12th International Conference on Advances in Steel-Concrete Composite Structures (ASCCS 2018)
Universitat Politècnica de València, València, Spain, June 27-29, 2018
Doi: http://dx.doi.org/10.4995/ASCCS2018.2018.7196

Influence of steel tube thickness and concrete strength on the axial capacity of stub CFST columns

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Abstract

In order to study the mechanical response of concrete-filled steel tubular (CFST) columns, several experimental and theoretical studies have been conducted in the last years. However, the influence of thin-walled steel tubes on the axial capacity of these composite columns is not completely stablished, especially when it is combined with high-strength concrete as infill. In this paper, the results of an experimental campaign on 18 concrete-filled steel tubular stub columns subjected to concentric load are presented. Different cross-section shapes are considered in this campaign, i.e. circular, square and rectangular. The influence of the steel tube wall thickness is analysed by including specimens with thin-walled tubes in the experiments, whose behaviour needs to be studied in depth given the issues arising when working under compression. The experimental program is designed so the analysis of the results permits to drawn consistent conclusions. For each series, the steel tube thickness is the only geometric parameter modified in order to properly study its effect. Besides, two different concrete strengths were considered for the concrete infill, i.e. normal and high- strength concrete, to observe their effect on the ultimate capacity of the columns. During the tests, the specimens are subjected to axial load and the evolution of the axial displacement with the load is registered. The ultimate capacity of each specimen is obtained and an analysis of the steel tube thickness and concrete strength influence is accomplished. Finally, the study of the dependency of the failure mode on these parameters is carried out.

Keywords: *stub columns; concrete-filled steel tubes; high strength concrete; sectional capacity; strength index; concrete contribution ratio.*

1. Introduction

It is widely extended the use of concrete-filled steel tubes (CFST) as composite columns around the world. Due to their high bearing capacity with reduced cross-sections, large energy absorption, high fire resistance without external protection, rapid erection times and ease construction [1], they have succeeded over traditional columns. The enhancement in the mechanical response of these columns is caused by the composite action between the hollow steel tube and the concrete core. The compressive strength and ductility of the section increase as a result of the steel tube confinement. Simultaneously, the concrete infill prevents the steel tube from local buckling, especially in CFST with thin-walled steel tubes. However, as pointed out by Schneider [2], 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.

Several experimental campaigns have been conducted by different authors with the aim of investigating the behavior of CFST stub columns under axial compression (Han [3], Giakoumelis and Lam [4], Lam and Williams [5], Sakino et al. [6], Han et al. [7], Ellobody et al. [8], Liang and Fragomeni [9], Ekmekyapar and Al-Eliwi [10]). In most of them normal strength concrete (NSC) was employed although, lately, high strength concrete (HSC) has been included as well.

Currently, the most employed shapes are still circular, square or rectangular CFST columns. 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. Using HSC as infill can significantly reduce the column size and permits to achieve higher strength to weight ratios still maintaining a reasonable level of ductility. The beneficial application of HSC in CFST columns makes interesting its study but the advantageous effect on the confinement when HSC is employed is not well established, especially for thin-walled steel tubes. In this line, Tao et al. [11] investigated the response of thin-walled CFST stub columns but the maximum concrete strength was 54 MPa and the research was mainly focus on the effect of stiffeners.

Examples of structures designed and built with high strength CFST columns can be found these days which according to Wang et al. [12], confirms the necessity of developing reliable design methods which consider high performance materials in order to normalize the use of these composite sections.

After analyzing the literature, it is detected a lack of experimental tests on CFST columns with HSC -especially with thin-walled sections susceptible to failure by local buckling- necessary for the complete understanding of its effect as infill on this type of composite members. Therefore, in this paper a new experimental program is presented where 18 CFST stub columns where tested. Square, rectangular and circular shapes were considered and the variation of the steel tube thickness was studied. For comparison, the experiments combined the use of NSC and HSC to study their effect on the load bearing capacity of the columns subjected to concentric loads.

2. Experimental program

2.1. Columns specimens and test setup

In this work, a total of 18 stub columns with different cross-sectional shape were tested with the objective of evaluating the effect of the steel tube thickness and the concrete infill on their ultimate capacity. Therefore, four series can be distinguished depending of the shape and dimensions of the cross-section. In Fig. 1, the schemes of the sections studied is presented. Three different cross-sectional shapes have been considered: circular (C), rectangular (R) and square (S). Furthermore, for each series, both the compressive strength of the concrete infill (C30 and C90) and the thickness of the steel tube varied, including thin-walled specimens.

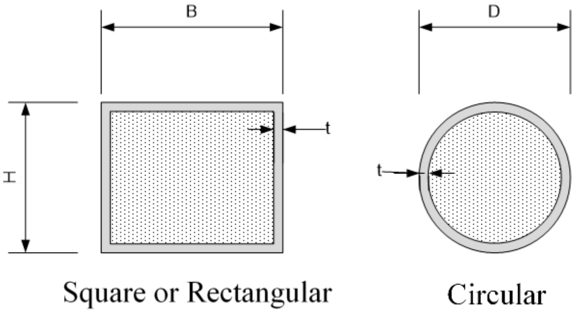

Fig. 1. CFST cross-sections studied.

In Table 1 data corresponding to the columns of each series is summarized.

*Table 1.*Details of the specimens.

S.	Name	Dim. (mm)	t (mm)	f_y (MPa)	f_c (MPa)
1	C101.6x2_30	101.6	2	397.94	40.8
	C101.6x3_30	101.6	3	425.03	34.04
	C101.6x5_30	101.6	5	409.35	34.04
	C101.6x2_90	101.6	2	397.94	93.51
	C101.6x3_90	101.6	3	425.03	93.51
	C101.6x5_90	101.6	5	409.35	93.51
2	C159x3_30	159	3	336.28	33.39
	C160x6_30	160	6	446.91	41.44
	C159x3_90	159	3	336.28	90.85
	C160x6_90	160	6	446.91	94.68
3	S125x125x3_30	125x125	3	296.06	46.67
	S125x125x4_30	125x125	4	342.59	46.67
	S125x125x3_90	125x125	3	296.06	94.33
	S125x125x4_90	125x125	4	342.59	94.33
4	R150x100x4_30	150x100	4	270.84	40.41
	R150x100x5_30	150x100	5	293.56	40.19
	R150x100x4_90	150x100	4	270.84	90.58
	R150x100x5_90	150x100	5	293.56	88.92

For convenience, the test specimens were named as follows: S-D_N (i.e. S125x125x3_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 represent 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. Fig. 2 shows the setup of one of the experiments. As can be seen, a steel plate with dimensions 300x300x15 mm was placed at both ends of each specimen. The columns were tested with pinned-pinned (P-P) boundary conditions and had a buckling length of 300 mm (L=300 mm). For the sake of accuracy, the corresponding displacement control test was performed after the correct collocation of the column.

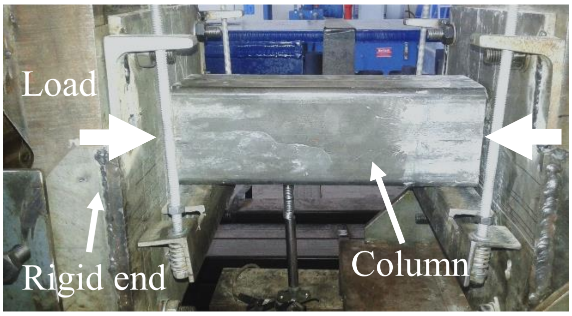

Fig. 2. Test setup.

2.2. Materials

Steel tubes

In this program, the nominal yield strength of all the steel tubes was S275. The actual values of the yield strength (f_y) are summarized in Table 1 for all the specimens and as can be seen it was higher than the nominal. Note that in every series there are thin-walled tubes included with thicknesses 2, 3 or 4 mm.

Concrete

As commented in the previous section, two types of nominal compressive strength were employed: 30 MPa and 90 MPa. The concrete infill was prepared in a planetary mixer and cured during 28 days until the day when the test was performed. Simultaneously, the corresponding tests on the concrete samples were carried out in order to obtain the actual compressive strength (f_c). Table 1 contains all the columns details regarding the concrete type and the actual compressive strength.

3. Results

3.1. Maximum load

For each specimen, the value of the experimental ultimate load was obtained. In Table 2, the ultimate load values are summarized.

Table 2. Test results and parameters of analysis.

S.	Name	N_{exp} (kN)	SI	CCR
1	C101.6x2_30	582.7	0.95	2.12
	C101.6x3_30	703.3	1.10	1.78
	C101.6x5_30	942.2	1.11	1.52
	C101.6x2_90	935.7	0.99	3.76
	C101.6x3_90	1075.5	1.01	2.72
	C101.6x5_90	1311.0	1.06	2.11
2	C159x3_30	1185.7	1.07	2.40
	C160x6_30	2154.5	1.07	1.66
	C159x3_90	2021.7	0.93	4.09
	C160x6_90	2933.2	1.00	2.26
3	S125x125x3_30	824.5	0.75	1.90
	S125x125x4_30	1159.2	0.89	1.75
	S125x125x3_90	1441.2	0.81	3.33
	S125x125x4_90	1882.5	0.96	2.84
4	R150x100x4_30	912.0	0.87	1.74
	R150x100x5_30	1168.0	0.96	1.66
	R150x100x4_90	1188.5	0.70	2.27
	R150x100x5_90	1641.8	0.90	2.33

From the analysis of Fig. 3, can be extracted that the specimens with HSC show the highest ultimate loads. With respect to the enhancement of the capacity when the tubes are filled with HSC, the circular C160 and the square S125x125 are the columns where it is most notable. In all the series, as expected, the capacity of the column increases with an increment in the steel tube thickness.

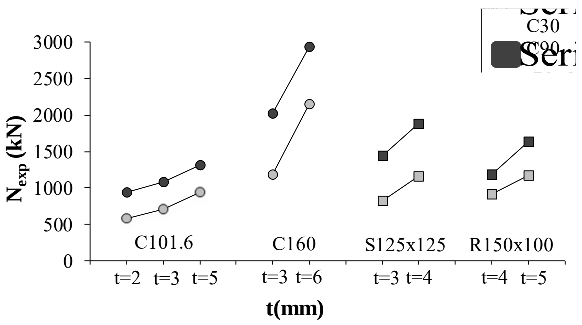

Fig. 3. Ultimate load variation with steel tube thickness.

3.2. Strength index

The strength index (SI) is the ratio between the theoretical cross-sectional capacity and the actual ultimate load which indicates the intensity of the composite action between the two components. It was calculated for each column by means of Eq. (1) and the values are summarized in Table 1 and plotted in Fig. 4 for each series.

$$SI = \frac{N_{\text{exp}}}{A_s f_y + A_c f_c} \qquad (1)$$

where N_{exp} is the experimental ultimate load; A_s is the cross-sectional area of the steel tube; f_y is the yield strength of the steel tube; A_c is the concrete cross-sectional area; and f_c the concrete strength.

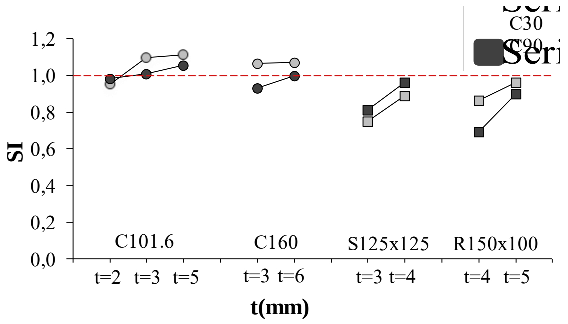

Fig. 4. Strength index variation with steel tube thickness.

It can be observed that the SI is higher for those series with circular sections (with values equal or higher than one) than for the square and rectangular series, for which is always less than one, which implies that the experimental value of the load is overestimated by the sum of the components.

In general, the composite action appears to be more efficient in those columns filled with NSC (higher values of SI), except from those specimens with square section, where the strength index values are slightly higher for the HSC columns.

For all the series, the SI increases with an increment in the steel tube thickness for both NSC and HSC infills. However, the increment is more evident in square and rectangular sections, where the confinement is not as effective as in circular sections with thin-walled tubes.

3.3. Concrete contribution ratio

In a similar way, the contribution of the concrete infill was analysed for each member by means of the concrete contribution ratio (CCR) which can be calculated by means of Eq. (2).

$$CCR = \frac{N_{\text{exp}}}{A_{s,eff}\, f_y} \qquad (2)$$

where N_{exp} is the experimental ultimate load; $A_{s,eff}$ is the effective cross-sectional area of the steel tube according to the Eurocode 3 model [13], that considers the local buckling of the steel hollow tube; and f_y is the yield strength of the steel tube.

This parameter is calculated for all the columns and the values are summarized in Table 2 and plotted in Fig. 5 for each series.

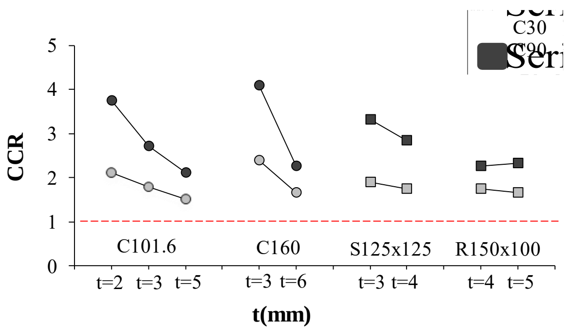

Fig. 5. Concrete contribution ratio variation with steel tube thickness.

The results obtained corroborate that observed for the ultimate load. When HSC is employed, the effect of the concrete infill is much higher than for those with NSC, and, again, this effect is less important with rectangular sections, given that the confinement exerted on the concrete core by the tube is less effective.

As expected, the CCR decreases for thicker steel tubes as a consequence of the inherent increment in the steel cross-sectional area. Also, for those columns with thin-walled steel tubes, the CCR values are the highest, since the concrete infill prevents the steel tube from local buckling, phenomenon very likely to occur in these cases. This fact implies a notable increment on the ultimate load of the columns in comparison to that of the hollow steel tube affected by premature local buckling.

4. Conclusions

In this work, the results from an experimental campaign on 18 concrete-filled steel tubular columns with different cross-sectional shape subjected to concentric loads are presented. The effect of the steel tube thickness and the concrete infill on their ultimate capacity were evaluated. Four series were assessed, depending of dimensions of the cross-section and all the series included thin-walled steel tubes. Two types of concrete strengths were involved in this study: normal (NSC) and high strength concrete (HSC). Several aspects from this study are worth noting:

- CFST columns with HSC had the highest maximum loads. CCR values proved the high efficiency of using HSC as infill, especially in circular CFST columns with thin-walled steel tubes.

- The highest values of CCR were registered for those columns with thin-walled tubes, since the concrete infill prevented the steel tube from local buckling.

- SI values showed the important effect of confinement in circular columns even for those with thin-walled steel tubes. For rectangular and square sections, the combined action improved for thicker steel tubes, although still the theoretical capacity overestimated the real capacity.

Acknowledgements

The authors would like to express their gratitude to Universitat Jaume I for the project P1-1A2015-06.

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