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Behavior of short circular tubed-reinforced-concrete columns subjected to eccentric compression

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ABSTRACT

The tubed-reinforced-concrete (TRC) column is a kind of confined reinforced-concrete (RC) columns using the outer encasing thin-walled steel tube which discontinues at the beam-column joints and thus does not carry any direct axial load. Although this composite column has been used in some practical applications in China, there is still a lack of sufficient experimental data and design methods for the TRC columns subjected to eccentric compression. In this paper, 18 short circular TRC columns are tested under axial and eccentric compression considering parameters of eccentricity and diameter-to-thickness ratio of the steel tube. Failure mode, axial load-carrying capacity, and stress in the steel tube of the specimens are discussed in detail. The test results indicate that the average confining stress in the columns with small eccentricity is close to that in the columns under axial load at the peak load. To validate the employed stress–strain relationship for the confined concrete, a fiber-based model is developed and the predicted results agree well with the test results. Based on the strain energy equivalence principle, a regression formula to estimate the ultimate compressive strain of concrete confined by the steel tube is proposed. The equivalent concrete stress block parameters of circular TRC members are theoretically studied and the modified values are purposely suggested for the calculation of capacity interaction diagram.

1. Introduction

In traditional RC columns, the concrete cover tends to spall off during an earthquake and the longitudinal bars are likely to buckle. To ensure the strength and ductility of the column, a higher volume ratio of stirrup is generally required especially for high-strength concrete, which will increase the difficulty of fabrication [1–4]. For a short RC column (shear span to depth ratio $\lambda \leqslant 2$) under high axial load level, it can hardly meet the seismic design requirement only by increasing the transverse tie ratio [5,6].

A tubed-reinforced-concrete (TRC) column is a special reinforced-concrete (RC) column where the densely arranged stirrups are replaced by an outer encasing thin-walled steel tube with only a few stirrups. The steel tube does not pass through the beam-column joints and is slightly shorter than the RC core. The construction procedure of TRC columns is similar to that of RC columns, where the steel tube acts as a permanent formwork for pouring of the concrete. Fig. 1 illustrates the TRC column and its connection with RC beams. The steel tube terminates at the column ends to ensure the axial load is applied to the RC core only, thus reducing the possibility of tube buckling and making a better use of the steel tube for confining the concrete. The confinement from the tube serves two purposes: (1) enhances the axial strength, shear strength, and deformability of the traditional RC columns; and (2) prevents the concrete cover from spalling off and protects the longitudinal bars from buckling during an earthquake event [7–15]. For traditional hollow steel composite members like concrete filled steel tube (CFST) columns, an allowable diameter to thickness ratio of steel tube is required to avoid the local buckling and this limiting value is even stricter for high-strength steel [16–20]. While the steel tube of the TRC column does not carry a direct axial load, high-strength steel tube with larger diameter-to-thickness ratio can therefore be utilized to improve the economic benefit of TRC columns [14,15]. Besides, compared to the traditional CFST columns, the TRC columns exhibit a good fire-resistance performance since most of the steel is embedded in the concrete in the form of reinforcements [21–24]. Therefore, the TRC column has been increasingly used recently in China due to its superior structural behavior [25].

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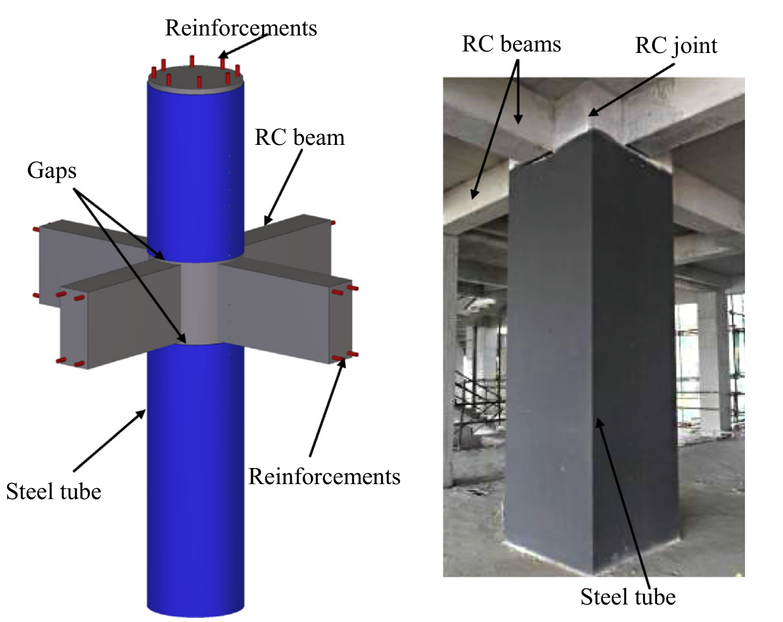
Notations

D	diameter of specimen cross-section
e	eccentricity of loading
E_c	elastic modulus of concrete
E_{sec}	secant modulus of concrete
$f_{cu,100}$	100 mm concrete cube strength
f_{co}	cylinder concrete strength
f_{cc}	confined concrete strength
f_{ty}	yield stress of steel tube
f_{by}	yield stress of longitudinal reinforcing bar
f_{sy}	yield stress of stirrup
f_l	effective confining stress
k	temporary coefficient $k = x_{cu}/\varepsilon_{cu}$
L	length of the specimen
M_c	bending moment of concrete
M_{ec}	equivalent bending moment of concrete
M_u	bending moment capacity
N_c	axial resistance of concrete
N_{ec}	equivalent axial resistance of concrete
N_u	axial load-carrying capacity
n_b	number of longitudinal reinforcing bars
P_u	peak axial load
P	axial load
r_b	radius of reinforcing bar circle
S_c	cross-sectional area of concrete
S_{bi}	cross-sectional area of the i_{th} longitudinal reinforcing bar
t	wall thickness of steel tube
x_{cu}	distance between the extreme compression fiber and the neutral axis
α	strength reduction factor for the concrete stress block
α_b	longitudinal reinforcement to concrete area ratio
α_t	steel tube to concrete area ratio
β	effective height factor for the concrete stress block
Δ	axial shorting of specimen
δ	mid-span lateral displacement of specimen
ε_c	strain of concrete
ε_{co}	residual strain of concrete corresponding to f_{co}
ε_{cc}	residual strain of confined concrete corresponding to f_{cc}
ε_{cu}	ultimate compressive strain of confined concrete
ε_{ht}	circumferential strain of steel tube
ε_{tf}	circumferential fracture strain of steel tube
ε_{sp}	strain at which the concrete covering has lost its strength totally
λ	shear span to depth ratio; $\lambda = \frac{M}{Vh_0}$, where M and V are the moment and shear force acting at the column end section, h_0 is the effective height of the cross-section
σ_b	stress of longitudinal reinforcing bar
σ_{bi}	stress of the i_{th} longitudinal reinforcement bar in the critical state
σ_c	stress of concrete
σ_{cc}	stress of confined concrete
σ_h	circumferential stress of steel tube
σ_v	longitudinal stress of steel tube
σ_z	equivalent stress of steel tube
φ_i	the angle between the horizontal line and the line connecting the centroid of the section and the centroid of the i_{th} longitudinal reinforcement bar
ξ	confinement coefficient $\xi = \alpha_t \frac{f_{yt}}{f_{co}}$

The concept of TRC column was first proposed by Tomii et al. [26,27] to improve the shear strength and ductility of short RC columns. In their tests, good seismic behavior was obtained and the brittle shear failure of the columns was effectively avoided by the confinement from the steel tube. Aboutaha [28,29] investigated the cyclic response of rectangular TRC columns and concluded that the rectangular TRC columns exhibited higher lateral strength and ductility than traditional RC columns. Han et al. [30] conducted experiments on the seismic behavior of TRC column to RC beam connections, and good seismic performance was obtained. Zhou



(a) Sketch (b) Photo showing the real column

Fig. 1. The TRC column and its beam to column connection.