Journal of Constructional Steel Research 144 (2018) 283–294

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Behaviour of hexagonal concrete-encased CFST columns subjected to cyclic bending

Dan-Yang Ma [a], Lin-Hai Han [a,*], Xiaodong Ji [a], Wei-Biao Yang [b]

[a] Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China
[b] Beijing Institute of Architectural Design, Beijing 100045, PR China

ARTICLE INFO

Article history:
Received 18 June 2017
Received in revised form 19 January 2018
Accepted 21 January 2018
Available online xxxx

Keywords:
Concrete-encased CFST
Hexagonal section
Cyclic behaviour
Full-range analysis
Strength prediction

ABSTRACT

The hexagonal concrete-encased CFST column consists of a CFST (concrete-filled steel tube) core and a hexagonal-shaped reinforced concrete (RC) encasement. This paper presents the finite element (FE) analysis of hexagonal concrete-encased CFST columns subjected to axial compressive forces and cyclic bending moments. High-fidelity finite element analysis (FEA) model is established and validated by comparison with the test data in terms of failure mode and hysteretic curves. From the FEA model, the hysteretic response of the composite columns, the contact stress between the steel tube and concrete, and the strength contribution of different components during the full range of loading are illustrated. Parametric analysis is conducted to investigate the influences of various parameters on force-displacement envelope curves of the hexagonal concrete-encased CFST columns. The parameters include the material strength, confinement factor of CFST section, stirrup characteristic value, area ratio of CFST core to RC encasement, and axial force ratio. Finally, simplified methods are proposed to predict the flexural strength of hexagonal concrete-encased CFST columns. The predictions from simplified methods showed good agreement with the experimental and analytical results.

Notation

A	Cross-sectional area of concrete-encased CFST
A_{core}	Cross-sectional area of CFST core
$A_{e,out}$	Equivalent area of outer concrete
B	Side length
D	Distance to the middle axis
E_s	Modulus of elasticity of steel
E_c	Modulus of elasticity of concrete
f_c'	cylinder strength of core concrete
$f_{c,core}$	Prismatic strength of core concrete
$f_{c,out}$	Prismatic strength of outer concrete
$f_{cu,core}$	Cube strength of core concrete
$f_{cu,out}$	Cube strength of outer concrete
f_{ys}	Yield strength of steel tube
f_{yl}	Yield strength of longitudinal rebar
f_{yh}	Yield strength of stirrup
M_{RC}	Flexural strength of the RC encasement component
M_{CFST}	Flexural strength of CFST component
M_u	Flexural strength
M_{uc}	Predicted flexural strength
M_{ue}	Measured flexural strength
n	Axial force ratio
N_0	Constant axial load
N_u	Compressive strength
P	Lateral load
P_{uc}	Predicted ultimate strength
P_{ue}	Measured ultimate strength
s	Stirrup spacing
t	Steel tube thickness of CFST
α	Area ratio of CFST core
α_s	Steel ratio of CFST core
β	Factor of equivalent rectangular stress block
Δ	Displacement
Δ_y	Yield displacement
Δ_u	Ultimate displacement
θ	Drift ratio
θ_u	Ultimate drift ratio
λ_v	Stirrup characteristic value
ρ_v	Volumetric stirrup ratio
ρ_s	Longitudinal rebar ratio
ξ	Confinement factor for CFST section

* Corresponding author.
E-mail address: lhhan@tsinghua.edu.cn (L.-H. Han).

https://doi.org/10.1016/j.jcsr.2018.01.019

1. Introduction

CFST consists of the steel tube filled with concrete. CFST members with hexagonal cross section are used in some high-rise buildings for their aesthetic performance, where the members act as mega columns in the mega frame-core wall systems [1]. Moreover, the hexagonal shape makes the column easier to be connected with beams and the core wall. In the past, the performance of hexagonal CFST column members under axial compression and bending has been investigated by Xu et al. [1]. The CFST component is found to have increased compressive strength and ductility.

The concrete-encased CFST column consists of an inner CFST component and an outer reinforced concrete encasement component. The steel tube can provide confinement to the core concrete, and the reinforced concrete encasement can provide fire protection and corrosion protection. Because of these benefits, the concrete-encased CFST column has been increasingly used in high-rise buildings and bridges in China [2], such as Baoli Square of Shanghai, Jialing River Bridge and Labajin Bridge. The cross sections of the concrete-encased CFST column are usually circle, square, and rectangular for an easy beam-to-column connection. Han et al. [3] conducted experimental tests on concrete-encased CFST columns with aforementioned cross section. Ji et al. [4,5] reported a series of experiments on the seismic performance of concrete-encased CFST columns with square section. Both sets of tests indicate that concrete-encased CFST columns have favorable ductility and energy dissipation. Qian et al. [6] presented an analytical study on the cyclic behaviour of concrete-encased CFST columns with square section. In some complicated structures like China Zun, the highest building in Beijing, the column is not only connected to beams and shear wall in the longitudinal direction or transverse direction, but also in the diagonal direction. In such a circumstance, the hexagonal column section is convenient to be connected to beams and shear wall. The concrete-encased CFST column with a hexagonal section is designed to be applied in that circumstance. However, the research on the hexagonal concrete-encased CFST columns is very limited. The whole response of the hysteretic curve, the contact stress between steel tube and concrete, and the strength contribution of different components of the hexagonal concrete-encased CFST column have yet to be clearly understood.

To this end, the main objectives of this research are thus threefold: (1) To develop a high-fidelity finite element analysis (FEA) model that can accurately represent the cyclic behaviour of the hexagonal concrete-encased CFST column; (2) To conduct full-range analysis of the hexagonal concrete-encased CFST column, for estimating the contact stress between steel tube and concrete, and the strength contribution of different components; and (3) To establish a simplified model for the flexural strength prediction of the hexagonal concrete-encased CFST column.

2. FEA model

A FEA model was developed using ABAQUS/Standard module [7] to represent the specimen of hexagonal concrete encased CFST column in Xu [8]. Using the symmetricity, a quarter model was considered.

The schematic view of the FEA model of the hexagonal concrete-encased CFST is shown in Fig. 1. This type of cross section is chosen to be a 'standard' hexagonal shape in this study. The dual-axisymmetric cross section has an equal side length (B) for each edge of CFST core, two interior angles of 90° (θ_1) and four interior angles of 135° (θ_2).

2.1. Material properties

The concrete damaged plasticity model was used to simulate the behaviour of the concrete under cyclic loading. The concrete section was divided into three regions according to different levels of confinement, as shown in Fig. 1(a). The uniaxial compressive strain-stress relation of the core concrete, outer stirrup-confined concrete and concrete cover were simulated by the constitute models proposed by Han et al. [9], Han and An [10] and Attard and Setunge [11], respectively. Note that there is no specific constitute model for the core concrete of the hexagonal CFST. The axial compressive behaviour of the hexagonal CFST [1] and rectangular CFST [12] was compared by experimental tests. Both sets of CFST columns for comparison had similar confinement factor ξ ($=\frac{\alpha_s f_{ys}}{f_{ck,core}}$) and compressive strength of core concrete $f_{cu,core}$. The experimental results are shown in Fig. 2. The hexagonal CFST specimens were named by 'C', and the rectangular CFST specimens by 'rc'. It can be concluded that the axial strain-force relationship curves of two different sections are similar, which means the uniaxial compressive model of core concrete for the rectangular CFST can be used for the hexagonal CFST. The uniaxial compressive model of core concrete for the rectangular CFST is used for the core concrete with the hexagonal section. The uniaxial tensile model suggested by Shen et al. [13] is used for those types of concrete. The elastic modulus E_c and Possion's ratio of concrete are taken as $4730\sqrt{f_c'}$ and 0.2 respectively according to ACI318-11 [14], where f_c' is cylinder compressive strength in MPa.

The longitudinal rebars are simulated using Clough model [15]. The steel tube and stirrups are simulated using combined hardening model as shown in Fig. 3. The Clough model is used for the reason that

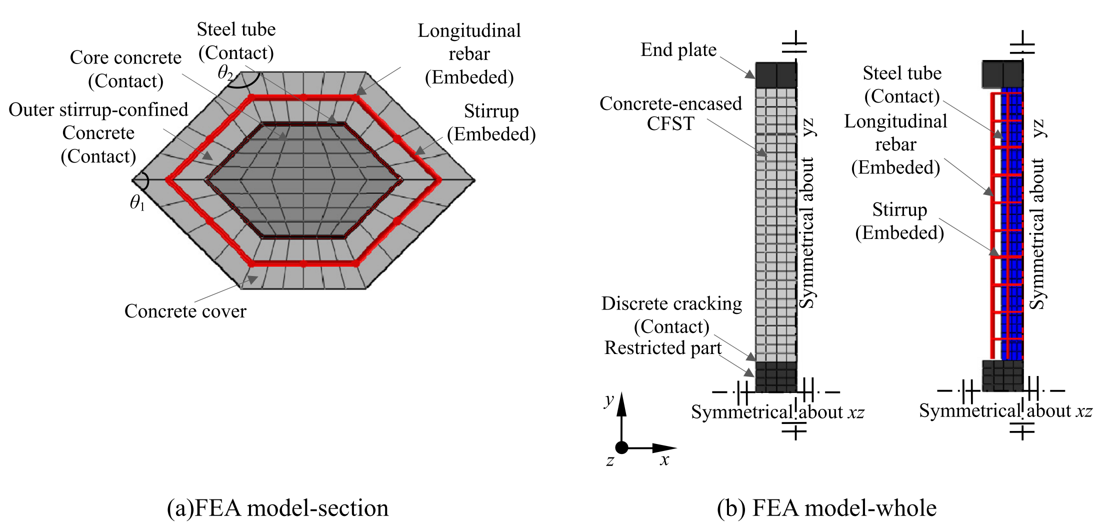

Fig. 1. Schematic view of the FEA model.