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Local stability of the steel tubes with concrete core

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Abstract

The paper deals with the experimental analysis of the local stability of short axially compressed rectangular concrete-filled steel tubes (CFSTs), in which the load acted on the steel pipe. This analysis is one part of the research oriented to the local and global stability of rectangular concrete-filled steel tubes. This part presents the comparison of the coefficients of critical stress, which were obtained from experimental tests of investigated members with standard value in Eurocode 3. Some results and research findings of this analysis are published in the paper.

Key words: stability, coefficient of critical stress, local buckling

1 Introduction

The composite columns made of rectangular concrete-filled hollow sections are definitely regarded as very cost-effective as they enable very fast construction and offer all the advantages of both materials – concrete and steel. These elements have distinct advantages over hollow steel tubes as described in the research works [1-3]. However, one of the main structural advantages is its significant resistance to loss of local and global stability, which allows designers to reduce the steel cross-section of the element.

Standards, described in [4], already exist for the design of the above mentioned structures. The European Union uses Eurocode 4 to design rectangular (CFSTs) [5], but the basic disadvantage of this standard is its limitations regarding the slenderness of the wall of rectangular cross-section. The design of more efficient or economical composite structures is driving the research on class 4 hollow steel cross-sections [6] filled with concrete, which already lie beyond the validity of Eurocode 4.

2 Stability of rectangular walls

The subject matter of local buckling of slender compressed walls was intensively researched by Timoshenko [7], where he represented a differential equation for a slender wall with a length *a*, and width *b* (Fig. 1), which is simply supported around its perimeter:

$$C\left(\frac{\partial^4 w}{\partial x^4}+2\frac{\partial^4 w}{\partial x^2 \partial y^2}+\frac{\partial^4 w}{\partial y^4}\right)+P\frac{\partial^2 w}{\partial x^2}=0 \tag{1}$$

where *w* is deflection of slender walls; *P* is compression force; and *C* is cylindrical wall stiffness.

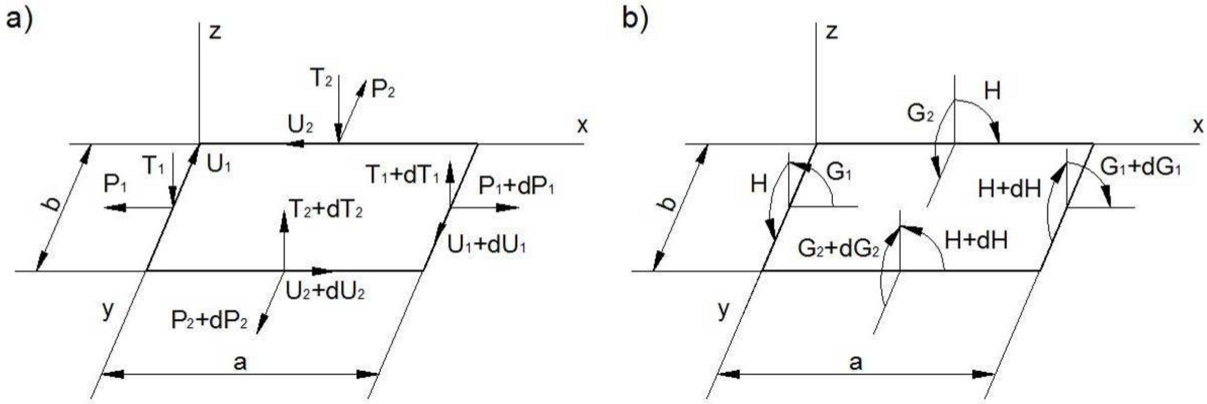


Figure 1: Mathematical model of slender wall: a) components force in a unit element of the wall; b) components of the bending moment in a unit element of the wall.

A particular solution of the differential equation:

$$w = A\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b} \tag{2}$$

The given solution satisfies the boundary conditions (Fig. 1a,b). Thus, the value of elastic critical stress of the wall:

$$\sigma_{cr}=k_\sigma\sigma_E=\left(m\frac{b}{a}+\frac{1}{m}\frac{a}{b}\right)^2\frac{\pi^2 E t^2}{12\left(1-\nu^2\right)b^2} \tag{3}$$

where k_σ is coefficient of critical stress; *E* is modulus of elasticity of the steel; *t* is the wall thickness; m is the half-waves of sinusoid; *ν* is Poisson ratio.

The basic principles of designing class 4 cross-sections were stipulated by prof. Bryan, which offers a critical analysis of the elastic stress σ_{cr} for local buckling of long right-angled wall elements. The term of this stress includes various boundary conditions with the aid of the coefficient of critical stress k_σ :

$$\sigma_{cr}=k_\sigma\frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 \tag{4}$$

The minimum values of the coefficient of critical stress k_σ are stipulated in EN 1993-1-5 [8]. This coefficient can be used for hollow rectangular tubes. When the tube is filled with concrete, the standard does not provide a k_σ value.

3 Experimental test

In this part of the research was tested one type of specimens (6 pcs) with tubes filled with concrete with cross-section RHS 200x100x3 [9, 10] (were identified as CFSTst-1, CFSTst-2, CFSTst-3) and with tubes filled with concrete with welded faceplates (were identified as CFSTstp-1, CFSTstp-2, CFSTstp-3). The investigated members have length 600 mm (Fig. 2). The stress of the walls of steel tubes specimens was measured using strain gauges placed in the middle of the broad sides along their width (Fig. 3, 4). Step of load was 20 kN to collapse of the samples. Before the test specimens were painted in white and on the wall of cross-section was drawn grid with a mesh size of 45 x 60 mm.

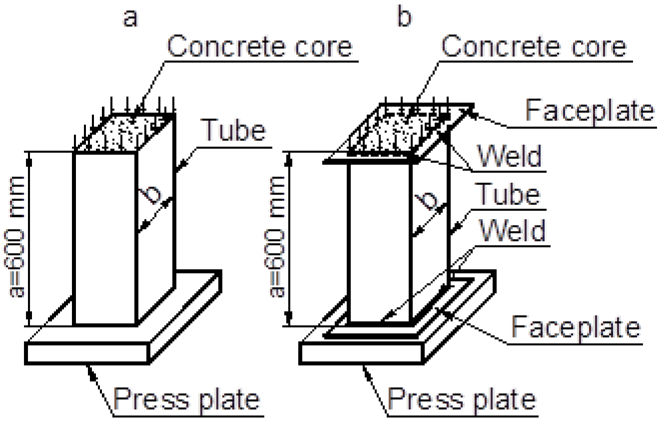


Figure 2: Scheme of loading steel-concrete specimens: a) on the steel tube; f) on the steel tube through the welded faceplates.

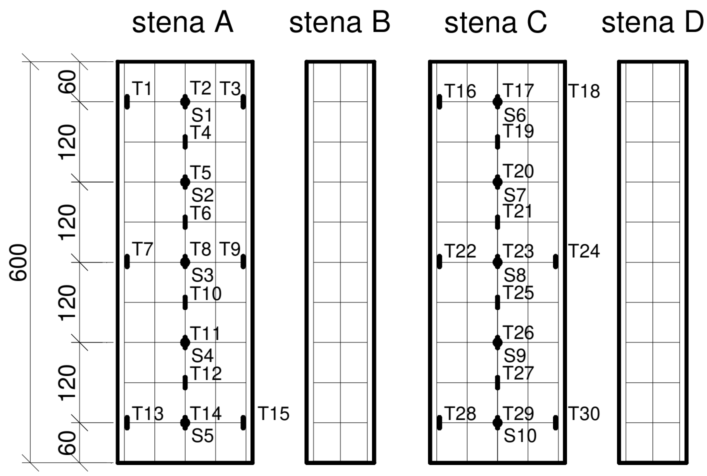


Figure 3: Scheme of the location of strain gauges and sensors on short samples

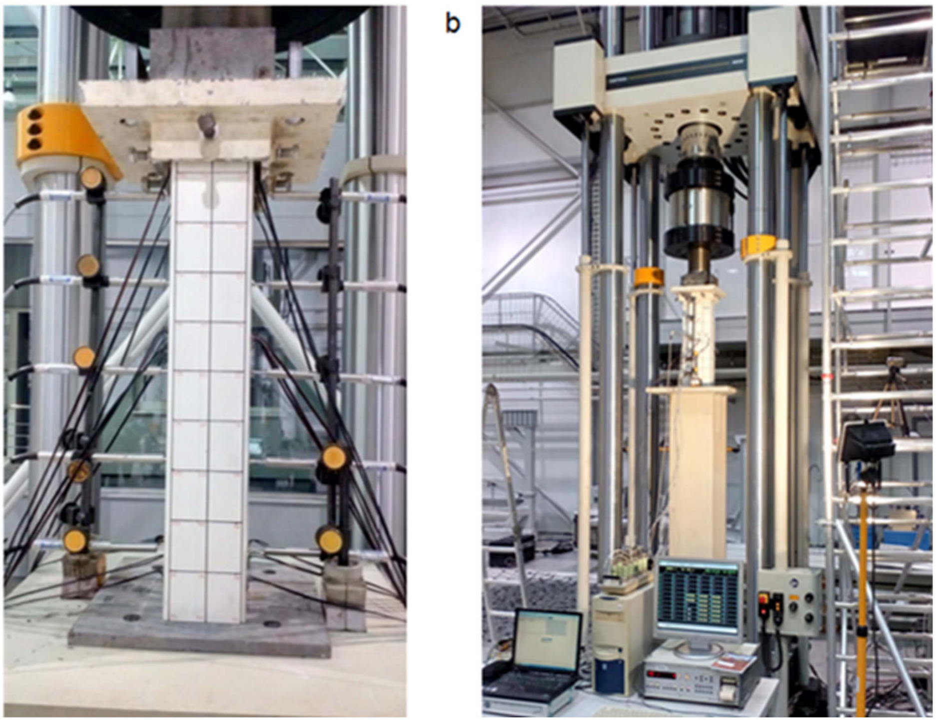
a b


Figure 4: Experimental test of researched members

For determine the material characteristics of steel, used in experimental elements were made the tensile test. All steel specimens (Fig. 5a) used in the tensile test were designed and tested according to standard ISO 6892-1 requirements [11]. The results of the tensile test are illustrated in Table 1.

Table 1: Results of the tensile test of the steel

F_m [kN]	R_E [MPa]	$R_{p0.2}$ [MPa]	R_m [MPa]	E [GPA]
23.71	241.86	374.89	425.56	198.31
Note: F_m – Maximum force; R_E – Limit of elasticity; $R_{p0.2}$ – Proof yield strength; R_m – Tensile strength; E – Modulus of elasticity				

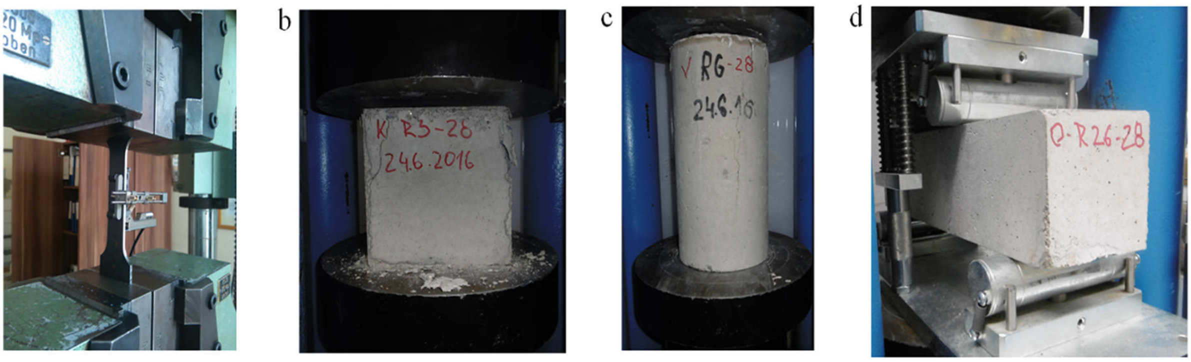
a b c d


Figure 5: a) tensile test of the steel; b) compression test of the concrete cube; c) compression test of the concrete cylinder; d) flexure test of the prism

Compressive strength (cylinder and cube), tensile strength (flexure test of the prism), modulus of elasticity are the basic material properties of concrete. All concrete specimens (Fig. 5b-d), used in material tests have been designed and tested in accordance with the requirements of EN 12390-1 [12]. The results of the tests are shown in Table 2.

Table 2: Results of the concrete test material

Day	Compressive strength		Tension bending strength	Modulus of elasticity
	f_{cm} [MPa]	$f_{cm,\,cube}$ [MPa]	$F_{ct,fl}$ [MPa]	E [GPa]
28	21.43	27.94	3.47	26.47

4 Results of the research

The minimum theoretical value for the coefficient of critical stress k_σ equals 4 for hollow sections. This value is given in EN 1993-1-5 [9] (see Fig. 6). Based on the results of the above mentioned experiments, the coefficient of critical stress was expressed by relationship (4). The minimum difference is 37.5% (specimen CFST st-3). The results are shown in Fig. 6.

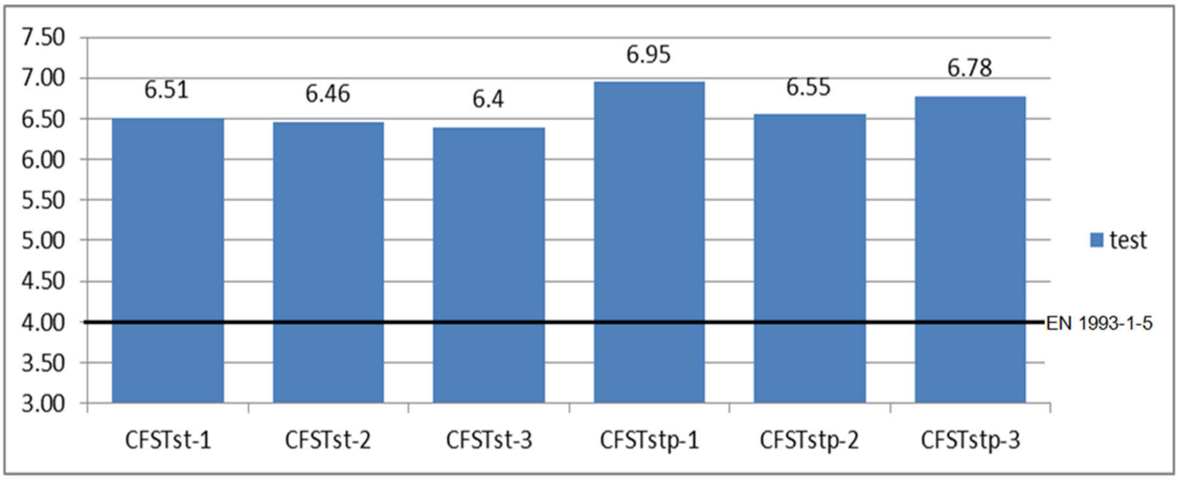


Figure 6: Comparison of the coefficient of critical stress for CFSTst(p) group specimens

5 Conclusion

The mentioned above paper focuses on the description of the research program currently carried out at the Institute of Structural Engineering of the Civil Engineering Faculty of the Technical University in Kosice. The program concerns the theoretical and experimental analysis of local and global stability of the composite columns in the form of rectangular concrete-filled steel tubes, for which cannot be used Eurocode 4 [5]. Upon the completion of all experiments, the members will be modelled using the numerical computational-graphics software ABAQUS whose results will be compared with the experimentally attained values. Based on such extensive findings, the recommendations for design these structures for the general public and professionals will be made.

Acknowledgements

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