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COMPARATIVE ANALYSIS OF TWO COMPOSITE COLUMNS

BY

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Abstract. The composite steel-concrete compression members can be made in two constructive solutions: members with concrete partially or total encased sections and members with concrete filled rectangular and circular tubes. This paper presents a comparative study concerning the plastic resistance of a concrete-filled rectangular square steel section and a concrete-filled circular hollow steel section, when the composite column is subjected to axial compression.

Keywords: composite steel-concrete columns; rectangular section; circular section; comparative analysis.

1. Introduction

The composite steel-concrete compression members can be made in two constructive solutions (Fig. 1) (SR EN 1994-1-1/2006; Moga, 2010):

– members with concrete partially or total encased sections (Fig. 1a; b; c);
– members with concrete filled rectangular and circular tubes (Fig. 1d; e; f).

In the case of composite steel-concrete compression members, the mechanism by which shear stresses can be transferred over the interface between the structural steel component and the encased concrete are adhesion,

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interface interlocking and friction, which are referred to as the *natural bond.* If the natural bond is not enough to achieve the required shear resistance, mechanical shear connectors may be used, the widely used types being headed studs and the shot-fired nails.

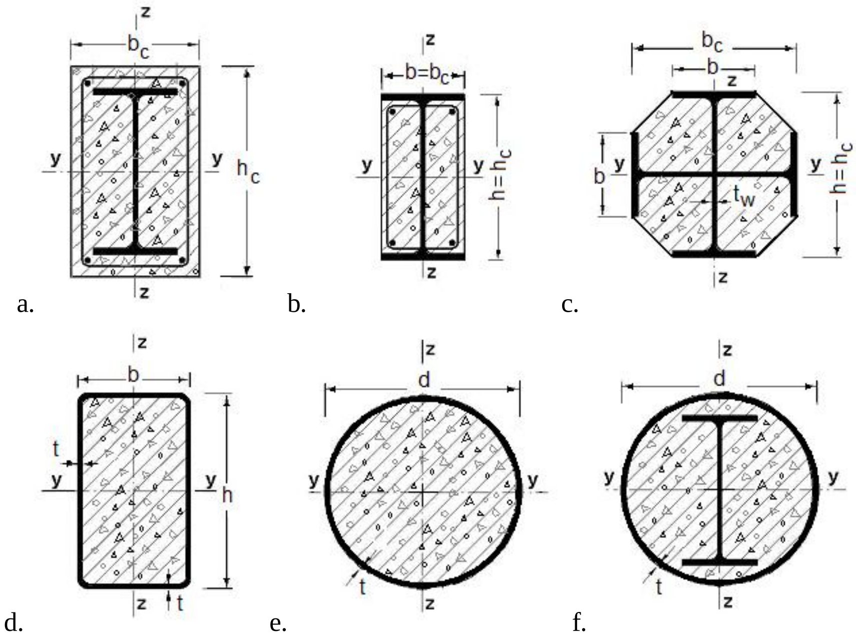


Fig. 1 – Composite columns.

The aim of this paper is to analyze the influence of the composite cross-section shape on the plastic resistance of the axial compression column, respectively a concrete-filled rectangular square steel tube and a concrete-filled circular hollow steel tube (Fig. 2) (Moga, 2010).

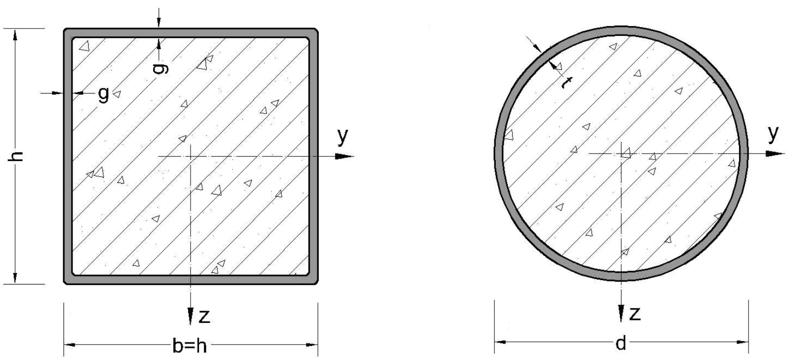


Fig. 2 – Rectangular and circular sections.

The following design data are imposed:

a) the main dimension of the cross-section is identical for the both type of columns;

b) the cross-section areas of the steel tubes are identical, which involves the same steel consumption for the analyzed columns.

The analysis is theoretically and practically important and takes into account the following considerations:

a) for an identical steel consumption, the cross-section of a square tube has a higher moment of inertia in comparison with a circular cross-section;

b) in the case of the concrete-filled circular hollow steel section, the confinement effect appears, which increasing the concrete resistance, but only in the case of a low slenderness ratio of the compression member;

c) the steel plate walls of the rectangular cross-section are exposed to the local buckling, while circular sections are less susceptible to this phenomenon;

d) the plate walls present the advantage that the joints with the adjacent elements are simpler comparative with the circular sections.

In Fig. 3, (Moga, 2010; XC Project, 2011), an example designed by the paper's authors where composite columns are used is presented.

Fig. 3 – Construction S+D+P+3E in Cluj-Napoca (execution phase), (XC Project, 2011).

2. Axial Compression Composite Columns

In accordance with Eurocode 4 (SR EN 1994-1-1/2006; Moga, 2010; Păcurar *et al.*, 2006; Păcurar *et al.*, 2007), the resistance capacity of an axial compression composite steel-concrete column is given by the expression:

$$N_{Rd} = \chi \cdot N_{pl.Rd} \tag{1}$$

where: $N_{pl.Rd}$ – plastic resistance to compression given by:

– for concrete-filled rectangular hollow section:

$$N_{pl.Rd} = A_a f_y \frac{1}{\gamma_a} + A_c \frac{f_{ck}}{\gamma_c} + A_s f_{sk} \frac{1}{\gamma_s} \tag{2.a}$$

– for concrete-filled circular hollow section:

$$N_{pl.Rd} = \eta_a A_a f_y \frac{1}{\gamma_a} + A_c \frac{f_{ck}}{\gamma_c}\left(1 + \eta_c \frac{t}{d}\frac{f_y}{f_{ck}}\right) + A_s f_{sk} \frac{1}{\gamma_s} \tag{2.b}$$

in which:

– A_a; A_c; A_s – cross-section areas of steel, concrete and reinforcement;

– f_y; f_{ck}; f_{sk} – characteristic strengths of steel, concrete and reinforcement;

– γ_a; γ_c; γ_s – partial safety factors of steel, concrete and reinforcement;

– η_a – coefficient which takes into account the diminishing of the steel strength caused by biaxial state of stresses:

$$\eta_a = \eta_{ao} + (1 - \eta_{ao})\frac{10\,e}{d} \tag{3.a}$$

where: $\eta_{ao} = 0.25\left(3 + 2\bar{\lambda}\right) \le 1$; η_c – coefficient which takes into account the increase in strength of concrete caused by confinement effect:

$$\eta_c = \eta_{co}\left(1 - \frac{10\,e}{d}\right) \tag{3.b}$$

where: $\eta_{co} = 4.9 - 18.5\,\bar{\lambda} + 17\,\bar{\lambda}^2 \ge 0$.

When $\bar{\lambda} > 0.5$ or $e > d/10$, the values of η_a ; η_c will be taken as 1 and 0 (the confinement effect is not taken into account).

The reduction factor for the relevant buckling mode, χ, is in term of the relevant relative slenderness $\bar{\lambda}$ and the relevant buckling curve for cross-section.

The effective elastic flexural stiffness of the composite column is evaluated with the relation:

$$(EI)_e = E_a I_a + 0.6\, E_{cm} I_c + E_s I_s \tag{4}$$

where: I_a, I_c, I_s are the second moment of area of the structural steel section, the un-cracked concrete section and the reinforcement; E_a, E_s – modulus of elasticity of structural steel and reinforcement; E_{cm} – secant modulus of elasticity of concrete.

The relevant relative slenderness is given by:

$$\bar{\lambda} = \sqrt{\frac{N_{\mathrm{pl}.Rk}}{N_{\mathrm{cr}}}} \tag{5}$$

where:

$$N_{\mathrm{pl}.Rk} = A_a f_y + A_c f_{ck} + A_s f_{sk}\,; \tag{6}$$

$$N_{\mathrm{cr}} = \frac{\pi^2 (EI)_e}{l^2}\,. \tag{7}$$

From the condition that the cross-section area of the steel square tube has to be equal to the cross-section area of the circular pipe:

$$A_{\mathrm{tube}} \cong 4dg = A_{\mathrm{pipe}} \cong \pi dt \tag{8}$$

the equivalent thickness of the circular pipe is obtained:

$$t \cong \frac{4}{\pi} g = 1.27\, g \tag{9}$$

Taking into account the value of the profile coefficient – $K = A^2 / I$, this has approximated a constant value for a certain cross-section shape:

– square tube: $K = 26\, g/h$;
– circular pipe: $K = 28\, t/d$.

It is obtained:

$$\frac{I_{\text{tube}}}{I_{\text{pipe}}}=\frac{A^2/\left(26g/h\right)}{A^2\left(28t/d\right)}=\frac{28t}{26g}\cong 1.37\ -\ \text{for}: t\approx 1.27g\,. \tag{10}$$

Referring to the concrete consumption, the following approximation can be made:

$$A_{c.\text{tube}}\cong d^2; \tag{11.a}$$

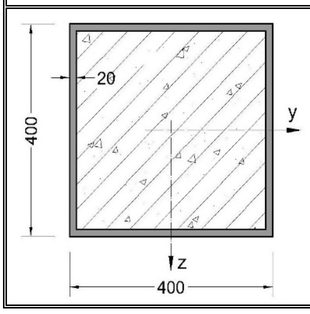
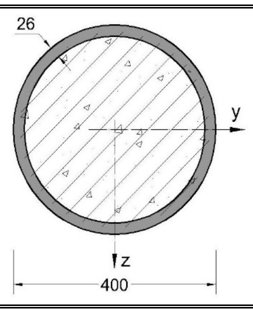
$$A_{c.\text{pipe}}\cong \frac{\pi d^2}{4}=0.785d^2. \tag{11.b}$$

3. Worked Example

It is analyzed the plastic resistance of two composite columns, one being a concrete-filled steel square tube section and the second is a concrete-filled circular section, both of them having the same main dimension of the cross-section and approximately the same steel area.

Table 1 presents the cross-section of the columns and the main design characteristics.

Table 1
Column Section Characteristics

Materials			
Steel: S 235 f_y = 235 N/mm^2 E = 210 000 N/mm^2		Concrete: C 25 / 30 F_{ck} = 20 N/mm^2 E_{cm} = 31 000 N/mm^2	
Cross-sections			
	A_a = 304 cm^2 I_a = 73 365 cm^4 A_c = 1296 cm^2 I_a = 139 968 cm^4		A_a = 305 cm^2 I_a = 53 644 cm^4 A_c = 951 cm^2 I_a = 71 956 cm^4

3.1. Concrete–Filled Steel Square Tube

It is calculated:

$$N_{\text{pl}.Rd} = A_a \frac{f_y}{\gamma_a} + A_c \frac{f_{ck}}{\gamma_c} + A_s \frac{f_{sk}}{\gamma_s} = \left(304\frac{2,350}{1.1} + 1,296\frac{200}{1.5}\right) = 822,255\,\text{daN} \quad (12)$$

$$N_{\text{pl}.Rk} = A_a f_y + A_c f_{ck} + A_s f_{sk} = 304 \times 2,350 + 1,296 \times 200 = 973,600\,\text{daN} \quad (13)$$

$$\left(EI\right)_e = E_a I_a + 0.6 E_{cm} I_c = 2.1\times10^6 \times 73365 + 0.6 \times 0.29 \times 10^6 \times \times 139,968 = 178.48 \times 10^9\,\text{daN.cm}^2, \quad (14)$$

a) for different length of the column, it is evaluated:

$$N_{\text{cr}} = \frac{\pi^2 \left(EI\right)_e}{L^2};\ \bar{\lambda} = \sqrt{\frac{N_{\text{pl}.Rk}}{N_{\text{cr}}}};\ \text{reduction factor } \chi \quad (15)$$

b) finally the plastic resistance of the column is obtained:

$$N_{Rd} = \chi N_{\text{pl}.Rd} \quad (16)$$

The results are all presented in Table 2.

Table 2
Design parameters

L, [m]	$N_{\text{cr}} \times 10^4$, [kN]	$\bar{\lambda}$	χ	N_{Rd}, [kN]
2.0	44.00	0.15	1.00	8 223
4.0	11.00	0.30	0.98	8 058
6.0	4.89	0.45	0.93	7 647
8.0	2.75	0.60	0.89	7 318
10.0	1.76	0.74	0.82	6 742
12.0	1.22	0.89	0.75	6 167
14.0	0.90	1.04	0.63	5 180

3.2. Concrete – Filled Circular Steel Tube

It is calculated:

$$N_{\text{pl}.Rd} = A_a \frac{f_y}{\gamma_a} + A_c \frac{f_{ck}}{\gamma_c} + A_s \frac{f_{sk}}{\gamma_s} = \left(305\frac{2,350}{1.1} + 951\frac{200}{1.5}\right) = 778,390\,\text{daN} \quad (17)$$

$$N_{\mathrm{pl}.Rk} = A_a f_y + A_c f_{ck} + A_s f_{sk} = 305 \times 2{,}350 + 951 \times 200 = 906{,}950\,\mathrm{daN} \quad (18)$$

$$(EI)_e = E_a I_a + 0.6 E_{cm} I_c = 2.1 \times 10^6 \times 53{,}644 + 0.6 \times 0.29 \times 10^6 \times 71{,}956 = 125.17 \times 10^9\,\mathrm{daN.cm}^2. \quad (19)$$

Finally the plastic resistance of the column is obtained. The results are presented in Table 3.

Table 3
Column Resistances

L, [m]	$N_{cr} \times 10^4$, [kN]	$\bar{\lambda}$	χ	N_{rd}, [kN]
2.0	30.75	0.17	1.00	8,922
4.0	7.69	0.34	0.96	7,508
6.0	3.42	0.51	0.92	7,161
8.0	1.92	0.69	0.84	6,538
10.0	1.23	0.86	0.76	5,916
12.0	0.85	1.03	0.62	4,826
14.0	0.63	1.20	0.53	4,125

It has to be underlined that for $\bar{\lambda} < 0.5$, respectively for L = 2.0 m and L = 4.0 m, the plastic resistance of the concrete-filled circular hollow section has been evaluated taking into account the confinement effect as follows:

a) for: L = 2.0.m, $\bar{\lambda} = 0.17$:

$$N_{\mathrm{pl}.Rd} = \eta_a A_a f_y \frac{1}{\gamma_a} + A_c \frac{f_{ck}}{\gamma_c}\left(1 + \eta_c \frac{t}{d} \cdot \frac{f_y}{f_{ck}}\right) = 892{,}232\,\mathrm{daN} \quad (20)$$

where:

$$\eta_a = \eta_{ao} + (1 - \eta_{ao})\frac{10\,e}{d} = \eta_{ao} = 0.25\left(3 + 2\bar{\lambda}\right) = 0.84 \quad (21)$$

$$\eta_c = \eta_{co}\left(1 - \frac{10e}{d}\right) = \eta_{co} = 4.9 - 18.5\bar{\lambda} + 17\bar{\lambda}^2 = 2.25 \quad (22)$$

$$\left(1 + \eta_c \frac{t}{d} \cdot \frac{f_y}{f_{ck}}\right) = 2.72 \quad (23)$$

b) for: L = 4.0 m, $\bar{\lambda} = 0.34 \Rightarrow \eta_a = 0.92$; $\eta_c = 0.58$;

$$\left(1+\eta_c \frac{t}{d} \frac{f_y}{f_{ck}}\right)=1.44 \tag{24}$$

$$N_{\mathrm{pl}.Rd} = 782{,}056\,\mathrm{daN}. \tag{25}$$

Fig. 4 presents the graphic of the plastic resistances for the two analyzed columns, function of the member length *L*, [m].

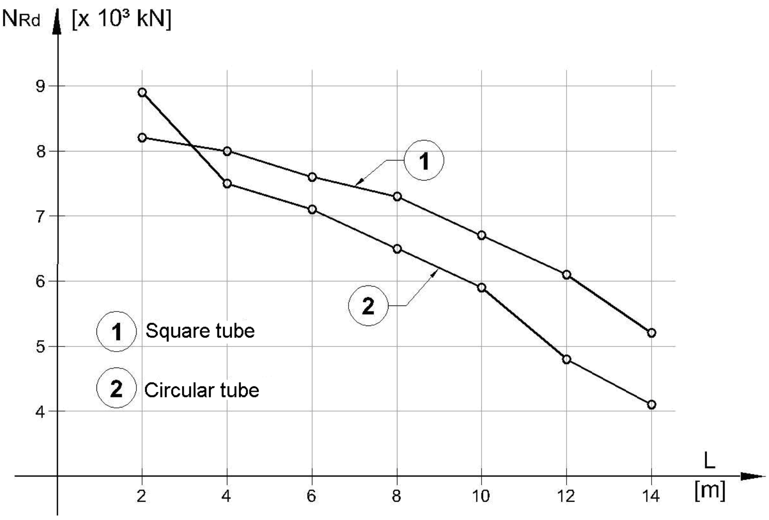


Fig. 4 – Graphic of column resistances.

In Table 4, the ratio between the plastic resistances of the columns made-up in those two constructive solutions is presented.

Table 4
Ratio of Plastic Resistances

L, [m]	2.0	4.0	6.0	8.0	10.0	12.0	14.0
N_{Rd}^{TUBE} / N_{Rd}^{PIPE}	0.92	1.07	1.07	1.12	1.14	1.27	1.26

4. Conclusions

From the presented analysis it results that the column of concrete-filled steel square tube has a higher plastic resistance in comparison with column of concrete-filled steel circular hollow section, when the column is subjected to axial compression.

The fact is owed to a higher moment of inertia of a square section in comparison with a circular section, which is not balanced by the confinement effect that takes place in the case of concrete-filled circular hollow section.

Exceptions from the above situation occur in the case of short columns where the confinement effect is very strong.

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ANALIZA COMPARATIVĂ A DOUĂ TIPURI DE STÂLPI CU SECŢIUNE COMPOZITĂ: STÂLPI CU SECŢIUNE PĂTRATĂ ŞI STÂLPI CU SECŢIUNE CIRCULARĂ

(Rezumat)

Se analizează influenţa formei secţiunii transversale a stâlpului cu secţiune compozită – respectiv tub metalic pătrat umplut cu beton şi tub metalic circular umplut cu beton, asupra capacităţii portante la compresiune axială.