Journal of Constructional Steel Research 130 (2017) 96–108

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Behavior of circular tubed-RC column to RC beam connections under axial compression

Xuhong Zhou [a,b], Guozhong Cheng [a,b], Jiepeng Liu [a], Dan Gan [a,b,c,*], Y. Frank Chen [d]

[a] Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China
[b] School of Civil Engineering, Chongqing University, Chongqing 400045, China
[c] School of Civil Engineering, Chang'an University, Xi'an 710061, China
[d] Department of Civil Engineering, The Pennsylvania State University, Middletown, PA 17057, USA

ARTICLE INFO

Article history:
Received 12 August 2016
Received in revised form 10 November 2016
Accepted 9 December 2016
Available online xxxx

Keywords:
Circular tubed-reinforced concrete column
Composite connection
Axial compressive behavior
Confined concrete
Equivalent stress-strain relationship
Complex confinement

ABSTRACT

The circular tubed-reinforced concrete (TRC) column is a kind of special concrete-filled steel tube (CFST) columns, in which the outer thin-walled steel tube does not pass through the beam-column joint and thus can avoid the direct transfer of an axial load and maximize the confinement effect from the steel tube. Although the columns possess high load-carrying capacities and good ductility performance in seismic zones, there is a possible decrease in the axial bearing capacity of the TRC column to RC beam connections due to the discontinuity of the column tube, which is a particular concern to engineers. To compensate for the discontinuity of the column tube, strengthening stirrups, a tube with rectangular openings, and horizontal haunches are adopted in the connection zone as Type A, Type B, and Type C connections, respectively. Nine connections aforementioned and four reference circular TRC columns were tested under axial compression. The experimental results show that Type B and Type C connections are effectively strengthened, while Type A connection needs further strengthening because of the lower axial bearing capacity than the reference columns. A finite element (FE) model was developed to simulate the behavior of connections under axial compression. The predicted load-stain curves are in good agreements with the measured ones. A theoretical model for predicting the axial bearing capacities of the connections which is based on the confined concrete theory and local compression theory is proposed.

1. Introduction

Composite structure frames composed of concrete-filled steel tube (CSFT) columns and reinforced concrete (RC) beams have been increasingly used in the world due mainly to better fire resistance, durability, and lower cost. However, the RC beam to CFST column connection detailing is complex and difficult to be implemented [1,2]. As a better solution for the connection, CSFT columns with their outer steel tubes cut off at both ends are adopted so that the reinforcement in columns and RC beams can pass through each other freely at the connections and the beam and column will work together as in a RC frame. The CFST column with the column tube not passing through the beam-column connection and reinforcement cage embedded in concrete is referred as "*tubed reinforced concrete*" (TRC) column [3]. They possess high load-carrying capacity and good ductility performance [3–8]. Fig. 1 illustrates TRC column to RC beam connections which is a new type of through-beam connections. The longitudinal steel reinforcing bars in RC beams can pass through the connection zone freely without interfering with the added steel strengthening ring or steel bracket in the connection zone like traditional CFT column to RC beam connections, thus simplifying the construction process and saving the cost. However, there is a possible decrease of the axial bearing capacity as a result of the discontinuity of the column tube, which is a particular concern to engineers.

Nie et al. [9,10] developed a through-beam connection system for concrete-encased CFST columns and RC beams, where multiple lateral hoops and a prefabricated steel cage with cast concrete were used to compensate for the discontinuity of the steel tube. Zhang et al. [11] investigated the seismic behavior of another type of through-beam connection which consists of a ring beam joint with a discontinuous outer tube between concrete-filled twin steel tubular columns and RC beams. Chen et al. [12,13] performed experimental and analytical studies on the seismic and axial compressive behavior of a new type of through-beam connections between CFST columns and RC beams, in which a strengthening RC ring beam was used to enlarge the connection zone to compensate for the possible decrease of axial load capacity due to the discontinuity of the column in the connection zone. Han et al. [14] studied the behavior of the composite joints of thin-walled steel tube confined plain concrete column to RC beam under cyclic loading.

* Corresponding author at: Key Laboratory of New Technology for Construction of Cities in Mountain Area (Chongqing University), Ministry of Education, Chongqing 400045, China.
E-mail address: gandan@cqu.edu.cn (D. Gan).

http://dx.doi.org/10.1016/j.jcsr.2016.12.005
0143-974X/

Nomenclature

A	area of cross section of the column
A_c	area of core of section enclosed by the center lines of the stirrup
A_{cc}	area of the concrete within the center lines of the stirrup or steel tube
A_s	total area of longitudinal steel reinforcing bars of the column
A_{sp}	area of the stirrup
B	width of the beam
d_s	diameter of the stirrup
D	diameter of the column
E_c	tangent modulus of elasticity of the concrete, set as $E_c = 4730\sqrt{f_{co}}$
E_s	modulus of elasticity of steel
f_a	yield strength of longitudinal steel reinforcing bar of the column
f_b	yield strength of the stirrup
f_{cc}	axial compressive strength of the confined concrete, set as $f_{cc} = f_{co}(-1.254 + 2.254\sqrt{1 + 7.94f_l/f_{co}} - 2f_l/f_{co})$ [34]
f_{co}	axial compressive strength of the concrete
f_d	yield strength of longitudinal steel reinforcing bar of the beam
f_l	confining pressure
f_y	yield strength of the steel tube
h	height of the beam
h'	clear vertical spacing between longitudinal steel reinforcing bars of the beam
h_0	total height of the rectangular opening
H	clear vertical spacing between the column tubes
K_c	strength ratio of the concrete under equal biaxial compression to triaxial compression, set as $K_c = 2/3$ which is the default value
L	length of the specimen
n	number of the connection beams
N	axial compressive load
N_{ue}	ultimate bearing capacity
r_s	radius of the stirrup
R	radius of the column
s	center to center spacing of the stirrup
s'	clear vertical spacing between the stirrups
t_s	thickness of the steel tube
Δ	axial shortening displacement of the specimen
ε	axial compressive strain
ε_1	strain corresponding to maximum principle stress
$\tilde{\varepsilon}_c^{pl}$	compressive plasticity strain
ε_{cc}	strain at maximum strength of the confined concrete f_{cc}, set as $\varepsilon_{cc} = \varepsilon_{co}[1 + 5(f_{cc}/f_{co} - 1)]$ [34]
ε_{ch}	transverse strain of the concrete
ε_{co}	strain at maximum strength of the unconfined concrete, set as $\varepsilon_{co} = (700 + 172\sqrt{f_{co}}) \times 10^{-6}$ [15]
ε_{cv}	vertical strain of the concrete
ε_h	transverse strain of the concrete
ε_v	vertical strain of the steel tube
ε_y	yield strain, set as f_y/E_s
ρ_{cc1}	ratio of A_s to A_c
ρ_{cc2}	ratio of A_s to A
σ_1	maximum principle stress
σ_2	middle principle stress
σ_3	minimum principal stress
f_{bo}/f_{co}	the ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress, set as $f_{bo}/f_{co} = 1.16$ which is the default value
σ_{cv}	vertical stress of the concrete
σ_h	transverse stress of the steel tube
σ_v	vertical stress of the steel tube
σ_z	equivalent stress of von Mises

Based on the literature review, research on circular TRC column to RC beam connections is still limited.

This paper proposes three types of circular TRC column to RC beam connections, where the discontinuity of the column tube is compensated in different manners. For Type A connection (Fig. 2(a)), strengthening stirrups within connection zone are utilized. For Type B connection (Fig. 2(b)), a tube with rectangular openings is used in the connection zone, which can provide confinement to the core concrete to increase the axial bearing capacity at the connections. The rectangular openings allow the longitudinal reinforcing steel bars in RC beams to pass through the connection zone directly. For Type C connection (Fig. 2(c)), horizontal haunches are adopted to enlarge the compression area of concrete at the connection.

For high rise buildings, the beam-column connections in the lower stories are subjected to large axial compressive force being the dominant action. To investigate the axial compressive behavior of circular TRC column to RC beam connections with the strengthening measures mentioned above, nine connections and four reference columns were tested. Additionally, a finite element (FE) model was developed to simulate the behavior of connections under axial compression loads. For practical purposes, a theoretical model for predicting the axial bearing capacities of the new connections is also proposed based on the confined concrete theory and local compression theory. The results of this paper also lay the groundwork for the study of seismic behavior of the connections.

2. Experimental program

2.1. Specimen description

Detailed specimen geometry is shown in Fig. 3. Gaps of 10 mm were provided at the top and bottom of each connection to avoid direct compression on the steel tube and two 10 mm thick steel endplates were welded at both ends of each specimen to ensure uniform loading. To assess the effects of connection location, corner, exterior, and interior

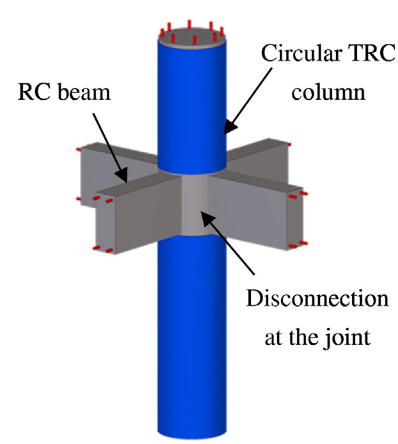

Fig. 1. Circular TRC column to RC beam connection.