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Course Description

Designing Structural Stainless Steel: Part 2
Presented by Nancy Baddoo
March 20, 2014

This webinar will explain why stainless steel needs its own design rules and how its unique properties impact both design and fabrication. The scope of the design rules given in the Design Guide will be explained, followed by an explanation of how the design rules were derived. The design rules will be presented, starting with design requirements, and moving on to tension members, members in compression, members in flexure and shear and members subject to combined forces. Aspects of designing bolted and welded connections will also be covered. Design rules for structural fire resistance will be described. The rules will be put into context by comparing them with the existing rules in AISC 360-10 for carbon steel.

Learning Objectives

- Learn and understand the design rules for using stainless steel structural members.
- Gain familiarity with the design of connections with stainless steel structural members.
- Become familiar with the design rules for structural fire resistance with stainless steel structural members.
- Learn and understand the requirements from the AISC Design Guide for structural stainless steel.

Part 2: Designing Structural Stainless Steel

Nancy Baddoo

Designing Structural Stainless Steel Part 2

SCI Steel Knowledge

Nancy Baddoo

20 March 2014

Overview of this Webinar

- Introduction to DG
- Why use stainless steel in construction?
- Stainless steel structural design
  - Why does stainless steel need special rules?
  - Scope of design rules
  - Derivation of resistance/safety factors
- Design rules for members
- Design rules for connections
- Fire resistance

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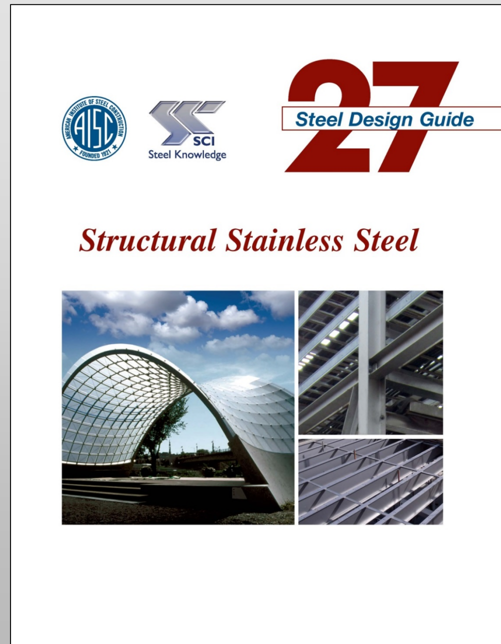

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2 Materials: properties, selection & durability
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7 Design of members for shear
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9 Design of connections
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Appendix B. Commentary to the design rules
Design examples
1 Round HSS in axial compression
2 Square HSS with a slender cross section in axial compression
3 W-shape in compression and bi-axial bending
4 C-shape member in bending about the major axis
5 Flexible end-plate connection
6 Round HSS in axial compression in a fire
Symbols
References

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Why use stainless steel?

- Corrosion resistance and long life
- No coatings and low maintenance
- Attractive metallic surface
- Good impact and blast resistance
- Hygienic properties
- Some types are non-magnetic

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Structural applications of stainless steel

Structural members in aggressive environments

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Structural applications of stainless steel

Structural members with aesthetic appeal

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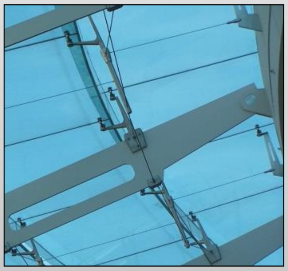
Structural applications of stainless steel

Cladding support, fittings & fasteners



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Structural applications of stainless steel

Safety and security structures

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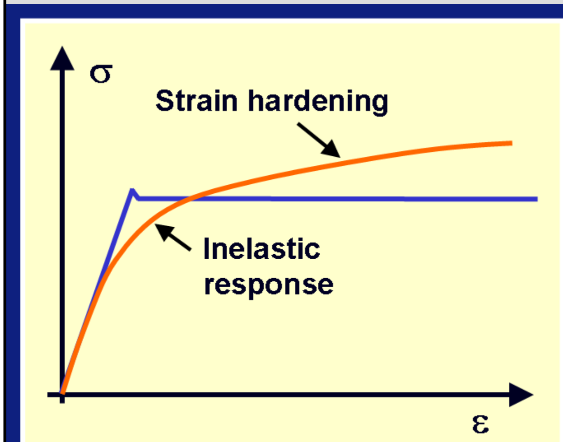
Why does stainless steel need its own design rules?

Stainless steel exhibits fundamentally different behaviour to carbon steel

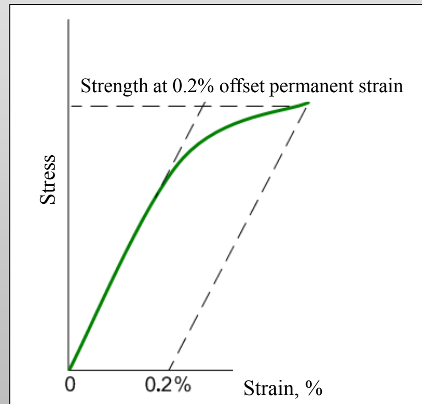


Carbon steel has a sharply defined yield point with a plastic yield plateau.

Stainless steel exhibits gradually yielding behaviour, with high strain-hardening.

What is the yield strength for design?

F_y = strength at the 0.2% offset permanent strain



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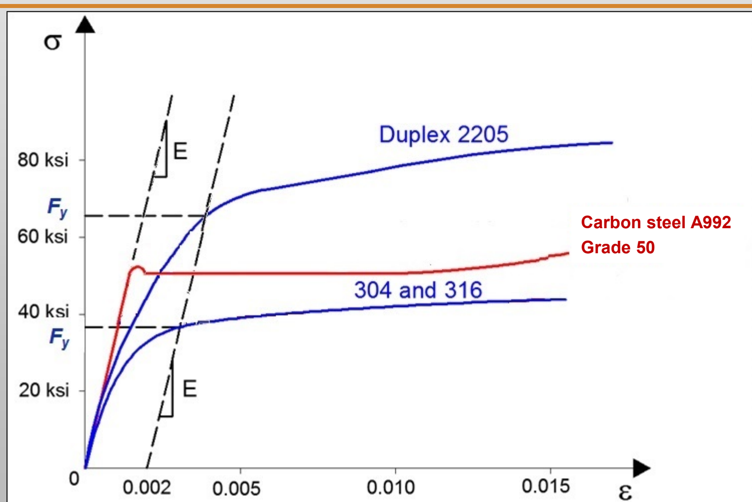
Stainless steel vs carbon steel



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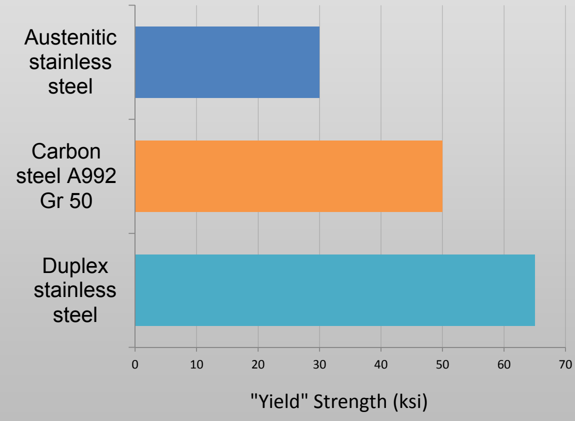
Strength and Elastic modulus



$E_{austenitic}$ = 28,000 ksi

$E_{carbon\ steel}$ = 29,000 ksi

E_{duplex} = 29,000 ksi

Density of stainless steel = 485-500 lb/ft^3

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Stress-Strain Characteristics

Nonlinearity………..leads to

- different limiting width to thickness ratios for local buckling
- different member buckling behavior in compression and bending
- greater deflections

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Impact on buckling performance

- **Low slenderness**
  columns attain/exceed the squash load,
  benefits of strain hardening apparent
  SS behaves at least as well as CS column
- **High slenderness**
  axial strength low, stresses low and in linear region,
  SS behaves similarly to CS, providing geometric and residual stresses similar

Impact on buckling performance

- **Intermediate slenderness**
  average stress in column lies between the limit of proportionality and the 0.2% permanent offset strain,
  SS column less strong than CS column

Strain hardening (work hardening or cold working)

- Increased strength by plastic deformation
- Caused by cold-forming operations e.g. roller leveling/flattening and fabrication

During the fabrication of an HSS, the 0.2% offset yield strength increases by about 50% in the cold-formed corners of cross sections

- ASTM A666 SS in 'cold-worked condition', e.g. ¼ hard, ½ hard etc

Strain hardening is not always useful!

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Stress-Strain Characteristics

- Non-symmetry of tensile and compressive behavior
- Anisotropy (differences in behavior of coupons aligned parallel and transverse to the rolling direction)

Anisotropy and non-symmetry increase with cold work

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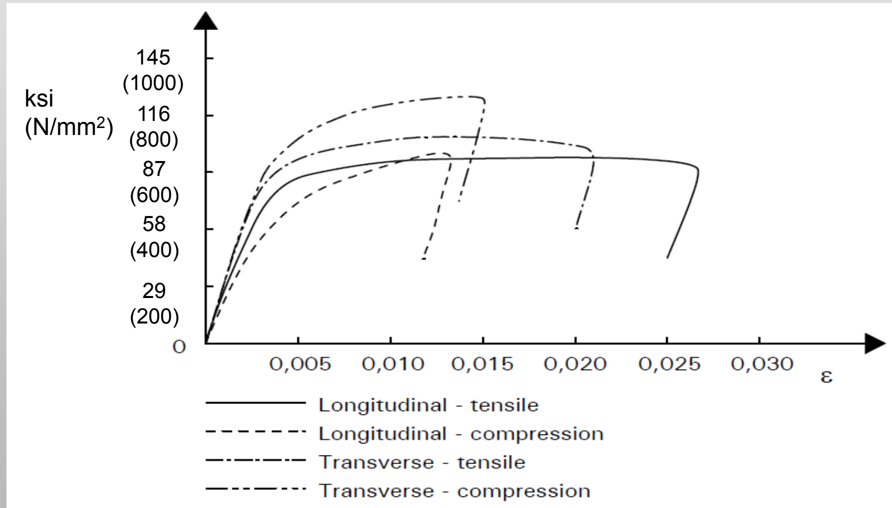
Typical stress-strain curves for grade 301LN in the cold worked condition ¼ hard



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But don't worry!

- The structural sections covered by this Design Guide are not made from heavily cold worked material
  - differences in the stress-strain behavior due to nonsymmetry and anisotropy are not large
  - the nonlinearity has a more significant effect
- Anisotropy and nonsymmetry are more significant in the design of lighter gage, heavily worked sections (covered by ASCE/SEI 8)

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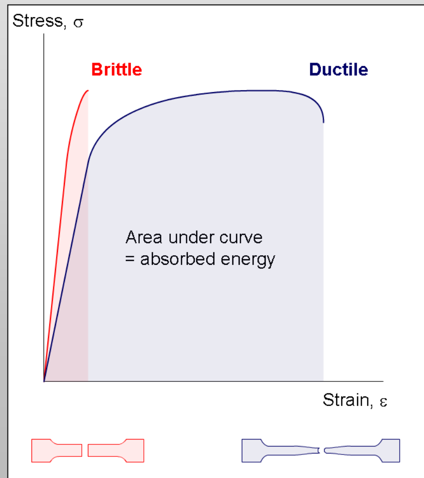
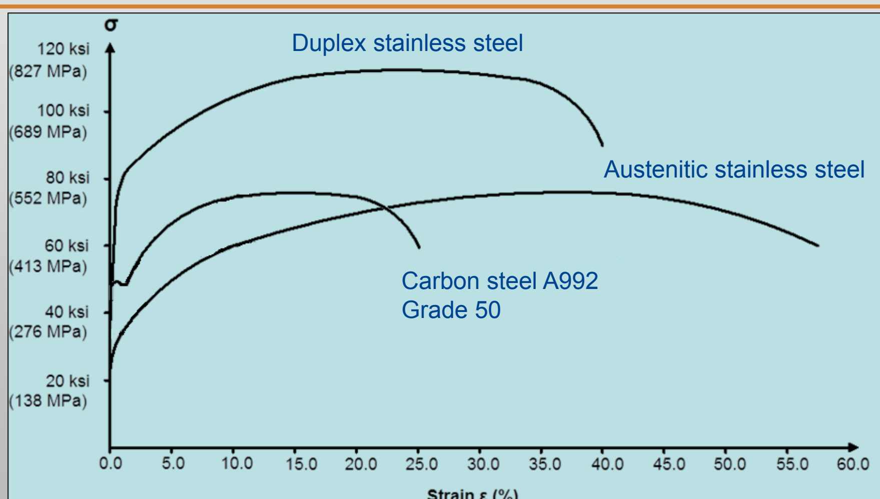
Ductility and toughness



- **Ductility** - ability to be stretched without breaking
- **Toughness -** ability to absorb energy & plastically deform without fracturing

Stress-Strain Characteristics – high strain



Better intrinsic energy absorption properties than Al or carbon steel due to high rate of work hardening & excellent ductility

Damage to the stainless steel railcars was contained within localized areas because of the energy absorbing properties

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Toughness

Austenitics:

No ductile-brittle transition, used for cryogenic applications

Duplexes:

Good low temperature toughness:
- *Lean duplexes show min 30 ftlbF (40 J) in base & weld metal at -58°F (-50°C) for 1.2 in. (30 mm)*
- *2205: even better….*

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Response to seismic loading

- Higher ductility (austenitic ss) + sustains more load cycles
  → greater hysteretic energy dissipation under cyclic loading
- Higher strain hardening
  → enhances development of large & deformable plastic zones
- Stronger strain rate dependency –
  → higher strength at fast strain rates

Design specifications for structural stainless steel

US – ASCE/SEI 8-02 Spec for cold-formed members

South Africa – Spec for cold-formed members

Australia/New Zealand – Spec for cold-formed members

Europe – Eurocode 3-1-4 for cold-formed & welded members

Japan - Specs for cold-formed & welded stainless members

Chinese standard under development

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Scope of design rules

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AISC DG: Structural Stainless Steel

SCOPE

- Hot rolled or welded open structural sections, e.g. I-shaped, channels, equal angles
- Round and rectangular HSS
- t > 0.125 in. (3mm)
- Austenitic and duplex stainless
- Precipitation hardening stainless bar & fasteners
- LRFD and ASD

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Group of Steels	Type	Heat Treatment Condition	F_u	F_y	Min Elong in 2 in.
			ksi	ksi	%
Basic chromium-nickel austenitic	S30400 304	–	75	30	40
	S30403 304L	–	70	25	40
Molybdenum-chromium-nickel austenitic	S31600 316	–	75	30	40
	S31603 316L	–	70	25	40
Lean duplex	S32101 LDX2101®	–	94	65	30
	S32304 2304	–	87	58	25
Standard duplex	S32205 2205	–	95	65	25
Precipitation hardening	S17400 17-4	H900	190	170	10
		H1025	155	145	12
		H1150	135	105	16
Carbon steel A992 Grade 50			65	50	21

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AISC DG: Structural Stainless Steel

Design rules also applicable to other types of austenitic, duplex and PH providing adequate elongation but check durability, fabrication, etc

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Design Guide compared to AISC 360

DG covers **commonly encountered structural shapes and load scenarios** and does not cover every scenario in AISC 360

Why are there omissions?
- no design data….yet
- unlikely that rules needed for stainless steel

Omissions – less commonly encountered structural shapes/load scenarios

- Angles and tees in flexure
- Sections in flexure with slender webs
- Unequal leg angles
- Equal leg angles with slender cross-section
- Round HSS with a slender cross-section

Omissions: no design data yet

- Ch G Tension field action
- Ch H Torsion
- Ch I Composite members
- Ch J Slip critical connections
- Ch K HSS connections
- App 1 Inelastic analysis
- App 2 Ponding
- App 6,7,8 Stability issues

Scope of applicability of stainless steel rules clearly stated in each chapter.

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How the design rules were developed

- Compare AISC 360 rules for carbon steel against all available stainless test data
- Where necessary, modify AISC 360 rules to suit the stainless data
- Calculate the resistance factors to use with the recommended stainless design rules

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Resistance/safety factors

- Comprehensive reliability analysis
- Followed protocol adopted for AISC 360

$$\beta = \frac{\ln\left(R_m / Q_m\right)}{\sqrt{V_R^2 + V_Q^2}} \longrightarrow \phi = \frac{1.481 M_m F_m P_m}{\exp\left(\beta\sqrt{V_R^2 + V_Q^2}\right)}$$

Target Reliability:
β = 2.6 for Members, β = 4.0 for connections

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Resistance/safety factors

- Statistics on material data and geometrical variations of sections
  Mean and **Scatter** both impact the resistance factor
- Database of test results worldwide on stainless structural sections
- Analyzed different failure modes
- App B of DG27 gives results in full

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Resistance/safety factors

Use carbon steel resistance factors

Except

Round HSS in compression ϕ_{ss} = 0.85, ϕ_{cs} = 0.90

Fillet Welds ϕ_{ss} = 0.55 for aust
ϕ_{ss} = 0.60 for duplex
ϕ_{cs} = 0.75

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Design topics

Topic	DG27	AISC 360
Design requirements	Ch 3	Ch B
Design of members for tension	Ch 4	Ch D
Design of members for compression	Ch 5	Ch E
Design of members for flexure	Ch 6	Ch F
Design of members for shear	Ch 7	Ch G
Design of members for combined forces	Ch 8	Ch H
Design of connections	Ch 9	Ch J
Fatigue	Ch 11	Appendix 3
Fire resistance	Ch 10	Appendix 4

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In a nutshell….

Use the same approach as for carbon steel but

- Ensure you use the correct F_y for the type of stainless steel
- Lower limiting width-to-thickness ratios for local buckling
- Different buckling curves for columns and unrestrained beams (LTB)

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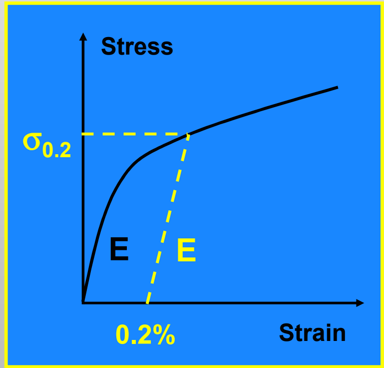
First things first!

Minimum specified
0.2% offset yield strength
in relevant ASTM

Austenitics: F_y = 30 ksi
(220-250 N/mm^2)

Duplexes: F_y = 58-67 ksi
(400-460 N/mm^2)

Young's modulus, E=28-29,000 ksi
(200,000 N/mm^2)



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Design requirements (DG27 Ch 3)

- Follow carbon steel rules for elastic analysis of frames (Ch C, using strengths from the DG27)
  Second order effects in sway frames may be more significant in stainless steel if stressed in the non-linear portion of the stress-strain curve
- No guidance on plastic analysis of stainless steel frames (yet!)

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Classification of sections for local buckling

- Follow same approach for carbon steel
- Lower limits than for carbon steel in most cases

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Section Classification: Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	
				Carbon Steel	Stainless Steel
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	$0.47\sqrt{\frac{E}{F_y}}$
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	$0.64\sqrt{\frac{k_cE}{F_y}}$ where $k_c=\frac{4}{h/t_w}$	$0.47\sqrt{\frac{E}{F_y}}$
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	$0.38\sqrt{\frac{E}{F_y}}$
Stiffened Elements	4	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	$1.24\sqrt{\frac{E}{F_y}}$
	5	Walls of rectangular HSS and boxes of uniform thickness	b/t	$1.40\sqrt{\frac{E}{F_y}}$	$1.24\sqrt{\frac{E}{F_y}}$
	6	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	$1.24\sqrt{\frac{E}{F_y}}$
	7	Round HSS	D/t	$0.11\frac{E}{F_y}$	$0.10\frac{E}{F_y}$

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Design of members for tension (DG27 Ch 4)

Same expressions as carbon steel

(a) For tensile yielding in the gross section:

$$P_n = F_y A_g \qquad \text{(D2-1)}$$

$$\phi_t = 0.90 \text{ (LRFD)} \qquad \Omega_t = 1.67 \text{ (ASD)}$$

(b) For tensile rupture in the net section:

$$P_n = F_u A_e \qquad \text{(D2-2)}$$

$$\phi_t = 0.75 \text{ (LRFD)} \qquad \Omega_t = 2.00 \text{ (ASD)}$$

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Design of members for tension

- Larger deformations expected for ss
  - $F_u/F_y \approx 2.2$ austenitic ss
  - $F_u/F_y \approx 1.4$ duplex ss
  - $F_u/F_y \approx 1.3$ A992 Grade 50 carbon steel
- For structures sensitive to deformation at serviceability, extra check at service loads

Tensile rupture in net cross-section ~~$P_n = F_u A_e$~~ $P_n = F_y A_e$

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Design of members for compression (DG27 Ch 5)

Without slender elements

Common equations Eq. E3-1 & E3-4:

Nominal compressive strength $P_n = F_{cr} A_g$

Elastic buckling stress $F_e = \dfrac{\pi^2 E}{\left(\dfrac{KL}{r}\right)^2}$

Modifications to Eq. E3-2 and E3-3

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Spec. Eq E3-2

Stainless Steel

When

$$\frac{KL}{r} \leq 3.77\sqrt{\frac{E}{F_y}}$$

or

$$\frac{F_y}{F_e} \leq 1.44$$

$$F_{cr} = \left[0.50^{\frac{F_y}{F_e}}\right] F_y$$

Carbon Steel

When

$$\frac{KL}{r} \leq 4.71\sqrt{\frac{E}{F_y}}$$

or

$$\frac{F_y}{F_e} \leq 2.25$$

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y$$

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Spec. Eq.E3-3

Stainless Steel

When

$$\frac{KL}{r} > 3.77\sqrt{\frac{E}{F_y}}$$

or

$$\frac{F_y}{F_e} \geq 1.44$$

$$F_{cr} = 0.531 F_e$$

Carbon Steel

When

$$\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$$

or

$$\frac{F_y}{F_e} \geq 2.25$$

$$F_{cr} = 0.877 F_e$$

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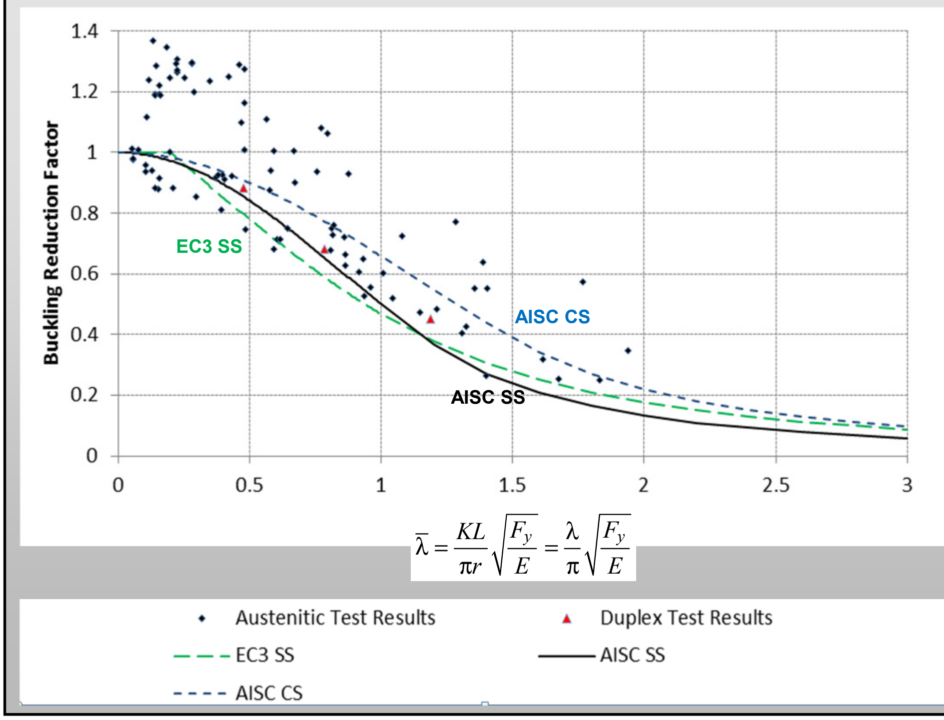

Compression members with slender elements

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Slender Elements: Modified *Spec.* Eq E7-2

Stainless Steel	Carbon Steel
When $\frac{KL}{r} \leq 3.77\sqrt{\frac{E}{QF_y}}$ or $\frac{QF_y}{F_e} \leq 1.44$	When $\frac{KL}{r} \leq 4.71\sqrt{\frac{E}{QF_y}}$ or $\frac{QF_y}{F_e} \leq 2.25$
$F_{cr} = Q\left[0.50^{\frac{QF_y}{F_e}}\right]F_y$	$F_{cr} = Q\left[0.658^{\frac{QF_y}{F_e}}\right]F_y$

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Slender Elements: Modified *Spec.* Eq E7-3

Stainless Steel	Carbon Steel
When $\frac{KL}{r} > 3.77\sqrt{\frac{E}{QF_y}}$ or $\frac{QF_y}{F_e} \geq 1.44$	When $\frac{KL}{r} > 4.71\sqrt{\frac{E}{QF_y}}$ or $\frac{QF_y}{F_e} \geq 2.25$
$F_{cr} = 0.531F_e$	$F_{cr} = 0.877F_e$

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Slender Unstiffened Elements: modified *Spec.* Eq E7-4

Stainless Steel

When

$$\frac{b}{t} \leq 0.47\sqrt{\frac{E}{F_y}}$$

$$Q_s = 1.0$$

Carbon Steel

When

$$\frac{b}{t} \leq 0.56\sqrt{\frac{E}{F_y}}$$

$$Q_s = 1.0$$

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Slender Unstiffened Elements mod. *Spec.* Eq E7-5

Stainless Steel

When

$$0.47\sqrt{\frac{E}{F_y}} < \frac{b}{t} \leq 0.90\sqrt{\frac{E}{F_y}}$$

$$Q_s = 1.498 - 1.06\frac{b}{t}\sqrt{\frac{F_y}{E}}$$

Carbon Steel

When

$$0.56\sqrt{\frac{E}{F_y}} < \frac{b}{t} \leq 1.03\sqrt{\frac{E}{F_y}}$$

$$Q_s = 1.415 - 0.74\frac{b}{t}\sqrt{\frac{F_y}{E}}$$

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Slender **Unstiffened** Elements mod. *Spec.* Eq E7-6

Stainless Steel

Reduction Factor Q_s

When

$$\frac{b}{t} > 0.90\sqrt{\frac{E}{F_y}}$$

$$Q_s = \frac{0.44E}{F_y\left(\frac{b}{t}\right)^2}$$

Carbon Steel

Reduction Factor Q_s

When

$$\frac{b}{t} > 1.03\sqrt{\frac{E}{F_y}}$$

$$Q_s = \frac{0.69E}{F_y\left(\frac{b}{t}\right)^2}$$

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Slender **Stiffened** Elements mod. *Spec.* Eq E7-17

Stainless Steel

Effective length b_e

When $\frac{b}{t} \geq 1.24\sqrt{\frac{E}{f}}$

$$b_e = 1.468t\sqrt{\frac{E}{f}}\left[1 - \frac{0.194}{(b/t)}\sqrt{\frac{E}{f}}\right] \leq b$$

$$f \approx F_y$$

Carbon Steel

Effective length b_e

When $\frac{b}{t} \geq 1.49\sqrt{\frac{E}{f}}$

$$b_e = 1.92t\sqrt{\frac{E}{f}}\left[1 - \frac{0.34}{(b/t)}\sqrt{\frac{E}{f}}\right] \leq b$$

$$f \approx F_y$$

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Design of members for flexure (DG27 Ch 6)

Lateral torsional buckling

- The guidelines given in AISC *Specification* Sections F2, F3, F4 and F6 for carbon steel generally still apply
- The exception are Equations F2-2, F2-3, F2-5, F4-2, F4-3 and F4-7
- Modifications to F2 are shown…..

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Modified *Spec*. Eq F2-2

When $L_p < L_b \leq L_r$

Stainless Steel

$$M_n = C_b \left[M_p - \left(M_p - 0.45 F_y S_x \right) \frac{\left(L_b - L_p \right)}{\left(L_r - L_p \right)} \right] \leq M_p$$

Carbon Steel

$$M_n = C_b \left[M_p - \left(M_p - 0.7 F_y S_x \right) \frac{\left(L_b - L_p \right)}{\left(L_r - L_p \right)} \right] \leq M_p$$

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Stainless Steel | Carbon Steel

Mod. *Spec.* Eq F2-3

When $L_b > L_r$

$$M_n = 0.64 F_{cr} S_x \leq M_p$$

Mod. *Spec.* Eq F2-5

$$L_p = 0.8 r_y \sqrt{\frac{E}{F_y}}$$

***Spec.* Eq F2-3**

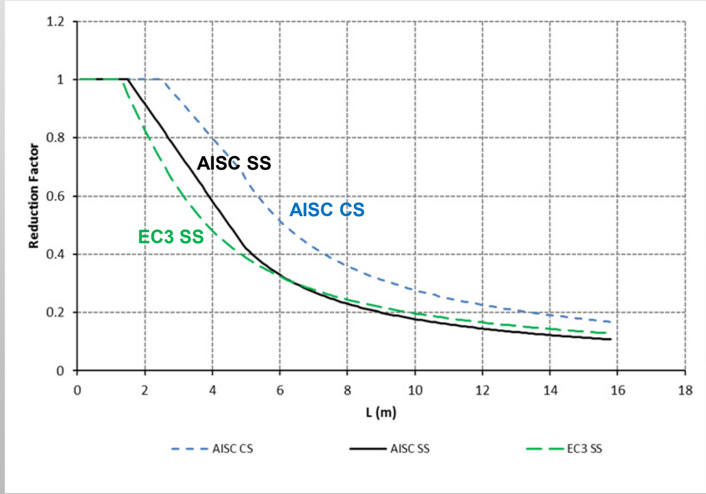
When $L_b > L_r$

$$M_n = F_{cr} S_x \leq M_p$$

***Spec.* Eq F2-5**

$$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}}$$

Comparison of AISC lateral torsional buckling curves for stainless and carbon steel



Square and rectangular HSS and box-shaped members: Flange Local Buckling

Modified *Spec.* Eq F7-2

Sections with noncompact flanges

Stainless Steel

$$M_n = M_p - (M_p - F_y S)\left(8.33\frac{b}{t_f}\sqrt{\frac{F_y}{E}} - 9.33\right) \leq M_p$$

Carbon Steel

$$M_n = M_p - (M_p - F_y S)\left(3.57\frac{b}{t_f}\sqrt{\frac{F_y}{E}} - 4.0\right) \leq M_p$$

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Square and rectangular HSS and box-shaped members: Flange Local Buckling

Slender Flanges: Modified *Spec*. Eq F7-4

Stainless Steel

Effective length b_e

$$b_e = 1.468t\sqrt{\frac{E}{F_y}}\left[1 - \frac{0.194}{(b/t)}\sqrt{\frac{E}{F_y}}\right] \leq b$$

$$f \approx F_y$$

Carbon Steel

Effective length b_e

$$b_e = 1.92t\sqrt{\frac{E}{f}}\left[1 - \frac{0.38}{(b/t)}\sqrt{\frac{E}{f}}\right] \leq b$$

$$f \approx F_y$$

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Square and rectangular HSS and box-shaped members : Web Local Buckling

Modified Spec. Eq F7-5

Sections with noncompact webs

Stainless Steel

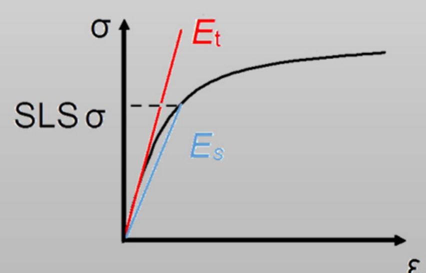
$$M_n = M_p - (M_p - F_y S)\left(1.69\frac{h}{t_w}\sqrt{\frac{F_y}{E}} - 4.09\right) \le M_p$$

Carbon Steel

$$M_n = M_p - (M_p - F_y S_x)\left(0.305\frac{h}{t_w}\sqrt{\frac{F_y}{E}} - 0.738\right) \le M_p$$

Deflections

- Non-linear stress-strain curve means that stiffness of stainless steel ↓ as stress ↑
- Deflections are greater in stainless steel than in carbon steel
- Use secant modulus for the maximum stress in the member at the serviceability limit state



Deflections

Secant modulus E_S determined from the Ramberg-Osgood model:

$$E_S = \frac{E}{1+0.002\frac{E}{F_{ser}}\left(\frac{F_{ser}}{F_y}\right)^n}$$

F_{ser} is the serviceability design stress

n is a material constant, called the Ramberg-Osgood parameter

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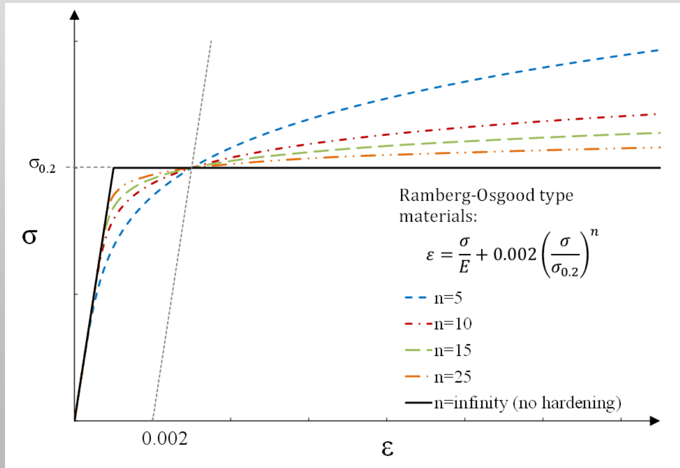
n Ramberg-Osgood Parameter

A measure of the nonlinearity of the stress-strain curve

Derived from the stress at the limit of proportionality

Low values of *n* indicate greater nonlinear



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E_S corresponding to $F_{ser}/F_y = 0.6$

Table 6-1. Values of Constants to be Used for Determining Secant Moduli

Stainless Steel		F_y ksi	n	E_S ksi
Austenitic	304 & 316	30	5.6	23,800
	304L & 316L	25		23,000
Duplex	LDX2101® & 2205	65	7.2	27,900
	2304	58		27,800

E = 28,000 ksi (austenitics) E = 29,000 ksi (duplexes)

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Design of members for shear (DG27 Ch 7)

- Adopt the rules for carbon steel in Ch G
- Outside the scope of the DG:
  - Tension field action in G3
  - Shear buckling of round HSS in G6

Design of members for combined forces (DG27 Ch 8)

- Adopt the rules for carbon steel in Ch H

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Appendix A – Continuous Strength Method (CSM)

- Less conservative method of determining member strength
- Low slenderness members $\bar{\lambda}_p \leq 0.68$
- Considers benefits of strain hardening
- Rectangular HSS and I sections

Summary

- Design of stainless steel members is very similar to design in carbon steel
- Limiting width-to-thickness ratios are lower
- Buckling curves are lower
- Deflections may be slightly higher

Overview - design of connections
(DG27 Ch 9)

- Welded connections
- Bolted connections
- Affected elements of members & connecting elements
- Flanges & webs with concentrated forces
- Fatigue

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Design of welded connections

Carbon steel design rules can generally be applied to stainless steel:

- Effective area
- Strength of groove, fillet, plug and slot welds

Austenitics:
$F_y/F_{u\,\mathrm{filler}}$ is low, more likely that base metal strength controls weld strength for fillet and partial-joint-penetration groove welds

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Resistance factors for welded joints

- Austenitic stainless steels:
  ϕ = 0.55 (LRFD)
- Duplex stainless steels:
  ϕ = 0.60 (LRFD)
- Carbon steels:
  ϕ = 0.75 (LRFD)

Bolted connections

- Corrosion resistance of the bolts and parent material should be similar
- Stainless steel bolts should be used to connect stainless steel members to avoid bimetallic corrosion
- Stainless steel bolts can also be used to connect galvanized steel and aluminium members

Table 2-4. Minimum Specified Mechanical Properties of Austenitic and Precipitation Hardening Stainless Steel Bolts to ASTM F593

Condition	Alloy Mechanical Property Marking		Nominal Diameter	Tensile Strength	Yield Strength
	Group 1: 304	Group 2 316	in.	ksi	ksi
AF	F593A	F593E	¼ to 1½ incl	65–85	20
A	F593B	F593F	¼ to 1½ incl	75–100	30
CW1	F593C	F593G	¼ to ⅝ incl	100–150	65
CW2	F593D	F593H	¾ to 1½ incl	85–140	45
SH1	F593A	F593E	¼ to ⅝ incl	120–160	95
SH2	F593B	F593F	¾ to 1 incl	110–150	75
SH3	F593C	F593G	1⅛ to 1¼ incl	100–140	60
SH4	F593D	F593H	1⅜ to 1½ incl	95–130	45
	Group 7: 17-4				
AH	F593U		¼ to 1½ incl	135–170	105

ASTM 738M, A320/320M, A193/193M and A1082/1082M also cover stainless steel fasteners…

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Design of bolted connections

Rules for carbon steel bolts in clearance holes can generally be applied to stainless steel (tension, shear, combined tension and shear) $R_n = F_n A_b$

Nominal tensile stress $F_{nt} = 0.75F_u$

Nominal shear stress $F_{nv} = 0.45F_u$ Threads not excluded from shear plane

$F_{nv} = 0.55F_u$ Threads excluded from shear plane

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Design of bolted connections

Special rules for bearing resistance required to limit deformation due to high ductility of stainless steel

- Where deformation at the bolt hole at service load is a design consideration

$$R_n = \alpha_d t d F_u$$

- Where deformation at the bolt hole at service load is not a design consideration

$$R_n = \alpha_1 t d F_u$$

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Design of bolted connections

Affected Elements of Members & Connecting Elements

- Guidance in *Spec.* Section J4 applies
- Use stainless steel resistance factors
- Use stainless steel buckling curves

Flanges & webs with concentrated forces

- Guidance in *Spec.* Section J10 applies

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Pretensioning stainless steel bolts

- No design rules for stainless pretensioned bolts - tests should always be carried out
- Use an appropriate pretensioning method (if highly torqued, galling may be a problem)
- Consider time-dependent stress relaxation

A carbon steel direct tension indicator will not give a correct prediction of the tension in a stainless steel bolt.

Turn-of-nut method, twist-off type tension control method or calibrated wrench method can be used on stainless steel bolts

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Fatigue strength (DG27 Ch 11)

- Fatigue behaviour of welded joints is dominated by weld geometry
- Performance of stainless steel is at least as good as carbon steel
- Conventional fatigue improvement techniques can be applied to stainless steel

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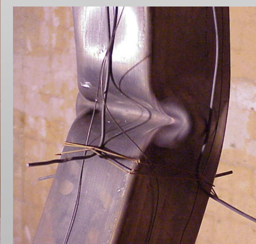
Fire Resistant Design

DG27 Ch 10

(Appendix 4 of AISC 360)



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Design for fire resistance

- Thermal properties at elevated temperatures
- Rate of temperature rise
- Mechanical properties at elevated temperatures
- Member strength at elevated temperatures

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Rate of heating up

Unprotected Steel Members. The temperature rise in an unprotected steel section in a short time period is determined by:

$$\Delta T_s = \frac{a}{c_s\left(\frac{W}{D}\right)}\left(T_F - T_s\right)\Delta t \qquad \text{(C-A-4-2)}$$

The heat transfer coefficient, a, is determined from

$$a = a_c + a_r \qquad \text{(C-A-4-3)}$$

where

a_c = convective heat transfer coefficient

a_r = radiative heat transfer coefficient, given as:

$$a_r = \frac{5.67 \times 10^{-8}\varepsilon_F}{T_F - T_S}\left(T_F^4 - T_s^4\right) \qquad \text{(C-A-4-4)}$$

Convective heat transfer coefficient, a_c = 4.4 Btu/(ft^2-hr-°F)

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Thermal properties

Emissivity

Stainless steel: ε_F = 0.4

Carbon steel: ε_F = 0.7

Specific thermal capacity at 68 °F

Stainless steel: 0.12 Btu/(lb-°F)

Carbon steel 0.12 Btu/(lb-°F)

Stainless steel member heats up at a very similar rate to an equivalent carbon steel member

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Other thermal properties

Thermal conductivity at 68 °F

Austenitic stainless steel:	8.7	Btu/(hr-ft-°F)
Duplex stainless steel:	9.2	Btu/(hr-ft-°F)
Carbon steel:	25	Btu/(hr-ft-°F)

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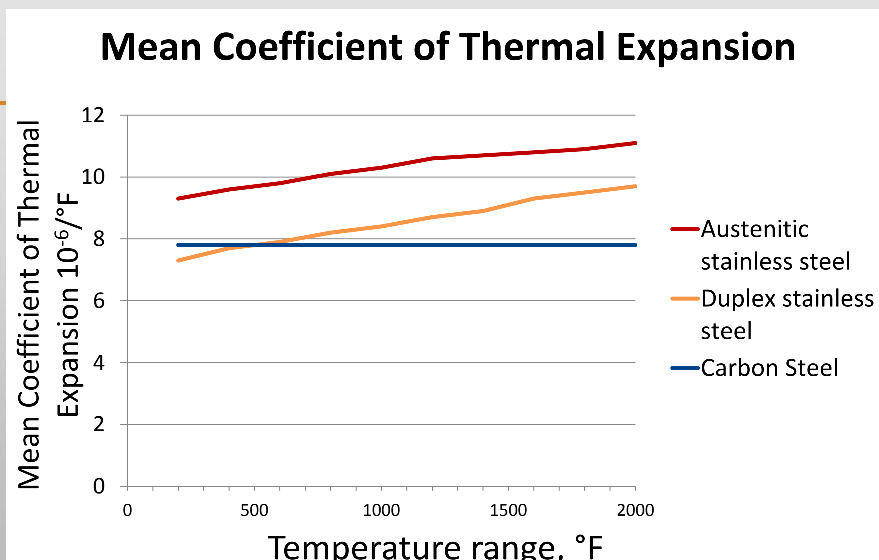

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Thermal expansion

Stainless steel expands more than carbon steel.

- In structural frames, restraint will exist from surrounding members
- Additional forces are therefore likely to result
- Precautions to minimize weld distortion

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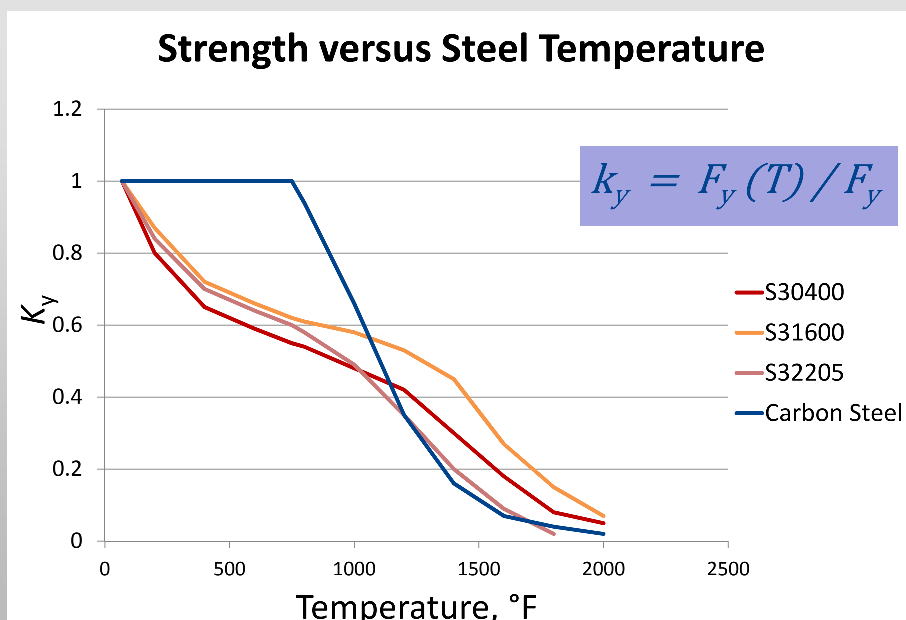

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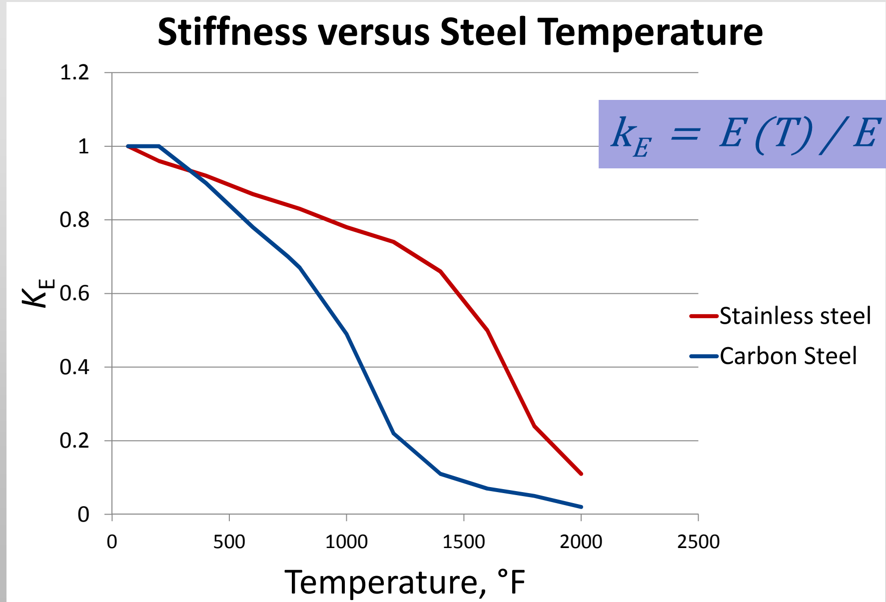

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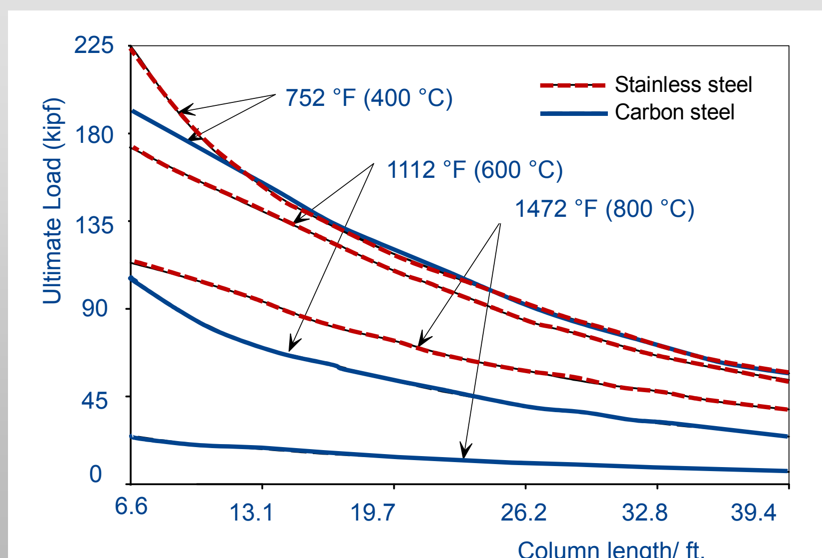
Carbon & stainless columns in fire



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Design rules for fire resistance

- Follow the same principles as Appendix 4 of AISC 360
- Use stainless properties at elevated temperatures
- Some modifications to carbon steel design expressions for columns and beams (only columns discussed in this webinar)

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Columns in Fire

- Use room temperature buckling curve with elevated temperature material properties
- Same expression for elastic bucking stress, $F_e(T)$

$$F_e(T) = \frac{\pi^2 E(T)}{\left(\frac{KL}{r}\right)^2}$$

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Columns in Fire

Stainless Steel

$$\frac{F_y(T)}{F_e(T)} \leq 1.44 \rightarrow F_{cr}(T) = \left[0.50^{\frac{F_y(T)}{F_e(T)}}\right] F_y(T)$$

$$\frac{F_y(T)}{F_e(T)} > 1.44 \rightarrow F_{cr}(T) = 0.531 F_e(\mathrm{T})$$

Carbon Steel

$$F_{cr}(T) = \left[0.42^{\sqrt{\frac{F_y(T)}{F_e(T)}}}\right] F_y(T)$$

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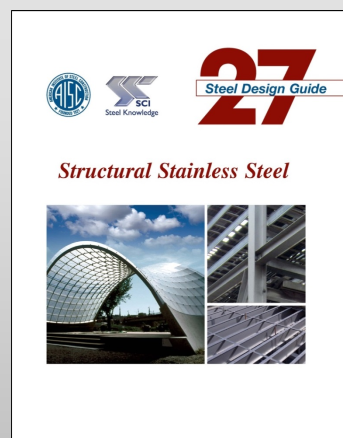
Summary

- Non-linear stress-strain characteristics of stainless steel mean some different design rules apply
- Simple design rules aligned with AISC 360 are given in DG27
- Design examples available



Also in DG27:
material selection, durability, fabrication etc

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