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Mechanical behavior of circular and square concrete filled steel tube stub columns under local compression

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ABSTRACT

This paper presents a combined experimental and numerical study on the behavior of both circular and square concrete-filled steel tube (CFT) stub columns under local compression. Twelve circular and eight square CFT stub columns were tested to study their bearing capacity and the key influential parameters. A 3D finite element model was established for simulation and parametric study to investigate the structural behavior of the stub columns. The numerical results agreed well with the experimental results. In addition, analytical formulas were proposed to calculate the load bearing capacity of CFT stub columns under local compression.

1. Introduction

Concrete filled steel tubular (CFT) columns have been increasingly used in bridges and high-rise buildings. They have much more advantages compared with the ordinary steel or concrete system including higher strength and stiffness, higher ductility, and larger energy absorption capacity [1]. With the benefits of CFT, the use of CFT columns is becoming more popular and the performance of concrete filled steel tubes has caught more and more research attentions [1–9]. In most cases, such as the pier of bridges and arch structures, CFT columns are subjected to axially compression loads. Limited research has been carried out to investigate the behavior of CFT stub columns under local compression and the influential factors on the load bearing capacity. Forty three circular CFT stub columns under local compression were experimentally studied by Cai et al. [1]. Effects of local compression area ratio, diameter–thickness ratio, relative height of the model and spiral stirrup on the performance and the load bearing capacity were studied. Formula for the ultimate load bearing capacity of CFT stub columns was also proposed. Han et al. [2,3] also conducted experiments to investigate the effects of parameters including section type and local compression area ratio, on the structural behavior of CFT stub columns and proposed a series of formulas for the local compression bearing capacity of CFT stub columns.

The previous study from reference [1–3] indicated that the CFT columns generally perform well, however, little success has been achieved so far in developing a concise formula of the load bearing capacity for CFT stub columns. Moreover, the behavior of CFT columns under local compression condition has not been well addressed in the current design code and hence further research is necessary to improve the design code specifications. In addition, the effects of loading plate shape on the performance of CFT stub columns also need to be investigated.

The aim of this study, therefore, is to develop a more concise and precise method to compute the load bearing capacity of CFT stub columns when subjected to local axially compression. More specifically, four objectives are included in the study: (1) to analyze the structural behavior of both circular and square CFT stub columns subjected to local compression with 12 circular CFT specimens and 8 square CFT specimens without endplate tested; (2) to develop finite element (FE) model using ABAQUS program to simulate the behavior of the CFT stub columns; (3) to analyze the effects of local compression area ratio, steel ratio, strength of steel and concrete on the behavior of locally loaded CFT specimens; (4) to establish a simplified approach to estimate the load bearing capacity of CFT stub columns subjected to local compression, and to verify formula with both experimental and numerical results.

2. Experimental study

2.1. Test materials and specimens

Twenty CFT specimens were included in this study, including 12 circular and 8 square specimens. The nominal dimension of the

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Nomenclature

A_c	cross-sectional area of concrete
A_s	cross-sectional area of steel tube
A_{sc}	cross-sectional area of specimen
A_{cb}	area of local compress concrete
B	outside width of the square section
b	width of loading plate
D	outside diameter of circular steel tube
d	diameter of loading plate
DI	ductility index
E_c	concrete modulus of elasticity
E_s	steel modulus of elasticity
E_{st}	strengthening modulus of steel
f_{cu}	concrete compressive cube strength
f_c	uniaxial compressive strength of concrete
f_y	yield strength of steel
L	length of the specimens
SI	strength index
t	wall thickness of steel tube
K	confinement coefficient
K_b	influence coefficient of the CFT stub columns local compression bearing capacity
N	axial load
N_b	ultimate load-bearing capacity of locally loaded circular CFT stub columns
$N_{b,e}$	ultimate load-bearing capacity of locally loaded circular CFT stub columns from experimental results
$N_{b,FE}$	ultimate load-bearing capacity of locally loaded circular CFT stub columns from FE results
$N_{b,f}$	ultimate load-bearing capacity of locally loaded square CFT stub columns from formulation
N_u	axial ultimate bearing capacity
Φ	Confinement index
$\Delta_{85\%}$	axial deformation when the load falls to 85% of the ultimate bearing capacity.
Δ_b	axial deformation at the ultimate strength of CFT stub columns subjected to local compression
ν_s	Poisson's ratio of steel
ν_c	Poisson's ratio of concrete
ε_L	axial strain of steel
$\varepsilon_{\theta,s}$	circumferential strain of steel
ε_i	equivalent strain of steel
ε_y	yield strain of steel
ε_{st}	hardening strain of steel
ε_u	ultimate strain of steel
ρ	area ratio of steel tube to concrete
β	local compression area ratio

circular specimen was $300(D)$ mm × $4(t)$ mm × $900(L)$ mm, where D is the diameter of the circular section, t is the wall thickness of the steel tube, and L is the length of the specimen. The nominal dimension of the square specimen was $300(B)$ mm × $4(t)$ mm × $900(L)$ mm, where B is the width of the square section. d is the diameter of loading plate, b is the width of loading plate. More detailed geometric properties and characteristics of the specimens are presented in Table 1.

In this paper, local compression area ratio is defined as $\beta = A_{cb}/A_{sc}$, where A_{sc} is the cross sectional area of specimen, and A_{cb} is the area subjected to local compressive load. f_y means the yield strength of steel and f_{cu} represents the concrete compressive strength. The main factors considered in the study included concrete strength and local compression area ratio. The steel tubes were molded by bending Q235 steel plates. Butt welds were used according to the standard GB 50017-2003 [10] and the ends of the steel grooves (as the sites of welding) were kept smooth after welding.

For the convenience of observation and record of deformation and failure model of the specimen, red paint was sprayed on the external surface of the steel tube and 50 mm × 50 mm white grids were plotted on the surface. A cover plate was initially welded to cover the bottom end of the steel tube before concrete pouring. Concrete was then pumped into the tube from the top and was vibrated to be well compacted and the concrete surface was leveled before finishing. Meanwhile standard concrete cubes with a dimension of 150 mm × 150 mm × 150 mm and prisms with a dimension of 100 mm × 100 mm × 300 mm were prepared and cured at the same condition as those of CFT specimens. Grade C30 and C50 commercial concretes were used in this study and the mix design is given in Table 2.

Table 1
Geometric properties and characteristics of steel tubes specimens.

No.	Section type	Specimen label	$B(D) \times t \times L$/ mm	$b(d)$/ mm	f_y/ MPa	f_{cu}/ MPa	β	$N_{b,e}$/ kN	$N_{b,FE}$/ kN	$N_{b,f}$/ kN
1	Square	CLST1-A	300 × 3.72 × 900	100	311	35.5	0.11	1880	1630	1908
2		CLST1-B	300 × 3.76 × 900	100	311	35.5	0.11	1900	1638	1922
3		CLST2-A	300 × 3.70 × 900	200	311	35.5	0.44	3310	2758	2856
4		CLST2-B	300 × 3.68 × 900	200	311	35.5	0.44	3200	2750	2848
5		C1-A	300 × 3.70 × 900	300	311	35.5	1.00	3780	3757	3625
6		C1-B	300 × 3.71 × 900	300	311	35.5	1.00	3540	3763	3630
7		CLST3-A	300 × 3.69 × 900	100	311	54.4	0.11	2090	2189	2255
8		CLST3-B	300 × 3.76 × 900	100	311	54.4	0.11	2090	2205	2281
9		CLST4-A	300 × 3.70 × 900	200	311	54.4	0.44	3810	3656	3620
10		CLST4-B	300 × 3.77 × 900	200	311	54.4	0.44	3950	3683	3651
11		C2-A	300 × 3.74 × 900	300	311	54.4	1.00	4896	5146	4977
12		C2-B	300 × 3.87 × 900	300	311	54.4	1.00	4976	5025	4851
13	Circular	SLST1-A	300 × 3.68 × 900	100	311	35.5	0.11	1140	882	994
14		SLST1-B	300 × 3.68 × 900	100	311	35.5	0.11	950	882	994
15		SLST2	300 × 3.70 × 900	200	311	35.5	0.44	2420	2324	2400
16		S1	300 × 3.75 × 900	300	311	35.5	1.00	4370	4060	3985
17		SLST3-A	300 × 3.72 × 900	100	311	54.4	0.11	1340	1312	1467
18		SLST3-B	300 × 3.72 × 900	100	311	54.4	0.11	1280	1312	1467
19		SLST4	300 × 3.72 × 900	200	311	54.4	0.44	3100	3265	3359
20		S2	300 × 3.70 × 900	300	311	54.4	1.00	5570	5555	5443