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# Experimental study on the hysteretic behavior of ECC-encased CFST columns

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ABSTRACT

Concrete-encased concrete-filled steel tube (concrete-encased CFST) columns, which is a conjunction of normal steel reinforced concrete (RC) and CFST columns, have been widely used in structural engineering. However, the outer RC component tends to crush in the early stage due to the significantly different mechanical performance of outer concrete and inner CFST. In this paper, it is proposed to substitute outer concrete with engineered cementitious composite (ECC) to form ECC-encased CFST columns. This paper presents an experimental study on the hysteretic behavior of ECC-encased CFST columns. Eleven specimens, including seven ECC-encased CFST columns and four concrete-encased CFST columns were tested under cyclic loading. According to the test results, ECC-encased CFST columns exhibited stable ductile behavior and the cumulative energy dissipation is about twice as much as that of concrete-encased CFST columns with same geometry. Also, the increase of steel tube diameter and stirrup ratio have positive effects on the hysteretic behavior of ECC- encased CFST columns.

## 1. Introduction

In recent years, a new composite column namely concrete-encased concrete filled steel tube (concrete-encased CFST) column has attracted broad interest from structural engineer and researchers [1,2]. Fig. 1 shows the typical schematic cross-section of a concrete-encased CFST column, which can be regarded as a conjunction of normal steel reinforced concrete (RC) column and CFST column. Compared with normal RC column, concrete-encased CFST column has a higher compressive and shear strength capacity as well as higher ductility due to the existence of inner CFST. Compared with normal CFST column, concrete-encased CFST column has a higher capacity to resist fire and corrosion due to the protection of outer concrete [3]. In recent years, concrete-encased CFST columns have been used as columns in structural engineering or arches in bridge construction. For example, this type of composite columns have been successfully used in the Labajin Bridge and Yalu Bridge in the Sichuan province of China [4].

In the past decades, a number of research work have been conducted to study the mechanical performance of concrete-encased CFST columns under compression [5], tension [6], bending [7] and dynamic loading [8–10]. Generally, it was found that the concrete-encased CFST columns have higher bearing capacity and stiffness than conventional RC columns. However, it was also noticed that the outer concrete was easily crushed while the inner CFST was still in the elastic-plastic stage, indicating a poor composite effect between the two components. This is due to the lack of deformation compatibility between the outer RC component and the inner CFST, since the inner CFST is ductile while the outer concrete is brittle. Moreover, since the outer concrete is brittle and easily-crushed, the long-term durability of concrete-encased CFST columns become a major concern especially for those columns exposed to severe environment such as marine or freezing-thawing environments.

In order to improve the ductility and durability of concrete-encased CFST columns, it is proposed to substitute the outer concrete with engineered cementitious composite (ECC) and to form ECC-encased CFST columns. ECC is designed based on the theory of micromechanics and fracture mechanics, 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 [11]. Also, the ultimate

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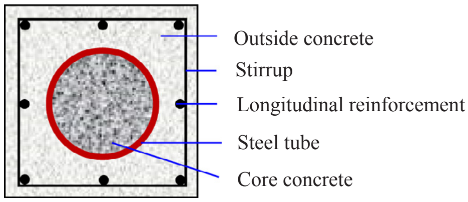


**Fig. 1.** Typical schematic cross-section of a concrete-encased CFST column.

compressive strain for ECC is nearly twice that of conventional concrete [12]. Due to its unique properties, this material has been successfully applied to structural members such as beams [13], columns [14], walls [15], beam-column connections [16] and so on. According to the previous research work conducted by the authors, ECC-encased CFST columns exhibited both superior ductility and high strength under eccentric loading when compared with conventional concrete-encased CFST columns [17].

In this study, seven ECC-encased CFST columns and four concrete-encased CFST columns were tested under the constant vertical load and horizontal cyclic load, simultaneously. The effects of axial load ratio, stirrup ratio and the steel tube diameter on the hysteretic behavior of ECC-encased CFST were also investigated.

## 2. Experimental programs

### 2.1. Test specimens

The details of all specimens are summarized in Table 1, where $H$ is the total height, $B$ is the outer dimension of the specimen, $S$ is the stirrup spacing, $D$ is the outside diameter of steel tube, $t$ is the thickness of steel tube and $n$ is axial load ratio which is defined as $N/N_u$, where $N$ and $N_u$ are the applied axial compressive load and ultimate load carrying capacity of the tested specimen, respectively. The ultimate load carrying capacity of ECC-encased CFST column ($N_u$) can be defined as $N_{RE} + N_{CFST}$, where $N_{RE}$ and $N_{CFST}$ are the load carrying capacities of outer reinforced ECC and inner CFST components, respectively. The parameter $\theta$ is the confinement index defined as $f_y A_{st}/f_{cc} A_{cc}$, where $f_y$ is the yield strength of steel tube, $f_{cc}$ is the compressive strength of internal concrete, $A_{st}$ and $A_{cc}$ are the cross-sectional area of steel tube and internal concrete, respectively. As for different specimens, specimen 'E-90-168-0.2' is used to explain the nomenclature: The first letter 'E' denotes the outer encased material is ECC while the first letter 'C' denotes the outer encased material is concrete. The first number '90' denotes the stirrup spacing and there are three types of stirrup spacing as can be seen in Table 1. The second number '168' indicates outside diameter of steel tube and the last number '0.2' indicates the axial load ratio. All the specimens have a total height of 1600 mm and with a

**Table 1**
Details of all specimens.

| Specimen | Encased material | $H$ (mm) | $B$ (mm) | $S$ (mm) | $D$ (mm) | $t$ (mm) | $n$ | $\theta$ |
|---|---|---|---|---|---|---|---|---|
| E-90-168-0.2 | ECC | 1600 | 300 | 90 | 168 | 6 | 0.2 | 1.22 |
| E-90-168-0.4 | ECC | 1600 | 300 | 90 | 168 | 6 | 0.4 | 1.22 |
| E-60-168-0.4 | ECC | 1600 | 300 | 60 | 168 | 6 | 0.4 | 1.22 |
| E-120-168-0.4 | ECC | 1600 | 300 | 120 | 168 | 6 | 0.4 | 1.22 |
| E-90-180-0.2 | ECC | 1600 | 300 | 90 | 180 | 10 | 0.2 | 1.93 |
| E-90-180-0.3 | ECC | 1600 | 300 | 90 | 180 | 10 | 0.3 | 1.93 |
| E-90-180-0.4 | ECC | 1600 | 300 | 90 | 180 | 10 | 0.4 | 1.93 |
| C-90-168-0.2 | Concrete | 1600 | 300 | 90 | 168 | 6 | 0.2 | 1.22 |
| C-90-168-0.4 | Concrete | 1600 | 300 | 90 | 168 | 6 | 0.4 | 1.22 |
| C-120-168-0.4 | Concrete | 1600 | 300 | 120 | 168 | 6 | 0.4 | 1.22 |
| C-90-180-0.4 | Concrete | 1600 | 300 | 90 | 180 | 10 | 0.4 | 1.93 |

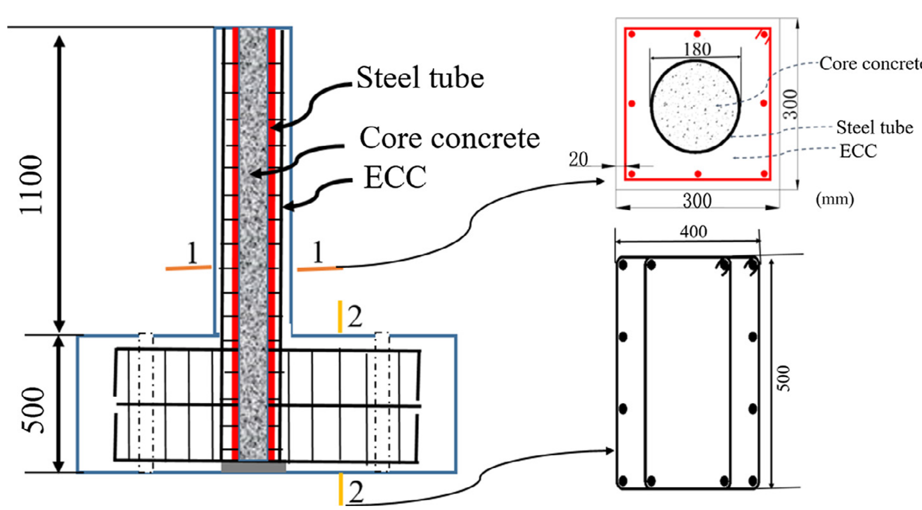


**Fig. 2.** Geometry of ECC-encased CFST column.