Journal of Constructional Steel Research 66 (2010) 28–36

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

journal homepage: www.elsevier.com/locate/jcsr

Behavior and strength of tubed RC stub columns under axial compression

Jiepeng Liu [a,*], Xuhong Zhou [b]

[a] *Architectural Design and Research Institute, Harbin Institute of Technology, Harbin, 150090, China*

[b] *School of Civil Engineering and Mechanics, Lanzhou University, Lanzhou 730000, China*

ARTICLE INFO

Article history:
Received 2 April 2009
Accepted 10 August 2009

Keywords:
Tubed RC
Stub column
Axial compression
Diameter/width to thickness ratio
Failure mode
Axial load strength
Elastic–plastic analysis

ABSTRACT

This paper presents an experimental and analytical study on the behavior of axially compressed tubed RC stub columns. Forty specimens including twenty circular tubed RC (STRC) and twenty square tubed RC (STRC) stub columns were tested to investigate the failure mode and axial load strength of tubed RC columns subjected to axial compression. The effect of diameter/width to thickness ratio of the tubes and compressive strength of concrete were also studied. The effect of height to diameter/width ratio of the separated tube in tubed RC columns was studied to investigate the effect of bond and friction between tube and concrete on the behavior of tubed RC columns. Elastic–plastic analysis on the steel tube was employed to study the mechanism of tubed RC stub columns subjected to axial compression. Equations for the prediction of the ultimate axial load strength of tubed RC stub columns were proposed and the results from prediction were compared with the test results.

1. Introduction

A tubed reinforced concrete (RC) column is a special concrete-filled tube (CFT) column where a part of the steel is in the form of a thin outer tube shorter than the core concrete and the rest of the steel is in the form of main reinforcement embedded in the concrete. Tubed RC columns are proposed to be used in structures for avoiding the complexity of connecting an RC beam to a CFT column in construction (Fig. 1). In high structure design, designers often use CFT columns instead of RC columns to decrease the size of the columns. While using CFT columns, some designers still use RC beams to save cost. The RC beams to CFT columns connections are very complicated and time consuming during construction. As a solution to overcome such shortage, tubed RC columns which have the outside steel tubes cut off at both ends are adopted so that the reinforcement in columns and RC beams can pass though each other and work together as in RC concrete frames.

Tubed RC columns offer more advantages compared with RC columns. In an ordinary RC column, the concrete is confined by transverse reinforcement; however, the ordinary reinforcing bars do not confine the concrete cover, which will spall off during an earthquake. The transverse ties cannot effectively prevent the longitudinal bars from buckling after the concrete cover spalls off unless they are very closely spaced [1]. Previous research on concrete has shown that high strength concrete is more brittle than normal strength concrete [2]. Thus, a higher transverse tie ratio is required if a high strength RC column is under high axial load level, which will increase the difficulty of its fabrication. If an RC column is tubed by an outer thin steel tube as plotted in Fig. 1, the whole concrete column including the cover will be confined and the strength as well as ductility of the RC columns can be improved effectively. The transverse reinforcement in a tubed RC column is not required except when it is used to erect the main reinforcement, which will decrease the difficulty of concrete fabrication.

Tubed RC columns also offer more advantages than CFT columns except the convenience of connecting with RC beam. The steel tube of a CFT column is in a state of biaxial (tension–compression) stress. Furlong [3] and Zhong [4] reported that if the steel tube is axially loaded, the confinement effect does not occur during the elastic stage when Poisson's ratio of steel is higher than Poisson's ratio of concrete. The tendency of buckling for steel tubes under biaxial stress will further decrease the ductility of CFT columns with high diameter to thickness ratio [5–7]. Test results from Gardner [8] and Amir Fam [9] illustrated that the axial load strength of CFT columns obtained by loading both the concrete core and the steel tube was lower than that by loading the concrete core alone. Therefore, tubed RC columns which have only concrete core carrying axial loads show a better performance when subjected to axial loads.

At present, research on tubed RC columns concentrates on the seismic behavior of short columns and beam–columns. Tomii et al. [10] investigated the seismic behavior of square tubed RC

* Corresponding address: Harbin Institute of Technology (2th District), PO Box 2551, 202 Haihe Road, Nan'gang District, Harbin 150090, China. Tel.: +86 0 451 8628 2083; fax: +86 0 451 86282083.

E-mail address: liujp@hit.edu.cn (J. Liu).

0143-974X/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2009.08.006

Notations

A_b	cross-sectional area of main reinforcement;
A_c	cross-sectional area of concrete;
A_s	cross-sectional area of steel tube;
D	diameter/width of the tube;
E_s	Young's modulus of steel;
f_{cc}	compressive strength of confined concrete;
f_{co}	compressive strength of unconfined concrete;
f_{cu}^{10}	100 mm concrete cubic strength;
$f'_{r,c}$	effective confining stress of the circular tube on the concrete
$f'_{r,s}$	effective confining stress of the square tube on the concrete;
f_y	yield strength of steel tube;
f_b	yield strength of main reinforcement;
h	height of the separated tube in the CTRC or STRC columns;
k_e	the confinement effectiveness coefficient for square tubed concrete columns;
L	length of the column;
N	axial load;
N_a	summation of the axial load strength of concrete, tube and main reinforcement;
N_u	axial load strength;
N_{uc}	predicted axial load strength from proposed equation;
N_{ue}	tested axial load strength;
t	thickness of the tube;
Δ	displacement;
σ	stress;
σ_v	longitudinal stress;
σ_h	transverse stress;
σ_{he}	transverse stress of the steel at the end of tube for STRC columns;
σ_z	equivalent stress;
$\sigma_{h,s}$	transverse stress of the square tube at the peak load point;
ε	strain;
ε_v	longitudinal strain;
ε_h	transverse strain;
υ_h	Poisson's ratio of steel.

short columns with the shear span to depth ratio 1.0. It was concluded that steel tubes were very effective in preventing shear failure in short columns. Sakino et al. [11] investigated the cyclic behavior of eight square tubed RC short columns with the shear span to depth ratio varying from 1.0 to 2.0. It was concluded that the confinement effect by the square steel tubes decreased as the width to thickness ratio of the tube and/or the concrete strength increased. They also concluded that the confining effects of the square steel tubes on the flexural behavior of tubed columns became more significant when the applied axial compression was higher. Aboutaha [12] investigated the cyclic behavior of three rectangular tubed RC beam–columns. It was concluded that the ductility of the columns was improved by the confinement of the rectangular tube, while the influence on the flexural strength was slight. Zhang et al. [13] investigated the seismic behavior of four square tubed RC beam–columns as well as one ordinary RC column as comparison. It was concluded that the ductility and flexural strength of the columns was improved by the confinement of

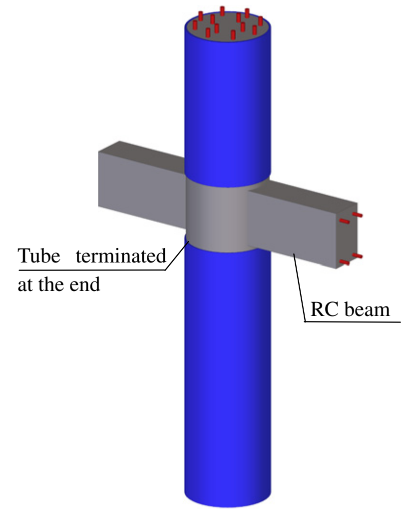

Fig. 1. Tubed RC column connected with RC beam.

square tube to concrete. Zhou et al. [14] investigated the seismic behavior of eight tubed RC beam–columns including four circular columns and four square columns. The test results indicated that tubed RC beam–columns exhibited excellent ductility under high axial load ratio, and the circular tubed RC columns exhibited better ductility than that of the square tubed RC columns. The creep and shrinkage of concrete maybe affect the confinement of the tube to the concrete in a tubed RC column, but to the knowledge of the authors no work has been published on this. Previous research on axially compressed stub columns concentrated on tubed plain concrete [13,15–19]. Columns resist combined compression and flexural moment in the real structures, therefore main reinforcement is necessary for tubed concrete columns to resist the flexural moment; which is the form of tubed RC columns. The review on previous research indicates that experiment on axially compressed tubed RC stub columns is insufficient. The current study is carried out to investigate the structural behavior and propose analytical model for tubed RC stub columns subjected to concentric compressive loading.

2. Experimental program

2.1. Details of specimens

Forty tubed RC stub columns including twenty circular tubed RC (CTRC) columns and twenty square tubed RC (STRC) columns were tested to failure under axial compression, where specimen details are provided in Tables 1 and 2. A length to diameter/width ratio of 3 was selected for the CTRC/STRC stub columns in order to ensure short column behavior. CTRC columns as well as STRC columns consisted of five groups of specimens and each group included four types of specimens. Fig. 2 depicts four types of specimens in a group. As shown in Fig. 2, only the core RC was directly loaded under compression since the tubes were separated in the tubed RC columns. The difference between type A, type B and type C columns were the h/D ratio of the separated steel tube, where h and D are the height and width of one separated steel tube. The purpose of varying the h/D ratio of the separated steel tubes was to investigate the effect of bond and friction between concrete and tube on the behavior of tubed RC columns under axial compression. The h/D ratio of the separated tube of type D columns was the same as that of type A columns, whereas there was no reinforcement in type D columns. The behavior of type A and type D specimens were compared to study the effect of reinforcement on the failure mode and strength of tubed RC stub columns under axial compression.