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Specific features of stainless steel compression elements

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Subject review

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Specific features of stainless steel compression elements

Stainless steel has a number of features that define different behaviour of structural elements made of this material, as related to equivalent carbon steel elements. These properties, especially prominent in case of compression elements, are manifested through the nonlinear stress and strain relationship, pronounced influences of material hardening due to cold forming. Basic principles for the analysis of cold-formed stainless steel compression elements, either included in modern technical regulations, or resulting from current research, are presented in this paper.

Key words:

stainless steel, cold forming, compression load, carrying capacity of cross-section, carrying capacity of element

Pregledni rad

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Specifičnosti ponašanja tlačnih elemenata od nehrđajućeg čelika

Nehrđajući čelik odlikuje niz specifičnosti koje određuju drugačije ponašanje konstrukcijskih elemenata od ovog materijala u odnosu na ekvivalentne od ugljičnog čelika. Ova svojstva, osobito izražena kod tlačnih elemenata, očituju se u nelinearnom odnosu naprezanja i deformacija i izraženim utjecajima očvršćenja materijala uslijed hladnog oblikovanja. U radu su prikazani osnovni principi proračuna tlačnih hladno oblikovanih elemenata od nehrđajućih čelika koji su obuhvaćeni suvremenim tehničkim propisima ili su rezultat aktualnih istraživanja.

Ključne riječi:

nehrđajući čelik, hladno oblikovanje, tlačno opterećenje, nosivost presjeka, nosivost elementa

Übersichtsarbeit

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Besonderheiten im Verhalten druckbeanspruchter Elemente aus rostfreiem Stahl

Rostfreier Stahl hat bestimmte Eigenschaften, die das Verhalten von Konstruktionselementen im Vergleich zu äquivalenten Elementen aus unlegiertem Stahl beeinträchtigen können. Diese Eigenschaften zeigen sich insbesondere bei druckbeanspruchten Elementen durch das nichtlineare Verhältnis von Spannungen und Verformungen, den betonten Einfluss des Kaltformungsverfahrens auf die Nachhärtung des Materials. In dieser Arbeit werden Grundlagen der Analyse kaltgeformter Elemente aus rostfreiem Stahl dargestellt, die entweder auf modernen Regelwerken oder auf derzeitiger Forschung beruhen.

Schlüsselwörter:

rostfreier Stahl, Kaltformung, Druckbeanspruchung, Tragfähigkeit von Querschnitten, Tragfähigkeit von Elementen

1. Introduction

Stainless steel is a general name for a wide array of steel alloys of various types and qualities, whose resistance to corrosion is obtained with at least 10.5 percent of chromium and no more than 1.2 percent of carbon. The austenitic and duplex types of steel are most widely used in construction industry. Austenitic stainless steels contain iron, 16–28 percent of chromium, and 6–32 percent of nickel. The 0.2 % proof stress varies from 190 to 350 N/mm², and the tensile strength may attain 950 N/mm². They have a pronounced hardening effect due to cold deformation, and they do not exhibit significant reduction of mechanical properties at high and low temperatures. They also present exceptional surface treatment capabilities, as exhibited in interesting aesthetic effects, but also in better corrosion resistance of the passive surface layer. They are non-magnetic and can easily be welded. Duplex steels contain a two-phase austenitic-ferritic microstructure with 18 to 26 percent of chromium and 3.5 to 8 percent of nickel. These steels combine best properties of austenitic and ferritic steels. Compared to austenitic steels, they have better mechanical properties: the 0.2 % proof stress varies from 400 to 650 N/mm², the tensile strength ranges from 630 to 900 N/mm², while the ductility value is lower amounts to about 25 %.

The design of stainless steel structural elements is of a relatively recent origin, and so it is covered with technical codes to a much smaller extent compared to carbon steel elements. The first official document in this area was published in 1968 in the USA by AISI [1]. The current American standard SEI/ASCE 8-02 [2] provides rules for the design of cold-formed structural stainless-steel elements, and allows equal application of either the load and resistance factor design or the allowable stress design. An extensive research project aimed at defining the European set of design recommendations has been initiated in Europe not earlier than in the last years of the past century under guidance of SCI. The Euro Inox published its "Design Manual for Structural Stainless Steel" [3] in three distinct editions, each complementing the previous one. At the same time, in 1996, CEN published a pre-standard and, six years later, the corresponding standard EN 1993-1-4 [4], which provides additional rules for stainless steels. This standard has been greatly harmonized with design manuals [3] and includes changes arising from the need to ensure harmonization with carbon steel standards EN 1993-1-1:2005 [5] and EN 1993-1-3:2006 [6]. Australia and New Zealand jointly published in 2001 the standard AS/NZS 4673 [7] which, traditionally, greatly relies on American regulations.

In accordance with European standards EN 10027-2 [8], stainless steels are designated numerically and alphanumerically, according to their chemical composition. The numerical designation consists of five Arabic digits and has the following form 1.4XXX. In this designation, the digit directly following number 4 depends of the percentage of nickel and proportion of molybdenum, niobium and titanium in the stainless steel alloy. In the alphanumeric designation, the first place is occupied by the sign X, which is followed by the number designating an average carbon percentage. This number is followed by: chemical symbols of main alloy elements and numbers divided by lines designating their average percentage. The chemical

composition of various stainless steel grades is defined in the first part of the standard EN 10088 [9].

The earliest but also the most comprehensive bearing capacity testing for compression members made of austenitic stainless steel grade 1.4310 was conducted in 1955 by Hammer and Petersen [10]. The testing involved the total of 200 samples of closed cross-section, formed of two cold shaped top-hat profiles, ranging from 15 to 120 in slenderness. Johnson and Winter [11] (1966) tested behaviour of columns and beams made of austenitic grade 1.4301. The samples were formed by continuous connection of cold shaped C-section elements without edge stiffeners into an I-section, and alternately into a box section. The analysis of results confirmed the application of the tangent modulus theory during calculation of resistance of elements to flexural buckling. The research in this area was intensified two decades later. Coetzee et al. [12] tested cold formed C-section samples with edge stiffeners, of varying slenderness values (from 10 to 104). The testing comprised a group of austenitic grades 1.4301 and 1.4401 and the ferritic grade 1.4003. Rhodes, Macdonald and McNiff [13] (2000) also tested cold shaped C-section members with edge stiffeners, of varying thicknesses. Bredenkamp and Van den Berg [14] analysed the bearing capacity of welded I-section members, varying from 878 to 3580 mm in length. The basic material was the ferritic grade 1.4003. Talja [15] and Stangenberg [16] conducted experimental and numerical analyses of resistance to flexural buckling of welded members and sections made of austenitic and duplex steels. Rasmussen and Hancock [17] (1990), Liu and Young [18] (2003), and Gardner and Nethercot [19] (2004), analysed the bearing capacity of cold-formed hollow section members made of austenitic stainless steel. Young and Wing-Man Lui [20] (2006) tested the bearing capacity of square and rectangular hollow section members whose length ranged from 300 mm to 3000 mm in radius, and the basic material was the duplex stainless high strength steel. Becque, Lecce, and Rasmussen [21] analysed resistance of cold formed thin-walled elements to distortional buckling, and the interaction between the section buckling and flexural stability of members. Theofanous and Gardner [22] (2009) continued with the bearing capacity testing for members made of hollow sections, with square and rectangular cross-sections, and extended the area of research to elliptically shaped members [23]. This paper sums up the existing knowledge about specific applications of stainless steels for cold formed compression members, which require different procedures for calculating resistance of cross-sections and elements to flexural buckling, when compared to members made of carbon steel.

2. Properties of the material

Specific mechanical properties of austenitic stainless steels are: nonlinear stress-strain relationship, anisotropy and nonsymmetry of material, ductility, and pronounced strain hardening. The stress-strain curve is markedly nonlinear, without a sharply defined yield point and yield plateau, it has a low stress at the proportionality limit, which points to gradual yielding of material. The stress $\sigma_{0.01}$ corresponding to permanent plastic deformation

of 0.01 % is normally used for the proportionality limit that is not sharply defined and conventionally determined [2, 3]. The curve curvature level depends on the type and percentage of alloy elements, heat treatment of material, and the cold working level of finished product. This property is presented by a comparative presentation of σ - ε curves for the austenitic grade 1.4301 and carbon steel grade S275 [24] (Figure 1).

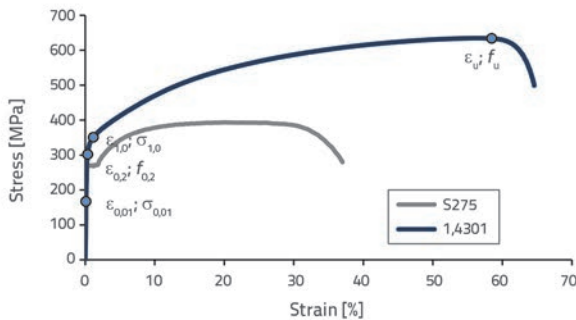


Figure 1. Tensile stress-strain curves for stainless steel grade 1.4301 and carbon steel grade S275 [24]

The real mathematical interpretation of the nonlinear stress and strain relationship, with the smallest possible number of parameters, is of considerable importance in the analytical and numerical analyses of various carrying capacity problems. The two-phase model of material, based on the known Ramberg – Osgood analytical expression [25], is most widely used for describing the σ - ε curve. In the stress region under the 0.2 % proof stress $f_{0.2}$, the strain value is determined using the Hill [26] (modified Ramberg-Osgood) analytical expression as a function of three parameters, 0.2 % proof stress $f_{0.2}$, modulus of elasticity E and strain hardening exponent n :

$$\varepsilon = \frac{\sigma}{E} + 0,002 \left(\frac{\sigma}{f_{0.2}} \right)^n \quad (1)$$

The strain hardening exponent n which defines the curvature of curve in the analysed stress zone is usually represented by a logarithmic function of the relationship between the stress values $f_{0.2}$ and $\sigma_{0.01}$ and the corresponding plastic strain. It has been demonstrated that the use of expression (1) provides satisfactory results in the stress region under the 0.2 % proof stress, but there are some significant deviations from experimental values in case of greater stress values. Mirambell and Real [27] modified the Ramberg-Osgood curve and analysed it in a new coordinate system with the beginning at point $(\varepsilon_{0.2}, f_{0.2})$, introducing as functional parameters the values f_u and ε_u , the tangent modulus corresponding to 0.2 % proof stress $E_{0.2}$, and the strain hardening exponent $n_{0.2-u}$. Using tensile test results for various stainless steel grades, Rasmussen [28] simplifies the Mirambell-Real model by reducing the number of functional parameters. The expression from [28] was inserted in EN 1993-1-4 [4]. During analysis of the Mirambell-Real model [27], Gardner, Ashraf and Nethercot [29, 30] conclude that it can

be used for the case of tension only. In case of compression, the values f_u i ε_u are missing, due to absence of contraction and section failure. In that respect, the authors modify the model [27] in the stress region above $f_{0.2}$ and, instead of the tensile strength f_u and the corresponding total strain ε_u , they introduce the values that correspond to the permanent plastic strain of 1.0 %. The Gardner-Nethercot expression [30] is generally applicable and exhibits a very great level of correspondence with experimental results. In addition to the model describing nonlinear behaviour of material as a function of stress, the Abdella's inverse form of equation [31], representing stress as a function of strain, is also used quite often.

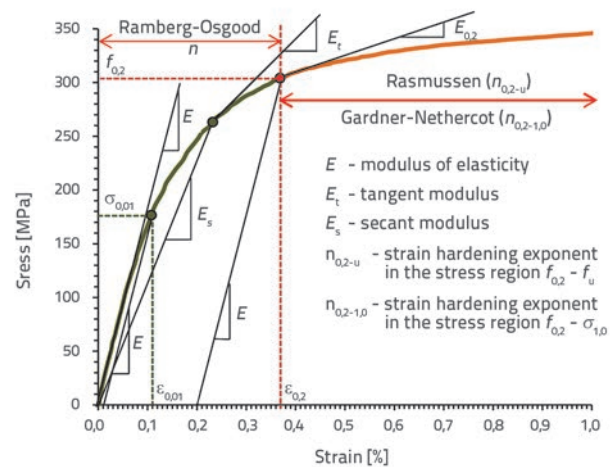


Figure 2. Stress and strain values in the initial part of the stress and strain curve for stainless steel grade 1.4301

Parameters that are usually used in mathematical description of the σ - ε curve are shown in Figure 2. Stainless steels are characterised by different mechanical properties in different directions with respect to the rolling direction (anisotropy), during compression and tension (nonsymmetry of material). A negligible influence of anisotropy is found in austenitic steels only. The influence of asymmetry is more significant and so the 0.2 % proof stress during compressive strength testing has values in longitudinal direction that are on an average by ten to fifteen percent lower when compared to the 0.2 % proof stress in longitudinal tension. This specific feature of material is known as the Bauschinger effect and is typical for materials subjected to elongation during the technological procedure for the manufacture of final products [32]. European standards EN 10088 [9] define technical requirements for the delivery of structural stainless steels by defining minimum values for mechanical properties of materials. In case of sheet steel and strips, these values are defined by standard tensile strength testing of samples oriented transversely to the direction of rolling. In addition to austenitic steels in the annealed condition, the standards define a 0.2 % proof stress or tensile strength for three different levels in the cold worked condition (CP350, CP500 and CP700) and (C750, C800, C1000). Unlike European standards [9], the US specifications [2] cover

Table 1. Mechanical properties for stainless steel grade 1.4301 according to [2, 4, 9]

1.4301 (SEI/ASCE 304)	SEI/ASCE 8-02				EN 10088, EN 1993-1-4	
	LT	TT	LC	TC	TT	LT
$f_{0.2}$ [N/mm ²]	206.9	206.9	193.1	206.9	210	-
f_u [N/mm ²]	517.1		-	-	520	-
E [N/mm ²]	193100				200000	-
n	8.31	7.78	4.1	8.63	6	8

LT – longitudinally oriented coupon subjected to tension; TT – transversely oriented coupon subjected to tension;
 LC – longitudinally oriented coupon subjected to compression; TC – transversely oriented coupon subjected to compression

in full detail the influence of nonsymmetry and anisotropy of material. Mechanical properties are systematically presented for the longitudinal and transverse stressing at tension and compression, for austenitic steels (SEI/ASCE 201, 301, 304, 316) that are heat treated (annealed) and differently hardened by cold worked procedures (1/16, 1/4 and 1/2 *hard*). Minimum values of 0.2 % proof stress $f_{0.2}$, tensile strength f_u , modulus of elasticity E , and strain hardening exponent n , are compared in Table 1 for structural austenitic steel grade 1.4301 (SEI/ASCE 304) according to European [4, 9] and the US standards [2].

Austenitic stainless steel is a highly ductile material with the elongation after fracture of 40 % to 60 %, which is almost two times more when compared to equivalent carbon steel values. This property is of special significance for dynamically loaded structures and structures exposed to impact. A significant plasticisation capacity enables the use of plastic analysis during calculation, and redistribution of influences between structural elements.

The thermal expansion for austenitic stainless steel in the temperature range from 20 to 500°C amounts to 18×10^{-6} 1/°C, which is by about 50 percent more compared to carbon steel, while the thermal conductivity is almost three times smaller, and amounts to 15 W/mK at 20°C. This causes higher levels of residual temperature stress and local deformation in the welding zone, especially in case of thin walled welded elements. Unlike carbon steel, due to high nickel content, most austenitic stainless steels are characterized by stability of mechanical properties at higher temperatures. In the zone of high temperatures from 600 to 800°C, the normalised value of 0.2 % proof stress (as related to ambient conditions) is by up to four times greater and in case of modulus of elasticity almost seven times greater, compared to carbon steel [33]. This fact, confirmed by numerous tests, influences reduction and even elimination of the need to use various fire protection systems in case of load bearing structural elements.

3. Influence of cold forming on mechanical properties of material

Mechanical properties of austenitic stainless steels greatly improve by cold forming. As a response to deformation, the material exhibits a hardening effect as manifested through an increase in the yield strength, smaller increase in tensile strength,

and reduction in ductility. The nature and scope of the change depends on the chemical composition, type of heat treatment, and the value of plastic deformation to which the material is exposed. Current research shows that the intensity of improvement of mechanical properties of material depends on the $f_u/f_{0.2}$ ratio, and the ratio between the internal corner radius and the thickness of the steel plate (r/t). The 0.2 % proof stress in the corner of a cold-formed section is by up to fifty percent greater compared to the 0.2 % proof stress of the virgin material of the steel plate. The comparison of stress–strain curves obtained by tensile strength testing for coupons taken from the corner of cold-formed cross section (c) and from the virgin material (v) for stainless steel grade 1.4301 is shown in Figure 3.

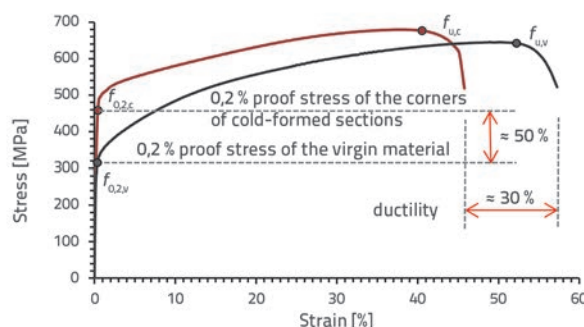


Figure 3. Tensile stress-strain curves obtained by testing coupons from section corner and virgin material for stainless steel grade 1.4301 [24]

The improvement of mechanical properties was not observed in case of products that were exposed to heat treatment after cold forming. In addition, the welding in the regions of bending of cold-formed sections degrades mechanical properties and brings them back almost to the pre-cold-forming level. Cruse and Gardner [34] propose equations for predicting the 0.2 % proof stress and ultimate tensile strength at the flat part of the cold-rolled cross-section, but also the 0.2 % proof stress in the corner of the press-braked and cold-rolled stainless steel sections. The authors confirm that a significant increase 0.2 % proof stress occurs in the corner region only, in case of press-braked sections and that, in case of cold-rolled sections, significant but somewhat lower plastic deformations are observed at flat parts in regards to the corner region of cross-section. For these sections, the curved corner region including the corner radius but which extends $2t$ beyond it. Rossi et al.

[35] define an innovative general analytical model for estimating the 0.2 % proof stress as a function of plastic strains that occur in all phases of the cold-forming process. Assuming that the hardening is distributed over the cross section according to patterns defined by Cruse and Gardner [34], the authors provide the expression for an average value of 0.2 % proof stress for the entire cold-formed section as a function of the corner region area and the total cross-sectional area.

Although stainless steel is most often used in construction industry as a cold-formed product, the influence of cold work on the improvement of mechanical properties is not comprised in European [4] and American [2] standards for stainless steel. According to EN 1993-1-3 [6], the expression for the average 0.2 % proof stress of cold-formed cross sections is not applied in case of stainless steel elements. Favourable cross-section forming using cold forming procedures improves mechanical properties of material, but also the resistance of cross-section to local buckling, which is significant in terms of rationalisation of material consumption, especially considering the high price of stainless steel.

4. Residual stress

The imperfection of real elements - residual stresses and geometrical imperfections - can greatly affect the ultimate resistance of compression members. Cruise and Gardner [36] conducted in 2008 an expensive research program aimed at determining the levels and distribution of residual stresses for hot-rolled, cold-formed and welded I-sections made of stainless steel.

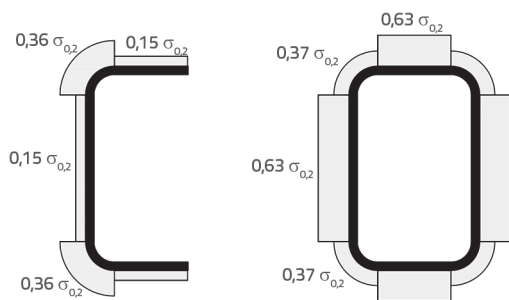


Figure 4. Proposed bending residual stress model for press braked and cold-rolled sections, [36]

In case of cold-formed sections, typical values of longitudinal stress due to bending have their maximum at corner section, where a significant local plasticisation of material occurs due to cold working, while in case of hollow cold-rolled sections the stress distribution follows an inverse pattern, as shown in Figure 4. A rectangular distribution along the wall thickness, and tensile stress at external areas of cross-section, can be assumed in both cases. In case of welded I-sections, the distribution of residual stress with the maximum tensile stresses in the weld regions, and lower compressive stress values in other parts of cross-section, were confirmed. It was observed that the tensile stress at the webto flange connection is of greater intensity

in case of austenitic and duplex steels, and that the area of influence is greater, which is due to thermal properties of these materials. As to ferritic stainless steels, the use of the carbon steel model proposed in the Swedish national standard BSK 99 is proposed. Analytical residual-stress distribution models for welded I-sections according to [36] are proposed in Figure 5.

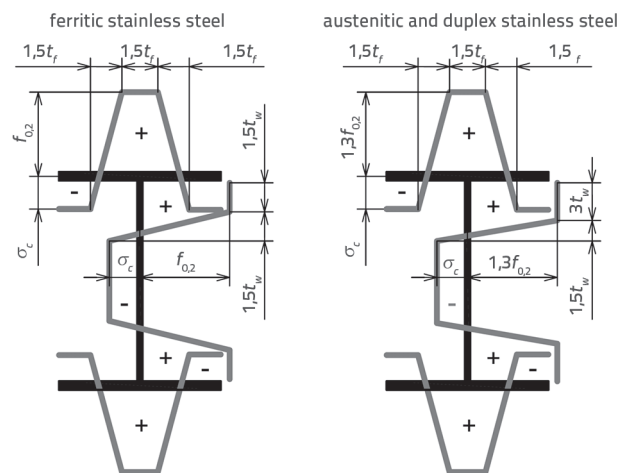


Figure 5. Proposed membrane residual stress model for welded I-sections [36]

5. Resistance of cross-section to compression

In case of elastoplastic materials, the theory of elastic buckling can be used in the initial part of stress only. Based on conclusion reached by Stowell (1948), Bleich [37] defines the expression for the critical local buckling stress $\sigma_{cr,inel}$ of a rectangular plate in the inelastic stress range, as a function of the tangent modulus E_t :

$$\sigma_{cr,inel} = \sqrt{(E_t / E)} \frac{k_\sigma \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = \eta \frac{k_\sigma \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = \eta \sigma_{cr,el} \quad (2)$$

where η is the plastic reduction coefficient, while k_σ is the buckling coefficient that has the same value as in the elastic stress range. When analysing influence of the nonlinear stress-strain relationship on the bearing capacity of the stiffened and unstiffened cold-formed sections, Van den Berg [38] confirms the influence of the tangent modulus on the critical local buckling stress as given in the expression (2), and concludes that the influence of the secant modulus E_s is more dominant in case of unstiffened cross-sections. Results obtained by Van den Berg [38] were included in the procedure for calculating the bearing capacity of cross-sections according to the US standard [2]. According to [2], the bearing capacity of cross-sections is determined as the multiplication of gross cross sectional area A and the allowed compressive stress σ_b that is obtained by reducing the critical buckling stress $\sigma_{cr,inel}$ which is not greater than the 0.2 % proof stress $f_{0,2}$.

The calculation of the bearing capacity of cross sections as per the European code for stainless steels [4] is based on the

effective cross section concept, according to which the cross-section failure may occur by material yielding or by local buckling in the initial elastic stress range. This design concept, based on the analysis of behaviour of elastoplastic materials with the bilinear stress-strain relationship, does not take into account the influence of gradual yielding of material that is exhibited by austenitic stainless steels. According to [4], the cross-sections compression resistance is defined as the multiplication of the 0.2 % proof stress $f_{0,2}$ and the gross cross-section area (class 1, 2 or 3), or the effective cross-section area in case of class 4. Taking as the basis the significantly greater number of available experimental data during analysis of behaviour of stub columns subjected to pure compression and beams subjected to bending (2008), Gardner and Theofanous [39] correct the existing slenderness limit values for cold formed and welded stainless steel cross sections according to [4] and greatly harmonise these values with those applicable to carbon steels.

5.1. Continuous strength method

The effective cross-section concept is a method by which the load bearing capacity of cross sections is defined as a function of the yield strength, as maximum limit values of stress that can be attained in cross-section. In case of austenitic stainless steel, this method neglects significant influence strain hardening of material due to cold working, which as a consequence may provide conservative results, especially in case of stocky cross-sections whose bearing capacity is defined with stress values in excess of the 0.2 % proof stress.

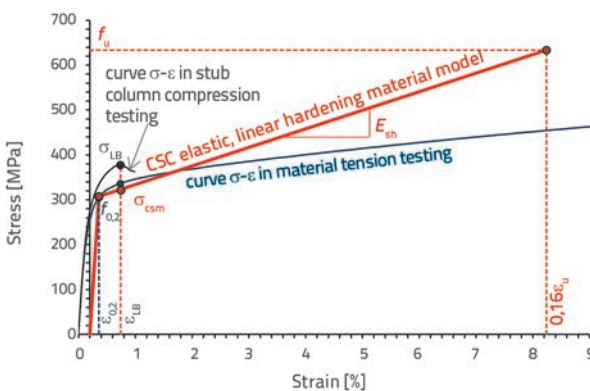


Figure 6. Model of material according to continuous strength method

The continuous strength method (CSM) [40] is a modern approach to the evaluation of the cross-section buckling that has been developed in recent years at the Imperial College in London, as a result of extensive study of the behaviour of stainless steel elements subjected to compression and bending. The very bases of this method are: the continuous relation between the cross-section slenderness and deformation capacity, material nonlinearity, and significant influence of strengthening material during the cold forming process. The nature of the stress-strain relationship in case of stainless

steel, with the absence of sharply defined yield point, implies that the resistance of cross sections is not defined by stress at which its yield begins. According to this method, the stress at which the cross-section buckling occurs represents the only physical limit to the continuous improvement of mechanical properties of the material. The continuous strength method can be applied for cross-sections whose relative slenderness λ_p amounts to less than 0.68. This value defines the limit between slender cross-sections where the bearing capacity is exhausted due to local buckling in the elastic stress region, and non-slender cross-sections where buckling occurs in inelastic region. The deformation capacity of cross section is expressed in a normalised form and, in case of non-slender cross-sections, it represents the ratio of value obtained by subtracting the plastic strain at the 0.2 % proof stress from the actual local buckling strain $\epsilon_{csm} (= \epsilon_{lb} - 0.002)$, and the elastic strain corresponding to the 0.2 % proof stress $\epsilon_{0,2,el} (= f_{0,2}/E)$.

First versions of the CSM are based on the Ramberg-Osgood material model, and they resulted in relatively complex equations. The research has proven that, by adoption of the simplified material model, the design equations obtain a form that is more acceptable for incorporation into technical regulations. That is why a two-phase elastic "linearly hardening" analytical model was adopted (Figure 6). The slope of the elastic region is defined by the elastic modulus $E = f_{0,2}/\epsilon_{0,2,el}$ and the slope of the strain hardening region E_{sh} is defined by the slope of the straight line passing through the points defined by the coordinates $(\epsilon_{0,2,el}; f_{0,2})$ and $(0,16\epsilon_u; f_u)$. Thus defined material model, with the coordinate start at 0.2 % off-set plastic strain, in combination with the cross-section deformation capacity ϵ_{csm} , provides an estimation of the limit stress value σ_{csm} at which the bearing capacity is exhausted:

$$\sigma_{csm} = f_{0,2} + \frac{f_u - f_{0,2}}{E(0,16\epsilon_u - \epsilon_{0,2,el})} \left(\frac{0,25}{\lambda_p^{3,6}} - 1 \right) \tag{3}$$

Finally, the design resistance of the compression cross-section is defined as the multiplication of the limit stress σ_{csm} and the gross cross-sectional area A that is reduced by the material partial safety factor γ_{M0} .

The implementation of the continuous strength method, with the observed influence of material improvements at corners of the cold-formed cross-section, shows an extremely great level of correspondence with experimental results on stainless steel stub columns [24] as compared to the European standard [4] that provides much more conservative results.

6. Analysis of flexural buckling of elements

Taking into account nonlinearity of stress-strain relationships, Engeser (1889) replaces the elastic modulus E with the tangent modulus E_t in the expression for the Euler critical buckling force. The tangent modulus theory, which is the basis for the design according to the US regulations [2], starts from the hypothesis that each element is ideally flat and that it has no structural

imperfections. According to [2], the nominal limit stress value at flexural buckling σ_n can be calculated as follows:

$$\sigma_n = \frac{\Pi^2 E_t}{(kL/i)^2} \quad (4)$$

where k is the buckling length coefficient, while i is the radius of gyration. The tangent modulus is the slope of the tangent on the σ - ε curve at the point corresponding to the stress at which the flexural buckling occurs, and is defined according to the Ramberg Osgood expression:

$$E_t = \frac{E f_{0,2}}{f_{0,2} + 0,002nE(\sigma / f_{0,2})^{n-1}} \quad (5)$$

The iterative calculation method must be used as the slope of the curve changes with the change in stress. The nominal, limit value of the flexural buckling force $F_{n'}$ is determined as the multiplication of the limit stress σ_n and the corresponding gross or effective cross-sectional area A , the calculation of which is based on the effective width concept.

The design of flexural buckling resistance of compression members according to the European standard [4] is based on the Ayrton-Perry function that takes into account imperfection of real elements with regard to limit bearing capacity: residual stresses and geometric imperfections. Some differences in the selection of imperfection factor α and the non-dimensional limiting slenderness λ_{cr} , as compared to standards for carbon steel [5, 6], lie in the influences of low proportionality limit, significant strain hardening of material, and different distribution of residual stresses. Only two buckling curves, C and D, are proposed. These curves take into account equivalent geometrical imperfections of elements, and their choice depends on the form of cross-section and axis around which the buckling occurs. It should be emphasized that the standard [4] does not explicitly consider the issue of element resistance to torsional and torsional-flexural buckling, or the buckling of the uniform built-up compression members, and in many provisions it makes reference to standards relating to carbon steel [5, 6]. The testing conducted in recent years on various types of stainless steel members have revealed that the Ayrton-Perry function should be modified by introducing the strain hardening exponent n , according to [41, 42]. The results

obtained by Rasmussen and Rondal [41] were implemented into the Australian regulation AS/NZS 4673 [7] as an alternative to the calculation procedure according to the tangent modulus theory. The influence of nonlinearity is the greatest in the region of average slenderness of members, where a material with a lower strain hardening exponent has a greater tangent modulus value, and hence also a greater bearing capacity of elements. In the region of high slenderness, when the flexural buckling of members occurs in the elastic range of stress, the influence of nonlinearity is negligible, while the differences in behaviour between carbon and stainless steel elements are insignificant. In the region of small slenderness values, where the bearing capacity of members exceeds the value of $Af_{0,2}$ due to strain hardening of material, stainless steels are less susceptible to flexural buckling, when compared to carbon steels.

7. Conclusion

It can generally be stated that the behaviour of stainless steel structures has been studied for a relatively short period of time, and is therefore still subject of topical research. As to the design of stainless steel members subjected to pure compression, the EN 1993-1-4:2006 is not as all-embracing and detailed as in the case of carbon steels. Latest research shows that the standard is conservative in some segments, which is certainly an aggravating factor hindering greater application of stainless steel, taking into account its high cost. The researches have pointed to the significance of a more detailed analysis of gradual yielding, and of the influence of material strain hardening due to cold working. The continuous strength method enables better prediction of the compression resistance of non-slender cross-sections, compared to the EN 1993-1-4:2006 and the US regulations SEI/ASCE 8-02. As to flexural buckling members, only two buckling curves (C and D) are planned, and these curves do not clearly define the form of cross-section. In addition, recommendations for the design of resistance to torsional and torsional-flexural buckling are not explicitly presented. In order to increase the competitive edge of stainless steel in construction industry, it is indispensable to conduct further investigations in order to shed more light on the specific features and advantages of this material, and to evaluate them through appropriate technical regulations.

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