



Overview of the Evolution of EN1993: Eurocode 3 — Design of steel structures

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Structure of this slide deck

- General overview of the evolution of EN 1993
- Specific overview of the evolution of EN 1993 parts:

PHASE 1

- *EN 1993-1-1: Eurocode 3 — Design of steel structures — Part 1-1: General rules and rules for buildings*
- *EN 1993-1-8: Eurocode 3 — Design of steel structures — Part 1-8: Design of joints*

Structure of this slide deck

- General overview of the evolution of EN 1993
- Specific overview of the evolution of EN 1993 parts:

PHASE 2

- *Part 1-3: General rules – Supplementary rules for cold-formed members and sheeting*
- *Part 1-5: Plated structural elements*
- *Part 1-6: Strength and Stability of Shell Structures*
- *Part 1-7: Plate assemblies with elements under transverse loads*
- *Part 1-2: General – Structural fire design*



General overview of the Evolution of EN1993: Eurocode 3 — Design of steel structures

15.10.2020

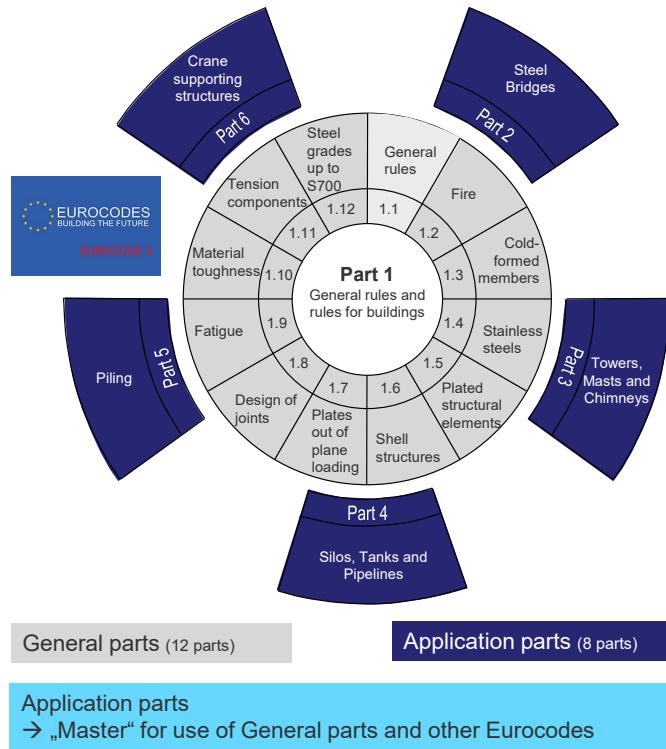
Agenda – Evolution of EN 1993

- Key changes to EN 1993
- New content included in the scope of EN 1993
- How ease of use has been enhanced

The following slides provide a general overview of the evolution of EN 1993. Complementary slides provide greater details for individual Eurocode Parts.

Key changes to EN 1993

→ Improve structure of Eurocode 3 parts



Existing

Issue 1

Date: 15/10/2020

Table 3. Structure of future Eurocode 3 on steel structures and responsible SC3 Working Groups

Part of Eurocode 3	Type	Topic	Working Group
EN 1993-1-1		General rules and rules for buildings	WG1
EN 1993-1-2		Structural fire design	WG2
EN 1993-1-3		Supplementary rules for cold-formed members	WG3
EN 1993-1-4		Stainless steels	WG4
EN 1993-1-5		Plated structural elements	WG5
EN 1993-1-6		Strength and stability of shell structures	WG6
EN 1993-1-7		Plate assemblies with elements under transverse loads	WG7
EN 1993-1-8		Design of joints	WG8
EN 1993-1-9		Fatigue	WG9
EN 1993-1-10		Material toughness and through-thickness properties	WG10
EN 1993-1-11		Design of structures with tension components	WG11
EN 1993-1-12		Additional rules for steel grades up to S960	WG12
EN 1993-1-13		Steel beams with large web openings	WG20
EN 1993-1-14		Design assisted by finite element analysis	WG22*
EN 1993-2	General parts	Steel bridges	WG13
EN 1993-3		Towers, masts and chimneys	WG14
EN 1993-4-1		Silos	WG15
EN 1993-4-2		Tanks	WG16
EN 1993-5		Piling	WG18
EN 1993-6		Crane supporting structures	WG19
EN 1993-7		Design of sandwich panels	WG21

* before AHG FE

New

Key changes to EN 1993

→ Improve structure of Eurocode 3 parts

➤ Enhanced Ease of Use

Avoiding or removing rules of little practical use in design

➤ **Withdrawal of part EN 1993-4-3:** Eurocode 3 - Design of steel structures - Part 4-3: Pipelines

➤ **Merge of EN 1993-3-1 and EN 1993-3-2:** Eurocode 3 - Design of steel structures- Part 3: Towers, masts and chimneys

➤ **Integrate EN 1993-1-12:** Additional rules for the extension of EN 1993 up to steel grades S700

Design Rules of existing Part 1-12 integrated in Part 1-1, 1-5, 1-8, 1-9 and 1-10

and define new EN 1993-1-12: Additional rules for steel grades up to S960

New content included in scope of EN 1993

→ Integrate new findings from research and technical developments

➤ **Inclusion of latest development:** Extension to new materials, new products, new methods and new market requirements

- **New part EN 1993-1-14:** Eurocode 3 - Design of steel structures - Part 1-14:
Design assisted by finite element analysis
In order to harmonize the different approaches in the different parts of EN1993 and define common basic rules and definitions
- **New part EN 1993-1-13:** Steel beams with web openings
together with SC4: Composite beams with **large web openings**
- **New part EN 1993-7:** Eurocode 3 - Design of steel structures –
Part 7: Sandwich Panels (not within Mandate)





Overview of the Evolution of EN1993-1-1:

Eurocode 3 — Design of steel structures — Part 1-1: General rules and rules for buildings

15.10.2020

Agenda – Evolution of Part 1-1

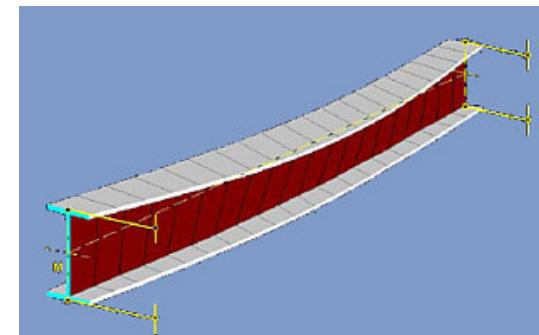
- Key changes to EN 1993-1-1
- New content included in the scope of EN 1993-1-1
- How ease of use has been enhanced

Key changes to EN 1993-1-1

➤ Enhanced Ease of Use

Improving and reducing number of methods for stability verification

- Simplification of the stability rules
- Unification of the rules between general and application parts
- Reduction of the rules in particular for lateral torsional buckling (LTB)



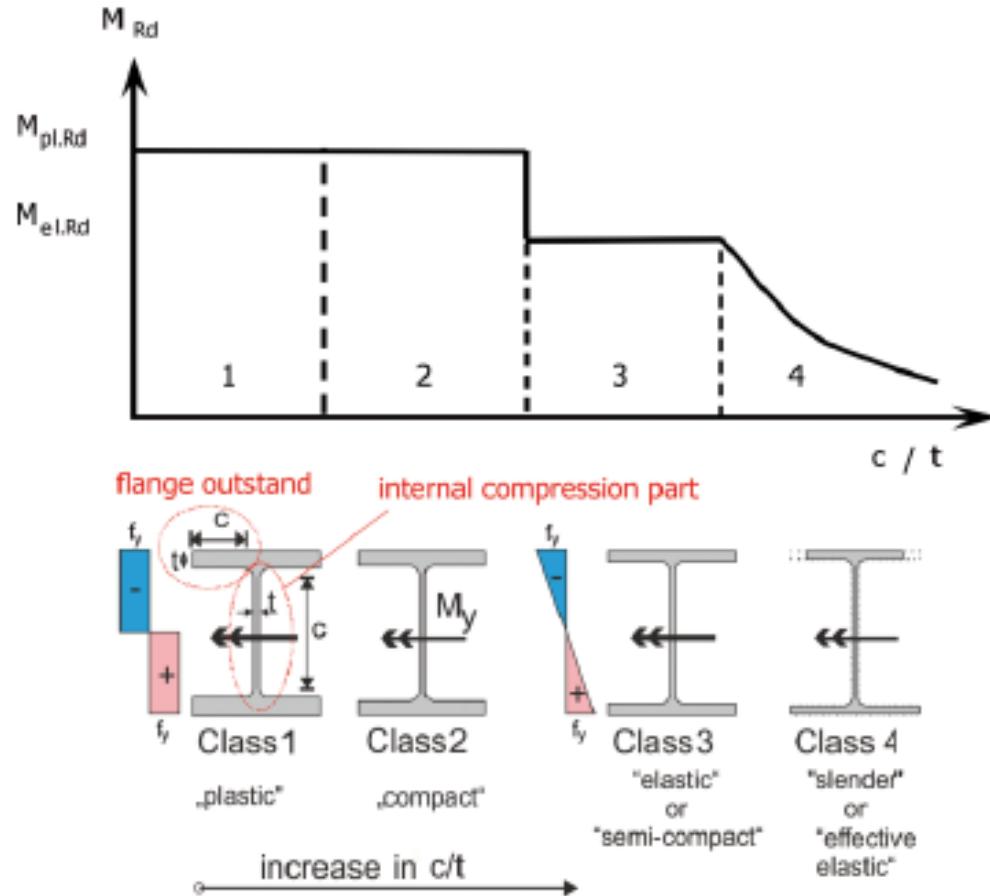
- Method for beam-column design: only Method 2, Annex B integrated in the main text, Method 1, Annex A transferred to a Technical Specification: CEN/TS 1993-1-101
- Reducing number of possible options of verifications from 7 to 3

Key changes to EN 1993-1-1 - Restructured

- *Reduction of number of (informative) Annexes*
- Annex AB.1: structural analysis taking into account material non-linearities -> moved to the main text.
- Annex AB.2 on load arrangements for continuous floor beams -> removed
- These two actions make Annex AB superfluous.
- Annex BB.1 on elastic flexural buckling in lattice structures has been moved to Technical Report CEN/TR 1993-1-103.
- Annex BB.2 on restraint stiffness has been made normative.
- Annex BB.3 on the stable length method for lateral torsional buckling (mainly used in UK) is of limited use in all countries using the Eurocode and has therefore been omitted.

New content included in scope of EN 1993-1-1

→ Design of semi-compact sections



Schematic representation of the cross-sectional resistance of I-sections in bending as a function of the local, geometric plate slenderness c/t ; discontinuity at the border between classes 2 and 3

New content included in scope of EN 1993-1-1

→ New informative Annex E: Basis for the calibration of partial factors

- Annex E not for direct use in design rules
- For the choice of $\gamma_{M1} = 1.0$ there are the following conditions:
 - For the steel the statistical values of Table E.1 and E.2 have to be guaranteed
 - The material values of product standards have to be used instead of Table 5.1

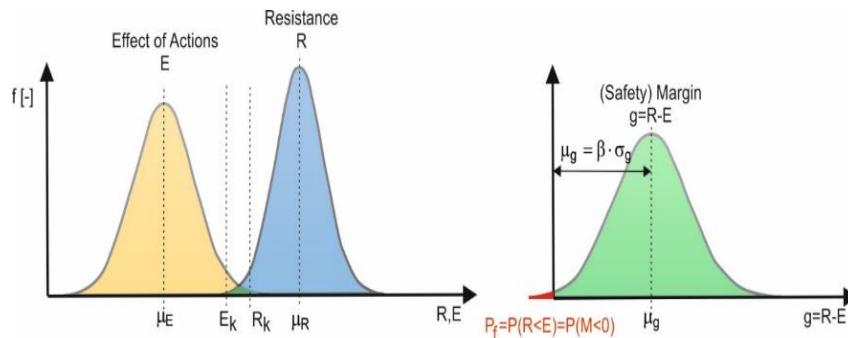


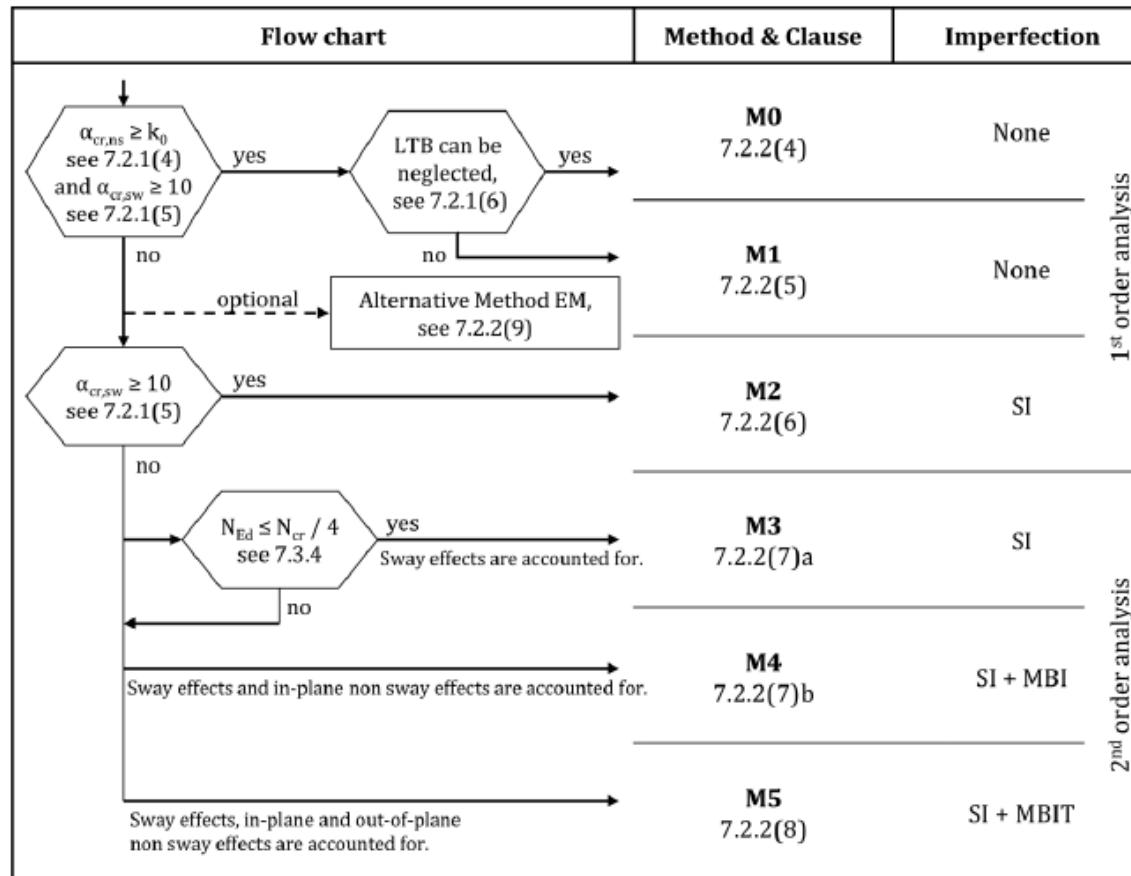
Table E.1 — Assumed variability of material properties

Parameter	Steel grade	Mean value X_m	Coefficient of variation	Upper reference value $X_{5\%}$	Lower reference value $X_{0,12\%}$
Yield strength, f_y	S235, S275	$1,25 R_{eH,min}^a$	5,5%	$1,14 R_{eH,min}^a$	$1,06 R_{eH,min}^a$
	S355, S420	$1,20 R_{eH,min}^a$	5,0%	$1,11 R_{eH,min}^a$	$1,03 R_{eH,min}^a$
	S460	$1,15 R_{eH,min}^a$	4,5%	$1,07 R_{eH,min}^a$	$1,00 R_{eH,min}^a$
	Above S460	$1,10 R_{eH,min}^a$	3,5%	$1,04 R_{eH,min}^a$	$1,00 R_{eH,min}^a$
Ultimate tensile strength, f_u	S235, S275	$1,20 R_{m,min}^a$	5,0%	$1,11 R_{m,min}^a$	$1,03 R_{m,min}^a$
	S355, S420	$1,15 R_{m,min}^a$	4,0%	$1,08 R_{m,min}^a$	$1,02 R_{m,min}^a$
	S460 and above	$1,10 R_{m,min}^a$	3,5%	$1,04 R_{m,min}^a$	$1,00 R_{m,min}^a$
Modulus of elasticity, E	All steel grades	210000 N/mm ²	3,0%	200000 N/mm ²	192000 N/mm ²

^a $R_{eH,min}$ and $R_{m,min}$ are the minimum yield strength R_{eH} and the lower bound of the ultimate tensile strength R_m , according to the applicable product standard, e.g. of the EN 10025 series.

How ease of use has been enhanced

→ Flowchart added on methods of structural analysis



- LTB Lateral torsional buckling
- EM Equivalent member method
- SI Sway imperfection
- MBI Member bow imperfection (in-plane)
- MBIT Member bow imperfection including torsional effects (in-plane and out-of-plane)



Overview of the Evolution of EN1993-1-8:

Eurocode 3 — Design of steel structures — Part 1-8: Design of joints

Agenda – Evolution of EN 1993-1-8: Design of joints

- Key changes to EN 1993-1-8
- New content included in the scope of EN 1993-1-8
- How ease of use has been enhanced

Key changes to EN 1993-1-8

→ *Restructuring to improve ease of use*

➤ Restructuring of Chapter 5 and 6

- Existing structure Chapter 5 and 6:
 - 5 Analysis, classification and modelling
 - 6 Structural joints connecting H or I sections
- New structure for Chapter 5 (7) and 6 (8) and Annexes:
 - 7 Structural analysis
 - 8 Structural joints connecting H or I sections
- Annex A (Normative). Structural properties of basic components
- Annex B (Normative). Design of moment-resisting beam-to-column joints and splices
- Annex C (Normative). Design of nominally pinned connections
- Annex D (Normative). Design of column bases



New content included in scope of EN 1993-1-8

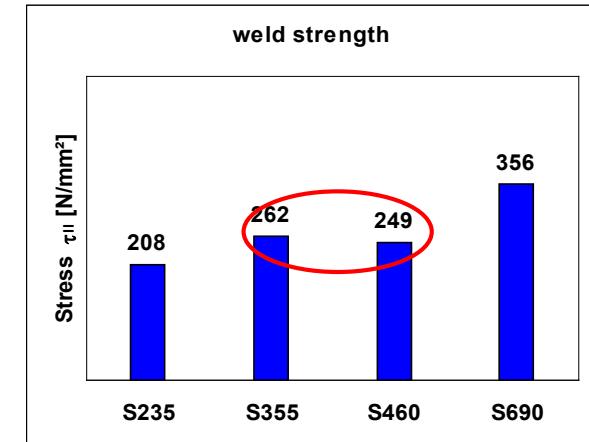
→ Improved rules for welding

➤ Load bearing capacity of **fillet welded connections** of high strength steels

→ modified correlation factor with equal parent and filler metal strength
 = Improved design specifications also for steel grades up to 700 N/mm²

→ new rule for fillet welded connections of steel grades ≥ S460 and with **different** parent and filler metal strength:

Possibilities to cover mismatch-effects,
 Undermatching may have advantages regarding ductility, weldability, quality



Remove inconsistency in existing rules

$$\sigma_{w,Rd} = \frac{\text{Parent metal} \quad \text{Filler metal}}{\beta_{w,mod} \cdot \gamma_{M2}}$$

$$0.25 \cdot f_{u,PM} + 0.75 \cdot f_{u,FM}$$

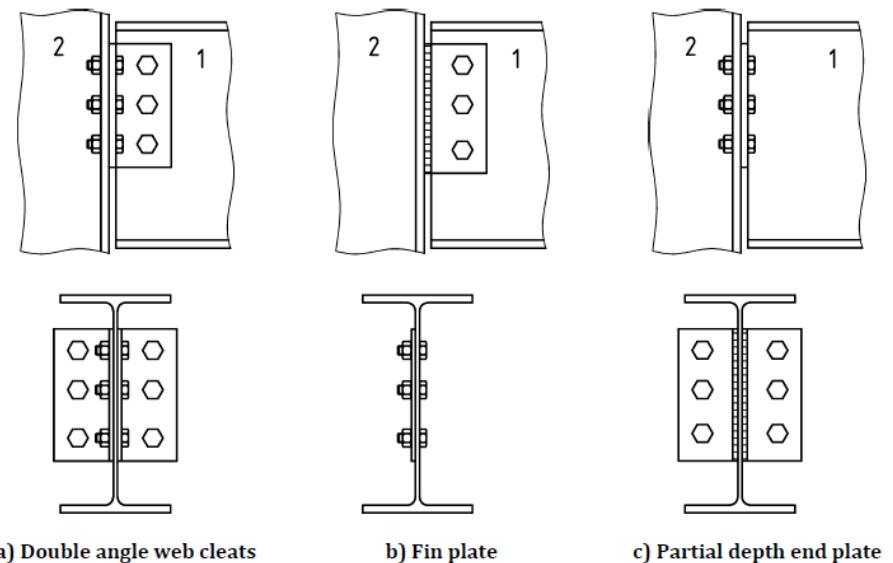
New content included in scope of EN 1993-1-8

→ Improved rules for nominally pinned connections

➤ New Annex C (normative)

The connections designed in accordance with this Annex may be classified as nominally pinned joints and are able to transmit shear forces without developing significant bending moments.

→ rules allow easy design in practice



Key
1 supported member
2 supporting member

Typical pinned connections

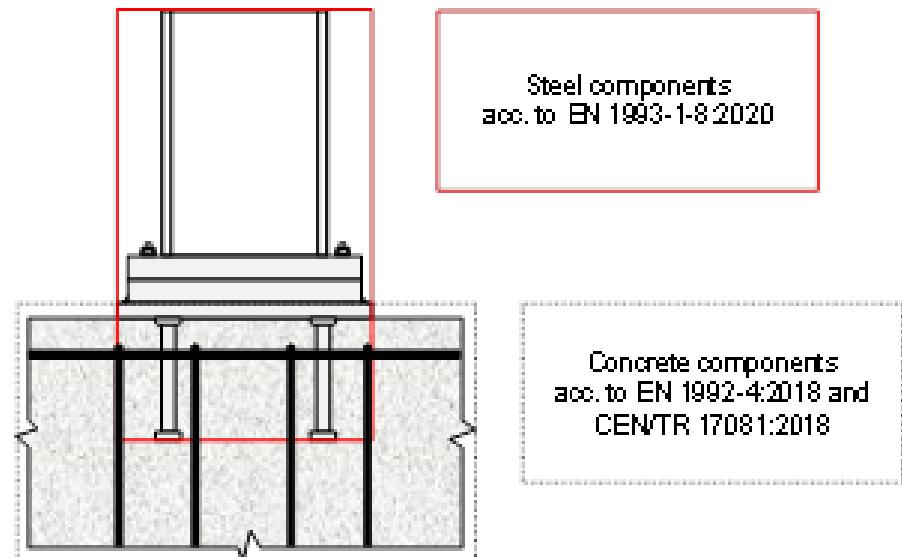
How ease of use has been enhanced

→ *Harmonisation with other Eurocodes*

➤ New Annex D (normative) Design of column basis

The design resistance of anchor bolts and anchoring components should be determined from A.16.1, A.17, A18 and A.19 of this Standard and **EN 1992-4**.

Rules for a plastic design of joints with multiple rows of anchor bolts and anchoring components are given in **CEN/TR 17081**.



➤ Harmonisation with EN 1998- 2 Seismic design regarding wording and definitions

Overview of the Evolution of EN1993-1-3:

Eurocode 3 — Design of steel structures — Part 1-3:
General rules – Supplementary rules for cold-formed
members and sheeting

2020-08-10

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Technical University of Dortmund, Germany

Agenda – Evolution of EN 1993-1-3

- Key changes to EN 1993-1-3
- New content included in the scope of EN 1993-1-3
- How ease of use has been enhanced

Key changes to EN 1993-1-3 - General

- Improvements according to **M515 Detailed Task Specification** given by Volume 3 (Call for Tenders – Grant Agreement SA/CEN/GROW/EFTA/515/2016-2)
- Inclusion of **new state-of-the-art material and new research results** dealing with cold-formed steel members and sheeting which has been validated by through scientific investigations, tests or sufficient practical experience
- Incorporation of about **90 technical amendments** worked out by the corresponding SC3.WG3, confirmed by SC3 (see list of amendments to EN 1993-1-3)

Key changes to EN 1993-1-3 - General

- *Reduction of NDPs (2006: 19 NDPs (131 pages); FIN DOC: 14 NDPs – 9 „old“ and 5 „new“ resulting from AMDs (197 pages, 50% more content))*
- *Reduction of informative Annexes (2006: A-E; FIN DOC: A-C)*
 - *Annex C removed because it contains textbook material*
 - *Annex E removed because it contains a second, simplified, alternative design provisions for purlins*
 - *Annex A improved and restructured for ease of use*
 - *Annex D improved and included as new Annex C*

Key changes to EN 1993-1-3 - Technical

→ Clause 5: Materials

- Inclusion and specification of new steel material with properties and chemical composition in compliance with the new standards to be used for cold-formed members/sheeting and the design acc. to EN 1993-1-3*

Extract from Table 5.1b - Nominal values of basic yield strength f_{yb} and ultimate tensile strength f_u

Type of steel	Standard	Grade	f_{yb} [N/mm ²]	f_u [N/mm ²]
Continuously hot-dip coated steel flat products for cold-forming	EN 10346	S220GD+Z, +ZF, +ZA, +ZM, +AZ	220	300
		S250GD+Z, +ZF, +ZA, +ZM, +AZ, +AS	250	330
		S280GD+Z, +ZF, +ZA, +ZM, +AZ, +AS	280	360
		S320GD+Z, +ZF, +ZA, +ZM, +AZ, +AS	320	390
		S350GD+Z, +ZF, +ZA, +ZM, +AZ, +AS	350	420
		S390GD+Z, +ZF, +ZA, +ZM, +AZ	390	460
		S420GD+Z, +ZF, +ZA, +ZM, +AZ	420	480
		S450GD+Z, +ZF, +ZA, +ZM, +AZ	450	510
New				

Key changes to EN 1993-1-3 - Technical

→ Clause 7: Structural analysis

- | | | |
|------|---|------------|
| 7.1: | <i>Structural modelling for analysis</i> | <i>NEW</i> |
| | <ul style="list-style-type: none">▪ <i>Providing relevant guidance for cold-formed sections and sheeting incl. FE-analysis with reference to new EN 1993-1-14</i> | |
| 7.2: | <i>Global analysis for ultimate limit design check</i> | <i>NEW</i> |
| | <ul style="list-style-type: none">▪ <i>Specification of methods for global analysis for cold-formed sections considering torsional- and torsional-flexural buckling modes including imperfections (consistency with EN 1993-1-1, harmonized with EN 1993-1-14)</i>▪ <i>Providing clear guidance in new Table 7.1</i> | |

Key changes to EN 1993-1-3 - Technical

→ Clause 7: Structural analysis

Providing clear guidance in new Table 7.1 NEW

NEW Table 7.1: Methods of structural analysis applicable to ultimate limit state design checks of cold-formed steel structures and members

Method acc. to EN 1993-1-1:2019, 7.2.2	Additional requirements for cold-formed steel sections	1 st /2 nd order effects for global analysis	Imperfections to be considered in the global analysis	Design check according to EN 1993-1-3, Clause 8.1 or 8.2
M0 7.2.2(4)	In-plane and out-of-plane buckling may be neglected	1 st order effects	None	8.1: Cross-sectional resistance
M1 7.2.2(5)	In-plane buckling may be neglected, Out-of-plane buckling (Flexural, torsional, torsional-flexural or lateral-torsional buckling) may not be neglected	1 st order effects	None	8.1: Cross-sectional resistance and 8.2: Out-of-plane member buckling check
EM 7.2.2(9)		1 st order effects	None	8.1: Cross-sectional resistance and 8.2: In-plane and out-of-plane member buckling check acc. to 8.2 based on an appropriate buckling length of "Equivalent Members"
M2 7.2.2(6)		1 st order effects	Global sway imperfections	8.1: Cross-sectional resistance and 8.2: In-plane and out-of-plane member buckling check
M3 7.2.2(7)a		2 nd order effects	Global sway imperfections	8.1: Cross-sectional resistance using γ_{M1} and 8.2: In-plane and out-of-plane member buckling check
M4 7.2.2(7)b		2 nd order effects	Global sway imperfections and in-plane member bow imperfections	8.1: Cross-sectional resistance using γ_{M1} and 8.2: Out-of-plane member buckling check
M5 7.2.2(8)		2 nd order effects	Global sway imperfections and in-plane and out-of plane member bow imperfections and torsional effects (torsional, torsional-flexural or lateral-torsional buckling modes)	Stress verification based on FE-analysis acc. to EN 1993-1-14

Key changes to EN 1993-1-3 - Technical

→ Clause 8: *Ultimate limit states*

8.1.6: Resistance to transverse forces *M515 task specification*

- Improved design provisions for cross-sections with a single unstiffened web (sections) and with two or more unstiffened webs (sheeting) according to new research (accounting for high-strength steel as well)*

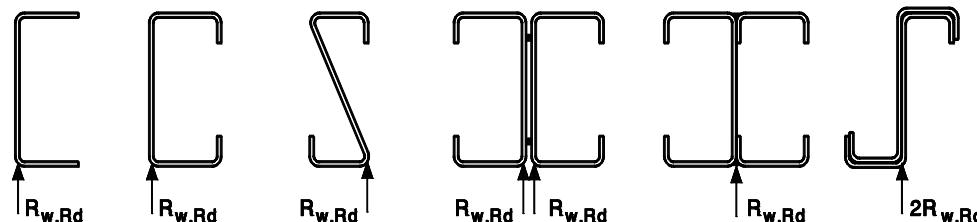


Figure - Examples of cross-sections with a single web

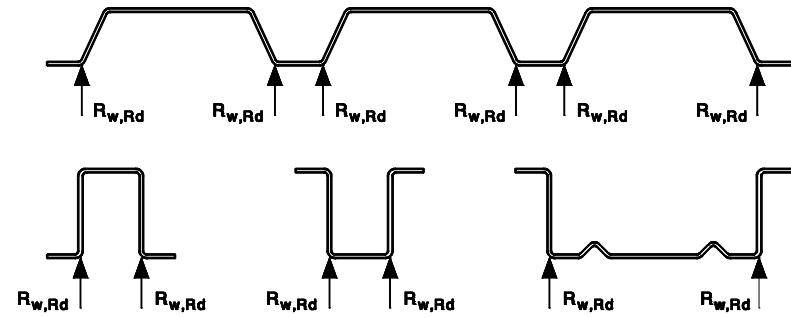


Figure - Examples of cross-sections with two or more webs

Key changes to EN 1993-1-3 - Technical

→ Clause 8: *Ultimate limit states*

8.2.5: *Bending and compression* *M515 task specification*

- *Improvement of design provisions for cold-formed steel members in bending and compression with regard to safe, but economic design and consistency with EN 1993-1-1, where possible*

For major principle axis buckling:

$$\left(\omega_{x,y} \frac{N_{Ed}}{\chi_y N_{c,Rd}} \right)^{\alpha_y} + \left(\omega_{x,LT} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} M_{cy,Rd}} \right)^{\beta_y} + \left(\frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{cz,Rd}} \right)^{\delta_y} \leq 1 \quad (8.71)$$

For minor principle axis buckling:

$$\left(\omega_{x,z} \frac{N_{Ed}}{\chi_z N_{c,Rd}} \right)^{\alpha_z} + \left(\omega_{x,LT} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} M_{cy,Rd}} \right)^{\beta_z} + \left(\frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{cz,Rd}} \right)^{\delta_z} \leq 1 \quad (8.72)$$

Key changes to EN 1993-1-3 - Technical

→ Clause 10: *Design of joints*

10.3: *Connections with mechanical fasteners*

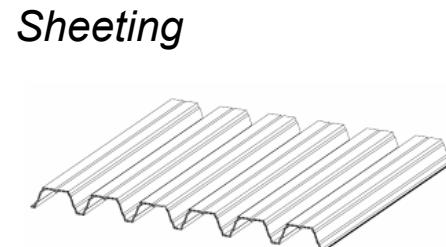
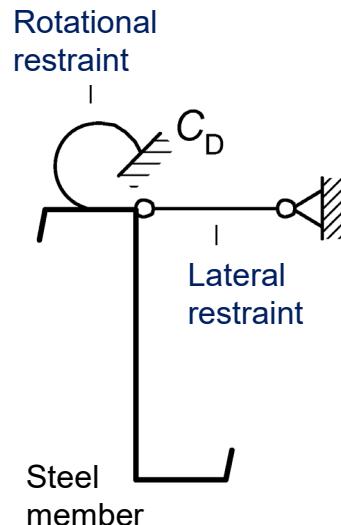
- *Enlargement and improvement of design provisions and specifications for mechanical fasteners used in cold-formed steel structures such as blind rivets, self-tapping screws, bolts and cartridge-fired pins according to new research*
- *Review of design rules for mechanical fasteners incl. revision of symbols and parameters in harmonization with EN 1993-1-8 and EN 1090-4 M515 task specification*

Key changes to EN 1993-1-3 - Technical

→ Clause 11: *Special consideration for members, liner trays and sheeting*

11.4: *Lateral and torsional restraints of members provided by sheeting, liner trays and sandwich panels*

- New Clause 11.4 which summarizes all design provisions for stabilization of steel members provided by the stabilizing elements



- Reference to the new Clause 11.4 can be made by other parts of EN 1993-1

Key changes to EN 1993-1-3 - Technical

→ Annex A: *Testing procedures*

- *Restructuring of design provisions and clear guidance for testing procedures of cold-formed structures, members and sheeting as well as evaluation with regard to harmonization with EN 1990*
 - *Tests on material*
 - *Tests on single beams and columns*
 - *Tests on structures and sub-assemblies*
 - *Tests on profiled sheeting and liner trays*
 - *Tests on torsionally restrained beams*
 - *Tests on fastenings*

Key changes to EN 1993-1-3 - Technical

→ Annex C: *Mixed effective widths/effective thickness method for outstand elements* *M515 task specification*

- Inclusion of an improved buckling curve for local plate buckling of outstand elements according to new researches and SC3.WG3 amendments to use overcritical buckling reserves*

(3) The reduction factor for local buckling is given by:

$$\rho = \begin{cases} \frac{1}{\bar{\lambda}_p} - \frac{0,188}{\bar{\lambda}_p^2} \leq 1 & \text{if } 0,749 \leq \bar{\lambda}_p < 1,2 \\ \frac{0,77}{\sqrt{\bar{\lambda}_p}} & \text{if } 1,2 \leq \bar{\lambda}_p \leq 3,2 \end{cases}$$

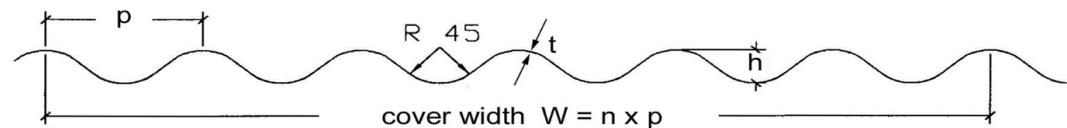
*consistency with EN1993-1-5
overcritical buckling reserves
verified by research and new
state-of-the-art material* (C.1)

where:

$\bar{\lambda}_p$ is the relative slenderness for local buckling of plane elements given in 7.6.2

New content included in scope of EN 1993-1-3

→ Clause 7.6.5: *Special provisions of sinusoidal or similar sheeting*



→ Clause 8.1.4.4: *Curved sheeting and sections*

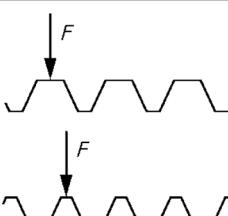
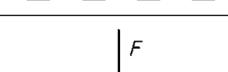
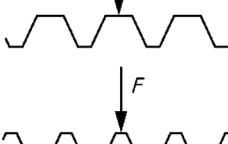
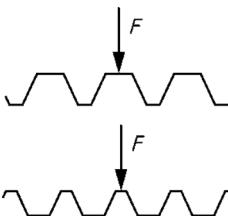


New content included in scope of EN 1993-1-3

→ Clause 9.4: *Walkability of trapezoidal sheeting (during and after installation)* M515 task specification

- *providing overall robustness and serviceability*
- *providing tests and assessment criteria in Clause A.5.6*

Table A.4 - Assessment criteria for walkability

Type of loading	Loading pattern	Loading F_{min} [kN]	Assessment criterion
Edge loading Outermost completely formed rib in direction of lay		1,2	significant permanent deformation
		1,5	failure load
		2,0	sudden failure without significant overall deformation
Central loading		2,0	failure load ^a

^a After a decrease in load following the first load peak, membrane effects may lead to a subsequent increase in load. Assessment criteria may be applied to the second load peak, provided that the additional criterion $F_{min} \geq 1,5$ kN is satisfied at the first load peak.

New content included in scope of EN 1993-1-3

→ Clause 11.3 and 8.1.6.5:

M515 task specification

Concentrated line loads and point loads on trapezoidal sheeting (without intermediate systems)

- Distribution of concentrated line loads introduced by photovoltaic systems and design of roofs (green and ecologic aspect)*

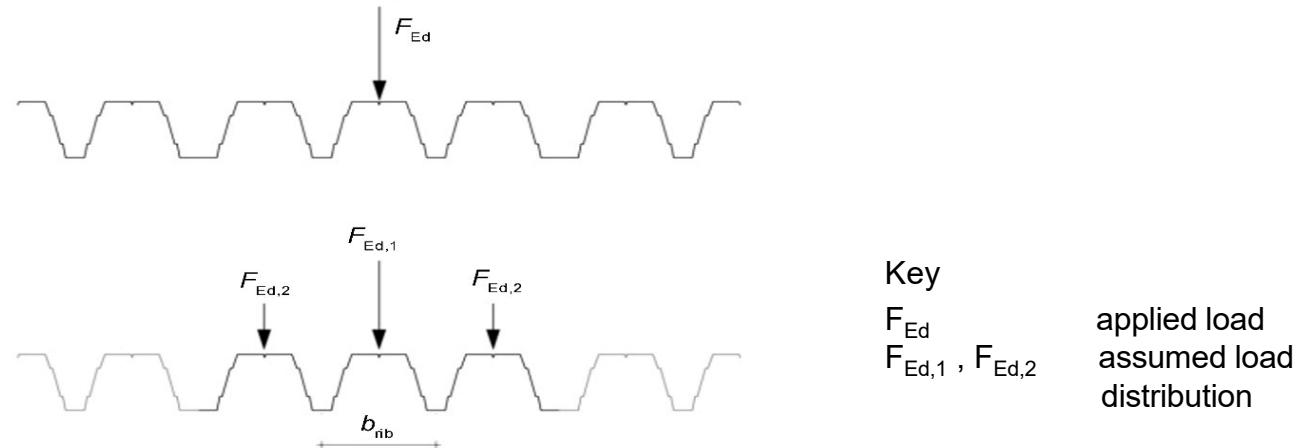
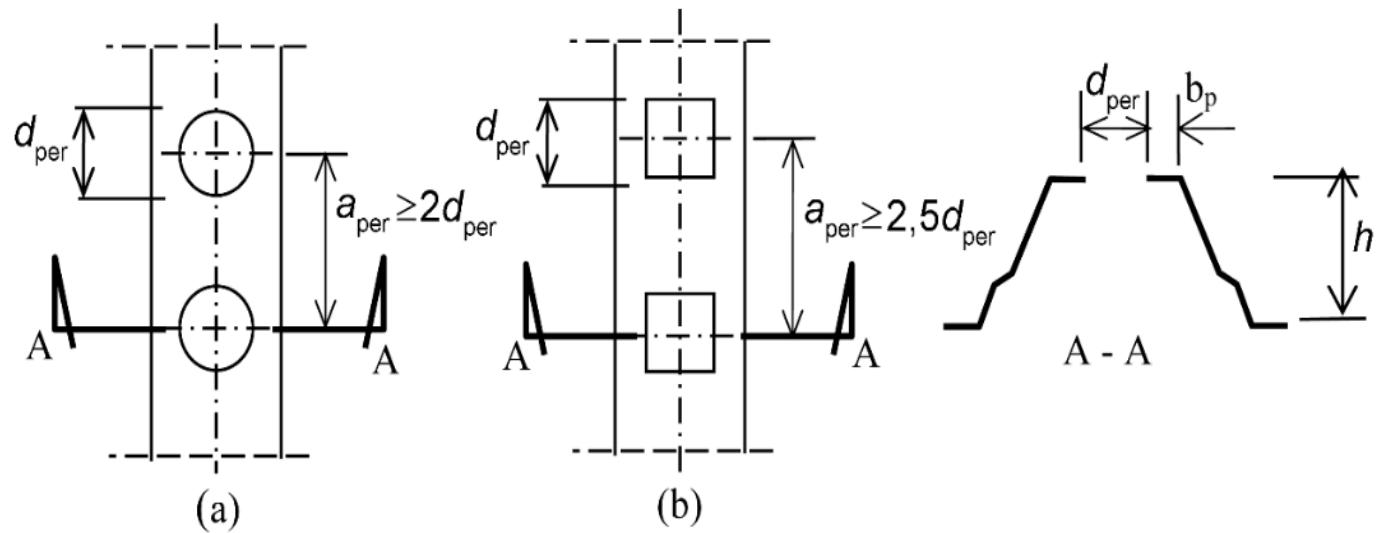


Figure - Load distribution without intermediate load-distributing systems

New content included in scope of EN 1993-1-3

→ Clause 11.3.3: *Sheeting with an opening*



Key

- (a) Top view on upper flange with circular holes
- (b) Top view on the upper flange with square holes

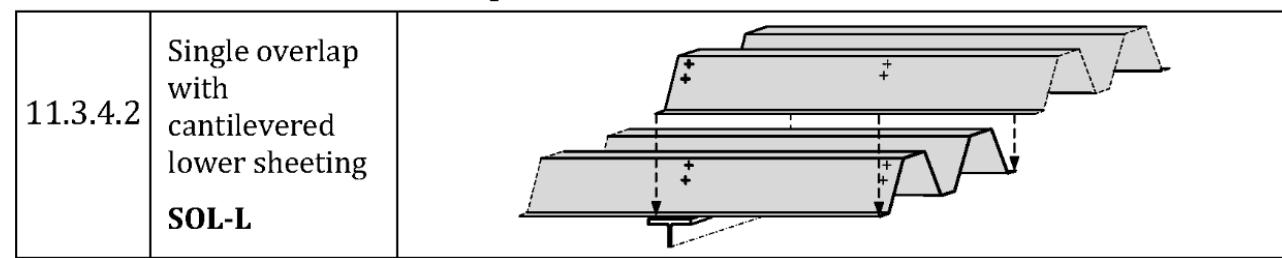
Figure - Sheeting with circular (a) or square (b) holes in flange

New content included in scope of EN 1993-1-3

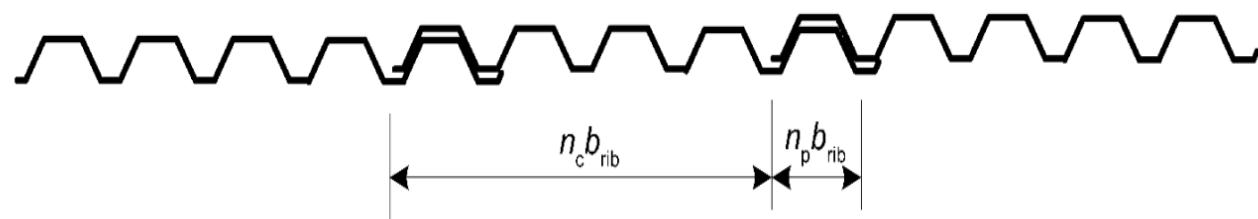
→ Clause 11.3.4: *Trapezoidal sheeting with overlap at support*

M515 task specification

Table 11.12 - Static system of the overlapping sheeting with single or double overlap or reinforcement



→ Clause 11.3.5: *Trapezoidal sheeting with side overlaps*



How ease of use has been enhanced

→ Clarification

- *Including explanatory text and additional information*
- *Specification of design provisions to provide clear guidance*
- *Including clear references (to EN 1993-1-3 and other EN 1993 provisions where required) to ease the navigation between the relevant standards*

→ Restructuring

- *Restructuring of e.g. Clause 11 and Annex A for clarification*

→ Harmonization with relevant parts of EN1993

- *All design provisions have been checked and harmonized with the relevant parts of EN 1993 (part 1-1, 1-5, 1-8, 1-14, EN 1090-2) and the product standards, if possible*



Overview of the Evolution of EN1993-1-5: Eurocode 3 — Design of steel structures — Part 1-5: Plated structural elements

15.10.2020

Agenda – Evolution of EN 1993-1-5: Plated structural elements

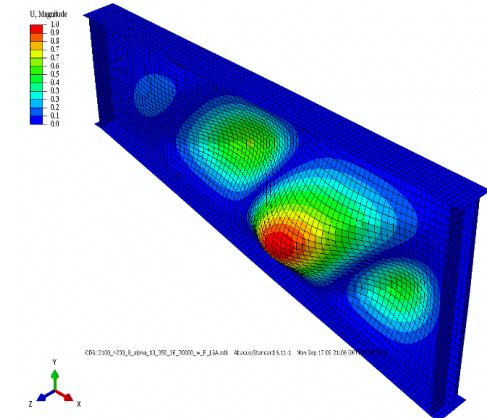
- Key changes to EN 1993-1-5
- New content included in the scope of EN 1993-1-5
- How ease of use has been enhanced

Key changes to EN 1993-1-5

- *Improved structure for ease of use*
- *Reduction of number of (informative) Annexes*
 - Annex C (informative) Finite Element Methods of Analysis (FEM) moved to EN 1993-1-14
 - Annex D Plate girders with corrugated webs integrated into main text
 - Annex E Alternative methods for determining effective cross sections integrated into main text
- *Section 10 Reduced stress method reorganized and improved for ease of use*
- *Reduction of NDP*

➤ Today: 15 NDPs

Final draft: only 3 NDPs



Key changes to EN 1993-1-5

→ Inclusion of latest developments

- Development of **new amendments** (2011-2020) for the implementation in the new draft

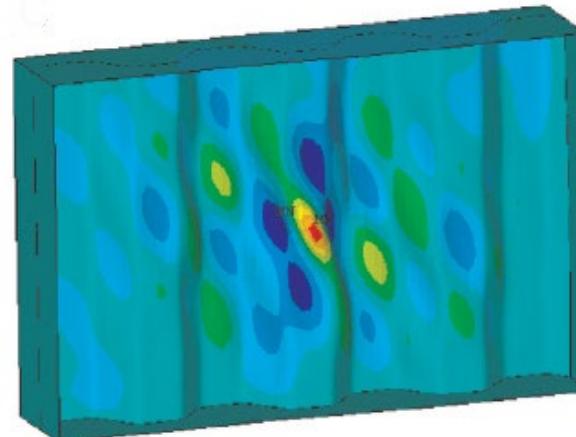
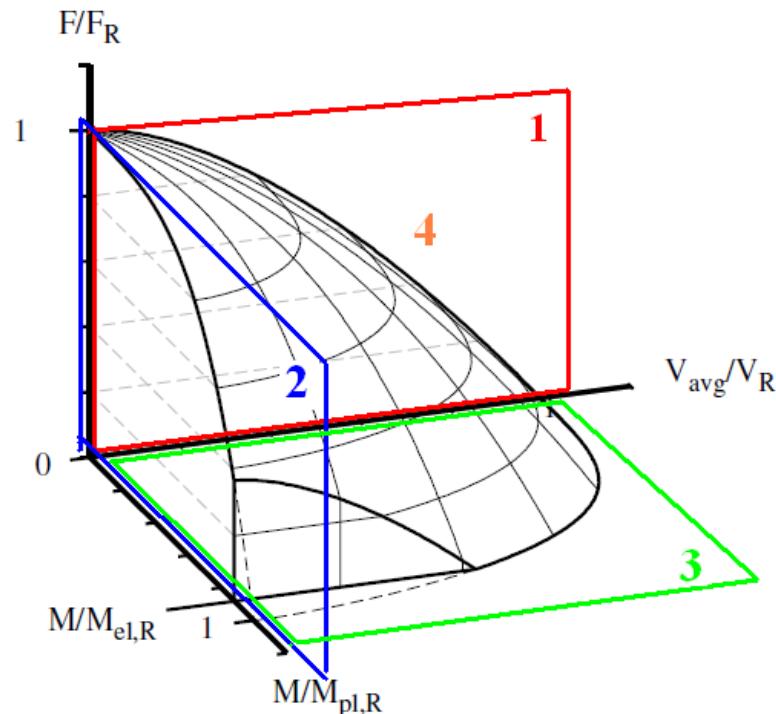
- shear resistance
- resistance to direct stresses
- resistance of girders subjected to patch loading
- minimum requirement for transverse stiffener
- rules for corrugated webs
- biaxial compression
- consideration of torsional stiffness of closed section stiffeners
- flange induced buckling



New content included in scope of EN 1993-1-5 (examples)

→ Improved rules for M-V-F interaction of corrugated web girders

- Based on new experimental and numerical research

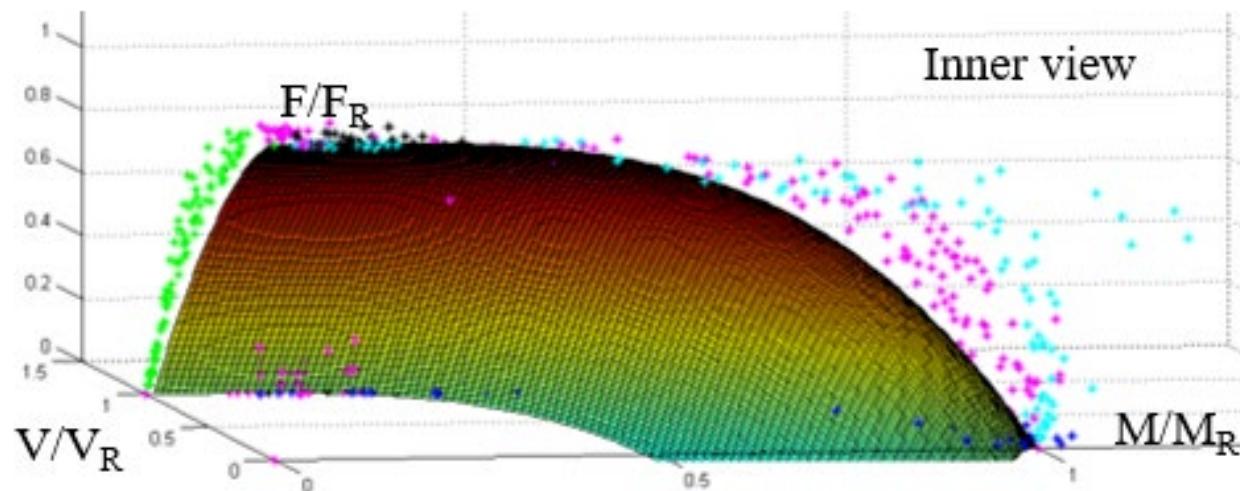


Balázs Kövesdi,
Technical University
of Budapest

New content included in scope of EN 1993-1-5 (examples)

→ New *M-V-F interaction design rules for stiffened and unstiffened girders*

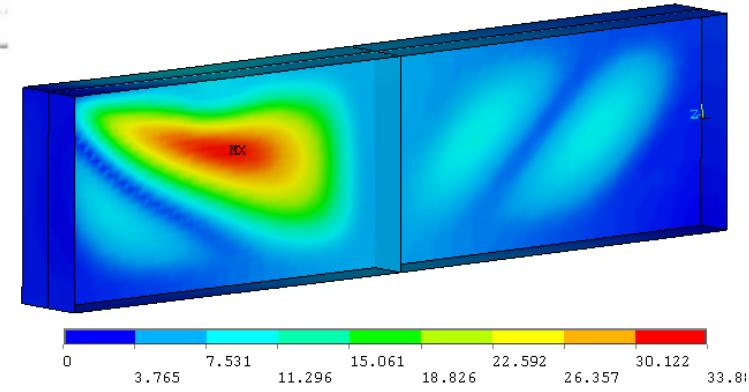
➤ Based on extended numerical research program



COMBRI research project

New design interaction equation:

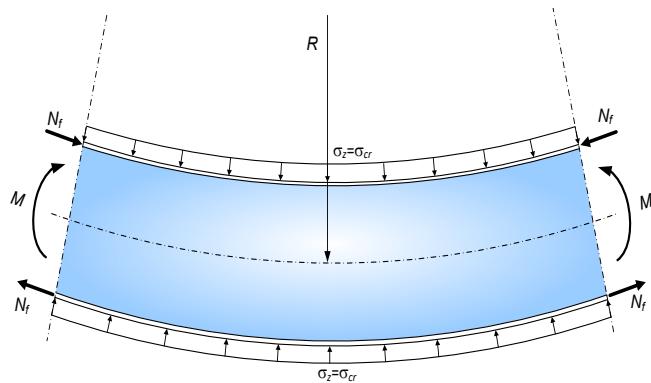
$$\bar{\eta}_1^{3.6} + \left[\bar{\eta}_3 \cdot \left(1 - \frac{F_{Ed}}{2 \cdot V_{Ed}} \right) \right]^{1.6} + \eta_2 \leq 1.0$$



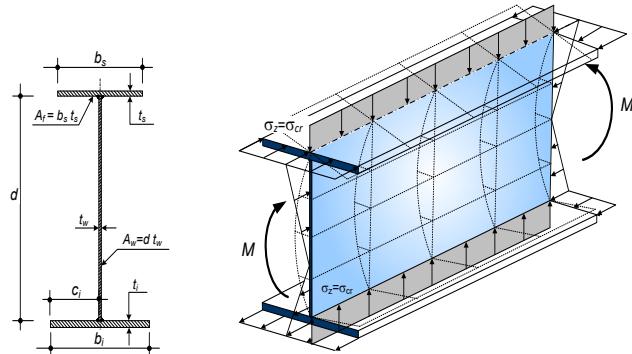
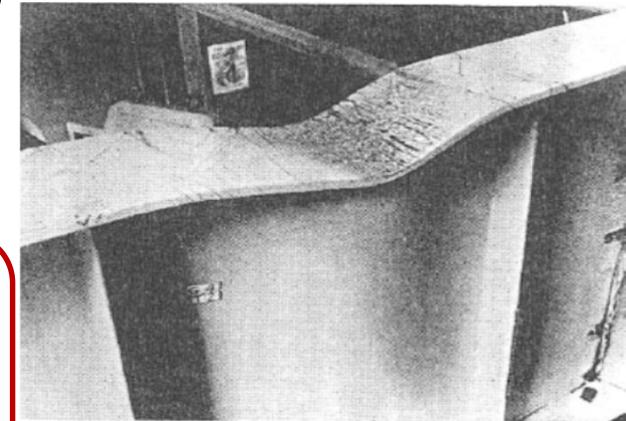
New content included in scope of EN 1993-1-5 (examples)

→ Improved rules for flange induced buckling

➤ Based on new experimental and numerical research



Very conservative assumptions with current EN 1993-1-5 formulas especially for HSS!



José Oliveira Pedro, Technical University of Lisbon

$$\frac{h_w}{t_w} \leq k \frac{E}{\beta f_{yf}} \sqrt{\frac{A_w}{A_{fc}}}$$

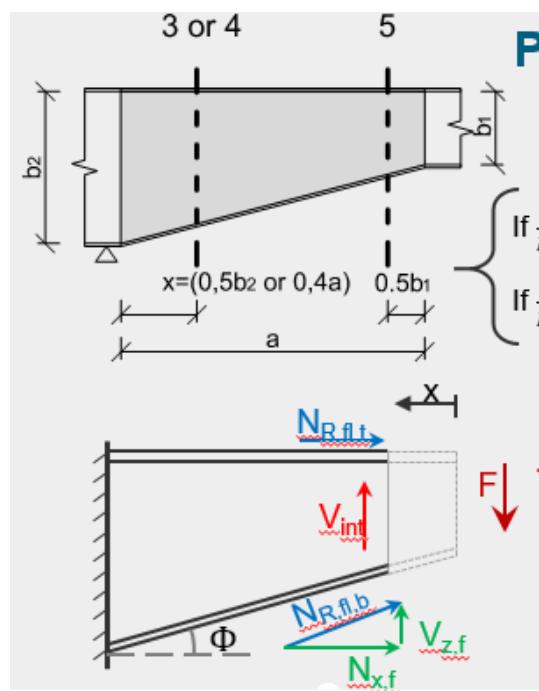
where A_w is the cross-section area of the web;
 A_{fc} is the effective cross-section area of the compression flange;
 h_w is the depth of the web;
 t_w is the thickness of the web.

New content included in scope of EN 1993-1-5 (examples)

→ Improved rules for non-rectangular panels



➤ Verification of cross sections in a non-rectangular panel



Proposal for non-rectangular panels:

- Section 3 or 4
and
- Section 5

→ Same sections like bending

$$N_{x,f} = \frac{M(x)}{(h_{wi} + t_f)} \quad V_{z,f} = N_{x,f} \cdot \tan \phi$$

$$V_{int} = V_{modified} = |F - V_{z,f}|$$

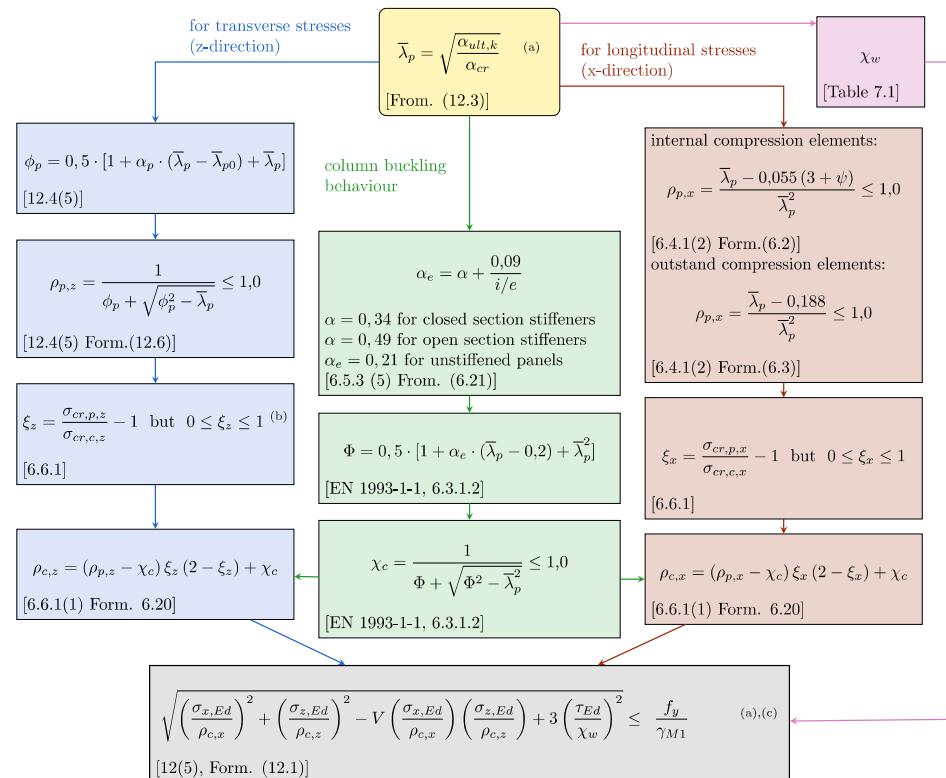
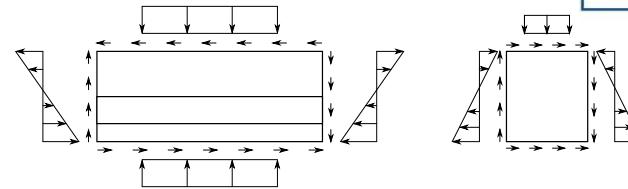
→ Shear stresses should be modified due to inclined flange

Based on new experimental and numerical research

How ease of use has been enhanced

- Complete restructuring of former section 10 now 12
- Reduced stresses method

- Flowchart added for the application of the reduced stress method



Notes:

- (a) For stiffened plates, the global buckling of the stiffened plate and each individual sub-panel should be verified.
- (b) In case of biaxial compression, section 6.5.3 and the modified buckling length according to section 6.4.2 (4) for transverse forces for each sub-panel should be considered.
- (c) In case of biaxial compression, the longitudinal stiffeners should be designed by using a beam model and second order analysis.



Overview of the Evolution of EN1993-1-6: Eurocode 3 — Design of steel structures — Part 1-6: Strength and Stability of Shell Structures

15.10.2020 Content has been taken from TC250/SC3/N3075 Presentation prepared in
the absence of Professor J. Michael Rotter by Adam J. Sadowski and Chris Brown,
University of Edinburgh, Scotland, Imperial College, London, Brunel University London, UK

Agenda – Evolution of EN 1993-1-6: Strength and Stability of Shell Structures

- Key changes to EN 1993-1-6
- New content included in the scope of EN 1993-1-6
- How ease of use has been enhanced

Key changes to EN 1993-1-6

- *Reduced number of NDPs*
- Published standard (2007) had 18 NDPs
- Third draft has 3 NDPs, e.g.
 - Gamma factors for different failure modes
 - Imperfection amplitudes for manufactured tubes



Key changes to EN 1993-1-6

- *Major technical changes*
- Extensive textual revisions to improve ease of use
- Many enhancements on imperfections and tolerances
- Enhancements on computational modelling
- Expansion of boundary condition cases for external pressure and removal of unsafe short cylinder rules
- Enhanced rules for buckling under axial compression including addition of stainless steel
- Extensive rules for global bending with axial compression and moment gradient
- Revised rules on spherical domes

New content included in scope of EN 1993-1-6

→ Imperfections and computational modelling

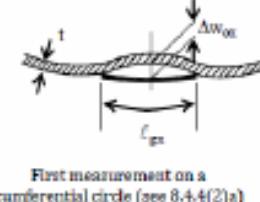
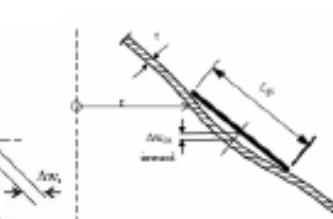
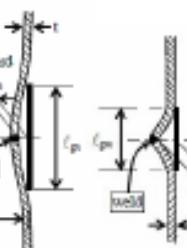
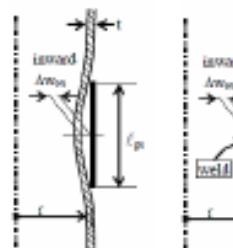
- The 4 buckling relevant tolerance controls
 - Out of roundness
 - Unintended eccentricity between constituent plates
 - Dimples
 - Interface flatness

- Dimple tolerances generally dominate (5 measures)

$$\ell_{gx} = 4 \sqrt{rt}$$

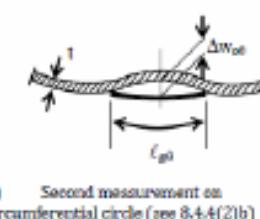
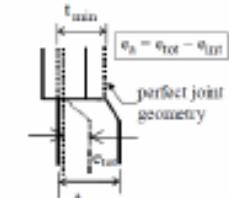
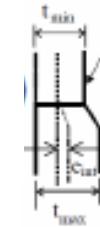
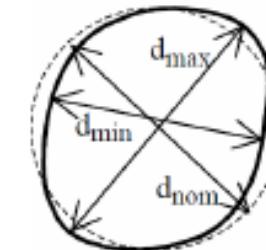
$$\ell_{g\theta} = 2,3 (\ell^2 rt)^{0,25}$$

$$\ell_{gw} = 25 t$$

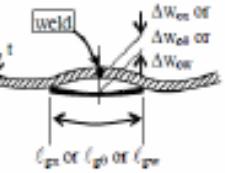


Issue 1

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b) Second measurement on circumferential circle (see 8.4.4(2)b)



New content included in scope of EN 1993-1-6

- *Imperfections and computational modelling*
- Each of the 4 tolerance measurements has its own limit for each Fabrication Quality Class
- The published standard (2007) says that the worst measure on all measurements determines the Fabrication Quality Class
- This is unfortunate because different tolerances are critical for different load cases
 - (e.g. Interface flatness is only important for axial compression)
- Result: many constructed shells are required to meet tolerances that are irrelevant to the true resistance of the structure



New content included in scope of EN 1993-1-6

→ *Imperfections and computational modelling*

- The designer now must identify and specify the tolerances that a particular shell should meet to achieve the required buckling resistance

Table 8.1 Required tolerance dependent on the shell stress state

Stress state dominated by membrane stresses	Out of roundness	Unintended eccentricity	Dimple	Interface flatness
Meridional compression	Applies	Applies	l_{gx} and l_{gw} only	Applies
Circumferential compression	Applies		l_{gs} and l_{gw} only	
Shear	Applies			



- This is particularly important in the context of legal disputes and insurance claims, because tolerances are often invoked to show that a structure is unsatisfactory when the tolerance has no relevance to the structural resistance

New content included in scope of EN 1993-1-6

→ *Imperfections and computational modelling*

- The new concept works well for simple structures with a dominant membrane stress, but is more difficult where all 3 membrane stresses are acting, identified by a new procedure
- “Assessment of the dominant stress condition”, identifies whether a stress state can be treated as simple or not
- It uses the ratios of each acting stress component to its resistance at every location

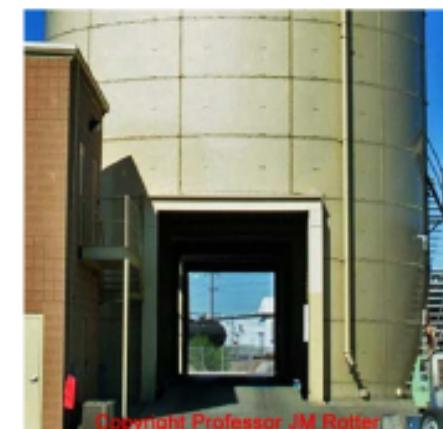
$$k_x = \sigma_{x.Ed} / \sigma_{x.Rd}$$

$$k_\theta = \sigma_{\theta.Ed} / \sigma_{\theta.Rd}$$

$$k_{x\theta} = \tau_{x\theta.Ed} / \tau_{x\theta.Rd}$$

Table 8.1 Required tolerance dependent on the shell stress state

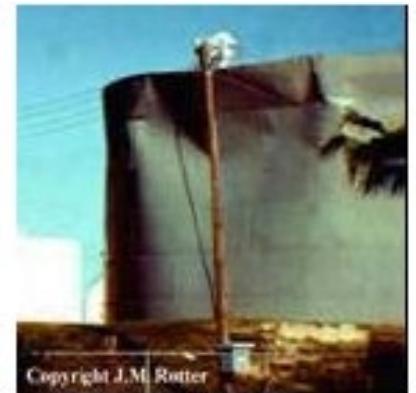
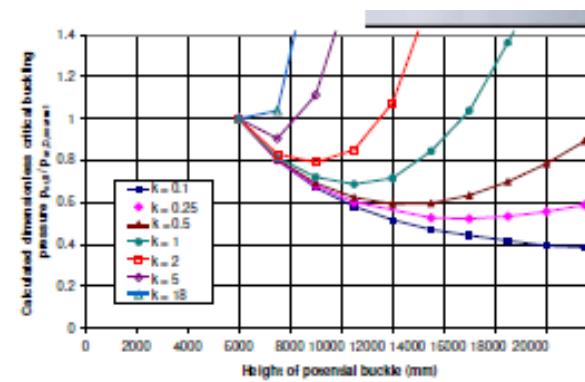
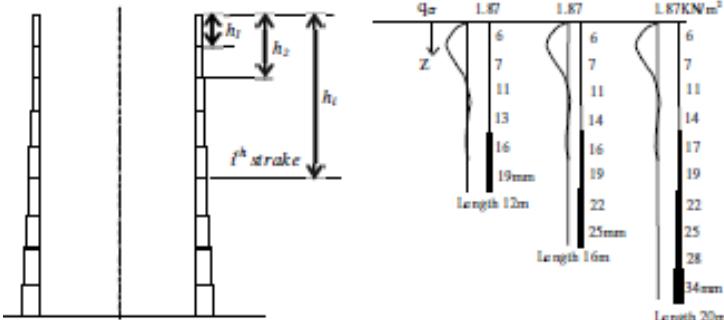
Stress state dominated by membrane stresses	Out of roundness	Unintended eccentricity	Dimple	Interface flatness
Meridional compression	Applies	Applies	l_{gx} and l_{gy} only	Applies
Circumferential compression	Applies		$l_{g\theta}$ and l_{gw} only	
Shear	Applies			



New content included in scope of EN 1993-1-6

→ Buckling of stepped walls under external pressure and wind

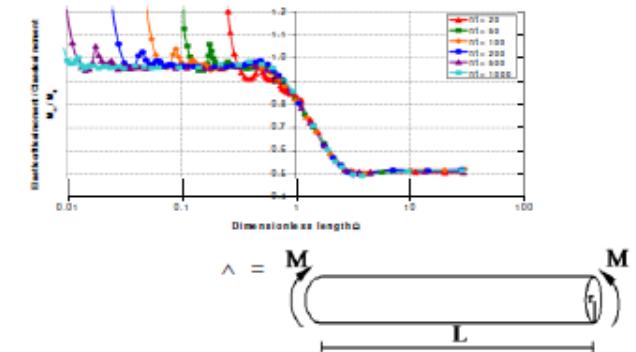
- The procedures in the 2007 published standard were very difficult to use, involving reading values from tiny charts
- This is replaced by the rationally based Weighted Smeared Wall Method, leading to a much simpler process for stepped walls, treating both external pressure and wind



New content included in scope of EN 1993-1-6

→ Cylindrical shells under global bending

- Very substantial new provisions have been introduced
- Uniform bending resistance carefully defined
- Bending combined with axial compression
- Bending with moment gradient (shear)
- Each of these has been fully defined in terms of Reference Resistance Design
 - The 2 reference resistances (LBA and MNA)
 - The 6 parameters that characterise the interaction, each of which depends on the geometry and imperfection amplitude
- Uniform bending
 - Reference resistances LBA and MNA relatively easily defined M_{cr} and M_{pl}
 - Geometric nonlinearity α_G mostly in ovalisation
 - Very sensitive length



$$\omega = \frac{\ell}{\sqrt{rt}}$$

Issue 1 \sqrt{rt}

$$\Omega = \frac{\ell}{r} \sqrt{\frac{t}{r}} = \omega \frac{t}{r}$$

$\alpha_{bg} = 0,9$ when $\Omega < 0,5$

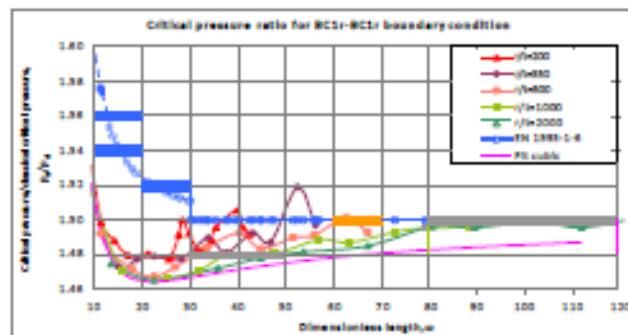
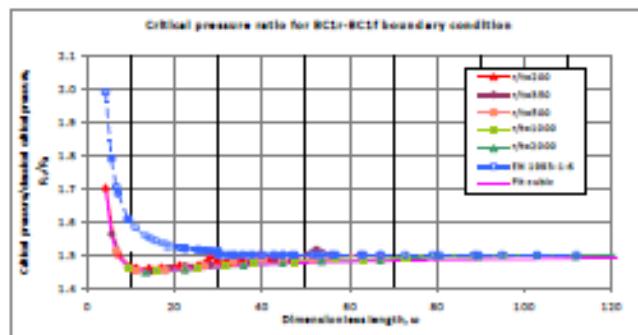
$\alpha_{bg} = 0,516 + (0,38 \sin \psi + 0,48 \cos \psi) * e^{-0,94\psi}$ when $\Omega \geq 0,5$

where $\psi = 0,85 \Omega$

Date: 15/10/2020

New content included in scope of EN 1993-1-6

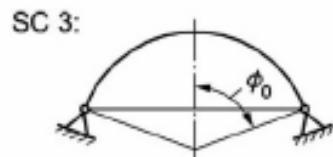
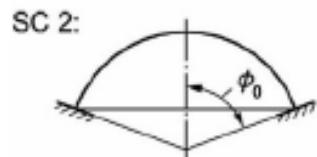
- *Shell buckling & boundary conditions*
- Boundary conditions are especially important under external pressure, where the conditions at each end of a cylinder of
 - Radial, axial and bending restraint are all important
- The 2007 standard had only 4 real boundary conditions
- The revised standard allows for all 14 possible bc combinations
- Some previous relationships for short cylinders were unsafe
- Short cylinders occur commonly in stepped walls of tanks and silos



New content included in scope of EN 1993-1-6

→ *Buckling of spherical and similar shells*

- Buckling of spherical and similar shells
- The focus of this ST5 has been on upgrading the treatment of spherical domes (important for tanks)
- The previous treatment used the wrong criteria to define both the plastic failure condition and the elastic critical condition
- This has been remedied now
- The previous treatment also used unrealistic boundary conditions that were difficult to relate to a real structure



$$p_{R,cr} = \frac{2}{\sqrt{3(1-v^2)}} \cdot C_{cr} \cdot E \cdot \left(\frac{t}{r_s}\right)^2$$

$$p_{R,pl} = f_{y,k} \cdot C_{pl} \cdot \frac{2t}{r_s}$$

How ease of use has been enhanced

- Implementation of the revised chapter structure
- Extensive critical examination of the text throughout the standard
- Addition of further definitions for clarity (now 59)
- More precise definitions of technical terms
- Extensive use of new explanatory NOTES to help the reader to understand the purpose and intention of new provisions
- Re-structuring of long or complicated sections (e.g. LBA-MNA)
- Retention of some Editorial Notes in the Third Draft to pose questions to the reviewer on choices to be made



Overview of the Evolution of EN1993-1-7:

Eurocode 3 — Design of steel structures — Part 1-7: Plate assemblies with elements under transverse loads

15.10.2020 Content has been taken from TC250/SC3/N3075 Presentation prepared in the absence of Professor J. Michael Rotter by Adam J. Sadowski and Chris Brown, University of Edinburgh, Scotland, Imperial College London, Brunel University London, UK

Issue 1

Date: 15/10/2020

Agenda – Evolution of EN 1993-1-7: Plate assemblies with elements under transverse loads

- Key changes to EN 1993-1-7
- New content included in the scope of EN 1993-1-7
- How ease of use has been enhanced



Key changes to EN 1993-1-7

- *Reduced number of NDPs*
- Published standard (2007) had 1 NDP
- Final draft (completely different standard) has 5 NDPs, e.g.
 - Gamma factors for different failure modes
 - Design by testing
 - Limiting strain at plastic failure (gross deformations)
 - Acceptable deflection ULS in the longest side of a plate assembly

Key changes to EN 1993-1-7

- *Major technical changes*
- Complete new structure for the later parts dividing into
 - Plate assemblies
 - Unstiffened plates in plate assemblies
 - Uni-directionally stiffened plates
 - Bi-directionally stiffened plates
- New annexes to give algebraic expressions for elastic and plastic design under different load patterns
- A significant body of text on plate assemblies
- Good links to EN 1993-1-5

New content included in scope of EN 1993-1-7

- Transformation of EN 1993-1-7 to deal with box-like assemblies of plates
- New clause structure implemented
- Plate assemblies
- Unstiffened plates including triangular and trapezoidal
- Uni-directionally stiffened plates
- Bi-directionally stiffened plates
- New annexes to give algebraic expressions for
 - Simple analysis for small plate assemblies
 - Elastic deflections and moments in single plates under practical load patterns
 - Plastic collapse of plates and assemblies under practical load patterns
- Significant advice on the interactions between and support requirements for plates in plate assemblies

How ease of use has been enhanced

- Complete new logical structure
- Extensive critical examination of the text throughout the standard
- Definitions for clarity (now 20)
- Use of explanatory NOTES to help the reader to understand the purpose and intention of new provisions
- Annexes containing extensive material that cannot be found in texts or guides



Overview of the Evolution of EN1993-1-2: Eurocode 3 — Design of steel structures — Part 1-2: General – Structural fire design

12.10.2020

Paulo Vila Real, Professor of Structural Engineering and Steel Construction,
Department of Civil Engineering, University of Aveiro

Agenda – Evolution of EN 1993-1-2: General – Structural fire design

- Key changes to EN 1993-1-2
- New content included in the scope of EN 1993-1-2
- How ease of use has been enhanced

Key changes to EN 1993-1-2

- Reduction in number of National Choices (NDPs): NDPs have reduced from 5 to 4;
- Enhanced ease of use;
- New structure harmonized with fire parts of other Eurocodes;
- High strength steels: Nominal fires are applicable to steel grades up to and including S700. Physically based thermal actions are applicable to steel grades up to and including S500;
- Emissivity coefficient for hot-dip galvanized steel;

Key changes to EN 1993-1-2

- Existing buckling curve for LTB has been improved to take in to account the beneficial effect of non-uniform bending diagrams;
- Annex C for stainless steel member has been changed with a completely new content;
- Annex D now include welded steel tubular joints;
- Former Annex E for Class 4 cross-sections was withdrawn. New design rules for class 4 cross-sections were included in EN 1993-1-2;
- New Annex E for beams with large web openings;

New content included in scope of EN 1993-1-2

→ *Emissivity coefficient for hot-dip galvanized steel*

Table 5.1 — Values of surface emissivity ε_m

Type of steel	$\varepsilon_m (\leq 500^\circ\text{C})$	$\varepsilon_m (> 500^\circ\text{C})$
Carbon steel		0,7
HDG steel ^a	0,35	0,7

^a Steel that has been hot-dip galvanized according to EN ISO 1461 and with steel composition according to Category A or B of EN ISO 14713-2, Table 1.

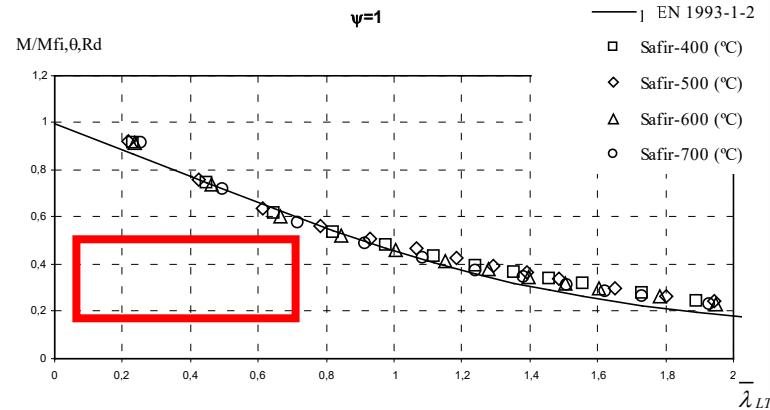
New content included in scope of EN 1993-1-2

→ *Emissivity coefficient for hot-dip galvanized steel Background documents*

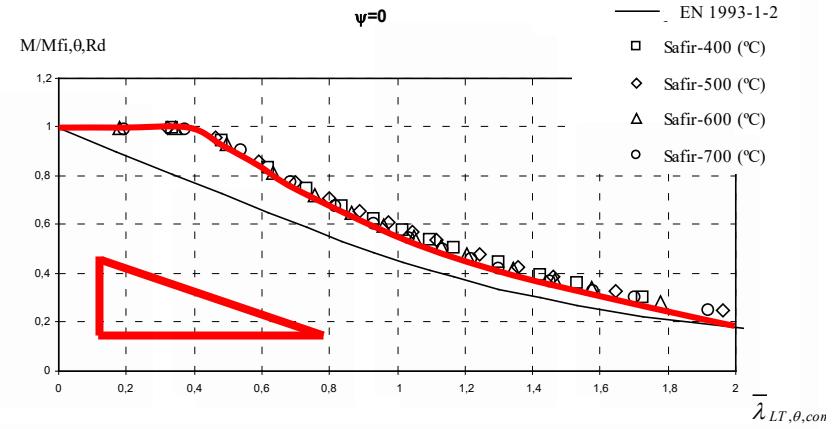
- Elich, J.J.P. & Hamerlinck, A.F. 1990. Thermal Properties of Galvanized Steel and its Importance in Enclosure Fire Scenarios, Fire Safety Journal 16.
- Gaigl, C. & Mensinger, M., 2017. Hot dip galvanized steel constructions under fire exposure. The 2nd International Fire Safety Symposium, IFireSS 2017.
- Mensinger, M. & Gaigl, C. 2016. The influence of hot dip galvanization to the temperature development of unprotected steel members in fire. Insights and Innovations in Structural Engineering, Mechanics and Computation - Proceedings of SEMC 2016
- Jirku, J. & Wald, F. & Jandera, M. Increase of the fire endurance of the structure by galvanizing
- Jirku, J. & Wald, F. & Jana, T. Heat transfer into galvanized components verification by fire tests in experimental.building
- Sala, A. 1986. Radiant Properties of Materials
- Gaigl C., Mensinger M.: Influence of hot dip galvanization to the heating of hot rolled steal section; research report, 2018

New content included in scope of EN 1993-1-2

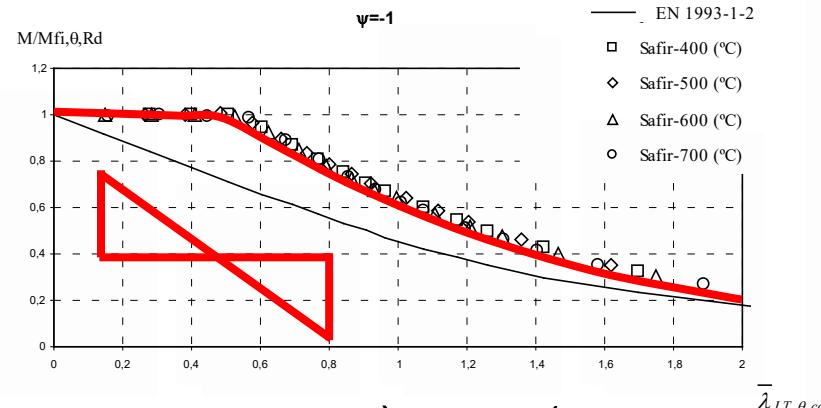
→ Influence of the bending diagrams on the LTB



a) $\Psi = 1$



b) $\Psi = 0$



c) $\Psi = -1$

New content included in scope of EN 1993-1-2

→ Influence of the bending diagrams on the LTB

(6) In order to take into account the effects of moment distribution between the lateral restraints of the members, the reduction factor may be modified as follows:

$$\chi_{LT,fi,mod} = \frac{\chi_{LT,fi}}{f} \quad \text{but} \quad \chi_{LT,fi,mod} \leq 1,0 \quad (7.23)$$

where f should be taken to depend on the loading type, according to the Formula:

$$f = 1 - 0,5(1 - k_c) \quad (7.24)$$

where k_c is a correction factor according to Table 7.1.

Moment distribution	k_c
	$0,6 + 0,3\psi + 0,15\psi^2$ but $k_c \leq 1,0$
	0,91
	0,90
	0,91
	0,79
	0,73
	0,75

NOTE For other bending diagrams $k_c = 1,0$.

New content included in scope of EN 1993-1-2

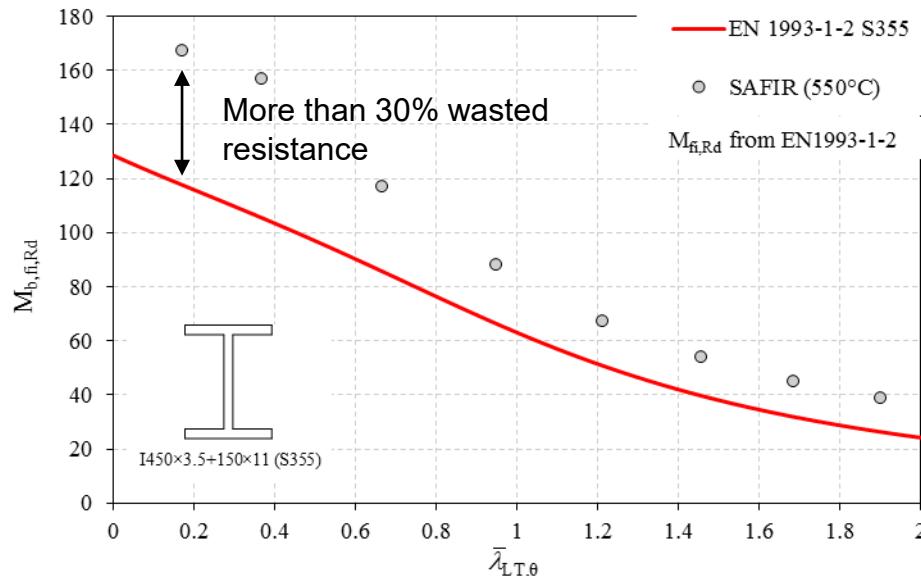
→ *Influence of the bending diagrams on the LTB Background documents*

- Vila Real, P.; Lopes, N.; Simões da Silva, L.; Franssen, J.-M. "New Proposal for Section 4.2.3.3 of EN 1993-1-2 - On Lateral-Torsional Buckling", document CEN/TC 250/SC 3/WG 2 N 30 of WG2 for EN 1993-1-2, 2012.
- Vila Real, P.; Lopes, N.; Simões da Silva, L.; Franssen, J.-M. "Lateral-torsional buckling of steel elements in case of fire: Improvement of the EC3", document CEN/TC 250/SC 3/WG 2 N 31 of WG2 for EN 1993-1-2, 2012, 2012.
- Vila Real, P.; Lopes, N.; Simões da Silva, L.; Franssen, J.-M. "Parametric analysis of the Lateral-torsional buckling resistance of steel beams in case of fire", Fire Safety Journal, Elsevier, vol 42 / (6-7), pp 416-424, 2007.
- Lopes, N.; Vila Real, P.; Simões da Silva, L.; Franssen, J.-M. "Lateral-torsional buckling on carbon steel and stainless steel beams with lateral loads plus end moments in case of fire", proce. 6th Int Conference on Structures in Fire SiF'10, pp. 67-74, ISBN 978-1-60595-027-3, Michigan State University, East Lansing, United States of America, 2010.
- CEN/TC 250/SC 3/WG 2 N 30
- CEN/TC 250/SC 3/WG 2 N 31

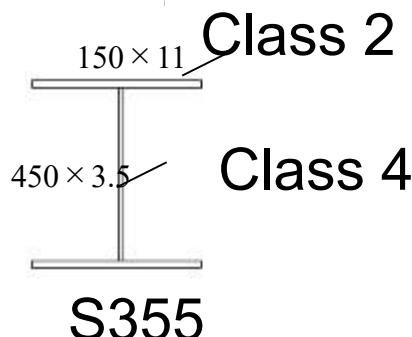
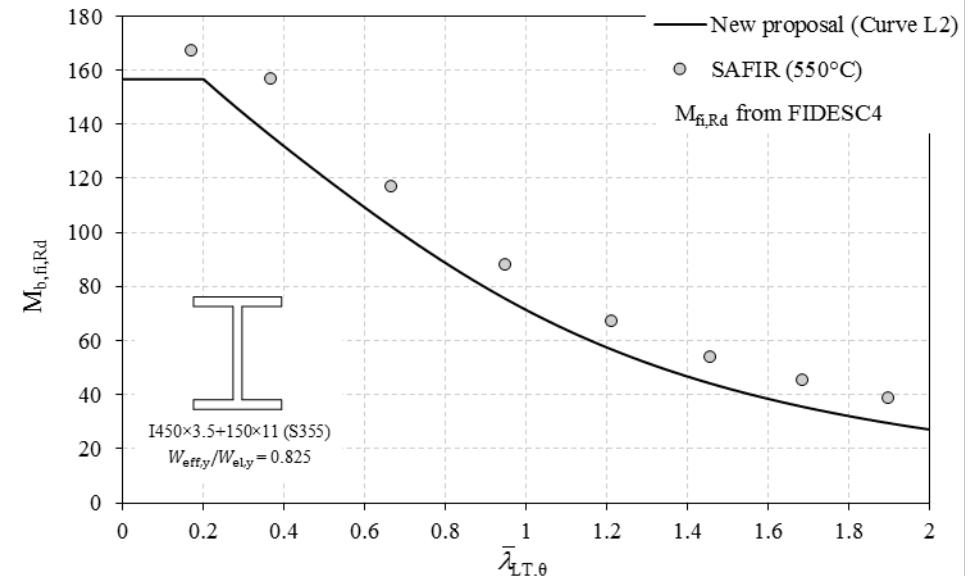
New content included in scope of EN 1993-1-2

→ Design rules for class 4 cross-sections

Present situation (EN1993-1-2:2005)



New proposal



New content included in scope of EN 1993-1-2

→ *Design rules for class 4 cross-sections*

Background documents (1)

- Couto C., Vila Real P., Lopes N., Zhao B. (2014) – Effective width method to account for the local buckling of steel thin plates at elevated temperatures. *Thin-Walled Struct* 2014;84:134–49.
doi:10.1016/j.tws.2014.06.003.
- Zhao B., Sanzel A., Wald F., Vila Real P., Hricak J., Jandera M., Couto C., Lopes, N. (2014) – Development of simple fire design method for I shape thin wall steel members under simple bending, *Revue Construction Métallique*, n° 2-2014, ISSN 0045-8198, CTICM, Paris, France.
- Couto C., Vila Real P., Lopes N., Zhao B. (2015) – Resistance of steel cross-sections with local buckling at elevated temperatures. *J Constr Steel Res* 2015;109:101–14.
doi:10.1016/j.jcsr.2015.03.005.
- Couto C., Vila Real P., Lopes N., Zhao B., (2015) – Numerical investigation of the lateral-torsional buckling of beams with slender cross sections for the case of fire. *Eng Struct* 2015;106:410–21.
doi:10.1016/j.engstruct.2015.10.045.
- Couto C., Sanzel A., Vila Real P., Lopes N., Zhao B. (2016) – Beam-columns with thin wall cross-sections in case of fire. 9th International Conference Structures in Fire (SiF'16).

New content included in scope of EN 1993-1-2

→ *Design rules for class 4 cross-sections* *Background documents (2)*

- Sanzel A., Zhao B., Couto, C., Lopes, N., Vila Real P. (2017) – Developpement d'une methode de calcul simplifiee pour l'evaluation de la resistance des elements de classe 4 comprimes et flechis en situation d'incendie », Revue Construction Métallique, n° 2-2017, pp. 1-40, ISSN 0045-8198, CTICM, Paris, France.
- Couto C., Maia É., Vila Real P., Lopes N. (2018) – The effect of non-uniform bending on the lateral stability of steel beams with slender cross-section at elevated temperatures, Engineering Structures 163:153-166, DOI: 10.1016/j.engstruct.2018.02.033.
- FIDES-C4 (2011-2014). Fire Design of Steel Members with Welded or Hot-Rolled Class 4 Cross-Section, RFCS-CT-2011-00030.
- Proposal from Prof. Paulo Vila Real, Prof. Nuno Lopes and Doctor Carlos Couto from University of Aveiro and Doctor Bin Zhao and Mr. Arnaud Sanzel from CTICM

New content included in scope of EN 1993-1-2

→ Annex C: Stainless Steel (*new formulations*)

There are no Classes for stainless steel cross-sections

(3) Compression elements with $\bar{\lambda}_{p,\theta} \leq \bar{\lambda}_{p0,\theta}$ should be classified as non-slender. Compression elements that do not satisfy the criteria for non-slender (i.e. those with $\bar{\lambda}_{p,\theta} > \bar{\lambda}_{p0,\theta}$) should be classified as slender, where $\bar{\lambda}_{p0,\theta}$ should be obtained from C.4.2.2(1).

(4) The class of a cross-section should be taken as slender if any of the constituting compression elements is classified as slender. A cross-section should be classified as non-slender only if all of the constituting compression elements are classified as non-slender.

C.4.3.2 Compression members

(1) The design buckling resistance $N_{b,fi,t,Rd}$ at time t of a compression member with a uniform temperature θ_a is given by:

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} A k_{2,\theta} f_y}{\gamma_{M,fi}} \leq N_{t,Rd} \quad \text{for non-slender sections} \quad (\text{C.23a})$$

$$N_{b,fi,t,Rd} = \frac{\chi_{fi} A_{eff} k_{2,\theta} f_y}{\gamma_{M,fi}} \leq N_{t,Rd} \quad \text{for slender sections} \quad (\text{C.23b})$$

New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations): Background documents (1)*

Stress-strain properties

- Gardner, L., Insausti, A., K. Ng, and Ashraf, M. (2010), "Elevated temperature material properties of stainless steel alloys", Journal of Constructional Steel Research, 66, 634-647.
- Gardner, L., Bu, Y., Francis, P., Baddoo, N., Cashell, K. and McCann, F. (2016), "Elevated temperature material properties of stainless steel reinforcing bar", Construction and Building Materials, 114, 977-997.
- Liang, Y., Manninen, T., Zhao, O., Walport, F. and Gardner, L. (2019), "Elevated temperature material properties of a new high-chromium austenitic stainless steel," Journal of Constructional Steel Research, 152, 261-273.
- SCI (2017), Stainless Steel Design Manual, Fourth Edition, Steel Construction Institute.
- Zhao, B. (2000), Work package 5.1: Material behaviour at elevated temperatures. ECSC project "Development of the use of stainless steel in construction". Contract no. 7210 SA/842. CTICM France.

New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations):
Background documents (2)*

Local buckling assessment of stainless steel elements in fire

- Ala-Outinen, T., & Oksanen, T. (1997). Stainless steel compression members exposed to fire. Technical Research Centre of Finland. Research Notes(Finland), 1864, 58.
- Couto, C., Vila Real, P., Lopes, N. and Zhao, B. (2015), "Resistance of steel cross-sections with local buckling at elevated temperatures," Journal of Constructional Steel Research, 109, 101-114.
- Gardner, L., & Baddoo, N. R. (2006). "Fire testing and design of stainless steel structures", Journal of Constructional Steel Research, 62(6), 532-543.
- Kruppa, J. (1999), "Eurocodes-Fire parts: Proposal for a methodology to check the accuracy of assessment methods," CEN TC 250, Horizontal Group Fire, Document no: 99/130.
- Pauli, J., Somaini, D., Knobloch, M., & Fontana, M. (2012). Experiments on steel columns under fire conditions. IBK test report no. 340, Institute of Structural Engineering (IBK), ETH Zürich

New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations):
Background documents (3)*

Resistance of stainless steel compression members in fire

- Ala-Outinen, T., & Oksanen, T. (1997). Stainless steel compression members exposed to fire. Technical Research Centre of Finland. Research Notes(Finland), 1864, 58.
- Gardner, L., & Baddoo, N. R. (2006). "Fire testing and design of stainless steel structures", Journal of Constructional Steel Research, 62(6), 532-543.
- Lopes, N., Vila Real, P., da Silva, L. and Franssen, J. (2010), "Axially loaded stainless steel columns in case of fire," Journal of Structural Fire Engineering, 1, 1, 43-60.
- Kruppa, J. (1999), "Eurocodes-Fire parts: Proposal for a methodology to check the accuracy of assessment methods," CEN TC 250, Horizontal Group Fire, Document no: 99/130.
- Pauli, J., Somaini, D., Knobloch, M., & Fontana, M. (2012). Experiments on steel columns under fire conditions. IBK test report no. 340, Institute of Structural Engineering (IBK), ETH Zürich

New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations): Background documents (4)*

Resistance of stainless steel beams in fire

- Ala-Outinen, T., & Oksanen, T. (1997). Stainless steel compression members exposed to fire. Technical Research Centre of Finland. Research Notes(Finland), 1864, 58.
- Gardner, L., & Baddoo, N. R. (2006). "Fire testing and design of stainless steel structures", Journal of Constructional Steel Research, 62(6), 532-543.
- Kruppa, J. (1999), "Eurocodes-Fire parts: Proposal for a methodology to check the accuracy of assessment methods," CEN TC 250, Horizontal Group Fire, Document no: 99/130.
- Pauli, J., Somaini, D., Knobloch, M., & Fontana, M. (2012). Experiments on steel columns under fire conditions. IBK test report no. 340, Institute of Structural Engineering (IBK), ETH Zürich

New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations): Background documents (5)*

Resistance of stainless steel beam-columns in fire

- Ala-Outinen, T., & Oksanen, T. (1997). Stainless steel compression members exposed to fire. Technical Research Centre of Finland. Research Notes(Finland), 1864, 58.
- Boissonnade, N., Greiner, R., Jaspart, J. and Lindner, J. (2006), "Rules for Member Stability in EN 1993-1-1: Background documentation and design guidelines", ECCS European Convention for Constructional Steelwork.
- Gardner, L., & Baddoo, N. R. (2006). "Fire testing and design of stainless steel structures", Journal of Constructional Steel Research, 62(6), 532-543.
- Kruppa, J. (1999), "Eurocodes-Fire parts: Proposal for a methodology to check the accuracy of assessment methods," CEN TC 250, Horizontal Group Fire, Document no: 99/130.
- Pauli, J., Somaini, D., Knobloch, M., & Fontana, M. (2012). Experiments on steel columns under fire conditions. IBK test report no. 340, Institute of Structural Engineering (IBK), ETH Zürich



New content included in scope of EN 1993-1-2

→ Annex C: *Stainless Steel (new formulations): Background documents (6)*

Thermal expansion thermal conductivity and specific heat

- DIN SEW 310:1992-08, Physikalische Eigenschaften von Stahlen

New content included in scope of EN 1993-1-2

→ *Annex D: Joints Temperature of joints in fire*

D.3 Temperature of joints in fire

D.3.1 General

- (1) The temperature of a joint may be assessed using the local A/V value of the parts forming that joint. For unprotected joints, the local A/V value may be calculated as $2/t$ where "t" is the total thickness of the connected steel plates (e.g. endplate/column flange, fin plate/beam web) in the thinnest part of the joint.
- (2) Alternatively, as a simplification, the unprotected joint temperature may be taken as the maximum temperature of the unprotected connected steel members.
- (3) For protected joints, the joint temperature should be taken equal to the maximum temperature of the protected connected steel members.

New content included in scope of EN 1993-1-2

→ Annex D: Joints

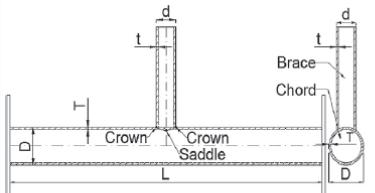
Temperature of joints in fire: Background documents

- Jána, T.; Wang, Y.C.; Wald, F., An analytical method to calculate temperatures of components of reverse channel connection to concrete filled steel section under fire conditions, Fire Safety Journal. 2016, 82 115-130.
- Jána, T.; Wang, Y.C.; Wald, F.; Horová, K., Temperatures and thermal boundary conditions in reverse channel connections to concrete filled steel sections during standard and natural fire tests Fire Safety Journal. 2015, 78 55-70. ISSN 0379-7112.
- Ding, J. and Wang, Y.C. (2007), Experimental study of structural fire behaviour of steel beam to concrete filled tubular column assemblies with different types of joints, Engineering Structures, 29(12), pp. 3485-3502 doi:10.1016/j.engstruct.2007.08.018

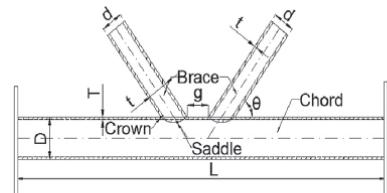
New content included in scope of EN 1993-1-2

→ Annex D: Joints

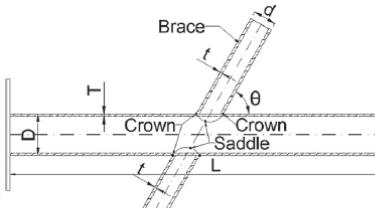
Elevated temperature resistance of welded tubular joints with axial load or in-plane bending in brace members



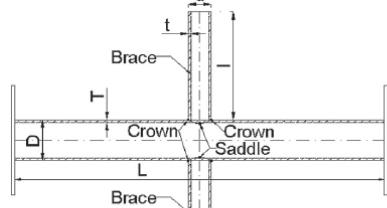
(a) T-joint



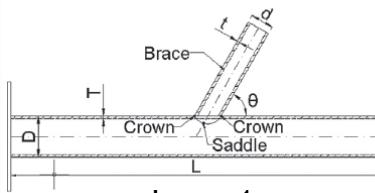
(b) K-joint



(c) X-joint

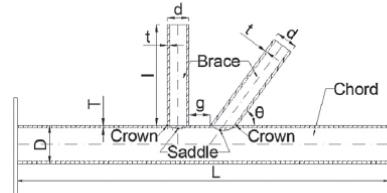


(d) X-joint



(e) Y-joint

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(f) N-joint

D.4 Welded steel tubular joints

D.4.1 General

- (1) D.4 covers uniplanar joints only.
- (2) The temperature (θ) of a welded tubular joint should be taken equal to the highest temperature of the connected members.
- (3) The elevated temperature resistance of the joint should be obtained by multiplying its resistance for normal temperature design by $k_{y,\theta}$, except for the cases in D.4.2 and D.4.3.

D.4.2 Welded tubular joints with axial compression in brace members

- (1) In T-, Y- and X-circular, rectangular, square, and elliptical hollow section joints where the brace member is connected to the wide face of the chord member, and when the joint fails by chord face plastification, the elevated temperature resistance of the joint should be obtained by multiplying its resistance for normal temperature design by a factor $k_{c1,\theta}$ given in Table D.2.

D.4.3 Welded tubular joints with in-plane bending moment in brace members

- (1) The elevated temperature resistance of a joint which fails by chord face plastification should be obtained by multiplying its resistance for normal temperature design by a factor $k_{c2,\theta}$ given in Table D.2.



New content included in scope of EN 1993-1-2

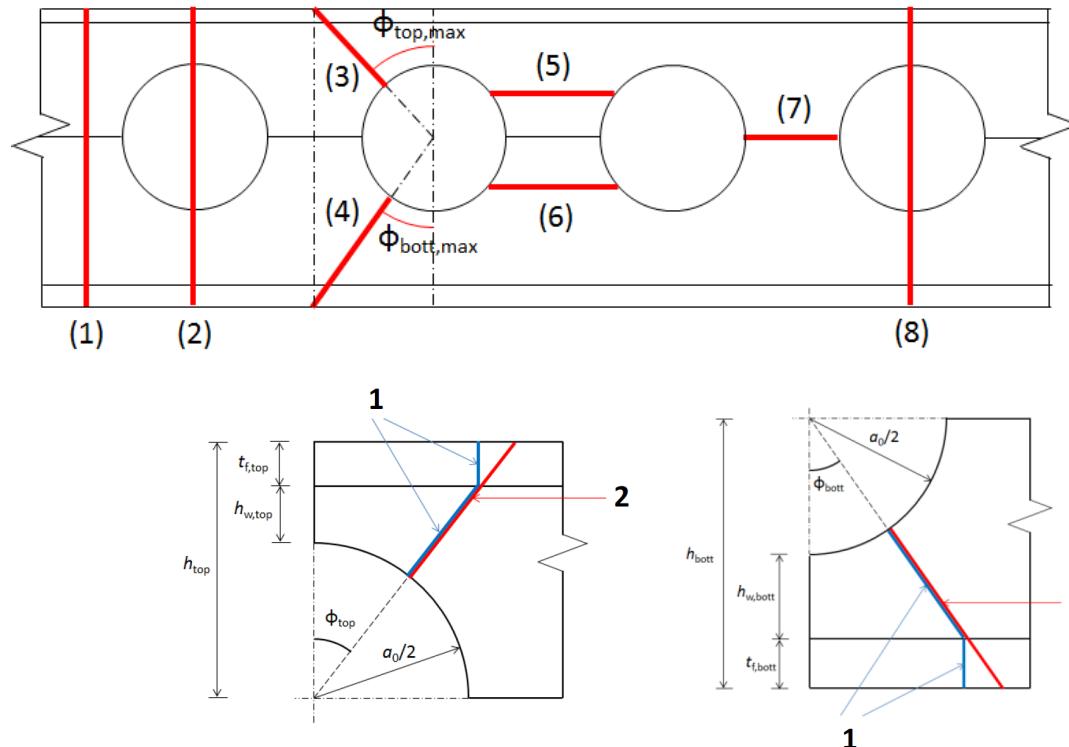
→ Annex D: Joints

*Elevated temperature resistance of welded tubular joints with axial load or in-plane bending in brace members:
Background documents*

- Ozyurt, E. and Wang, Y.C. (2018), Resistance of Axially Loaded T- and X-Joints of Elliptical Hollow Sections at Elevated Temperatures - A Finite Element Study, *Structures*, Vol. 14, pp. 15-31,
<https://doi.org/10.1016/j.istruc.2018.01.004>
- Ozyurt, E., Wang, Y.C. and Tan, K.H. (2014), Elevated Temperature Re-sistance of Welded Tubular Joints under Axial Load in the Brace Member, *Engineering Structures*, Vol. 59, pp. 574-586,
<http://dx.doi.org/10.1016/j.engstruct.2013.11.014>
- Ozyurt, E. (2015), Behaviour of Welded Tubular Structures in Fire, PhD thesis, University of Manchester
- Wang, Y.C. and Ozyurt, E. (2018), Welded joint strength at elevated temperature, 1st Interim report of CIDECT project 15U, CIDECT, August 2018

New content included in scope of EN 1993-1-2

→ Annex E: Beams with large web openings



Key

- 1 Cross-section used in the section factor calculation
- 2 Cross-section used in the load-bearing capacity calculation

New content included in scope of EN 1993-1-2

→ *Annex E: Beams with large web openings: Background documents (1)*

- “Fire resistance of long span cellular beam made of rolled profiles (FICEB)”, Contract No RFSR-CT-2007-00042, EUR 25112, 2012.
- Vassart O., “Analytical model for cellular beams made of hot rolled sections in case of fire”, Ph. D. Thesis, University Blaise Pascal Clermont-Ferrand, France, September 2009.
- “Comportement des poutres en acier et des poutres mixtes à ouvertures d’âmes isolées en situation normale et d’incendie», Internal Report, Centre de Recherches ArcelorMittal Esch-sur-Alzette, 2019.

Additional related documents (1)

- Bihina G, Zhao B., Bouchair A., “Behaviour of composite steel-concrete cellular beams in fire”, Engineering Structures 56, 2217-2228, 2013.
- Nadjai A. et al., “Performance of cellular composite floor beams at elevated temperatures”, Fire Safety Journal 42, 489-497, 2007.

New content included in scope of EN 1993-1-2

→ *Annex E: Beams with large web openings: Background documents (2)*

Additional related documents (2)

- Vassart et al., "Parametrical Study on the Behaviour of Steel and Composite Cellular Beams Under Fire Conditions", Proc. of the 6th International Conference Structures in Fire, East Lansing (MI), USA, 2010.
- "RT 1356 - Fire Design of Composite Beams with Rectangular and Circular Web Openings", SCI, December 2012.
- Bitar D., Martin P.-O., Galéa Y., Demarco T., « Poutres cellulaires acier et mixtes Partie 1. Proposition d'un modèle pour la résistance des montants », Revue Construction Métallique n°1-2006.
- Lawson R.M., Lim J., Hicks S.J., Simms W.I., « Design of composite asymmetric cellular beams and beams with large web openings », Journal of Constructional Steel Research, pp 614-629, Vol. 62, No 6, June 2006.
- Lawson R.M., Hicks S.J., « Design of beams with large web openings », P355, SCI Publication, 2011.

How ease of use has been enhanced

→ Some clauses were improved in terms of ease of use
 Example:

Before

The non-dimensional slenderness $\bar{\lambda}_{\theta}$ for the temperature θ_a , is given by:

$$\bar{\lambda}_{\theta} = \bar{\lambda} [k_{y,\theta} / k_{E,\theta}]^{0.5} \quad (4.7)$$

where:

- $k_{y,\theta}$ is the reduction factor from section 3 for the yield strength of steel at the steel temperature θ_a reached at time t ;
- $k_{E,\theta}$ is the reduction factor from section 3 for the slope of the linear elastic range at the steel temperature θ_a reached at time t .

After

$$\bar{\lambda}_{\theta} = \bar{\lambda} \sqrt{\frac{k_{y,\theta}}{k_{E,\theta}}} \quad (7.12)$$

where:

$$\bar{\lambda} = \sqrt{\frac{A_f y}{N_{cr}}} \quad \text{for class 1, 2 or 3 cross-sections; } \quad (7.13)$$

$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} \quad \text{for class 4 cross-sections; } \quad (7.14)$$

- $k_{y,\theta}$ is the reduction factor from 5 for the yield strength of steel at the steel temperature θ_a reached at time t ;
- $k_{E,\theta}$ is the reduction factor from 5 for the slope of the linear elastic range at the steel temperature θ_a reached at time t ;
- N_{cr} is the elastic critical force for the relevant buckling mode based on the gross cross-sectional properties, using the buckling length under fire conditions.

How ease of use has been enhanced

→ Some clauses were improved in terms of ease of use
 Example:

Before

$$\bar{\lambda}_{LT,\theta,com} = \bar{\lambda}_{LT} [k_{y,\theta,com}/k_{E,\theta,com}]^{0.5}$$

where:

$k_{E,\theta,com}$ is the reduction factor from section 3 for the slope of the linear elastic range at the maximum steel temperature in the compression flange $\theta_{a,com}$ reached at time t .

(4.15)

$$\bar{\lambda}_{LT,\theta,com} = \bar{\lambda}_{LT} \sqrt{\frac{k_{y,\theta,com}}{k_{E,\theta,com}}}$$

where:

$k_{E,\theta,com}$ is the reduction factor from 5 for the slope of the linear elastic range at the maximum steel temperature in the compression flange $\theta_{a,com}$ reached at time t .

and the relative slenderness $\bar{\lambda}_{LT}$ is given by:

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y}f_y}{M_{cr}}} \quad (7.20)$$

M_{cr} is the elastic critical moment for lateral-torsional buckling based on the gross cross-sectional properties, taking into account loading conditions, actual moment distribution and lateral restraints.

After

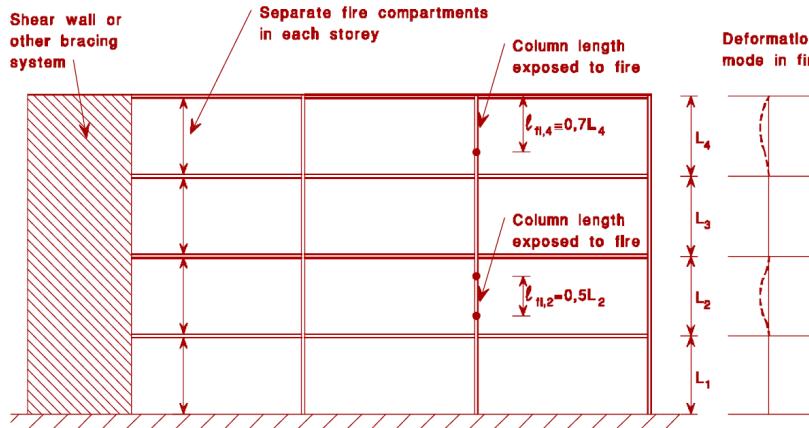
How ease of use has been enhanced

→ Some clauses were improved in terms of ease of use
 Example:

Before

(3) The buckling length l_{fi} of a column for the fire design situation should generally be determined as for normal temperature design. However, in a braced frame the buckling length l_{fi} of a column length may be determined by considering it as fixed in direction at continuous or semi-continuous joints to the column lengths in the fire compartments above and below, provided that the fire resistance of the building components that separate these fire compartments is not less than the fire resistance of the column.

(5) In the case of a braced frame in which each storey comprises a separate fire compartment with sufficient fire resistance, in an intermediate storey the buckling length l_{fi} of a continuous column may be taken as $l_{fi} = 0,5L$ and in the top storey the buckling length may be taken as $l_{fi} = 0,7L$, where L is the system length in the relevant storey, see figure 4.1.



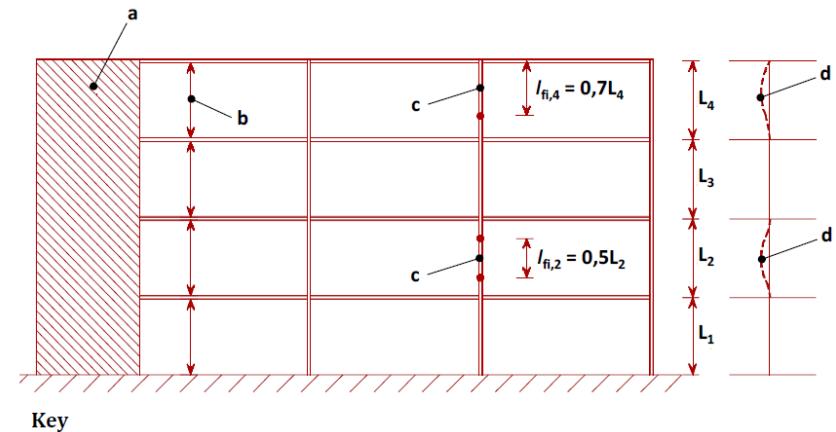
Issue 1

Date: 15/10/2020

After

(3) The buckling length l_{fi} of a column for the fire design situation should generally be determined as for normal temperature design.

(4) In the case of a non-sway frame in which each storey comprises a separate fire compartment with a fire resistance not less than the fire resistance of the column, the buckling length l_{fi} of a continuous column may be taken as $l_{fi} = 0,5 L$ in an intermediate storey and as $l_{fi} = 0,7L$ in the top storey, where L is the system length in the relevant storey, see Figure 7.1.



Key

- a Shear wall or other bracing system
- b Height of separate fire compartments in each storey
- c Columns buckling length exposed to fire
- d Deformation mode in fire

Summary and Conclusions

→ *Summary of procedure*

➤ Principles for the future development of Eurocode 3

- Principles have been accepted by SC3 at an early stage of development which are in conformity with TC250 aims of **Reduction of NDPs and Ease of Use**

➤ Technical issues to be extensively discussed and decided

- Development of amendments by the relevant experts of the CEN/TC250/SC3 Working Groups
- Allow for sufficient discussion and clarification in TC250/SC3 and in National Mirror Groups

➤ Clear decisions as guidance for Project Team Work

- Transparent decisions of SC3 form a reliable basis for work of Project Teams

Thanks for attention !

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