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Behavior of steel-reinforced concrete-filled square steel tubular stub columns under axial loading

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ABSTRACT

The objectives of this paper is to investigate the mechanical behavior of steel reinforced concrete-filled square steel tubular (SRCFT) stub columns under axial loading through combined experimental and numerical studies. In total of six specimens are tested to investigate the effect of the concrete strength and steel ratio on the mechanical behavior of SRCFT stub columns. The ultimate bearing capacity, ductility, and confinement effects are discussed and clarified based on the experimental results. The inserted steel section can effectively prevent shear cracks in the core concrete from propagating quickly. The strength-weight-ratio of SRCFT stub column is larger than SCFT stub column. In addition, ABAQUS is used to establish the 3D finite element (FE) model and analyze the composite action of SRCFT stub columns under axial loading. Based on the experimental and numerical results, a simplified formula is proposed to estimate the ultimate bearing capacity of SRCFT stub columns using superposition method. The predicted results show satisfactory agreement with both experimental and FE results.

1. Introduction

Over the last several decades, steel-concrete composite systems have been widely utilized in building structures and bridges, even in regions with high seismic risk, due to the ideal combination of the advantages of both steel and concrete [1,2]. Therefore, the performance of steel-concrete composite systems has caught more and more research attentions.

At present, there exist two types of composite columns, namely the steel reinforced concrete (SRC) column and the concrete-filled steel tube (CFT) column. In SRC columns, the steel core can improve the shear resistance of the column. The concrete encasement effective improves the resistance of the steel core against both local and over buckling. The concrete encasement also provides protection against corrosion from chemical and insulation from rapid temperature rise in the presence of fire. And yet, it is a very complicated process for construction and requires extensive formwork, especially at the beam-column connections. In CFT column, the concrete infill adds stiffness to the steel tube and prevents the occurrence of local buckling, while the steel tube improves the compressive strength and deformation performance of the core concrete. On the other hand, the CFT columns require no reinforced cage and no formwork as the steel tube can sever as formwork. However, the fire resistance of the CFT column is not as good as that of the SRC column, because of the exposed steel tube. So far, experimental and numerical studies have been carried out on the behavior of CFT columns under the axial loading including Aslani et al. [3], Ellobody [4], El-Heweity [5], Kim et al. [6], Mashiri et al. [7], Tu et al. [8], Uenaka et al. [9], Wan et al. [10], Yu et al. [11] etc. Ding et al. [12–14] also investigated the behavior of CFT stub columns under axial loading with consideration different cross sections, and practical formulas of the ultimate bearing capacity have been proposed with the corresponding confinement coefficient.

Based on the literature, a new form of composite column, steel reinforced-concrete filled-steel tubular column (SRCFT), was proposed by Zhu et al. [15], attempting to combine the advantages of both SRC and CFT columns, as shown in Fig. 1. Limited studies are available on the compressive behavior of the SRCFT column under axial loading compared with CFT column in the filed mentioned above. Zhu et al. [15] performed tests on SRCFT stub columns with varied concrete strength, confinement index and length-to-diameter under axial loading and a formula for calculating the ultimate bearing capacity was presented. Nonetheless, the composite action between steel tube, steel section and core concrete still need to be clarified for SRCFT stub columns.

Finite element method has been widely used as the main analysis method on the mechanical performances and predicting the response of steel-concrete composite structural in the past few years. Chang et al.

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Nomenclature

A_c	Cross-sectional area of core concrete
A_{c1}	Non-constrained area of core concrete
A_{c2}	Constrained area of core concrete
A_g	Cross-sectional area of steel section
A_s	Cross-sectional area of steel tube
A_{sc}	Total area of cross-section
A_{st}	Cross-sectional area of steel
b	Edge length of core concrete
B	Edge length of the square section
DI	Ductility index
E_s	Elastic modulus of steel tube
f_{b0}	Initial equibiaxial compressive yield stress of concrete
f_c	Uniaxial compressive strength of concrete
f_{c0}	Initial uniaxial compressive yield stress of concrete
f_{cu}	Compressive cubic strength of concrete
f_g	Yield strength of steel section
f_{sc}	Ultimate strength of SRCFT column
f_u	Ultimate strength of steel tube
f_s	Yield strength of steel tube
G	Weight of the specimen
L	Height of specimens
N_u	Axial ultimate bearing capacity
$N_{u,Exp}$	Ultimate bearing capacity of SRCFT stub columns from experimental results
$N_{u,FE}$	Ultimate bearing capacity of SRCFT stub columns from FE results
N_u,Eq. (10)	Ultimate bearing capacity of SRCFT stub columns from Eq. (10)
$N_{u,[15]}$	Ultimate bearing capacity of SRCFT stub columns from calculated results by [15]
p	Lateral pressure coefficient
t	Wall thickness of steel tube or steel section
σ	Axial stress of concrete
σ_i	Equivalent stress of steel tube
$\sigma_{L,c}$	Axial compressive stress of core concrete
$\sigma_{L,s}$	Axial compressive stress of steel tube
$\sigma_{r,c}$	Radial concrete stress of the confined area
$\sigma_{\theta,s}$	Tensile transverse stress of steel tube
$\varepsilon_{0.75}$	Axial strain when the load attains of 75% the ultimate load in the pre-peak stage
$\varepsilon_{0.85}$	Strain when experimental bearing capacity is decreased to 85% of ultimate value
ε	Axial strain of concrete
ε_c	Strain corresponding with the peak compressive stress of concrete
ε_L	Axial strain of columns
ε_i	Equivalent strain of steel tube
ε_b	Yield strain of steel tube
ε_{st}	Hardening strain of steel tube
ε_u	Ultimate strain of steel tube
ν_{sc}	Strain ratio of steel tube
ρ	Steel ratio of columns
γ	Strength-weight-ratio

[16–18] investigated the performance of composite structures and rock structures by ABAQUS. Hassanein et al. [19,20] applied a finite element computer code to study behavior of circular concrete-filled double skin tubular short columns with external stainless steel tubes under axial loading. FE models were established and found to capable to accurately predict the capacity of circular concrete-filled double-skin steel tubular stub columns by Pagoulatou et al. [21]. The model relies on the use of the commercial software ABAQUS.

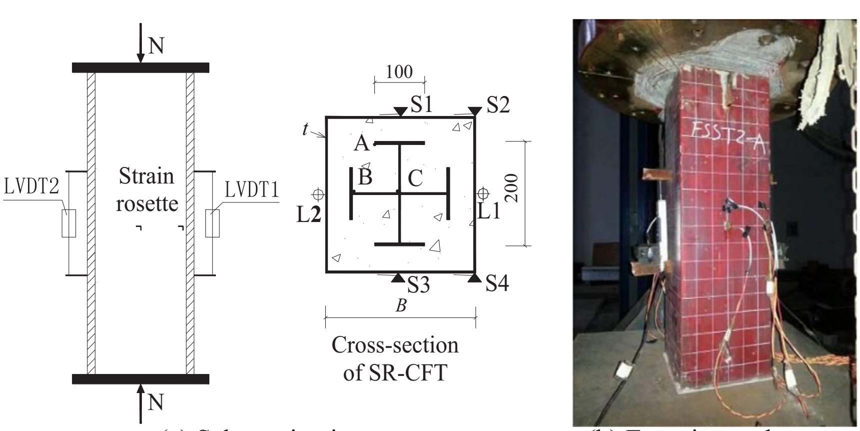
With consideration of the research gaps mentioned above, this paper is devoted to developing a more concise and precise formula to compute the ultimate bearing capacity of SRCFT stub column, and investigating the behavior of SRCFT stub columns under axial loading. More specifically, based on the theoretical, numerical and experimental research in the research team [12–14,22], the main contents of this paper are listed below: (1) Compression tests are conducted on six specimens with varied steel ratios and concrete strength. The effect of various parameters on the ultimate bearing capacity and ductility are discussed in detail. (2) Finite element models were established and validated by experimental results, by which the composite action of SRCFT stub columns under axial loading is investigated. (3) Based on both experimental and numerical results, a simplified formula to estimate the ultimate bearing capacity of SRCFT stub columns is proposed by using superposition principle with ration simplification, and adopting a same concept as Ding et al. [12].

2. Experimental investigation

2.1. Test specimens

A total of 6 specimens were designed in this study, including 2 square concrete filled steel tubular (SCFT) stub columns and 4 steel-reinforced concrete-filled square steel tubular (SRCFT) stub columns. The details of specimens are given in Table 1, where B is the width of the square section, t is the wall thickness of steel tube and steel section, L is the height of the specimen.

The square steel tubes were fabricated in two steps. Firstly, flat steel



(a) Schematic view. (b) Experimental setup.

Fig. 1. Experimental instrumentation for all specimens.