Designing Structural Stainless Steel Members To Eurocode 3

Nancy Baddoo, SCI Manager, Materials, explains the engineering techniques required to design stainless steel sections to Eurocode 3.

Structural stainless steel at Gent Sint Pieters railway station in Belgium. Photo: Patrick Lints.

1. Structural stainless steel grades

Stainless steels have been used for structural applications ever since they were invented. They are attractive and highly corrosion resistant, whilst at the same time having good strength, toughness and fatigue properties alongside low maintenance requirements. They can be fabricated using a wide range of commonly available engineering techniques.

Both austenitic and duplex stainless steels are used for structural applications. Austenitic stainless steels provide a good combination of corrosion resistance, forming and fabrication properties, with design strengths around 220N/mm^2. The most commonly used grades are 1.4301/1.4307 (widely known as 304/304L) and 1.4401/1.4404 (widely known as 316/316L). Grades 1.4301/1.4307 are suitable for rural, urban and light industrial sites whilst grades 1.4401/1.4404 are more highly alloyed grades and will perform well in marine and industrial sites. Duplex stainless steels such as grade 1.4462 have high strength (around 450 N/mm^2), good wear resistance with very good resistance to stress corrosion cracking. The new 'lean duplexes' offer high strength combined with a leanly alloyed chemical composition, for example grade 1.4162 has a proof strength of around 450 N/mm^2, and a corrosion resistance between the austenitic grades 1.4301/1.4307 and 1.4401/1.4404.

The mechanical and physical properties for use in designing stainless steel structural members are given in EN 10088 *Stainless Steels*. Parts 4 and 5 of this standard are shortly to be issued which concentrate on grades for use in construction.

2. Development of a European design standard

Stainless steel structural members behave similarly to carbon steel members, although there are some important differences arising from the material's distinctive strength, stiffness and physical properties. The major difference between the mechanical properties of carbon and stainless steel is the stress-strain relationship: stainless steel has a continuous, but non-linear, relationship between stress and strain, whereas carbon steel has a clearly defined yield point. This means that different section classification limits and buckling curves apply, and a different approach to estimating beam deflections is necessary to account for the non-linear stiffness.

In recognition of the many desirable properties of stainless steel, SCI, with a number of European partners, have carried out a series of research projects to generate design guidance over the last 20 years. Based on the results of this work, CEN issued EN 1993-1-4 *Design of steel structures, Supplementary rules for stainless steels* in 2006 and the accompanying UK National Annex has just been published by BSI. EN 1993-1-4 extends the application of EN 1993-1-1 (covering general rules for the structural design of hot rolled and welded carbon steel sections) and EN 1993-1-3 (covering design of cold-formed light gauge carbon steel sections) to a wide range of austenitic and duplex stainless steels.

As EN 1993-1-4 has supplementary status, it only contains expressions where the carbon steel rules are unsuitable, and as such it cannot be used in isolation but alongside EN 1993-1-1, EN 1993-1-3, EN 1993-1-5 etc. To provide designers with one guidance document containing nearly everything needed for designing structural stainless steel, the Third Edition of the Euro Inox *Design Manual for Structural Stainless Steel* was published in 2006 (*www.steel-stainless.org/designmanual*). Aligned to EN 1993-1-4, the recommendations in the Design Manual cover member and joint design, fatigue and fire resistant design, supported by design examples and a detailed commentary. Free online design software is also available at *www.steel-stainless.org/software*.

EN 1993-1-4 contains three informative annexes which give guidance on:

- grade selection and durability of different grades
- special design rules for work hardened stainless steel
- how to model material behaviour in finite element analyses.

3. Classification of cross sections

Stainless steel members are classified in the same way as carbon steel members although the actual limits differ to suit the particular stress-strain characteristics of the material (generally the limits are lower). A more conservative approach is adopted for taking into account the reduced resistance of Class 4 stainless steel cross sections which depends on whether the element is internal or external, and welded or cold-formed.

The reduction factor ρ is calculated as follows:

Cold formed or welded internal elements: $\rho = \dfrac{0.772}{\bar{\lambda}_p} - \dfrac{0.125}{\bar{\lambda}_p^{\,2}}$ but ≤ 1

Cold formed outstand elements: $\rho = \dfrac{1}{\bar{\lambda}_p} - \dfrac{0.231}{\bar{\lambda}_p^{\,2}}$ but ≤ 1

Welded outstand elements: $\rho = \dfrac{1}{\bar{\lambda}_p} - \dfrac{0.242}{\bar{\lambda}_p^{\,2}}$ but ≤ 1

where $\bar{\lambda}_p = \dfrac{\bar{b}/t}{28.4\varepsilon\sqrt{k_\sigma}}$ is the element slenderness, defined as for carbon steel.

4. Resistances of cross sections

Cross section design is generally the same as that for carbon steel in EN 1993-1-1 and EN 1993-1-3.

5. Resistances of compression members

When considering the buckling of stainless steel columns, it is necessary to take into account the effect of the low proportional limit, residual stresses and the gradual yielding behaviour of stainless steel. The buckling curves in EN 1993-1-4 were derived by calibration against experimental data; based on the initial modulus, they take a similar form as the equivalent expressions for carbon steel. It was considered preferable to have this explicit design solution as opposed to using the tangent modulus corresponding to the buckling stress which would have required an iterative solution.

As for carbon steel, the reduction factor to be applied to the squash load to account for flexural buckling, χ is given by:

$$\chi = \frac{1}{\varphi + \left[\varphi^2 - \bar{\lambda}^2\right]^{0.5}} \leq 1$$

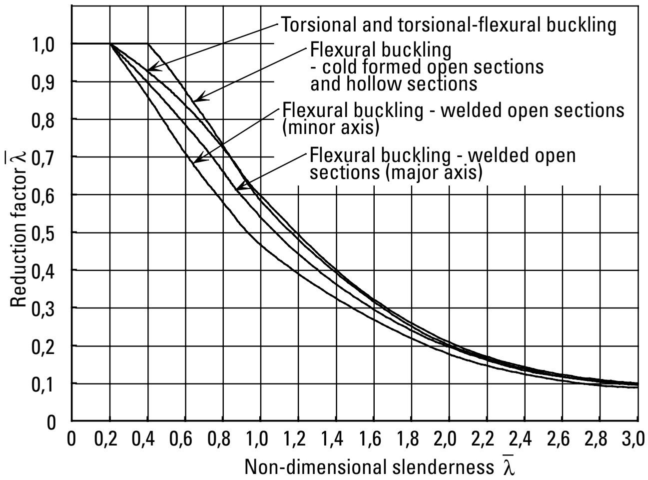
in which

$$\varphi = 0.5\left(1 + \alpha\left(\bar{\lambda} - \bar{\lambda}_0\right) + \bar{\lambda}^2\right) \quad \text{and} \quad \bar{\lambda} = \frac{l}{i}\,\frac{1}{\pi}\sqrt{\frac{f_y \beta_A}{E}}$$

where:

- f_y is the yield strength
- l is the buckling length
- i is the radius of gyration of the gross cross section
- β_A is the ratio of the effective cross section area to the gross cross section area
- α is the imperfection factor
- $\bar{\lambda}_0$ is the limiting slenderness
- E is the initial modulus, given in EN 10088-1 as 200 000 N/mm² for the typical grades of structural stainless steel

The values for α and $\bar{\lambda}_0$ depend on the mode of buckling and the type of member and the buckling curves are shown in Figure 1.



Type of member	α	$\bar{\lambda}_0$
Flexural buckling:		
Cold formed open sections	0.49	0.40
Hollow sections (welded and seamless)	0.49	0.40
Welded open sections (major axis)	0.49	0.20
Welded open sections (minor axis)	0.76	0.20
Torsional and torsional flexural buckling		
All members	0.34	0.20

Figure 1: Buckling curves for flexural, torsional and torsional-flexural buckling

6. Resistance of flexural members

The guidance for calculating the lateral torsional buckling resistance of stainless steel beams is the same as for carbon steel except that $\bar{\lambda}_0$, the limiting slenderness, is taken as 0.4 and α_{LT}, the imperfection factor, is taken as 0.34 for cold formed sections and hollow sections and 0.76 for welded open sections.

When it comes to shear buckling, the expression for χ_f, the contribution to shear buckling resistance from the flanges, is modified for stainless steel to suit the results of tests on stainless steel plate girders.

7. Determination of deflections

The deflection of stainless steel beams may be estimated by standard structural theory, except that the secant modulus of elasticity E_s should be used instead of the initial modulus. Although E_s varies with the stress level in the beam, as a simplification, this variation may be neglected and the minimum value of E_s for that member may be used throughout (corresponding to the maximum values of the stresses σ_1 and σ_2 in the member). The value of E_s may be obtained as follows:

$$E_s = (E_{s,1} + E_{s,2})/2$$

where:

- $E_{s,1}$ is the secant modulus corresponding to the stress σ_1 in the tension flange
- $E_{s,2}$ is the secant modulus corresponding to the stress σ_2 in the compression flange

$$E_{s,i} = \frac{E}{1 + 0.002\,\dfrac{E}{\sigma_{i,Ed,ser}}\left(\dfrac{\sigma_{i,Ed,ser}}{f_y}\right)^n} \quad \text{and } i = 1, 2$$

where:

$\sigma_{i,Ed,ser}$ is the serviceability design stress in the tension or compression flange

EN 1993-1-4 gives values for n, the Ramberg Osgood parameter.

8. Design aids for structural stainless steel

Euro Inox *Design Manual for Structural Stainless Steel* (with design examples and a background commentary, available in seven languages).
www.steel-stainless.org/designmanual
European software for designing structural stainless steel (including fire resistant design, recently extended to cover hot rolled and welded sections as well as cold formed sections and including an online database of sections).
www.steel-stainless.org/software
Online Information Centre for Stainless Steel in Construction which contains resources about the design, specification, fabrication and installation of stainless steel in construction.
www.stainlessconstruction.com