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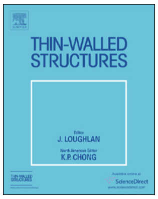

Behavior of square tubed reinforced-concrete short columns subjected to eccentric compression

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ABSTRACT

This paper presents the experimental and theoretical studies on square tubed reinforced-concrete (TRC) short columns under eccentric compression. The main parameters of the test specimens included eccentricity and width-to-thickness ratio of the steel tube. The axial load versus lateral deformation curves, stresses in the steel tubes and the observed failure modes were discussed. The test results indicated that the eccentrically loaded specimens exhibited good ductile behavior with a bending failure mode. A new approach to determine the effective lateral confining pressure for TRC columns with square section was proposed. A numerical analysis model was developed to simulate the mechanical behaviors of square TRC short columns. Valuable attempts were made to describe the variation rules between the parameters in stress block method for tubed concrete and the magnitude of confinement. Furthermore, the axial force versus moment capacity interaction diagrams of square TRC columns were calculated.

1. Introduction

Tubed reinforced-concrete (TRC) columns are a new type of reinforced-concrete (RC) columns wrapped with outer thin-wall steel tubes. The steel tube does not pass through the beam-to-column connection and terminate at ends of the column by girth gaps, as illustrated in Fig. 1, which insures that no direct axial load is applied on the steel tube. The possibility of tube buckling could be reduced and the steel tube is fully used for confining the concrete to a great extent [1,2]. The confinement from the tube can effectively prevent the concrete cover from spalling off and protect the longitudinal bars from buckling in an earthquake. Besides, high-strength steel tube with large diameter-to-thickness ratio can be used to improve the economic benefit of TRC columns.

The axial compression behavior and seismic performance of TRC columns have been investigated in previous studies. Tomii et al. [3–5] first investigated TRC columns in building structures to improve the shear strength and ductility of RC short columns which are characterized with shear span-to-depth ratio, and a good seismic behavior was obtained from their experiment. Aboutaha and Machado [6,7] investigated the cyclic behavior of rectangular steel tube confined reinforced-concrete columns. They concluded that the rectangular TRC columns exhibited higher lateral strength and ductility than traditional RC columns, while the influence on the flexural strength was slight. Liu and Zhou [8–11] conducted a series of experimental studies to investigate the axial compression behavior and seismic performance of TRC columns with circular and square sections. In addition, they proposed design methods for predicting axial and shear bearing capacity for the TRC columns, which enhanced the application of TRC columns in practical constructional work.

In practical situation, most columns are subjected to combined axial and flexural loadings. However, there is no published literature focused on the behavior of TRC columns subjected to eccentric compression. In this paper, eccentric compression behavior of square TRC short columns was experimentally and theoretically investigated. The confinement mechanism and the stress block parameters for square TRC members were analyzed, based on which the axial force versus moment capacity interaction diagrams were obtained.

2. Experimental program

2.1. Specimens

A total of 12 specimens of square TRC short columns, with the key parameters including diameter-to-thickness ratio of the steel tube and the eccentricity, were tested to failure by eccentric loading. All specimens were cast from the same batch of concrete. Samples of concrete cubes and prisms were prepared and cured

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Notations

A_c	cross-sectional area of concrete core
A_b	cross-sectional area of longitudinal reinforcing bar
A_e	area of confined concrete
A_n	area of un-confined concrete
A_t	cross-sectional area of steel tube
a_s	distances between steel bar and extreme fiber in tension sides
a'_s	distances between steel bar and extreme fiber in compression sides
B	length of the square side
e	eccentricity of loading
E_c	elastic modulus of unconfined concrete
E_{sec}	secant modulus of unconfined concrete
$F_{cu,100}$	100 mm concrete cube strength
f'_c	concrete cylinder strength or unconfined concrete strength
f_{cc}	confined concrete strength
f_{ty}	yield stress of the steel tube
f_{by}	yield stress of the longitudinal reinforcing bar
f_{sy}	yield stress of stirrup
f_{el}	effective lateral confining stress
f'_l	average lateral confining stress for confined region
k_e	confinement effective coefficient
L	length of the specimen
M_u	ultimate bending moment
N_u	ultimate axial load
t	thickness of the steel tube
x_{cu}	distance between the extreme compression fiber and the neutral axis
α	strength reduction factor
α_b	steel ratio of longitudinal reinforcing bar
α_t	steel ratio of steel tube
β	effective height factor
δ	mid-span deformation of eccentrically loaded specimen
ε_b	strain of the longitudinal reinforcing bar in the tension sides
ε'_b	strain of the longitudinal reinforcing bar in the compression sides
ε_c	strain of concrete
ε_{co}	strain of unconfined concrete corresponding to f'_c
ε_{cc}	strain of confined concrete corresponding to f_{cc}
ε_{cu}	ultimate strain of confined concrete
σ_b	stress of longitudinal reinforcing bar in the tension sides
σ'_b	stress of longitudinal reinforcing bar in the compression zone sides
σ_c	stress of concrete
σ_{cc}	stress of confined concrete, shown in Eq. (2)
σ_h	horizontal stress of steel tube
σ_v	vertical stress of steel tube
σ_z	equivalent stress of steel tube
ξ	confinement coefficient $\xi = \alpha_t(f_{yt}/f'_c)$

under the same condition as the specimens, to get the compressive strength and elastic modulus of the concrete. The yield strengths of the steel tube and reinforcing bars were determined by tensile tests. Two 10 mm thick end plates were welded at the ends of each test specimen. The steel tube was disconnected at 30 mm away from both of the end plates by 10 mm wide girth gaps to prevent the tube from direct external loading. Eight longitudinal reinforcing bars with a diameter of 20 mm, tied at 200 mm intervals with 8 mm diameter stirrups, were symmetrically arranged in the concrete. The concrete cover from the perimeter of the reinforcing bars to the edge of the concrete was 20 mm. Table 1 and Fig. 2 provide details of the test specimens.

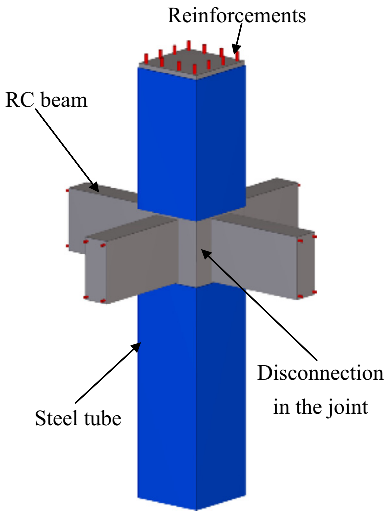

Fig. 1. Square TRC column and its beam to column connection.

2.2. Test setup

The columns were tested under monotonically increasing axial compression with constant eccentricity using a hydraulic testing machine at Harbin Institute of Technology. Knife edge plates and adjustable V-blocks were placed to produce the required end eccentricity and pin supports. The applied load was initially at a rate of 2 kN/s until it reached approximately 85% of the expected load bearing capacity, and after that the loading was controlled by axial strain at a rate of 600 με/min. Three linear variable displacement transducers (LVDTs) were applied to measure the lateral displacements of the specimens. Four additional LVDTs were used to monitor the overall axial displacement. Four pairs of strain gauges arranged at 90° were placed on the tube's corner and center region at the mid-height to monitor the longitudinal and transverse strains. The details of the testing machine and the instruments are shown in Fig. 3.

2.3. Test results

2.3.1. Failure modes

Fig. 4 shows the typical failure modes of square TRC short columns subjected to concentric compression ($e=0$). The concrete was crushed at the diagonal section and the longitudinal reinforcing bars buckled. The failure mode is characterized by shear failure. Fig. 5 shows the typical failure modes of specimens under eccentric compression. Local buckling of the steel tubes was seen at the mid-height of the specimens. Crushed concrete at the compression region and flexural cracks at the opposite tension region were observed after separating the steel tube from the concrete. The typical lateral deformation shapes along the specimen's height were similar to the second-order parabolas as shown in Fig. 6. The failure of eccentrically loaded specimens was considered as bending failure.