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# Concrete-filled steel tubular columns. Shear connection design

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Summary

*This paper presents an analytical evaluation method for the longitudinal shear stresses over the interface between the structural steel and the concrete filled steel tubular section.*

*A working example is also given in this paper, which can be useful in the design activity of such type of structures.*

KEYWORDS: composite columns, concrete filled tube, shear connection.

## 1. INTRODUCTION

Where composite columns of the type concrete filled rectangular hollow sections are subjected to significant transverse shear, provision shall be made for the transfer of the corresponding longitudinal shear stress at the interface between steel and concrete.

If the *natural bond* (adhesion, interface interlocking and friction) is not enough to achieve the required shear resistance, the mechanical connectors will be used.

Shear connectors should be provided, based on the distribution of the design value of longitudinal shear, where this exceeds the design shear strength $\tau_{Rd}$, given in Table 1.

Table 1

| CROSS-SECTION TYPE | $\tau_{Rd}$ (N/mm$^2$) |
|---|---|
| Concrete filled circular hollow section | 0.55 |
| Concrete filled rectangular hollow section | 0.40 |

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## 2. LONGITUDINAL SHEAR STRESSES

To determine the longitudinal shear at the interface between concrete and steel, the filled concrete, Figure 1, is transformed into an equivalent steel section, Figure 2.a, using the modular ratio n.

The equivalent in steel width of the concrete, Figure 2.a, will be::

$$t_e = \frac{b_c}{n} \tag{1}$$

where the modular ratio can be taken as:

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

$E_a$ - modulus of elasticity of structural steel;

$E_{cm}$ - secant modulus of elasticity of concrete.

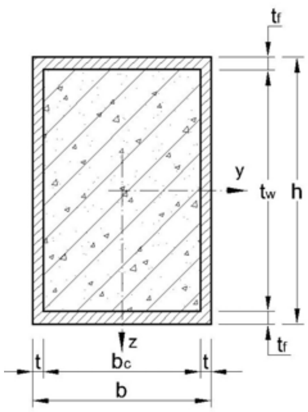


Figure 1

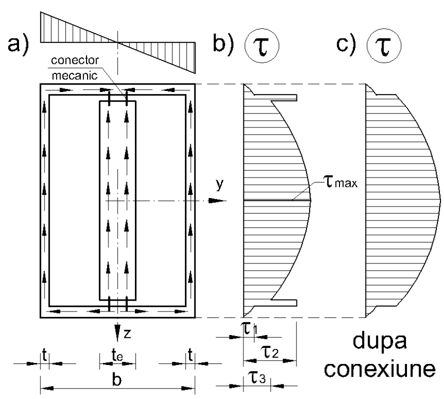


Figure 2

In the case of the columns of type concrete filled rectangular hollow steel section, in the absence of connection at the interface between steel and concrete, the shear stresses in accordance with Juravsky formula, Figure 2.b, will be:

$$\tau_1 = \frac{V_{Sd}S_a}{b \cdot I} \tag{3.a}$$

$$\tau_2 = \frac{V_{Sd}S_a}{2t \cdot I} \tag{3.b}$$

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$$\tau_3 = \frac{V_{Sd} S_a}{(2t + t_e) \cdot I} \tag{3.c}$$

$$\tau_{max} = \frac{V_{Sd}(S_a + \frac{1}{n} S_c)}{(2t + t_e) \cdot I} \tag{3.d}$$

where:

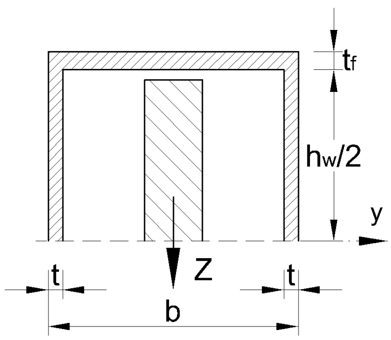


Figure 3

$S_a$ – section modulus of the steel component referred to neutral axis y-y:

- $$S_a = bt_f\left(\frac{h_w + t_w}{2}\right) + 2t\frac{h_w^2}{8} \tag{4}$$

$S_c$ - section modulus of the concrete referred to neutral axis y-y:

- $$S_c = b_c \frac{h_w^2}{8} \tag{5}$$

I - moment of inertia of the equivalent in steel of the entire cross-section:

$$I = I_a + \frac{1}{n} I_c \tag{6}$$

The longitudinal shear force between steel and concrete will be:

$$L = (\tau_2 - \tau_3) t_e = \Delta\tau \cdot t_e \tag{7}$$

By replacing the shear stresses values $\tau_2, \tau_3$ into eq. (7) it results:

$$L = \frac{V_{Sd} S_a}{I}\left(\frac{1}{2t} - \frac{1}{2t + t_e}\right) t_e = \frac{V_{Sd} S_a}{I} \frac{t_e^2}{2t(2t + t_e)} \quad [F/L] \tag{8}$$

The average shear stress at the interface between steel and concrete is:

$$\tau_F = \frac{L}{\sum b_i} \quad [F/L^2] \tag{9}$$

where: $\sum b_i = b_c + 2\frac{h_w}{2} = b_c + h_w$ is the half perimeter of the contact surface between steel and concrete.



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If: $\tau_f > \tau_{Rd}$, the natural bond is not enough to achieve the shear resistance and will be necessary to use mechanical shear connectors.

The number of the mechanical shear connectors for the entire length *l* of the column results from the condition:

$$N \geq L\frac{1}{P_{Rd}} = \frac{V_{Sd}S_a}{I}\frac{t_e^2}{2t(2t+t_e)}\frac{1}{P_{Rd}} \quad (10)$$

## 3. WORKING EXAMPLE

The connection for a composite column of type concrete filled rectangular hollow steel section is designed.

Design data (Figure 4)

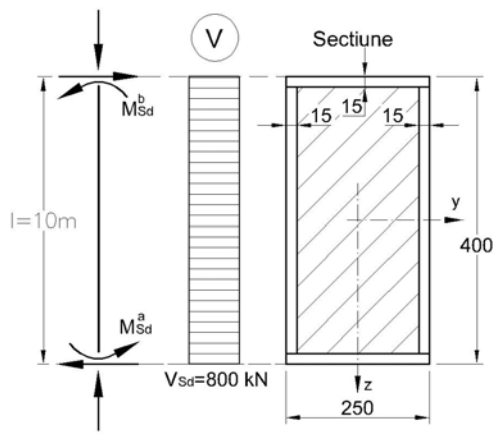


Figure 4

*Materials and characteristics:*

Box section - Steel: S 355

- $f_y$=355 N/mm$^2$

- $E_a$= 210 000 N/mm$^2$

$$I_a = \frac{25 \cdot 40^3}{12} - \frac{22 \cdot 37^3}{12} = 40470 \text{ cm}^4$$

Concrete - Class: C 25/30:

$f_{ck}$= 25 N/mm$^2$

$E_{cm}$= 30 500 N/mm$^2$

$$I_c = \frac{22 \cdot 37^3}{12} = 92864 \text{ cm}^4$$

Connectors: headed welded studs:

d = 19 mm;  h= 100 mm

$f_u$ = 450 N/mm$^2$

$\gamma_v = 1.25$

*Connection design*

The mechanical design model is presented in Figure 5.

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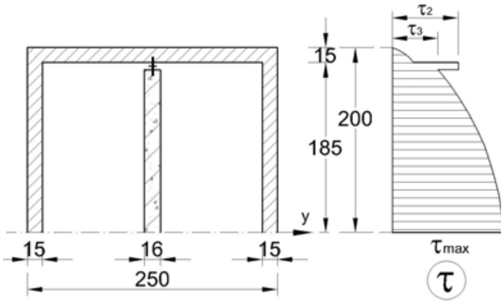


Figure 5

It results:

$S_a = 1235\ cm^2$

$$I = I_a + \frac{1}{n} I_c = 40470 + \frac{1}{13.8} 92864 = $$

$$= 47200\ cm^4$$

where:

$n = 2 \cdot n_i = 13.8$

$$n_i = \frac{E_a}{E_{cm}} = \frac{210000}{30500} = 6.88$$

The longitudinal shear force will be:

$$L = \frac{V_{Sd} S_a}{I} \frac{t_e^2}{2t(2t + t_e)} = \frac{80000 \cdot 1235}{47200} \frac{1.6^2}{2 \cdot 1.5(2 \cdot 1.5 + 22/13.8)} = 388\ daN/cm$$

where: $t_e = 22/13.8 = 1.6$ cm

The adhesion-friction stress over the interface between concrete and steel is:

$$\tau_f = \frac{L}{\sum b_i} = \frac{388}{59} 10^{-1} = 0.66\ N/mm^2 > \tau_{Rd} = 0.40\ N/mm^2,$$

so it results that are necessary mechanical connectors,

where: $\sum b_i = 2 \cdot 18.5 + 22 = 59\ cm$.

The design shear resistance of a headed stud automatically welded, in accordance with EC 4, is:

$$P_{Rd} = \min \begin{cases} \dfrac{0.8 f_u \pi d^2/4}{\gamma_v} = \dfrac{0.8 \cdot 450 \pi \cdot 19^2/4}{1.25} 10^{-3} = 81.65\ kN \\ \dfrac{0.29 \alpha d^2 \sqrt{f_{ck} \cdot E_{cm}}}{\gamma_v} = \dfrac{0.29 \alpha 19^2 \sqrt{25 \cdot 30500}}{1.25} = 73.13\ kN \end{cases}$$

The number of connectors will be:

$$N \geq \frac{388 \cdot 1000}{7313} = 53.$$

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For two rows of connectors the maximum distance between these will result:

$$e = \frac{10000}{1 + N/2} = 385 \text{ mm}.$$

The proposed arrangement of the headed stud connectors on the composite cross-section is presented in figure 6.

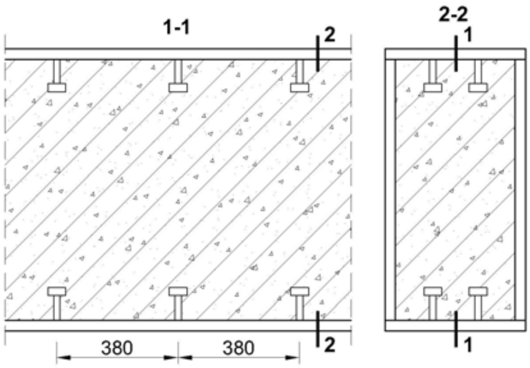


Figure 6

## 4. CONCLUSIONS

This paper presents an analytical method for the evaluation of the shear stresses over the interface between concrete and steel component for the composite columns of type concrete filled rectangular hollow steel section.

If the natural bond is not enough to achieve the required shear resistance, it is possible to use mechanical shear connectors, the widely used types being headed studs.

The numerical example which is also given in the paper can be useful for the design of composite steel-concrete columns.

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