Content

- Introduction
- Amendments EN 1993-1-1
    - Scope with respect to material thickness
    - Shear resistance
    - Semi-compact cross-section design
    - Buckling curves for angles, heavy sections and rolled I- and H- sections in S460
    - Parameter α for cross-section classification
    - Torsion and its interaction with other internal forces
    - Local load introduction without stiffeners
    - Tubular members – cross-section classification
    - Elliptical hollow sections
    - Initial imperfections of table 5.1 of EN 1993-1-1
    - Structural analysis + design rules
- Other ongoing work
- Conclusions

Introduction

- All Eurocodes are under revision or will shortly undergo revision
- EU Mandate M/515: Mandate for amending existing EC's and extending the scope of structural EC's
- There are 4 phases
- Concentrate on the steel Eurocodes only, i.e. EN 1993
- The 4 phases have their own timeline

Milestone	Phase 1	Phase 2	Phase 3	Phase 4
Drafts available	June 2018	June 2020	June 2021	June 2022
Final Technical approval in SC3	October 2018	October 2020	October 2021	October 2022
Start of CEN enquiry phase	October 2019	March 2021	March 2022	March 2023
Start translation and legislation	End of 2020	End of 2022	End of 2023	End of 2024
Available circa	End of 2021 / 2022	End of 2023 / 2024	End of 2024 / 2025	End of 2025 / 2026
	Codes in phase 1	Codes in phase 2	Codes in phase 3	Codes in phase 4
	EN1993-1-1 (general+buildings)	EN 1993-1-2 (fire)	EN 1993-1-4 (stainless)	EN 1993-3-1 (tower +masts)
	EN 1993-1-8 (joints)	EN 1993-1-3 (cold-formed)	EN 1993-1-9 (fatigue)	EN 1993-3-2 (chimneys)
	EN 1993-1-12 (high-strength)	EN 1993-1-5 (plates)	EN 1993-1-10 (material)	EN1993-4-1 (silos)
		EN 1993-1-6 (shells)	EN 1993-1-11 (tension)	EN1993-4-2 (tanks)
		EN 1993-1-7 (out-of-plane)	EN 1993-2 (bridges)	~~EN1993-4-3 (pipelines)~~
				EN1993-5 (piling)
				EN1993-6 (crane support)

- It was decided to keep the structure of EN 1993 and its parts
- However, part 1-12 on HSS is to be dissolved in the other relevant parts of EN 1993
- Work in progress on a new part:
  - EN 1993-1-12, “Design of steel structures - Part 1-12: Additional rules for steel grades up to S960”
- New parts:
  - EN 1993-1-13, “Eurocode 3: Design of steel structures – part 1-13: Steel beams with large web openings”
  - EN 1993-1-14 “Eurocode 3 - Design of steel structures - Part 1-14: Design assisted by finite element analysis”

- EC’s are in force, experience gained
- Proposals for change and improvement
- Brought forward by National Standardization Bodies: ASRO, BSI, DIN, NEN, etc.
- Subcommittee CEN/TC250/SC3 for Eurocode 3 on steel
- Concentrate on EN 1993-1-1
- WG1 works on part EN 1993-1-1: about 20 members
- Amendments: ‘kept in the basket’ to keep stable version
- Unless there is a safety issue
- Since September 2015 a PT was formed under EU Mandate M/515

- **PT consists of about 6 members**
- **For part EN 1993-1-1:**

  Bureau (France, convener), Lagerqvist (Sweden), Taras (Austria), Knobloch (Germany), Pope (UK), Gantes (Greece)

- **PT responsible for technical work and writing new draft**
- **PT reports to CEN/TC250/SC3**
- **Uses amendments ‘kept in the basket’ and results of systematic review**
- **WG1 monitors the work op the PT**

Amendments

- Longlist of work items of WG1 originated from:
  - National Standardization Bodies
  - individual National Delegates to CEN/TC250/SC3
- Different kinds of work items:
  - Editorial remarks
  - Easy to solve work items within short time (S)
  - Work requiring a lot op work: ‘projects’ (P)

Table 1: Part of the longlist of possible work items to be treated by WG1.

6.2	Reconsider developing new rules for the resistance of net-sections.	[15]	S	LO KJ
6.2.6	Improvement of rules for plastic shear strength of webs in HSS	[15]	S	
6.2.3(2) b)	The formula for the ultimate resistance of net cross-sections seems conservative for steel grades ≥ S355 and small holes (see also 6.2.5(4))	[14]	S	
6.2.3(3)	Tension – The rule for capacity design leads to very conservative results due to the presence of the partial safety factors in the formulas for net and gross section resistance.	[1]	S	
6.2.3(5)	Change EN 1993-1-8, 3.6.3 into EN 1993-1-8 3.10.3	[14]	S	
6.2.4	New proposal for design of sections in compression	[23] [28]	P	SR SH CL
6.2.6(3)	Addition of the shear area for rolled I- and H-sections, loaded parallel to flanges	[14]	S	
6.2.6(3)	Reconsider the definition of h_w. For rolled I- or H-Profiles the distance between the flanges seems conservative.	[14]	S	
6.2.5	New proposal for design of sections in bending	[23] [28]	P	
6.2.5(4)	Bending moment – The rule for ignoring fastener holes is very conservative due to the partial safety factors not being equal; is this really necessary? Also see under 6.2.3(3).	[1]	S	

- Other source of amendments: Systematic Review
  - Every 5 years
  - Till end of September 2014 for EN 1993-1-1
  - Increase ‘ease of use’
  - Questions answered by National Standardization Bodies:

    - Does any clause require editorial or technical correction?
    - Which clause would benefit from improvements in clarity?
    - Where should the scope of EN 1993-1-1 be extended?
    - Where could EN 1993-1-1 be shortened?
    - Are there any clauses leading to uneconomic design?
    - Are there any clauses leading to excessive design effort?

  - Resulted in a again longlist again of possible work items

- **These work items were classified:**

(1) Accepted (PT):

Editorial and obvious mistakes that can be directly dealt by PT

(2) Accepted (WG):

Relevant comment that need to be dealt and further elaborated by WG, and probably accepted by SC3 decision

(3) Rejected:

In this case a reason should be given, e.g. demand is against policy of "clarity" and "ease of use"

(4) Clarification (WG):

Comment that cannot easily be answered and needs further considerations and discussions in WG

(5) Decided (SC3):

Comment and issue that is already treated by SC3 and decided as "basket"-decision, no discussion again

(6) Under discussion (WG):

Comment and issue that is already under discussion within WG and may have reached already a certain status of agreement which should not be rolled up again.

- Work items classified as (2) and (4) were treated by WG1 in more detail
- This led to recommendations for modifications to be implemented by the PT
- Work ready by November 2017
- PT now works on final draft
- PT should be ready by end of June 2018
- New draft expected at the earliest in 2020
- Translations and embedding in national law

- **Meeting of CEN/TC250/SC3 of October 2015: Main directions:**

1. Elastic critical buckling: CEN Technical Report should be made and cited in the code:
   CEN/TR1993-1-103 “Eurocode 3 – Design of steel structures – Part 1-103: Elastic critical buckling of members”

2. Serviceability limit state criteria: not in EN 1993-1-1 but in EN 1990; open to NDP’s; Task Group should be formed

3. Alternative methods for beam-columns: Method 2, Annex B to become the only method; Method 1, Annex A as a Technical Specification to be referenced from the code:
   CEN/TS1993-1-101 “Eurocode 3 – Design of steel structures – Part 1-101: Alternative interaction method for members in bending and compression”

4. Shear lag: keep shear lag in EN 1993-1-5

5. Second order analysis and design based on FE: Merge existing clauses in one Annex and decide later where to place this: Ad-hoc Group FE

- **Meeting of CEN/TC250/SC3 of October 2015: Main directions:**

6. Buckling shape as imperfection: keep clause 5.3.2(11) and improve it
7. ‘Fall back’ safety level: keep it in clause 6.1(1) and change text such that the safety level for bridges is a minimum level
8. Informative annexes are to be avoided. For that reason:
   Annex AB.1 should be moved to main text of chapter 5
   Annex AB.2 should – if necessary – be moved to EN1990 or EN 1991
   Annex BB.1 should be made normative and the content needs to be clarified
   Annex BB.2 should be made normative
   ~~Annex BB.3 (stable lengths) should be transferred to a technical specification:~~
   ~~CEN/TS1993-1-102 “Eurocode 3 – Design of steel structures – Part 1-102: Stable length method for members containing plastic hinges subject to out-of-plane buckling”~~

- **Amendments are drafted according to format:**
  - **topic**
  - **clause of EN 1993-1-1**
  - **reason for amendment**
  - **proposed change**
  - **background information**
- **The latter is very important for future code drafting**

Scope with respect to material thickness

- Clause 1.1.2(1) of EN 1993-1-1
- Current limit on material thickness $t \geq 3 \text{ mm}$ is too tight for some hollow sections
- Considering EN 1993-1-3 and EN 1993-1-8 and product standards EN 10210 and EN 10219 the design rules apply if:
  - nominal thickness $t \geq 3 \text{ mm}$;
  - nominal thickness is between 3 and 1.5 mm but then use the design thickness:

$$t_d = t_{cor} \qquad if \quad tol \leq 5\%$$

$$t_d = t_{cor} \frac{100 - tol}{95} \qquad if \quad tol > 5\%$$

$$where:$$

$$t_{cor} = t - t_{mc}$$

TU/e Technische Universiteit **Eindhoven** University of Technology

Shear resistance

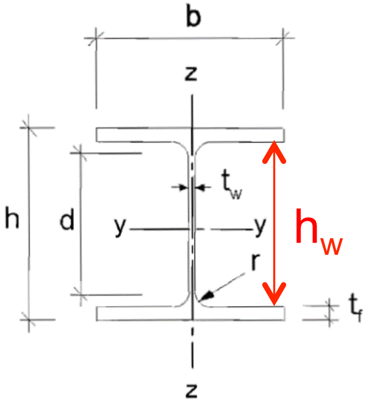
- **Clause 6.2.6(3) and (6) of EN 1993-1-1**
- **Repair of omissions and clarification:**
  - **Shear area for rolled I- and H- sections if shear force acts parallel to flanges is missing**
  - **Definition of h_w not clear**
  - **Assumption $\eta = 1.0$ in clause 6.2.6(6) for the demarcation criterion $h_w/t_w \geq 72\varepsilon/\eta$ on shear buckling is not conservative**

- **Add in the list for the shear areas:**

b) rolled I and H sections, load parallel to flanges $2bt_f$

- **Add in the definitions:**

h_w *is the clear depth of the web measured between the flanges; for rolled and welded beams with prismatic or tapered flanges:* $h_w = h - 2t_f$*, for* t_f *see Fig. 1*



- **Change the note to clause 6.2.6(6) as follows**

'In addition the shear buckling resistance for webs without intermediate stiffeners should be according to section 5 of EN 1993-1-5, if

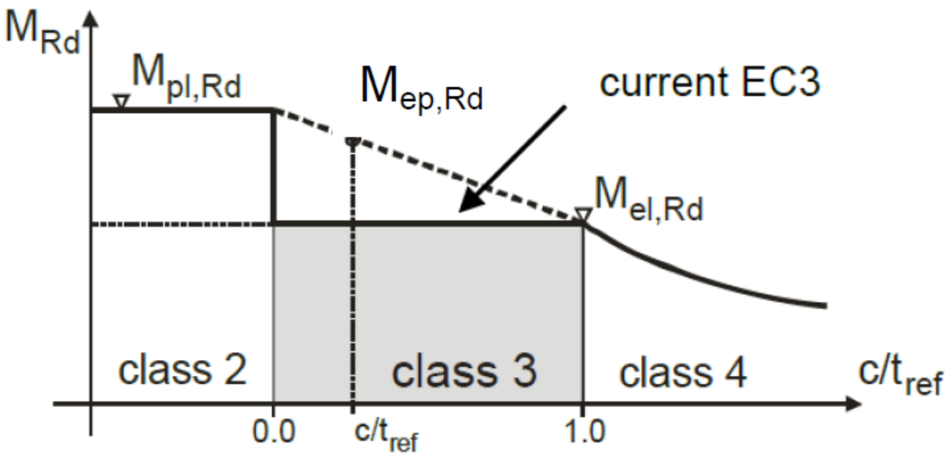
$$\frac{h_w}{t_w} > 72\frac{\varepsilon}{\eta} \qquad (6.22)$$

For η see section 5 of EN 1993-1-5.

NOTE *For the value* η *see Note 2 to clause 5.1(2) of EN 1993-1-5. For the criterion (6.22)* $\boxed{\eta = 1.2}$ *can be assumed'*.

Semi-compact cross-section design

- 'Jump' in resistance between class 3 and classes 1 and 2
- For I- and H-sections and RHS and SHS: Use partly-plastic capacity of class 3 cross-sections
- Also stability design rules become more economic
- Pure bending:



- **Modify clause 6.2.5(2) as follows:**

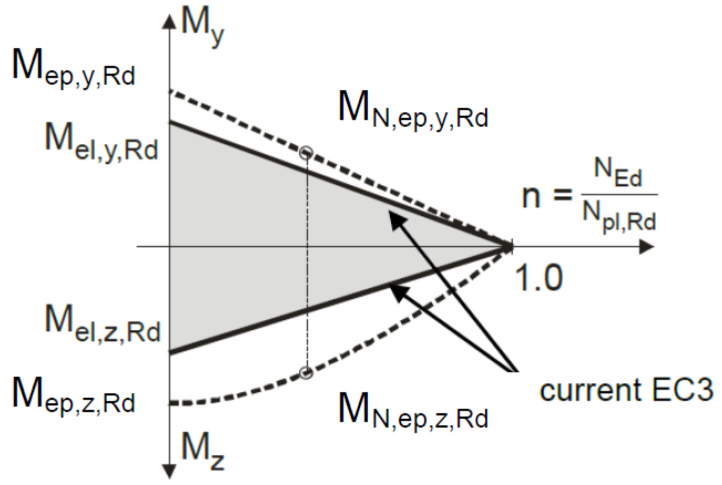
'(2)…..

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el,\min} f_y}{\gamma_{M0}} \text{ for class 3 cross-sections}$$

$$= M_{ep,Rd} = \frac{W_{ep} f_y}{\gamma_{M0}}$$ *alternatively, for double-symmetric I-, H- and rectangular hollow sections, rolled or welded*

with $W_{ep} = W_{pl} - \left(W_{pl} - W_{el}\right) c/t_{ref}\ ;\ c/t_{ref}$ *defined as in 6.2.9.2'*

- **Implications for cross-sections resistance under combined M + N**



• Modify clause 6.2.9.2 as follows:

'(2) Alternatively to equation (6.42), the partial plastic resistance of class 3 cross-sections can be taken into account by applying the rules given in (3) to (5). These rules directly apply to cross-sections where fastener holes are not to be accounted for.

(3) The partial plastic resistance of double-symmetric rolled or welded I- or H-sections may be calculated as follows, with the coefficient n as defined in 6.2.9.1:

$$M_{N,ep,y,Rd} = M_{ep,y,Rd}(1-n)$$

$$M_{N,ep,z,Rd} = M_{ep,z,Rd}(1-n^2)$$

$$c/t_{ref,y} = \max\left[\frac{c/t_f - 10\varepsilon}{4\varepsilon}; \frac{c/t_w - 83\varepsilon}{41\varepsilon}; 0\right] \leq 1$$

$$c/t_{ref,z} = \max\left[\frac{c/t_f - 10\varepsilon}{6\varepsilon};\ 0\right] \leq 1$$

(4) The partial plastic resistance of double-symmetric rectangular structural hollow sections and welded box sections may be calculated as follows, with the coefficient n as defined in 6.2.9.1:

$$M_{N,ep,y,Rd} = M_{ep,y,Rd}(1-n)$$

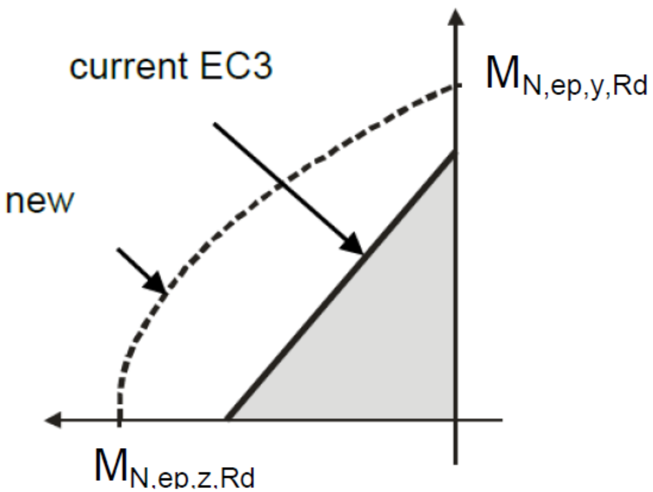
$$M_{N,ep,z,Rd} = M_{ep,z,Rd}(1-n)$$

$$c/t_{ref,y} = \max\left[\frac{c/t_f - 34\varepsilon}{4\varepsilon}; \frac{c/t_w - 83\varepsilon}{41\varepsilon}; 0\right] \leq 1$$

$$c/t_{ref,z} = \max\left[\frac{c/t_w - 34\varepsilon}{4\varepsilon};\ 0\right] \leq 1\text{'}$$

Technische Universiteit
Eindhoven
University of Technology

- **Bi-axial bending + N is also affected; addition to clause 6.2.9.2**



‘(5) For bi-axial bending the following criterion may be used

$$\left(\frac{M_{y,Ed}}{M_{N,ep,y,Rd}}\right)^{\alpha}+\left(\frac{M_{z,Ed}}{M_{N,ep,z,Rd}}\right)^{\beta}\leq 1$$

in which α and β are constants, defined as follows:

- *I- and H-sections:* $\alpha = 2;\quad \beta = 5n \geq 1$;
- *rectangular hollow sections and welded box sections:*

$$\alpha=\beta=\frac{1.66}{1-1.13n^2}\leq 2+4\left[1-\max(c/t_{ref\,(y,z)})\right]^4,$$

- **Stability of members subjected to combined bending and compression: change in Table 6.7:**

Table 6.7: Values for $N_{Rk} = f_y A_i$, $M_{i,Rk} = f_y W_i$ and $\Delta M_{i,Ed}$.

Class	1	2	3	4
A_i	A	A	A	A_{eff}
W_y	$W_{pl,y}$	$W_{pl,y}$	$W_{el,y}$ or alternatively $W_{ep,y}$	$W_{eff,y}$
W_z	$W_{pl,z}$	$W_{pl,z}$	$W_{el,z}$ or alternatively $W_{ep,z}$	$W_{eff,z}$
$\Delta M_{y,Ed}$	0	0	0	$e_{N,y} N_{Ed}$
$\Delta M_{z,Ed}$	0	0	0	$e_{N,z} N_{Ed}$

- **Stability of members subjected bending: LTB, clause 6.3.2.1(3):**

‘(3) The design buckling resistance moment of a laterally unrestrained beam should be taken as:

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$$

Where W_y is the appropriate section modulus as follows:

- $W_y = W_{pl,y}$ for Class 1 or 2 cross-sections
- $W_y = W_{el,y}$ for Class 3 cross-sections

  $\boxed{W_y = W_{ep,y} \textit{ alternatively, see 6.2.5(2)}}$
- $W_y = W_{eff,y}$ for Class 4 cross-sections

NOTE….’

Buckling curves for angles

- **Differentiated between rolled and welded angles**
- **Due to different residual stress patterns**

Table 3: Part of adjusted Table 6.2 of EN 1993-1-1 for the selection of a buckling curve for angles.

Cross-section		Limits	Buckling about axis	Buckling curve S235 S275 S355 S420	Buckling curve S460
L-sections		*Rolled sections*	any	b	*a*
L-sections		*Welded sections* $t_f \leq 40mm$	any	*c*	*c*

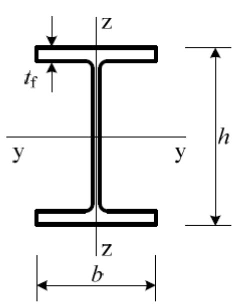
+ S450

to S700

Buckling curves for heavy sections

- **Rolled I- and H-sections with $h/b > 1.2$ and $t_f > 100\text{mm}$ are currently not covered: heavy sections**

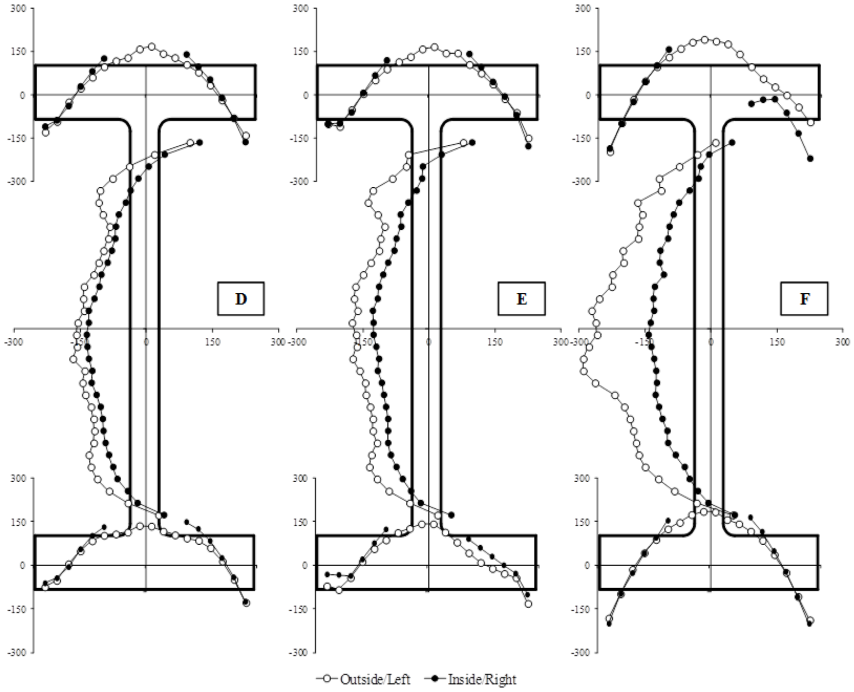
Table 5: Part of adjusted Table 6.2 of EN 1993-1-1 for the selection of a buckling curve for rolled sections.

Cross-section		Limits		Buckling about axis	Buckling curve	
					S235 S275 S355 S420	S460 *S500*
Rolled sections		$h/b > 1.2$	$t_f \le 40$ mm	y-y z-z	a b	a_0 a_0
			$40 < t_f \le 100$ mm	y-y z-z	b c	a a
			$t_f > 100$ *mm*	*y-y* *z-z*	*b* *c*	*a* *b*
		$h/b \le 1.2$	$t_f \le 100$ mm	y-y z-z	b c	a a
			$t_f > 100$ mm	y-y z-z	d d	c c

+ S450

to S700

• **Based on residual stress measurements, database of numerical test results and statistical analyses - TU/e**

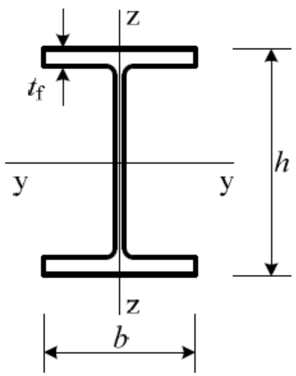


TU/e Technische Universiteit Eindhoven University of Technology

Buckling curves for rolled I- and H-sections in S460

- Research in Berlin (Prof. Lindner) and Coimbra (Prof. Da Silva) showed there are inconsistencies in buckling curve selection table for S460
- Currently for weak and strong axis buckling the same curves are used
- Residual stresses are more detrimental for weak axis buckling
- Changes are necessary in buckling curve selection table to reach consistent safety levels

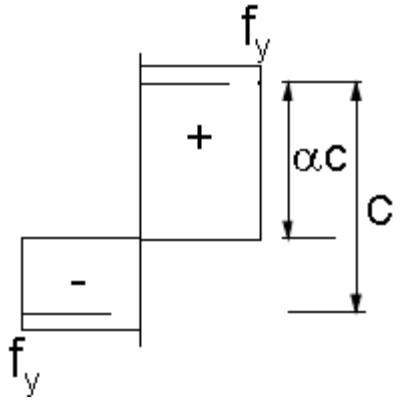
Table 6: Part of adjusted Table 6.2 of EN 1993-1-1 for the selection of a buckling curve for rolled sections with focus on S460.

Cross-section		Limits		Buckling about axis	Buckling curve: S235 S275 S355 S420	Buckling curve: S460 S500
Rolled sections		$h/b > 1.2$	$t_f \leq 40$ mm	y-y	a	a_0
				z-z	b	$\boxed{a}$
			$40 < t_f \leq 100$ mm	y-y	b	a
				z-z	c	$\boxed{b}$
			$t_f > 100$ mm	y-y	b	a
				z-z	c	b
		$h/b \leq 1.2$	$t_f \leq 100$ mm	y-y	b	a
				z-z	c	$\boxed{b}$
			$t_f > 100$ mm	y-y	d	c
				z-z	d	c

Parameter α for cross-section classification

- α is used to determine the cross-section class
- Internal parts subjected to bending and compression
- Table 5.2 (sheet 1/3):

‘*Note: for I or H sections with equal flanges, under axial force and bending moment about the main axis parallel to the flanges, the parameter α that defines the position of the plastic neutral axis may be calculated as follows:*
If $N_{Ed} \geq c\ t_w\ f_y$ *then* $\alpha = 1{,}0$;
If $N_{Ed} \leq -c\ t_w\ f_y$ *then* $\alpha = 0$;
In other cases: $\alpha = 0{,}5\ [1 + N_{Ed} / (c\ t_w\ f_y)]$
Where N_{Ed} *is the design axial force taken as positive for compression and negative for tension.*’

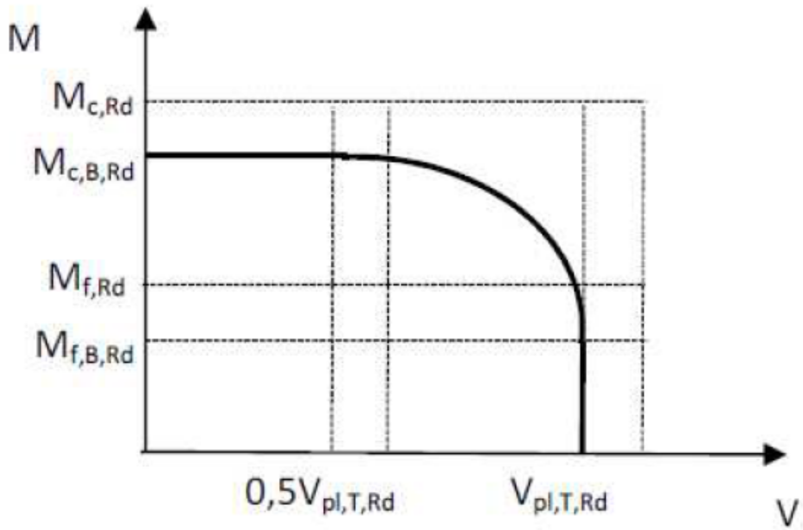


Torsion and its interaction with other internal forces

- **EN 1993-1-1 currently does not treat this**
- **Rules were added based on shear-torsion interaction**
- **To cl. 6.2.7(6) the bending moment resistance allowing for bimoment is added:**

$$M_{c,B,Rd} = \sqrt{1 - \frac{\sigma_{w,Ed,\max}}{1{,}25 f_y / \gamma_{M0}}} M_{pl,Rd}$$

- **Cl. 6.2.7(8) is changed such that the bending-shear-torsion interaction is:**

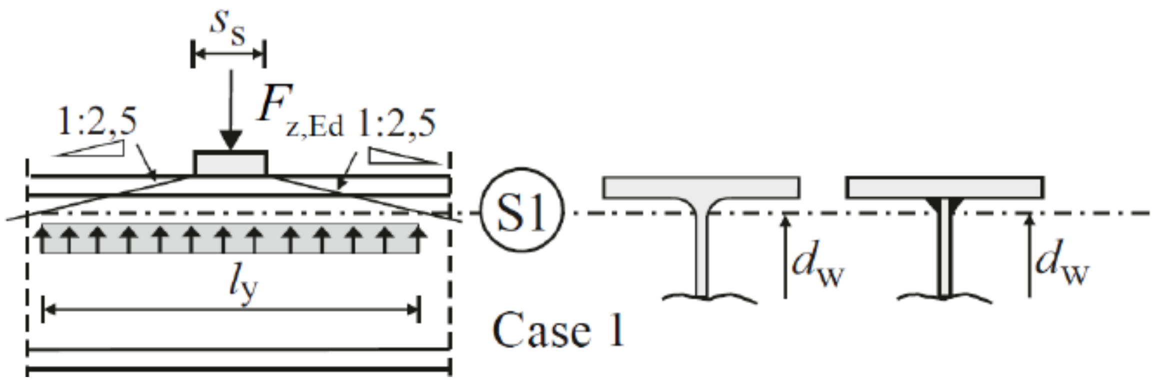


Local load introduction without stiffeners

- Simplified rules for this existed in national codes
- Now EN 1993-1-5 should be used: difficult to apply
- EN 1993-1-8 'component method' where 'compression in unstiffened column web' is relevant
- Combined simple design rule was added to cl. 6.2 for the resistance against transverse force:

$$F_{z,Rd} = \frac{l_y t_w f_y}{\gamma_{M0}}$$

$$\frac{d_w}{t_w} \leq 23{,}1\,\varepsilon \sqrt{\frac{d_w / l_y}{F_{z,Ed} / F_{z,Rd}}}$$

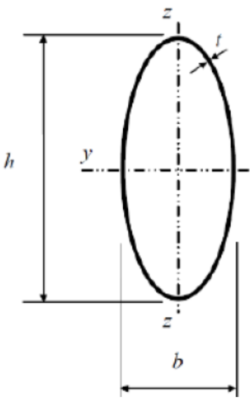


Tubular members

- **Cross-section classification**

	Section in compression	Section in bending	Compression and bending
Class 1	$d_e \leq 50\ \varepsilon^2$	$d_e \leq 50\ \varepsilon^2$	$d_e \leq 50\ \varepsilon^2$
Class 2	$d_e \leq 70\ \varepsilon^2$	$d_e \leq 70\ \varepsilon^2$	$d_e \leq 70\ \varepsilon^2$
Class 3	$d_e \leq 90\ \varepsilon^2$	$d_e \leq 140\ \varepsilon^2$	$d_e/t \leq \dfrac{2520\ \varepsilon^2}{5\psi + 23}$

Elliptical hollow sections



- **Cross-section classification: equivalent diameter**

For CHS $d_e = d$; for EHS d_e depends on the nature of loading.

For EHS in compression: $d_e = h\left[1 + \left(1 - 2{,}3(t/h)^{0{,}6}\right)\left(\frac{h}{b} - 1\right)\right]$ *or conservatively* $d_e = \frac{h^2}{b}$.

For EHS in major (y-y) axis bending: if $\frac{h}{b} \leq 1{,}36$ *then* $d_e = \frac{b^2}{h}$, *if* $\frac{h}{b} > 1{,}36$ *then* $d_e = 0{,}4\frac{h^2}{b}$.

For EHS in minor (z-z) axis bending or compression and minor axis bending: $d_e = \frac{h^2}{b}$.

For EHS in compression and major (y-y) axis bending, d_e may be determined by …

- **Class 4 effective cross-section properties:**

$$A_{eff} = A\left[\frac{90}{d_e/t}\frac{235}{f_y}\right]^{0.5} \quad for\ d_e/t \leq 240\,\varepsilon^2 \qquad W_{eff} = W_{el}\left[\frac{140}{d_e/t}\frac{235}{f_y}\right]^{0.25} \quad for\ d_e/t \leq 240\,\varepsilon^2$$

- **Shear area for EHS:**

load parallel to the depth	*2(h-t)/t*
load parallel to width	*2(b-t)/t*

- **N-M_y-M_z-interaction and Stability**

Initial bow imperfections of table 5.1 of EN 1993-1-1

- **Current recommended values are too optimistic**
- **Relative local bow imperfection j should be:**

$$j = \frac{L}{e_0} = \frac{\beta\,\varepsilon}{\alpha}$$

α *imperfection factor depending on the relevant buckling curve from Table 6.1*

β *according to Table 5.1*

$$\varepsilon = \sqrt{235/f_y}$$

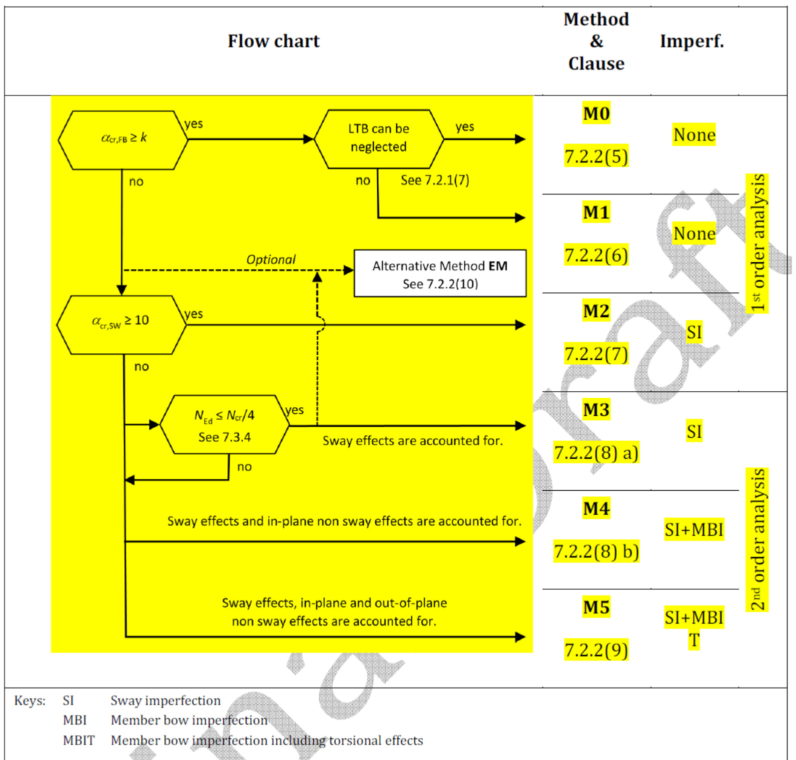
Table 5.1. Values β for initial bow imperfections

Buckling rectangular to axis	elastic cross section utilization	plastic cross section utilization
y-y	110	75
z-z	200	68

- **If plastic cross-section design rules are used:**
  - **Use linear interaction**
  - **Restrict shape factor to** $\frac{M_{pl}}{M_{el}} \leq 1,25$

Structural analysis + design rules

- **Better link between structural analysis and associated design rules for checking:**
- **Flow chart in cl. 5.2 of EN 1993-1-1**



Other ongoing work

- Topics in progress:
  - Moment-shear interaction
  - Buckling design rules for equal legged angles
  - Simplified LTB rules for beams with restraints
- PT works on final draft
  - Annex B moves to main text; Annex C renamed Annex A; New Annex B for semi-compact sections

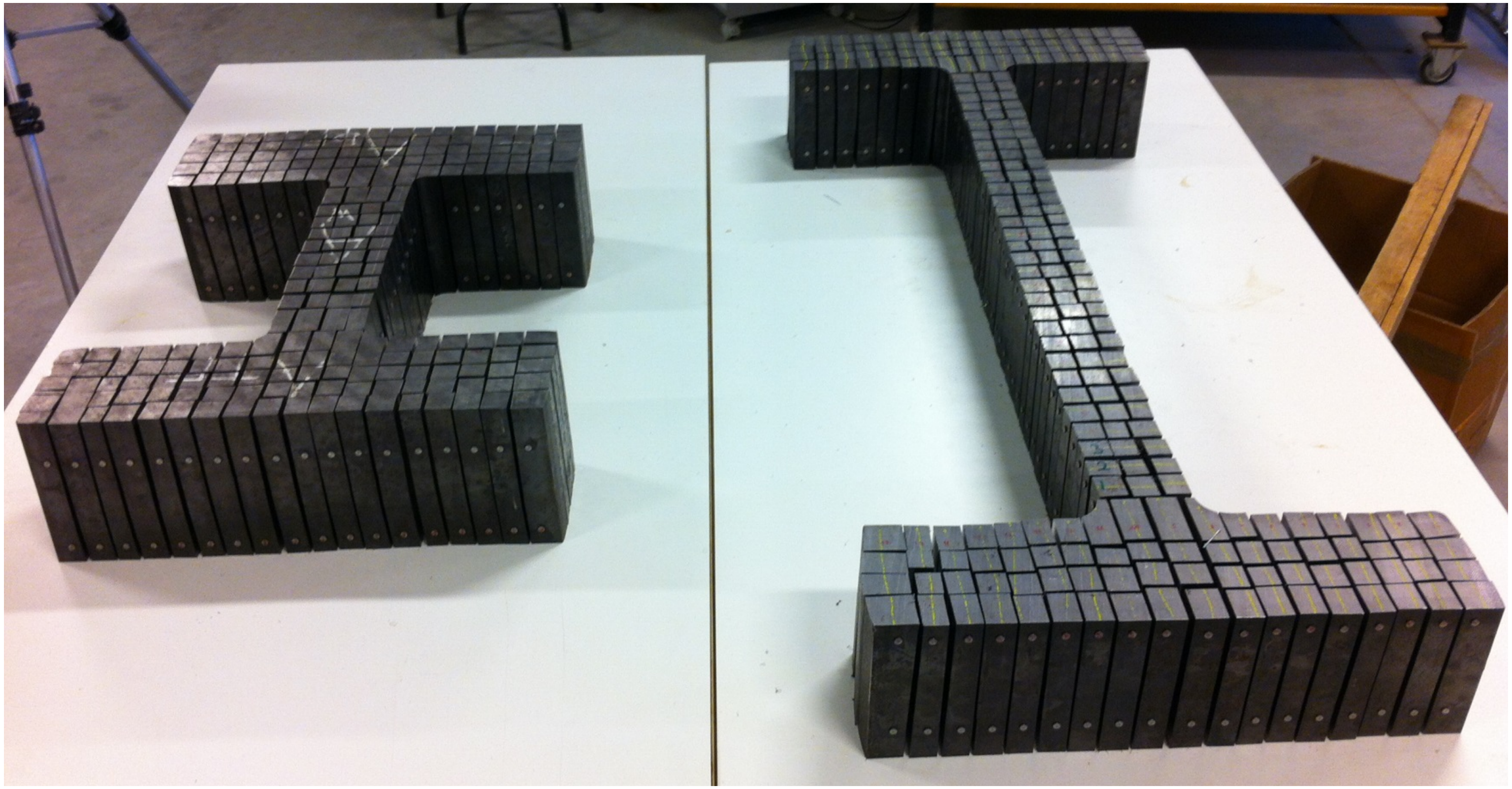
Technische Universiteit Eindhoven University of Technology

Conclusions

- Many proposals were on the table for changing and improving EN 1993-1-1
- Many amendments were already accepted by CEN/TC250/SC3
- Amendments were reported on
- These were used by the PT that works on a new draft for EN 1993-1-1 due now
- Next draft version of EN 1993-1-1 at the earliest in 2020 (implementation in 2022 ???)

Thanks for your attention (and to my colleagues in WG1)

- **Questions?**



Technische Universiteit
Eindhoven
University of Technology