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EC3: The New Eurocode for Steel Structures

EC3: Nouvel Eurocode pour les structures en acier

EC3: Der neue Eurocode für Stahlbauten

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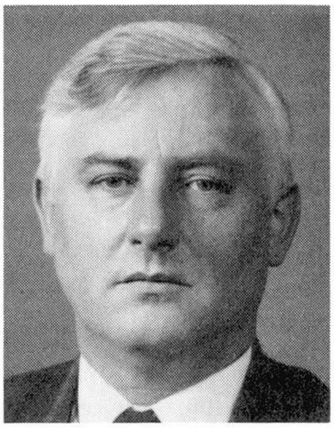

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SUMMARY

The background, scope and contents of Eurocode 3 are reviewed in this paper. Some special features of the code are highlighted. Aspects of the safety bases of the code, its use for innovative and economical design of steel structures, and its user-friendliness are outlined as an introduction to the four more detailed papers accompanying this overview. The paper concludes with a brief description of the developments planned for Eurocode 3.

RESUME

L'article présente les bases, l'objectif et le contenu de l'Eurocode 3. Il souligne quelques caractéristiques particulières de la norme. En guise d'introduction aux quatre contributions suivantes, cet article explique les aspects fondamentaux de sécurité dans l'Eurocode 3, son utilisation pour un projet innovateur et économique de structures en acier, et son emploi facile pour l'utilisateur. En conclusion, une brève description est donnée des développements prévus pour l'Eurocode 3.

ZUSAMMENFASSUNG

Hintergrund, Umfang und Inhalt von Eurocode 3 werden bezüglich einigen Eigenheiten hervorgehoben. Sein Sicherheitskonzept, seine Verwendung im innovativen und wirtschaftlichen Tragwerksentwurf und seine Benutzerfreundlichkeit werden profiliert als Einleitung zu den nachfolgenden vier speziellen Beiträgen. Anschliessend wird kurz die weitere Entwicklungsplanung für Eurocode 3 angesprochen.

BACKGROUND TO EUROCODE 3

The new European Prestandard for the design of steel structures, ENV 1993-1-1[1], which is generally referred to as Eurocode 3, or EC3, is the result of some twelve years of collaborative effort between engineers drawn from all the member states of the EEC and more recently, from the EFTA countries. The principal source document, which formed an appropriate starting point for the drafting, was produced under the aegis of the European Convention for Constructional Steelwork and issued by them in 1978 as the "ECCS Recommendations for Steel Construction"[2]. The ad-hoc drafting panel nominated by the ECCS to the CEC comprised six experts chaired by the author, most of whom had been previously involved in the preparation of the ECCS Recommendations. This panel produced several initial drafts between 1979 and 1984 when the CEC published a draft for public comment (in English, French and German), Eurocode No 3: Common Unified Rules for Steel Structures[3].

During the consultation period which followed there was considerable interaction between the mainly newly constituted Editorial Group (comprised of members drawn from the Drafting Panel and some new experts) and the liaison engineers chosen to represent the various member states. There was also close collaboration with the various technical committees of the ECCS which proved to be invaluable in formulating amended proposals to satisfy the various comments raised on the CEC draft.

The process of redrafting EC3 was undertaken by the Editorial Group in cooperation with the Eurocode Coordinating Group which was responsible for the harmonised presentation and editing of those parts of the code which are material independent; for example safety principles, terminology, accidental damage. The various liaison engineers worked with the Editorial Group to produce the final draft of "Eurocode 3: Design of steel structures; Part 1.1 General rules and rules for buildings" which was completed in 1989 and passed to CEN for publication as an ENV. The transfer of responsibility for publication from the CEC to CEN was somewhat protracted. However, various editorial matters, some connected with translating the English version into French and German, were attended to during the two years leading up to its recent issue.

Scope of EC3

Part 1.1 of EC3 contains principles which are valid for all steel structures as well as detailed application rules for ordinary land-based buildings. Many of the application rules will also be cross-referenced for bridges, towers and other structures which will be dealt with in subsequent parts of EC3 but the rules in Part 1.1 are only considered complete in respect of buildings.

CONTENTS AND LAYOUT

There are 9 chapters and 9 annexes in the new code. Annexes are classified as either normative, and have the same statistics as the material in the main body of the text, or informative, providing additional information. The chapter titles are given below and the annex titles and status thereunder.

Chapter 1 :	Introduction
Chapter 2 :	Basis of design
Chapter 3 :	Materials
Chapter 4 :	Serviceability limit states
Chapter 5 :	Ultimate limit states
Chapter 6 :	Connections subjected to static loading
Chapter 7 :	Fabrication and erection
Chapter 8 :	Design assisted by testing
Chapter 9 :	Fatigue

The Annexes and their status are listed hereunder

Annex B	Reference standards	Normative
Annex C	Design against brittle fracture	Informative
Annex E	Buckling length of a compression member	Informative
Annex F	Lateral-torsional buckling	Informative
Annex J	Beam-to-column connections	Normative
Annex K	Hollow section lattice girder connections	Normative
Annex L	Column bases	Normative
Annex M	Alternative method for fillet welds	Normative
Annex Y	Guidelines for loading tests	Informative

The design procedures in EC3 are only valid if the workmanship criteria during fabrication and erection given in Chapter 7 are satisfied. For example, the levels of initial geometric imperfections assumed in many of the strength rules are directly related to these criteria and are therefore invalid if they are exceeded. A separate CEN committee, TC 135 "Execution of Steel Structures" has drafted the fabrication and erection rules using annexes prepared by the original EC3 Drafting Panel as source documents.

Ten Reference Standards are mentioned in Annex B, each of which defines a product or process and makes reference to a number of CEN and/or ISO Standards, only some of which are already drafted. Where no such standard is available each member state's National Application Document (NAD) defines the appropriate national standard which should be used with the code.

BASIS OF DESIGN

Chapter 2 of EC3 follows to a large extent the harmonised version of the General Principles and Basis of Design prepared by the Coordinating Group which adopts a limit state approach with the use of partial safety factors. The code gives indicative values for the various safety factors in boxes, the so-called boxed-values. The background to the adoption of these values is given in the accompanying paper by Brozzetti and Janss(4).

Material Properties

The code currently covers only three nominal grades of structural steel with yield stresses of 235, 275 and 355 N/mm^2 which are modified at thicknesses of 40 and 100 mm. Annex D which is currently in draft form will cover steels of higher grade with yield stresses of the order of 460 N/mm^2.

Nominal values of yield and ultimate tensile strength for various bolt grades are also given. Stark(5) in another paper accompanying this one deals with the background to the design of bolted connections.

Design against brittle fracture is treated in some detail in Annex C which gives formulae covering the various design criteria including service conditions, loading rate and consequences of failure. The table in Chapter 3 limits itself to the cases of welded tension members, to members either non-welded or in compression subjected to static loading and to normal consequences of failure. The table gives the maximum thickness for various grades and qualities of steel for temperatures down to -20°C.

The modulus of elasticity of steel is taken to be $E = 210{,}000$ N/mm^2 and the coefficient of linear thermal expansion to be $\alpha = 12 \times 10^{-6}$ per °C.

Serviceability and Ultimate Limit States

For verifying the serviceability limit state EC3 gives various deflection limits for beams under unfactored variable loads and incudes values for total (permanent and variable) deflection limits. Horizontal deflection limits for each storey of a multi-storey building and for the structures as a whole are also given. Other rules are designed to limit the effects of rainwater ponding on roofs and the effects of vibration on floors.

Methods of Analysis

Elastic or plastic global analysis may be used to calculate the internal forces and moment in a statically indeterminate structure. Distinction is made between first-order theory using the initial geometry of the structure and second-order theory which accounts for the change in shape of the structure under load. The former may be used for braced frames, non-sway frames and with design methods which make indirect allowances for second-order effects. The latter may be used in all cases but, of course, is not normally required except for sway frames.

Plastic analyses range from the commonly adopted rigid-plastic method to advanced computer-based elastic-plastic methods. Two forms of elastic-plastic analysis are distinguished. In the elastic-perfectly plastic method the members remain elastic until a plastic hinge has fully formed, whereas in the elasto-plastic method the spread of plasticity through the depth and along the length of a member is followed in an incremental computer-based analysis.

A special feature of the code is the treatment of semi-continuous frames as well as simple and continuous framing. Plastic analyses may be used for such frames. It involves the consideration of partial-strength joints which develop plastic hinges with a smaller plastic-moment resistance than the members they connect, but with sufficient rotation capacity to justify plastic analysis. The use of such joints can lead to worthwhile economies in construction, compared to simple connections.

Structural Stability

The effects of imperfections are to be taken into account in frame analysis, analysis of bracing systems and member design.

The effects of frame imperfections are dealt with by means of an initial sway imperfection which is a function of the number of columns and storeys. These sway deflections can be represented by equivalent horizontal forces. Allowance for these notional forces must be made in all load combinations including ones involving wind forces.

In the case of bracing systems allowance is made for imperfection, or bow, in the members to be restrained. Normally the effects of imperfections on member design are accounted for within the buckling strength formulae given in the code.

Clear definitions of sway or non-sway frames are given in the code. A non-sway frame is one which is sufficiently stiff for it to be acceptably accurate to neglect any additional internal forces or moments arising from horizontal displacements of its nodes. A simple criterion is given to help distinguish the two.

Distinction is also made between braced and unbraced frames. A frame is said to be braced if the bracing system reduces its horizontal displacements by at least 80%. All braced frames are treated as non-sway frames but some unbraced frames may also be non-sway frames using this definition.

The code allows the use of simple rigid-plastic analysis for braced frames and for unbraced frames up to two storeys high, with amplified sway moments if they are sway frames. Sway frames may be designed using rigid plastic analyses provided the simplified method given in the code is used and all the accompanying conditions are met. Otherwise a second-order elastic-plastic sway analysis must be used.

DESIGN OF MEMBERS

In designing structural members consideration needs to be given to cross-section resistance, buckling resistance of the member and where appropriate, shear buckling resistance and web crippling including stiffener design.

Cross sections are divided into four classes. Class 1 sections are ones for which it is possible to take advantage of the full plastic cross-sectional resistance and use rigid-plastic analysis with full moment redistribution. Class 2 sections are ones which can develop their plastic resistance but have limited rotation capacity. Class 3 sections are ones which can reach yield in their extreme compression fibre, but in which local buckling prevents the attainment of the full plastic moment capacity. Class 4 sections are ones where appropriate allowances must be made for the effects of local buckling when determining their resistance.

The limitations on slendernesses of the various elements of the cross-section have been selected from the best available data and the tables presented allow a separate classification under axial load for the compression term and under bending for the moment term when combined bending and axial loading is being considered. The concept of effective width is used to reduce the section properties of class 4 to sections whilst retaining the full yield strength in calculating the resistance.

Fastener holes in compression zones of the cross-section are neglected whereas the design tension resistance is taken as the smaller of the design plastic resistance of the gross area based on the yield stress and the design ultimate resistance of the net area using 90 per cent of yield and a larger safety factor. The shear resistance of a web need not be reduced due to bolt holes unless the ratio of net to gross area is less then the ratio of yield to ultimate strength. It is, however, necessary to check block shear strength at the ends of a member.

The effects of shear on the plastic moment of resistance must be accounted for when shear exceeds 50 per cent of the plastic shear resistance and an appropriate expression is given for the reduced plastic moment of resistance. Interaction expressions for axial force and bending moments are also given.

Buckling Resistance of Members

The bases for the checks on buckling resistance of columns are the European Column Buckling Curves contained in the ECCS Recommendations[(2)] which have been derived from the statistical evaluation of test results of a large number of experiments on columns with different sections, production methods and steel grades. Four column curves are given, the selection of which is based on the type of cross-section and axis of bending. A non-dimensional slenderness is calculated based on buckling length. The latter can be obtained from Annex E. When used with the appropriate column curve this slenderness leads to a reduction factor which is applied to the compression resistance of the cross-section to give the buckling resistance.

Lateral-torsional buckling strength is calculated by a method which also refers back to the column buckling curves with an appropriate slenderness to determine the reduced design buckling resistance moment. Annex F may be used to arrive at this slenderness which is a function of the elastic critical moment for lateral-torsional buckling of the beam, the type of loading and the degree of warping restraint. If the non-dimensional slenderness is less than 0.4 no reduction in strength need be made.

Shear Buckling Resistance

Unstiffened webs with depth to thickness slenderness ratios less than given values (e.g 69 for Fe 360) need not be checked for shear buckling. Where these limits are exceeded two methods may be used to check the shear buckling resistance. The first is a simple postcritical buckling approach and the second allows for tension field action. Both may be used for transversely stiffened webs and rules are also given for the design of the stiffeners which includes checks on their compressive buckling strength and their bending stiffness.

Plate girders with more complex stiffening arrangements rarely occur in buildings so the rules are felt to be sufficient for the scope of Part 1.1. It is intended to produce more comprehensive design rules for plated structures which will have more general application to other forms of construction such as bridges and offshore structures.

Design rules for flange buckling in the plane of the web, as well as guidance for members curved in elevation are included in the code. The resistance of webs to inplane transverse forces such as occurs at supports and in some beam-column connections is treated by considering three modes of failure. These are web crushing, local buckling or crippling of the web, and overall buckling of the web. Limited expressions are given to cover each mode.

Triangulated Structures

Built up compression members such as laced or battened columns are treated in some detail. Rules are given for the buckling resistance of the chords, lacing members and battens based on an analogous model of a member subjected to finite shear deformations and including the effects of initial imperfections.

DESIGN OF CONNECTIONS

The code contains an unusually large section on connection design because of the importance of this topic in relation to the economical design of steel structures. The accompanying paper by Stark[5] is dedicated to a discussion of this part of the code.

Bolted connections are divided into five categories which distinguish between connections loaded in shear and tension, and connections with preloaded bolts which are designed to resist slip. Advantage is taken of the larger deformations which are allowed to occur in the design of connections where rotation is required at the end of beams. In the case of welded connections advantage has been taken of the best information available for the design of fillet welds, both side and end, long lap joints and intermittent welds.

Beam to column connections, both welded ones and ones with bolted end-plate connections, are treated in Annex J. It also contains data on the calculation of prying forces. A special feature of the code is the treatment given to semi-rigid and partial strength connections[5] which should lead to more economical design of frames by avoiding the use of expensive stiffening of joints in many cases.

Design Against Fatigue

A chapter covering fatigue is included in Part 1.1 as part of the general rules for design of steel structures which can be referred to from other future parts,but, of course, can also be used for building design where fatigue is an issue. The paper by Brozzetti and Janss[4] gives a more detailed description of the background to these rules.

THE RELIABILITY AND POTENTIAL ECONOMY OF EUROCODE 3

Eurocode 3 can be claimed to be amongst the most extensively calibrated and cross-checked code ever written for steel structures. The numerous background studies carried out to calibrate element design rules as described by Brozzetti and Janss[4], together with the trial calculations carried out at national and international level, as described by Finzi and Taylor[6], together with the enormous contribution made by member states and channelled through their liaison engineers, have combined to ensure that the code has been subjected to extensive checking. Potential economies can only be judged at a national level by comparing the outcome of design to EC3 with designs done using national codes and loading. Calibrations against designs done using EC3 and the proposed loadings in EC1 have yet to be carried out and are planned for the future.

However, several aspects of EC3 have been introduced specifically to encourage efficient and economical design of steel structures. These include the previously mentioned semi-rigid design methods and design for partial-strength connections. A feature of these developments and others relating to web design and joint design for hollow sections is that fabrication is reduced to a minimum by avoiding, where possible, the use of stiffeners, welding etc. whilst compensating for any possible apparent reduction in strength by exploiting postbuckling or plastic reserves which are and often ignored in more traditional codified design procedures. An efficient application of the code should lead, therefore, to more cost-effective structural detailing.

Yet another feature of the code has been the attempt to encourage innovation. Recognising the increasing use of computers in design, methods of global analysis, frame design, etc. are permitted which, potentially, should lead to more innovation in design. This matter is treated in greater detail in the accompanying paper by Sedlacek[7].

Design assisted by testing, which may often be resorted to by innovative engineers introducing new systems is encouraged by the code which includes a chapter on the subject outlining the principles which should be followed. Annex Y develop principles in greater detail and covers test conditions and procedures including acceptance tests, strength tests, tests to failure, check tests and other test procedures.

EASE OF USE OF EUROCODE 3

The drafters of the code have been conscious of he need for the code to be user friendly from the outset of their work[6].

However, the problem is not an easy one to solve solely within the code itself. This is because potential users vary from engineers in large consultancy offices with full computer aided engineering facilities available, to designers in offices of small steel fabricators with few such facilities available and with an interest confined to a very restricted range of steel structures. Other potential users include engineers within offices of regulatory authorities, proof engineers, engineers and students based in educational establishments and construction engineers on site. It is only with a hierarchy of supporting material ranging from concise versions of the code for a restricted range of applications, through design aids, dedicated software and text books that it will be possible to satisfy all the demands for user-friendliness. Happily steps are being taken at national and international level to provide this essential backup to the code[6].

FUTURE DEVELOPMENTS OF EUROCODE 3

Further parts of EC3 which are being prepared at present include the following annexes to Part 1.1 and other Parts.

Annex D	The use of steel grade Fe E 460
Annex K	Hollow section lattice girder connections
Annex G	Design for torsion resistance
Annex H	Modelling of building structures for analysis
Annex N	Openings in webs
Annex S	The use of stainless steel
Part 1.2	Fire resistance
Part 1.3	Cold formed thin gauge members and sheeting
Part 2	Bridges and plated structures

Work has now yet commenced on the following parts which are planned for the future.

Part 3	Towers, masts and chimneys
Part 4	Tanks, silos and pipelines
Part 5	Piling

Part 6	Crane structures
Part 7	Marine and maritime structures
Part 8	Agricultural structures

The part dealing with cold formed members and sheeting, Part 1.3, should be available shortly, together with Annex D on high yield steel and a revised Annex K which includes multiplanar as well as single plane connections of hollow section members. The remainder of the work in progress should follow a year later. Of the planned new work, Part 3 on towers, masts and chimneys and Part 5 on piling will receive priority.

CONCLUDING REMARKS

Eurocode 3 has been produced by the combined efforts of a large number of experts throughout the EEC and EFTA. It has also had a not inconsiderable input from colleagues in central and eastern Europe as well as experts from the United States and Japan and elsewhere. Although no code can be perfect and satisfy all its potential users the Editorial Group has gone to great lengths to ensure maximum exposure for the code so as to attract as much useful feedback as possible, which has been incorporated into the ENV 1993-1-1.

It is to be hoped that it will not just be studied but used extensively during the ENV period so that when it is issued in modified form as an EN in a few years time it will prove to be a powerful tool in uniting Europe in the field of steel construction and will help fuel further growth in the proper and effective use of steel in construction.

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