



EUROCODES

EN 1993

Design of steel structures



Prof. Dr.-Ing. U. Kuhlmann, Prof. Dr. M. Knobloch

EUROCODE Conference | Berlin | 24 May 2023

EUROCODE Conference | Berlin | 24 May 2023

2023
EURO
CODE
DIBt

Introduction | Structure and Overview of the 1st Gen. Eurocode 3

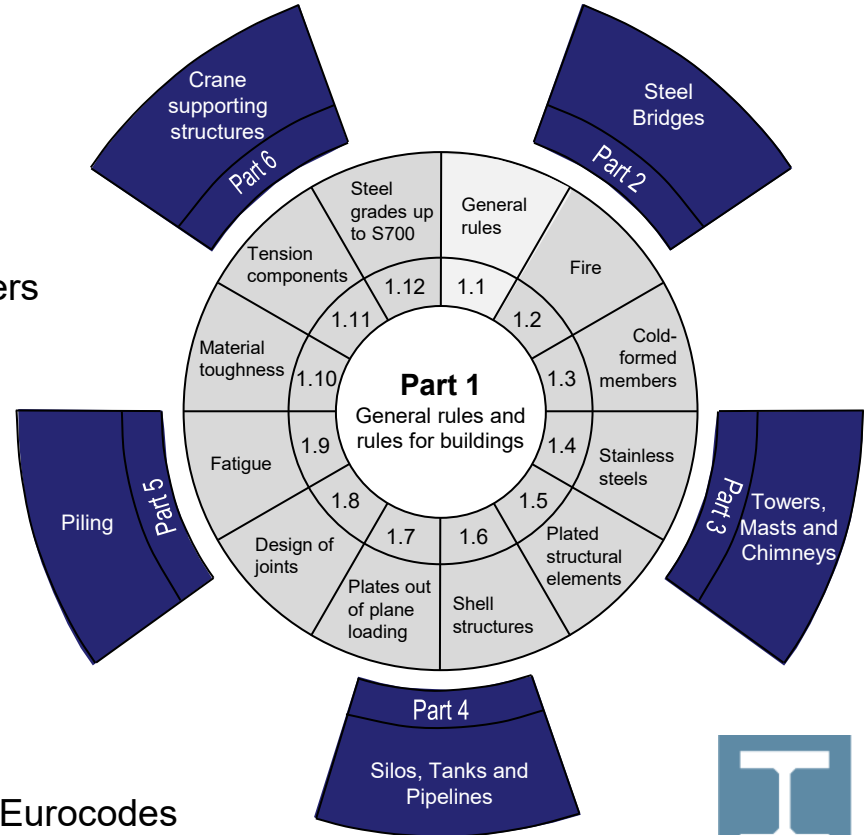
20 parts consisting of

■ 12 General parts EN 1993-1

- General rules and rules for buildings
- Structural fire design
- Supplementary rules for cold-formed members
- ...
- Design of steel structures with regard to strength and stability

■ 8 Application parts EN 1993-2 – EN 1993-6

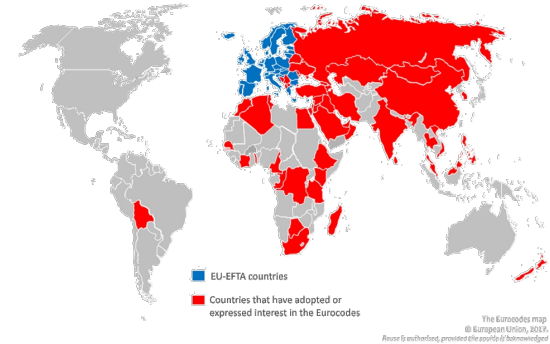
- Steel bridges
- Towers, masts, chimneys
- ...
- „Master“ for use of General parts and other Eurocodes



Introduction | Second Generation of Structural Eurocodes

Strategy of TC250

- Incorporation of **new findings**
- Improvement and harmonization of existing rules:
Reduction of Nationally Determined Parameters (**NDPs**)
- Enhanced **Ease of Use**



Application of the Eurocodes

Strategy of SC3 (*Decision 4/2013*)

- CEN /TC 250/SC 3 agrees to establish the following principles for the further evolution of EN 1993
 - **keep** the overall **structure** of EN 1993 and its parts
 - improve the **clarity**
 - **harmonize** and **simplify rules** (same format, structure, notations,..) | Harmonization of the different parts of Eurocode 3 and with other relevant Eurocodes wherever possible
 - **reduce** the overall **volume** (e.g. by avoiding Informative Annexes)
 - **reduce** number of **alternatives**



Procedure for the Revision of Eurocode 3

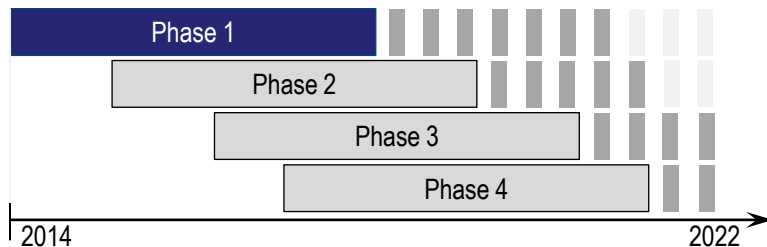
Mandate M/515

- Agreement between the European Commission and CEN for the further development and revision of the existing Eurocodes

→ technical processing through “Project Teams” (PT)

- 13 PT/Tasks for Eurocode 3 | **4 phases**

- Phase 1: Basic parts Part 1-1 and 1-8
- Phase 2: Parts dealing with stability
- Phase 3: Parts dealing with material
- Phase 4: Application parts



Overview of the SC3-Tasks within mandate M/515

Task-Ref.	Task-Phase	Corresponding Part of EN 1993	Task-Name
SC3.T1	1	EN 1993-1-1	Design of Sections and Members according to EN 1993-1-1
SC3.T2	1	EN 1993-1-8	Joints and Connections according to EN 1993-1-8
SC3.T3	2	EN 1993-1-3	Cold-formed members and sheeting - Revised EN 1993-1-3
SC3.T4	2	EN 1993-1-5	Stability of Plated Structural Elements - Revised EN 1993-1-5
SC3.T5	2	EN 1993-1-6, EN 1993-1-7	Harmonisation and Extension of Rules for Shells and Similar Structures - Revised EN 1993-1-6 and EN 1993-1-7
SC3.T6	2	EN 1993-1-2	Fire design of Steel Structures - Revised EN 1993-1-2
SC3.T7	3	EN 1993-1-4	Stainless Steels - Revised EN 1993-1-4
SC3.T8	3	EN 1993-1-9	Steel Fatigue - Revised EN 1993-1-9
SC3.T9	3	EN 1993-1-10	Material and Fracture - Revised EN 1993-1-10
SC3.T10	4	EN 1993-2, EN 1993-1-11	Steel bridges and tension components- Revised EN 1993-2 and EN 1993-1-11
SC3.T11	4	EN 1993-3	Consolidation and rationalisation of EN 1993-3
SC3.T12	4	EN 1993-4	Harmonisation and Extension of Rules for Storage Structures - Revised EN 1993-4-1 and EN 1993-4-2
SC3.T13	4	EN 1993-5, EN 1993-6	Evolution of existing parts of EN 1993 not included in the other parts. Revised EN 1993 -5, -6 [-1-12, -4-3]*



Revision and further Developments of Eurocode 3 | Changes

EN 1993-1-12:2007 – Additional rules for the extension of EN 1993 up to steel grades S700

Design Rules of the previous Part 1-12 were integrated into the new Parts 1-1, 1-5, 1-8, 1-9 and 1-10

- Extension of the material tables for high-strength steels up to $f_y = 700 \text{ N/mm}^2$
- Integration of the product standard **EN 10149**
- Adaption of the requirements on the **ductility** and for **plastic design**
- Adaption for **tensile elements**
- Extension of **buckling curves**

Enhanced Ease of Use

- i.) Improving the clarity
- ii.) Simplifying routes through the Eurocodes



Revision and further Developments of Eurocode 3 | Changes prEN 1993-1-12:2022 (draft)

Eurocode 3 – Design of steel structures - Part 1-12
Additional rules for steel grades up to S960

New Title

■ New scope

- Extension of rules for steel grades stronger than S700 up to and including S960
 - additional material rules + product codes
 - extension of buckling rules
 - additional rules for connections
 - extension of EN 1993-1-9, Annex F HFMI
 - extension of EN 1993-1-10 rules for toughness

Incorporation of new findings

- Extension to new materials, new products, new methods and new market requirements



Organisation of SC3 | 22 Working Groups (CEN/TC250/SC3)

Part of EN 1993	Type	Scope	WG	Current Convenor
EN 1993-1-1	General parts	General rules for buildings	WG 1	Bert Snijder
EN 1993-1-2		Structural fire design	WG 2	Peter Schaumann
EN 1993-1-3		Cold-formed members and sheeting	WG 3	Thomas Misiek
EN 1993-1-4		Stainless steels	WG 4	Nancy Baddoo
EN 1993-1-5		Plated structured elements	WG 5	Ulrike Kuhlmann
EN 1993-1-6		Strength and stability of shell structures	WG 6	Adam Sadowski
EN 1993-1-7		Plated assemblies with elements under transverse loads	WG 7	Andreas Taras
EN 1993-1-8		Joints	WG 8	Ana Girão Coelho
EN 1993-1-9		Fatigue	WG 9	Mladen Lukic
EN 1993-1-10		Material toughness and through-thickness properties	WG 10	Bertram Kühn
EN 1993-1-11		Tension components	WG 11	Heinz Friedrich
EN 1993-1-12		Additional rules for steel grades up to S960	WG 12	Ove Lagerqvist
EN 1993-1-13		Beams with large web openings	WG 20	Louis-Guy Cajot
EN 1993-1-14		Design assisted by finite element analysis	WG 22	László Dunai
EN 1993-2	Application parts	Bridges	WG 13	Ian Palmer
EN 1993-3		Towers, masts and chimneys	WG 14	John Rees
EN 1993-4-1		Silos	WG 15	J. Michael Rotter
EN 1993-4-2		Tanks	WG 16	J. Michael Rotter
EN 1993-5		Piling	WG 18	Cecile Prüm
EN 1993-6		Crane supporting structures	WG 19	Ulrike Kuhlmann
EN 1993-7		Sandwich panels	WG 21	Bernd Naujoks



Main Changes | Innovations

Phase 1

- EN 1993-1-1: General rules and rules for buildings
- EN 1993-1-8: Joints

Phase 2

- EN 1993-1-2: Structural fire design
- EN 1993-1-5: Plated structural elements

Phase 3

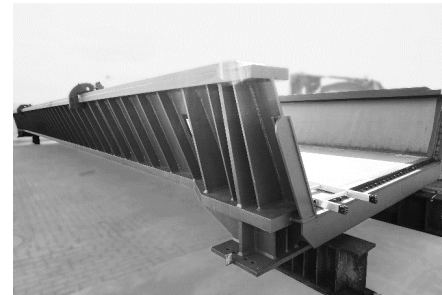
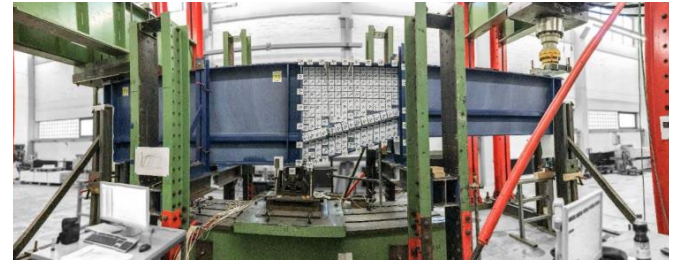
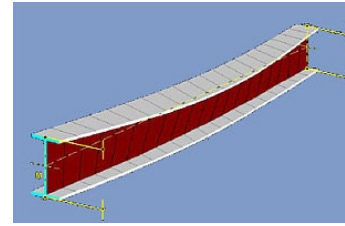
- EN 1993-1-9: Fatigue

Phase 4

- EN 1993-2: Bridges
- EN 1993-5: Piling
- EN 1993-6: Crane supporting structures

Codes outside Mandate

- EN 1993-1-14: Design assisted by finite element analysis



Phase 1 | EN 1993-1-1: General Rules and Rules for Buildings

Status

- EN 1993-1-1 and CEN/TS 1993-1-101 passed the Formal Vote unanimously (06/2022)
- Documents were published by CEN on 2022-11-09

Main Changes

- Simplification of the stability rules
- Harmonization of the rules between general and application parts
- Reduction of the rules in particular for lateral torsional buckling
- Extension of application limit up to and including S700

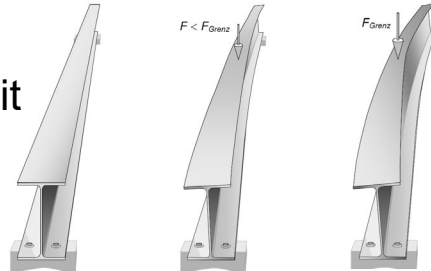


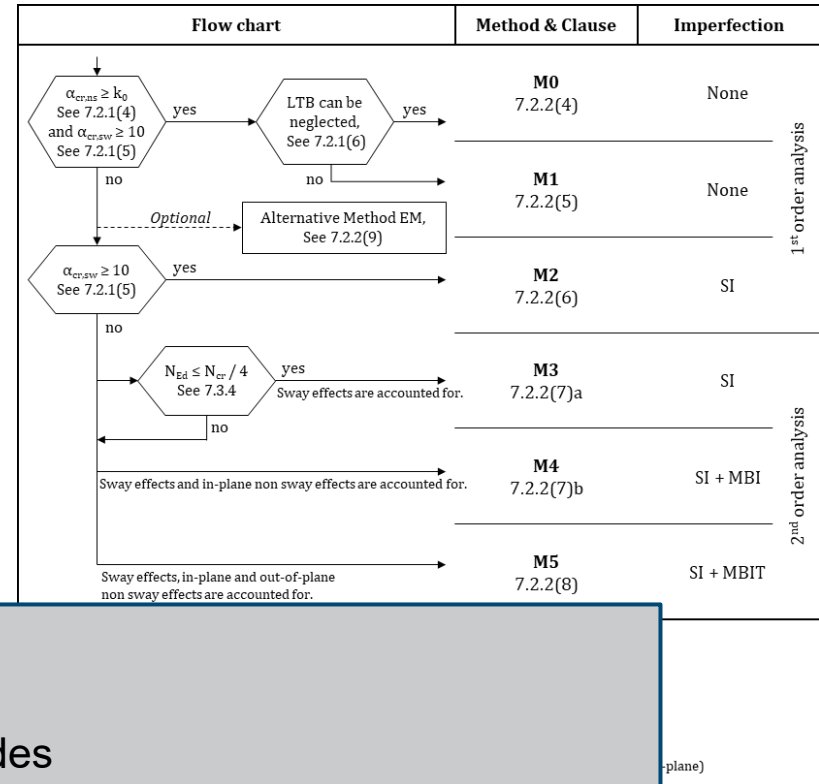
Table 8.3 – Selection of buckling curve for flexural buckling [3]

Cross-section	Limits	Buckling about axis	Buckling curve	
			S 235 S 275 S 355 S 420	S 460 Up to S 700 inclusive
Rolled sections 	$hb > 12$	$t_f \leq 40$ mm	y-y z-z	a a
		$t_f > 40$ mm	y-y z-z	b c
	$hb \leq 12$	$t_f \leq 100$ mm	y-y z-z	b c
		$t_f > 100$ mm	y-y z-z	d c
Welded I-sections 	$t_f \leq 40$ mm	y-y z-z	b c	
		$t_f > 40$ mm	y-y z-z	c d
Hollow section 	hot finished	any	a a ₀	
	cold finished	any	c c	
Welded box sections 	generally (except as below)	any	b b	
	thick welds: $a > 0.5 t_f$ and $b/t_f < 30$, and $h/t_w < 30$	any	c c	
U- and solid sections 		any	c c	

Phase 1 | EN 1993-1-1: General Rules and Rules for Buildings

Methods of analysis for ultimate limit state design checks

- Checking both criteria whether **second order effects** have to be considered or not
- **Six different methods (M0 – M5)** + equivalent member method (EM)
- Determine with the **flow chart** which method (M0 – M5) may be used for the stability verification
- **Increasing complexity:** no imperfections and first order analysis (M0), spatial imperfections and second order analysis including torsional



Enhanced Ease of Use

- Improving the clarity
- Simplifying routes through the Eurocodes

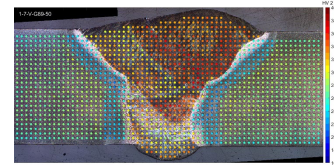
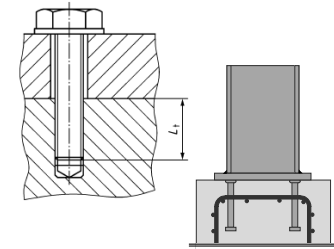
Phase 1 | EN 1993-1-8: Joints

Status

- Positive decision to send to Formal Vote (Start 2023-10)

Main Changes

- Restructuring of former Sections 5 and 6 (**Ease of use**)
- **Harmonization with EN 1090-2**: Execution of steel structures
- Provisions for connections with bolts in **threaded holes**
- New Annex C: Improved rules for **nominally pinned connections**
- New Annex D: Design of **column basis**, harmonization with EN 1992-4
- Improved design specifications also for **steel grades up to 700 N/mm²**



Enhanced Ease of Use

- i.) Improving the clarity
- ii.) Simplifying routes through the Eurocodes

Improved harmonization with other codes



Phase 1 | EN 1993-1-8: Joints

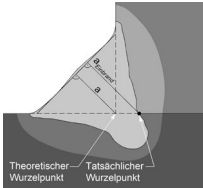
■ Further developments concerning welding HSS

■ Load bearing capacity of fillet welded connections of high strength steels

$$\sigma_{w,Rd} = \frac{0.25 \cdot f_{u,PM} + 0.75 \cdot f_{u,FM}}{\beta_{w,mod} \cdot \gamma_{M2}}$$

Parent metal Filler metal

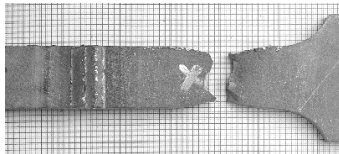
- Possibilities to cover mismatch-effects
- Undermatching has advantages regarding ductility, weldability, quality
- Possible increase of strength



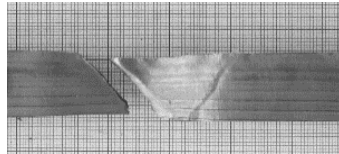
■ For fillet welded connections of steel grades \geq S460 and with different parent and filler metal strength

■ For butt-welded connections (HSS) resistance depend on failure modes:

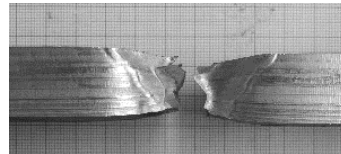
Base metal



Heat-affected zone



Weld seam



>> also new rule



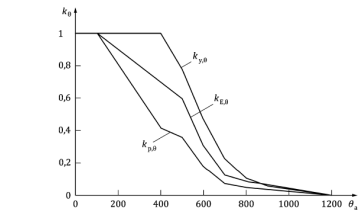
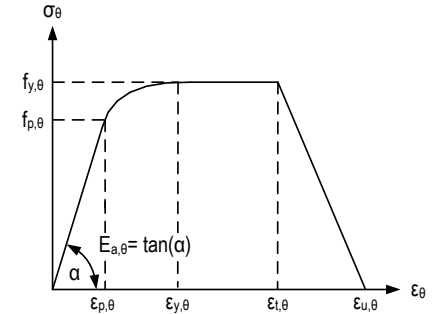
Phase 2 | EN 1993-1-2: Structural Fire Design

Status

- Positive decision to send to Formal Vote (Start 2023-10)

Main Changes

- Reduction of NDPs **from 5 to 4**
- 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**
- Existing buckling curve for LTB has been improved to take into account the beneficial effect of non-uniform bending diagrams
- New Annex C for **stainless steel**
- New Annex D for **hollow section joints**



Key
 k_θ Reduction factor
 θ Steel temperature in °C
 $k_{y,\theta} = f_{y,\theta}/f_y$ Reduction factor for the effective yield strength
 $k_{E,\theta} = E_{a,\theta}/E_a$ Reduction factor for the slope of linear elastic range
 $k_{p,\theta} = f_{p,\theta}/f_y$ Reduction factor for the proportional limit

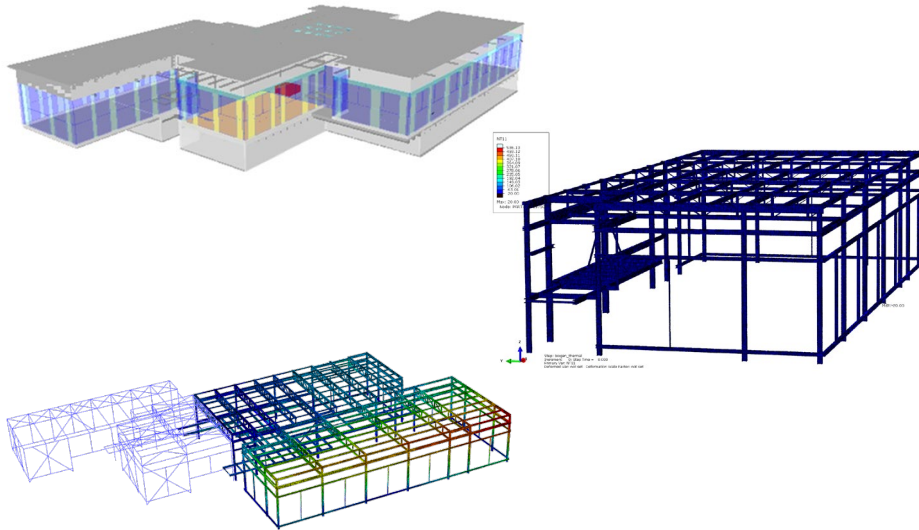
Figure 5.4: Reduction factors for the stress-strain relationship of carbon steel at elevated temperatures



Phase 2 | EN 1993-1-2: Structural Fire Design

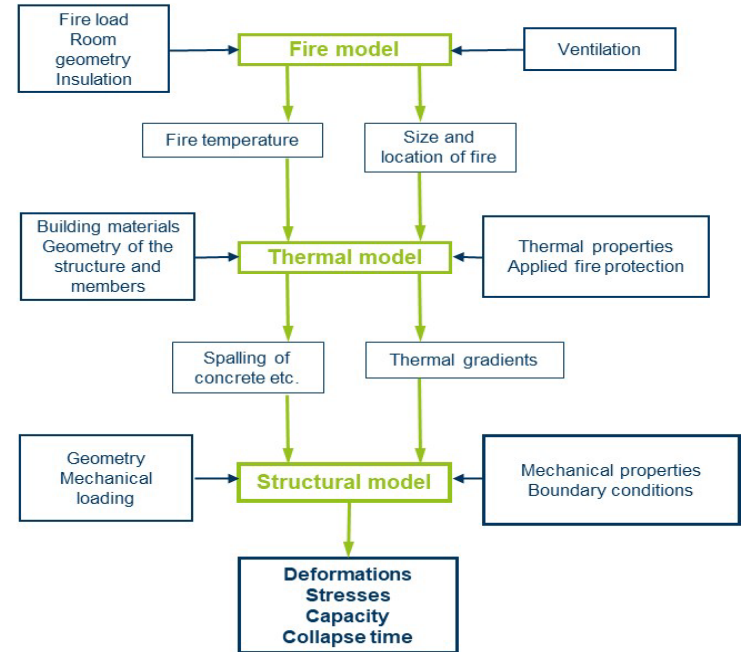
Advanced design methods

- Structural behavior in case of fire
 - Thermal analysis
 - Mechanical analysis



Input that is constant during the fire:

Input that may change during the fire:



Phase 2 | EN 1993-1-5: Plated Structural Elements

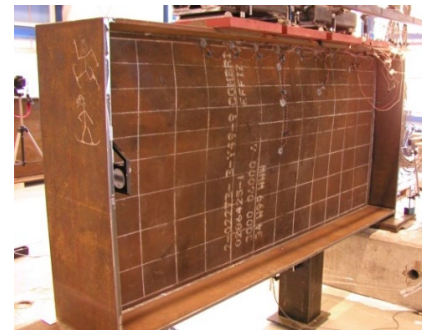
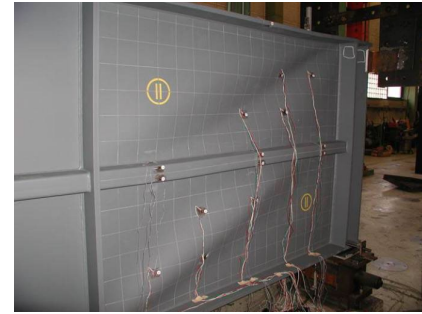
■ Incorporation of new findings

Status

- Positive decision to send to Formal Vote (Start 2023-10)

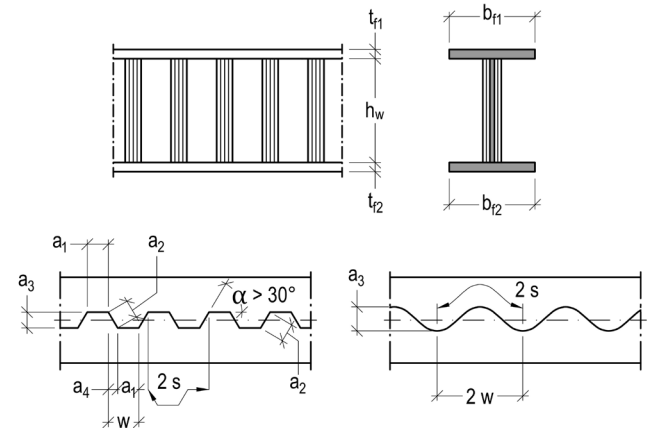
Development of approx. **25 new amendments** for the implementation in the new draft:

- Shear resistance of longitudinally stiffened girders
- Minimum requirements for transverse stiffeners
- Resistance to patch loading including interaction
- Rules for **corrugated webs**
- Biaxial compression
- Consideration of torsional stiffness of closed section stiffeners
- New design **rules for tapered panels** with an angle up to 17.5°
- Improved rules for flange induced buckling



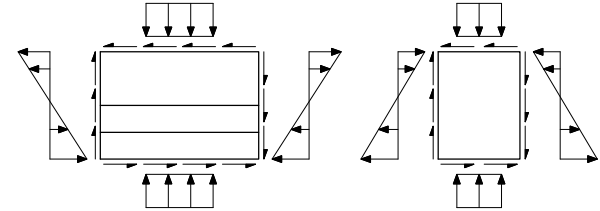
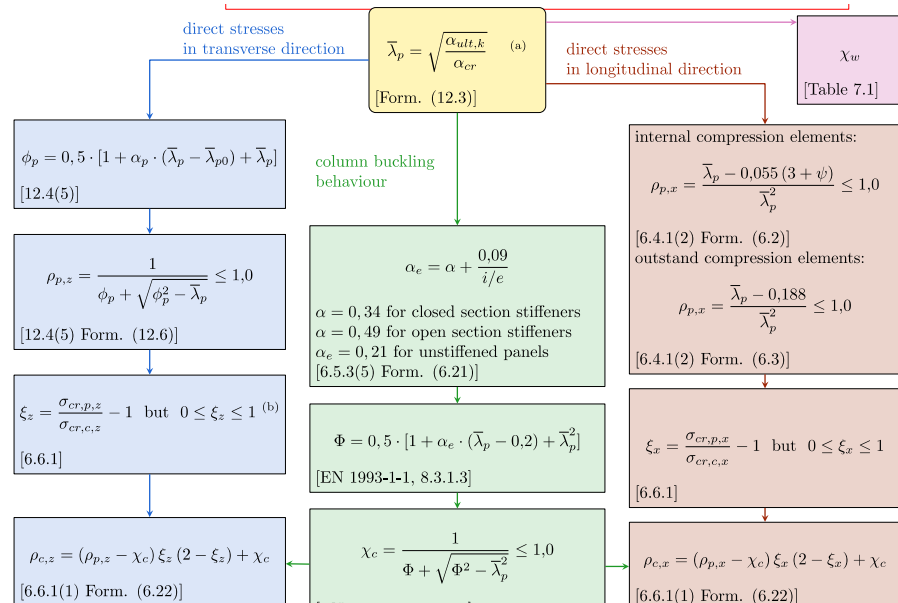
Phase 2 | EN 1993-1-5: Plated Structural Elements

- Improved structure
- Ease of use
 - **Section 10** Reduced Stress Method reorganized and improved for ease of use
 - **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
- **Reduction of NDPs**
 - Currently: 15 NDPs
 - Final Draft: only 3 NDPs



Phase 2 | EN 1993-1-5: Plated Structural Elements

Flow chart for application of Reduced Stress Method (RSM)



Enhanced Ease of Use

- i.) Improving the clarity
- ii.) Simplifying routes through the Eurocodes



Phase 3 | EN 1993-1-9: Fatigue

Status

- Positive decision to send to CEN-Enquiry (Start 2023-03)

Main Changes

- **Ease of use:** more exact definitions, clear statement on required weld quality level
- **Harmonization with EN 1090-2:** only supplementary requirements in detail tables
- Increased efficiency: **distinction between details of different notch effects**, for example: greater slope parameter $m = 5$ and earlier CAFL for details with light notch effect
- Editorial revision (new figures!) and deletion of inexact or deviating information in classification tables of constructional details, **partly update of detail categories**
- Extended scope: Annex B (**Hot-spot stress**), new Annex C (**Effective notch**



Enhanced Ease of Use

- i.) Improving the clarity
- ii.) Simplifying routes through the Eurocodes



Phase 3 | EN 1993-1-9: Fatigue

- Revision of Detail Tables
- More detailed figures showing stress distribution, inclusion of weld symbols for clarity

Table 10.3: Welded built-up sections and longitudinal welds

Detail category	Constructional detail	Symbol	Description	Supplementary Requirements
125			① Automatic or fully mechanised butt welds, welded from both sides, without stop-starts	None.
112			as aforementioned, but with stop-starts	
125			② Automatic or fully mechanised fillet welds, without stop-starts	For cover plates two parallel single fillet welds are necessary. Cover plate ends should be checked using ⑥, ⑦ or ⑧ of Tab. 10.6.
112			as aforementioned, but with stop-starts	



Phase 3 | EN 1993-1-9: Fatigue

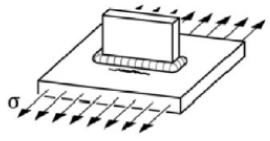
■ New Informative Annex F – Fatigue design of welded joints subjected to High Frequency Mechanical Impact Treatment

■ Scope

- Increase of fatigue resistance due to application of HFMI-treatment (post-weld treatment) [30]
- Detail categories are given for the details of transverse stiffener, longitudinal stiffener and butt weld
- As a function of stress ratio and yield strength > **advantages for HSS**
- Definition of suitable application limits and application requirements



Table F.23: Reference value of detail category of HFMI treated details $\Delta\sigma_{HFMLC}$ of transverse stiffeners due to qualified HFMI treatments for the nominal stress method

	Detail category ^{a) c)}		
	Stress ratio R [-] ^{b)}		
Steel grade according to EN 10025	-1,0	0,1	0,5
S235 ≤ S < S355	125	125	80
S355 ≤ S < S650	160	140	90
S650 ≤ S ≤ S700	160	160	125

^{a)} Table applies for $\ell \leq 50\text{mm}$; if $50 < \ell \leq 80\text{mm}$, $\Delta\sigma_{HFMLC}$ should be reduced by one fatigue detail category.
^{b)} For other stress ratios R, linear interpolation is allowed.
^{c)} Limitations of applied stresses calculated according to F.3.1: $-0,7 f_y < \sigma \leq f_y$

Extract of prEN 1993-1-9

Introduction of rules for innovative methods which are of relevance also for existing structures



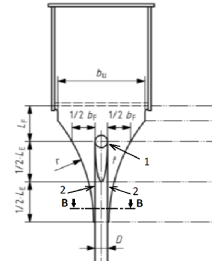
Phase 4 | EN 1993-2: Bridges

Status

- Positive decision to send to CEN-Enquiry (Start 2024-03)

Main Changes

- Improvements in 8.3.5 - Simplified method for lateral and lateral torsional buckling of structural components
- Current Annex A – Technical specifications for bearings: content moved to new EN 1990, Annex G
- **New Annex A – Design of hangers** for tied-arch bridges
- Current Annex B – Technical specifications for expansion joints for road bridges
Content: moved to new EN 1990, Annex B
- New Annex B – Supplementary rules for the design of plate girders curved in plan with rigid restraints to the compression flange
- New Annex F: “Damage equivalent factors λ for fatigue verification of road bridge decks” with two sets of damage equivalent factors



Phase 4 | EN 1993-5: Piling

Status

- Positive decision to send to CEN-Enquiry (Start 2023-09)

Main Changes

- **Extensions** e.g. New chapters regarding **buckling** of bearing piles in soils, **lateral torsional** of H-piles in soils, extension in regarding of steel grades
- Increased efficiency and harmonization with EN 1993-1-1: **Semi-plastic design of Z- and U-piles** and **stability verifications**
- **Ease of use**: more exact definitions, clear statements with regard to usage, e.g. flow chart for stability verification
- **Harmonization with EN 1997**: coordination with regard to designations and definitions
- **Editorial improvement** of figures for better usability and revision of inexact or deviating information



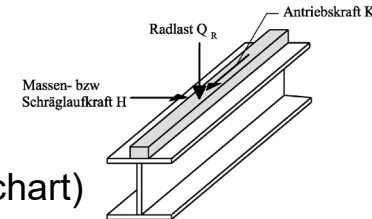
Phase 4 | EN 1993-6: Crane Supporting Structures

Status

- Positive decision to send to CEN-Enquiry (Start 2024-03)

Main Changes

- **Ease of use:** adding a clear definition of **interface** between crane and its supporting structure; eliminating 2 NDPs of the current 17 NDPs
- **Harmonization with EN 1991-3:** using a joint set of consistent definitions, clarification on eccentricity of wheel loads → incorporating 1 NDP from prEN 1991-3
- **Consideration of local stresses due to wheel loads:** new user-friendly guidance for the different limit states; new rules for box sections; improvement of calculation methods for local stresses in bottom flanges; new rules for rail welds
- **Serviceability limit state:** clarification how to check elastic behaviour
- **Classification in terms of fatigue:** improved classification scheme in new Annex C, guidance for simplified calculation of damage equivalent factors (flow chart)
- **New informative annexes:** A – Design of crane rails with foot flange, B – Inspections of crane runway beams according to EN 1993-1-9, important for choice of γ_{Mf}



New Part | EN 1993-1-14: Design assisted by Finite Element Analysis

Status

- Positive decision to send to CEN-Enquiry (Start 2023-09)

Scope

- Rules for the use of finite element analysis and other numerical methods in the design of steel structures
- Rules for ultimate limit state (including fatigue) and serviceability limit state verifications
- Clear differentiation between validation and verification
- Direct resistance check with partial factor γ_{FE}
- Background and commentary: CEN/TR 1993-1-141 “Eurocode 3 Part 1-141: Background and Guidance on the use of EN 1993-1-14

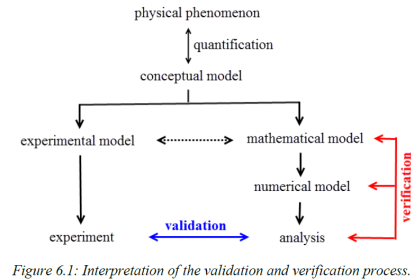
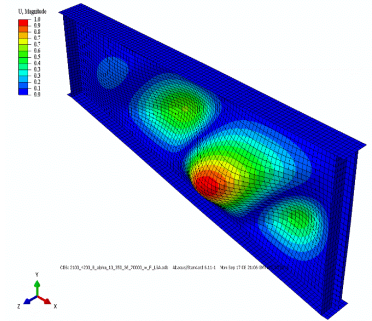


Figure 6.1: Interpretation of the validation and verification process.

Part 1-14 will be a future oriented tool to take care of the increasing importance of numerical simulations and design by analysis and ensure that the same level of safety is achieved.

Summary and Conclusion

Aims

- Incorporation of new findings
- Improvement and harmonization of existing rules:
Reduction of Nationally Determined Parameters (NDPs)
- Enhanced Ease of Use

Achieved by

- A clear organization with 22 working groups of experts, each of them responsible for one part
- A staggered development in 4 overlapping phases
- A stringent review process for each of the PT drafts as well as for the final documents by Technical Approval
- A high + strong involvement and support by practitioners and scientists



Summary and Conclusion

Aims

- Incorporation of new findings
- Improvement and harmonization of existing rules:
Reduction of Nationally Determined Parameters (NDPs)

**We want to thank all our colleagues for their strong support
and especially our secretariat by Susan Kempa (DIN)**

Let us work together and influence development.

— CREATE CODES FOR THE FUTURE —

for the final document by Technical Approval

- A high + strong involvement and support by practitioners and scientists



Thank you for your attention!



Presented by

Prof. Dr. Ulrike Kuhlmann

University of Stuttgart
Institute of Structural Design
Pfaffenwaldring 7
70569 Stuttgart

Phone: +49 711 685 66246

Email: ulrike.kuhlmann@ke.uni-stuttgart.de



University of Stuttgart
Germany

Prof. Dr. Markus Knobloch

Ruhr-Universität Bochum
Chair of Steel, Lightweight and Composite Structures
Universitätsstraße 150
44801 Bochum

Phone: +49 234 32 26131

Email: stahlbau@rub.de

RUHR
UNIVERSITÄT
BOCHUM

RUB

2023
**EURO
CODE**
DIBt 