IOP Conf. Series: Materials Science and Engineering **451** (2018) 012053 doi:10.1088/1757-899X/451/1/012053

Strength of compressed concrete filled steel tube elements of circular and square cross- section

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Abstract. The purpose of the research is to determine the values of compressive force eccentricities at which the strength of square-sectioned compressed concrete filled steel tube elements (CCSTEs) is not lower than that of circular-sectioned elements that are similar in materials consumption. Strength calculations are carried out using a specially developed "CFST" computer program. The reliability of calculations, obtained with this program, is pre-verified basing on the calculation data, related to 203 circular-sectioned CCSTEs and 264 square-sectioned elements. The results of the calculations demonstrate that, given eccentric compression, where eccentricities are slightly outside the bounds of the core of section, the CCSTE strength criterion should not significantly influence the selection of their geometric shape. Based on this criterion, when relative eccentricities exceed 0.2-0.25, the preference should be given to the elements with a square cross-section. Moreover, the area of rational use of square-sectioned CCSTEs is extended with the increase in structural flexibility.

1. Introduction

The applied quantities of compressed concrete filled steel tube elements (CCSTEs) are increasing year by year [1-7]. Due to the high strength under heavy loads, they have significant economic benefits when compared to steel structures [8] and the presence of the external steel shell provides them with substantial technological advantages over reinforced concrete structures.

CCSTEs of circular cross-section are generally used in practice [6-8]. This fact is explained by a number of reasons. The main reason is the great confinement effect, which appears in such structures under compressive forces applied with accidental or small eccentricities. As a result, when the materials consumption is equal, the strength of square-sectioned CCSTEs is usually considerably lower in comparison with circular-sectioned elements [9].

At the same time, the scope of research on square-sectioned CCSTE strength has recently increased [10-15]. The prismatic surface of these structures is often preferable when they are used as columns of multi-storey buildings. Besides, the square-sectioned concrete filled steel tube structures may prove to be more efficient when working in eccentric compression. With increased flexibility, the confinement effect occurring in a circular-sectioned CCSTE is reduced [16]. In this case, their strength will decrease faster than the strength of square-sectioned columns.

These issues are of great interest to the designers although they are not sufficiently studied. The purpose of this research is to determine the values of compressive force eccentricities at which the strength of square-sectioned CCSTEs is not lower than that of circular-sectioned elements that are similar in materials consumption.

2. Research technique

To attain the determined goal, the calculations of the strength of circular- and square-sectioned CCSTEs, working in compression with different eccentricities, were carried out.

Geometric and design parameters of studied samples are presented in table 1. Their cross-sectional dimensions are defined in such a way as to make the cross-section areas of steel tubes and concrete cores as equal as possible. The cross-section area of a circular-sectioned tube with 530×6 mm dimensions is 99 cm^2, and the cross-section area of a square-sectioned tube with 450×450×6 mm dimensions is 105.6 cm^2. The difference is only 6 %. The cross-section area of concrete of a circular tube is 2107 cm^2, which exceeds the corresponding parameter of a square tube by 10 %. Considering such small differences, it can be stated that the elements with comparable strength are quite similar in terms of the material consumption.

Strength calculations were carried out on the computer using the specially developed “CFST” computer program. This program is designed to solve the problems of calculating the bearing capacity and evaluating the stress-strain state of centrally and eccentrically compressed CCSTEs of circular, annular and square cross-section. The program takes into account the complex and constantly-changing stress state of the concrete core and steel shell during the loading process.

A preliminary comparison between the calculated breaking loads and the experimental data published in the papers [17-28] was carried out to verify the accuracy of calculation procedures implemented in the program. Based on the results of this comparison, the error vector variation coefficient for circular-sectioned CCSTEs (203 samples) was 9.5% and for square-sectioned CCSTEs (264 samples) was 8.8 %. Therefore, the calculation accuracy should be regarded as wholly satisfactory**.**

3. Research results

Table 2 presents the results of calculating the strength of circular- and square-sectioned CCSTEs. Calculations are carried out for elements with a length of 3300 and 6600 mm working both in central and eccentric compression. Relative eccentricities of the compressive force e_0/d and e_0/b (e_0 is the initial eccentricity; d is the circular section diameter and b is the square section side) are assumed to be equal within the range of 0 to 0.5.

Figure 1 illustrates the comparison of load-bearing capacity dependencies on relative eccentricity of external load application for circular- (line 1) and square-sectioned (line 2) CCSTE samples.

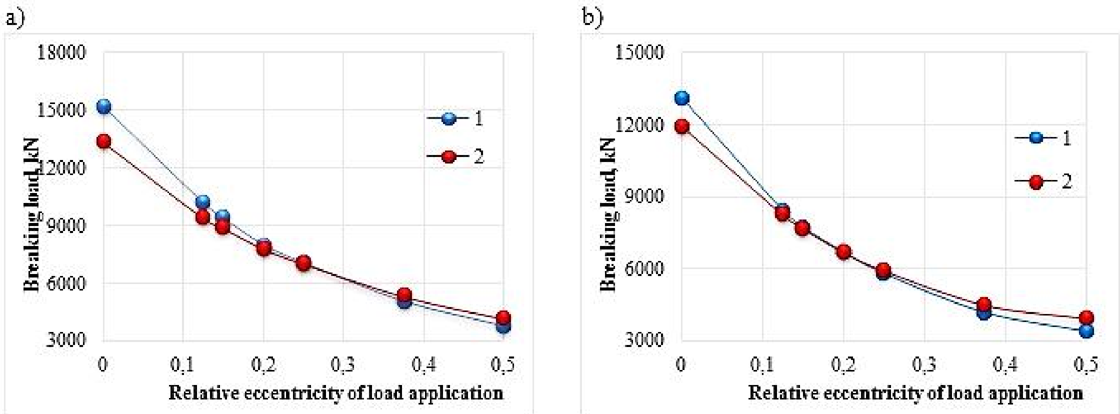

Figure 1. Load-bearing capacity dependencies on the relative eccentricity value for concrete filled steel tube columns of circular cross-section (line 1) and square cross-section (line 2): a) sample height 3300 mm, b) sample height 6600 mm.

The results of the performed comparison demonstrate that the strength of examined circular-sectioned samples is higher when eccentricity values are within the core of cross-section. Square-sectioned CCSTEs become stronger with greater eccentricities. The particular value of relative eccentricity, when the strengths of circular- and square-sectioned samples are approximately equal, largely depends on their flexibility.

Table 1. Parameters of the investigated CCSTE

Section shape	Size dimensions, mm			Eccentricity variation range, mm	Strength characteristics of concrete and steel	
	section diameter or width	wall thickness of the steel shell	sample height		concrete grade	steel grade
Circular	530	6	3300, 6600	0÷265	C60	S345
Square	450	6	3300, 6600	0÷225	C60	S345

Table 2. Comparison of the strength of circular- and square-sectioned CCSTEs

Relative eccentricity	Sample height,mm	Breaking load, kN		$\frac{N_{u1}}{N_{u2}}$
		$N_{u1}{}^{a}$	$N_{u2}{}^{b}$	
0	3300	15212	13376	1,14
0,125		10182	9414	1,08
0,15		9395	8894	1,06
0,20		8015	7828	1,02
0,25		**7085**	**7048**	1,00
0,375		5086	5357	0,95
0,5		3790	4186	0,90
0	6600	13133	11960	1,10
0,125		8440	8261	1,02
0,15		7742	7689	1,01
0,20		**6711**	**6693**	1,00
0,25		5822	5938	0,98
0,375		4186	4504	0,93
0,5		3411	3952	0,86

Note: [a] is the breaking load for a circular-sectioned CCSTE sample;
[b] is the breaking load for a square-sectioned CCSTE sample

Flexibility of concrete-steel structures must be determined according to the following formula:

$$\lambda_{eff} = l \cdot \sqrt{\frac{(EA)_{eff}}{(EI)_{eff}}} \tag{1}$$

where l is the effective length of the rod; $(EI)_{eff}$ and $(EA)_{eff}$ are the effective stiffness values of the most loaded transformed section under bending and compression.

It is recommended to calculate the stiffness $(EI)_{eff}$ and $(EA)_{eff}$ in a first approximation using the following formulas:

$$(EI)_{eff} = 0.5E_{\mathrm{c}}I_{\mathrm{c}} + 0.5E_{\mathrm{p}}I_{\mathrm{p}} \tag{2}$$

$$(EA)_{eff} = 0.5E_{c}A_{c} + 0.5E_{p}A_{p} \tag{3}$$

where I_c, I_p are concrete core and steel shell inertia moments; A_c, A_p are their cross-sectional areas; E_c, E_p are concrete and steel shell elasticity moduli.

The value of flexibility is $\lambda_{eff} = 23.2$ for 3300 mm high circular-sectioned structures and $\lambda_{eff} = 26.8$ for square-sectioned structures, which is slightly larger. At such flexibility values, circular- and square-sectioned samples have almost the same strength when the value of relative eccentricity is 0.25. It is important that the difference between the sample strength values does not exceed 6% when the relative eccentricities are between 0.15 and 0.375. The flexibility values for 6,600 mm high circular-sectioned structures and square-sectioned structures are $\lambda_{eff} = 46.5$ and $\lambda_{eff} = 53.6$ respectively. At such flexibility values, the strengths of circular- and square-sectioned samples are approximately equal when the value of relative eccentricity is 0.2. It should be noted that the difference between the sample strength values does not exceed 2% when the relative eccentricities are between 0.125 and 0.25.

The results of carried out calculations show that, given eccentric compression where eccentricities are slightly outside the bounds of the core of section, the CCSTE strength criterion should not significantly influence the selection of their geometric shape. Based on this criterion, when relative eccentricities exceed 0.2-0.25, preference should be given to elements with square cross-section. Moreover, the area of rational use of square-sectioned CCSTEs is extended with increase in the flexibility of structures.

4. Conclusions

The values of compressive force relative eccentricities, at which the strength of square-sectioned CCSTEs is not lower than that of circular-sectioned columns that are similar in terms of materials consumption, are determined by means of calculation. The particular values of eccentricities at which the elements with a square cross-section are preferable depend on their flexibility. Moreover, the area of rational use of square-sectioned CCSTEs is extended with increase in the structural flexibility.

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Acknowledgments
This article was prepared on the results of the scientific project within the framework of the state task of the Ministry of Education and Science of the Russian Federation 7.3379.2017 / 4.6.