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Size effect of circular concrete-filled steel tubular short columns subjected to axial compression

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ABSTRACT

In this paper, thirty-six short columns with different diameters (150 mm ≤ d ≤ 460 mm) and steel ratios (4.0% ≤ α ≤ 10.0%) were tested to failure to investigate the size effect of circular concrete-filled steel tubular short columns subjected to axial compression. Size effects on the peak axial stress, peak axial strain, composite elastic modulus, and ductility coefficient were studied. The experimental results showed that the peak axial stress, peak axial strain and ductility coefficient of the specimens tended to decrease with the increase in the column diameter. The values of the composite elastic modulus remained almost constant when the diameter of the specimens increased, indicating that size effect on the composite elastic modulus was not obvious. Meanwhile, size effect on the peak axial stress was influenced by the steel ratio in the range of 4–10%. Furthermore, the size effect tended to decrease as the steel ratio increased. By comparing with the current codes, a reduction coefficient was introduced to consider the size effect of concrete core. Based on the reduction coefficient, the size effect of the concrete core inside the steel tube is found to be weaker compared with that of the unconfined concrete columns because of the confinement effect.

1. Introduction

Concrete-filled steel tubular (CFST) arch ribs are widely used in the construction of arch bridges due to their excellent performance, such as high compressive strength, good plasticity, excellent seismic performance and convenient construction. Compared with reinforced concrete arches, CFST arch bridges show great advantage in simplifying concrete casting procedures because the thin-walled steel tube can serve as template formwork. Compared with steel arches, less steel is used in CFST arches to meet the requirements for stiffness and stability [1,2]. In the last 20 years, more than 300 arch bridges (maximum span is 530 m) have employed CFST as their arch ribs. According to the survey from [3] on over 230 CFST arch bridges shows that, more than 96.1% arch ribs have an external diameter larger than 600 mm, among which more than 53.2% ribs' diameters are larger than 900 mm. The maximum external diameter of an arch rib has reached 1800 mm, shown in Fig. 1(a). Similarly, diameters of CFST columns in high-rise buildings are also usually larger than 600 mm. In 2012, the section size of the CFST columns with multi-cavity in the Guangzhou CTF Finance Centre (Guangzhou, China) has already reached 3.5 m × 5.6 m [4].

The compressive strength of concrete is generally accepted to decrease as the size of concrete increases (i.e., size effect) [5–9]. Based on the size effect equation proposed by Sakino [10], the compressive strength of a concrete column reduces by 18.3% when the diameter varies from 150 mm to 900 mm. Concrete core is an essential component of the CFST column, thus size effect of concrete may also affect the compressive behavior of CFST columns, especially for those with large section sizes. In addition, the size effect of CFST columns is more complicated than that of unconfined concrete columns, because the confinement from the steel tube can inhibit crack propagation, thereby influencing the size effect of the concrete core to some extent.

Current codes for CFST columns, such as EC4 (EN 1994-1-1) [11], AIJ (AIJ2008) [12], AISC (AISC 360-10) [13], and GB (GB50936-2013) [14], are all based on the experimental results obtained from small-dimension CFST specimens. Whether or not the current codes could accurately predict the performance of CFST members with a large cross-section remains a question when considering the influence of size effect. Although the compressive behavior of CFST columns has already been extensively studied [15–22], researches on the size effect on the compressive behavior of CFST short columns are still limited. Only Yamamoto et al. [23] conducted a test on the size effect of 21 CFST specimens with circular/square cross-sections under axial compression. The

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Nomenclature

CFST	concrete-filled steel tube
D	external diameter of the steel tube
d	diameter of the concrete core
E_c	elastic modulus of the unconfined concrete
E_s	elastic modulus of the steel tube
E_{sc}	composite elastic modulus of the concrete-filled steel tube short column
$f_{cu,28}$	concrete cubic strength at 28 days
$f_{cm,28}$	concrete cylinder strength at 28 days
$f_{cm,test}$	concrete cylinder strength at test days
$f_{cu,test}$	concrete cubic strength at test days
f_u	ultimate tensile strength of the steel tube
f_y	yield strength of the steel tube
L	height of the specimen
N_u	load-carrying capacity of the concrete-filled steel tube short column
t	thickness of the steel tube
α	ratio of the steel area over the concrete area
γ_u	reduction coefficient of concrete in the compressive strength
δ	ductility coefficient
ε_v	longitudinal strain of the column
ε_u	peak axial strain
μ_s	Poisson's ratio of the steel tube
σ_u	peak axial stress of the concrete-filled steel tube short column

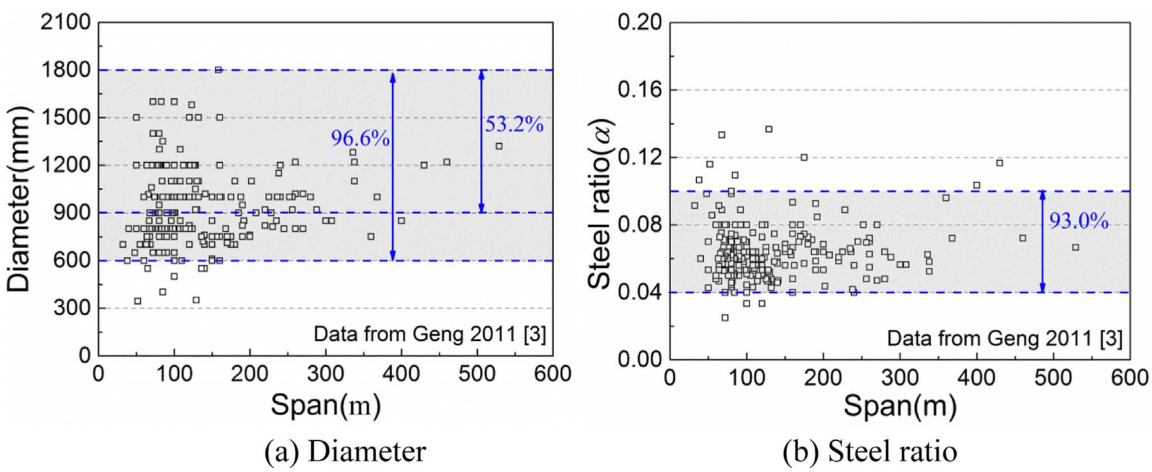

Fig. 1. Survey of CFST arch bridges. The figures show the diameter and steel ratio of arch rib used in CFST arch bridges.

external diameter of the circular CFST specimens varied from 100 mm to 320 mm with a constant steel ratio of 13%. It was found through the test that the size effect did not exist in circular CFST specimens. This test has provided fundamental understanding for the size effect in CFST columns, but another essential parameter, i.e. steel ratio, has not been investigated apart from diameter/width. The authors believe that it is the steel ratio what makes CFST columns differing from concrete columns. The applicability of Yamamoto's conclusion is doubtful for CFST columns with varied steel ratios especially for those with lower steel ratios. Actually, based upon the statistics for over 230 CFST arch bridges shown in Fig. 1(b), the steel ratio of CFST arch ribs is predominantly distributed in the range of 4–10%, accounting for 93.0% of the total. In building structures, the steel ratio is usually designed in the range of 8–10% in China to reduce the amount of steel. This means that further work on the size effect of those CFST columns with lower steel ratios is necessary.

In addition to Yamamoto's experimental research, two studies on the size effect were also conducted by analyzing the existing test data. Sakino et al. [10] investigated the size effect based on the existing test data of 36 circular and 48 square CFST short columns. Subsequently, the authors proposed an equation to predict the size effect by directly importing the size effect of unconfined concrete. However, the influence of steel ratio on the size effect was not considered. Lu et al. [24] compared the existing test results with the predicted results calculated by different design codes according to the analysis of 252 test data of square specimens with sizes varying from 80 mm to 320 mm. The comparison showed that the design codes might overestimate the load-carrying capacity of the square CFST short columns with a large size. In the study, the influence of steel ratio on size effect was also not considered. In addition, the statistical data were collected from square CFST short columns, which were different with circular CFST specimens in terms of confining pressure distribution.

It can be concluded that previous studies on size effect of CFST columns are limited. The only related experimental research mainly focused on the analysis of specimens with a constant steel ratio (13%), while the specimens with lower steel ratios were lacking. In addition, the influence of steel ratio on size effect was also not considered in the analysis of existing test data. To obtain the size effect law of CFST specimens with low steel ratios, the present study intends to perform a research to extend the minimum steel ratio to 4.1%, and the maximum diameter of the specimens to 460 mm. A total of 36 specimens with different diameters and steel ratios were included in the test. Both the influences of diameter and steel ratio on the size effect were investigated. The size effect on the peak axial stress, peak axial strain, composite elastic modulus, and ductility coefficient was analyzed. The limitations of the current codes were then studied by comparing the test data with the current CFST design provisions, and a reduction coefficient was proposed to consider the size effect of concrete core.

2. Experiment program

2.1. Specimen design

Two key parameters, namely, diameter D and steel ratio α (Eq. (1)), were studied in the test. Four sizes (150 mm $\le d \le$ 460 mm) were designed for each steel ratio to obtain the size effect law of the specimens. Three steel ratios (i.e., 4.1%, 6.6% and 10.3%) were designed herein to cover the low steel ratio range. Each specimen group included three identical specimens to reduce the effect of data scatter. Details of the specimens are shown in Table 1. In the Table, CFST stands for

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