Structural Mechanics

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Composite columns with circular section.
Shear transfer mechanism

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Summary

The mechanisms of the shear transfer over the interface between the circular steel tube and the concrete core as well as the design of the shear connection are presented in this paper.

A numerical example for the evaluation the longitudinal shear stresses over the interface between structural steel and concrete is also presented here.

KEYWORDS: composite columns, shear stresses, shear transfer, connection.

1. INTRODUCTION

A composite column may either be a concrete partially or completely encased section or a concrete- filled section, Figure 1.

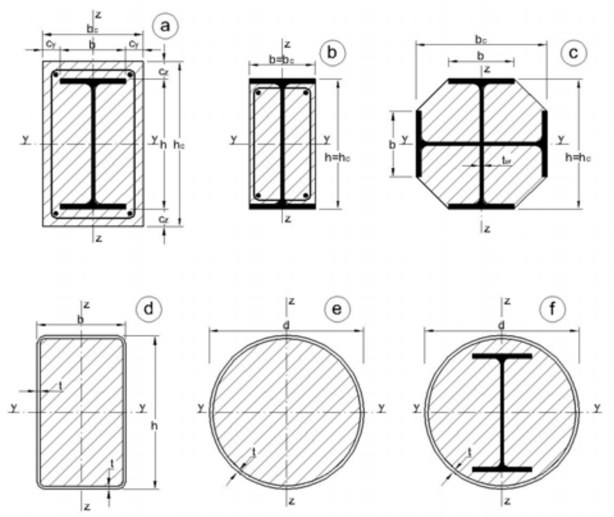

Figure 1

In case of the concrete-filled hollow steel sections, there are three mechanisms

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which are often referred to as the natural bond, by which shear stresses can be transferred over the interface between the steel tube and the concrete core, these are: adhesion, interface interlocking and friction, Figure 2.

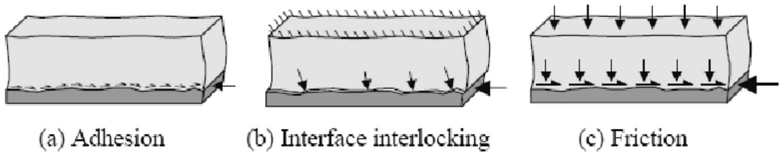

Figure 2

If the natural bond is not enough to achieve the required shear resistance there is the possibility of using mechanical shear connectors, the most widely used types being headed studs and the shot-fired nails.

The shear stresses, which take place on the interface steel-concrete, are shown in Figure 3.

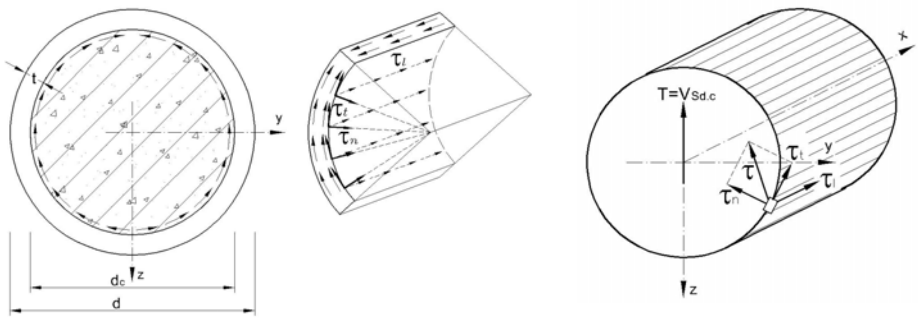

Figure 3

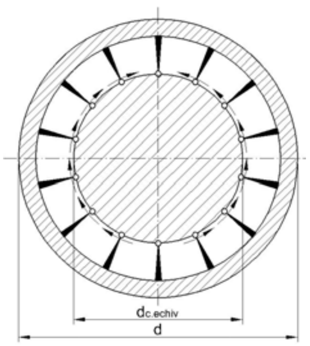

Figure 4

Taking into account that the structural steel and the concrete have different mechanical characteristics, the concrete core is transformed into an equivalent steel section using the modular ratio *n*.

The mechanical model is presented in Figure 4.

The equivalent in the steel area of the concrete core will be:

$$A_{c.echiv} = \frac{A_c}{n} \tag{1}$$

where the modular ratio can be taken as:

$$n \approx 2 \cdot n_i = 2\frac{E_a}{E_{cm}} \tag{2}$$

2. TANGENTIAL STRESSES

The state of tangential stresses caused by the shear force $T=V_{Sd.c}$ is presented in Figure 5, where τ_{xz} is the shear stress given by the Juravski formula:

$$\tau_{xz} = \tau_{zx} = \frac{TS_y}{bI_y} \tag{3}$$

where:

- Sy – section modulus of the slipping portion referred to neutral axis:

$$S_y = \frac{2}{3}\sqrt{\left(R^2 - z^2\right)^3} \tag{4}$$

- b – width of the section at the distance z from the neutral axis:

$$b = 2\sqrt{R^2 - z^2} \tag{5}$$

- Iy – moment of inertia of the cross-section:

$$I_y = \frac{\pi R^4}{4} = \frac{\pi D^4}{64} \tag{6}$$

By replacing the above parameters into relation (3) it results:

$$\tau_{xz} = \frac{T(R^2 - z^2)}{3I_y} \tag{7.a}$$

$$\tau_{xz} = \frac{4}{3}\frac{T}{A}\left(1 - \frac{z^2}{R^2}\right) \tag{7.b}$$

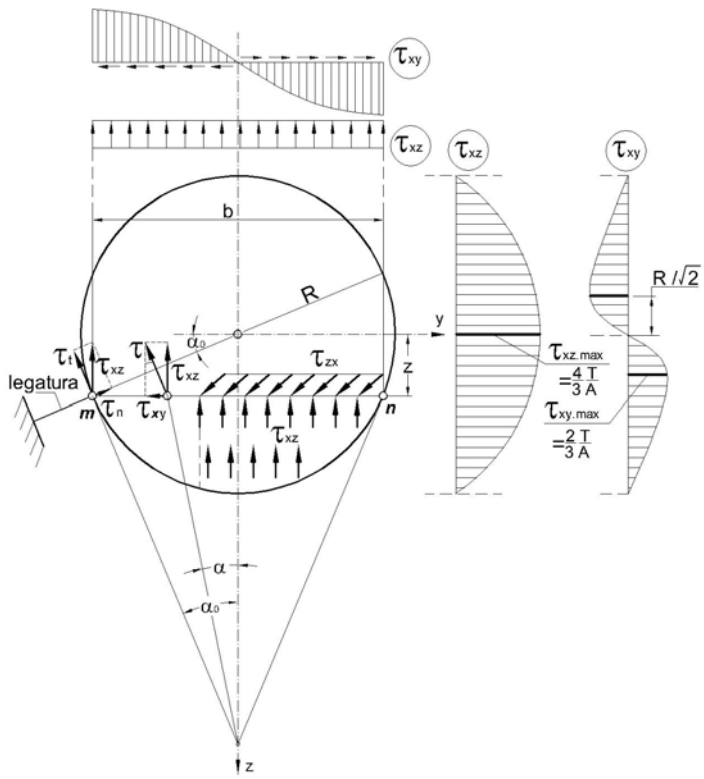

Figure 5

3. LONGITUDINAL SHEAR BETWEEN STEEL TUBE AND CONCRETE

The longitudinal shear stress τ_l, equal with the normal component τ_n, of the shear stress τ_{xz}, will be:

$$\tau_n = \tau_l = \tau_{xz}\sin\alpha_0 = \frac{4}{3}\frac{T}{A}\left(1-\frac{z^2}{R^2}\right)\cdot\frac{z}{R}, \qquad \tau_l = \frac{4}{3}\frac{T}{A}\frac{1}{R^3}z(R^2-z^2) \qquad (8)$$

The maximum value of τ_l and τ_n is obtained from the condition: $f'(z)=0 \quad \Rightarrow z=\frac{R}{\sqrt{3}}$.

It results:

$$\tau_{n.\,max} = \frac{8}{9\sqrt{3}}\frac{T}{A} = 0.51\frac{T}{A}$$

The longitudinal and the normal shear stresses variation are presented in Fig 6.

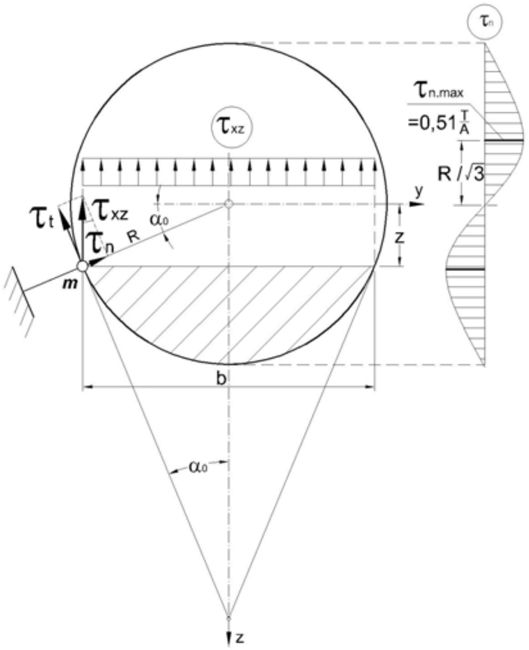

Figure 6

The sum of τ_n divided by a quarter of the interior surface of the steel tube will give the value of the longitudinal tangential stress on the interface between steel pipe and concrete core:

$$\tau_f = \frac{4\sum\tau_n}{2\pi R_c} = \frac{4\left(\frac{2}{3}R\cdot\tau_{n.max}\right)}{2\pi R_c} = 689\cdot 10^{-4}\frac{T}{R_c R} \quad (9)$$

where:

R_c - the interior radius of the steel tube;

R - the radius of the concrete core taking into account the modulus ratio and results from:

$$A_{c.echiv} = \frac{\pi R_c^2}{n} = \pi R^2 \quad \Rightarrow R = \frac{R_c}{\sqrt{n}} \quad (10)$$

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By replacing the value R in the relation (9) it is obtained:

$$\tau_f = 689 \cdot 10^{-4} \frac{\sqrt{n}}{R_c^2} T = 0.275 \frac{\sqrt{n}}{d_c^2} T \tag{11}$$

The longitudinal shear force for the entire length of the composite column and respectively for a half of cross-section, will be given by:

$$L_1 = \tau_f \frac{1}{2} \pi d_c \cdot 1 = 0.43 \frac{\sqrt{n}}{d_c} T \cdot 1 \tag{12}$$

If the natural bond is not enough to achieve the shear resistance, it will be necessary to use mechanical shear connectors and their number will result from the condition:

$$N \geq \frac{2 \cdot L_1}{P_{Rd}} \tag{13}$$

In accordance with Eurocode 4, the design value of the longitudinal shear strength τ_{Rd} in case of a concrete filled circular hollow sections is τ_{Rd} =0.55 N/mm^2.

From the relation (12) the maximum value of the shear force when it is not necessary to use mechanical shear connectors will result:

$$T_{max} = 2 \frac{d_c^2}{\sqrt{n}} \quad \text{(results T in [N] for } d_c \text{ in [mm])} \tag{14}$$

It is necessary to underline that the shear force T represents the part of the shear force, taken over by the concrete component of the composite column, which can be evaluated with the relation:

$$V_{Sc} = V_{Sd} \frac{A_{cv}}{A_{av} + A_{cv}} = V_{Sd} - V_{Sa} \tag{15}$$

where: $A_{av} = \frac{2}{\pi} A_a$ and $A_{cv} = A_{c.echiv} = \frac{A_c}{n}$

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4. NUMERICAL EXAMPLE

For a composite steel-concrete column the longitudinal shear stress over the interface between the circular steel tube and the concrete core is evaluated.

4.1. Design data

Composite column cross-section and loading (Figure 7)

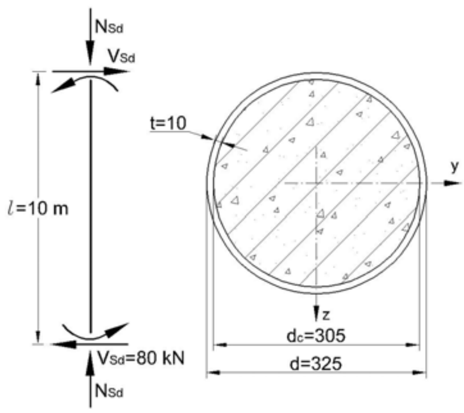

Figure 7

Cross-section characteristics:

Circular pipe: 325 × 10 mm

Steel: S 355:

- f_y=355 N/mm^2
- E_a= 210 000 N/mm^2
- A_a=99 cm^2

Concrete: C 25/30:

- f_{ck} = 25 N/mm^2
- E_{cm} = 30 500 N/mm^2
- $A_c = 731\ cm^2$

4.2. Longitudinal shear

Modulus ratio n:

$$n = 2 \cdot n_i = 2\frac{E_a}{E_{cm}} = 13.8$$

Equivalent in steel area of the concrete core:

$$A_{c.echiv} = \frac{731}{13.8} = 53\ cm^2$$

Shear force of the concrete component:

$$A_{av} = \frac{2}{\pi} A_a = \frac{2}{\pi} 99 = 63\ cm^2$$

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$$V_{Sc} = 80\frac{53}{63+53} = 36.55\ \text{kN}$$

The shear force, which can be achieved by the natural bond:

$$T_{max} = 2\frac{d_c^2}{\sqrt{n}} = 2\frac{305^2}{\sqrt{13.8}}10^{-3} = 50\ \text{kN} > V_{Sc} = 36.55\ \text{kN},$$

so it results that are not necessary mechanic shear connectors.

The longitudinal shear stress:

$$\tau_f = 0.275\frac{\sqrt{n}}{d_c^2}T = 0.275\frac{\sqrt{13.8}}{305^2}36550 = 0.40\ \text{N/mm}^2 < \tau_{Rd} = 0.55\ \text{N/mm}^2$$

5. CONCLUSIONS

The method to design the longitudinal shear connection between the circular steel tube and the concrete core, which is presented in this paper, is very simple and easy for applying in the design activity.

The presented method is one originally method, based on the elasticity theory, so experimental tests are useful.

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