimens

The details of all specimens are summarized in Table 1, where e is the load eccentricity, L is the specimen length, B is the outer dimension of the specimen, t is the thickness of the steel tube, e_r is eccentricity ratio of the specimen which is defined as e/B, α_s is the stirrup ratio, α_l is the longitudinal reinforcement ratio, and N_u is the ultimate load carrying capacity of the tested specimen. As for different specimens, specimen 'C1-0.2' is used to explain the nomenclature: the first number '1' denotes the type of the column and there are four types of columns with different component parameters. Specimen C2 has a different stirrup ratio with specimen C1, while specimen C3 and C4 have different steel tube thickness and longitudinal reinforcement ratio with specimen C1, respectively. The last number '0.2' indicates the eccentricity ratio (e_r). All the specimens have a total height of 1400 mm and a cross-section of 300 mm × 300 mm. The protective cover for all specimens is 20 mm. The typical geometry of ECC -encased CFST column is depicted in Fig. 2. For all specimens, steel bars with diameter of 8 mm and 10 mm were used as stirrup and longitudinal reinforcements respectively.

Table 1
Details of all specimens.

Specimen	e (mm)	L (mm)	B (mm)	t (mm)	e_r	α_s (%)	α_l (%)	N_u (kN)
C1-0.2	60	1400	300	6	0.2	0.4	1	3671
C1-0.4	120	1400	300	6	0.4	0.4	1	2768
C1-0.6	180	1400	300	6	0.6	0.4	1	1846
C1-0.8	240	1400	300	6	0.8	0.4	1	1178
C2-0.4	120	1400	300	6	0.4	0.2	1	2643
C3-0.4	120	1400	300	10	0.4	0.4	1	3055
C4-0.4	120	1400	300	6	0.4	0.4	0.5	2586

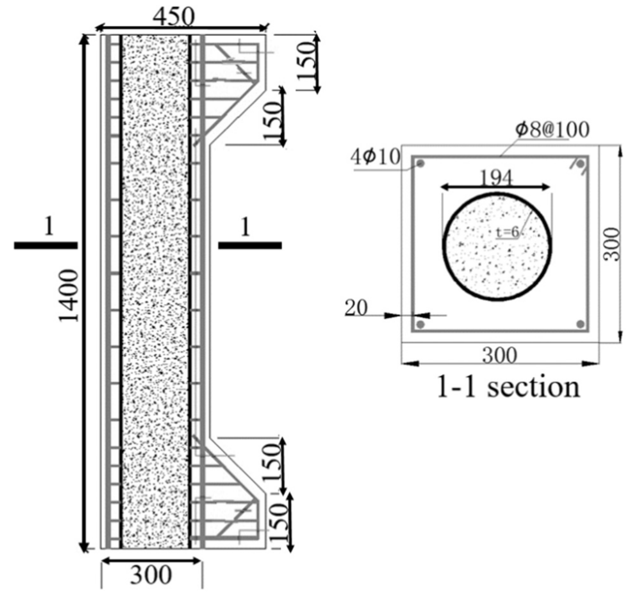

Fig. 2. Geometry of ECC -encased CFST column.

2.2. Material properties

In this research, ECC mixture contained Portland cement, quart sand, fly ash and PVA fiber. The PVA fiber content was 2% by volume fraction, while the water-binder ratio and the sand-binder ratio were set as 0.28 and 0.2 respectively. To ensure the matrix for ECC maintained proper flowability, superplasticizer was used with the amount 0.5% of binder content by weight. The inner concrete mixture included cement, river sand and granite stone. The mixture proportions of ECC and concrete are listed in Table 2. A number of concrete and ECC cubes (100 mm × 100 mm × 100 mm) were cast in steel molds and cured in the curing room with the temperature of 20 °C and relative humidity of 95% for 28 days. The uniaxial tensile test for ECC material was conducted with dog- bone specimen, which is shown in Fig. 3(a). According to the uniaxial tensile tests shown in Fig. 3(b), the tensile strength for ECC material exceeded 5 MPa and the ultimate tensile strain approached about 3.5%. Tensile coupon tests for steel were also conducted in order to determine the yield strength of the steel tubes and steel reinforcements. The main material properties are shown in Table 3.

2.3. Specimen preparation

Before casting concrete into the steel tube, one end of the steel tube was welded to a steel plate with a dimension of 450 mm × 300 mm. The concrete was uniformly mixed with a mechanical mixer and cast into the steel tube via three-layer vibration. Then the CFST column was set into the steel reinforcement cage, and the other end of the CFST column was welded to another steel plate, as shown in Fig. 4(a). After that, the steel reinforcement cage along with the inner CFST and steel plates were placed into the mold, and ECC was then cast. All specimens were demolded after two days and then naturally cured in the natural atmosphere, as shown in Fig. 4(b).

2.4. Test set-up and instrumentation

A universal testing machine with a capacity of 10,000 kN was applied in this study. The compression load was applied with the increment of 50 kN before the specimen reached its peak load. After the peak load, the compression load was applied with displacement control with the increment of 2 mm in order to record the post-peak behavior of the specimen and each load interval was maintained for 2–3 min. As can be