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Shape effect on axially loaded high strength CFST stub columns

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ABSTRACT

In this paper, the results of an experimental investigation of 12 concrete-filled steel tubular (CFST) stub columns subjected to concentric loads are presented. In this program, different cross-sectional shapes are considered: circular, square and rectangular. In order to study the effect of the concrete infill strength in the ultimate capacity of the columns, two types of concrete infill are employed: normal and high strength concrete of grades C30 and C90 respectively.

The specimens are classified into three different series so all the columns of a series have equivalent cross-sectional area to perform a proper comparison and draw consistent conclusions. During the tests, the response in terms of load versus column shortening is registered. In view of the experimental results, the dependency of the type of response and failure mode on the cross-sectional shape and type of infill of the columns is analysed. Besides, the influence of the concrete infill, the result of the composite action and the level of ductility are also studied.

Finally, the experimental ultimate loads of the specimens are compared with the corresponding failure loads given by the codes. In this case, comparison showed that Eurocode 4 and the Chinese and Australian standards overestimate the failure load of the specimens, particularly for square and rectangular CFST columns. The American code tends to be more conservative in its predictions for circular columns, although it is still unsafe for those with square and rectangular steel tubes.

1. Introduction

The use of concrete-filled steel tubes (CFST) as composite columns is widely extended around the world. Their high bearing capacity with reduced sections, large energy absorption in case of seismic, rapid erection times or ease of construction are some of the advantageous characteristics that have made CFST successful over traditional columns [1]. In general, it was found out that the enhancement in the mechanical response of these columns is due to the composite action between the hollow steel tube and the concrete core. The concrete core is confined by the steel tube which increases the compressive strength of the section and its ductility. In turn, the concrete infill prevents the steel tube from local buckling, especially in rectangular CFST with thin-walled steel tubes. However, this effect is influenced by the cross-sectional aspect ratio, the strength of the materials and the confining factor, highly dependent of the cross-sectional shape [2].

The behaviour of CFST stub columns under axial compression over different cross-sectional shapes have been investigated by several authors through various experimental programs (Schneider [2], Han [3], Giakoumelis and Lam [4], Lam and Williams [5], Sakino et al. [6], Tao et al. [7], Han et al. [8], Ellobody et al. [9], Liang and Fragomeni [10], Tahyalan et al. [11], Ekmekyapar and Al-Eliwi [12]). Most of them focused on the use of normal strength concrete (NSC), but, more recently, also high strength concrete (HSC) has been included.

Currently, although the performance of special-shaped CFST columns under axial compression is starting to be investigated (Ren et al. [13], Ding et al. [14], Xu et al. [15]), the most employed shapes are still circular, square or rectangular CFST columns. Confinement in circular sections is enhanced due to the hoop stresses appearing because of the composite action. However, the advantageous effect on the confinement when high strength concrete (HSC) is employed is not well established, especially for thin-walled steel tubes.

Given the structural benefits of CFST columns and their high load bearing capacity they are commonly employed in high rise buildings, heavy loaded structures or underground structures. As the required column loading capacity increases, the dimensions of the CFST column also become larger. As pointed out by Wang et al. [16], the size effect is enhanced in plain concrete for higher values of D/t and leads to a reduction of the hoop stresses in the steel tube which, in turn, leads to a reduction of the confinement effect. For these members with large dimensions, the adoption of HSC can significantly reduce the column size and permits to achieve higher strength to weight ratio still maintaining a reasonable level of ductility. The beneficial application of HSC in the building industry makes interesting its study, particularly when employed in CFST columns.

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Notation

AISC	American Institute of Steel Construction
AS	Australian Standard
CCR	concrete contribution ratio
CFST	concrete-filled steel tube
D	diameter of the steel tube
DBJ	Chinese code
DI	ductility index
EC4	Eurocode 4
f_c	compressive cylinder strength (150 × 300 mm) of concrete (test date)
f_{ck}	characteristic compressive strength of concrete
f_{cu}	compressive cubic strength (150 × 150 × 150 mm) of concrete (test date)
f_y	yield strength of structural steel
HSC	high strength concrete
NSC	normal strength concrete
N_{exp}	ultimate axial load from tests
N_{cr}	Euler critical load $N_{cr} = (\pi^2 EI)/L^2$
L	column length
SI	strength index
t	thickness of the steel tube
$\overline{\lambda}$	relative slenderness $\overline{\lambda} = \sqrt{N_{pl}/N_{cr}} = \sqrt{(A_c f_c + A_s f_y)/N_{cr}}$
δ	axial displacement at maximum load
$\delta_{85\%}$	axial displacement at 85% of the maximum load at the decay branch
ρ	concrete density

Together with the investigations on the behaviour of CFST columns, many design codes have been extended or created in order to try to cover the structural applications of these composite sections and give design and calculation guidance. Nevertheless, the application of the methods included in the codes is still limited to a certain range of material strengths, geometries and cross-sectional slenderness. Some investigations can be found dealing with the assessment of the existing codes for predicting the ultimate strength of CFST stub columns [3,4,7,12,17]. For columns whose characteristics are within the limits, comparisons of the strength predictions given by the codes with experimental results sometimes are not completely satisfactory, either overpredicting or underpredicting the ultimate strength of the columns. Applying the current code provisions to any other CFST column out of the applicability range will produce less accurate strength predictions.

At present, some examples of structures designed and built with high strength CFST columns can be found. As pointed out by Wang et al. [17], this fact evidences the imminent normalization of the use of these composite sections and confirms the necessity of developing reliable design methods which consider high performance materials.

In the view of the analysis of the literature, it is detected a lack of experimental tests on CFST columns with HSC to completely understand its effect on this type of composite members. Therefore, a new experimental program on CFST stub columns was designed where specimens with circular, square and rectangular cross-sections were tested. The experiments combined the use of NSC and HSC to study their effect on the load bearing capacity of columns with different shape subjected to concentric loads.

Finally, the specifications of current codes for the design of CFST columns are assessed. In this comparison, four commonly used codes are considered: European code Eurocode 4 (EC4) [18], American code (AISC) [19], Chinese code (DBJ) [20], and the Australian code (AS) [21].

2. Experimental investigation

2.1. Column specimens and test setup

In this work, a total of 12 CFST stub columns were tested with the objective of evaluating the effect of the concrete infill strength and cross-sectional shape on their load bearing capacity. Three different series were distinguished depending on the amount of steel area of the tubes. For each series, the compressive strength of the concrete poured inside the steel tubes varied between C30 and C90. Besides, different cross-sectional shapes were compared: circular (C), rectangular (R) and square (S), as shown in Fig. 1.

It is important to note that this experimental program was designed to assure that all the specimens of a series had the same steel cross-sectional area so as this parameter did not affect the conclusions drawn from the shape effect analysis. In Table 1, cross-sectional properties of all test specimens and other data corresponding to each series are summarized. For convenience, the test specimens were named as follows: S-D_N (i.e. C159x3_30), where S stands for the cross-sectional shape of the steel tube (C for circular steel tubes, R for rectangular and S for square); D represents the cross-sectional dimensions in mm; and N is the nominal concrete strength in MPa.

All the columns were manufactured and tested at the Universitat Jaume I in Castellón (Spain) in a horizontal testing frame with capacity of 5000 kN. Figs. 2 and 3 show some of the specimens prior to be tested and the setup of one of the experiments respectively. During the tests, all the columns had a buckling length of 300 mm with pinned-pinned (P-P) boundary conditions. For the sake of accuracy of the measurements, the corresponding displacement control test was performed after the correct collocation of the column.

2.2. Material properties

2.2.1. Steel tubes

In this experimental program, all of the steel tubes were cold-formed carbon steel and supplied by the same manufacturer. The

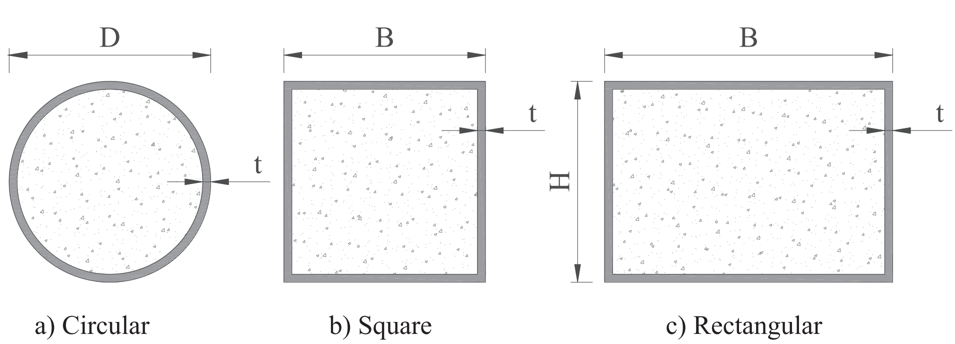

Fig. 1. CFST sections: a) Circular b) Square c) Rectangular.