THE FUTURE OF STEEL CONSTRUCTION

Eurocode 3

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THE FUTURE OF STEEL CONSTRUCTION

CONTENTS

- Overview of Eurocode 3
- Eurocode 3 Part 1.1 – General rules
- Eurocode 3 Part 1.8 – Design of joints
- Eurocode 3 Part 1.10 – Brittle fracture

Overview of Eurocode 3

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Eurocode 3 – Design of Steel Structures

EN 1993 contains seven parts

- Part 1 – General rules
- Part 2 – Bridges
- Part 3 – Towers, Masts and Chimneys
- Part 4 – Silos and Tanks
- Part 5 – Piling
- Part 6 – Crane supporting structures
- Part 7 – Sandwich panels

Overview of Eurocode 3

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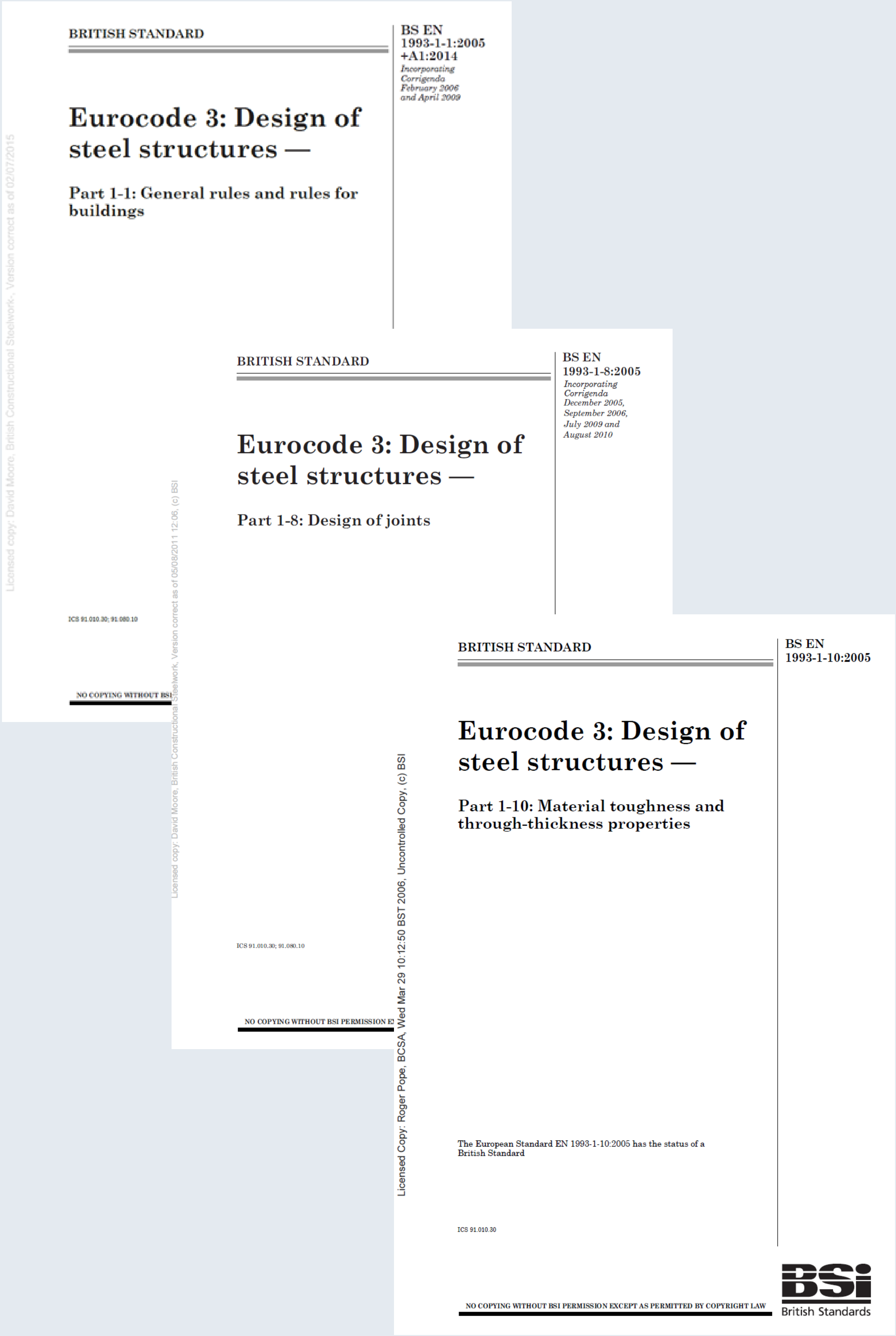
Eurocode 3 – Design of Steel Structures

EN 1993 Part 1 has 14 sub-parts:

- Part 1-1 – General rules and rules for buildings
- Part 1-2 – Structural fire design
- Part 1-3 – Cold-formed members and sheeting
- Part 1-4 – Stainless steel structures
- Part 1-5 – Plated structural elements
- Part 1-6 – Strength and stability of shell structures
- Part 1-7 – Plate assemblies and elements under transverse loads
- Part 1-8 – Joints
- Part 1-9 – Fatigue
- Part 1-10 – Material toughness and through thickness properties
- Part 1-11 – Structures with tension components
- Part 1-12 – Additional rules for steel grades up to S960
- Part 1-13 – Beams with large web openings
- Part 1-14 – Design assisted by finite element analysis



Overview of EN 1993-1-1 – General Rules

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Main Changes:

1. The scope has been extended to include steel grades up to S700
2. The scope has been extended to include the design of elliptical hollow sections
3. Simplification of the stability rules
4. Changes to section classification
5. A new method for the design of semi-compact sections (Class 3)
6. Improved resistance of cross-sections subject to torsion
7. A new method for beams subject to lateral torsional buckling
8. The simplified method for lateral torsional buckling has been fully revised
9. The design of uniform members with mono-symmetric cross-sections is covered
10. A simplified approach for fatigue design has been introduced
11. A new informative annex for the calibration of partial factors has been introduced

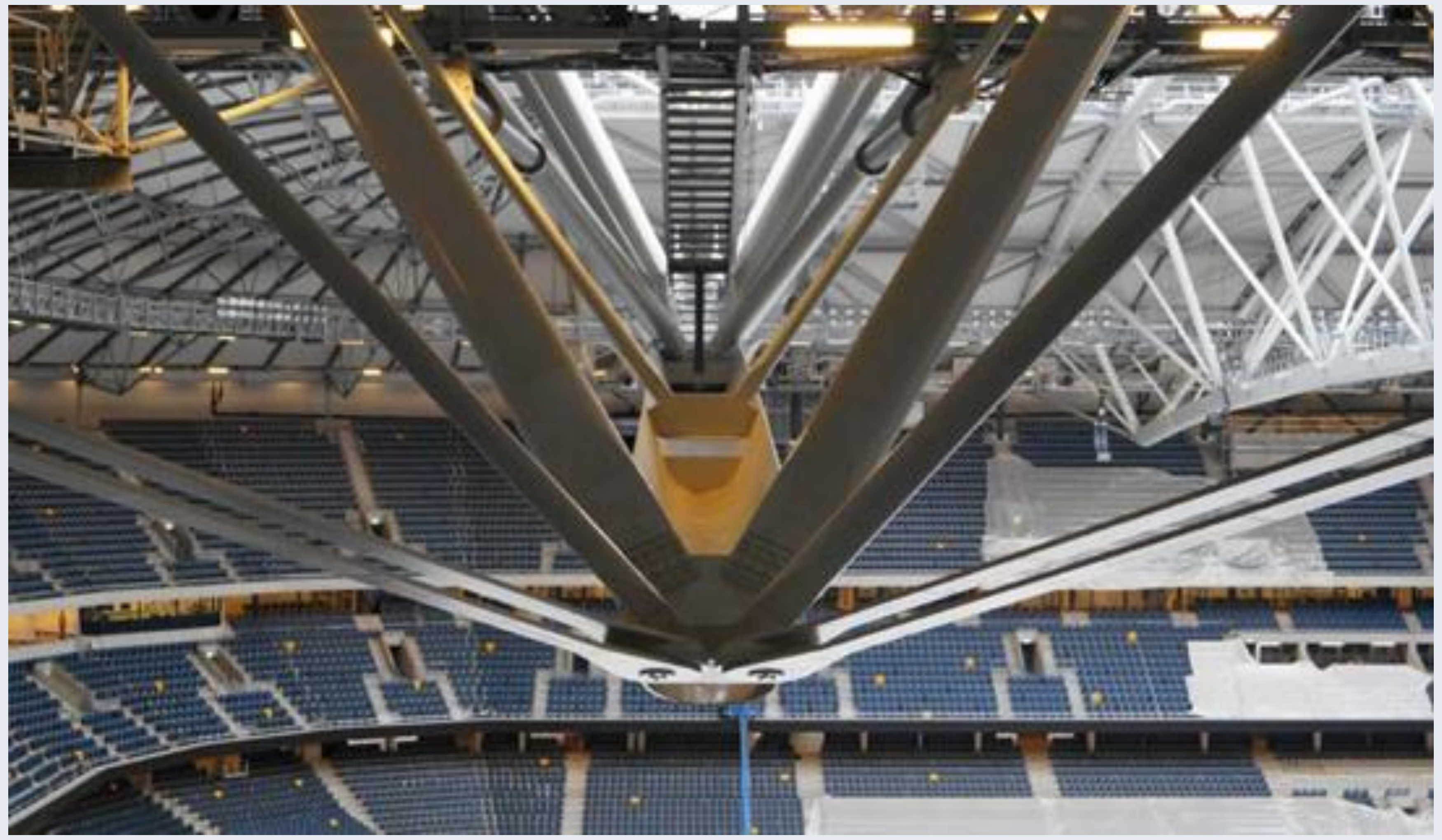
Eurocode 3 part 1-1

Scope:

There have been two main changes to the scope of EN 1993-1-1.

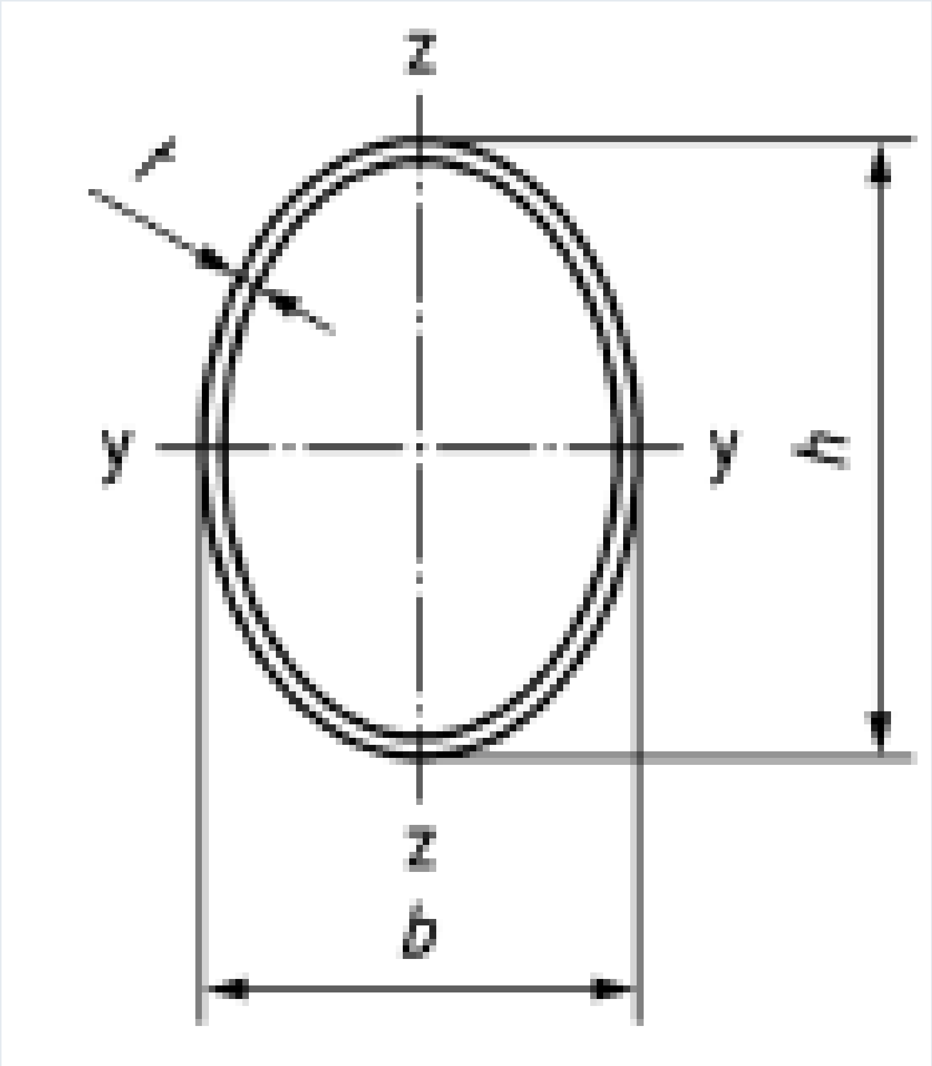
These include:

- An extension to include steel grades up to S700



Friends Arena roof truss, Stockholm

- 17m space truss spanning 162m;
- Top chord – S460,
- Bottom chord and outer diagonals are S690 and S900)



- The inclusion of elliptical hollow sections

Methods of Structural Analysis

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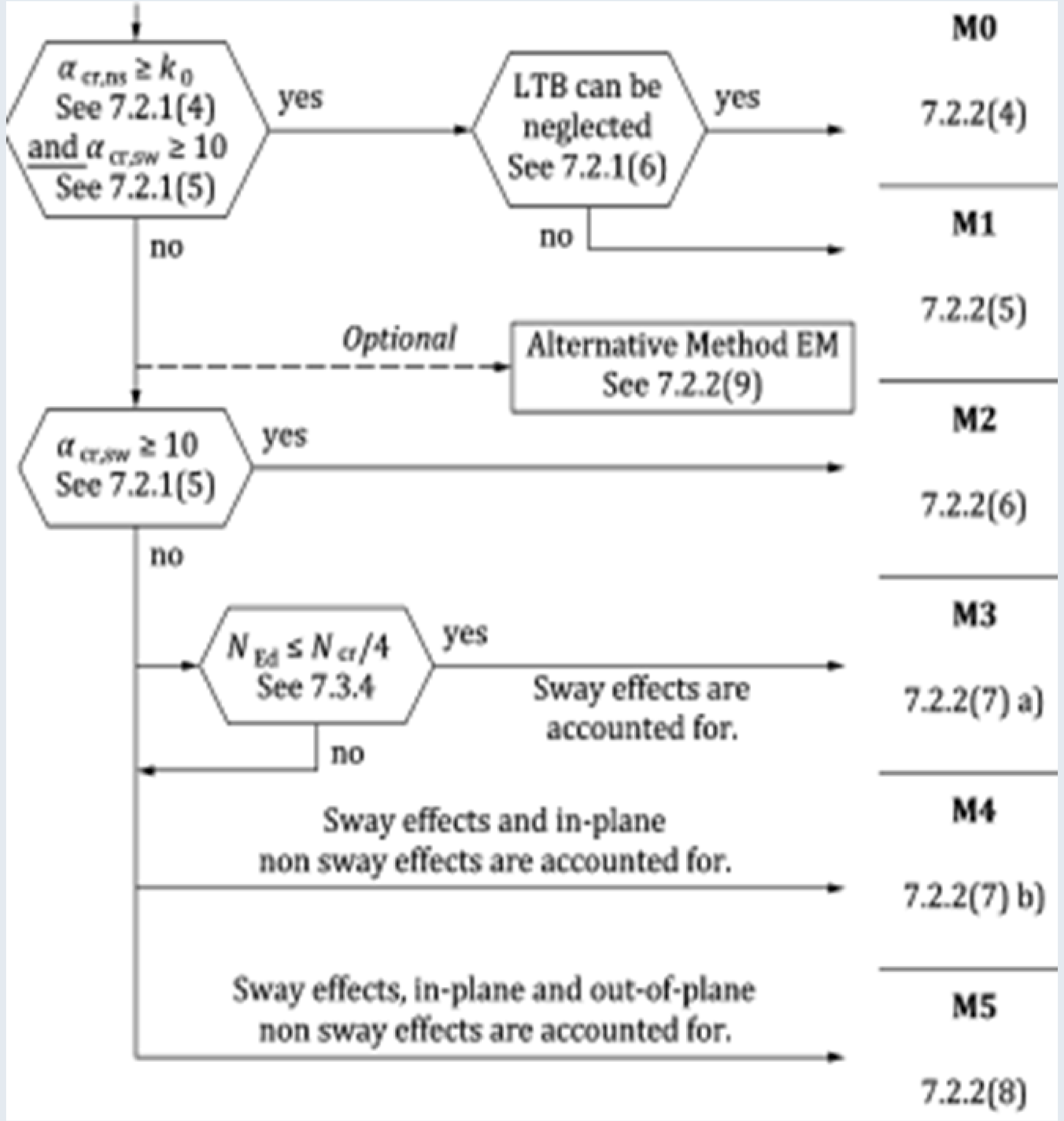
Flow Chart for Determining Methods of Structural Analysis

1. Seven Methods (M0-M5 and EM)

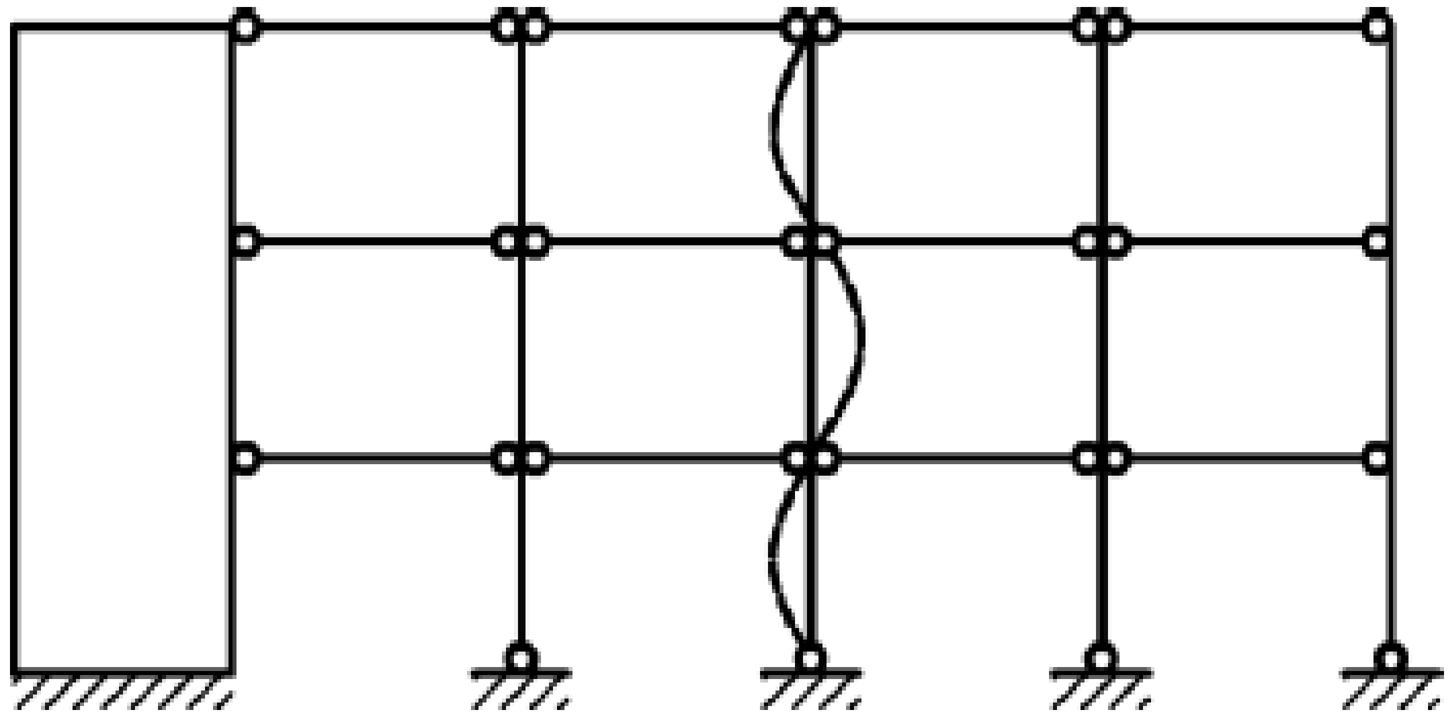
2. Parameters

   i. Non-sway member buckling mode
   ii. Sway global buckling mode
   iii. Secondary effects due to lateral torsional buckling
   iv. Equivalent bow imperfections for global analysis of frames



Methods of Structural Analysis

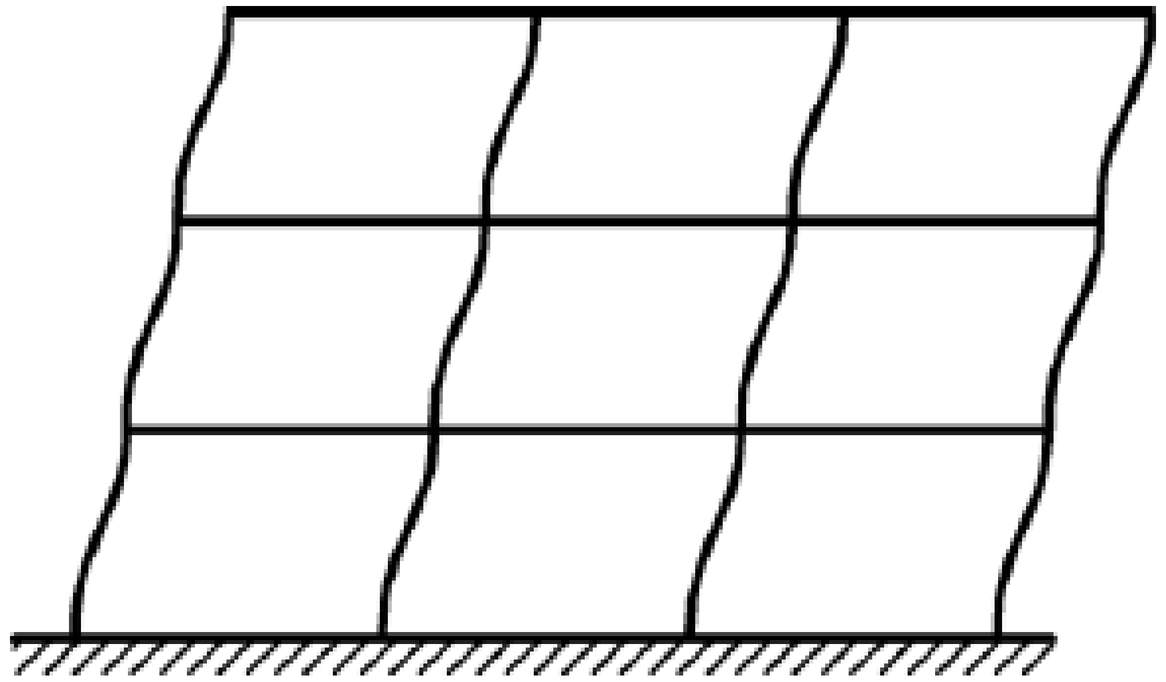
Buckling Modes of Frames



(a) Non-sway member buckling mode

$$\alpha_{cr,ns} = \frac{F_{cr,ns}}{F_d} \geq K_0$$

NDP – Default = 25



(b) Sway global buckling mode

$$\alpha_{cr,sw} = \frac{F_{cr,sw}}{F_d} \geq 10$$

$\alpha_{cr,sw}$ can be difficult to calculate and a simplified method for Portal Frames and multi-storey buildings is given in 7.2.10B

Methods of Structural Analysis

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Second Order Effects due to Lateral Torsional Buckling

These can be neglected for global analysis provided:

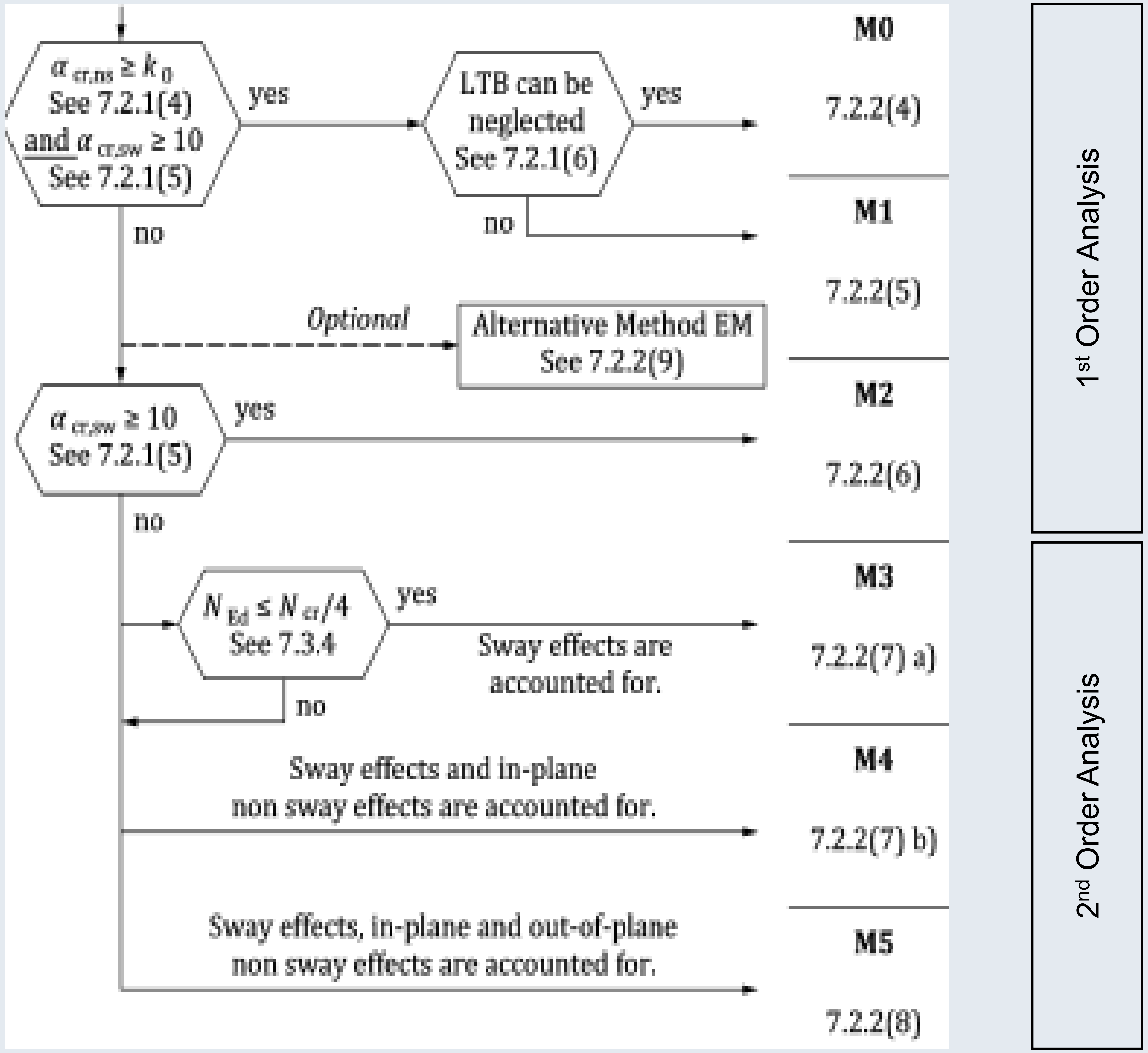
- When certain types of sections – e.g. structural hollow sections and equivalent welded box sections
- When only weak-axis bending moments act on members with mono-symmetric or double symmetric sections

Combination of sway and equivalent bow imperfections for global Analysis

For frames sensitive to second order effects equivalent bow imperfections of members should be included in the global analysis if the following conditions are met:

- A least a moment resistant joint at one end
- $N_{ed} > 0.25\ N_{cr}$

Methods of Structural Analysis



M2

Sway prevented (by bracing, lift shaft etc)
Check column buckling
Check Lateral Torsional Buckling
This would typically be for a medium rise braced (or concrete cored) steel-framed building

M3

Sway buckling effects are significant
Apply sway buckling imperfections
2nd Order analysis of the frame
Member buckling checks on individual columns and beams
This would apply to a moment frame

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Cross-Section Classification

- Cross-section resistance and rotation capacity are limited by the effects of local buckling

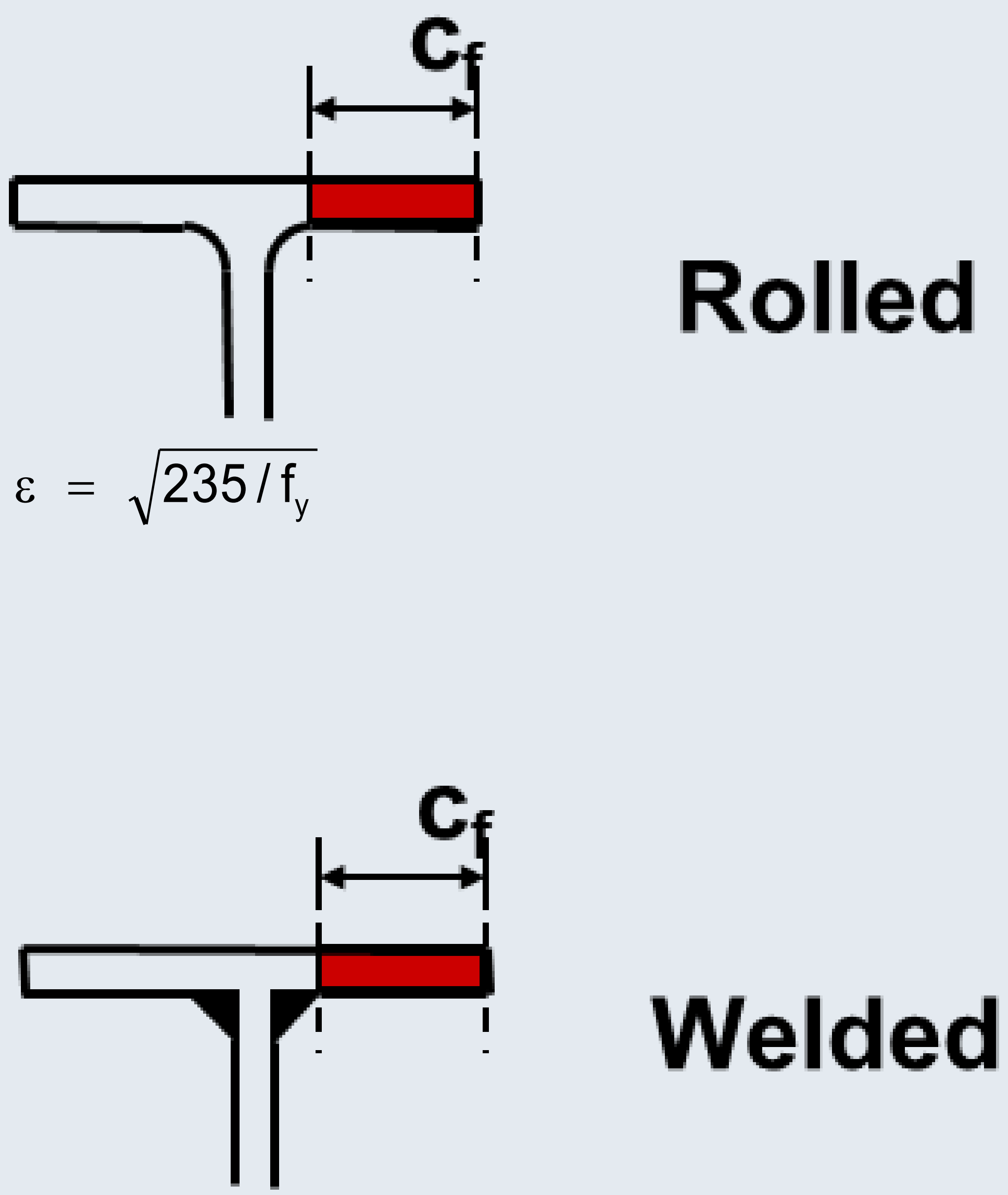
- EN 1993-1-1 accounts for the effects of local buckling through cross-section classification

- There are four classifications of cross-sections in EN 1993-1-1

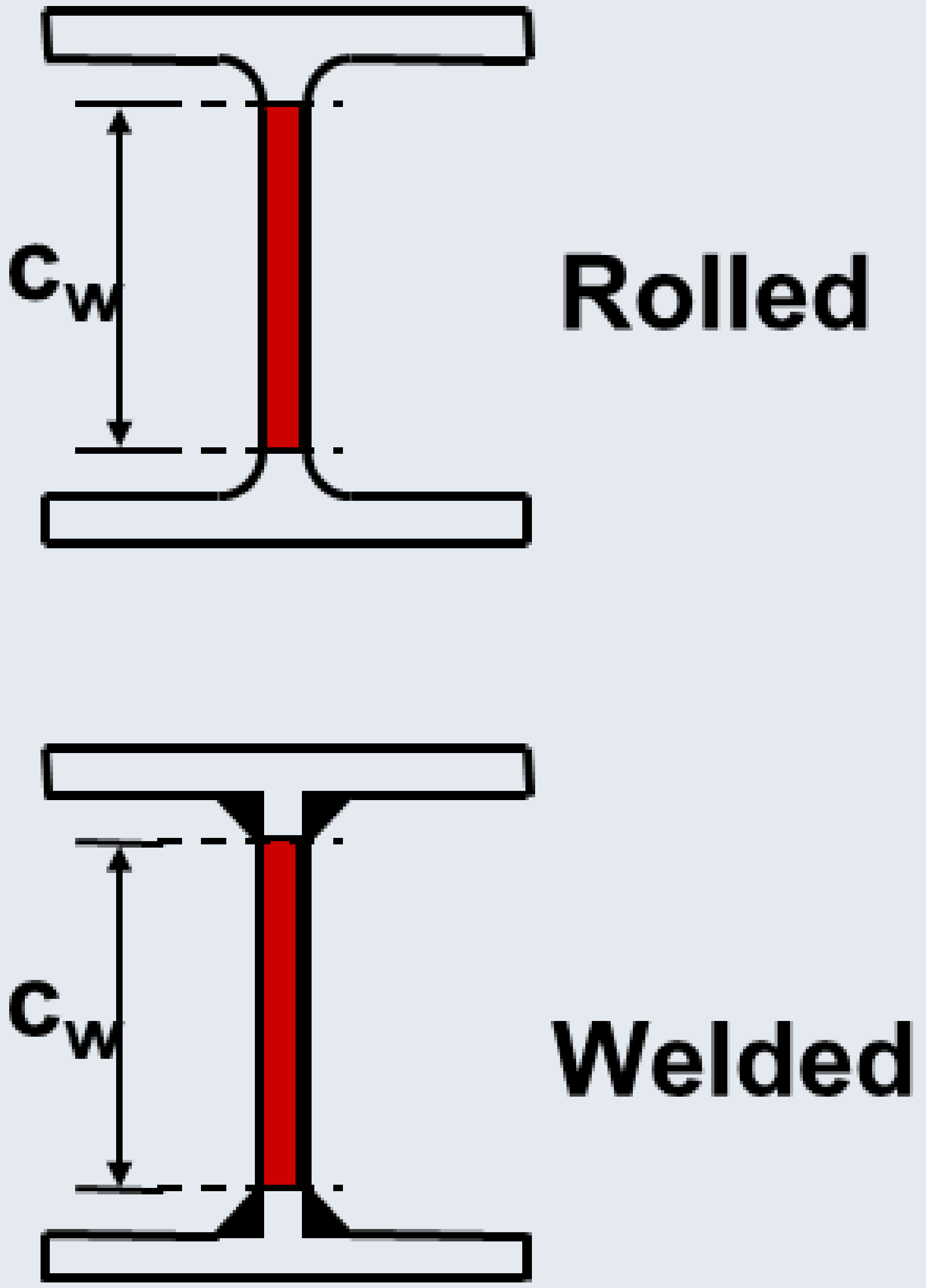
    - Class 1 – can form plastic hinges with rotation capacity
    - Class 2 – can form plastic hinges with limited rotation capacity
    - Class 3 – elastic distribution
    - Class 4 – local buckling can occur before full yield strength

Compressed Width C

Definition of compressed widths – flat widths



(a) Outstand flanges



(b) Internal compression parts

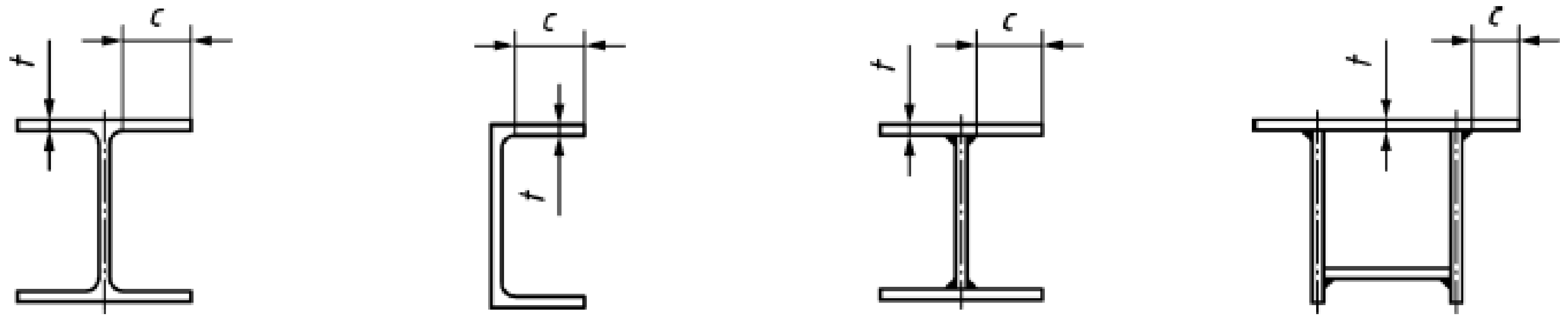
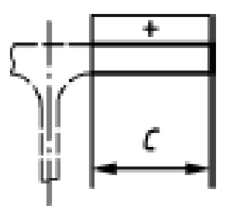
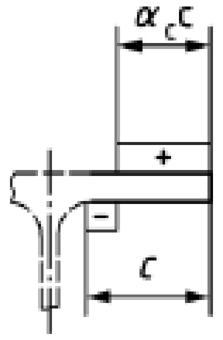
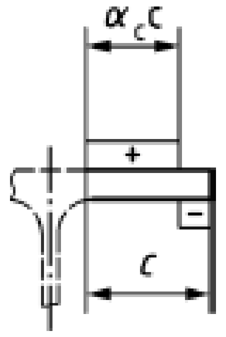
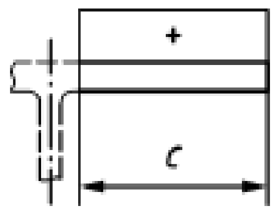
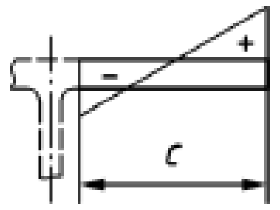
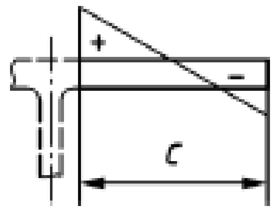
Typical - Class 1 *c*/*t* ≤ 9ε

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

Eurocode 3 Part 1-1

Classification of Cross-Sections

- The maximum width to thickness ratios for outstand flanges in compression
  - These remain the same

Outstand flanges			
 Rolled sections / Welded sections			
	Part subject to bending	Part subject to compression	Part subject to bending and axial force
Stress distribution in parts (compression positive)			
Class 1	$c/t \le 9\,\varepsilon$	$c\,/\,t \le \dfrac{9\varepsilon}{\alpha_c}$	$c\,/\,t \le \dfrac{9\varepsilon}{\alpha_c\sqrt{\alpha_c}}$
Class 2	$c/t \le 10\,\varepsilon$	$c\,/\,t \le \dfrac{10\varepsilon}{\alpha_c}$	$c\,/\,t \le \dfrac{10\varepsilon}{\alpha_c\sqrt{\alpha_c}}$
Stress distribution in parts (compression positive)			
Class 3	$c/t \le 14\,\varepsilon$	$c\,/\,t \le 21\,\varepsilon\sqrt{k_\sigma}$ For k_σ see EN 1993-1-5	

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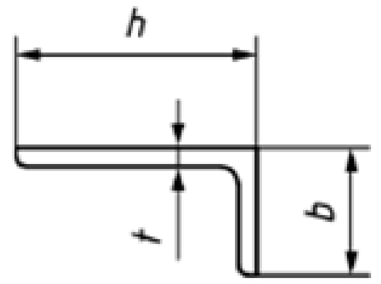
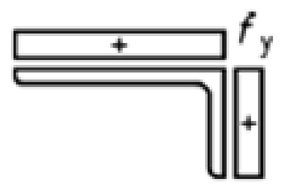
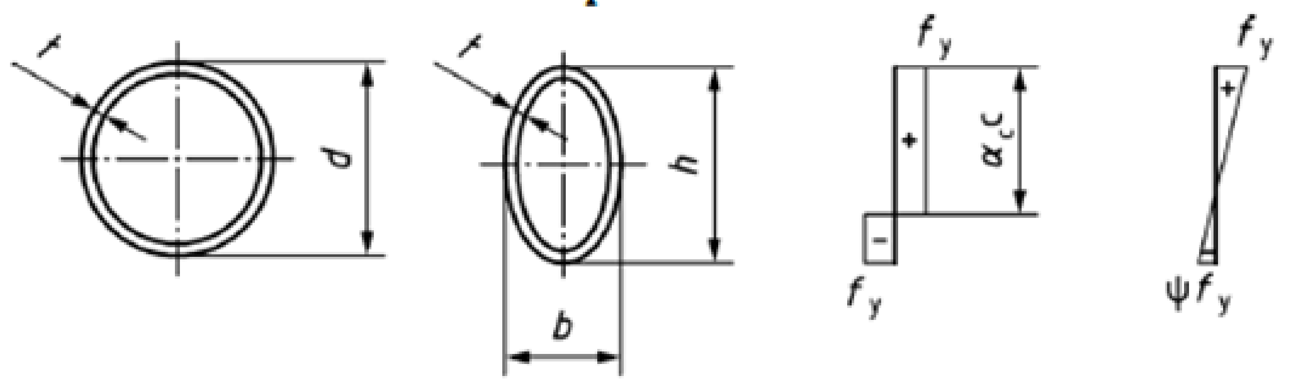
Classification of Cross-Sections

- The maximum width to thickness ratios for compression parts of angles and circular and elliptical hollow sections
    - Angles remain the same
    - Elliptical sections have been introduced
    - The diameter to thickness ratios for circular hollow sections for Class 3 sections have been improved

Angles		
Refer also to "Outstand flanges" (see sheet 2 of 3)		Does not apply to angles in continuous contact with other components
Stress distribution across section (compression positive)		
Class 3	$\frac{h}{t} \le 15\,\varepsilon$ and $\frac{b+h}{2t} \le 11{,}5\,\varepsilon$	

Circular and elliptical hollow sections			
			
	Section in compression	Section in bending	Section under bending and axial force
Class 1	$d_e/t \le 50\,\varepsilon^2$	$d_e/t \le 50\,\varepsilon^2$	$d_e/t \le 50\,\varepsilon^2$
Class 2	$d_e/t \le 70\,\varepsilon^2$	$d_e/t \le 70\,\varepsilon^2$	$d_e/t \le 70\,\varepsilon^2$
Class 3	$d_e/t \le 90\,\varepsilon^2$	$d_e/t \le 140\,\varepsilon^2$	$d_e\,/\,t \le \frac{2520\,\varepsilon^2}{5\psi + 23}$

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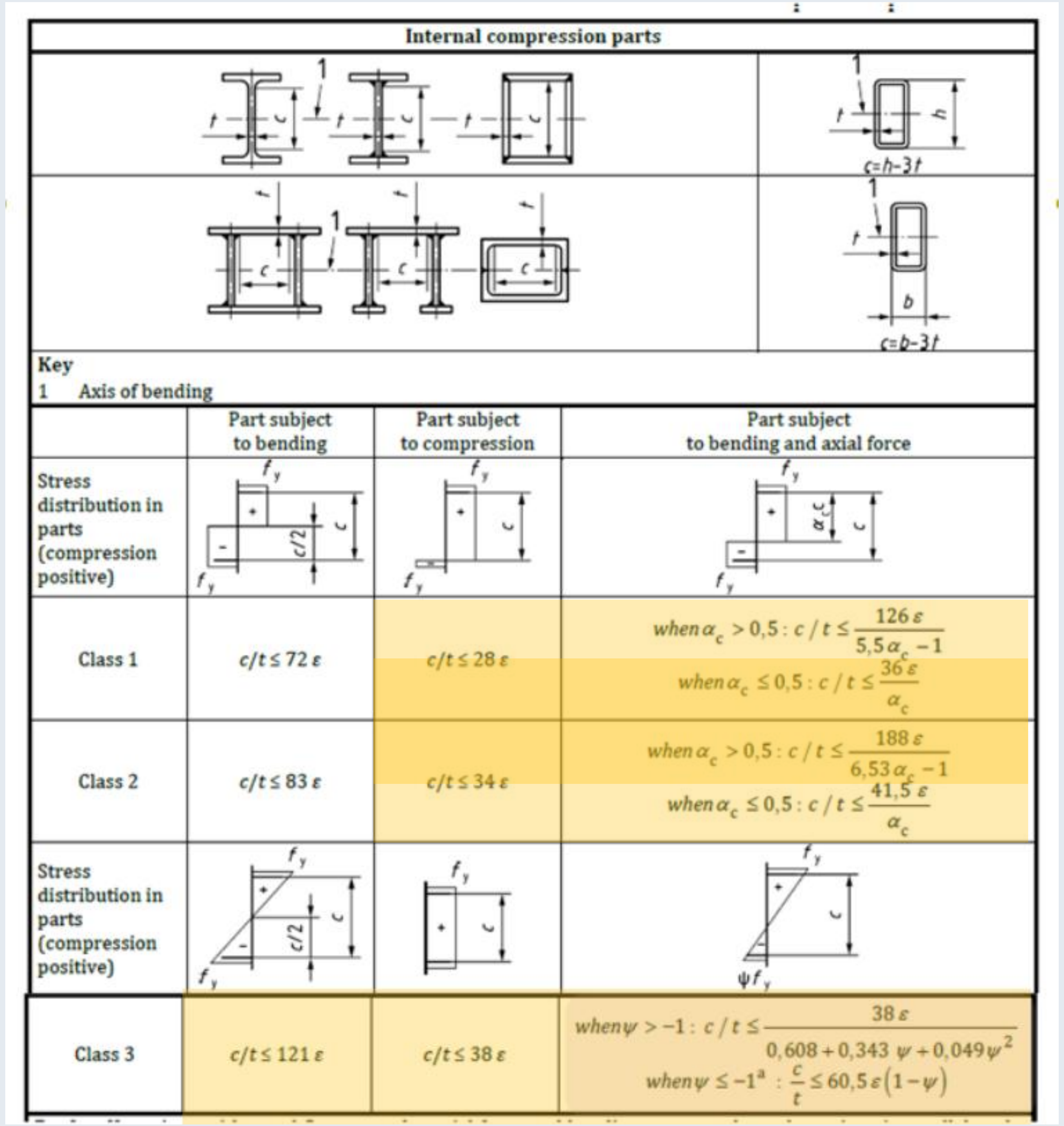
Classification of Cross-Sections

- The maximum width to thickness ratios for parts in compression have been reduced.

- Some members will change class and have a lower resistance:
  - Not many UBs
  - Some RHS change class, particularly when bending about the minor axes

- The maximum width to thickness ratios for parts in combined bending and axial force have changes



Internal compression parts			
Key 1 Axis of bending			
	Part subject to bending	Part subject to compression	Part subject to bending and axial force
Stress distribution in parts (compression positive)			
Class 1	$c/t \le 72\,\varepsilon$	$c/t \le 28\,\varepsilon$	when $\alpha_c > 0,5: c/t \le \frac{126\,\varepsilon}{5,5\alpha_c - 1}$ when $\alpha_c \le 0,5: c/t \le \frac{36\,\varepsilon}{\alpha_c}$
Class 2	$c/t \le 83\,\varepsilon$	$c/t \le 34\,\varepsilon$	when $\alpha_c > 0,5: c/t \le \frac{188\,\varepsilon}{6,53\alpha_c - 1}$ when $\alpha_c \le 0,5: c/t \le \frac{41,5\,\varepsilon}{\alpha_c}$
Stress distribution in parts (compression positive)			
Class 3	$c/t \le 121\,\varepsilon$	$c/t \le 38\,\varepsilon$	when $\psi > -1: c/t \le \frac{38\,\varepsilon}{0,608 + 0,343\,\psi + 0,049\psi^2}$ when $\psi \le -1^a: \frac{c}{t} \le 60,5\,\varepsilon(1-\psi)$

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Class 1 Limits for Combined Bending and Axial Load

- Current EN 1993-1-1

$$\text{when } \alpha > 0{,}5: \ c/t \leq \frac{396\varepsilon}{13\alpha - 1}$$

$$\text{when } \alpha \leq 0{,}5: \ c/t \leq \frac{36\varepsilon}{\alpha}$$

- 2022 EN 1993-1-1

$$\text{when } \alpha_c > 0{,}5: c/t \leq \frac{126\,\varepsilon}{5{,}5\,\alpha_c - 1}$$

$$\text{when } \alpha_c \leq 0{,}5: c/t \leq \frac{36\,\varepsilon}{\alpha_c}$$

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Class 2 Limits for Combined Bending and Axial Load

- Current EN 1993-1-1

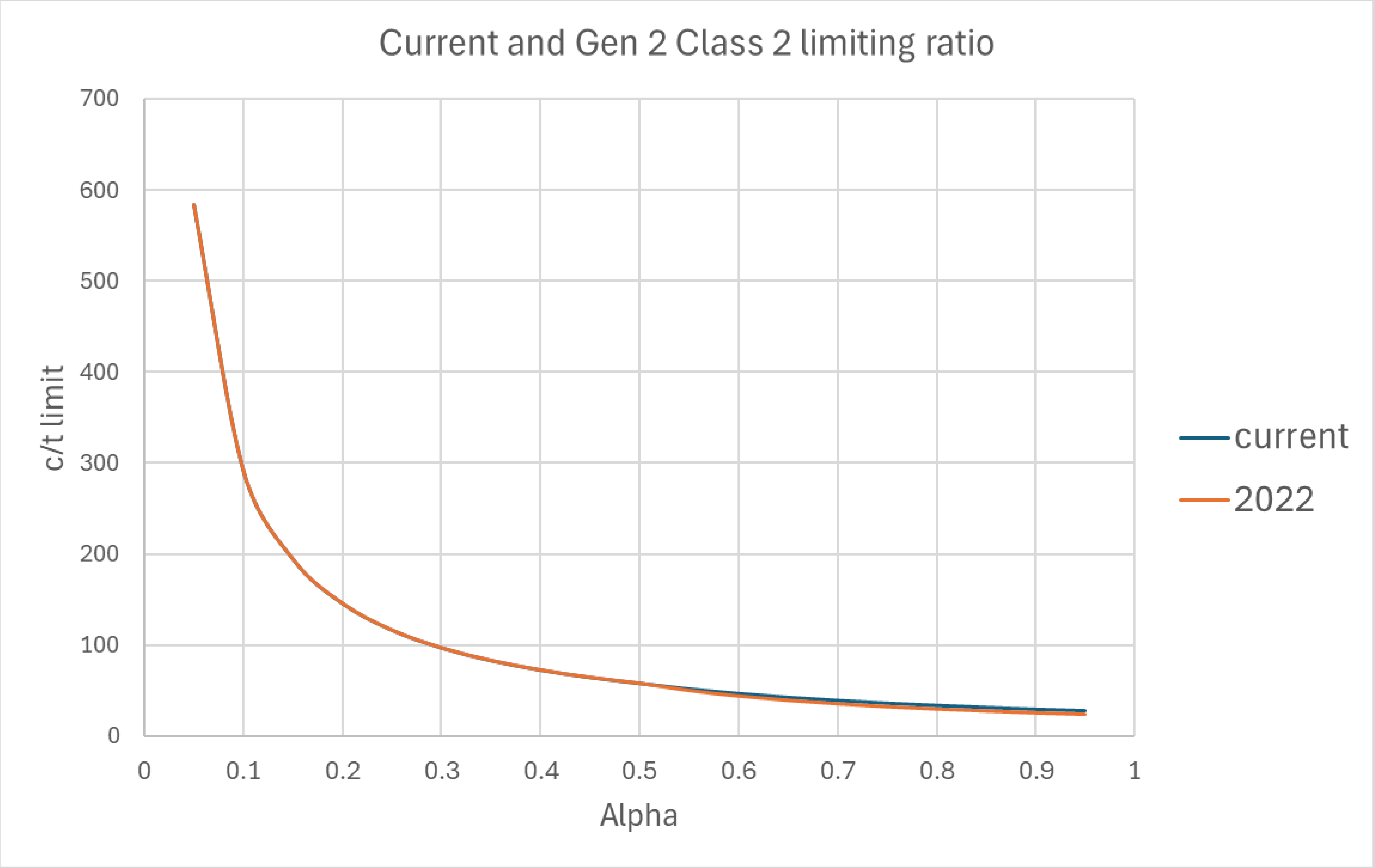
$$\text{when } \alpha > 0{,}5: \; c/t \le \frac{456\varepsilon}{13\alpha - 1}$$

$$\text{when } \alpha \le 0{,}5: \; c/t \le \frac{41{,}5\varepsilon}{\alpha}$$

- 2022 EN 1993-1-1

$$when\, \alpha_c > 0{,}5: c/t \le \frac{188\,\varepsilon}{6{,}53\,\alpha_c - 1}$$

$$when\, \alpha_c \le 0{,}5: c/t \le \frac{41{,}5\,\varepsilon}{\alpha_c}$$



Eurocode 3 Part 1-1

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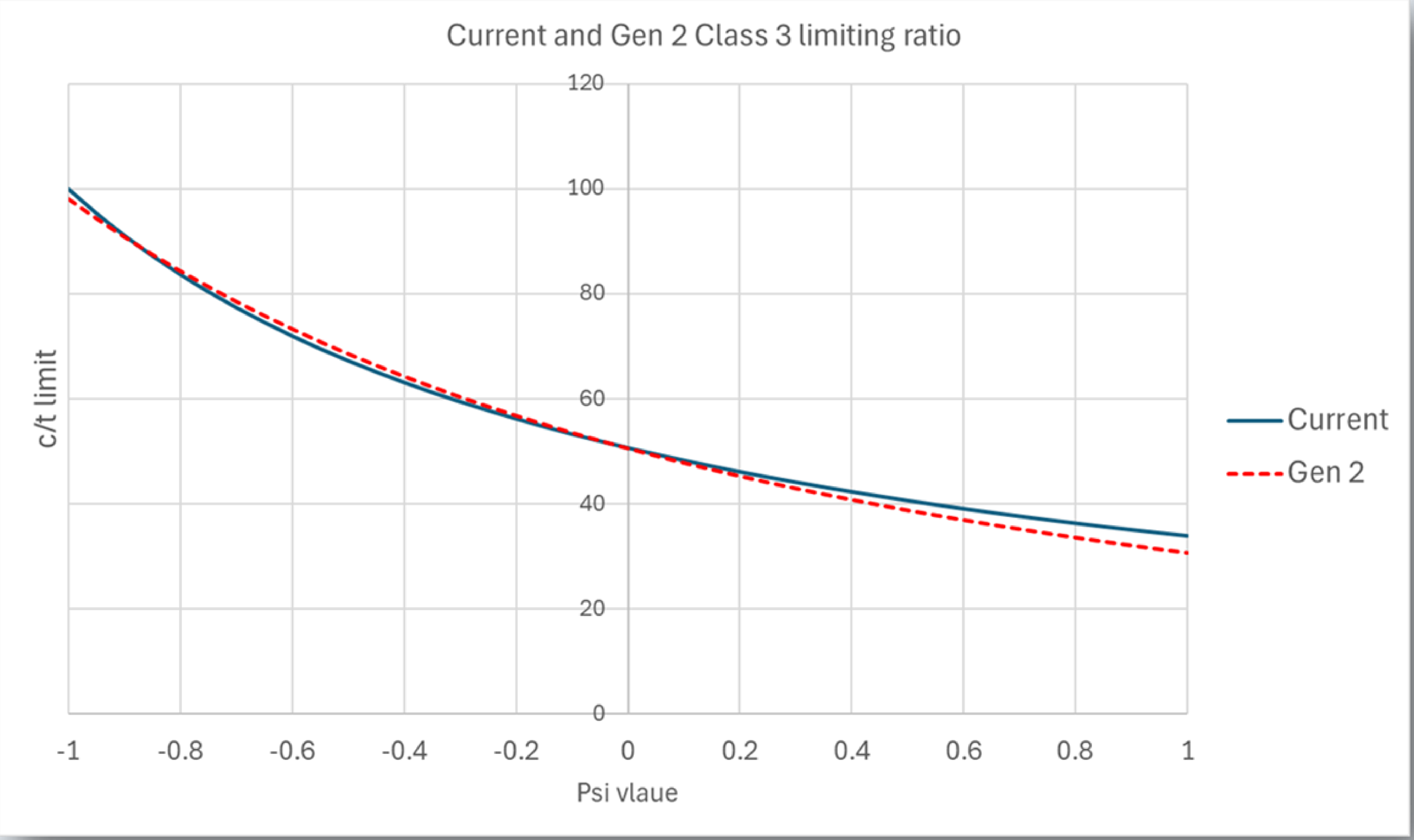
Class 3 Limits for Combined Bending and Axial Load

- Current EN 1993-1-1

$$\text{when } \psi > -1: \; c/t \leq \frac{42\varepsilon}{0{,}67 + 0{,}33\psi}$$

$$\text{when } \psi \leq -1^{*)}: \; c/t \leq 62\varepsilon(1-\psi)\sqrt{(-\psi)}$$



- 2022 EN 1993-1-1

$$when\,\psi > -1: \; c/t \leq \frac{38\,\varepsilon}{0{,}608 + 0{,}343\,\psi + 0{,}049\,\psi^2}$$

$$when\,\psi \leq -1^{a}: \; \frac{c}{t} \leq 60{,}5\,\varepsilon\left(1-\psi\right)$$

Eurocode 3 Part 1-1

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Annex B – Design of semi-compacted sections

Annex B of EN 1993-1-1: 2022 is new and gives alternative rules for the design of semi-compact, Class 3 for:

- doubly symmetric I and H sections,
- doubly symmetric box sections,
- circular hollow sections and
- elliptical hollow sections

The effective modulus of the section is a value between the elastic and plastic modulus

$$W_{ep.y} = W_{pl,y} - (W_{pl,y} - W_{el,y})\,\beta_{ep,y}$$

This means that a section that just goes into Class 3 may be able to use an effective modulus close to the plastic modulus in resistance calculations

The resistances will therefore be higher under EN 1993-1-1: 2022 than under EN 1993-1-1: 2005

Lateral Torsional Buckling

Methods

- The revised EN 1993-1-1 has three options:
- A general method (see 8.3.2.3(2)),
- A special method (see 8.3.2.3(3)) and
- A simplified method (see 8.3.3)

Lateral Torsional Buckling

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Lateral Torsional Buckling

The design buckling resistance $M_{b,Rd}$ of a laterally unrestrained beam (or segment of beam) may be taken as:

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

Reduction factor for LTB

Lateral Torsional Buckling

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Current EN 1993-1-1	2nd Gen. EN 1993-1-1
6.3.2.2 General case $\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}}$ but $\chi_{LT} \le 1,0$ where $\Phi_{LT} = 0,5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0,2\right) + \bar{\lambda}_{LT}^2\right]$	**8.3.2.3 (2) General case** Similar to the current code Can be used for all sections Rules to apply to mono-symmetric sections
6.3.2.3 Rolled (or equiv welded) sections $\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \beta\bar{\lambda}_{LT}^2}}$ but $\begin{cases} \chi_{LT} \le 1,0 \\ \chi_{LT} \le \frac{1}{\bar{\lambda}_{LT}^2} \end{cases}$ $\Phi_{LT} = 0,5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}\right) + \beta\bar{\lambda}_{LT}^2\right]$	**8.3.2.3 (3) Doubly symmetric I & H** $\chi_{LT} = \frac{f_M}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - f_M\,\bar{\lambda}_{LT}^2}}$ but $\chi_{LT} \le 1,0$ $\phi_{LT} = 0,5\left[1 + f_M\left(\left(\frac{\bar{\lambda}_{LT}}{\bar{\lambda}_z}\right)^2 \alpha_{LT}(\bar{\lambda}_z - 0,2) + \bar{\lambda}_{LT}^2\right)\right]$
6.3.2.4 Simplified method $\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}}$ but $\chi \le 1,0$ where $\Phi = 0,5\left[1 + \alpha\left(\bar{\lambda} - 0,2\right) + \bar{\lambda}^2\right]$ $\bar{\lambda}_f = \frac{k_c L_c}{i_{f,z}\lambda_1} \le \bar{\lambda}_{c0}\frac{M_{c,Rd}}{M_{y,Ed}}$	**8.3.3 Simplified method** Similar to current code but changes to $\overline{\lambda_f}$

Lateral Torsional Buckling

Special Case (Double Symmetric I and H)

Factor f_M – relates to the BMD

$$\chi_{LT} = \frac{\boxed{f_M}}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - f_M \bar{\lambda}_{LT}^2}} \quad \text{but} \quad \chi_{LT} \leq 1,0$$

where

Imperfection factor, α_{LT}

$$\Phi_{LT} = 0,5\left[1 + \boxed{f_M}\left(\left(\frac{\bar{\lambda}_{LT}}{\boxed{\bar{\lambda}_z}}\right)^2 \boxed{\alpha_{LT}}\left(\boxed{\bar{\lambda}_z} - 0,2\right) + \bar{\lambda}_{LT}^2\right)\right]$$

The minor axis slenderness

Lateral Torsional Buckling

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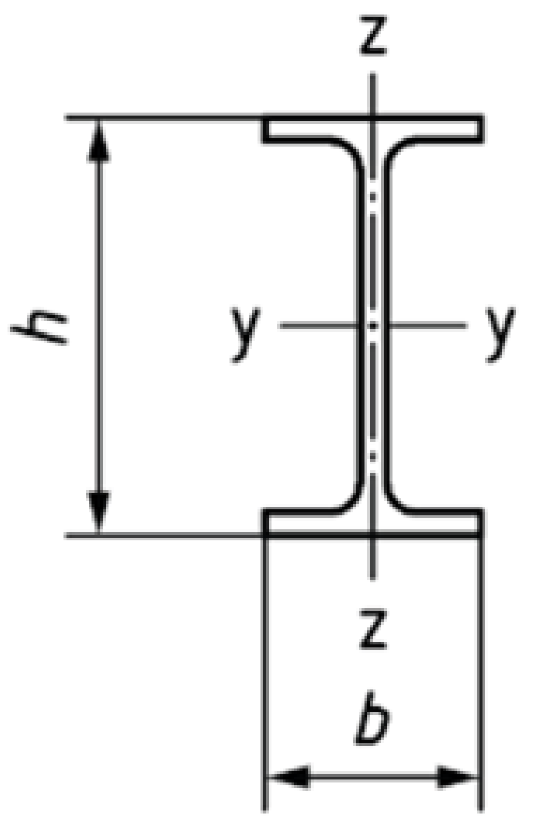
Special Case (Double Symmetric I and H)

Imperfection factor, α_{LT}

Table 8.5 — Imperfection factor α_{LT} for lateral torsional buckling of doubly symmetric I- and H-sections

Cross-section		Limits		α_{LT}
Rolled I- or H-sections		$h/b > 1,2$	$t_f \leq 40$ mm	$0,12\sqrt{\frac{W_{el,y}}{W_{el,z}}}$ but : $\alpha_{LT} \leq 0,34$
			$t_f > 40$ mm	$0,16\sqrt{\frac{W_{el,y}}{W_{el,z}}}$ but : $\alpha_{LT} \leq 0,49$
		$h/b \leq 1,2$	—	$0,16\sqrt{\frac{W_{el,y}}{W_{el,z}}}$ but : $\alpha_{LT} \leq 0,49$

Lateral Torsional Buckling

Special Case (Double Symmetric I and H)

Imperfection factor, α_{LT}

Of 96 UB:

- 62, $\alpha_{LT=}$ 0.34
- 3, α_{LT}= 0.49
- 31, α_{LT}= unique

Of 36 UC

- All 36 have α_{LT}= unique

Lateral Torsional Buckling

Factor f_M

- Relates to the <u>shape</u> of the BMD

- Does <u>not</u> relate to C_1

(C_1 can have the same value from a range of BMD)

Load case	Factor f_M	Factor k_c
M = uniform	1,0	1,0
M ψM $-1 \le \psi \le +1$	$1{,}25 - 0{,}1\psi - 0{,}15\psi^2$	$\frac{1}{1{,}33 - 0{,}33\psi}$
	1,05	0,94
M_h M_0 M_h M_0	For $0 \le \frac{M_0}{M_h} < 2{,}0$: $1{,}0 + 1{,}35\frac{M_0}{M_h} - 0{,}33\left(\frac{M_0}{M_h}\right)^3$ For $\frac{M_0}{M_h} \ge 2$: 1,05	$\frac{M_0}{M_h} < 1{,}0$: 1,00 $\frac{M_0}{M_h} \ge 1{,}0$: 0,90
M_h M_0	For $0 \le \frac{M_0}{M_h} < 1{,}47$: $1{,}25 + 0{,}5\left(\frac{M_0}{M_h}\right)^2 - 0{,}275\left(\frac{M_0}{M_h}\right)^4$ For $\frac{M_0}{M_h} \ge 1{,}47$: 1,05	$\frac{M_0}{M_h} < 0{,}5$: 0,75 $\frac{M_0}{M_h} \ge 0{,}5$: 0,91
	1,10	0,86
M_h M_0 M_h M_0	For $0 \le \frac{M_0}{M_h} < 2{,}0$: $1{,}0 + 1{,}25\frac{M_0}{M_h} - 0{,}30\left(\frac{M_0}{M_h}\right)^3$ For $\frac{M_0}{M_h} \ge 2{,}0$: 1,10	$\frac{M_0}{M_h} < 1{,}0$: 1,00 $\frac{M_0}{M_h} \ge 1{,}0$: 0,77
M_h M_0	For $0 \le \frac{M_0}{M_h} < 1{,}5$: $1{,}25 + 0{,}325\left(\frac{M_0}{M_h}\right)^2 - 0{,}175\left(\frac{M_0}{M_h}\right)^4$ For $\frac{M_0}{M_h} \ge 1{,}50$: 1,10	$\frac{M_0}{M_h} < 0{,}5$: 0,75 $\frac{M_0}{M_h} \ge 0{,}5$: 0,82

Lateral Torsional Buckling

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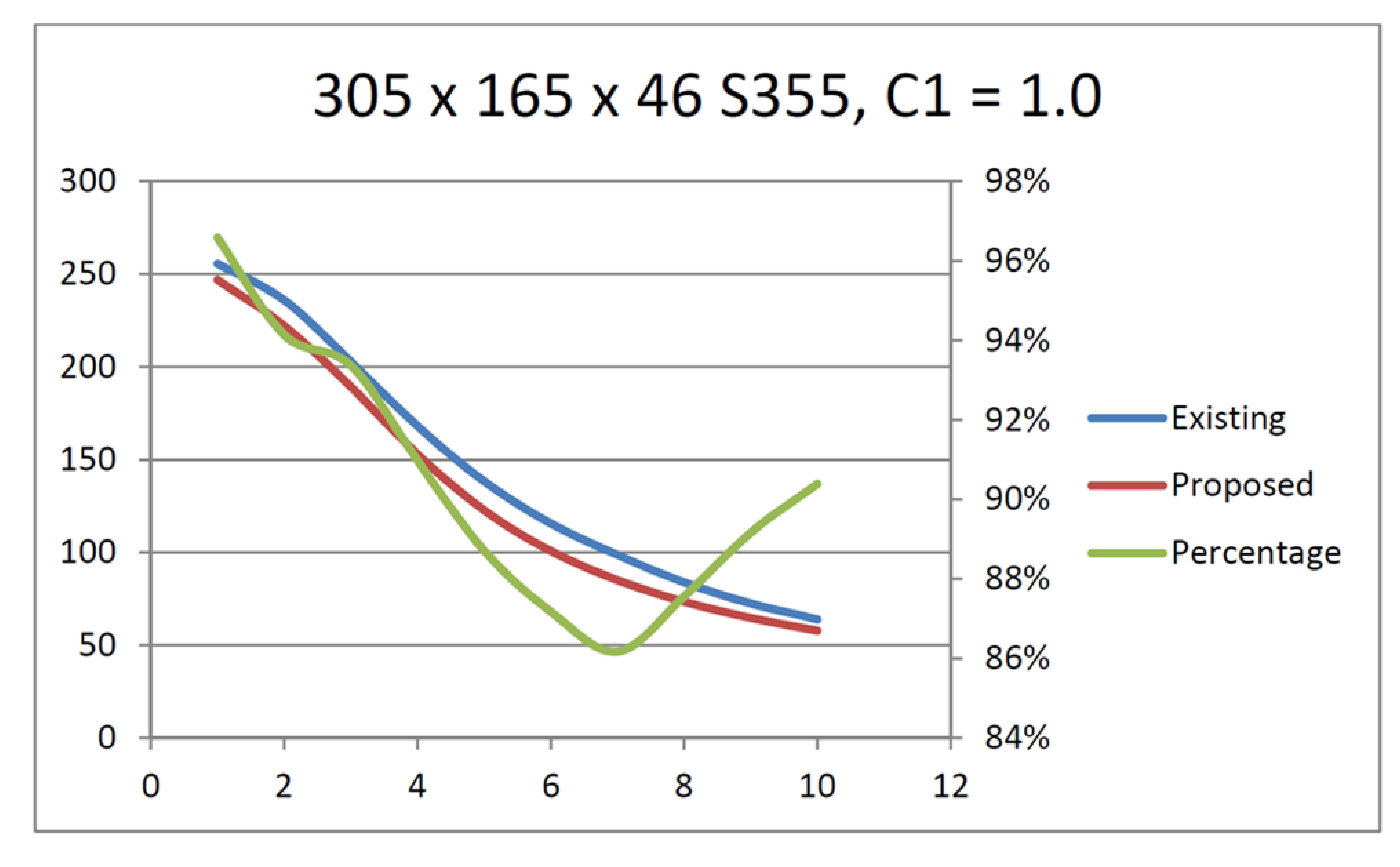
The LTB resistance drops in a range up to about 15%



Overview of EN 1993-1-8 - Joints

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The main changes addressed include:

1. The scope has been extended to cover the design of nominally pinned connections
2. New provisions for the design and fabrication of connections with bolts in threaded holes
3. A non-linear model to calculate the deformation of the bolt hole due to bearing of the fasteners against the plate and a revised formulation for the design bearing resistance
4. Supplementary web plates

EN 1993-1-8 - Joints

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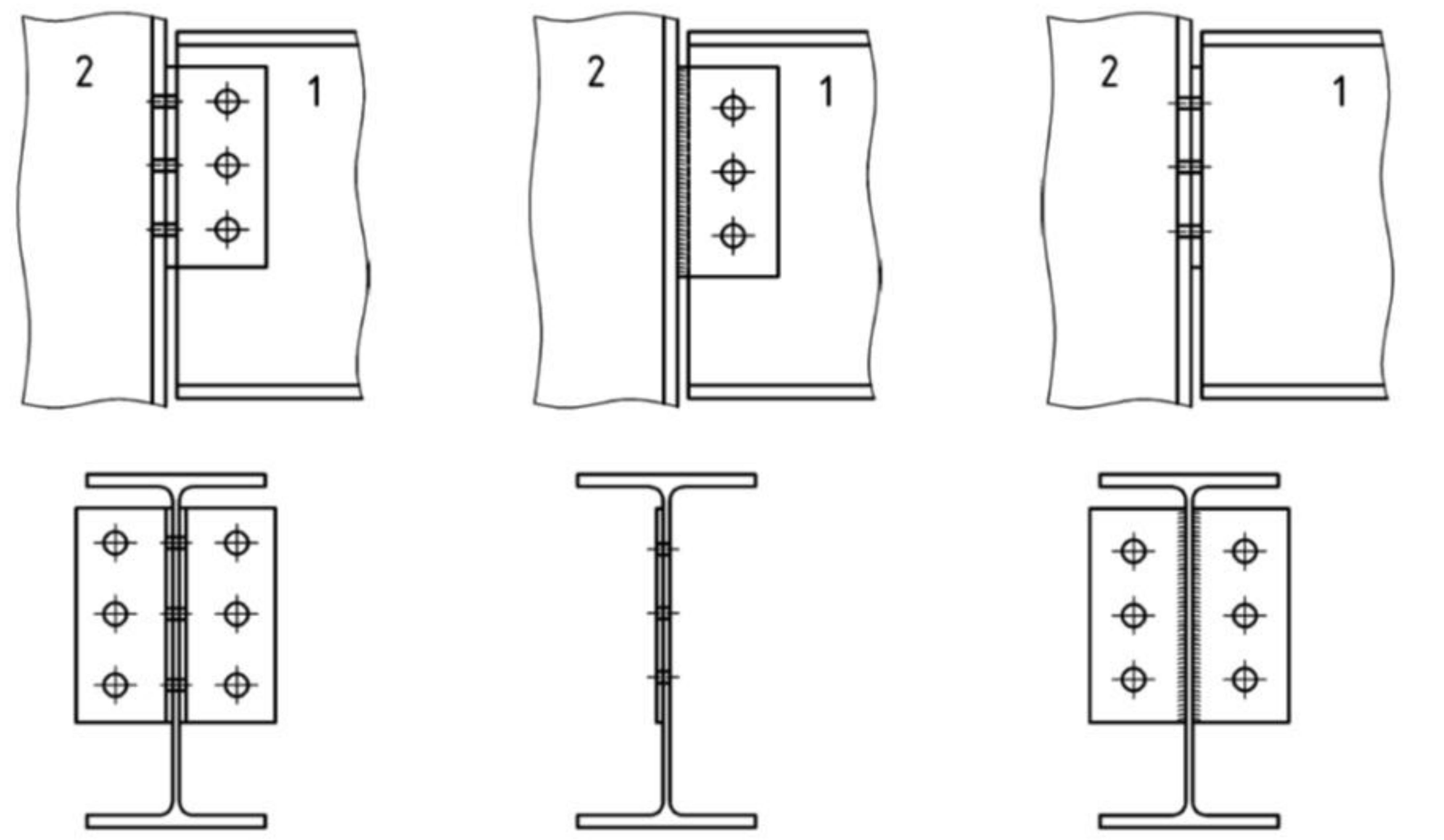
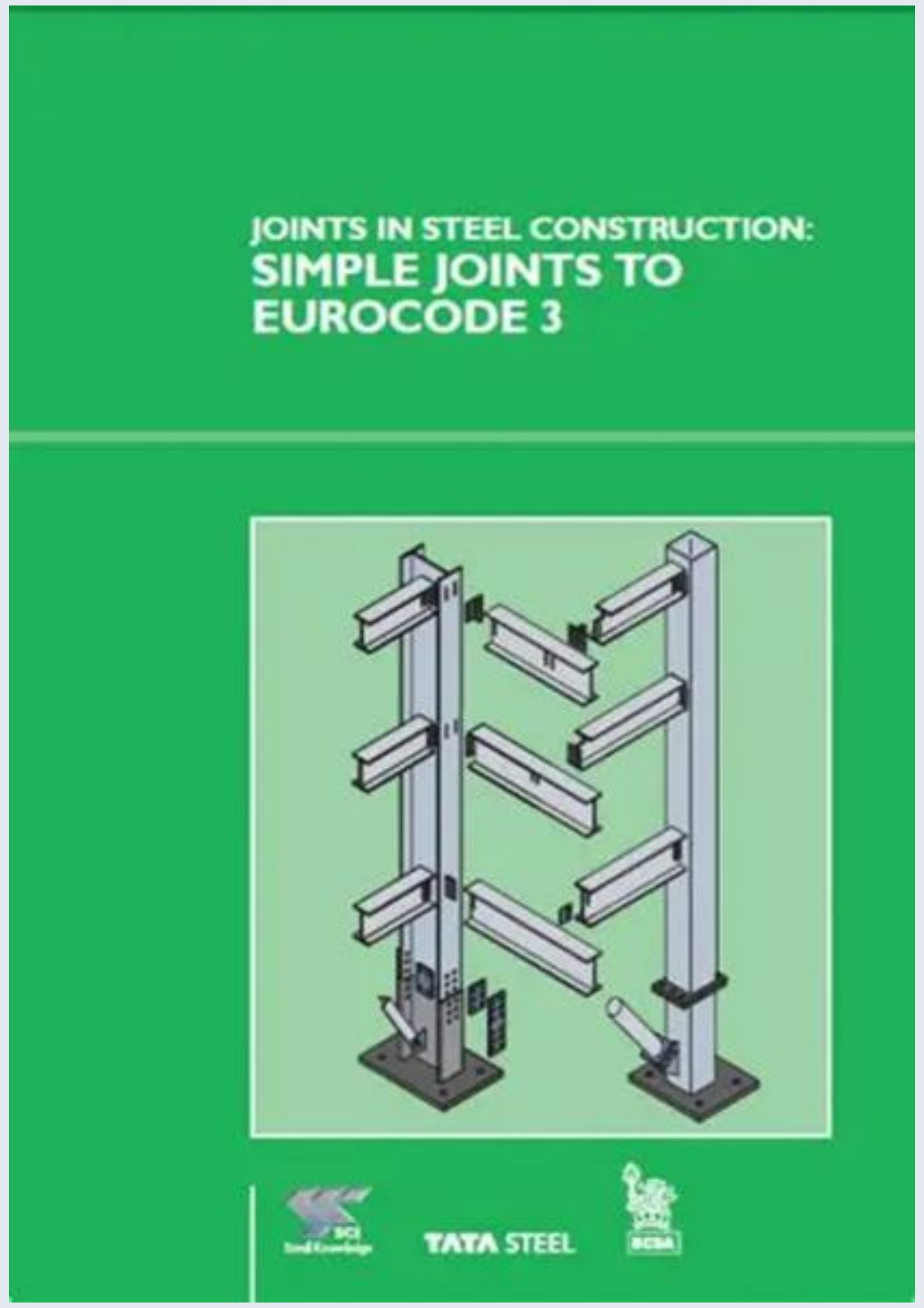
Annex C – Design of Nominally Pinned Connections

This **new** Annex applies to the design of nominally pinned connections, connecting H and I sections (from hot-rolled or welded profile with similar dimensions) with double angle web cleats, fin plates, and partial depth end plates



a) Double angle web cleats b) Fin plate c) Partial depth end plate

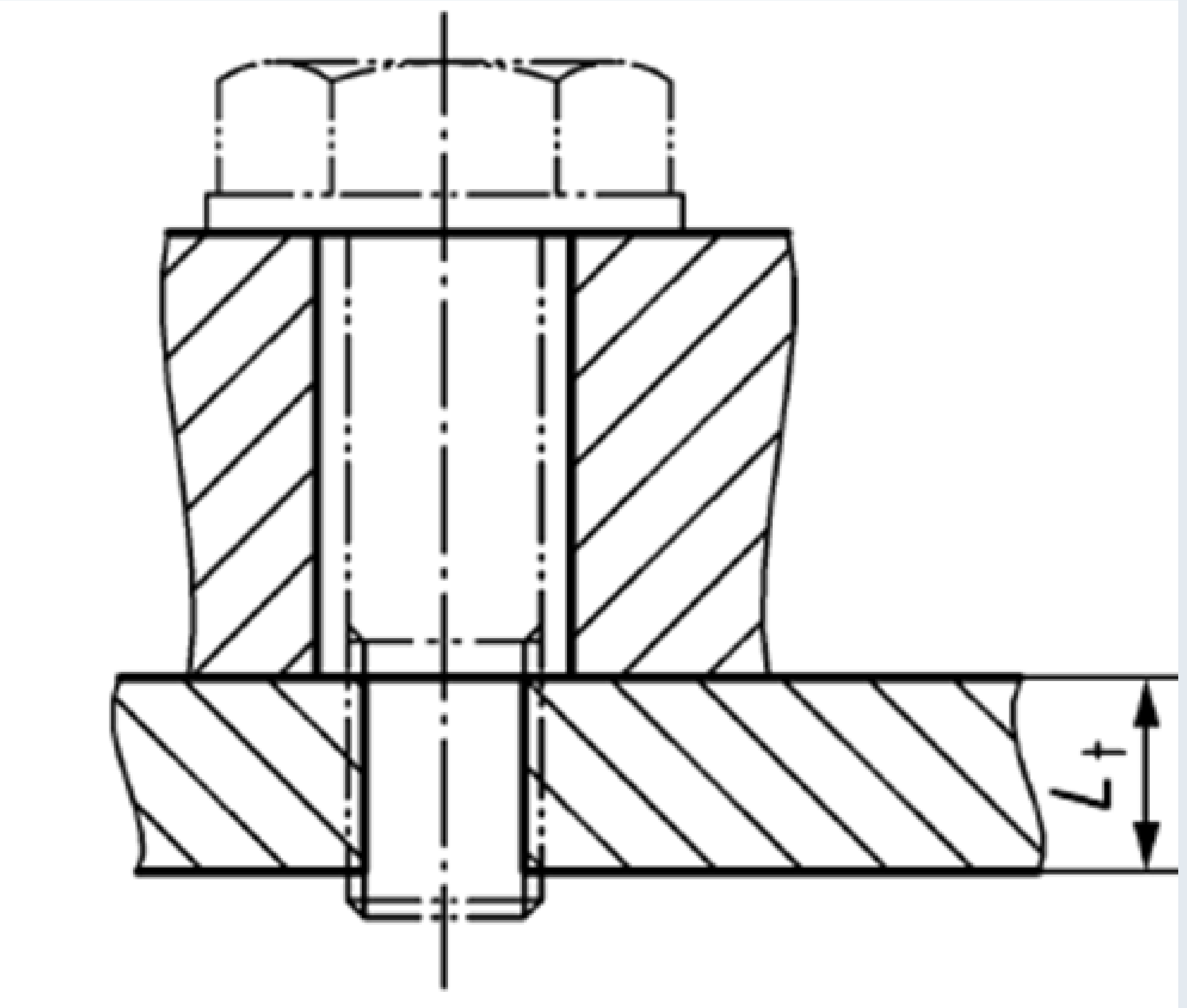


EN 1993-1-8 - Joints

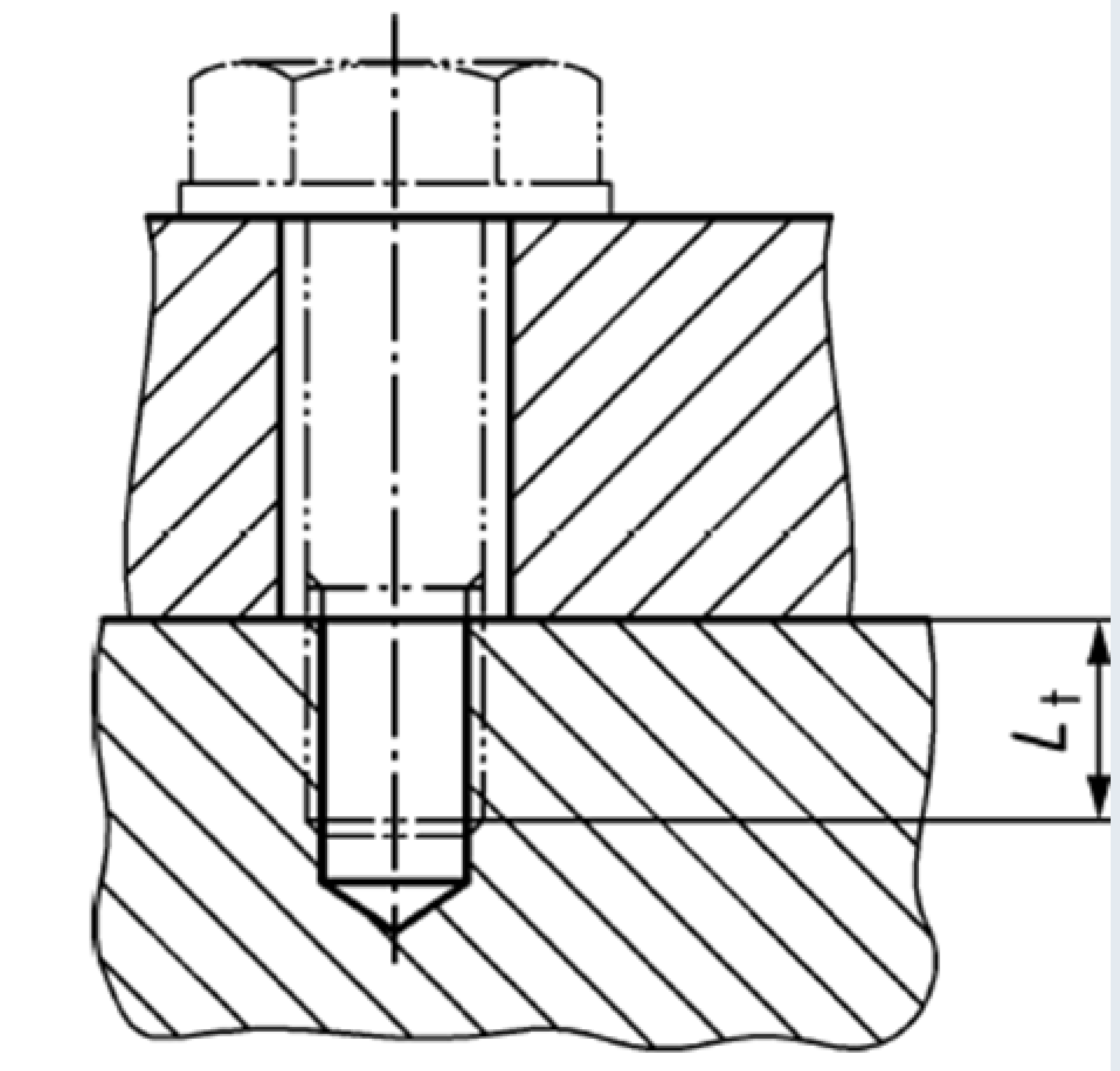
Bolts in Tapped Holes

Clause 5.9.3 ‘Bolts in tapped holes’ is new and applies to:

- Bolts in threaded through holes and
- Bolts in threaded blind holes



Bolts in threaded through holes



Bolts in threaded blind holes

EN 1993-1-8 - Joints

THE FUTURE OF STEEL CONSTRUCTION

Bolts in Tapped Holes

The minimum engagement length is given in the Table below and is a national determined parameter and can be changed in the National Annex:

Table 5.10 — Minimum thread engagement lengths L_t to bolt diameter d ratio for bolts M12 to M36

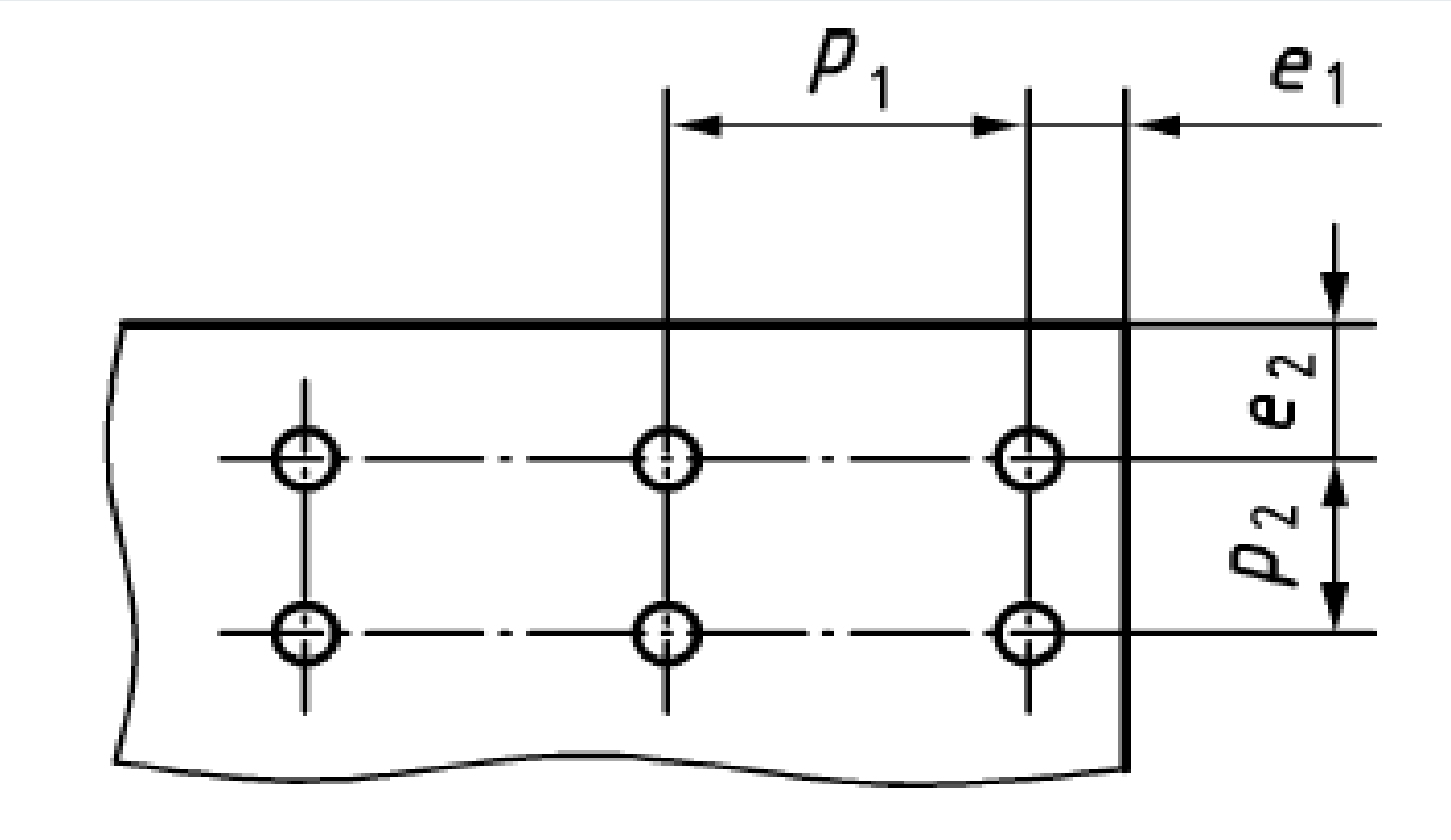
Bolt property class and steel grade	L_t/d for steel of grade			
	S235	S275	S355	≥ S460
4.6	1,00	1,00	1,00	1,00
5.6	1,02	1,00	1,00	1,00
8.8	1,34	1,23	1,11	1,06
10.9	1,58	1,43	1,26	1,19

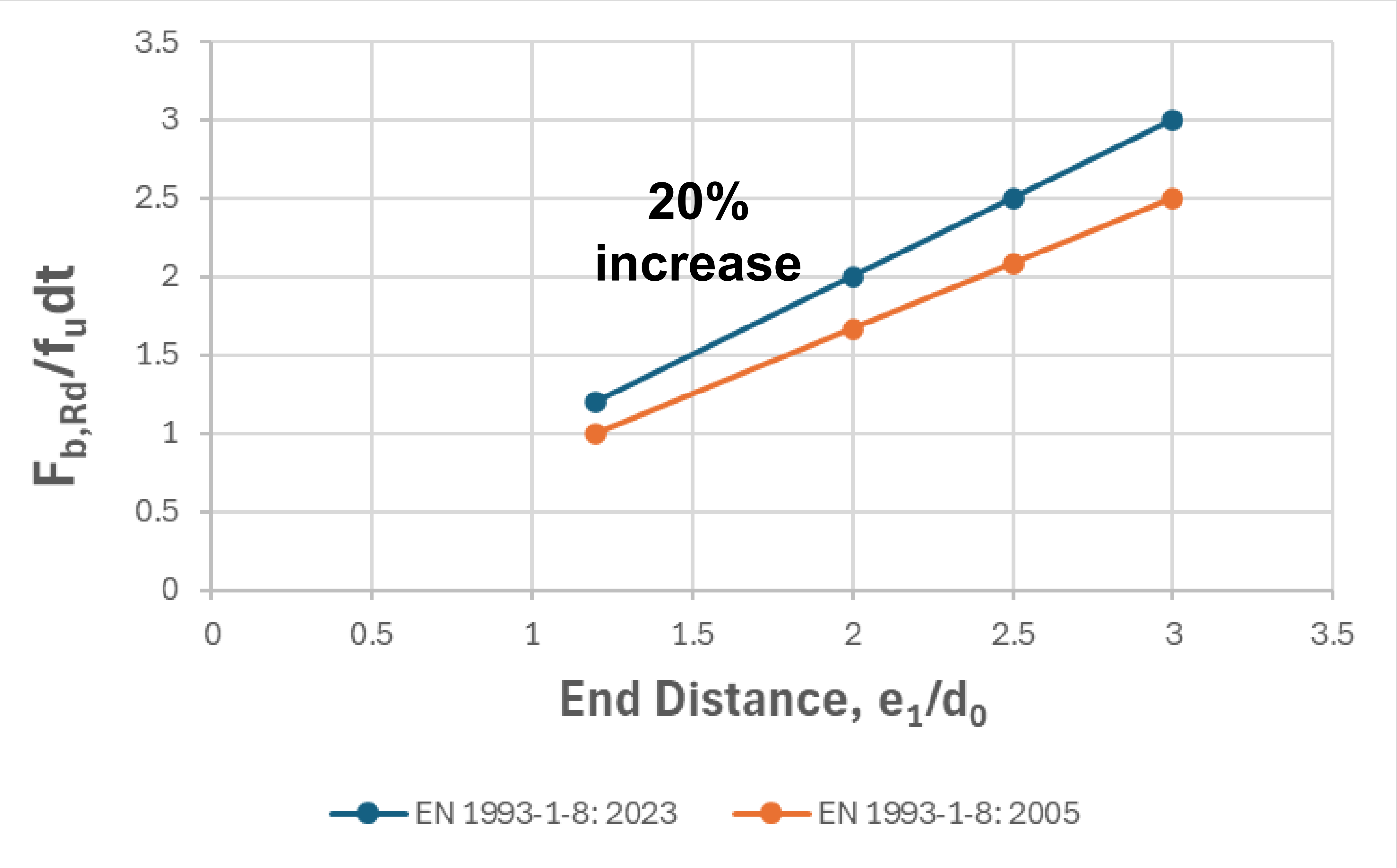
EN 1993-1-8 - Joints

Bearing Resistance of Bolts

Current EN 1993-1-8
Based
- e_1 for end bolts
- e_2 and $p_1$for edge and inner bolts

2024 EN 1993-1-8
Based on:
- e_1 for end bolts
- p_1 for internal bolts





Bearing Resistance for end bolt (M20, Property Grade 8.8, S355, e_2 and P_2 max)

EN 1993-1-8 - Joints

Bearing Resistance of Bolts (cont'd)

Deformation
Current EN 1993-1-8

- didn't allow for deformation
- Increased safety factor included in the National Annex

EN 1993-1-8: 2024

- Allows for deformation

$$F_{b,Rd,red} = \frac{k_m\, \alpha_{b,red}\, f_u d t}{\gamma_{M2}}$$

$$\alpha_{b,red} \begin{cases} \text{Min } (\alpha_b\, ;\, 2) \text{ for steel grades higher that S460} \\ \text{Min } (0.8\, \alpha_b\, ;\, 2) \text{ for steel grades up to S460} \end{cases}$$

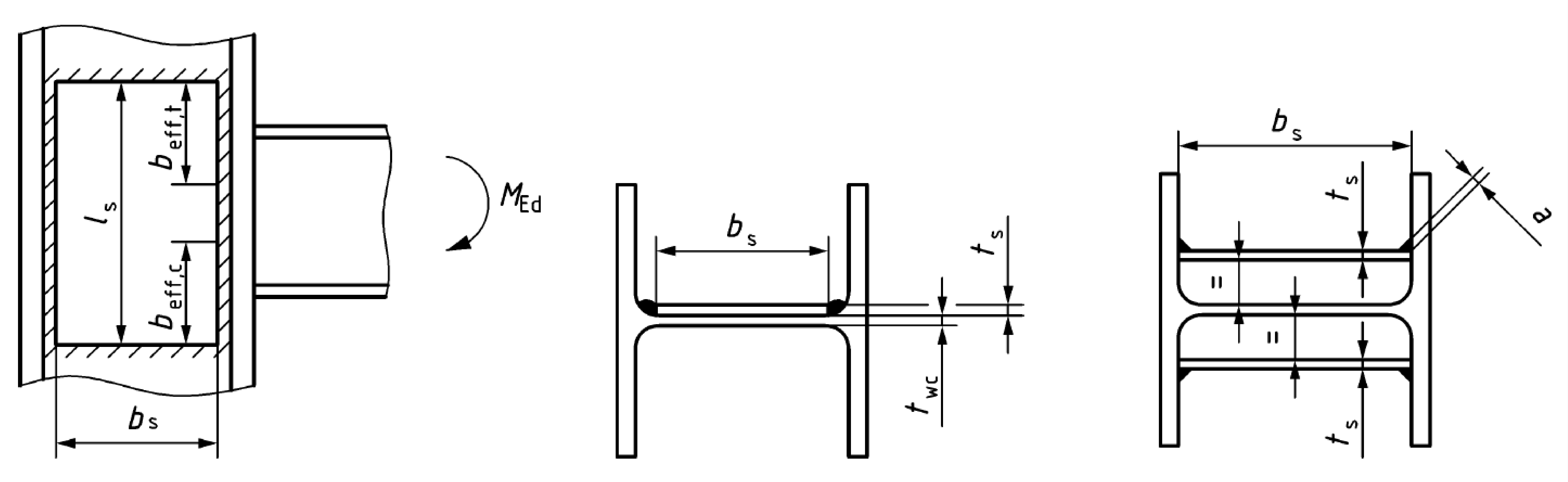
Deformations limited to d/6 (i.e. 3.33 mm for M20)

EN 1993-1-8 - Joints

THE FUTURE OF STEEL CONSTRUCTION

Supplementary Web Plates

The revised EN 1993-1-8 includes recommendations for supplementary web plates including those spaced away from the web of the column.



Examples of supplementary web plates placed in contact with the web and those spaced away from the web

Overview of EN 1993-1-10 – Facture Toughness

THE FUTURE OF STEEL CONSTRUCTION

Brittle Fracture and the Selection of Sub-Grades

- Steel always contains some imperfections, albeit very small
- When subject to tension these imperfection can open
- If the steel is not tough enough the crack can propagate rapidly without plastic deformation and failure may result
- This is called Brittle fracture and depends on the toughness of the steel
- The toughness of the steel
  - decreases with temperature and
  - increases with the thickness
- The EN 1993-1-10 includes guidance on brittle fracture and the selection of sub-grades to avoid brittle facture

Overview of EN 1993-1-10 – Facture Toughness

THE FUTURE OF STEEL CONSTRUCTION

Brittle Fracture and the Selection of Sub-Grades

- Brittle fracture is considered an accidental combination of actions
- EN 1993-1-10 uses the reference temperature to assess susceptibility to brittle fracture

$$T_{ed} = T_{N.min} + \Delta T_{\sigma} + \Delta T_{R} + \Delta T_{\acute{\varepsilon}} + \Delta T_{\varepsilon,cf}$$

Where

T_{ed}	is the reference temperature
$T_{N.min}$	is the minimum uniform steel temperature – See EN 1991-1-5
ΔT_{σ}	is the adjustment for stress and yield strength of the material, crack imperfection and members shape and dimensions – usually taken as 0 K
ΔT_{R}	is a safety allowance - taken as 0 K unless a different value is given in the NA - taken as -38K if material values are based on tests
$\Delta T_{\acute{\varepsilon}}$	is the adjustment for strain rate
$\Delta T_{\varepsilon,cf}$	is the adjustment for the degree of cold forming

Overview of EN 1993-1-10 – Facture Toughness

THE FUTURE OF STEEL CONSTRUCTION

Degree of cold-forming

Current EN 1993-1-10

$\Delta T_{\varepsilon,cf} = -3\ \varepsilon_f$ [ºC]

Where, ε_f is the degree of cold forming

Overview of EN 1993-1-10 – Facture Toughness

THE FUTURE OF STEEL CONSTRUCTION

Degree of cold-forming

Second generation of EN 1993-1-10

$\Delta T_{\varepsilon,cf} = -3\ \varepsilon_{cf}$ [K]

Where, ε_{cf} is the value of the plastic strain due to cold-forming (see Tables 4.2 and 4.3)

For circular cold-formed hollow sections to EN 10219-1 and EN 10219-2 and other cold-formed sections to EN 1993-1-3 the adjustment is:

$\Delta T_{\varepsilon,cf} = -3\ \varepsilon_{eff}$ [K] for $\varepsilon_{eff} > 2\%$

Where ε_{eff} is the average value of plastic strain in the net section

For $r_i/t > 15$ cold forming effects due to production may be neglected

For $r_i/t \leq 15$ the max value for $\Delta T_{\varepsilon,cf} = -20$K

For RHS to EN 10219:

- $\boldsymbol{\Delta T_{\varepsilon,cf} = -35}$ **(K) for t ≤ 16 mm**
- $\boldsymbol{\Delta T_{\varepsilon,cf} = -45}$ **(K) for t > 16 mm**

Overview of EN 1993-1-10 – Facture Toughness

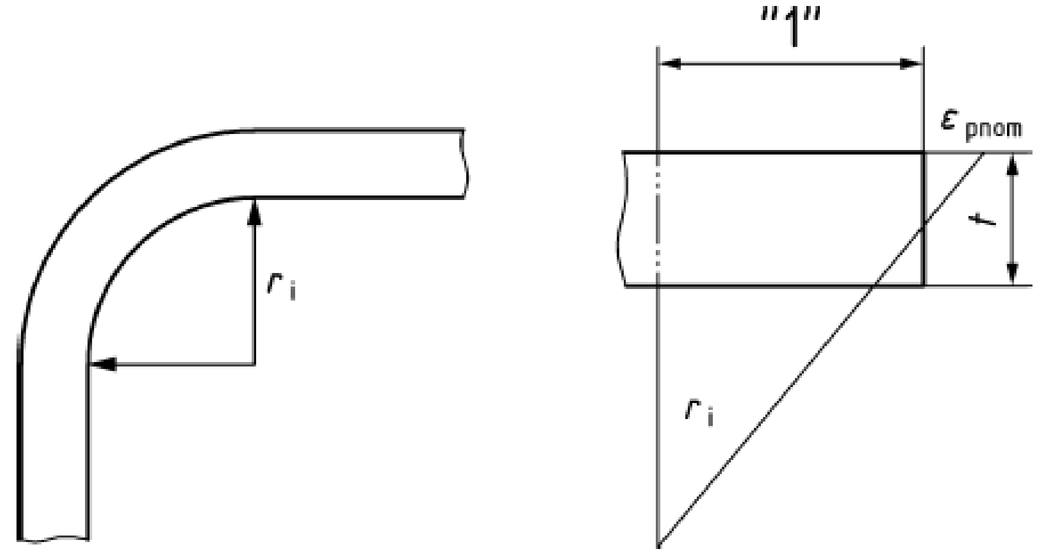
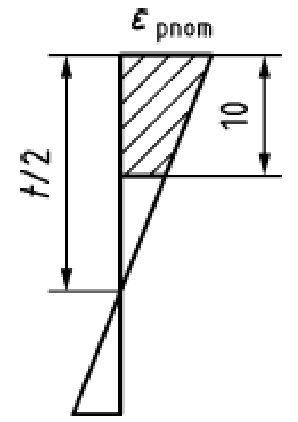
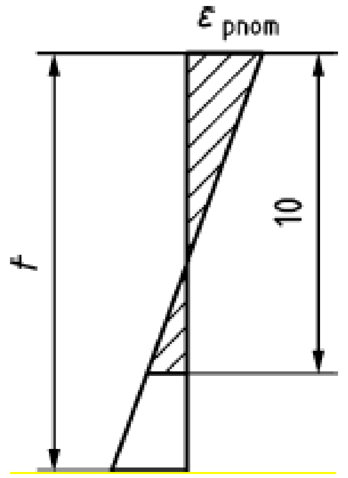
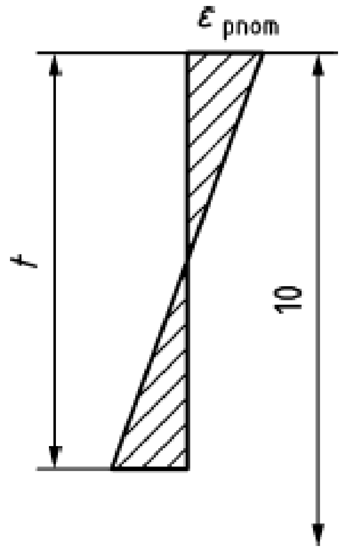
THE FUTURE OF STEEL CONSTRUCTION

Degree of cold-forming

Second generation of EN 1993-1-10

- Includes Table 4.2
- Difficult to apply as radius of cold bend not give in section tables

Table 4.1 — Definition of ε_{pnom} and ε_{eff} for radius r_i of cold bend

		$\varepsilon_{pnom} = \frac{t}{2r_i + t}$
Determination of effective strain ε_{eff}		
t	ε_{pnom} distribution	ε_{eff}
≥ 20		$\varepsilon_{pnom}\left(1-\frac{10}{t}\right)$
< 20 ≥ 10		$\frac{\varepsilon_{pnom}}{2}\left(\frac{t}{20}+\frac{(20-t)^2}{20t}\right)$
< 10		$\frac{\varepsilon_{pnom}}{2}\frac{t}{10}$

Overview of EN 1993-1-10 – Facture Toughness

Brittle Fracture and the Selection of Sub-Grades

Table 4.2 — Maximum permissible values of element thickness t_{max} in mm for Execution Classes EXC3 and EXC4

Steel grade	Quality	KV		Reference Temperature T_{Ed} [°C]																										
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120
				$\sigma_{Ed} = 0,75 f_y(t)$									$\sigma_{Ed} = 0,5 f_y(t)$									$\sigma_{Ed} = 0,25 f_y(t)$								
S235	JR	20	27	60	50	40	35	30	25	20	10	5	90	75	65	55	45	40	35	20	15	135	115	100	85	75	65	60	40	30
	J0	0	27	90	75	60	50	40	35	30	15	10	125	105	90	75	65	55	45	30	15	175	155	135	115	100	85	75	50	35
	J2	−20	27	125	105	90	75	60	50	40	25	10	170	145	125	105	90	75	65	40	20	200	200	175	155	135	115	100	65	40
S275	JR	20	27	55	45	35	30	25	20	15	10	5	80	70	55	50	40	35	30	20	10	125	110	95	80	70	60	55	40	25
	J0	0	27	75	65	55	45	35	30	25	15	5	115	95	80	70	55	50	40	25	15	165	145	125	110	95	80	70	45	30
	J2	−20	27	110	95	75	65	55	45	35	20	10	155	130	115	95	80	70	55	35	20	200	190	165	145	125	110	95	60	40
	K2,M,N	−20	40	135	110	95	75	65	55	45	25	10	180	155	130	115	95	80	70	40	20	200	200	190	165	145	125	110	70	40
	ML,NL	−50	27	185	160	135	110	95	75	65	35	15	200	200	180	155	130	115	95	55	30	200	200	200	200	190	165	145	95	55
S355	JR	20	27	40	35	25	20	15	15	10	5	5	65	55	45	40	30	25	25	15	10	110	95	80	70	60	55	45	30	20
	J0	0	27	60	50	40	35	25	20	15	10	5	95	80	65	55	45	40	30	20	10	150	130	110	95	80	70	60	40	25
	J2	−20	27	90	75	60	50	40	35	25	15	5	135	110	95	80	65	55	45	25	15	200	175	150	130	110	95	80	55	30
	J4	−40	27	130	110	90	75	60	50	40	20	10	180	155	135	110	95	80	65	40	20	200	200	195	170	150	130	110	70	40
	K2,M,N	−20	40	110	90	75	60	50	40	35	20	5	155	135	110	95	80	65	55	30	15	200	200	175	150	130	110	95	60	35
	J5,ML, NL	−50	27	155	130	110	90	75	60	50	25	10	200	180	155	135	110	95	80	45	25	210	200	200	200	175	150	130	80	45

- EXC3 and EXC4 used in the title is confusing
- Generally thought to refer to fatigue
- This will be clarified in the National Annex
- Tables given for S235. S275, S355, S420, S460, S500, S550, S600, S620 , S650 and S700
- Reference temps include -80 and -120.
- Thickness similar to current EN 1993-1-10

THE FUTURE OF STEEL CONSTRUCTION

Overview of EN 1993-1-10 – Facture Toughness

THE FUTURE OF STEEL CONSTRUCTION

Brittle Fracture and the Selection of Sub-Grades

Table 4.3 — Maximum permissible values of element thickness t_{max} in mm for Execution Classes EXC1 and EXC2

Steel grade	Quality	KV		Reference Temperature T_{Ed} [°C]																										
		T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120	10	0	-10	-20	-30	-40	-50	-80	-120
				$\sigma_{Ed} = 0{,}75 f_y(t)$									$\sigma_{Ed} = 0{,}5 f_y(t)$									$\sigma_{Ed} = 0{,}25 f_y(t)$								
S235	JR	20	27	250	250	170	120	90	65	50	25	15	250	250	250	250	190	145	110	55	30	250	250	250	250	250	250	250	135	75
	J0	0	27	250	250	250	250	170	120	90	40	15	250	250	250	250	250	250	190	85	40	250	250	250	250	250	250	250	200	100
	J2	-20	27	250	250	250	250	250	250	170	65	25	250	250	250	250	250	250	250	145	55	250	250	250	250	250	250	250	250	135
S275	JR	20	27	250	185	130	95	70	50	40	20	10	250	250	250	205	150	115	90	45	25	250	250	250	250	250	250	215	120	65
	J0	0	27	250	250	250	185	130	95	70	30	15	250	250	250	250	250	205	150	70	30	250	250	250	250	250	250	250	175	85
	J2	-20	27	250	250	250	250	250	185	130	50	20	250	250	250	250	250	250	250	115	45	250	250	250	250	250	250	250	250	120
	K2,M,N	-20	40	250	250	250	250	250	250	185	70	25	250	250	250	250	250	250	250	150	55	250	250	250	250	250	250	250	250	140
	ML,NL	-50	27	250	250	250	250	250	250	250	130	40	250	250	250	250	250	250	250	250	90	250	250	250	250	250	250	250	250	215

Max Permissible thicknesses about Four times those in the current EN 1993-1-10

- EXC1 and EXC2 used in the title is confusing
- Generally thought to refer to static
- This will be clarified in the National Annex
- Tables given for S235. S275, S355, S420, S460, S500, S550, S600, S620 , S650 and S700
- Reference temps include -80 and -120.

Overview of EN 1993-1-10 – Facture Toughness

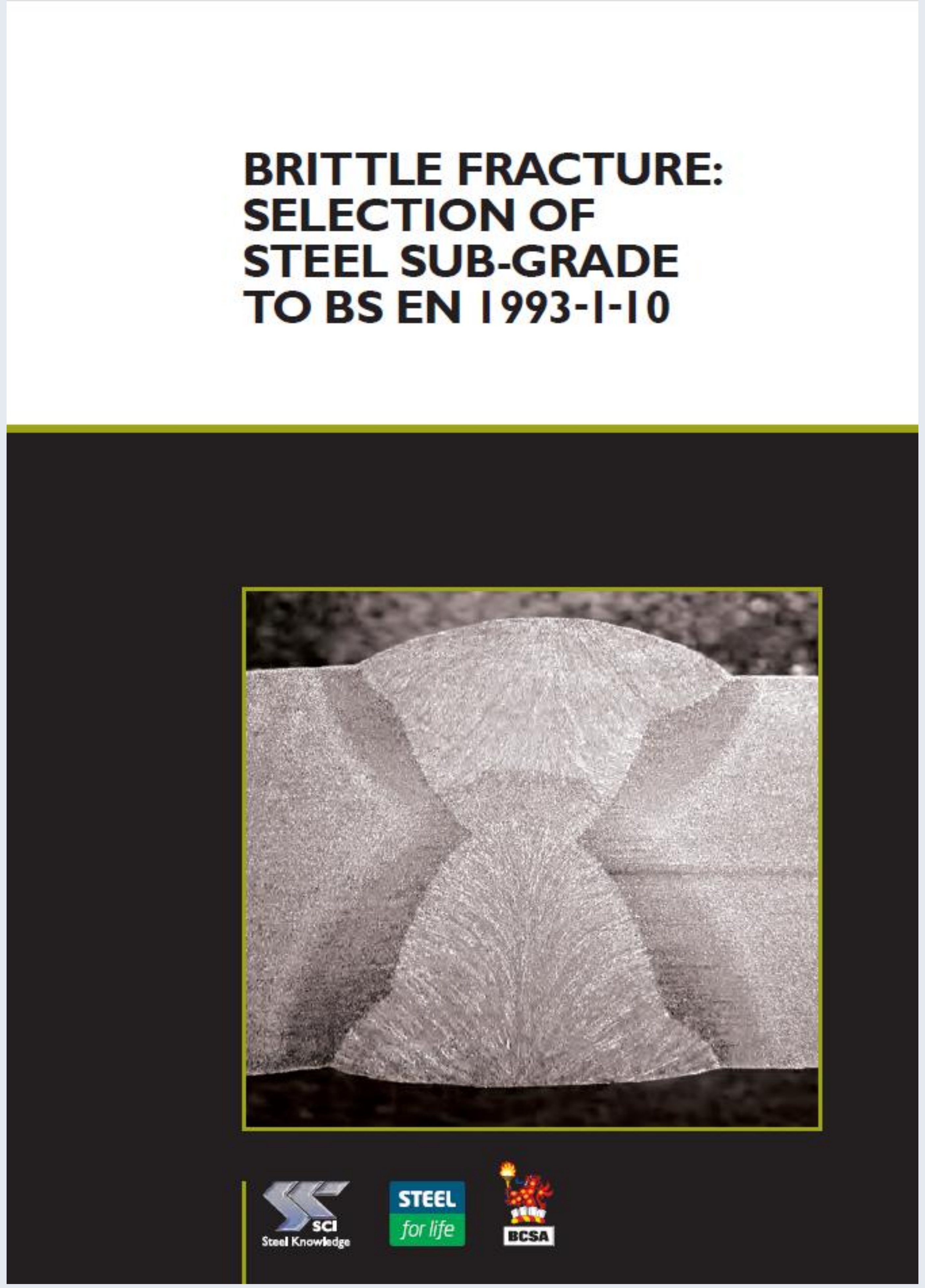
THE FUTURE OF STEEL CONSTRUCTION

Brittle Fracture and the Selection of Sub-Grades

- Max permissible thickness values are similar to those given in '***Brittle Fracture: Selection of Steel Sub-Grade to BS EN 1993-1-10***'

- The table in Current EN 1993-1-10 are conservative for static structures

- Enables a lower sub-grade to be used



Eurocode 3 - Second generation

THE FUTURE OF STEEL CONSTRUCTION

General comments

- This is evolution rather than revolution
- Changes to the scope for higher strength steels might be seen as an opportunity for constructional steelwork
- Some changes to expressions for local buckling but have limited effect on design
- Changes to LTB can result in up to 15% fall in resistance
- Inclusion of new details:
  - Bolts in threaded holes
  - Supplementary web plates away from the web
- Significant increase in max permissible thicknesses for static structures

THE FUTURE OF STEEL CONSTRUCTION

SUMMARY

- Overview of Eurocode 3
- Eurocode 3 Part 1.1 – General rules
- Eurocode 3 Part 1.8 – Design of joints
- Eurocode 3 Part 1.10 – Brittle fracture

THE FUTURE OF STEEL CONSTRUCTION

Eurocode 3

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