Journal of Constructional Steel Research 109 (2015) 101–114

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Resistance of steel cross-sections with local buckling at elevated temperatures

Carlos Couto [a], Paulo Vila Real [a,*], Nuno Lopes [a], Bin Zhao [b]

[a] RISCO, Civil Engineering Department, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[b] CTICM — Centre Technique Industriel de la Construction Métallique, Parc Technologique L'Orme des Merisiers, Immeuble Apollo, 91193 Saint Aubin, Paris, France

ARTICLE INFO

Article history:
Received 31 July 2014
Accepted 6 March 2015
Available online 22 March 2015

Keywords:
Local buckling
Fire
Steel
Cross-section
Thin-walled
Eurocodes

ABSTRACT

In this work, the resistance of slender I-shaped cross-sections, where local buckling has a predominant role in the ultimate capacity, is investigated at elevated temperatures. A numerical study considering several cross-sections submitted to compression or bending about the major-axis is performed using a finite element analysis software. The results are compared with the existing formulae available in Part 1.2 of Eurocode 3 showing that they need to be improved. For Class 3 cross-sections, it is observed that the existing rules lead to unsafe results because local buckling occurs at elevated temperatures prior to the development of the elastic bending resistance or the gross cross-section compression resistance. For Class 4 cross-sections, the results show that these rules are not adequate because it is recommended for the design yield strength of steel the use of the 0.2% proof strength even if the cross-section has plates not prone to local buckling. A new methodology to account for the local buckling in steel I-sections at elevated temperatures is presented based on the expressions previously developed by the authors to calculate the effective width of thin plates at elevated temperatures. According to this new methodology, an effective cross-section is calculated for Class 3 and Class 4 cross-sections and the yield strength at 2% total strain is used for Class 4 cross-sections as recommended by Eurocode 3 for the other section classes. Finally, it is demonstrated that this methodology leads to good results when compared against numerical and experimental results.

1. Introduction

Slender cross-sections when submitted to compression stresses are prone to local buckling that prevents the attainment of the yield stress in the compressed parts of the cross-section thus affecting their ultimate capacity. At normal temperature, according to Eurocode 3 [1] these cross-sections are classified as Class 4 – the highest class – and Part 1.5 [2] provides two methods to take local buckling into account, namely the effective width method, that leads to a reduced cross-section, and the reduced stress method.

At elevated temperatures, Part 1.2 of Eurocode 3 [3] suggests for Class 4 cross-sections a default critical temperature of 350 °C if no fire design is made, which means that even for a requirement of 15 min of fire resistance, passive fire protection should normally be used for current profiles. Alternatively, the informative Annex E of Part 1.2 of Eurocode 3 suggests the use of a reduced cross-section calculated with the effective width method using the steel properties at normal temperature and for the design yield strength of steel the 0.2% proof strength ($f_{0.2p,\theta}$, see Fig. 1).

Previous investigations of Fontana and Knobloch [5], Renaud and Zhao [6] and Quiel and Garlock [7] demonstrated that this methodology is too conservative. Hence, the need of more realistic formulae to account for the local buckling at elevated temperatures. Studies have been done previously within the scope of one research project [8], for welded or hot-rolled Class 4 steel members. However, these type of studies are limited and cover only, for example, the buckling of Class 4 steel columns [5,9–11] or are related to other types of steel, for example stainless steels [12], for which the constitutive laws differ from carbon steel. In Fig. 2, an example of column showing local buckling from a test performed at elevated temperatures at the University of Liège is shown.

In this work, a parametric investigation based on the finite element analysis using the software SAFIR [14] is made to assess the resistance of several slender cross-sections in bending and compression. In line with previous investigations by other authors, the obtained results show that the existing formulae of Part 1.2 of Eurocode 3 could be improved. For Class 3 cross-sections, it is observed that the existing rules lead to unsafe results because local buckling occurs at elevated temperatures prior to the development of the elastic bending resistance or the gross cross-section compression resistance. For Class 4 cross-sections, the results obtained show that the use of the 0.2% proof strength as the design yield strength for the whole cross-section is

---

[*] Corresponding author. Tel.: +351 234370049; fax: +351 234370094.
E-mail address: pvreal@ua.pt (P. Vila Real).

http://dx.doi.org/10.1016/j.jcsr.2015.03.005
0143-974X/

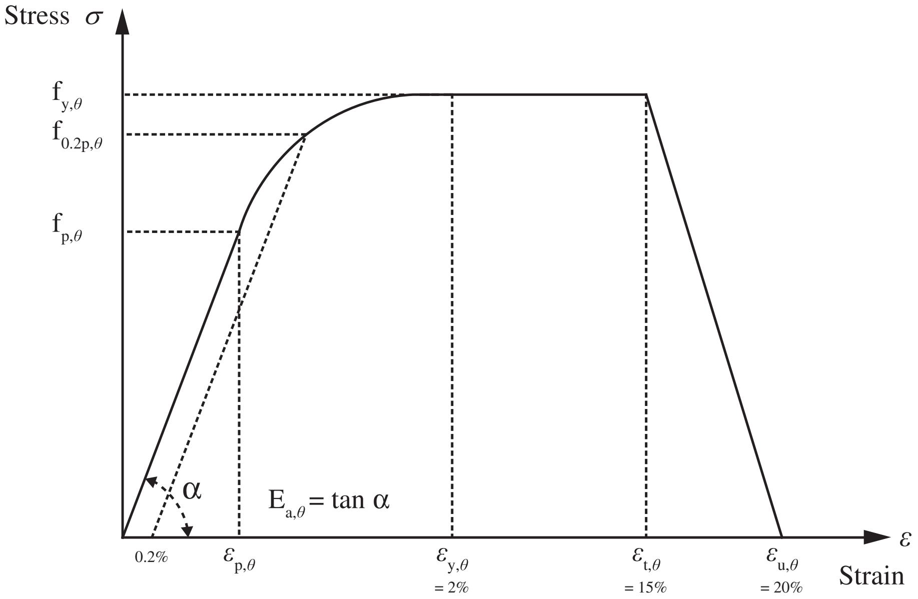

Fig. 1. Stress–strain relationship for carbon steel at elevated temperatures [4].

very conservative, especially if they contain also plates with inferior classes, i.e. without local buckling.

To overcome these inconsistencies and limitations, a new methodology to calculate the cross-sectional resistance of slender cross-sections at elevated temperatures is presented in this work. Accordingly, an effective cross-section is calculated for Class 3 and Class 4 cross-sections based on the expressions previously developed by the authors to calculate the effective width of thin plates at elevated temperatures [15] and the yield strength at 2% total strain is used for Class 4 as recommended in Eurocode 3 for the other section classes. A comparison of the predicted cross-sectional capacity using the proposed methodology against numerical and experimental results shows the considerable advantages as well as the validity and accuracy of this proposal.

Fig. 2. Example of column showing local buckling from a test performed at elevated temperatures at the University of Liège (taken from [13]).

2. Design provisions to take local buckling into account in the cross-sectional resistance according to Eurocode 3

I-shaped cross-sections can be considered as an assembly of plates often referred as internal (webs) and outstand (flanges) elements. If the width-to-thickness ratios of these plates are high, they are normally referred to as thin and may buckle when submitted to compression, preventing the attainment of the yield strength in one or more parts of the cross-section, thus reducing the resistance of the cross-section and consequently the load bearing capacity of the structural members. To account for this phenomenon, the cross-section is classified as a function of the width-to-thickness ratio of its plates and this issue is addressed in Subsection 2.1. In order to consider local buckling in the design, a reduced cross-section can be used, this method being referred in the literature as the effective width method. The rules to calculate effective width of plates are indicated in Part 1.5 [2] and are described in Subsection 2.2. The code provisions to take local buckling into account at elevated temperatures are presented in Subsection 2.3. In Section 3, the expressions previously developed by the authors to calculate the effective width of thin plates at elevated temperatures, which are used later in this study, are presented.

2.1. Cross-section classification

In Eurocode 3, four classes (Classes 1 to 4) of cross-sections are defined in respect to how the local buckling affects the load bearing capacity of the members, with a higher class denoting a higher influence of the local buckling on resistance. According to the definition of Eurocode 3, Class 1 cross-sections are those that can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance. Class 2 cross-sections are those that can develop their plastic moment resistance, but have limited rotation capacity because of local buckling. Class 3 cross-sections are those in which the stress in the extreme compression fibre of the steel member assuming an elastic distribution of stresses can reach the yield strength, but local buckling is liable to prevent development of the plastic moment resistance. Finally, Class 4 cross-sections are those in which local buckling will occur before the attainment of yield strength in one