Stalatube stainless steel member calculation guide

Eurocode comparison and learning material for structural engineers

Foreword

This report is an introduction to the Eurocode based design of stainless steel members for structural engineers, who are already familiar with Eurocode design of carbon steel. We have chosen austenitic 1.4307 and duplex 1.4062 as example materials, and their properties have been compared to S355 carbon steel. The material properties are introduced in chapter 1 and summarized in chapter 3. In chapter 2, EN 1993-1-4 design rules for stainless members have been compared to the corresponding rules of EN 1993-1-1. This report includes the latest updates from EN 1993-1-4/A1 and SCI Design Manual for Structural Stainless Steel 4th Edition. The updates referred from the new SCI Design Manual are expected to be also in the next versions of Eurocodes EN 1993-1-4 and EN 1993-1-2.

Our purpose is to offer the structural engineers a practical package of knowledge and help them to learn the essential structural differences and benefits of stainless steels compared to carbon steels. This report is a quick overview to stainless steel design and it should not be used as a replacing engineering tool of Eurocodes or SCI Design Manual.

This report has been written in cooperation with Stalatube Oy and A-Insinöörit Oy.

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1 Material properties

1.1 Material selection guidance

The stainless steels used in structural members can be divided into three main groups according to crystal structure; austenitic, ferritic and duplex stainless steels. The standard steel grades included in Stalatube´s product program are presented in table 1.2 with strength values for different product groups. The austenitic steel grades 1.4404 and 1.4571 are often named “acid proof” stainless steels. The Duplex grades 1.4062 and 1.4162 are named Lean Duplex due to less alloying elements compared to 1.4362 and 1.4462.

Austenitic steel grades have the best formability and duplex steel grades have the highest strength. The main alloying elements characteristic for stainless steels are Chromium (Cr), Nickel (Ni) and Molybdenum (Mo). Chromium and Molybdenum increase corrosion resistance and Nickel is added to increase formability. Price of Nickel is fluctuating strongly, therefore the prices of austenitic steel grades are very volatile, compared to ferritic and duplex grades, which contain less Nickel. Chemical compositions of the steel grades are in accordance with the standard EN 10088.

Strength and corrosion resistance are the main selection criteria for the steel grade. Pitting Resistance Equivalent (PRE) is used in order to compare stainless steels in terms of their resistance to pitting corrosion, which is the most important form of corrosion in stainless steels. Higher PRE value means better pitting corrosion resistance. PRE values for Stalatube´s standard steel grades are shown in table 1.1.

A more specific procedure for material selection based on environment is presented in EN 1993-1-4/A1 [4]. A corrosion resistance factor (CRF) is determined based on three criteria:

1. Risk of exposure to chlorides from salt water or deicing salts.
2. Risk of exposure to Sulphur dioxide.
3. Cleaning regime or exposure to washing by rain.

Based on the value of the CRF factor, the environment is classified to a corrosion resistance class (CRC). The CRC classification of Stalatube´s standard grades are shown in table 1.1. A material selection tool based on this procedure is also available on Stalatube website www.stalatube.com.

Table 1.1 *Corrosion resistance class (CRC) of Stalatube´s standard steel grades according to Eurocode* [4] . *PRE-values are shown in brackets for each grade.*

Corrosion resistance class CRC				
I	II	III	IV	V
1.4003 (12)	1.4301 (18) 1.4307 (18)	1.4404 (24) 1.4571 (24) 1.4062 (26) 1.4162 (26) 1.4362 (28) *)	1.4462 (35)	Requires a special grade (non-standard grade)
*) EDX 2304				

1.2 Strength and stress-strain behaviour

Typical stress-strain curves of stainless steels are shown in Figure 1.1. Unlike carbon steels, stainless steels don’t have a clear yield strength. Therefore 0,2% proof strength is usually used as a design strength. In EN 1993-1-4 the yield strength f_y means the 0,2% proof strength, which is the stress limit, where 0,2 % plastic strain is reached.

The material strengths of EN 1993-1-4 are updated in the amendment EN 1993-1-4/A1 [4]. The applied yield and ultimate strength depend on the product type and thickness. The thickness ranges of Stalatube’s products are less than the thickness limits given in EN 1993-1-4/A1 [4]. For structural hollow sections and welded sections the strength is applied according to the base material product form. The strengths given in table 1.2 can be applied in design for Stalatube’s products.

Table 1.2 *Minimum strengths for Stalatube’s standard steel grades.*

Grade			Roll formed hollow sections		Press brake hollow sections and welded I-Beams	
			(hot rolled strip values)		(hot rolled plate values)	
	US	EN	f_y [MPa]	f_u [MPa]	f_y [MPa]	f_u [MPa]
Ferritic	S40977	1.4003	280	450	250	450
Austenitic	304	1.4301	210	520	210	520
	304L	1.4307	200	520	200	500
	316L	1.4404	220	530	220	520
	316Ti	1.4571	220	540	220	520
Duplex	S32202	1.4062	480	680	450	650
	S32101	1.4162	480	680	450	650
	S32304	1.4362 1)	500	690	420	630
	S32205	1.4462	460	700	460	640
1) EDX 2304						

In EN 1993-1-4 the elastic modulus is 200 GPa for austenitic and duplex and 220 GPa for ferritic grades. In SCI Design Manual it is recommended that the value 200 GPa is used for all stainless steels. [9]

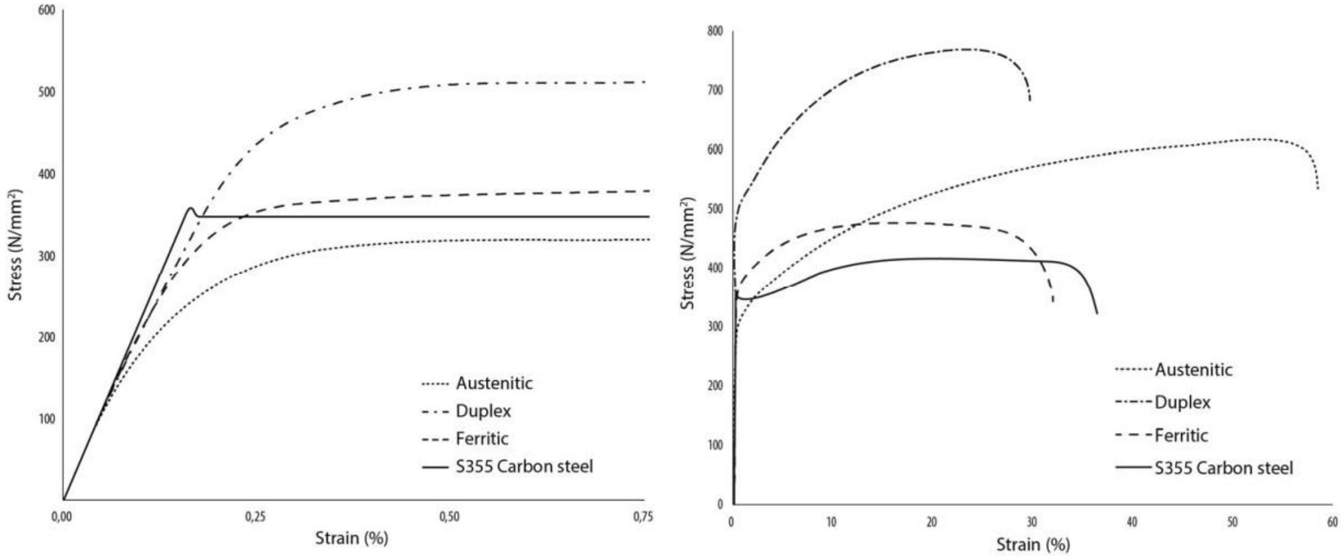

Figure 1.1 *Typical stress strain curves for stainless and carbon steel. Left: strain from 0 to 0,75%. Right: full strain ranges.* [9]

1.3 Utilizing the strain hardening

For cold formed hollow sections it's possible to utilize the strain hardening effect caused by the cold forming. Stalatube has austenitic hollow sections available in cold worked condition according to strength class CP 350 [3]. For these products, named Stala 350, a minimum 0,2% proof strength f_y of 350 MPa and a minimum tensile strength f_u of 600 MPa are guaranteed.

A method for calculating the strength enhancement in cold formed sections is presented in the SCI Design Manual [9]. The idea is to estimate the enhanced strength in the cold formed regions of the section and calculate the average f_{ya} strength for the whole cross section area and use it in lieu of f_y in member design.

SCI Design Manual [9] also presents the Continuous Strength Method (CSM), that gives less conservative design rules to utilize the strain hardening of the cross section in service. CSM can be used for increasing the cross section's resistance, but the increased capacities cannot be used in the design equations, where member stability is considered. Figure 1.2 shows the ratio of the increased design stress $f_{y,csm}$, corresponding the maximum attainable strain ε_{csm}, and yield strength f_y. In the example presented in figure 1.2 the slenderness and cross section class limits (table 2.2) are determined as internal parts subjected to compression. The maximum attainable strain is restrained by the cross section's slenderness (i.e. local buckling effects). With compact cross sections the benefit reached by CSM is significant.

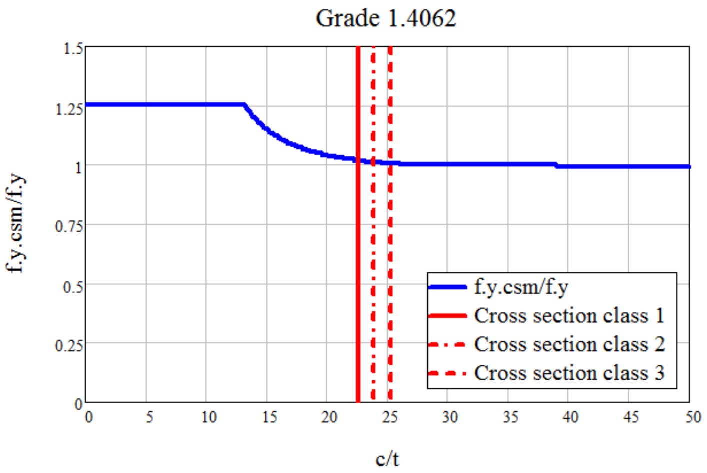

Figure 1.2 *Ratio of design stress $f_{y,csm}$ (corresponding the maximum attainable strain) and yield strength f_y according to Continuous Strength Method* [9].

1.4 Toughness and ductility

It can be seen from figure 1.1 right side, that duplex and austenitic material have high ability for energy absorption in plastic deformation compared to carbon steel. This property is called toughness, and it can be measured by the area under the stress strain curve [11]. Austenitic steels also have high ductility, which can be measured as the ratio of ultimate strain and yield strain $\frac{\varepsilon_u}{\varepsilon_y}$ [10].

Many stainless grades maintain their good ductility also in low service temperatures. Duplex and ferritic grades exhibit a ductile to brittle transition, but austenitic grades don't; their toughness gradually reduces with decreasing temperature [9]. Austenitic grades have the best ductile performance in low temperatures. However, all stainless grades, which are listed in EN 1993-1-4/A1 strength tables, should be accepted as satisfying the ductility requirements of EN 1993-1-1, which apply also for stainless steels [4].

There is no evidence that lamellar tearing occurs in stainless steels [9]. In Eurocode there's no requirement to take lamellar tearing into account in design.

1.5 Material properties in fire design

Stainless steels, especially austenitic and duplex, have several advantages in fire design compared to carbon steel. It is possible to reach up to 30 min fire resistance reasonably without fire protection. Usually carbon steel structures are competitive in fire only 15 min without protection.

The present version of EN 1993-1-2 provides the material parameters in fire for stainless grades 1.4301, 1.4401, 1.4571, 1.4003 and 1.4462. For other stainless grades the effective yield strength $f_{y,\theta}$ can be calculated using carbon steel parameters, which should be on the safe side. However, the EN 1993-1-2 is currently being updated and the expected updates are shown in latest SCI Design Manual [9]. Author's recommendation is to use the design methods of the latest SCI Design manual rather than present version of EN 1993-1-2 Annex C.

SCI Design Manual provides the fire design parameters for the stainless grade groups listed below. All Stalatube's standard materials are included (bolded).

- Austenitic I: **1.4301**, **1.4307**, 1.4318
- Austenitic II: 1.4401, **1,4404**, 1.4541
- Austenitic III: **1.4571**
- Duplex I: **1.4362**, **1.4062**, 1.4482
- Duplex II: **1.4462**, **1.4162**, 1.4662
- Ferritic I: 1.4509, 1.4521, 1.4621
- Ferritic II: **1.4003**, 1.4016

The principal difference to present Eurocode version is, that according to SCI Design Manual [9] 0,2% proof strength $f_{0,2p,\theta}$ or strength at 2 % total strain $f_{2,\theta}$ is used as follows:

- $f_{0,2p,\theta}$ for members subjected to buckling (columns and unrestrained beams) and all Class 4 cross sections
- $f_{2,\theta}$ for restrained beams (lateral torsional buckling not possible) and tension members [9] i.e. members that are not subjected to buckling.

In the present version of EN 1993-1-2 the effective yield f_y, that is used in the design of restrained and non-restrained members, corresponds the strength at 2 % total strain $f_{2,\theta}$.

According to EN 1993-1-2, the emissivity related to the steel surface ε_m is 0,4 for stainless steel and 0,7 for carbon steel. This is an advantage for stainless steel when calculating the net heat flux. In other words, stainless surface reflects away a greater proportion of the heat radiation compared to carbon steel, causing slower temperature development.

The reduction factors for elastic modulus and strength for austenitic 1.4307, duplex 1.4062 and carbon steel S355 are presented in Figure 1.3. When comparing stainless and carbon steel, the following remarks can be done:

- Austenitic and duplex materials maintain their elastic modulus significantly better than carbon steel in high temperatures. This property can be utilized especially in design against buckling. Euler's critical buckling load is linearly depended on the elastic modulus.

- The strength of stainless steel decreases smoothly. The strength decreasing starts immediately after 20 ˚C, while carbon steel maintains its nominal strength until 400 ˚C, after which the strength decreases steeply.

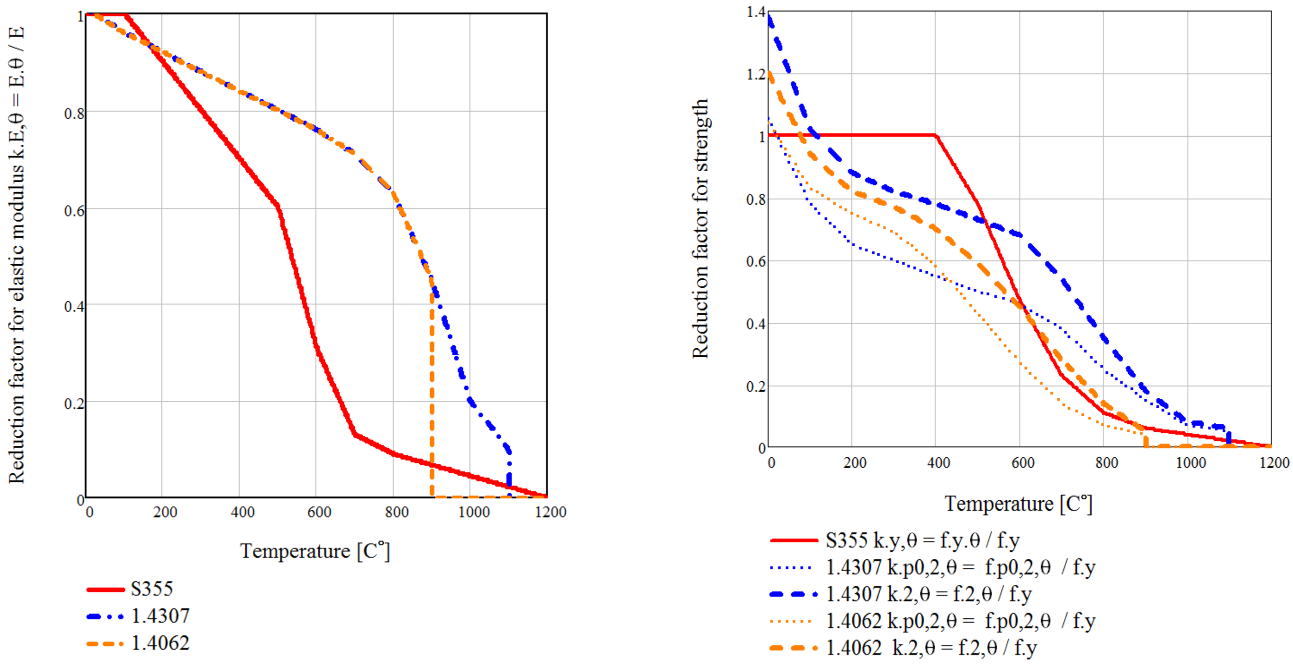

Figure 1.3 *Temperature reduction factors for elastic modulus and strength for S355* [2], *austenitic 1.4307 and duplex 1.4062* [9]. *The effective yield strength reduction factor* $k_{y,\theta}$ *for S355 corresponds the strength at 2 % total strain.*

The present version of EN 1992-1-2 (Annex C) gives only one equation for the specific thermal capacity and thermal conductivity of stainless steel. SCI Design guide provides equations for ferritic materials steels, while the equations given in EN 1992-1-2 is used for austenitic and duplex materials. Specific thermal capacity and thermal conductivity is presented in figure 1.4. Following remarks can be done:

- Specific thermal capacity curves of stainless steels are quite linear, while carbon steel has the infinite peak at 735 ˚C.

- Stainless steels have low thermal conductivity compared to carbon steel. This property can be utilized not only in high temperatures, but also against cold conduction when the steel part penetrates though the wall insulation.

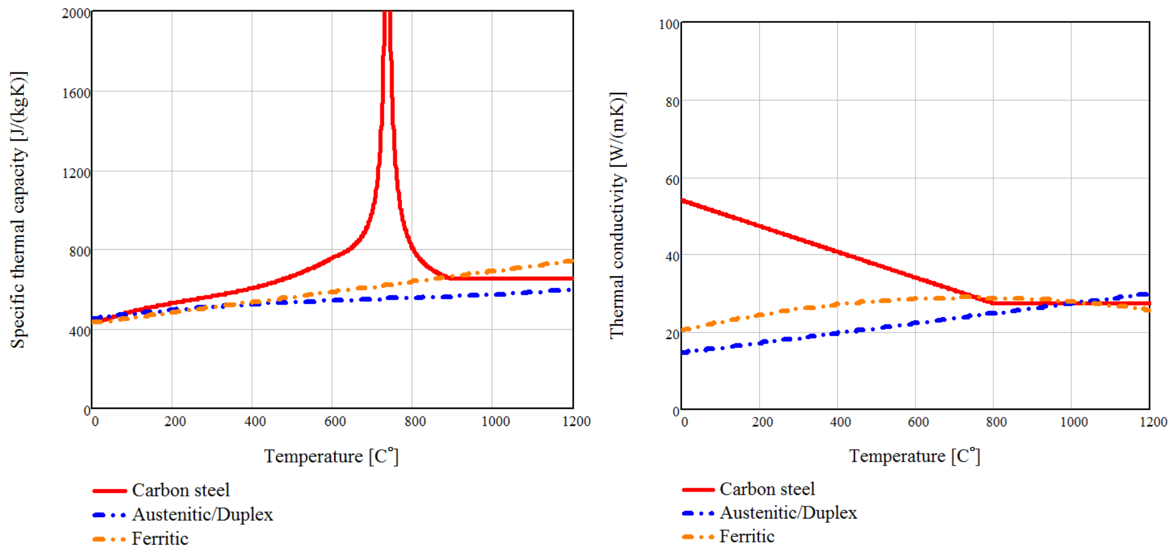

Figure 1.4 *Specific thermal capacity and thermal conductivity for carbon steel, austenitic/duplex and ferritic stainless steel.*

2 Comparison of stainless steel and carbon steel design rules according to EN 1993-1-1 and EN 1993-1-4

2.1 Partial safety factors

The partial safety factors for cross-section resistance and member stability is 1,1 for stainless members (Table 2.1).

Table 2.1 *Recommended partial safety factors for member and cross-section design (can be different in National Annex).*

Purpose	Symbol	EN 1993-1-4	EN 1993-1-1
Cross-section resistance	γ_{M0}	1,1	1
Member stability	γ_{M1}	1,1	1
Cross-section in tension to fracture	γ_{M2}	1,25	1,25

2.2 Serviceability limit state and deflections

The same deflection limits are usually applied for both stainless and carbon steel structures. Bending stiffness can be determined using the secant modulus of elasticity $E_{s,ser}$. Secant modulus is calculated separately for top and bottom flange and the secant modulus used for deflection calculation is the average of top and bottom flange.

The secant modulus for top and bottom flange can be obtained from

$$E_s = \frac{E}{1 + 0{,}002 \frac{E}{\sigma_{Ed,ser}} \left(\frac{\sigma_{Ed,ser}}{f_y} \right)^n}$$

where $\sigma_{Ed,ser}$ is the corresponding stress in top or bottom flange and n is the Ramberg Osgood parameter, which is a measure of non-linearity of the stress-strain curve. [9] EN 1993-1-4 values for parameter n are updated in the SCI Design Manual [9]. The new recommended values are

- $n = 14$ for ferritic
- $n = 7$ for austenitic
- $n = 8$ for duplex

Stress levels and therefore also secant modulus vary in the structural member. The problem can be simplified by calculating the secant modulus $E_{s,ser}$ in the location, where the flange stresses are at the greatest, and use the same secant modulus for the whole member.

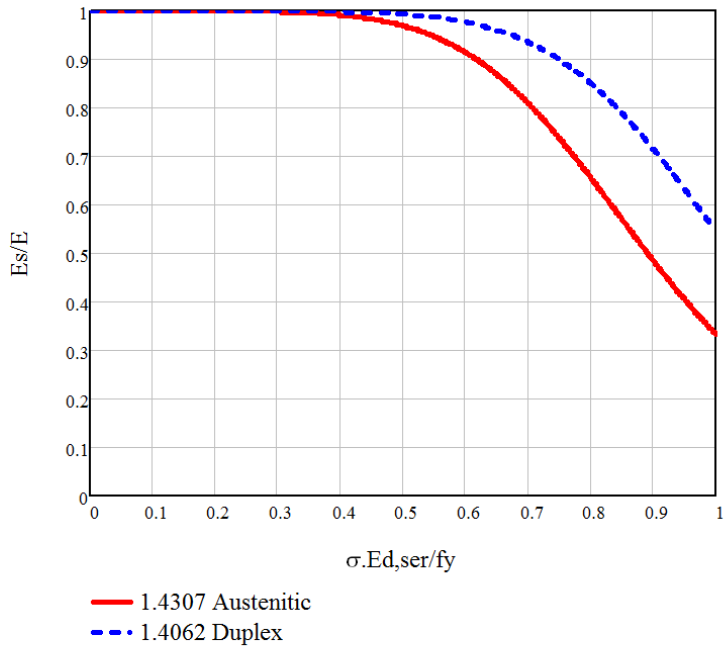

***Figure 2.1** Reduction of elastic modulus as a function of stress ratio.*

2.3 Cross-section classification

Table 2.2 represents some examples of the c/t-limits for stainless and carbon steel. [4] It can be seen, that usually the c/t-limit is lower for stainless steel than the corresponding limit for carbon steel.

Table 2.2 *Examples of c/t-limits in cross-section classification.* [4]

	Internal parts				Outstand flanges	
	Bending		Compression		Compression	
Class	Stainless steel	Carbon steel	Stainless steel	Carbon steel	Stainless steel	Carbon steel
1	72 ε	72 ε	33 ε	33 ε	9 ε	9 ε
2	76 ε	83 ε	35 ε	38 ε	10 ε	10 ε
3	90 ε	124 ε	37 ε	42 ε	14 ε	14 ε

In practice, the lower cross-section classification limits mean, that the strength of a stainless part should be less than a corresponding carbon steel part in order to have the same cross-section class.

2.4 Ultimate limit states

2.4.1 Flexural buckling

When the buckling resistance is calculated, in EN 1993-1-4 the term Φ has an additional paramater $\bar{\lambda}_0$, while in EN 1993-1-1 the corresponding number is always 0,2.

EN 1993-1-4	EN 1993-1-1
$\Phi = 0{,}5\left(1 + \alpha\left(\bar{\lambda} - \bar{\lambda}_0\right) + \bar{\lambda}^2\right)$	$\Phi = 0{,}5\left(1 + \alpha\left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right)$

EN 1993-1-4 values for α and $\bar{\lambda}_0$ are updated in SCI Design Manual [9] (table 2.3) and are expected to be in the next version of EN 1993-1-4. The updated values in table 2.3 are more conservative than in EN 1993-1-4.

The buckling effects may be ignored if

EN 1993-1-4	EN 1993-1-1
$\bar{\lambda} \leq \bar{\lambda}_0$ or $\frac{N_{Ed}}{N_{cr}} \leq \bar{\lambda}_0{}^2$	$\bar{\lambda} \leq 0{,}2$ or $\frac{N_{Ed}}{N_{cr}} \leq 0{,}04$

Table ***2.3*** *Values for α and $\bar{\lambda}_0$ according to SCI Design Manual* [9] *(cold formed angles and channels not shown here) and α for S355 according to EN 1993-1-1.*

Member type	Axis of buck-ling	Austenitic and duplex		Ferritic		S355
		α	$\bar{\lambda}_0$	α	$\bar{\lambda}_0$	α
Cold formed RHS	Any	0,49	0,3	0,49	0,2	0,49
Welded sections	Major	0,49	0,2	0,49	0,2	NA1)
	Minor	0,76	0,2	0,76	0,2	NA1)

1) Different buckling curves for welded I-sections, welded box sections and rolled sections. The buckling curves of welded I-sections depends on the thickness.

Figure 2.2 presents the reduction factor χ for cold formed RHS as a function of non-dimensional slenderness $\bar{\lambda}$. It can be seen, that stainless steel curve is slightly above the carbon steel curve due to the term $\bar{\lambda}_0$.

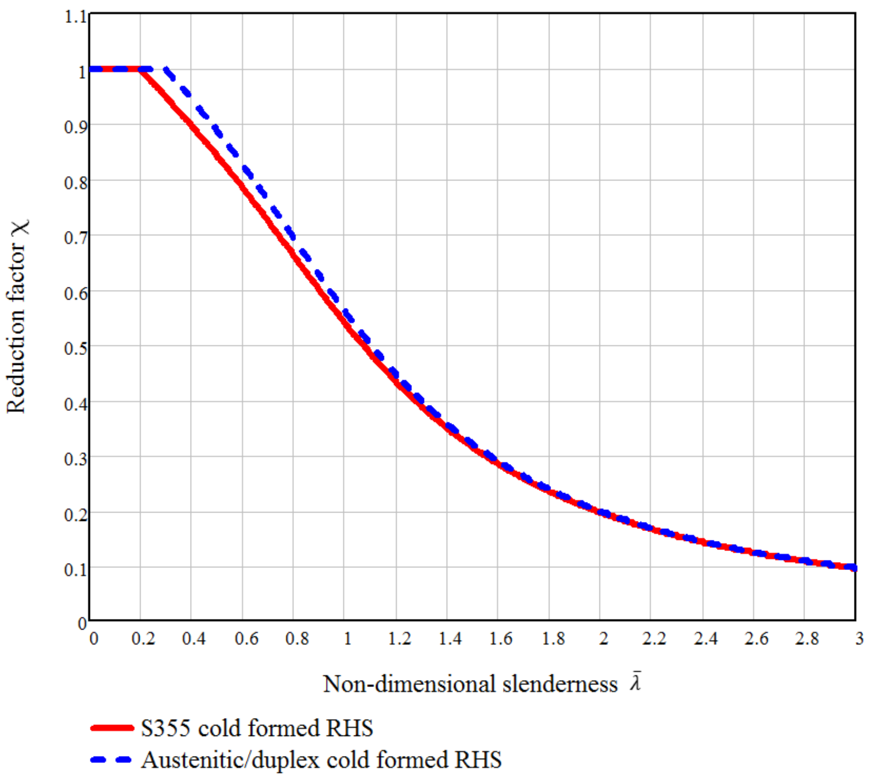

Figure ***2.2*** *Reduction factor χ for austenitic/duplex and S355 cold formed RHS.*

2.4.2 Lateral torsional buckling

When the buckling resistance is calculated, the term Φ_{LT} is

EN 1993-1-4

$$\Phi_{LT} = 0{,}5\left(1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0{,}4) + \bar{\lambda}_{LT}{}^2\right)$$

EN 1993-1-1

General case:

$$\Phi_{LT} = 0{,}5\left(1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0{,}2) + \bar{\lambda}_{LT}{}^2\right)$$

Rolled or equivalent welded sections:

$$\Phi_{LT} = 0{,}5\left(1 + \alpha_{LT}(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}) + \beta\bar{\lambda}_{LT}{}^2\right)$$

where recommended values are (if not given in national annex)

- $\bar{\lambda}_{LT,0} = 0{,}4$
- $\beta = 0{,}75$

Reduction factor is

EN 1993-1-4

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}{}^2 - \bar{\lambda}_{LT}{}^2}}$$

but

$$\chi_{LT} \leq 1$$

EN 1993-1-1

General case:

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}{}^2 - \bar{\lambda}_{LT}{}^2}}$$

but

$$\chi_{LT} \leq 1$$

Rolled or equivalent welded sections:

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}{}^2 - \beta\bar{\lambda}_{LT}{}^2}}$$

but

$$\chi_{LT} \leq 1$$

$$\chi_{LT} \leq \frac{1}{\bar{\lambda}_{LT}{}^2}$$

Imperfection factor α_{LT} for stainless members:

- 0,34 for cold formed sections and hollow sections (welded and seamless)
- 0,76 for welded open sections and other sections

As seen before, EN 1993-1-1 provides two methods for evaluating the lateral torsional buckling curve (general case and rolled or equivalent welded sections) while EN 1993-1-4 provides only one method, which is analogical to EN 1993-1-1 “general case”. In the latter method of EN 1993-1-1 it is also possible to calculate modified reduction factor $\chi_{LT,mod}$, where the reduction factor χ_{LT} is increased by taking the moment distribution between the lateral restraints into account. Modified reduction factor $\chi_{LT,mod}$ is not provided for the “general case”. However, the method for evaluating $\chi_{LT,mod}$ for stainless steel is presented in SCI Design Manual [9].

2.4.3 Combined axial compression and bending

The following conditions are checked for combined compression and biaxial bending:

EN 1993-1-4

$$\frac{N_{Ed}}{(N_{b,Rd})_{min}} + k_y \frac{M_{y,Ed}+N_{Ed}e_{Ny}}{\frac{\beta_{W,y}W_{pl,z}f_y}{\gamma_{M1}}} + k_z \frac{M_{z,Ed}+N_{Ed}e_{Nz}}{\frac{\beta_{W,z}W_{pl,z}f_y}{\gamma_{M1}}}$$

$$\leq 1$$

and

$$\frac{N_{Ed}}{(N_{b,Rd})_{min1}} + k_{LT} \frac{M_{y,Ed}+N_{Ed}e_{Ny}}{M_{b,Rd}} + k_z \frac{M_{z,Ed}+N_{Ed}e_{Nz}}{\frac{\beta_{W,z}W_{pl,z}f_y}{\gamma_{M1}}}$$

$$\leq 1$$

EN 1993-1-1

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy} \frac{M_{y,Ed}+\Delta M_{y,Ed}}{\frac{\chi_{LT} M_{y,Rk}}{\gamma_{M1}}} + k_{yz} \frac{M_{z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}}$$

$$\leq 1$$

and

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + k_{zy} \frac{M_{y,Ed}+\Delta M_{y,Ed}}{\frac{\chi_{LT} M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}}$$

$$\leq 1$$

Term $\beta_{W,y}$ or $\beta_{W,z}$ is

- 1 for class 1 or 2 cross-sections
- $\frac{W_{el}}{W_{pl}}$ for class 3 cross-sections
- $\frac{W_{eff}}{W_{pl}}$ for class 4 cross-sections

Therefore $\beta_{W,y}W_{pl,z}f_y = M_{y,Rk}$ and $\beta_{W,z}W_{pl,z}f_y = M_{z,Rk}$. Also $\frac{\chi_{LT}M_{y,Rk}}{\gamma_{M1}} = M_{b,Rd}$.

In the EN 1993-1-1 inequations the first term considers flexural buckling about y or z axis. In EN 1993-1-4 the first term includes also torsional buckling and torsional-flexural buckling:

- $(N_{b,Rd})_{min}$ is the smallest of the following buckling modes: flexural buckling about the y axis, flexural buckling about the z axis, torsional buckling and torsional-flexural buckling
- $(N_{b,Rd})_{min1}$ is the smallest of the following buckling modes: flexural buckling about the z axis, torsional buckling and torsional-flexural buckling

The logic behind the inequations of EN 1993-1-4 and EN 1993-1-1 is slightly different:

EN 1993-1-4	EN 1993-1-1
<u>1st inequation</u>	<u>1st inequation</u>
"Compressive buckling (flexural or torsional) + bending about y axis + bending about z axis"	*"Flexural buckling about y axis + lateral torsional buckling + bending about z axis"*
<u>2nd inequation</u>	<u>2nd inequation</u>
"Compressive buckling (flexural or torsional) + lateral torsional buckling + bending about z axis"	*"Flexural buckling about z-axis + lateral torsional buckling + bending about z axis"*

The interaction factors of EN 1993-1-4 are updated in SCI Design Manual [9]. They may also be defined in National Annex. The interaction factors for open cross sections according to SCI Design Manual [9] are

- $k_y = 1 + 2(\bar{\lambda}_y - 0{,}5)\frac{N_{Ed}}{N_{b,Rd,y}}$ but $1{,}2 \leq k_y \leq 1{,}2 + 2\frac{N_{Ed}}{N_{b,Rd,y}}$
- $k_z = 1 + 2(\bar{\lambda}_z - 0{,}5)\frac{N_{Ed}}{(N_{b,Rd})_{min1}}$ but $1{,}2 \leq k_z \leq 1{,}2 + 2\frac{N_{Ed}}{(N_{b,Rd})_{min1}}$
- $k_{LT} = 1$

The equations above are the only interaction factors given in EN 1993-1-4. In addition, SCI Design Manual [9] provides different interaction factor for circular and rectangular hollow sections:

- $k_y = 1 + D_1(\bar{\lambda}_y - D_2)\frac{N_{Ed}}{N_{b,Rd,y}}$ but $k_y \leq 1 + D_1(D_3 - D_2)\frac{N_{Ed}}{N_{b,Rd,y}}$
- $k_z = 1 + D_1(\bar{\lambda}_z - D_2)\frac{N_{Ed}}{(N_{b,Rd})_{min1}}$ but $k_z \leq 1 + D_1(D_3 - D_2)\frac{N_{Ed}}{(N_{b,Rd})_{min1}}$

The parameters D_1, D_2 and D_3 can be obtained from table 2.4.

***Table 2.4** Parameters D_1, D_2 and D_3 according to SCI Design Manual* [9].

Cross-section	Grade	D_1	D_2	D_3
RHS	Ferritic	1,3	0,45	1,6
	Austenitic	2,0	0,30	1,3
	Duplex	1,5	0,40	1,4

2.4.4 Shear resistance and shear buckling

If shear buckling doesn't have to be checked, the shear resistance for stainless members is $V_{pl,Rd}$ as given in EN 1993-1-1.

Shear buckling should be checked, if the web height to thickness ratio exceeds the limit value given in the design code. The limit ratios are updated in EN 1993-1-4/A1.

EN 1993-1-4/A1

Webs without transverse stiffeners

$$\frac{h_w}{t_w} > 56{,}2\frac{\varepsilon}{\eta}$$

Webs with transverse stiffeners

$$\frac{h_w}{t_w} > 24{,}3\frac{\varepsilon}{\eta}\sqrt{k_\tau}$$

Recommended $\eta = 1{,}2$ (EN 1993-1-4, may be defined in National Annex)

EN 1993-1-1, EN 1993-1-5

Webs without transverse stiffeners

$$\frac{h_w}{t_w} > 72\frac{\varepsilon}{\eta}$$

Webs with transverse stiffeners

$$\frac{h_w}{t_w} > 31\frac{\varepsilon}{\eta}\sqrt{k_\tau}$$

Recommended values for η (may be defined in National Annex)

$\eta = 1{,}2$ usually

$\eta = 1$ steel grades higher than S460

In EN 1993-1-5 the shear buckling resistance $V_{b,Rd}$ consists of the contribution of web $V_{bw,Rd}$ and the contribution of flanges $V_{bf,Rd}$. Shear buckling resistance is

$$V_{b,Rd} = V_{bw,Rd} + V_{bf,Rd} \leq \frac{\eta f_{yw} h_w t}{\sqrt{3}\gamma_{M1}}$$

where

$$V_{bw,Rd} = \frac{\chi_w f_{yw} h_w t}{\sqrt{3}\gamma_{M1}}$$

and

$$V_{bf,Rd} = \frac{b_f {t_f}^2 f_{yf}}{c\gamma_{M1}}\left(1 - \left(\frac{M_{Ed}}{M_{f,Rd}}\right)^2\right)$$

$M_{f,Rd}$ is the moment resistance of the cross-section, that consists only the flanges.

The method for calculating the reduction factor χ_w is updated in EN 1993-1-4/A1. The reduction factor χ_w for the contribution of web is

EN 1993-1-4/A1		EN 1993-1-5	
With rigid end post		With rigid end post	
η	if $\bar{\lambda}_w < \frac{0,65}{\eta}$	η	if $\bar{\lambda}_w < \frac{0,83}{\eta}$
$\frac{0,65}{\bar{\lambda}_w}$	if $\frac{0,65}{\eta} \leq \bar{\lambda}_w < 0,65$	$\frac{0,83}{\bar{\lambda}_w}$	if $\frac{83}{\eta} \leq \bar{\lambda}_w < 1,08$
$\frac{1,56}{0,91 + \bar{\lambda}_w}$	if $\bar{\lambda}_w \geq 0,65$	$\frac{1,37}{0,7 + \bar{\lambda}_w}$	if $\bar{\lambda}_w \geq 1,08$
With non-rigid end post		With non-rigid end post	
η	if $\bar{\lambda}_w < \frac{0,65}{\eta}$	η	if $\bar{\lambda}_w < \frac{0,83}{\eta}$
$\frac{0,65}{\bar{\lambda}_w}$	if $\frac{0,65}{\eta} \leq \bar{\lambda}_w < 0,65$	$\frac{0,83}{\bar{\lambda}_w}$	if $\bar{\lambda}_w \geq \frac{83}{\eta}$
$\frac{1,19}{0,54 + \bar{\lambda}_w}$	if $\bar{\lambda}_w \geq 0,65$		

When calculating the contribution of flanges the only difference is the term c.

EN 1993-1-4	EN 1993-1-5
$c = \left(0,17 + \frac{3,5 b_f {t_f}^2 f_{yf}}{t_w {h_w}^2 f_{yw}}\right) a$	$c = \left(0,25 + \frac{1,6 b_f {t_f}^2 f_{yf}}{t_w {h_w}^2 f_{yw}}\right) a$
but $c \leq 0,65a$	

The term a is the distance between stiffeners.

3 Summary

The essential differences of the material properties and the structural design rules between stainless and carbon steel members were introduced in this report. There are numerous stainless materials and their properties vary a lot due to their chemical composition. The most important structural benefits that can be achieved using stainless materials are

- resistance against corrosion and low life cycle costs
- large ductility and toughness
- reasonable fire resistance up to 30 min without protection
- low thermal conductivity

The mechanical and physical properties of the example materials 1.4307, 1.4062 and S355 are summarized in table 3.1. The strengths for stainless steels correspond to the hot rolled strip in table 1.2. For S355 the material properties correspond to the thickness range t ≤ 16 mm. Temperature is 20 ˚C if not mentioned otherwise.

Table 3.1 *Summary of mechanical and physical properties for the example materials.*

Property	Symbol	Austenitic 1.4307	Duplex 1.4062	S355
Mechanical				
Nominal yield strength (for stain-less 0,2 % proof strength) [6],[9]	f_y	200 MPa	480 MPa	355 MPa
Ultimate strength [1],[9]	f_u	520 MPa	680 MPa	510 MPa
Elastic modulus [1],[9]	E	200 GPa	200 GPa	210 GPa
Shear modulus [1],[9]	G	76,9 GPa	76,9 GPa	81 GPa
Poisson's ratio [1],[9]	ν	0,3	0,3	0,3
Elongation at fracture [7][6],[9]	A	45 %	20 %	22 %
Ductility	$\frac{A}{\varepsilon_y}$ 1)	450	83	130
Physical				
Density	ρ	7900 kg/m³ [9]	7800 kg/m³ [9]	7850 kg/m³
Thermal expansion factor [1],[9]	α	16,7·10⁻⁶/˚C	13,2·10⁻⁶/˚C	12·10⁻⁶/˚C
Thermal conductivity [2],[9]	λ	15 W/(m·K)	15 W/(m·K)	53 W/(m·K)
Specific thermal capacity	c	500 J/(kg·˚K)	480 J/(kg·˚K)	440 J/(kg·˚K)
Fire design				
Reduction factor for strength at 2 % total strain at 600 ˚C [2],[9]	$k_{2,\theta}$, $k_{y,\theta}$	0,68	0,45	0,47
Elastic modulus reduction factor at 600 ˚C [2],[9]	$k_{E,\theta}$	0,76	0,76	0,31
Steel surface emissivity [2]	ε_m	0,4	0,4	0,7

1) Elongation at fracture A is used in lieu of ultimate strain ε_u, because ultimate strain is not given in the material standards. Yield strain $\varepsilon_y = \frac{f_y}{E}$.

4 References

Eurocodes

[1] SFS-EN 1993-1-1

[2] SFS-EN 1993-1-2

[3] SFS-EN 1993-1-4

[4] SFS-EN 1993-1-4/A1

[5] SFS-EN 1993-1-5

Material standards

[6] SFS-EN 10025-2

[7] SFS-EN 10088-2

Literature

[8] The Steel Construction Institute (SCI), P413 Design Manual for Structural Stainless Steel, 3rd Edition, 2006

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http://www.steel-stainless.org/media/1036/english.pdf (23.8.2017)

[9] The Steel Construction Institute (SCI), P413 Design Manual for Structural Stainless Steel, 4th Edition, 2017. Available online: www.steel-stainless.org/designmanual 11.10.2017

[10] V. Gioncu, Framed structures. Ductility and seismic response. General Report, Journal of Constructional Steel Research 55/2000, p. 125–154

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[11] https://www.nde-ed.org/EducationResources/CommunityCollege/Materials/Mechanical/Toughness.htm (27.8.2017)

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