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SHS AND RHS STAINLESS STEEL SLENDER BEAM-COLUMNS

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Abstract: *Presented research shows behavior of square hollow section (SHS) and rectangular hollow section (RHS) stainless steel slender members loaded by axial compressive force and bending moment. Numerical parametric study in software Abaqus was conducted. Numerical model validation was made based on the 4 conducted experiments. Results provided by study were compared to the existing design procedures and served as a background for the new interaction factor formulae development. The investigated parameters are mainly the column slenderness, cross-section slenderness, material properties and ratio between the applied axial compressive force and buckling resistance. The new developed design approach is presented in this paper and compared with numerical parametric study results. The comparison shows that the new procedure provides accurate and safe results for all investigated parameters.*

Keywords: stainless steel, slender member, beam-column, interaction factor

1. Stainless steel beam-columns behavior

This paper is focused only on the SHS slender members subjected to flexural buckling and major axis bending. So, the minor axis deflection is prevented. Current codified design procedure provided by EN 1993-1-4 (2006) and other approaches developed by several researchers are summarized and evaluated in Jandera et al. (2017). Generally, the results show some deviation. Recently, another approach was developed by Zhao (2015). The evaluation of Zhao's (2015) approach conducted by Židlický and Jandera (2017) showed that the procedure is generally representing the real behaviour well, however in some cases may be inaccurate.

Therefore, a comprehensive numerical parametric study was made. Based on the study results, new interaction factor formulae were developed and evaluated. Information of numerical parametric study are shown below, as well as the new formulae and their evaluation.

2. Numerical model

The numerical 3D model was created in FE (Finite Element) software Abaqus using four-node shell element with reduced integration, S4R. GMNIA method (geometrically and materially non-linear analysis with imperfections) was used for calculations. Boundary conditions and load application were introduced through the reference points in the member centroid on its both ends. Reference points were rigidly coupled with the member edges. Both global and local imperfections were introduced through appropriate eigenmodes. Amplitude of global imperfection was considered as $L/1000$ and local imperfection amplitude was calculated according to Dawson (1972) formula.

Numerical model was successfully validated based on the experimental data. Four experiments were conducted, namely, SHS 80 × 3 and 80 × 5 – two members of each. Material behaviour was obtained from tensile tests conducted both for flat and corner coupons. Experiment procedure and successful

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validation are described in detail in Židlický and Jandera (2017) and will be also presented in the conference.

3. Numerical parametric study

Investigation of SHS members only is presented in this paper. Cross-sections of 80 mm width and thicknesses from 1.5 to 10 mm were considered in order to cover all cross-section classes (depending on section slenderness). The member lengths were calculated based on the investigated non-dimensional slenderness, $\bar{\lambda}$, values (Table 1). Three main stainless steel groups provided by EN 1993-1-4 (2006) were considered in the numerical study: austenitic; ferritic and duplex. One grade with two different values of strain hardening factors n of each stainless steel group was investigated. This material selection covered materials with low yield strength f_y and ultimate strength f_u (ferritic), low f_y and high f_u (duplex) and material with the greatest ratio of f_u to f_y (austenitic). Young modulus E_0 was considered according to EN 1993-1-4 (2006) for all materials. Material properties are summarized in Table 2.

Tab. 1: Non-dimensional slenderness values.

$\bar{\lambda}$	0.2	0.3	1.0	1.5	2	3

Tab. 2: Material properties.

Grade	E_0 [MPa]	f_y [MPa]	f_u [MPa]	n
Ferritic	200 000	210	380	4.5
Ferritic	200 000	210	380	14
Austenitic	200 000	220	520	4.5
Austenitic	200 000	220	520	14
Duplex	200 000	480	660	4.5
Duplex	200 000	480	660	14

Each investigated member was loaded by combination of axial compressive force and uniform bending moment. For preliminary prediction of the applied bending moment in the numerical model, recently published procedure developed by Zhao (2015) was used. The study covers various values of the ratio between the axial compressive force N_{Ed} and member resistance in compression $N_{b,Rd}$. The ratio is expressed by symbol $n_b = N_{Ed}/N_{b,Rd}$ and the considered values are shown in Table 3. Both $N_{b,Rd}$ and bending moment resistance $M_{b,Rd}$ were obtained from numerical GMNIA model.

Tab. 3: Considered n_b values.

n_b	0	0.05	0.3	0.5	0.7	0.8	1

4. New Procedure

Based on the numerical parametric study a new design procedure for SHS stainless steel beam-columns was developed. For the new approach, the same interaction formula as provided by the code EN 1993-1-4 (2006) for stainless steel was considered, see Equation (1). However, different interaction factor formulae were developed. They are given by Equations (2) and (3).

Evaluation of the new procedure is provided below. Results of the whole interaction formula given by EN 1993-1-4 (2006) with consideration of the new interaction factor calculation are shown in Figure 1 and Figure 2. The figures provide results with dependency on the non-dimensional slenderness $\bar{\lambda}$ and n_b ratio, respectively (the non-dimensional slenderness values presented in Figure 1 are established from the GMNIA results, therefore, they could vary slightly from those in Table 1). Values greater than one indicate safe results. Statistical assessment of the new approach is provided by Table 4 where the average value, standard deviation and coefficient of variation are presented.

$$\frac{N_{\mathrm{Ed}}}{N_{b,Rd}} + k_y \frac{M_{\mathrm{Ed}}}{M_{\mathrm{b,Rd}}} \leq 1 \tag{1}$$

$$k_{\mathrm{y}} = 1 + \left(1.2\bar{\lambda}_{\mathrm{y}} - 0.4\right) n_{\mathrm{b}}^{\frac{\beta_y (f_y - 70)}{f_y}} \quad \text{for } \bar{\lambda}_{\mathrm{y}} \leq 1.5 \tag{2}$$

$$k_{\mathrm{y}} = 1 + \left(0.2\bar{\lambda}_{\mathrm{y}} - 1.5\right) n_{\mathrm{b}}^{\frac{2\beta_y^2 (f_y - 70)}{f_y}} \quad \text{for } \bar{\lambda}_{\mathrm{y}} > 1.5 \tag{3}$$

where N_{Ed} is the design compressive force,
M_{Ed} is the design bending moment,
$N_{\mathrm{b,Rd}}$ is the flexural buckling resistance,
$M_{\mathrm{b,Rd}}$ is the bending resistance,
k_{y} is the interaction factor,
$\bar{\lambda}_{\mathrm{y}}$ is the non-dimensional slenderness,
n_{b} is the N_{Ed} to $N_{\mathrm{b,Rd}}$ ratio,
β_{y} is the $W_{\mathrm{el,y}}$ to $W_{\mathrm{pl,y}}$ ratio ($W_{\mathrm{el,y}}$ and $W_{\mathrm{pl,y}}$ is the elastic and plastic section modulus, respectively),
f_{y} is the yield strength.

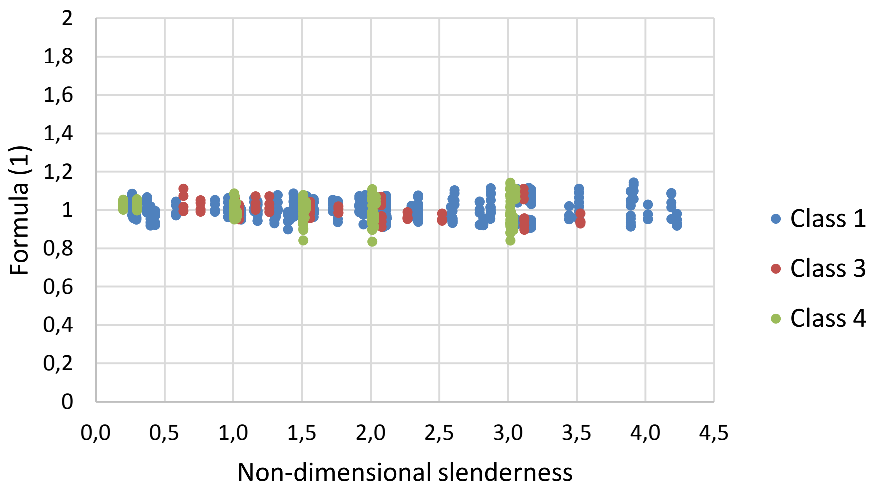

Fig. 1: Evaluation of the new approach - $\bar{\lambda}$*.*

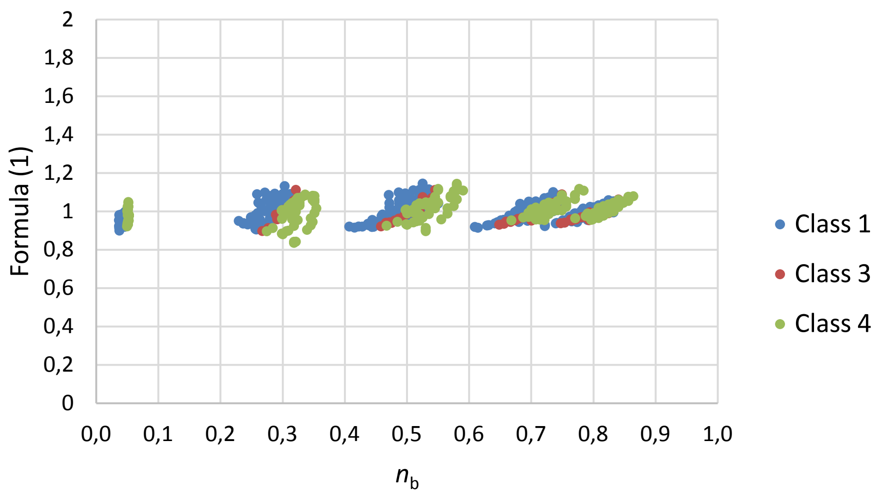

Fig. 2: Evaluation of the new approach - n_{b}*.*

Tab. 4: Statistical evaluation.

Average	1.002
Standard deviation	0.049
Coefficient of variation	0.049

Generally, the new procedure provides safe and consistent results. The low scatter and great accuracy of the new procedure results could be seen in Figures 1 and 2. Furthermore, it is confirmed by the statistical results given by Table 4. Both Figure 1 and 2 shows that the new procedure providing safe results with no dependency on the non-dimensional slenderness, cross-section slenderness (cross section class), material properties and n_b ratio. Figure 1 shows results of all considered non-dimensional slenderness values, although the results with values higher than 2 are not so common in real structures.

5. Conclusions

This paper is focused on the behavior of SHS stainless steel slender members loaded by both compression and major bending moment. Although, many design approaches for stainless steel beam-columns exists, none of them is accurate enough for all the variables. Therefore, a new procedure was developed and presented in this paper.

For the evaluation a 3D shell element model using GMNIA was created in software Abaqus in order to obtain realistic behavior of the members. The numerical model was successfully validated based on the data obtained from the conducted experiments. Subsequently, a comprehensive numerical parametric study was made.

Evaluation of the new procedure has showed that the results are accurate, safe and with small scatter for all the investigated variables. Therefore, the new approach is very suitable for the design of SHS stainless steel beam-columns.

Further investigation of the developed procedure, especially its suitability for RHS stainless steel beam-columns, is underway.

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