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Eurocode 3: Design Code for Steel Structures

Eurocode 3: Règlement de dimensionnement et de planification des constructions métalliques

Eurocode 3: Bemessungsnorm für Stahlbauten

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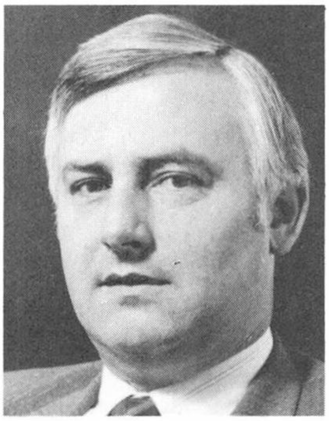

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SUMMARY

This paper outlines the technical contents of the draft EC 3 and suggests how it can be improved to match more closely the perceived needs of the member states of the European Community.

RÉSUMÉ

Cet article donne un aperçu du contenu technique de la version préliminaire de l'Eurocode 3 et suggère les améliorations à lui apporter pour mieux répondre aux besoins des Etats membres de la Communauté européenne.

ZUSAMMENFASSUNG

Dieser Vortrag umreisst den technischen Inhalt des Entwurfs des EC 3 und schlägt Verbesserungen vor, um die spürbaren Bedürfnisse der Mitglieder-Staaten der Europäischen Gemeinschaft besser befriedigen zu können.

1. INTRODUCTION

The draft European code for steel structures, Eurocode 3(1) has now been officially available for comment for some 12 months and it seems timely to review its scope, strength and shortcomings so as to ensure an informed debate which will lead to an even better draft than currently exists. Before doing so, however, it would be fair to record that the document issued from Brussels appears to have had a more favourable general reception than many of the sceptical members of our profession expected and, indeed, the members of the drafting panel dared expect. However, nobody, least of all the drafting panel, anticipated that the draft would be acceptable in all its detail, and for this reason it is very satisfying to note how constructive the comments received to date appear to be. If this paper elicits further useful comments from those who have not already commented it will have achieved its purpose.

2. AIMS, SCOPE AND FORMAT OF EC3

2.1 Aims of EC3

The general objectives of Eurocodes are treated by Verdiani (2). The specific aim of EC3 is to provide rules for the design, fabrication and erection of steel structures which produce safe and economical structures for the use and life for which they are intended. It was also the aim of the drafting panel to produce a code in a format with which steel designers are familiar; that is, an element (tension members, beams, columns etc) based format. This contrasts with the so-called action (tension, bending, compression etc) format which the concrete draft code, EC2 (3), adopts. Furthermore it was envisaged by the drafting panel that the code would be a stand-alone document containing both principles and operational rules which could be used without cross reference to EC1 (4) which contains the common unified rules for different types of construction and material.

2.2 Scope of EC3

The code is concerned with buildings and civil engineering structures and the basic principles apply to all types of steel structures. Because of the limitations imposed by time and finance the drafting panel considered that the most realistic and useful course of action was to write the code initially with buildings primarily, but not exclusively, in mind. Therefore while the treatment of buildings is relatively complete, supplementary information would be needed for anything other than the most commonly encountered short span steel bridge (a composite bridge which would be designed by cross referencing EC2 and EC4 (5)). Larger span bridges of orthogonally stiffened plated construction and other special structures such as nuclear power stations and marine platforms would need a significant amount of additional information to be included to ensure their satisfactory coverage.

It must be admitted that even in the case of buildings there is a serious omission in that cold formed sections and sheeting, much used in such construction, could not be incorporated within the document within the constrictions of time and finance. A point worthy of discussion would be whether such clauses should be included within the main draft code or added in a supplementary document. Indeed special structures such as bridges, towers and masts etc. might be best dealt with in the form of documents supplementary to EC3.

2.3 Format of EC3

The format adopted was to a certain extent influenced by EC1, the general format of which must be followed by all other Eurocodes. In an attempt to coordinate the formats of EC2 and EC3 those clauses which were identified by the panel as principles were marked by a vertical line in the margin, whereas those not so marked were classified as operational rules. As the text was not prepared with such classification of clauses in mind the exercise was only partly successful. It should be stated that there exists considerable reservation about the use of principles together with alternative opeational rules. This could create a dangerous loophole in safety requirements and appears to many to run counter to the concept of harmonisation.

The general format is given below and comprises three main sections. The first embracing Chapters 1 to 3 is concerned with basic principles, the second embraces Chapters 4, 5, 6, 8 and 9 and contains design information for both static and repeated loading and the third consisting of Chapter 7 deals with aspects of construction.

Preface
1 Introduction
2 Basis of Design
3 Materials
4 Serviceability Limit States
5 Ultimate Limit States
6 Connections
7 Fabrication and Erection
8 Test Loading
9 Fatigue

CHAPTER HEADINGS OF EC3

Chapters 5 and 6 are roughly of equal length and occupy between them approximately half of the code. Design is considered in the sequence of cross-sectional strength, component design and design of assemblages in Chapter 5, although an introductory piece does focus the designer's attention on the way the overall structure carries its loading. Chapter 6 follows a sequence of classification of joints and design methods for joints, bolted joints, welded joints, hybrid connections, and connections in cold formed sections.

3. MAJOR TECHNICAL FEATURES OF INTRODUCTORY CHAPTERS

3.1 Source Documents

A major source document for EC3 was the European Convention for Constructional Steelwork (ECCS) document, *Recommendations for Steel Construction* (6). This admirable document was not itself in a suitable form to be used as a draft Eurocode. It may be considered as a code drafter's code and is difficult to use directly by the designer in a similar manner to an equivalent national code. Other documents consulted included the draft German code (7), the Swiss code (8), the draft British code (9) and modified ECCS Recommendations prepared in Darmstadt (10). However, among the most important source documents were the technical papers produced by various committees of the ECCS on subjects varying from column buckling to fatigue. These committees drew on the best information available on an international basis.

3.2 Basic Design Philosophy and Materials

The units and notation used are in accordance with ISO standards. The most commonly occurring notation is listed at the outset but special notation is also defined within the text of particular clauses. Definitions of technical terms presented a difficulty because of the confusion over words which are used differently in separate member states. For example, the UK still has difficulty in accepting the term 'actions'.

Chapter 2 also covers calculation models and allows linear elastic models and non-linear materials models. In addition, either first order models based on initial geometry of the structure or second order (non-linear geometric) ones based on the deformed shape of the structure, may be applied. In most cases calculations are, of course, based on simple linear first order theory.

Materials are covered in Chapter 3. Non-alloy and low-alloy steels with yield strengths less than or equal to 450 N/mm^2, ultimate to yield strength ratios greater than 1.2, minimum strain to fracture greater or equal to 15% and fracture toughnesses corresponding to at least quality B of the International Institute of Welding Classification are covered.

4. MAJOR TECHNICAL FEATURES OF DESIGN CHAPTERS

4.1 Serviceability Limit States

A short Chapter 4 gives some suggested limiting values for deflections for floor and roof construction. Guidance is also given in relation to the dynamic response of floors. For example, the lowest natural frequency should not be lower than 3 cycles per second for regular floors whereas the floors of a gymnasium or a dance hall should not have a natural frequency lower than 5 cycles per second. Simple criteria which can be checked under static loading may be used to satisfy these values instead of a laborious estimate of their natural frequencies and accelerations.

4.2 Ultimate Limit State

4.2.1 Classification of Structures

A distinction is drawn between skeletal structures - which are braced and unbraced against sway. Guidance on the design of both of these classes is contained within Chapter 5 of the code.

4.2.2 Section Design

Section Design Depending on the degree of slenderness of cross-sectional elements the components may be designed in different ways, e.g. elastic theory or plastic hinge theory. Four classes of cross-section, are identified and the way the design basis is altered with slenderness is indicated. Similar classifications have been defined in the draft BS 5950 (10). There is scope here for improving the basis of the information on which these clauses are founded.

Interaction equations in terms of stress resultants are provided for cross-sections designed on an elastic or a plastic basis. For example, expressions are given for the reduction in plastic moment capacity of I-sections in the presence of both axial load and shear.

In the case of slender cross-sections the full cross-sectional area may be used provided stresses are within the limits of the buckling stress. This latter value is given by expressions which make due allowance for all parameters affecting the true inelastic buckling strength of the elements of the cross-section. Alternatively slender cross-sections can be checked using a reduced cross-section subjected to the full yield stress.

The only form of stiffened plate construction specifically covered is transversely stiffened webs in plate girders. The web buckling strength may be calculated using tension field theory. The load carrying capacity of the web is calculated by a simple expression which does not involve trial and error. Guidance on end panel and end post design is given as well as on the design of intermediate stiffeners. Preliminary independent studies suggest that the design methods given agree well with all known data.

4.2.3 Component Design

Components under compressive axial loading are designed using the so-called European Column Curves which were introduced in the ECCS Recommendations (7). Columns are assumed to have geometrical imperfections of 0.1% of their length and idealised residual stress distributions in different rolled and welded sections which are illustrated in the code. There are five buckling curves and the appropriate one is arrived at by means of a selection table depending on cross-section shape and axis of buckling. It is gratifying to note that this is one area where European harmonisation has already occurred in advance of EC3.

Members in bending which have unbraced compression flanges must be checked for lateral torsional buckling. (Strength and stiffness criteria for bracing design are codified). A simple approximate method treating the compression flange as a column consisting of flange and 1/6 of the area of the web simply supported and buckling between bracing points may be used to produce speedy conservative designs. Alternatively a more complex check depending on bending moment distributions over the length of the beam may be used. Guidance is, of course, given for situations where no such check is necessary. Preliminary studies indicate that the formulae contained in EC3 produce a mean fit to test data rather than a lower bound.

Beam-columns buckling in the load plane are designed using a simple interaction formula. Other interaction formulae covering beam-column buckling involving lateral torsional buckling and biaxial bending and compression are given. Considerable simplifications are possible in all cases by reducing the formulae to linear interaction ones. This is achieved at the expense of accuracy and inevitably involves some conservatism. The resulting formulae are a considerable improvement on those previously suggested in the ECCS Recommendations (7).

Chapter 2 is a key chapter as it covers the basic limit state design philosophy, the method of partial safety factors and the rules for their application. Ultimate, serviceability and fatigue limit states are identified.

The drafting panel attempted to simplify the application of the general procedures laid down in EC1 particularly with respect to the number of different partial safety factors and load combinations to be considered in design (11). To do this it was necessary to quantify the partial safety factors and so the simplified approach could not be contained within the main body of the text. Instead it is to be found in the Preface to the code where it is put forward not as an official CEC proposal but by the drafting panel to stimulate discussion.

4.2.4 System Design

The draft code, having dealt with components, goes on to consider assemblages of components, or systems. This section deals with braced and sway frames and includes particular systems such as truss girders and built-up columns. Braced frames are defined as ones having a bracing shear stiffness of at least 5 times the shear stiffness of the frame itself, in which case all horizontal actions can be considered to be transmitted by the bracing elements.

In the case of sway frames a simple criterion is given to show when first order (linear) analysis may be used to calculate stress resultants. This criterion will be satisfied by the majority of practical single storey rigid portal frame type buildings and indeed in most multistorey buildings also.

There may be a case for a fuller treatment of methods of design for assemblages, to include, for example, the "simple" design approach to braced frames used extensively in many countries.

4.3 Connection Design

4.3.1 Bolted Connections. At the outset of Chapter 6 joints are classified according to the requirements of the design approach, e.g. partial or full strength joints in a plastically designed frame.

The most up to date guidance on edge distances and pitches etc is given, followed by similar information on the strength of individual fasteners. These latter include dowel bolts, rivets, pin connections and high-strength bolts in slip-resistant connections.

Bolted connections loaded in shear are categorised as follows
Category A: Bearing type connections with black or non-preloaded high strength bolts.
Category B: Connections with preloaded high strength bolts with no slip at serviceability limit state.
Category C: As in B except no slip at ultimate limit state.

Joints loaded in tension may be in either of two categories
Category D: Connections with non-preloaded bolts.
Category E: Connections with preloaded high strength bolts.

Special attention is paid to the problems of long connections, splices and beam to column connections. The quantification of prying forces is made possible by a simple formula based on a collapse mechanism approach.

4.3.2 Welded Connections. As in the case of bolted connections, welded connections are classified and then guidance given on the strength of butt, fillet and plug welds. The strength of welded connections is covered including the special problems of long connections, splices, beam to column connections, and welded joints in hollow section lattice girders. This latter must represent the most comprehensive set of such rules available in any code. It might be argued indeed that too much has been provided in this case.

4.3.3 Other Connections. A detailed treatment is given for the design of column base plates, including holding-down bolts. There is also a section dealing with connections in thin walled elements, covering blind rivets, bolts, screws and powder actuated fasteners. This treatment of thin walled element connections is slightly anomalous as the design of thin walled elements and sheeting is not included in this first draft as mentioned earlier.

4.4 Test Loading

An important section of EC3 is that contained in Chapter 8 relating to test loading as this encourages innovation in design when a structure does not comply with the requirements of the other sections of the code by allowing the engineer to resort to experimental verification. This is, of course, only one type of testing envisaged. The four types referred to are

(i) acceptance tests
(ii) quality tests

(iii) prototype tests, and
(iv) destructive tests.

The first two are envisaged as non-destructive tests. The second two are ultimate load tests of which test type (iii) would be used when it is desired to substitute experimental tests for other design verifications for members or structures whose serial production is under consideration. The final set are of the type carried out in research laboratories to define computational verification methods for structures similar to those tested. Statistical methods suitable for analysing prototype tests are outlined within the code. To date few comments have been received on this section and additional observations would be very welcome.

4.5 Fatigue

The fatigue rules were based on work by the ECCS committee TC6. Fatigue checks are not usually necessary for buildings although parts such as crane gantry girders may have to be designed for fatigue. No fatigue check is necessary if the number of stress cycles, n, is such that

$$n \leq 2 \times 10^6 \left[\frac{36}{\Delta\sigma}\right]^3 \quad (\Delta\sigma \text{ in N/mm}^2)$$

where $\Delta\sigma$ is the stress range, or where $\Delta\sigma \leq 26$ N/mm².

The theoretical life is assumed to depend primarily on the applied stress range and the detail class which is applicable to the particular structural component or joint. Classifications of details with pictorial representations are given for four basic groups, i.e.
Group 1: non-welded details,
Group 2: welded details,
Group 3: bolted connections and other details,
Group 4: welded details in hollow sections.

The influence of mean stress level in non-welded details can be taken into account by modifying the stress ranges either by dividing the stress ranges by a "bonus factor" or by reducing the compression component of stress ranges by 0.6. The stress range-number of cycles ($\Delta\sigma_R$ - N_R) curves used for design are based on mean minus two standard deviations in relation to test results. The different details all have relationships with the same slope on a log-log plot and are identified by the stress range tolerable at 2×10^6 cycles.

5. MAJOR TECHNICAL FEATURES OF CHAPTER ON FABRICATION AND ERECTION

Chapter 7 represents a minimum specification for the standard of workmanship to ensure that the assumptions made in the design clauses are valid. The specification relates to predominantly statically loaded structures. When fatigue predominates more rigorous standards may be required.

Items covered include preparation of materials, clearance of holes for bolted connections, washers and nuts, tightening procedures for non-preloaded and preloaded bolts, fit of contact surfaces and inspection and checks.

In the case of welding reference is made to materials, welding procedures, and preheating. For welded structures subject to predominantly static loading two sets of requirements for weld tolerances are distinguished, i.e. "quality control level" and "fitness for purpose level". The first can justifiably be required of the manufacturer. The second is based mainly on strength considerations for statically loaded structures. For fatigue prone structures the former could be regarded as the fitness for purpose level. These levels are quantified with respect to cracks, lack of fusion, slag inclusions etc.

Acceptable non-destructive testing methods are listed, as are the tolerances on end preparations and root openings.

A set of tolerance levels based on recommendations of the appropriate ECCS committees is also included. (National standards or structural calculations based on maximum tolerances or indeed special requirements of a compulsory nature may take precedence over these rules.) None of these tolerances would be difficult to achieve by the normal competent European fabricator.

6 FUTURE DEVELOPMENTS

At the time of writing the CEC is organising the Editorial Groups to deal with the various comments on the draft EC3 which are received in Brussels. In the member states committees have been coordinating activities at a national level during the period for comment. Of particular interest are the many valuable in-depth appraisals and design studies which have been carried out on the draft. The results of these studies should be available in time for the Symposium. No doubt these will be invaluable in helping to improve EC3, and they are eagerly awaited.

In the meantime the writer offers his own reflections on some aspects of the work which remains to be done. These are as follows:

(1) It is essential to provide a commentary to the Code if it is to be applied correctly. Such a commentary should contain background information to the clauses, including references, and should also give guidance to the user on the intended application of the rules.

(2) Careful thought needs to be given to the way in which supplementary clauses needed for the design of particular structures should be handled. A series of supplementary documents, dealing with specialised applications, seems to merit serious consideration. Priority should be given to the provision of clauses on cold formed steel sections and sheeting to complete the information needed for the design of building structures. Such information has alrady been prepared by the ECCS and could be made available with little extra effort.

(3) It is necessary to keep the load factor format as simple as possible in the interests of safety. Some modification to the general format contained within the body of the Code is needed for the final draft. Several suggestions, including that in the preface, are available, so it should be possible to achieve a satisfactory solution.

(4) There is a certain unevenness in the depth of coverage given to the various topics within the Code. The Editorial Groups will need to address this problem so as to produce a more consistent coverage.

(5) Decisions are needed within the Commission on the status of the principles and operational rules contained within the Code. There is a strong body of opinion within the steel industry which is firmly opposed to the concept of alternative operational rules being substituted for those in the Code. Furthermore it is essential to clarify the type of user at which the Eurocode has been aimed. Does it include architects and builders with no formal qualifications?

(6) The editorial errors and inconsistencies identified within the draft will of course need to be corrected, as indeed will any error of substance, of which, hopefully, there are few. All comments received must be given careful

consideration.

(7) Conclusions: The members of the drafting panel are pleased that, on balance, the Code has been received favourably. Those involved in steering it to its final conclusion are determined that it will be the best Structural Steel Code available, so that designers will want to use it and not merely be forced to do so.

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