Design of Steel Structures
U.K. Edition

Eurocode 3: Design of Steel Structures
Part 1-1: General rules and rules for buildings

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SCI Steel Knowledge
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ECCS Eurocode Design Manuals

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FOREWORD

The development program for the design manuals of the European Convention for Constructional Steelwork (ECCS) represents a major effort for the steel construction industry and the engineering profession in Europe. Conceived by the ECCS Technical Activities Board under the leadership of its chairman, Professor Luis Simões da Silva, the manuals are being prepared in close agreement with the final stages of Eurocode 3 and its national Annexes. The scope of the development effort is vast, and reflects a unique undertaking in the world.

The publication of the first of the manuals, *Design of Steel Structures*, is a signal achievement which heralds the successful completion of the Eurocode 3 work and brings it directly to the designers who will implement the actual use of the code. As such, the book is more than a manual – it is a major textbook that details the fundamental concepts of the code and their practical application. It is a unique publication for a major construction market.

Following a discussion of the Eurocode 3 basis of design, including the principles of reliability management and the limit state approach, the steel material standards and their use under Eurocode 3 are detailed. Structural analysis and modeling are presented in a chapter that will assist the design engineer in the first stages of a design project. This is followed by a major chapter that provides the design criteria and approaches for the various types of structural members. The theories of behavior and strength are closely tied to the Eurocode requirements, making for a unique presentation of theory into practice. The following chapters expand on the principles and applications of elastic and plastic design of steel structures.

The many design examples that are presented throughout the book represent a significant part of the manual. These will be especially well received by the design profession. Without a doubt, the examples will facilitate the acceptance of the code and provide for a smooth transition from earlier national codes to the Eurocode.

Reidar Bjorhovde
Member, ECCS Editorial Board

PREFACE

This book is the first of a series of joint SCI-ECCS publications, a series that will be extremely helpful to U.K. designers helping them through the change that Eurocodes represent. This joint publication is the 1st Edition, revised second impression of the ECCS Eurocode Design Manual to EN 1993-1-1, supplemented by a U.K. Foreword. In this edition, the reader will find information that is either of a general nature, or relevant to specific sections of the publication, to facilitate its application in a U.K. context.

The General rules and rules for buildings of part 1-1 of Eurocode 3 constitute the core of the code procedures for the design of steel structures. They contain the basic guidance for structural modeling and analysis of steel frameworks and the rules for the evaluation of the resistance of structural members and components subject to different loading conditions.

According to the objectives of the ECCS Eurocode Design Manuals, it is the objective of this book to provide mix of "light" theoretical background, explanation of the code prescriptions and detailed design examples. Consequently, this book is more than a manual: it provides an all-in-one source for an explanation of the theoretical concepts behind the code and detailed design examples that try to reproduce real design situations instead of the usually simplified examples that are found in most textbooks.

This book evolved from the experience of teaching Steel Structures according to ENV 1993-1-1 since 1993. It further benefited from the participation in Technical Committees TC8 and TC10 of ECCS where the background and the applicability of the various clauses of EN 1993-1-1 was continuously questioned. This book covers exclusively part 1-1 of Eurocode 3 because of the required level of detail. Forthcoming volumes discuss and apply most of the additional parts of Eurocode 3 using a consistent format.

Chapter 1 introduces general aspects such as the basis of design, material properties and geometric characteristics and tolerances, corresponding to chapters 1 to 4 and chapter 7 of EN 1993-1-1. It highlights the important topics that are required in the design of steel structures. Structural analysis is discussed in chapter 2, including structural modelling, global analysis and classification of cross sections, covering chapter 5 of EN 1993-1-1. The design of steel members subjected to various types of internal force (tension, bending and shear, compression and torsion) and their combinations is described in chapter 3, corresponding to chapter 6 of EN 1993-1-1. Chapter 4 presents the design of steel structures using 3D elastic analysis based on the case study of a real building. Finally, chapter 5 discusses plastic design, using a pitched-roof industrial building to exemplify all relevant aspects.

Furthermore, the design examples provided in this book are chosen from real design cases. Two complete design examples are presented: i) a braced steel-framed building; and ii) a pitched-roof industrial building. The chosen design approach tries to reproduce, as much as possible, real design practice instead of more academic approaches that often only deal with parts of the design process. This means that the design examples start by quantifying the actions. They then progress in a detailed step-by-step manner to global analysis and individual member verifications. The design tools currently available and adopted in most design offices are based on software for 3D analysis. Consequently, the design example for multi-storey buildings is analysed as a 3D structure, all subsequent checks being consistent with this approach. This is by no means a straightforward implementation, since most global stability verifications were developed and validated for 2D structures.

The authors are indebted to Prof. Reidar Bjorhovde who carried out a detailed technical review of the manuscript and provided many valuable comments and suggestions. Warm thanks to Prof. David Anderson who carried out an additional detailed revision of the book and also made sure that the English language was properly used. Further thanks to Liliana Marques and José Alexandre Henriques, PhD students at the University of Coimbra, for the help with the design examples of chapter 4. Additional thanks to Prof. Tiago Abecasis who spotted innumerous "bugs" in the text. Finally, thanks to Joana Albuquerque and the staff of cmm and ECCS for all the editorial and typesetting work, making it possible to bring to finalize this project.

Luís Simões da Silva
Rui Simões
Helena Gervásio
Graham Couchman
Coimbra, 2014

U.K. FOREWORD

INTRODUCTION

SCI has a history going back over 25 years of producing design guides aimed at structural engineers. These have typically been of a 'how to do' nature, aimed at designers with a certain level of experience and within the context of a given design standard.

This publication represents a departure from that tradition. It is the first in an envisaged series of joint ECCS-SCI publications, a series we hope will be extremely helpful to U.K. designers given the step change that the move to Eurocodes represents. We believe its format complements other SCI guidance. This joint publication is the 1st Edition, revised second impression of the ECCS Eurocode Design Manual to EN 1993-1-1, which was published in 2013, supplemented by a U.K. Foreword.

The content includes much useful background to the code rules (pointers to reasoning and research work that should help ensure correct application of the rules), and a reminder of some engineering principles. Helpfully, this information is presented in the context of Eurocode terminology and notation, and with reference to clause numbers etc, to aid the reader's familiarity with EN 1993-1-1. A significant number of SCI publications and other work are cited in the references.

Within this so-called U.K. Foreword the reader will find information that is either of a general nature, or relevant to specific sections of the publication. In both cases this information is presented to facilitate application of the rest of the publication in a U.K. context.

It is noted and should be accepted that there will inevitably be some differences of interpretation between the recommendations of ECCS and those previously published by SCI.

GENERAL COMMENTS

The Eurocodes contain so-called Nationally Determined Parameters (NDPs), which permit specific parts of the codes to be subject to national variations. The base ECCS publication uses either the default (recommended) Eurocode values, or in some cases Portuguese values for these NDPs. For a given design the NDPs must be in accordance with the rules for the country in which the structure is to be constructed. Some uses of specific NDPs in the U.K. are noted below.

The examples are described as being 'realistic', but it must be recognised that practice varies between nations so they do not necessarily reflect typical U.K. practice. Some specific exceptions are noted in this U.K. Foreword. Similarly, some references to 'common practice' may not reflect common U.K. practice, and these are highlighted.

Some units may be unfamiliar to U.K. designers, in particular 1 $GPa = 1\ N/mm^2$

The following comments are also included in the specific sections throughout the book.

SECTION SPECIFIC COMMENTS

Section 1.2

Reference is made to the need for integration between standards, to ensure that design rules are compatible with execution tolerances. When complementary material is used, which it invariably will be because even a set of standards as comprehensive as the Eurocodes cannot cover every need, the designer should take care to ensure it is appropriate.

Section 1.3.2

At the time of writing (Autumn 2014) an amendment is about to be published that moves the decision regarding Execution Class from EN 1090 to EN 1993-1-1.

Section 1.3.3.3

Reference is made to material partial safety factors (γ_m), which are NDPs. Both recommended and U.K. values are based on extensive analysis of

European steel production. When steel from other sources is used these values may not be appropriate.

Section 1.3.5

Reference is made to rules of thumb that may be used to assure satisfactory dynamic performance. SCI has produced guidance on this subject (SCI, 2009a) and suggests rules of thumb are only used with care, as they can be misleading.

Section 1.4.1

Its U.K. National Annex states that Table 3.1 of EN 1993-1-1 should not be used, moreover that when a range of ultimate strengths is quoted in a product standard the lowest value should be taken.

Section 1.5

The National Structural Steelwork Specification 5th edition (CE Marking Version) was configured to complement EN 1090-2 (BCSA, 2010).

Section 2.2.2

The Eurocodes use a different convention for axis notation than has traditionally been used in the U.K. Also, the Eurocodes are not entirely consistent within themselves concerning axis definition. Care is therefore needed!

Section 2.2.3

Common U.K. practice is to determine forces and moments at centreline intersections, not to use rigid links and to determine forces and moments at (for example) the face of a column.

Section 2.2.5

Although non-linear springs may be used to model joint behaviour, it is very difficult to model the complex behaviour of a joint (connection) – its stiffness, strength, rotation capacity, and indeed different behaviour in loading and unloading. This is mentioned in Section 5.2 of the guide. Traditional U.K. practice is to predict joint behaviour on the basis of past experience.

Section 2.2.7 – Example 2.1

It should be noted that European sections are not commonly used in the U.K. (although they are the subject of growing interest). S 235 steel is not used in the U.K., where S 355 is the current (2014) common grade.

Normal U.K. practice is to assume joint classification (generally 'rigid' or 'nominally pinned') and subsequently to ensure that the joint details satisfy the assumptions made.

Figures 2.29 and 2.30 show a joint with a stiffener that appears to prevent fitting of bolts/nuts. A Morris Stiffener could be used to avoid this problem.

Section 2.3.2.1

Reference is made to amplifying internal forces and displacements to model second order effects. In the U.K. an alternative approach is to reduce resistance rather than increasing forces, by use of effective lengths. However this can be laborious and for that reason is not recommended.

For certain frame geometries the U.K. National Annex to EN 1993-1-1 permits second order effects to be ignored at $\alpha_{cr} > 5$ for the so-called gravity load combination.

Section 2.3.3

The definition of *m* as the 'number of columns in a row' is not strictly correct. It should be defined as the 'number of columns having an effect on the stability system'. An amendment to EN 1993-1-1 is anticipated.

Section 2.4

All UB sections are Class 1 in bending alone.

Section 3.1.1

The U.K. National Annex to EN 1993-1-1 defines values of $\gamma_{M0} = 1.0$, $\gamma_{M1} = 1.0$, and $\gamma_{M2} = 1.1$. Note these values may vary between Eurocodes, and indeed Eurocode Parts.

Section 3.2.2

Since EN 1993 does not cover what is, in the U.K. at least, a common situation of more than one bolt in the width of an angle leg, it is common practice to use complementary guidance from BS5950 when calculating members resistances.

Section 3.3.5 – Example 3.5

The example assumes that the restraint provided by the composite floor is sufficient. SCI has provided guidance on how a designer can ensure it is sufficient (SCI, 2009b), as in practice it should never be simply assumed.

Section 3.6.2.2

The omission of rules on how to calculate M_{cr} is one of the gaps in EN 1993 that many U.K. designers are aware of. Some useful complementary information is given here.

Section 3.7.2.2

Reference is made to the two alternative methods for beam-column design given in EN 1993-1-1. It is anticipated that only one method will be given in future editions of the code, although this publication highlights that economy of design effort and economy of design result can sometimes vary depending on the method chosen.

Section 4.1

It should not be assumed that most U.K. design offices use 3D analysis. Reference is also made to the so-called wind moment method having been popular in the past in the U.K. – with modern computing power and knowledge it is not recommended, as its use beyond specific (empirical) limits has no justification.

Reference is made to braced and unbraced frames, and it is worth noting that this does not mean the same thing as non-sway sensitive and sway sensitive. It is not uncommon for a frame that is braced to be sway sensitive – it depends how stiff the bracing mechanism is.

Section 4.2.4 – Example 4.1

The example considers column bases that are fully restrained. These should be avoided if possible – more because of the cost and practicalities of the foundations than the steelwork – and in any case correctly modelled.

Section 4.4.3.4

It should be noted that the calculation of wind actions should follow the U.K. National Annex, which differs significantly from the Eurocode.

Section 4.4.3.6

The definition of m as the 'number of columns in a row' should be changed to the 'number of columns having an effect on the stability system'. In U.K. practice it would generally be assumed that the floor diaphragm constrains all columns to have the same imperfection.

Section 4.4.3.7

For economy, U.K. designers are likely to favour the use of expressions 6.10a and 6.10b of EN 1990 to determine ultimate loads. The combination factors should be taken from the U.K. National Annex to EN 1990.

At the Serviceability Limit State (SLS) the U.K. National Annex recommends using the characteristic combination, and that permanent actions should not be included.

Section 4.4.3.8

In a braced frame, typical U.K. practice would be to design all the floor beams as simply supported. Columns would be designed considering only nominal moments (from eccentric beam reactions), and floors would be considered as fully loaded.

Section 5.2.4.1

An alternative approach to calculate α_{cr} for a portal frame is considered in SCI (2014).

Section 5.2.5 – Example 5.1 (and Section 5.4.6.3)

U.K. practice is that having allowed for second-order effects and frame imperfections, the effects of in-plane member imperfections are small enough to be ignored. Thus, in addition to cross-section checks, only out-of-plane member verifications are needed. This is considered in SCI (2014).

Section 5.4.2

The example is for a portal frame with height to rafters of 7 *m*, but many modern portal frames in the U.K. are significantly taller, and therefore potentially more flexible, than this.

REFERENCES TO NATIONAL FOREWORD

BCSA (2010). *National Structural Steelwork Specification for Building Construction (5th Edition CE Marking Version)*, Publication No. 52/10, The British Constructional Steelwork Association.

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SCI (2009b). *Composite Slabs and Beams using Steel Decking. Best Practice for Design and Construction*, P300, Revised Edition, Steel Construction Institute, United Kingdom.

SCI (2014). *Design of Steel Portal Frame Buildings to Eurocode 3*, P399, The Steel Construction Institute.

TABLE OF CONTENTS

Chapter 3