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Safety Assessment of Different Stability Design Rules for Beam-columns

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ABSTRACT

In EC3-EN 1993-1-1, there are three different methods to check the global stability resistance of steel columns, beams, and beam-columns. The design formulas are based on buckling curves, which are available for purely compressed or purely bended members with uniform cross-sections. Beam-columns are subjected to compressive force and the bending moment can be designed using the so-called interaction formula where the interaction factors may be alternatively determined. Over the past few years, many research groups have worked on correcting and improving the accuracy of the available design methods for steel members. The aim of this paper is to compare the accuracy of the different revised methods for steel beam-columns. In order to investigate the accuracy of the above-mentioned design methods, numerous geometrically and materially nonlinear analyses with imperfections (also known as GMNIA) were executed by previous research projects. The results of the semi-probabilistic safety assessments may help the designer choose the most reasonable method for their design works.

1. Introduction

Stability problems of relatively thin-walled steel members are inevitable, so their design should be properly taken into consideration. Initial out of straightness and residual stress arose in the steel members during production and these imperfections influence the buckling resistance of the loaded members. In design practice, based on EN 1993-1-1, two approaches are applied to calculate this reduced strength: (i) is the reduction factor method and (ii) is the Overall Imperfection Method. The reduction factor method has a strong theoretical background for the case of column buckling but intense revision was needed for lateral-torsional buckling. The theoretical background of the revision is well summarized in [6] and was carried out by Taras and Greiner [5].

To check the stability resistance of beam-columns the 'interaction method' can be used (EN 1993-1-1: paragraph 6.3.3). This method uses the previously-mentioned reduction factors. The revision of the interaction method was carried out by Taras and Unterweger in [10]. In this study the accuracy of the revised interaction formula is examined.

The 'general method' is an alternative formula to evaluate the load carrying capacity of beam-columns, especially when the previous interaction method cannot be used (EN 1993-1-1: paragraph 6.3.4). The formula is based on the overall slenderness of the examined member. Using this slenderness the reduction factors for the column and for the beam can be calculated. The 'general method' introduces the out-of-plane reduction factor which may be determined by two alternative approaches. The conservative concept takes the minimum of the two pure case factors, while the progressive approach interpolates it among the pure cases (EN 1993-1-1: paragraph 6.3.4 (4)). The progressive approach is the subject of debate in the research community. Moreover, some national application documents prohibit using it. However, Szalai in his new study has shown that the progressive formula has a strong theoretical background [20]. Therefore, in this study we use the progressive formula of the 'general method'. Furthermore, to ensure the consistency of the method, the LTB reduction factor is calculated using the new formula published by Taras and Greiner [4].

The 'Overall Imperfection Method' is another alternative method to check the stability resistance of members (EN 1993-1-1: paragraph 5.3.2 in [1]). The most general approach of this concept uses equivalent unique local and global imperfection in the shape of the relevant elastic buckling mode of the examined member. The principles and applications of this method were presented by Chladný and Stujberová [2]. Later, more researchers have indicated that this method may be used for lateral-torsional buckling and additionally for buckling problems of beam-columns [3,19,20]. In this study, the method proposed by Papp is followed [3].

In order to investigate the accuracy of the above-mentioned design methods, a large number of geometrically and materially nonlinear analyses with imperfections (also known as GMNIA) were executed by [7]. The (semi-) probabilistic safety level assessment of the different design methods was performed according to [4] where the difference between the theoretical and experimental resistance is being used to

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measure the accuracy. The following denominations will be used in this paper for the different methods, as referred to in the Eurocode 3:

- ○ EN 1993-1-1 6.3.3 Uniform members in bending and axial compression – Interaction Method
- ○ EN 1993-1-1 6.3.4 General method for lateral and lateral-torsional buckling of structural components – General Method
- ○ EN 1993-1-1 5.3.2 (11) – Overall Imperfection Method

2. Background of the study

2.1. Numerical database

The examination of the accuracy of different methods is based on advanced numerical simulations. The source of numerical results is a parametric study performed at the University of Coimbra in the scope of a Master thesis by [7]. For initial validation of the parametric study of [7], results by Ofner [15] were used. The advanced analysis allows the second order effect to be taken into consideration which are essential for stability problems for beam-columns. All the loaded members were modeled using an initial imperfection in the shape of the first global buckling mode with an amplitude of L/1000, where L is the length of the loaded beam. Residual stresses were considered according to Fig. 1. The steel grade is S235 in all cases. The material nonlinearity is defined in the model by using elastic-plastic constitutive law, according to Fig. 2.

In this work, only class 1 and class 2 cross-sections were tested. The examined hot-rolled sections can be found in Table 1. Each member is modeled with four-node linear shell elements (S4) with the finite element software Abaqus. The slenderness of the examined members are in Table 2. More detailed information about the advanced analysis is in [4] and in [7].

2.2. The examined design methods

2.2.1. Revised interaction method

The basic assumptions and main rules of this well-known method are in EC3-1-1 Section 6.3.3. This method combines the ultimate strengths of the member (for flexular buckling and for lateral-torsional buckling) with interaction formulas. The values of the interaction factors k_{ij} could be defined by two methods (Annex A - Method 1, Annex B - Method 2) in [1]. The derivation of the interaction factors and the mechanical background of Method 2 can be found in [14]. The improvement and the extension for mono-symmetric I-section of the interaction factors in Method 2 were presented in [10] and its behaviour

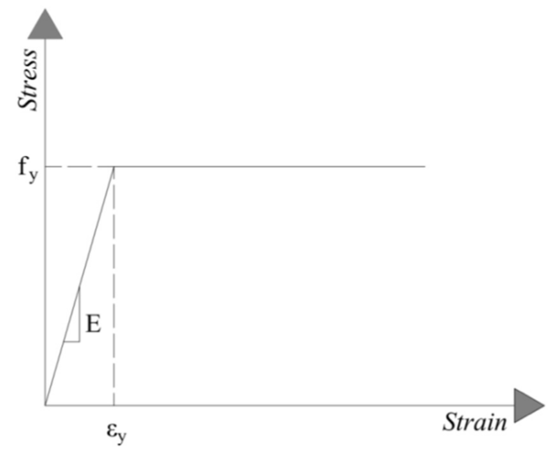

Fig. 2. Constitutive law.

Table 1
The examined sections.

Section	h	b	t_w	t_f	f_y	h/b
IPE360	360	170	8	12.7	235	2.12
IPE180	180	91	5.3	8	235	1.98
IPE160	160	82	5	7.4	235	1.95
IPE100	100	55	4.1	5.7	235	1.82
HE650x343	680	309	25	46	215	2.20
HE650B	650	300	16	31	225	2.17
HE600x337	632	310	25.5	46	215	2.04
HE500B	500	300	14.5	28	225	1.67
HE400A	390	300	11	19	225	1.30
HE340B	340	300	12	21.5	225	1.13
HE300C	320	305	16	29	225	1.05
HE300B	300	300	11	19	225	1.00
HE300A	290	300	8.5	14	235	0.97
HD400x347	407	404	27.2	43.7	215	1.01

Table 2
Slenderness of the examined sections.

Limits	Number of sections		Slenderness	Steel
h/b > 1.2	$t_f \le 40$ mm	7	0.4; 0.6; 0.8; 1.0; 1.2; 1.4; 1.6; 1.8	S235
	$40 < t_f \le 100$	2	0.4; 0.6; 0.8; 1.0; 1.2; 1.4; 1.6; 1.8	S235
h/b ≤ 1.2	$t_f \le 40$ mm	4	0.4; 0.6; 0.8; 1.0; 1.2; 1.4; 1.6; 1.8	S235
	$40 < t_f \le 100$	1	0.4; 0.6; 0.8; 1.0; 1.2; 1.4; 1.6; 1.8	S235

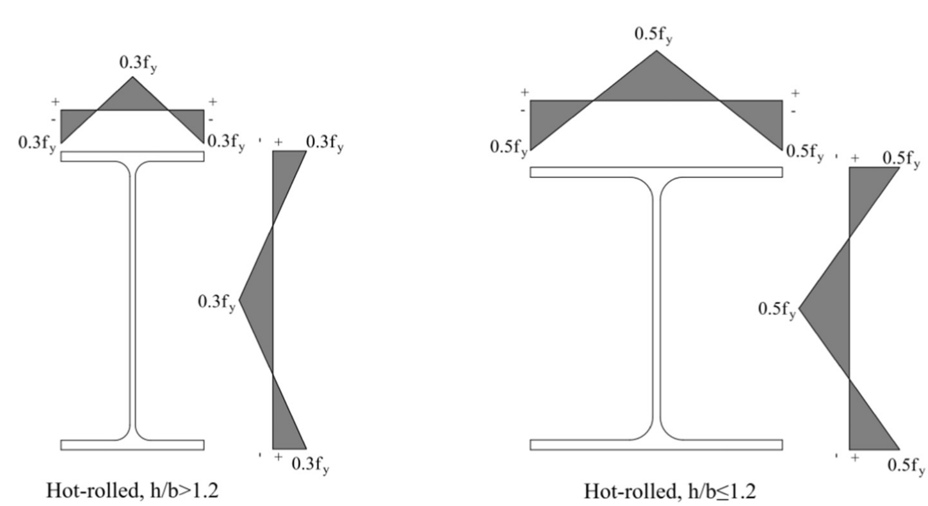

Fig. 1. Residual stresses, fy = 235 MPa ("+" tension, "−" compression).