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ARTICLE

Update on the revision of Eurocode 3

Evolution by improvement and harmonization

Extended keynote paper of Eurosteel 2021

This paper provides an overview of recent work regarding the revision of Eurocode 3 on the European level. Selected scientific and technical issues are described and there is a summary of the activities executed within European Standardization Committee CEN/TC250/SC3 "Design of Steel Structures" chaired by Prof. Dr.-Ing. Ulrike Kuhlmann. This includes the description of current normative developments for the 2nd Generation of Eurocodes, which aim at evolution through improvements and harmonization of the existing codes. In addition, a technical review of selected rules is given for several issues, which support the code revision and reflect well the recent tendencies in steel structures.

Keywords Mandate M/515; working group; project team; lateral torsional buckling; flow chart; final draft; calibration of partial factors; plate buckling; fillet welds; fatigue; detail tables, standardization

1 Introduction

The next generation of Eurocode 3, i.e. EN 1993 "Design of Steel Structures", is being developed at the moment as part of the whole development of the 2nd Generation of Eurocodes. Therefore, first of all there is an overview of the integration of Eurocode 3 into the whole system of Eurocodes, the organizational structure and its further development in general within the framework of Mandate M/515. More specifically, the normative development of Eurocode 3 is addressed in the following. How the main aims of the revision of the Eurocodes are reached with respect to ease of use, harmonization and technical improvements will be demonstrated for a number of examples.

Additionally, a technical review of selected rules is given for several new developments in some of the basic parts of Eurocode 3. This results in new chances for steel structures and the further development of the design of steel structures.

2 Procedure for the development of the 2nd Generation of Eurocodes

2.1 General

All 10 of the existing Structural Eurocodes – from Basis of structural design (EC0) and Actions on structures (EC1) to Design of concrete (EC2), steel (EC3) and composite steel and concrete structures (EC4) up to Design of aluminium structures (EC9), in altogether 58 parts – were published prior to June 2007. Their development was a great achievement and represented the culmination of over 30 years' collaborative effort. Their impact has been considerable, affecting the day-to-day work of around 500,000 professional engineers across Europe [1], [2]. In the Eurocodes, in order to allow countries to decide on their own safety levels and to give national geographic and climatic data, so-called Nationally Determined Parameters (NDPs) are available within the framework of National Annexes. As a consequence, the full implementation of the Eurocodes in the European countries was not completed until 2010 and even later, after all national codes had been withdrawn and replaced by the Eurocodes and associated National Annexes.

It is widely recognized that long-term confidence in the codes requires the Eurocodes to evolve in an appropriate manner. The accepted work programme [2] for the 2nd Generation of Eurocodes focuses on ensuring that the standards remain fully up to date by including new methods, new materials and new regulatory and market requirements.

Furthermore, the revision work focuses on further harmonization and a major effort to improve the ease of use of the suite of standards for practitioners. In order to show opportunities for participation in the development of these new design rules, the normative process is explained in the following. Fig. 1 gives an overview of the recent organizational structure of CEN/TC250, responsible for all Eurocodes.

2.2 Scope of Mandate M/515

The further evolution of the Eurocodes is realized within the scope of Mandate M/515 [1], which was agreed in December 2012 between the European Commission and CEN. Among the aims of the mandate are the extension of the Eurocode rules in terms of new materials, products and construction methods, improving the practical use for day-to-day calculations and achieving better harmonization by reducing the number of NDPs.

The mandate started in 2015 and will end in 2022. The first revised version of the Eurocodes should be available in 2021/2022. However, due to the necessary formal procedures including, for example, CEN Enquiry and CEN

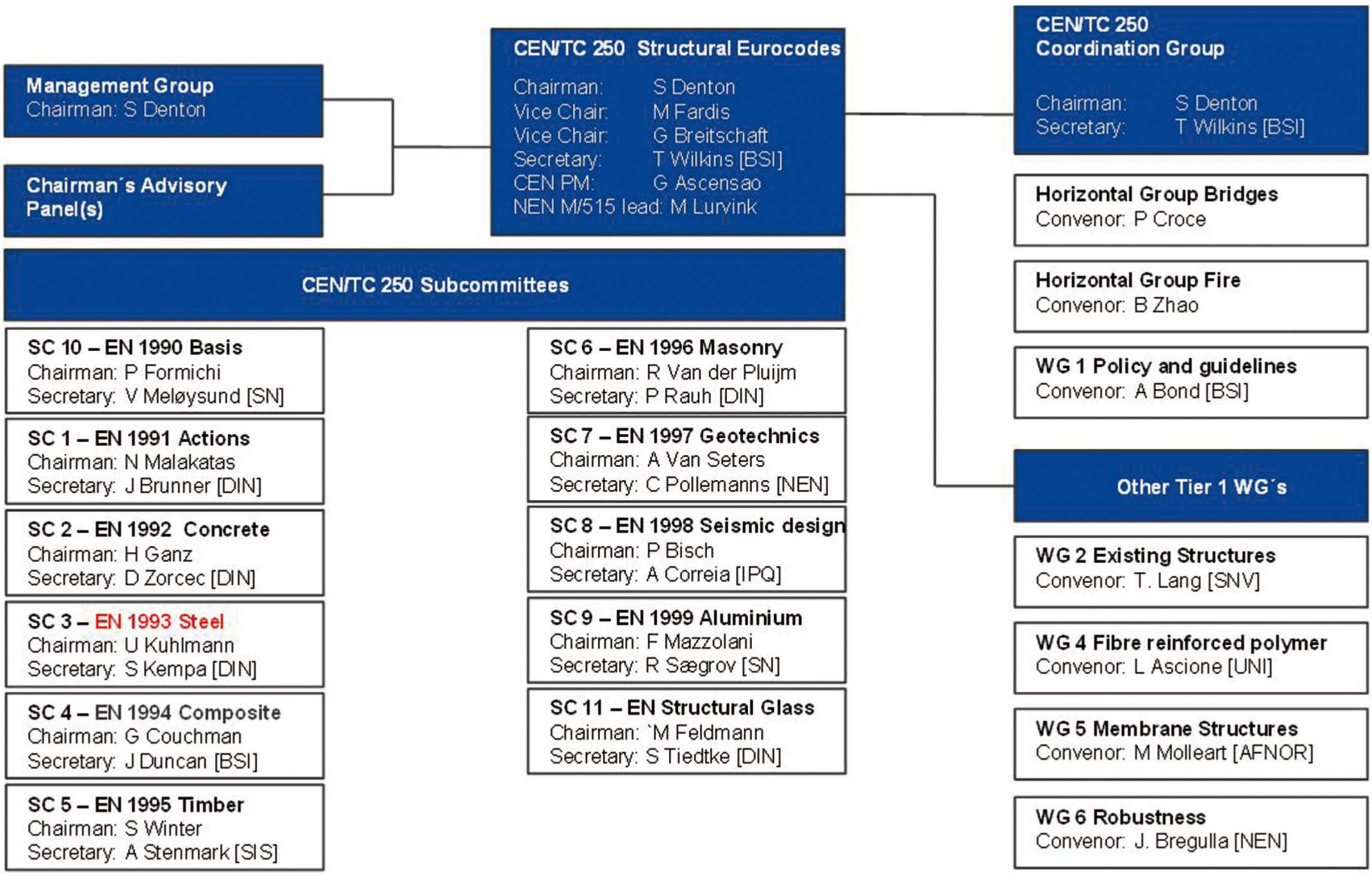


Fig. 1 Organizational structure of CEN/TC250 [3]

formal vote, publication may not be completed until 2024.

In general, the revision can be subdivided into the following two activities:

- General revisions and maintenance of the Eurocodes: This is the usual procedure for a code revision according to CEN, which is launched in the form of a call for "systematic reviews" to the NSBs (National Standardization Bodies, e.g. DIN, AFNOR, BSI, AENOR, etc.). The evaluation and implementation of the suggestions and comments is then carried out by the CEN TC250 Subcommittees and Working Groups.
- Technical enhancements of the Eurocodes within the scope of Mandate M/515: Further development takes place simultaneously with the general revision within Mandate M/515. Similarly to the transfer of the ENV versions into the EN versions, the realization is conducted by Project Teams (PTs) that consist of a maximum of five or six members.

The CEN/TC 250 work programme has been split into four overlapping phases. This has been done to enable the interdependencies between activities to be managed effectively and to ensure that the work is undertaken as efficiently as possible.

Phase 1 includes those parts of the work programme upon which other activities are primarily dependent for reasons of overall coordination, technical scope or because they are essential for achieving the target dates for delivery of the next generation of Eurocodes. Phase 1 of the mandate started in 2015 and ended in 2018 after three years. Phase 2 started in 2017, also for a term of three years. Phase 3 and Phase 4 started in 2018 [3].

There are two main aims of the mandate work concerning the improvement and harmonization of existing rules: reduction in the number of NDPs and enhancing ease of use. Tab. 1 gives a summary of the number of NDPs in the current Eurocodes relative to the number of parts in each Eurocode and number of pages. In fact, Eurocode 3 has one of the the highest number of NDPs in comparison to the other Eurocodes, but also the highest number of pages.

The especially large variety of different steel structures has led to altogether 20 parts, which cover an exceptionally large scope of different steel structures including buildings, bridges, silos, tanks, masts and towers. The very uneven distribution also shows that for some Eurocodes, NDPs form a means to overcome different views on technical items. In these cases document N1250 [2] recommends a procedure to overcome these differences in order to achieve better harmonization.

As a second point "enhancing ease of use" has been defined as a major aim of the development of the 2nd Generation of Eurocodes. A number of principles and related priorities have been defined after long discussions in

Tab. 1 Analysis of NDPs in the current ECs [2]

Eurocode	No. of parts	No. of pages	No. of NDPs
EN 1990	1+Annex A2	90+30	54
EN 1991	10	770	292
EN 1992	4	450	176
EN 1993	20	1250	236
EN 1994	3	330	42
EN 1995	3	225	21
EN 1996	4	300	31
EN 1997	2	340	42
EN 1998	6	600	103
EN 1999	5	500	58

TC250, the committee responsible for Structural Eurocodes in CEN. The "General principles" especially demonstrate the common understanding of "ease of use". This has also been summarized by:

1. improving the clarity,
2. simplifying routes through the Eurocodes,
3. limiting, where possible, the inclusion of alternative application rules, and
4. avoiding or removing rules of little practical use in design.

3 Eurocode 3 – Development of 2nd Generation

3.1 Overview

Of all the Eurocodes (EN 1990 to EN 1999), Eurocode 3 (EN 1993) with its 20 parts and approximately 1250 pages is the most extensive one. Fig. 2 gives an overview of the structure of the existing Eurocode 3 showing the "application parts", such as Part 2 for bridges or Part 3 for towers, masts and chimneys, which refer to the "general parts" within Part 1 and to the relevant parts in Eurocode 1 for Actions.

TC250/SC3, the relevant subcommittee for Eurocode 3 on steel structures, agreed on a defined approach for the revision and harmonization of Eurocode 3 as early as April 2010:

The questions relating to the revision and harmonization of Eurocode 3 are solved in cooperation between CEN/TC250/SC3 and the Working Groups of SC3 and are elaborated in the form of proposals for amendments. These proposals are then sent to CEN for approval and for final inclusion in the Eurocode. The Working Groups consist of members who are specialists in particular areas of expertise and who are nominated by the National Standardization Bodies (NSBs) of the different member countries. The SC3 submitted its last technical review in the form of amendments to the existing parts of Eurocode

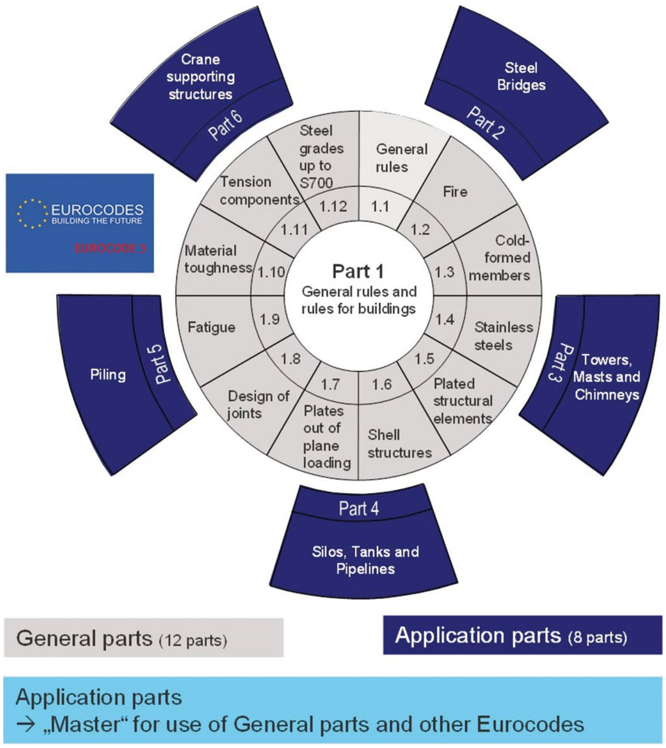


Fig. 2 Structure and overview of existing Eurocode 3

3 during the meeting of the CEN/TC250 in Delft in November 2013. In the future, technical modifications will be carried out within the scope of the mandate work. The only exception is for amendments relevant to safety, which can still be submitted and decided on for the existing versions of Eurocode 3.

Meanwhile, SC3 has also agreed to follow the same procedure for the development of and agreement on technical changes that are to be implemented in the new version of Eurocode 3. These agreed "amendments" were put into the "basket" for the time when the Project Team started its work and were then implemented in the new versions. Further, to advise and follow the work of the Project Teams, the Working Groups of SC3 play an important role.

Tab. 2 gives an overview of the future structure of Eurocode 3 and the different SC3 Working Groups responsible for the different parts.

In general, the structure of Eurocode 3 has been kept the same compared with the existing code, see Fig. 2. Small modifications to the structure of Eurocode 3 are explained in the following.

As an example of following the principle of "Enhanced ease of use by avoiding or removing rules of little practical use in design", TC250/SC3 decided to withdraw Eurocode 3: Design of steel structures – Part 4-3: Pipelines. There are many other EN standards for pipelines for a specific common purpose, whereas Part 4-3 seemed to have been used very little. However, when drafting the decision for withdrawal, it turned out that there was an

Tab. 2 Structure of future Eurocode 3 on steel structures and SC3 Working Groups responsible

Part of Eurocode 3	Type	Topic	Working group
EN 1993-1-1	General parts	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	Application parts	Steel bridges	WG13
EN 1993-3		Towers, masts and chimneys	WG14
EN 1993-4-1		Silos	WG15
EN 1993-4-2		Tanks	WG16
EN1993-5		Piling	WG18
EN 1993-6		Crane supporting structures	WG19
EN 1993-7		Design of sandwich panels	WG21

* prior to AHG FE

Austrian National Annex to Part 4-3 covering the design of penstocks (high-pressure water pipelines used in hydroelectric applications) which seemed to be in use. Therefore, it was decided to develop a Technical Specification based on the Austrian National Annex to allow the use of these design methods. A preliminary work item for the development of TS 1993-4-301: Eurocode 3 – Penstocks has been accepted.

Further, the current parts EN 1993-3-1 (masts and towers) and EN 1993-3-2 (chimneys) have been merged into one EN 1993-3, thus avoiding overlaps in the content of the current two parts.

EN 1993-1-13 is a new part on steel beams with large web openings (e.g. cellular and castellated beams). The current draft has mainly been developed within the mandate as a special task and by a Project Team of CEN/TC250/SC4 responsible for composite steel concrete structures. A final document has been developed further in TC250/SC3/WG20 and is now being distributed in SC3 for decision [4].

In order to improve clarity by simplifying routes through the Eurocodes, the current content of EN 1993-1-12 on additional rules for the extension of EN 1993 up to steel grades S700 has been distributed to the relevant other parts of Eurocode 3 (since the application of these parts has been extended to high-strength steels – HSS), meaning that the current version of EN 1993-1-12 could be withdrawn. However, SC3 decided to develop a new EN 1993-1-12 with a different scope, namely, high-strength steels up to grade S960. This activity is not covered by the mandate given by the EU and will be finalized later when sufficient knowledge and experience is available. Regarding the general aims, this development supports the inclusion of the latest development by extending the scope to new materials, new products, new methods and new market requirements.

Furthermore, a new part EN 1993-7 on the design of sandwich panels will be added to complement the mandated work. This again is a sign of the inclusion of the latest developments by extending the scope to new materials, new products, new methods and new market requirements.

As a very innovative development, a new part EN 1993-1-14 on design assisted by finite elements, which anticipates the wider use of finite element analysis in the design of steel structures in the future, will be added. Here, first of all an Ad-Hoc-Group (AHG FE) consisting of members of various SC3 Working Groups developed a first draft, transferring, among other things, rules from other parts of Eurocode 3, such as Annex C of EN 1993-1-5, to this general part. Meanwhile, a dedicated Working Group WG22 is dealing with this subject.

3.2 Development of EC3 within the framework of Mandate M/515

For the work within the mandate, the 20 parts of Eurocode 3 have been subdivided into 13 tasks. For these 13 tasks, the technical contents were developed in the form of so-called Project Proposals in collaboration with the convenors of the respective Working Groups and coordinated within SC3 [1].

As EN 1993-1-1 and EN 1993-1-8 are the basic parts of Eurocode 3, it is necessary to harmonize a number of issues with other parts, so these two parts were dealt with right at the beginning in Phase 1. Furthermore, four SC3 tasks, most of them dealing with stability, were assigned to the early part of Phase 2 of the mandate. The material-specific parts of Eurocode 3, e.g. EN 1993-1-4

Tab. 3 Tasks of Mandate M/515 concerning Eurocode 3

Task ref.	Task phase	Corresponding Part of EN 1993	Task name
SC3.1	1	EN 1993-1-1	Design of sections and members according to EN 1993-1-1
SC3.2	1	EN 1993-1-8	Joints and connections according to EN 1993-1-8
SC3.3	2	EN 1993-1-3	Cold-formed members and sheeting. Revised EN 1993-1-3
SC3.4	2	EN 1993-1-5	Stability of plated structural elements. Revised EN 1993-1-5
SC3.5	2	EN 1993-1-6, -1-7	Harmonization and extension of rules for shells and similar structures. Revised EN 1993-1-6 and EN 1993-1-7
SC3.6	2	EN 1993-1-2	Fire design of steel structures. Revised EN 1993-1-2
SC3.7	3	EN 1993-1-4	Stainless steels. Revised EN 1993-1-4
SC3.8	3	EN 1993-1-9	Steel fatigue. Revised EN 1993-1-9
SC3.9	3	EN 1993-1-10	Material and fracture. Revised EN 1993-1-10
SC3.10	4	EN 1993-2, -1-11	Steel bridges and tension components. Revised EN 1993-2 and EN 1993-1-11
SC3.11	4	EN 1993-3	Consolidation and rationalization of EN 1993-3
SC3.12	4	EN 1993-4	Harmonization and extension of rules for storage structures. Revised EN 1993-4-1 and EN 1993-4-2
SC3.13	4	EN 1993-5, -6	Evolution of EN 1993-5 Piling and EN 1993-6 Crane supporting structures

and EN 1993-1-10, are assigned to Phase 3, whereas Phase 4 of the mandate primarily covers the application parts, e.g. EN 1993-2 on steel bridges. The assignment of the tasks to the phases is shown in Tab. 3.

3.3 Status of development of Eurocode 3 and its parts

As part of the Project Teams' contract within the mandate, they have to deliver a "Final Draft" at a certain point in time, which is sent out to the NSBs for the so-called Informal Enquiry. National Mirror groups comment on these drafts, the comments are collected and the Project Teams consider them and, if possible, modify the drafts accordingly. At the end of the Project Team contract, these modified drafts are handed over to the relevant subcommittee in order to solve any unanswered questions and find a harmonized view on them, and also to prepare the text for the official CEN Enquiry. SC3 decided at a relatively early stage on a "publication plan" for the various drafts in order to schedule this procedure (SC3 Decision 20/2018). Further, it was decided to attain official Technical Approval of SC3 based on the single drafts before starting the final editing and correction. So, for example, prEN 1993-1-1:2020 gained Technical Approval in October 2018, which allowed the other Project Teams in the following phases to rely on the content of this basic general part of Eurocode 3 for the development of their own parts.

This enables optimal harmonization to be achieved within the different parts of Eurocode 3. Reference groups of four to seven experts were established in WG1 and WG8 to give advice or seek confirmation by the Working Groups if needed for the necessary editorial changes or small technical corrections during the preparation of the drafts for the CEN Enquiry by DIN as the SC3 Secretariat responsible. Finally, in the SC3 meeting in October 2019, there was an official decision in SC3 that prEN 1993-1-1 should be proceeded to the CEN Enquiry, whereas for prEN 1993-1-8 this decision was taken in April 2020.

The planned timetable for all parts and phases of Eurocode 3 is given in Tab. 4.

CEN/TC250 has fixed, for all Eurocodes, possible dates for the start of the formal CEN Enquiry and necessary preparatory times beforehand. This preparatory time includes phases for the checking of the draft by the TC250 secretariat, for the editing by CCMC (the CEN institution responsible) and for the translation into German and French by DIN and AFNOR. During the CEN Enquiry of about 16 weeks, the draft is distributed in all member countries and official agreement and comments are requested by all NSBs. Following that, the draft is returned to the subcommittee for review of the comments and possible modifications of the text if necessary. This modified draft then runs through the same procedure as for the formal CEN Enquiry in order that it can be sent out to the member countries for the Formal Vote, which lasts about eight weeks. The agreement by the NSBs to the Formal Vote should not contain any technical comments, only editorial remarks. After editorial corrections, if necessary, by CCMC and translation, the draft is sent out to the NSBs to be published in the different countries together with a National Annex.

The whole implementation procedure for new Eurocodes may seem a rather protracted process, but the various possibilities for commenting and correcting represent an important chance to influence the content.

Tab. 4 Planned timetable for development of EC3

Task phase	Corresponding part of EN 1993	Start of informal enquiry	Draft available for SC3	Technical Approval of SC3	SC3 decision for start of CEN Enquiry	Start of formal CEN Enquiry
1	EN 1993-1-1	December 2017	June 2018	October 2018	October 2019	September 2020
1	EN 1993-1-8	December 2017	June 2018	March 2019	March 2020	March 2021
2	EN 1993-1-3	October 2019	June 2020	October 2020	March 2021	March 2022
2	EN 1993-1-5	October 2019	June 2020	October 2020	March 2021	March 2022
2	EN 1993-1-6, -1-7	October 2019	June 2020	March 2021	March 2022	March 2023
2	EN 1993-1-2	October 2019	June 2020	October 2020	March 2021	March 2022
3	EN 1993-1-4	October 2020	June 2021	October 2021	March 2022	March 2023
3	EN 1993-1-9	October 2020	June 2021	October 2021	March 2022	March 2023
3	EN 1993-1-10	October 2020	June 2021	October 2021	March 2022	March 2023
4	EN 1993-2, -1-11	March 2021	February 2022	October 2022	March 2023	March 2024
4	EN 1993-3	March 2021	February 2022	October 2022	March 2023	March 2024
4	EN 1993-4	March 2021	February 2022	October 2022	March 2023	March 2024
4	EN 1993-5, -6	March 2021	February 2022	October 2022	March 2023	March 2024

4 Technical review of selected code rules

4.1 EN 1993-1-1

To enhance ease of use, the focus of the revision of EN 1993-1-1 was on simplifying and clarifying the stability rules, unifying the rules between general and application parts and reducing the number of rules (for lateral torsional buckling in particular). In the current code there are seven different options for verifying lateral torsional buckling, which were reduced to just three in the new version prEN 1993-1-1:2020 [5], again following the principle of "limiting the inclusion of alternative application rules": standard method (see 8.3.2.1 and 8.3.3), simplified method (8.3.2.4) and general method (8.3.4). One decisive step here was the replacement of the two different sets of lateral torsional buckling curves for the "general case" (EN 1993-1-1, cl. 6.3.2.2), which usually concerns sections without pronounced torsional properties, and the "special case" (EN 1993-1-1, cl. 6.3.2.3), mainly for rolled and similar welded cross-sections, by a new approach that has been developed by Taras [6] and can also be followed in more detail in [7]. In addition, of the, currently, two methods for beam-column design, only "Method 2", as given in Annex B of the current EN 1993-1-1, has been retained and integrated into the main text. The content of "Method 1", as given in Annex A, has been transferred to a Technical Specification, "CEN/TS 1993-1-101 Eurocode 3 – Design of steel structures – Part 1-101: Alternative interaction method for members in bending and compression" [8], to allow for the continued use of these rules in the countries that have traditionally chosen to use Annex A exclusively.

For the sake of clarity, the new section 7 "Structural analysis" in the draft prEN 1993-1-1:2020 [5] has been restructured compared with the current section 5 on structural analysis, while largely retaining the same content. The new section 7 links the calculation of the internal forces with the verification at the ultimate limit state. This section deals with the conditions under which second-order effects have to be considered for the calculation of internal forces, whether and which imperfections have to be assumed and if a stability member check may be performed. Similar guidance is currently given in EN 1993-1-1, cl. 5.2.2. However, it has been shown that these rules often led to misunderstandings in practice and are interpreted very differently depending on traditional approaches. Within the revision, these different views and traditions were harmonized and put together in a flow chart, see Fig. 3, which clearly connects the type of structural analysis and the choice of imperfections with the way of verifying the member resistance at the ultimate limit state.

Depending on the extent and type of consideration of structural deformations according to second-order theory and imperfections, three approaches are possible:

- Complete calculation of internal forces according to second-order theory including the consideration of global and local imperfections (method M5).
- Partial consideration of second-order effects and imperfections in the global analysis and partial consideration through individual member stability checks (methods M2 to M4).
- For simple systems, through individual stability checks of equivalent members, considering buckling lengths corresponding to the overall structural behaviour (alternative method EM).

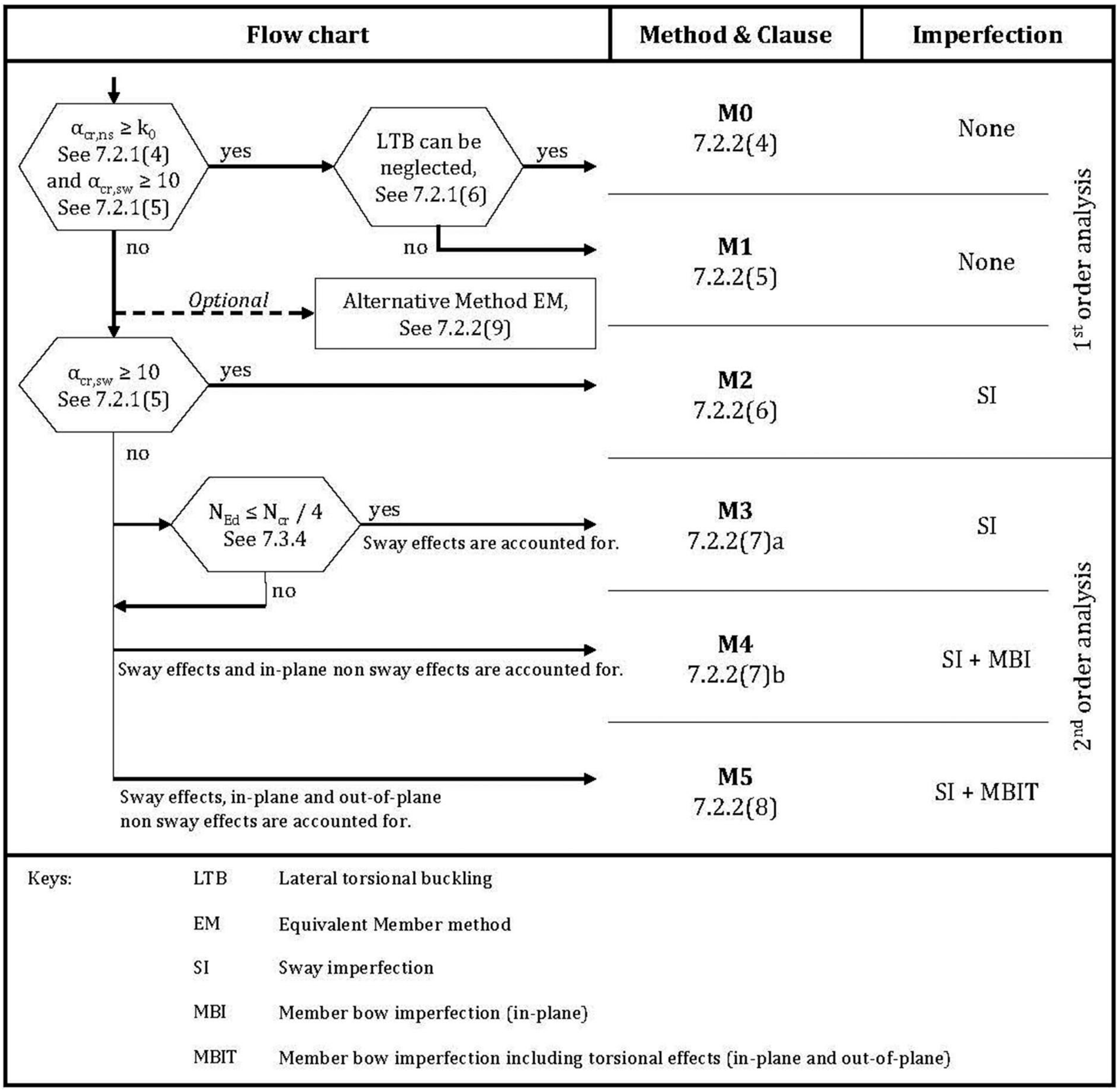


Fig. 3 Methods of structural analysis applicable to ultimate limit state design checks (Fig. 7.3 in prEN 1993-1-1:2020 [5])

The choice of method is clearly based on certain decisions concerning the need to consider second-order effects. The list of methods starts with the simplest case, i.e. a first-order analysis suffices (method M0) and ends up with a calculation based on second-order theory also taking into account torsional effects and global and local imperfections, in-plane and out-of-plane.

During the development and validation of new design rules for the next generation of EN 1993-1-1, it became apparent that a standardized procedure was needed to assess the reliability level of these rules. The basis for this procedure is formed by uniform sets for the statistical distribution of the mechanical and geometric properties of European steel products. The new, informative Annex E explicitly states the most important assumptions and procedures on which the determination of the recommended values of the partial safety factors γ_M relies. As a new feature introduced to contribute to clarity and transparency, a new, informative Annex E is given in prEN 1993-1-1:2020 which contains the basic assumptions for the calibration of partial factors. The recommended partial factors for the design of buildings as given for ultimate limit states in para. 8.1 [5] are based on calibrations assuming certain distributions for material strength as well as geometry. As stated, the intended users of this annex are mainly the National Standardization Bodies, which are responsible for structural reliability in general and thus for the setting of the various Nationally Determined Parameters (NDPs) in Eurocode 3, for which the values of the partial factors γ_M represent one of the most prominent examples.

New tables in Annex E contain the relevant statistical parameters for the most important mechanical (Tab. E.1) and geometric properties (Tab. E.2). They are derived from a database that is representative for the materials and products currently available on the European market which satisfy the relevant European product standards. More background is also given in [7]. These values are not intended for direct use by designers but should aid National Mirror Committees when agreeing or disagreeing on the partial factors. They also form a basis for discussions with steel producers regarding identifying possibilities for ways in which appropriate product qualities may be guaranteed. This kind of information might finally be part of a Technical Specification or a code supplied by steel producers.

4.2 EN 1993-1-5

To improve the existing rules in EN 1993-1-5 [9] on plate buckling in view of the next generation of prEN 1993-1-5:2020 for EN 1993-1-5 "Plated structural elements", so-called amendments were developed at a very early stage. These amendments were decided on by SC3 and then put in the "basket" up to the time when the Project Team started its work and could implement these improved rules in the new draft without major discussions. More than 25 new amendments (2011–2020) have been developed for implementation in the new draft; they include:

- Shear resistance of longitudinal stiffeners
- Resistance of longitudinal stiffeners to direct stresses
- Resistance of girders subjected to patch loading
- Rules for corrugated webs
- F-M-V interaction
- Biaxial compression
- Consideration of torsional stiffness of closed-section stiffeners
- Flange-induced buckling

Aiming for "ease of use" and more clarity, again the structure in the new version prEN 1993-1-5:2020 [10] has largely been improved; for example:

- the former Annex C (informative) "Finite Element Methods of Analysis (FEM)" mainly moved to EN 1993-1-14,
- the former Annex D (informative) "Plate girders with corrugated webs" integrated into the main text, and
- the former Annex E (normative) "Alternative methods for determining effective cross-sections" integrated into the main text.

In particular, the former Section 10 "Reduced stress method" was completely reorganized and improved to achieve better clarity so that in future this method, which had been used mainly in Germany and Austria, may also be accessible for others. Again, a flow chart developed within the framework of a German BASt project [11] helps to explain the different steps in the verification.

One big achievement resulting from discussions with each other and with the relevant Working Group 5 was that the Project Team was able to reduce the number of NDPs from the current 15 to just four in the final draft [10].

As an example of improvements to design rules, the new rules for non-rectangular steel plates, which are increasingly used in the design of new bridges due to architectural and/or structural advantages, are explained in the following. The application of the effective width method according to the existing EN 1993-1-5 [9] is limited to rectangular panels with parallel flanges. According to the existing rules [9], the effective width method is only valid for an angle $\Phi < 10°$, see Fig. 4. However, the design approach for non-rectangular panels is not clearly explained.

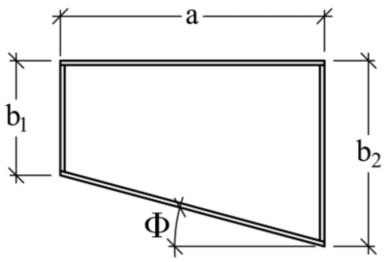


Fig. 4 Definition of dimensions of a non-rectangular panel

Based on numerical and experimental investigations, design rules for non-rectangular buckling were proposed in [12] to [15]. This proposal has been integrated into the new version prEN 1993-1-5:2020 [10]. In doing so, the validity of the effective width method has been increased to 17.5° and more clarity for the design of non-rectangular panels is provided.

According to the new rules, the buckling verifications of non-rectangular panels should be carried out based on the action effects at each end of the panel:

- at a distance $0.5b_1$ from the end of the panel with smaller width (b_1) (section 1, see Fig. 5),
- and a distance of

$$0.5b_2 \quad \text{if} \quad \frac{M_{\mathrm{Ed,2}}}{M_{\mathrm{f,Rk,2}}} \geq \frac{M_{\mathrm{Ed,3}}}{M_{\mathrm{f,Rk,3}}}$$

$$0.4a \quad \text{if} \quad \frac{M_{\mathrm{Ed,2}}}{M_{\mathrm{f,Rk,2}}} < \frac{M_{\mathrm{Ed,3}}}{M_{\mathrm{f,Rk,3}}}$$

from the panel end with larger width (b_2) (section 2 or 3, see Fig. 5)

where:

$M_{\mathrm{Ed,2}}$ and $M_{\mathrm{Ed,3}}$ are the bending moments acting at the section at a distance $0.5b_2$ and $0.4a$ respectively from the panel end with larger width (see cross-sections 2 and 3 in Fig. 5).

$M_{\mathrm{f,Rk,2}}$ and $M_{\mathrm{f,Rk,3}}$ are the characteristic plastic moments of resistance of the cross-section consisting of the effective area of the flanges only at a distance of $0.5b_2$ and $0.4a$ respectively from the panel end with larger width.

The comparison of the bending moments at sections 2 and 3 with the flange bending resistances allows the user

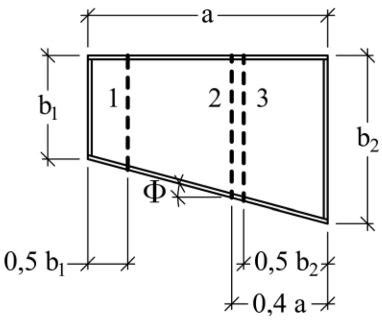


Fig. 5 Position of sections for verification of non-rectangular panels

to check which is the critical verification beforehand: the one for section 2 or for section 3. According to the rules for the design of non-rectangular panels, the critical section should be used for all verifications such as bending (M), shear (V) and M-V interaction. The gross cross-section should also be checked at both ends of the panel.

Owing to the geometry of the inclined compression flange, the shear force may be modified. The force distribution due to the inclined compression flange is shown in Fig. 6, where $N_{x,f}$ is the horizontal force resulting from the bending moment. The inclined flange force N_{Flange} is composed of this horizontal force $N_{x,f}$ and the vertical force $V_{z,f}$ acting on the web. The modified shear force in the web V_{Mod} is calculated by Eqs. (1) and (2). The shear (V) and M-V interaction should be verified using the modified shear force V_{Mod}.

$$V_{z,f} = N_{x,f} \cdot \tan(\Phi) \quad (1)$$

$$V_{Mod} = \left| V_{Ed} - V_{z,f} \right| \quad (2)$$

One of the main questions in the design of girders with a variable cross-section concerns the buckling coefficients. Differently from rectangular panels, which always have higher stresses on the support side, this is not always the case for non-rectangular panels. In some cases, under bending, there are higher stresses on the side with lower web depth. The larger side is often more relevant for the buckling analysis than the smaller side; however, the stresses are usually smaller. That is why both sides of the panel need to be checked, see Fig. 5.

The critical stresses or buckling coefficients may be calculated using linear buckling analysis (LBA) considering the non-rectangular (real) shape of the panel. The panel may be modelled by applying the real stresses at the end of the panel as acting stresses. If the exact determination of the critical stress is not possible with LBA, the critical stresses or buckling coefficients can be calculated on the safe side by assuming the panel is rectangular but with the larger width. The corresponding stresses at the end of the panel are applied on both sides of panels. The critical load factors α_{cr} determined may be used in buckling verifications for all sections. Since, in the case of a non-rectangular panel, the stresses vary at each section, a unique slenderness should be determined for each section using the critical load factors α_{cr} of the panel. Finally, using the unique slenderness of each section, the reduction factors or the effective cross-section should be determined and buckling verifications carried out.

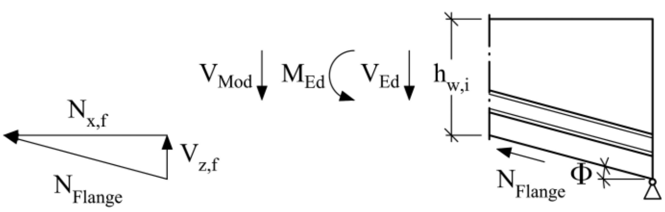


Fig. 6 Influence of inclined compression flange

4.3 EN 1993-1-8

The use of high-strength steels (HSS) represents one of the main developments for modern steel structures. However, for the particular situation of joining HSS elements, the present design rules, e.g. in EN 1993-1-8 [16], for the design of joints are in many cases inadequate because the recent rules were developed for standard steels and then transferred to high-strength steels. This is obvious from Fig. 7, where the current weld strength is shown in grey. The weld strength of S460 is in fact lower than for S355. Several research projects [17], [18], which included a large number of tests on fillet welds, resulted in the development of a realistic and coherent design model for determining the load-carrying capacity of welded connections for HSS; meanwhile, this has been accepted for the future version of Eurocode 3 by TC250/SC3.

New correlation factors β_w have been defined for S460 and S690 steels to achieve a constant level of safety. This results in an improved loadbearing capacity for S460, but a reduced loadbearing capacity for S690, see Fig. 7. Correlation factors for S420 to S700 have been chosen accordingly.

In addition, based on [19], a new formula has been introduced which differentiates between $f_{u,PM}$ (parent materi-

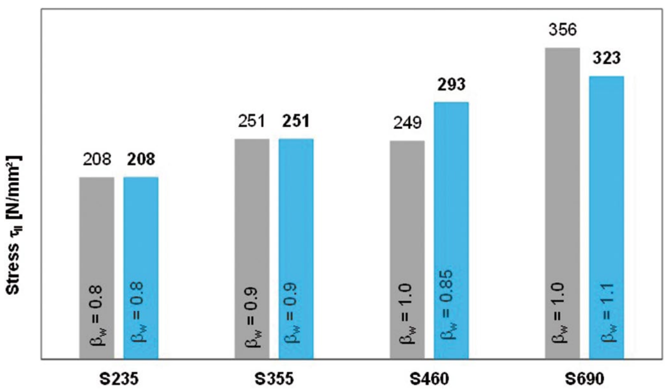


Fig. 7 Comparison of weld strength now (grey) and in the future (blue)

al) and $f_{u,FM}$ (filler material), see Eq. (3). Using this formula it is possible to cover mismatch effects, i.e. higher (overmatching) or lower (undermatching) strength of the filler metal compared with the parent metal. Undermatching may have advantages regarding ductility, weldability and quality.

$$\sqrt{\sigma_{\perp}^2 + 3 \cdot \left(\tau_{\perp}^2 + \tau_{\parallel}^2\right)^2} \leq \frac{0.25 \cdot f_{u,PM} + 0.75 \cdot f_{u,FM}}{\beta_{w,mod} \cdot \gamma_{M2}} \text{ and} \quad (3)$$

$$\sigma_{\perp} \leq \frac{0.9 \cdot f_{u,PM}}{\gamma_{M2}}$$

where:

$f_{u,PM}$ nominal ultimate tensile strength of the parent metal, which is of lower strength grade

$f_{u,FM}$ nominal ultimate tensile strength of the filler metal, see Tab. 5 and according to EN ISO 2560, EN ISO 14341, EN ISO 16834, EN ISO 17632 and EN 18276

$\beta_{w,modt}$ modified correlation factor that depends on the filler metal strength, see Tab. 5

From the results it can be seen that the strength of fillet welds is dominated by the filler metal (75 %). This design model may be used for fillet-welded connections in steel grades equal to or greater than S460 and with different parent and filler metal strengths. Additionally, this method can be used for partial penetration butt welds.

Another important change of prEN 1993-1-8:2020 is the restructuring of the existing chapter 5 “Analysis, classification and modelling” and chapter 6 “Structural joints connecting H or I sections” into new chapters 7 “Structural analysis” and 8 “Structural joints connecting H or I sections” which clearly describe only the procedure and the basic principles, see [20], whereas the details of the components and application rules for specific joints – such as moment-resisting beam-to-column joints and splices connecting H or I sections, simple connections and column bases – are given in new, normative annexes:

- Annex A (normative) “Structural properties of basic components”
- Annex B (normative) “Application rules for moment-resisting beam-to-column joints and splices”
- Annex C (normative) “Application rules for simple connections”
- Annex D (normative) “Application rules for column bases”

4.4 EN 1993-1-9

Without changing the basic rules of the existing part EN 1993-1-9 Fatigue [24], but with the aim of clarification, the future prEN 1993-1-9:2020 [21] will distinguish between fatigue design concepts representing the design philosophies (such as damage-tolerant and safe-life concepts) and the different fatigue design methods that are the tools used for the design concepts. One major change is the introduction of specific recommendations for other stress-based design methods, in particular the hot-spot stress method and the notch stress method, besides the well-known nominal stress method. To distinguish between the different stress methods, a far more precise stress definition has been added to clarify how hot-spot and notch stresses should be computed. As before, the main document of prEN 1993-1-9:2020 focuses on the fatigue verification based on the nominal stress method because of its great practical importance. Specific annexes are additionally provided for the hot-spot stress and the notch stress methods.

Tab. 5 Ultimate strength of filler metals $f_{u,FM}$ and modified correlation factor $\beta_{w,mod}$ according to Tab. 6.2 [20]

Filler metal strength class	42	46	69	89
Ultimate strength of filler metal $f_{u,FM}$ [N/mm^2]	500	530	770	940
Correlation factor $\beta_{w,mod}$ [–]	0.89	0.85	1.09	1.19

For filler metals different to those given in Tab. 5, the correlation factor should be chosen conservatively according to the given values.

Another important change in comparison to the existing EN 1993-1-9 [24] concerns the detail tables, which are the heart of the nominal stress method and have been completely revised (Fig. 8). Up to now the tables represented the corresponding details in descending order of detail category. Therefore, all details in a table are more or less mixed. In contrast, for user-friendliness, the revised tables in the new draft [21] treat the details in sequence. The user gets better illustrations and an improved and clarified compilation of different execution qualities and associated detail categories for each detail.

As before, the tables start with a “detail category” column on the left followed by a “constructional detail” column with illustrations. In comparison to the current standard, the illustrations have essentially been improved. For many constructional details, the illustrations have been scaled up so that the point of potential fatigue failure is clear and to support the literal characterization in the “description” column. Moreover, a “symbol” column has been added for welded details to indicate the appropriate weld quality compatible with the detail category considered. The introduction of weld symbols facilitates the communication between design office and workshop and is far better for preventing misunderstandings.

In general, the use of the detail tables requires a weld quality level B according to EN ISO 5817 [22], an accredited assignment of personnel and an extent of non-destructive testing (NDT) as specified by EN 1090-2 [23]. Consequently, the last column in each table only contains supplementary requirements beyond the specifications of EN 1090-2.

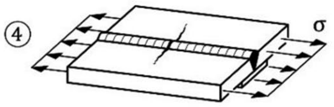
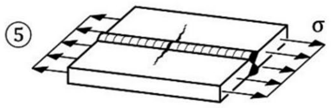
Detail category	Constructional detail	Symbol	Description	Supplementary Requirements
⋮	⋮	⋮	⋮	⋮
112			④ Automatic or fully mechanised butt welds, welded from one side, with a continuous root backing, without stop-starts	
100			as forementioned, but with stop-starts or manual butt welds	
125			⑤ Butt welds, welded from both sides, ground flush parallel to load direction, without stop-starts	Extent of NDT according to EN 1090-2: 100%.
112			as forementioned, but no grinding	
90			as forementioned, but with stop-starts	

Fig. 8 Extract from revised detail table for built-up members [21]

5 Summary and conclusions

This paper has shown the normative evolution for steel structures within the framework of the development of the 2nd Generation of Eurocodes. In doing so, the revision process within the scope of Mandate M/515 of the Eurocodes in general and the 20 parts of EN 1993 in particular is described, which aims at improvements to and harmonization of the existing codes. Besides the general revision and maintenance of the Eurocodes, some selected technical issues are explained. They also represent some of the new developments based on recent research, which present new chances for steel structures and the further development of the design of steel structures, e.g. the use of high-strength steels. Thanks to diverse international research activities and the implementation of research results in the new harmonized code version, the competitiveness of steel structures will be increased.

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