Journal of Constructional Steel Research 73 (2012) 66–79

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Seismic performance of CFST column to steel beam joint with RC slab: Joint model

Wei Li, Lin-Hai Han *

Department of Civil Engineering, Tsinghua University, Beijing, 100084, PR China

A R T I C L E I N F O

Article history:
Received 27 September 2011
Accepted 28 January 2012
Available online 7 March 2012

Keywords:
Concrete filled steel tubes (CFST)
Joint
Seismic behavior
Hysteretic model
Joint macro element

A B S T R A C T

Based on the previous experimental and numerical investigations presented in Han and Li (2010)and Li and Han (2011), this paper studies the joint model for the composite joint consisted of circular concrete filled steel tubular (CFST) column and steel beam with external diaphragm. The elastic shear stiffness and the shear deformation of the joint panel zone are investigated by parametric study using the finite element analysis (FEA) model. A hysteretic model incorporating the shear stiffness, shear strength, shear deformation and the hysteretic rules is proposed for the panel zone of the composite joint. This hysteretic model is then integrated in a fiber-based joint macro element. The joint macro element is validated by both FEA and experimental results. The overall and the local behavior of CFST joints and frame with macro elements are investigated. The proposed model is featured with a favorable accuracy and amenable modeling method, and could be applied to simulate the seismic behavior of large-scale and complex composite structural systems.

1. Introduction

The concrete filled steel tubular (CFST) structures have gained a widespread usage in constructions all over the world. It is well known that the beam to column joint in frame is constraint by other members, and the behavior of this region may have an influence on the nonlinear seismic performance of the whole structure. Therefore it is of great importance to study the load versus deformation relation of the joint, as well as the simplified model for the overall structural analysis that could reflect the joint behavior.

The behavior of the panel zone is the key issue on the behavior of the CFST composite joint. Previous research works had revealed that the shear capacity of the panel zone was contributed by the "compressive strut" mechanism of the inner core concrete and the shear mechanism of the outer steel tube (Li and Han [1]) , as shown in Fig. 1. The analytical shear versus shear deformation (V_j–γ_j) relation of the panel zone is usually obtained by the superposition of relations of the steel tube and core concrete parts. Fukumoto and Morita [2] suggested V_j–γ_j relations for circular and square CFST joints, where tri-linear relations were applied for both steel tube and core concrete. Cheng and Chung [3] considered that the shear relation for the steel tube could be expressed as a similar tri-linear relation, and a nonlinear relation for the core concrete was applied. Qin [4] established a V_j–γ_j relation for the square CFST joint. A tri-linear relation for the steel tube and a nonlinear relation for the core concrete were applied, where the σ–ε relation for confined concrete suggested by Han [5] was used. Fukumoto and Morita [2] and Qin [4] also proposed hysteretic rules for the V_j–γ_j relation of the panel zone.

For the overall analysis of CFST structures, basically two kinds of analytical models were developed in current research. One used 3-D continuum finite element analysis (FEA) elements to represent the detailed behavior, and the other used simplified elements with concentrated or distributed plasticity. It is convenient to obtain an accurate and detailed results using fine FEA model. However, it is more suitable to apply the simplified model in the overall structure analysis. In the simplified model, the beam and the column are usually simulated by using beam elements, and the wall and the floor are usually simulated by using shell elements. In the previous studies on CFST frames, Hajjar et al. [6] investigated the cyclic behavior of CFST column to beam assemblage with distributed plastic elements. Tort and Hajjar [7] proposed an analytical model for composite frames composed of rectangular CFST columns and steel beams. The column elements were simulated using distributed plasticity beam elements, and the steel tube and the core concrete were considered separately with the inter-slip behavior. Valipour and Foster [8] conducted the static and cyclic analysis on CFST column with 1-D fiber element.

In these researches, various simplified models for the structure were proposed though the deformation of joint was usually neglected. The CFST joint was usually treated as "common nodes" shared by beam and column elements or a "rigid" one. It is necessary to apply the hysteretic models from experimental or numerical researches for structural members and joints, so as to obtain accurate results in some key region with a favorable efficiency. Fukumoto and Morita [2] proposed a beam to column connection element for CFST frame analysis, where the panel zone and the connector element within the joint region were included with the beam and column elements. Zhao et al. [9] studied the macro model on the simulation of the nonlinear behavior of square CFST column to steel concrete composite beam joints, and the model was shown to be available on the nonlinear analysis of CFST structures.

---

* Corresponding author. Tel.: +86 10 62797067; fax: +86 10 62781488.
E-mail address: lhhan@tsinghua.edu.cn (L.-H. Han).

0143-974X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2012.01.011

Nomenclature

$A_{c,p}$	Cross-sectional area of panel zone core concrete
$A_{s,p}$	Cross-sectional area of panel zone steel tube
$A_{vy,p}$	Shear area of panel zone steel tube, for circular CFST section, $A_{vy,p}=A_{s,p}/2$
$A_{v,p}$	Shear area of panel zone steel tube when ultimate strength is reached, $A_{v,p}=2A_{s,p}/\pi$ for circular CFST section
D	Diameter of panel zone steel tube
E_c	Elastic modulus of concrete
E_s	Elastic modulus of steel
f'_c	Compressive strength of concrete cylinder
$f_{ck,p}$	Compressive strength of panel zone concrete
$f_{cu,b}$	Concrete cubic strength of slab
$f_{cu,c}$	Concrete cubic strength of column
$f_{cu,p}$	Concrete cubic strength of panel zone
$f_{y,b}$	Yield strength of beam steel
$f_{y,c}$	Yield strength of column steel
$f_{y,p}$	Yield strength of panel zone steel
$f_{y,r}$	Yield strength of reinforcement steel
G_s	Shear modulus of steel
h	Height of panel zone
K_{el}	Elastic stiffness of panel zone
$K_{el,c}$	Stiffness contribution of core concrete
$K_{el,s}$	Stiffness contribution of steel tube
N_0	Axial load on CFST column
N_u	Ultimate compressive strength of CFST column
$N_{u,p}$	Ultimate compressive strength of CFST panel zone
n	Axial load level of CFST column, $n=N_0/N_u$
n_p	Axial load level of CFST panel zone, $n_p=N_0/N_{u,p}$
t	Thickness of panel zone steel tube
$\mathrm{tg}\theta_p$	Height to diameter ratio of panel zone, $\mathrm{tg}\theta_p=h/D$
V_j	Shear force of panel zone
V_u	Shear strength of panel zone for CFST joint
$V_{u,c}$	Shear strength of panel zone concrete
$V_{u,s}$	Shear strength of panel zone steel
V_y	Yield strength of panel zone for CFST joint
α_p	Steel ratio of panel zone section
γ_j	Shear deformation of panel zone
γ_u	Shear deformation of panel zone when ultimate strength is reached
ξ_p	Confinement factor of panel zone
ρ_s	Reinforcement ratio of RC slab
θ_p	Angle of panel zone diagonal and horizontal

In the previous research, Han and Li [10] studied the CFST column to steel beam joint with reinforced concrete (RC) slab experimentally, then a finite element analysis (FEA) model for the simulation of composite joint under cyclic loading was proposed (Li and Han [1]). A mechanism analysis of CFST joint was conducted as well. The main objectives of this research are as follows: (i), to provide a hysteretic model for the panel zone behavior of CFST joint through parametric study; (ii), to provide a joint macro element on CFST column to steel beam joints with and without RC slabs under cyclic loading. The proposed hysteretic model is used in the panel zone of joint macro element, and the fiber-discretized beam elements are applied for the CFST column and beams.

2. Hysteretic model for CFST panel zone

2.1. General description

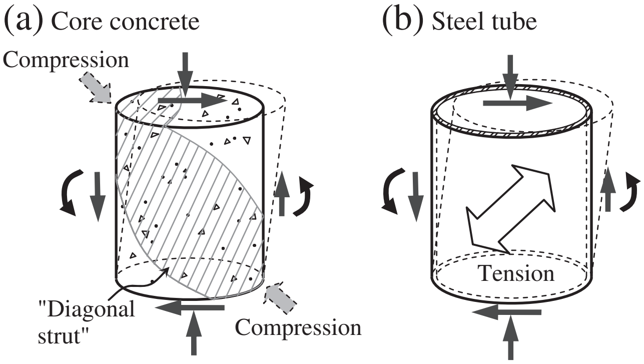

Fig. 1. Schematic view of CFST panel zone mechanism.

In this research, a set of joint specimens are designed referencing joints in real buildings, and an extensive numerical investigation is conducted by using the validated FEA model developed in Li and Han [1]. The schematic view of the joint specimen is shown in Fig. 2. The shear versus shear deformation (V_j–γ_j) relation is especially studied in order to draw the hysteretic model for the panel zone of CFST joint.

Fig. 3(a) shows the calculated hysteretic curve of the panel zone as well as those of the steel tube and the core concrete, where V_j is the shear force, $V_{j,max}$ is the maximum shear force of panel zone, γ_j is the shear deformation of panel zone. Shear forces of steel tube and core concrete are obtained by the summation of element nodal forces. The deformation of the steel tube and the inner concrete is unified, which is consistence with the phenomenon in the experiment that no slippage was found between steel tube and core concrete in the panel zone region.

A trilinear V_j–γ_j relation is proposed for the panel zone of circular CFST joint, as shown in Fig. 3(b). The total shear resistance of the panel zone is obtained by the superposition of shear forces from steel tube and core concrete. The descending section of the V_j–γ_j relation is not significant in the circular CFST joint, and the shear force remains unchanged in the proposed model when ultimate strength is reached. It is due to the fact that when the ultimate strength is reached, the shear resistance of the core concrete decreases while that of the steel tube increases for the strengthening of steel material. As a result, the total shear of the panel zone nearly remains the same.

It was found from the previous research that the properties of beam and column had minor effect on the envelop curve of V_j–γ_j relation of panel zone (Li and Han [1]). Therefore the panel zone of

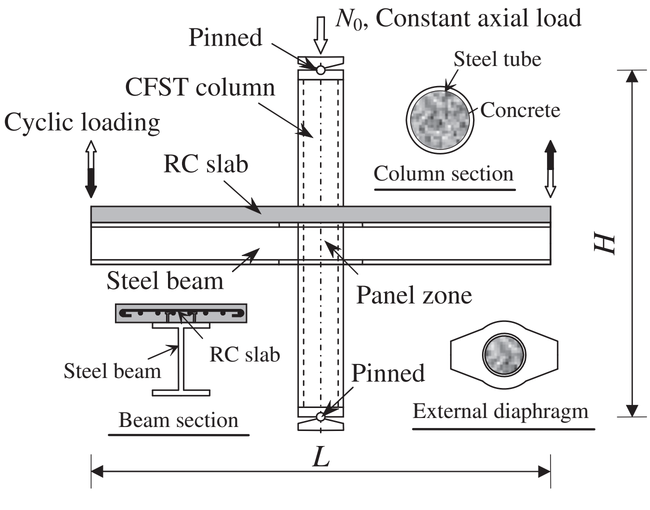

Fig. 2. Schematic view of CFST joint specimen.