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Experiments of Class 4 open section beams at elevated temperature

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ABSTRACT

At elevated temperature, behaviour of Class 1 to 3 open cross-section beams have been investigated experimentally and numerically, whereas for slender Class 4 sections only few experimental data have been collected. Due to the economic assumptions of members with Class 4 cross section and general validity of the existing design rules, further investigation is desired. This paper presents tests and numerical simulation of welded slender (Class 4) I-section beams at elevated temperature. The design of the test set-up, as well as progress of the experiments is presented. Detailed information about the geometrical data, measured geometrical imperfections, temperature, load and actual mechanical properties were collected. The tests were subsequently used for a FE model validation. The described research allows better understanding to the fire behaviour of steel members of Class 4 cross-section beams.

1. Introduction

The area of research in slender cross-sections in case of fire is very important as only little investigation was made and structural fire design became an inseparable part of structural design. The correctness of the design is essential regarding safety of the structure as well as its economy, concerning also possible additional fire protection costs. Therefore, well representing design models, which simulate the actual behaviour of the structures exposed to fire, are crucial as a base of such design formulas.

Steel members with thin-walled cross-sections are commonly used in buildings due to its lightness and long span capacity. The design principles of Class 4 sections are very specific and usually more difficult than for stocky sections. Despite the current EC3 contains a number of simple rules for design of Class 4 cross-sections at elevated temperature, based on recent numerical simulations they were found to be not accurate [1]. Through refining these rules, a significant material savings could be achieved which would lead to higher competitiveness of the steel structures. However, the lack of numerical and experimental data have been collected until now, which may serve as a base to such changes.

The structural steel members of slender cross-sections (Class 4 section according to EC3 1.1 [2]) subjected to bending are characterized by having the possibility of failure by both local and global buckling modes. The local buckling mode occurs due to the compression of thin plates in the section (see Fig. 1a). Therefore, the section resistance is significantly affected by deformations of the area in compression. The lateral torsional buckling (global buckling mode for members in bending) is an instability induced by the compressed flange of unrestrained open section beams subjected to bending around the major axis as shown in Fig. 1b. The actual bending resistance is reduced by this effect compared to simple bending (section) resistance.

The effect of local buckling may be considered in the structural design by using the effective areas of plate elements in compression for Class 4 sections by effective sectional properties (effective cross section method) or using stress limits for plates (reduced stress method). The reduction factor ρ depending on the plate slenderness $\overline{\lambda}_p$ is used in both of these two methods. In the first method, the effective cross-section method, the reduction factor reduces cross-section area A_c (resp. the section modulus). The effective area of the compression zone $A_{c,eff}$ should be obtained from (1) as a result of effective (reduced) widths of the plates:

$$A_{c,eff} = \rho A_c \tag{1}$$

In the second method, the reduced stress method, the reduction factor reduces the maximum allowed stress, where the components of the stress field ($\sigma_{x,Ed}$, $\sigma_{z,Ed}$, τ_{Ed}) in the ultimate limit state are considered as acting together. This method does not take into account the second-order effect in the possible shift of the neutral axis position. The advantage of this method is the possibility to use gross cross section properties for calculation, resulting in lower computational cost as it isn't necessary to

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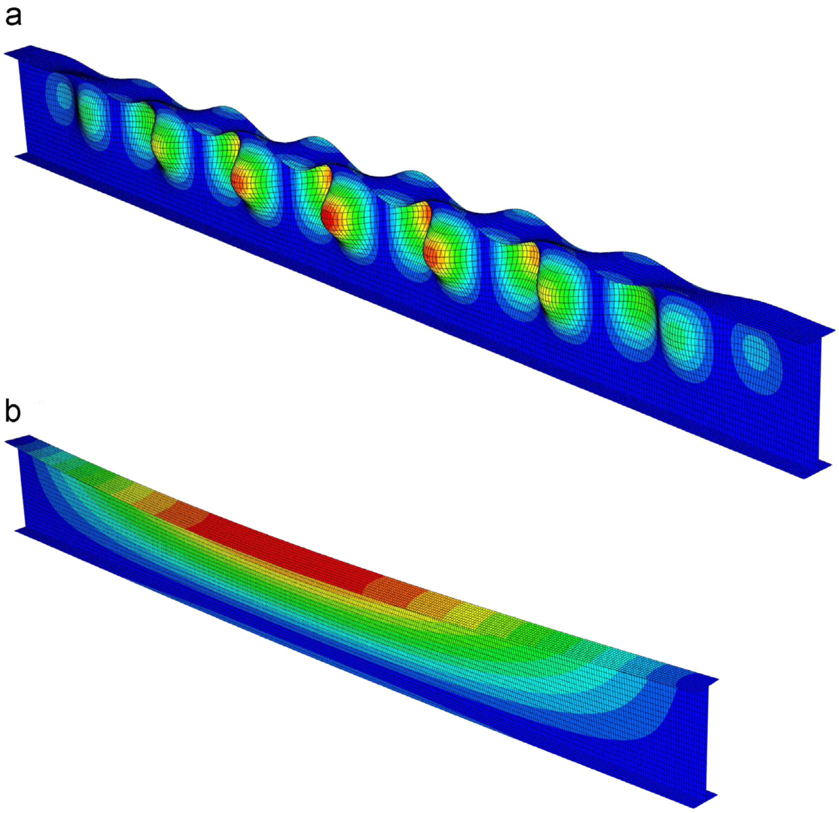

Fig. 1. Buckling mode shapes: (a) local buckling (left); (b) lateral-torsional buckling (right).

determine effective section properties. One (general) possibility of the verification formula is given by (2), others are given by EC3 1.5 [3]:

$$\left(\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\right)^2+\left(\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}}\right)^2-\left(\frac{\sigma_{x,Ed}}{\rho_x f_y/\gamma_{M1}}\right)\left(\frac{\sigma_{z,Ed}}{\rho_z f_y/\gamma_{M1}}\right)+3\left(\frac{\tau_{Ed}}{\chi_w f_y/\gamma_{M1}}\right)^2\le\rho^2 \tag{2}$$

As described above, the reduction factor depends on the plate slenderness. According to EC3 1.5 [3], the plate slenderness $\overline{\lambda}_p$ is given by Eq. (3).

$$\overline{\lambda}_p=\sqrt{\frac{f_y}{\sigma_{cr}}}=\sqrt{\frac{f_y}{\frac{k_\sigma\ \pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2}}=\frac{b/t}{0.95\sqrt{\frac{\boldsymbol{E}}{\boldsymbol{f_y}}}\ \sqrt{k_\sigma}}=\frac{b}{28.4\,t\,\varepsilon\,\sqrt{k_\sigma}} \tag{3}$$

where σ_{cr} is the elastic critical plate buckling stress, k_σ is the buckling factor, t is the thickness of the plate, b is the appropriate width, ε is a factor depending on f_y and E (f_y and E to be expressed in N/mm^2)

$$\varepsilon=\sqrt{\frac{235}{f_y}} \tag{4}$$

Both highlight values in Eq. (3) depends on temperature. It brings additional term, which reflects degradation of material properties, see Eq. (5):

$$\sqrt{\frac{k_{E,\theta}}{k_{y,\theta}}}\sqrt{\frac{E}{f_y}} \tag{5}$$

The cross-section classification is therefore different at fire situation than at normal temperature. According to EC3 1.2 [4], for the purpose of these simplified rules, the cross-sections may be classified as for normal temperature design with a reduced value

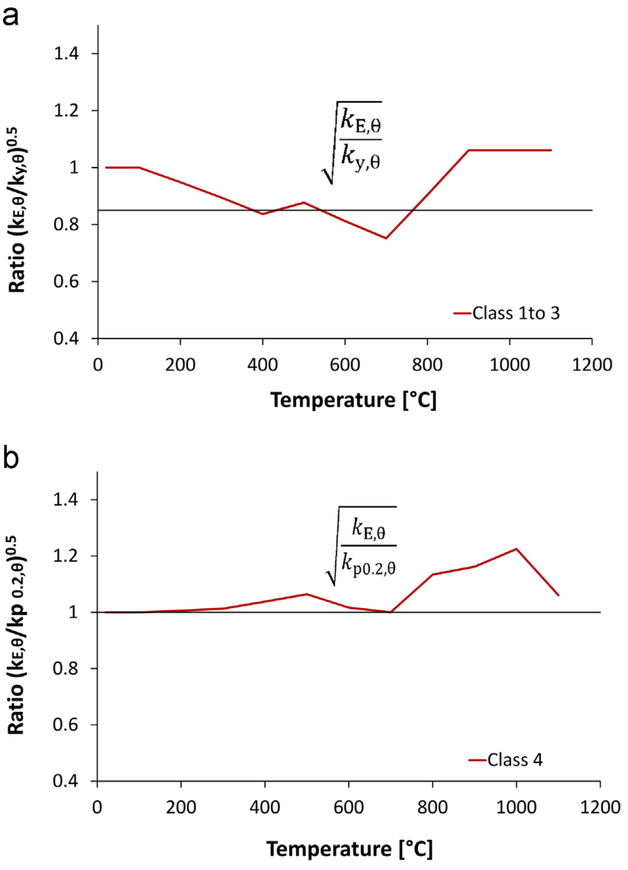

Fig. 2. Ratio of material properties reduction as a function of temperature.