A New Design Method for Stainless Steel Column Subjected to Flexural Buckling

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Abstract

This paper develops a new design method for stainless steel column failure in flexural buckling. Finite element analysis is conducted to establish the strength curve database. These curves are separated into two groups using Cluster Analysis according to the strain harden exponent *n* of the Ramberg-Osgood model. In each group, one type of material is selected as the base one and the corresponding strength curve is expressed in modified Perry formula. A slenderness conversion formula is deduced between the columns of different material. The predictions of the proposed method are in good agreement with the finite element strengths.

Keywords

Stainless steel column; Flexural buckling; design method; Conversion formula

1 Introduction

Stainless steel members have been used in building structures due to its attractive architectural rendering and corrosion resistance. Most of the current design codes adopt the design method, which developed for low carbon steel, to determine the stainless steel column buckling strength. Compared to low carbon steel, an artificial specified 0.2% proof strength takes the place of the well-defined yield plateau in the definition of the strain-stress curve for stainless steel. In addition, the material property of stainless steel is more sensitive to cold work, including cold form and cold correction. Thus, the mechanical properties of stainless steel become complex and diverse. When establishing design methods for stainless steel members, the feature and the wide range of stainless steel material property should be taken into consideration.

Eurocode 3:1993-1-4[1] utilises the Perry formula to calculate the column buckling strength. Hence, the features of stainless steel are not well recognised in European specification. SEI/ASCE 8-02[2] adopts the tangent elastic modulus method, and iterations are needed in the calculation. In 1997, Rasmussen[3] proposed a design method for column of metallic materials, in which the imperfect parameters are expressed using material parameters of Ramberg-Osgood mode, but the expressions are a bit complex. In 2012, Hradil [4] developed a new method by combining methods used in European and American specifications. However, iterations are also necessary in this calculation.

The object of this paper is to develop a design method that takes into account material properties of stainless steel without any iteration during calculation. First, Finite element model, utilizing the advanced material model, is employed to build the strength curve base. Second, the finite element strength is compared with the predictions of current design methods. Third, two strength curves combined with a slenderness conversion formula are deduced based on the strength curves to predict the column strength.

2 Finite Element Analysis

2.1 Finite element model and verification

TANSYS was employed to develop Finite element model. A square hollow section, 80mm×3mm, was used with a variety of material properties and column slenderness. The detail geometric information of this section is the same as that in [3]. For each column, the full length and half of the cross section was modelled, with symmetry conditions along the vertical edges. Constraint equations were used to ensure that all node at both ends act as a rigid plane, which was represented by a specified master node in each end. The master nodes were fixed against all degrees of freedom, except for minor axis rotation at both ends and for vertical displacement at the loaded end. The boundary conditions of the loaded end are depicted in Fig.1.

Shell 181, a 4-node Structural shell element in ANSYS element library, was used. Shell 181 is suitable for analysing thin to moderately thick shell structures. It is a 4-node element with six degrees of freedom at each node, translations in the x, y, z directions and rotations about the x, y, z-axes. Shell 181 is well-suited for linear, large rotation and large strain nonlinear applications.

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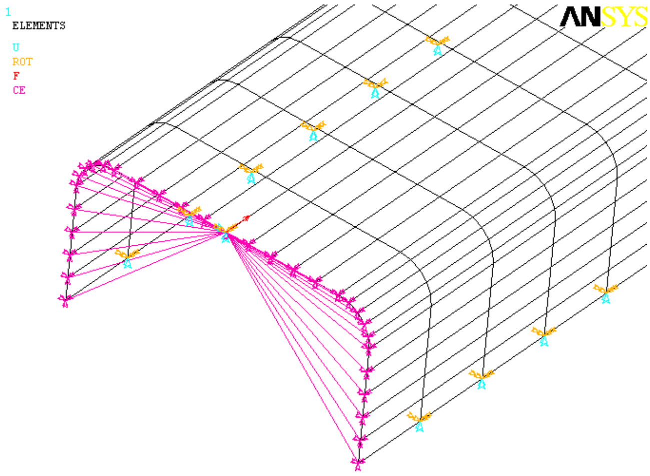


Fig. 1 Boundary conditions

In recent years, the understanding of stainless steel material properties has been deeply developed. Two-stage model and three-stage model for stainless steel were proposed to rectify the inaccurate predictions of Ramberg-Osgood as the stress exceeds 0.2% proof stress. This study adopts two-stage model proposed by Gardner [5]. This model is defined by Eq. (1), where σ and ε are engineering stress and strain respectively, E_0 is the material Young's modulus, $\sigma_{0.2}$ is the material 0.2% proof stress, n is the strain hardening exponent, $\sigma_{1.0}$ is the material 1.0% proof stress and $n_{0.2;1.0}$ is the strain hardening coefficient representing a curve that passes through $\sigma_{0.2}$ and $\sigma_{1.0}$. At present, Euro code and American code do not list the value for $n_{0.2;1.0}$ and $\sigma_{1.0}$. Thus, formula proposed by Qunch[6] is used to predict $n_{0.2;1.0}$ and $\sigma_{1.0}$. This formula is shown in Eq. (2).

$$\begin{cases} \varepsilon = \dfrac{\sigma}{E_0} + 0.002\left(\dfrac{\sigma}{\sigma_{0.2}}\right)^n & \sigma \le \sigma_{0.2} \\ \varepsilon = \dfrac{\sigma - \sigma_{0.2}}{E_{0.2}} + \left(0.008 - \dfrac{\sigma_{1.0} - \sigma_{0.2}}{E_{0.2}}\right)\left(\dfrac{\sigma - \sigma_{0.2}}{\sigma_{1.0} - \sigma_{0.2}}\right)^{n_{0.2,1.0}} + \varepsilon_{t0.2} & \sigma_{0.2} \le \sigma \le \sigma_{2.0} \end{cases} \tag{1}$$

$$\begin{cases} \dfrac{\sigma_{1.0}}{\sigma_{0.2}} = 0.662\dfrac{1}{n} + 1.085 \\ n_{0.2,1.0} = 6.399\left(\dfrac{E_{0.2}}{E_0}\right)\left(\dfrac{\sigma_{1.0}}{\sigma_{0.2}}\right) + 1.145 \end{cases} \tag{2}$$

Residual stress was not included in the finite element model. The imperfection was introduced into the finite element model using the first eigenvalue buckling mode with the amplitude equal to 1/1000 of the column length.

Zheng[7] reported column tests on stainless steel square hollow sections. Tab. 1 shows comparisons of the test strength and the strength calculated using the model described above, in which measured material properties and imperfection were used. In this table, B is the width of the section; t is the thickness of the section; r is the outer radius of corner region; L is the length of the specimen; F_t is the tested ultimate strength; F_{FEM} is the ultimate strength predicted using finite element model.

In general, the finite element model could predict the ultimate strength well with the average error 2.0%. The maximum discrepancy is less than 5.0%, except for SHS 80×3-950a. For this specimen, the high error may be caused by the incorrect imperfection.

Table 1 Comparison of the test results from Zheng and the predictions of the FEM

Specimens	Geometry				Imperfection	Material properties			F_t/kN	F_{FEM}/kN	F_t/F_{FEM}
	B/mm	t/mm	r/mm	L/mm	e/mm	E_0/Mpa	$\sigma_{0.2}$/ Mpa	n			
SHS80×3-950a	80.4	2.72	4.63	1030	2.11	186430	480.33	3.33	368	334	1.10
SHS80×3-1450a				1530	0.5				294	308	0.95
SHS80×3-1950a				2031	1.14				220	216	1.02
SHS80×3-1950b				2028	*				217	216	0.97
SHS80×3-2450a				2530	0.32				181	175	1.03
SHS-80×3-2950a				3030	0.3				133	136	0.97
SHS80×3-3520a				3520	1.44				105	103	1.02
Avg.											1.02
Cov.											0.04

Note: *the imperfection was not obtained for this specimen and the imperfection of SHS80×3-1950a was used in FEM

2.2 Range of material properties

The range of material properties for longitudinal compression in European [1] and American[2] specifications are listed in Table 2. The non-dimensional measure of the proof stress *e* and the hardening exponent *n* are the important parameters that affected the reduced factor of stainless steel column [3]. The parameter *e* is defined by $e=\sigma_{0.2}/E_0$. In this study, these two parameters were also used.

According to Table 2, the range of material properties in European specification is larger than that in American specification, since 21 types of stainless steel are included in European specification 3:1993-1-4, while only 7 types in American specification. Therefore, five values of non-dimensional stress (*e*=0.0010, 0.0015, 0.0025, 0.0030) and seven values of hardening exponent (*n*=3, 4, 5, 6, 7, 8, 9) were considered. The range of values covers the range of properties of all common stainless steel.

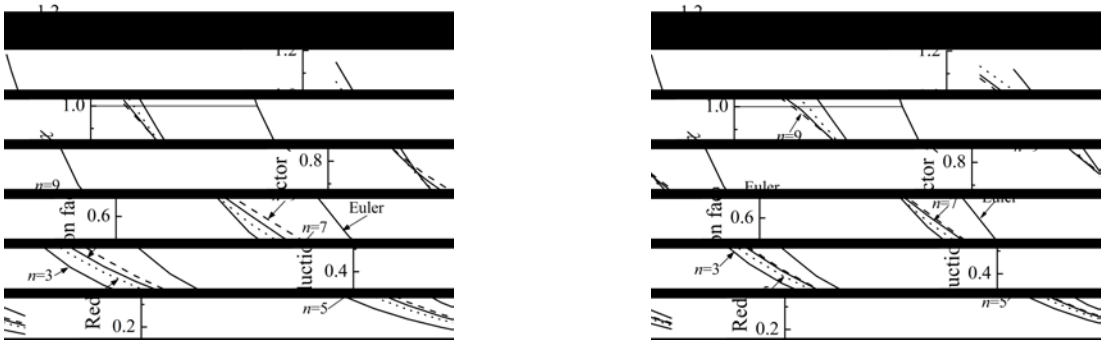
For each type of material, 13 Finite element models with different slenderness (λ=0.2, 0.4, 0.45, 0.5, 0.55, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0) were calculated. In order to show a clear tendency between the slenderness 0.4 to 0.6, two specimens with slenderness 0.45 and 0.55 were added into the array from 0.2 to 2.0 with 0.2 as the interval.

Table 2 The range of material properties in European and American specifications

	E_0/Mpa		$\sigma_{0.2}$/Mpa		e		n	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
EN1993	200000	186200	448.2	193.1	0.0024	0.0009	9.7	2.61
ASCE-02	220000	195000	480	175	0.0024	0.001	9	5

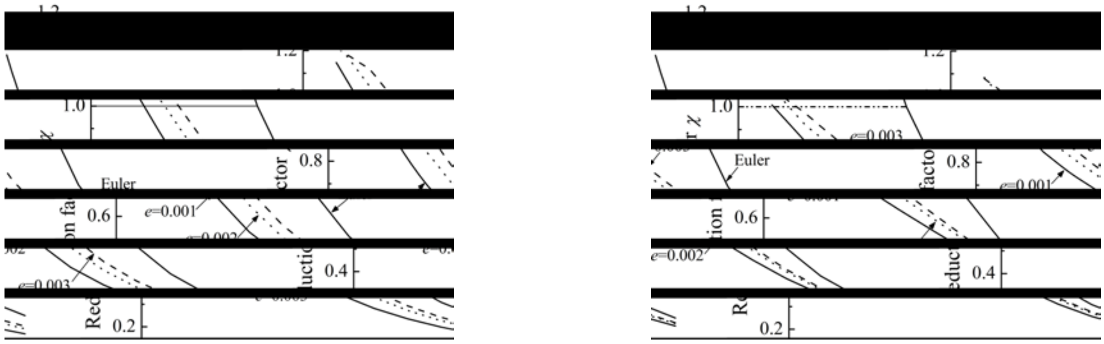
2.3 Finite element results

Finite element results are shown in Fig. 2 for *e*=0.0010 and *e*=0.0030, and Fig. 3 for *n*=3 and *n*=9. In these figures, the abscissa and the ordinate is slenderness and reduction factor, respectively.



a) *e*=0.001, *n*=3,5,7,9 b) *e*=0.003, *n*=3, 5, 7, 9

Fig. 2 Strength curves for different *n*



a) *n*=3, *e*=0.001,0.002,0.003 b) *n*=9, *e*=0.001, 0.002, 0.003

Fig. 3 Strength curves for different *e*

According to Fig. 2 and Fig. 3, the effect of *n* on the strength curve decreases as the non-dimensional stress *e* increases. At the condition proof strength *e* is unchanged, the curvature of the strength curve decreases with a gradually slow-down rate as the strain hardening exponent *n* increases. When the strain hardening exponent *n* is set as a constant, the shape of the strength curve is similar, and the increasing in non-dimensional proof stress *e* makes the strength curve move upward. Therefore, the shape of the strength curve depends more on the strain hardening exponent *n*, while the effect of varying non-dimensional proof stress *e* is to change the position of the strength curve.

3 Current Design Methods

At present, there are four types of design method to predict the ultimate strength for stainless steel column. The concept of these methods and comparisons with the finite element result are described in the following.

3.1 Eurocode 3:1993-1-4

Perry formula is adopted in European specification[1] to calculate the buckling strength of stainless steel column. The reduction factor χ is defined as follows:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}} \le 1 \tag{3}$$

$$\phi = 0.5[1 + \eta + \lambda^2] \tag{4}$$

where η is imperfection parameters $=\alpha(\lambda\text{-}\lambda_0)$. For cold formed members, α and λ_0 are equal to 0.49 and 0.40, respectively.

Comparison of the strength curve in European specification and finite element results is shown in Fig. 4. According to this figure, for columns with slenderness less than 0.6 or higher than 1.2, the strength curve approximately lies in the centre of the belt of finite element results. However, for columns with slenderness between 0.6 and 1.2, the strength curve provides unconservative predictions especially for columns of low material proof strength. Thus, a single strength curve could not provide accurate predictions.

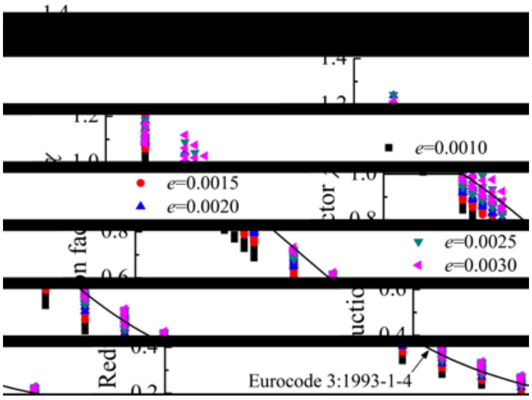


Fig. 4 Comparisons of the strength curve in European specification and finite elements results

3.2 SEI/ASCE 8-02

In American specification [2], the tangent modulus theory is adopted. For sections not subject to torsional or torsional-flexual buckling, the flexural buckling stress, F_{n} , is defined by Eq. (5).

$$F_{\mathrm{n}} = \frac{\pi^2 E_{\mathrm{t}}}{\left(KL/r\right)^2} \le F_{\mathrm{y}} \tag{5}$$

where: F_{n} is flexural buckling stress; E_{t} is tangent modulus in compression corresponding to buckling stress; K is the effective length factor; L is un braced length of members; r is radius of gyration of full, unreduced section.

E_{t} is determined by buckling stress F_{n}, and is also the parameter used to calculate F_{n}. Therefore, they are interdependent, and iterations are needed in the calculations.

The average ratios of the strength predicted using American specification (F_{ASCE}) to finite element results (F_{FEM}) are shown in Fig. 5. According to this Figure, the column strength predicted using American code is higher than finite element result for all the calculated material. The discrepancy decreased as the proof stress becomes higher. The maximum discrepancy is about 15% encountered at (e, n) = (0.0010, 7). Although a relative low resistance factor 0.85 was used in producing design strength, a consistent safety index β could not be reached for stainless steel column.

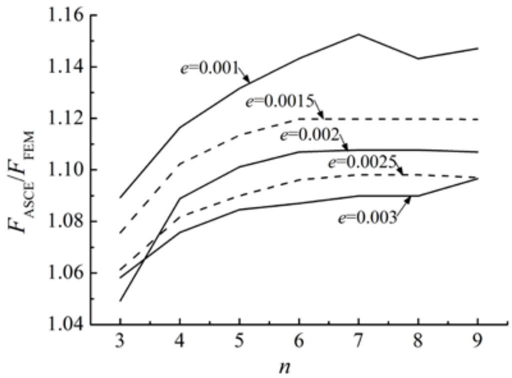


Fig. 5 Comparisons of the strength predicted using American specification and finite elements results

3.3 Method proposed by Rasmussen

In 1997, Rasmussen[3] proposed a modification to the imperfection parameter (η) of the Perry formula. The modified imperfection factor is defined by Eq. (6), where the parameters (α, β, λ_1 and λ_0) are expressed by material parameters (E_0, $\sigma_{0.2}$, n). Thus, each type of material has a strength curve. Details of these expressions are available in [1].

$$\eta = \alpha\left(\left(\lambda - \lambda_1\right)^{\beta} - \lambda_0\right) \tag{6}$$

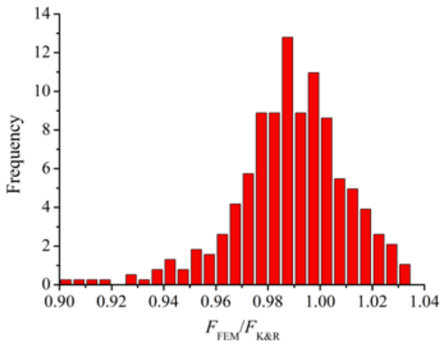


Fig. 6 Comparisons of the strength predicted using Method proposed by Rasmussen and finite elements results

The predicted strengths using the method proposed by Rasmussen ($F_{K\&R}$) are compared with finite element results. The results are shown in Fig 6. For most of the specimens, the ratio $F_{FEM}/F_{K\&R}$ lies in the range of 0.96 to 1.02 with the average ratio 0.98. The method proposed by Rasmussen is based on finite element results of specimen with L/1500 as the imperfection amplitude. Thus, the average prediction is a little higher than finite element result in this paper.

The only shortage of this method may be that the expressions of the parameter (α, β, λ_1 and λ_0) are a bit complex to apply in practical design.

3.4 Method proposed by Hradil

In 2012, Hradil [4] studied the design method in European and American specification deeply. He found that nonlinear material properties and geometry imperfection are not appropriately recognized in American and European specification, respectively. Thus, he proposed a concept of transformed slenderness λ^*, defined by Eq.(7). By taking λ^* into the Perry formula, a new design curve called Transformed Ayrton-Perry Curve was produced. This approach has a similar accuracy with the method proposed by Rasmussen in calculation the flexural strength of stainless steel column. The drawback of this method is the need for iterations in the calculation of the reduction factor.

$$\lambda^* = \lambda \cdot \sqrt{\frac{E_0}{E_t}} = \lambda \cdot \sqrt{1 + 0.002n \frac{E_0}{\sigma_{0.2}} \chi^{n-1}} \tag{7}$$

4 The Proposed Method

The object of this section is to develop a design method that regards the character of stainless steel material properties but without iterations in calculation. Similarity between the strength curves of stainless steel is used in this section. The strength curves with similar shape are assigned into one group. In each group, one curve is selected as the base curve which is then expressed through modified Perry formula. A conversion formula for slenderness between different materials is developed to produce other strength curves from the base curve.

4.1 Base curves

As we discussed in section 2.3, the shape of the strength curve is similar with each other for material with the same strain hardening exponent n. therefore, we can take the similarity of the shape between the strength curve as the ruler to distinguish them and to find the base curves.

Cluster analysis is conducted with *Pearson Product-Moment Correlation* as the measure of similarity between two strength curves. *Within-Groups linkage Method* is used to aggregate two groups. In this study, the reduction factor in each strength curve forms an object. The similarity r between every two objects is calculated using Eq. (8), where, n is the number of point in the strength curve; X_i is an array consisted of reduction factor in a strength curve. In each step, two objects, one object and a group or two groups are merged. Two objects are merged if they have the highest similarity r. Two groups are merged into a new group only if the average similarity of the objects in the new group is the highest. In this paper, the strength curves are assigned into two groups, named Group A and Group B. As expected, the strength curves for n=3,4,5 are in Group A, and those for n=6,7,8,9 are in Group B.

$$r = \frac{n\left(\sum X_i X_j\right) - \left(\sum X_i\right)\left(\sum X_i\right)}{\sqrt{\left[n\sum X_i^2 - \left(\sum X_i\right)^2\right]\left[n\sum X_j^2 - \left(\sum X_j\right)^2\right]}} \tag{8}$$

In each group, the strength curve that has the highest *Pearson Product-Moment Correlation* with other curves, is picked out as the base curve. According to this rule, the strength curve for (e, n)=(0.0020,4) and (e, n)=(0.0020,7) are selected for Group A and Group B, respectively.

Nonlinear imperfection parameter expression has been proved to provide more accurate prediction than linear expression for stainless steel column [3]. In this study, the imperfection formula is expressed as a quadratic polynomial. Utilizing the *Least Square Method*, the imperfection formula is obtained and shown in Eq. (9). It should be mentioned that the point for λ=0.2 is not included in these regressions, because the reduction factor for this column is higher than 1.0 for most of the calculated material types. The maximum discrepancy between the finite element result and the prediction calculated using Eq.(9) is 1.8% and 4.3%, for e=0.0020, n=4 and e=0.0020, n=7, respectively.

$$\eta = \begin{cases} -0.40 + 1.13\lambda - 0.31\lambda^2 & e = 0.0020, n = 4 \\ -0.21 + 0.83\lambda - 0.29\lambda^2 & e = 0.0020, n = 7 \end{cases} \tag{9}$$

4.2 Conversion formula

In this section, we suppose the reduction factor of two columns of different material is the same, and deduce the function between the column slenderness.

For the column with sinusoidal imperfection, the displacement of the column under axial compression is

$$y = \frac{v_0}{1 - \dfrac{P}{P_{\mathrm{E}}}} \sin\frac{\pi x}{l} \tag{10}$$

where y is the lateral displacement; x is the coordinate along the centroidal axis of the column; p is the axial compression load; P_{E} is the Euler critical load; l is the length of the column; v_0 is the imperfection amplitude.

When column buckles in inelastic range or column of nonlinear material, Eq. (10) should be changed to

$$y = \frac{v_0}{1 - \dfrac{P}{P_{\mathrm{E}}} \cdot \dfrac{E_0}{E_{\mathrm{t}}}} \sin\frac{\pi x}{l} \tag{11}$$

where E_{t} is the tangent elastic modulus corresponding to load P.

The maximum compressive stress is

$$\sigma_{\max} = \frac{P}{A} + \frac{P \cdot v_0}{W\left(1 - \dfrac{P}{P_{\mathrm{E}}} \cdot \dfrac{E_0}{E_{\mathrm{t}}}\right)} \tag{12}$$

where A is the cross section area; W is the section modulus.

According to the *Edge Yield Criteria*, the ultimate strength of the column is reached as the maximum strength equals $\sigma_{0.2}$. Thus, the ultimate function is

$$\sigma_{0.2} = \frac{P}{A} + \frac{P \cdot v_0}{W\left(1 - \dfrac{P}{P_{\mathrm{E}}} \cdot \dfrac{E_0}{E_{\mathrm{t}}}\right)} \tag{13}$$

Submitting $P=\chi A\sigma_{0.2}$ into Eq.(13) and rearranging it, the following expression is obtained:

$$1 = \chi + \chi \frac{A \cdot v_0}{W\left(1 - \chi \dfrac{A \cdot \sigma_{0.2}}{P_{\mathrm{E}}} \cdot \dfrac{E_0}{E_{\mathrm{t}}}\right)} \tag{14}$$

For the two columns of different material properties, we suppose that the section area (A), section modulus (W), the imperfection amplitude (v_0=l/1000) and the reduction factor (χ) are the same, while the length of the column (l) is different. Using Eq. (14), the relationship between the two columns of different material could be expressed as follows:

$$\frac{l_{\mathrm{c}}}{1 - \chi \dfrac{A \cdot \sigma_{0.2,\mathrm{c}}}{P_{\mathrm{E,c}}} \cdot \dfrac{E_{0,\mathrm{c}}}{E_{\mathrm{t,c}}}} = \frac{l_b}{1 - \chi \dfrac{A \cdot \sigma_{0.2,\mathrm{b}}}{P_{\mathrm{E,b}}} \cdot \dfrac{E_{0,\mathrm{b}}}{E_{\mathrm{t,b}}}} \tag{15}$$

In this equation, the parameter with subscript b and c represents that of the column of base material and that of the material needed to be converted, respectively.

Submitting the definition of column slenderness, Eq. (16), and the relationship between the column length and slenderness, Eq. (17), Eq. (15) could be transformed into Eq. (18).

$$\lambda^2 = \frac{A \cdot \sigma_{0.2}}{P_{\mathrm{E}}} \tag{16}$$

$$l = \lambda \cdot \pi \sqrt{\frac{E_0}{\sigma_{0.2}}} \cdot i_0 \tag{17}$$

$$\frac{\lambda_{\mathrm{c}} \sqrt{\dfrac{E_{0,\mathrm{c}}}{\sigma_{0.2,\mathrm{c}}}}}{1 - \chi \cdot \lambda_{\mathrm{c}}^2 \cdot \dfrac{E_{0,\mathrm{c}}}{E_{\mathrm{t,c}}}} = \frac{\bar{\lambda}_{\mathrm{b}} \sqrt{\dfrac{E_{0,\mathrm{b}}}{\sigma_{0.2,\mathrm{b}}}}}{1 - \chi \cdot \bar{\lambda}_{\mathrm{b}}^2 \cdot \dfrac{E_{0,\mathrm{b}}}{E_{\mathrm{t,b}}}} \tag{18}$$

Eq. (18) is a quadratic equation of λ_{b}. When we know the value of geometry and material parameters, the unknown parameter left in Eq. 18 are χ and λ_{b}. The approximation of the reduction factor χ could be obtained using Eqs. (3),(4)and (9).

4.3 Proposed design procedures

Before the calculation of reduction factor χ, The parameters that we should obtained the values are the slenderness (λ_{c}) and the material parameters ($E_{0,\mathrm{c}}$, $\sigma_{0.2,\mathrm{c}}$, n_{c}).

The design steps required in calculating the reduction factor χ of the column failure in flexural buckling are given as follows:

a. Determine which group the column belongs to according to the strain hardening exponent n_{c}. We approximately consider that columns with strain hardening exponent n_{c} in the range from 5 to 6, are belong to Group A.

b. Calculate the approximate reduction factor χ using Eqs. (3),(4)and (9).

c. Calculate the conversion slenderness (λ_{b}) using Eq. (18). In using Eq. (18), take the result in step 2 as the approximate reduction factor.

d. Calculate the final reduction factor (χ) corresponding to λ_{b} using Eqs. (3),(4)and (9).

4.4 Comparisons

According to the above steps, 35 strength curves are calculated. Comparisons between the predictions of the proposed method and the finite element strength are shown in Fig. 7, for n=3, 5, 7, 9 and e=0.001, 0.0015, 0.0025 and 0.0030.

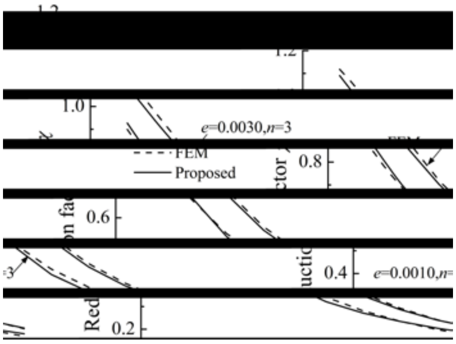
It shows that the proposed strength curves are in good agreement with the finite element results. The fit results for n=7, 9 are generally better than that for n=3, 5. The maximum safe discrepancy between the finite element results and the proposed column curves is 9.8%, encountered at λ =2.0 for (e,n)=(0.001 ,6). The maximum unsafe discrepancy is 4.8%, encountered at λ=1.2 for (e,n)=(0.001 ,3).

For each of the 35 curves, the mean and the coefficient of variation of the ratio (F_{Pred} /F_{FEM}) are shown in Fig. 8. The mean ratio lies in the range from 0.975 to 1.015. For most of the curves, the coefficient of variation is generally less than 0.025. The largest coefficient variation is 0.043, found at (e,n)=(0.001 ,6). The narrow range of the mean ratio and the small variation indicate that the proposed method could provide accurate predictions for column failure in flexural buckling.

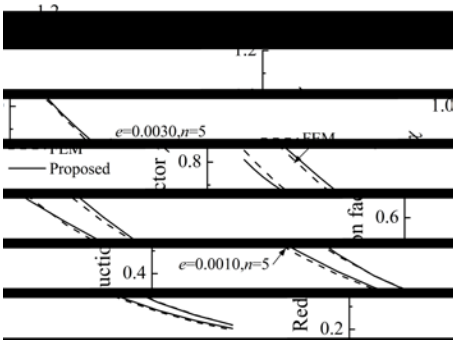
5 Conclusions

A new method to design the stainless steel column failure in flexural buckling has been presented. Two base strength curves and a conversion formula for slenderness are combined to provide predictions for columns strength with material properties covering all the normal stainless steel.

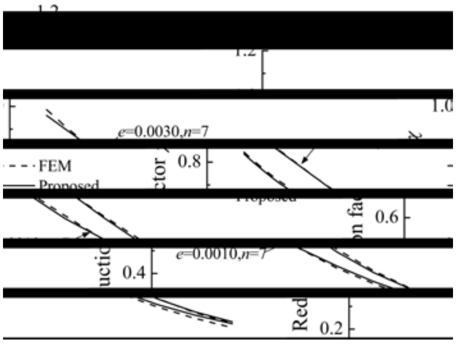
An advanced finite element model that adopted the latest material model has been developed to establish the strength curves database for the new method. Finite element result has been compared with the prediction of current design methods in European [1] and American [2] specification and the methods proposed by Rasmussen [3] and by Hradil [4]. The strength curve adopted in European specification is suitable for high strength stainless steel column, but provides unsafe prediction for stainless steel column with low proof strength. The predictions of American specification are higher than the finite element result on average and the maximum discrepancy exceeds 15%. The predictions of the methods propose by Rasmussen and by Hradil are close to the finite element results. The complex expression and the iteration is the shortage for these two methods respectively.



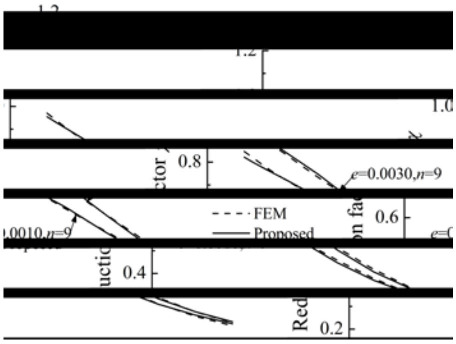
(a) *e*=0.001,0.003, *n*=3



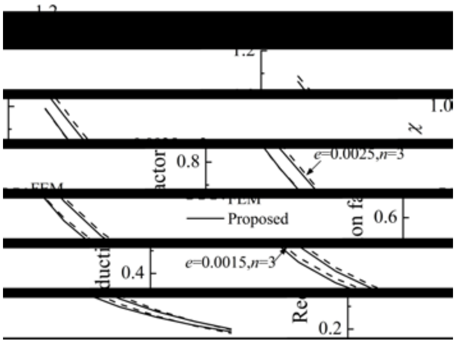
(b)*e*=0.001,0.003, *n*=5



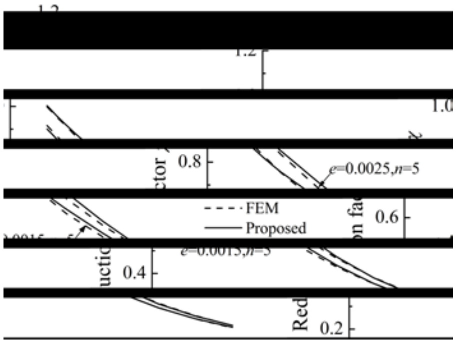
(c) *e*=0.001,0.003, *n*=7



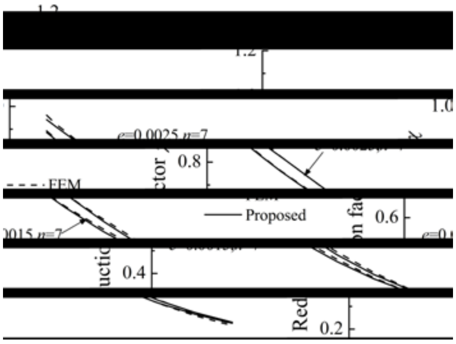
(d) *e*=0.001,0.003, *n*=9



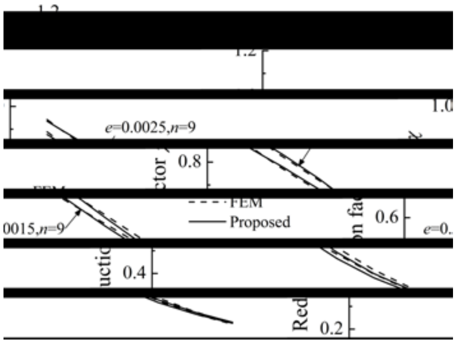
(e) *e*=0.0015,0.0025, *n*=3



(f) *e*=0.0015,0.0025, *n*=5

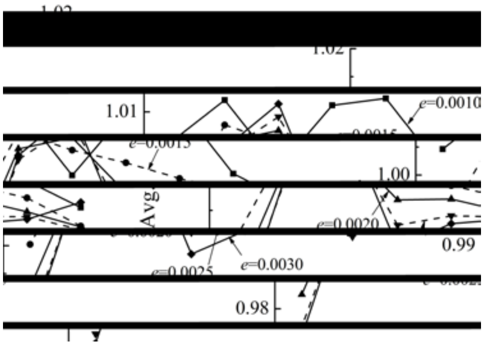


(g)*e*=0.0015,0.0025, *n*=7

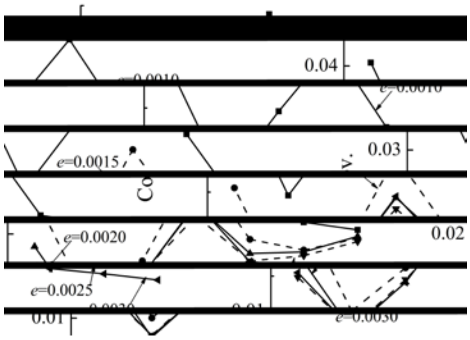


(h)*e*=0.0015,0.0025, *n*=9

Fig. 7 Comparisons between the FEM results and the prediction of the proposed method



a) Average



b) Coefficient of variation

Fig. 8 Statistic results of F_{Pred} /F_{FEM}

Based on the similarity in the shape of the strength curve, Cluster analysis has been conducted and the strength curves are separated into two groups. Group A includes columns with n= 3, 4, 5. Group B includes columns with n=6, 7, 8, 9. Strength curve with (e, n)=(0.0020,4) and (e, n)=(0.0020,7), were picked out as base curves and were expressed in terms of Perry formula with nonlinear imperfect factor. Based on the *Edge Yield Criteria*, Eq. (18) was deduced to transform the column slenderness of the normal material into that of base material.

Comparisons between the finite element results and the predicted strengths have been performed. The mean ratio of F_{Pred} /F_{FEM} lies in the range of 0.975~1.015. The maximum coefficient of variation is 0.043. The proposed method could provide accurate prediction for stainless steel columns failure in flexural buckling.

In this paper, there is no discussion about the columns strength with small slenderness, for which the overall buckling strength may be higher than the proof strength and local bucking may be involved. An expression that harmonizes the local buckling strength curve and the overall strength curve will be discussed in the future.

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References

[1] EC3, Eurocode 3:Design of steel structures—Part 1.4: General rules—supplementary rules for stainless steels. Brussels, 2006.

[2] ASCE, Specification for the design of cold-formed stainless steel structural members, in, Reston, Virginia, 2002.

[3] K.J.R. Rasmussen, J. Rondal, Strength curves for metal columns, J Struct Eng-Asce, 123 (1997) 721-728.

[4] P. Hradil, L. Fülöp, A. Talja, Global stability of thin-walled ferritic stainless steel members, Thin-Walled Structures, 61 (2012) 106-114.

[5] L. Gardner, D.A. Nethercot, Experiments on stainless steel hollow sections—Part 1: Material and cross-sectional behaviour, J Constr Steel Res, 60 (2004) 1291-1318.

[6] W.M. Quach, J.G. Teng, K.F. Chung, Three-stage full-range stress-strain model for stainless steels, J Struct Eng-Asce, 134 (2008) 1518-1527.

[7] B.F. Zheng, Theoretical and experimental investigations on cold-formed stainless steel columns and beam-columns, in: School of Civil Engineering, Southeast University, Nanjing, 2010.

