

The Essential Guide to Eurocodes Transition

Edited by John Roberts



The essential guide to Eurocodes transition

The essential guide to Eurocodes transition

Edited by John Roberts



First published in the UK in 2010

by
BSI
389 Chiswick High Road
London W4 4AL

© British Standards Institution 2010

All rights reserved. Except as permitted under the *Copyright, Designs and Patents Act 1988*, no part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means – electronic, photocopying, recording or otherwise – without prior permission in writing from the publisher.

Section 7 © Andrew Bond and Andrew Harris 2008–9. Used with permission.

Whilst every care has been taken in developing and compiling this publication, BSI accepts no liability for any loss or damage caused, arising directly or indirectly in connection with reliance on its contents except to the extent that such liability may not be excluded in law.

While every effort has been made to trace all copyright holders, anyone claiming copyright should get in touch with the BSI at the above address.

BSI has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this book, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

The rights of: Edmund Booth, Owen Brooker, David Brown, Haig Gulvanessian, Andrew Harris, Chris Hendy, Stephen Hicks, David Nethercott, Arnold Page, John Roberts and Phil Tindall to be identified as the authors of this Work have been asserted by the authors in accordance with sections 77 and 78 of the *Copyright, Designs and Patents Act 1988*.

Typeset in Sabon and Helvetica Neue by Helius – www.helius.biz
Printed in Great Britain by Berforts. www.berforts.co.uk

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 978-0-580-69451-6

Contents

Foreword	vii
<i>Professor John Roberts, Principal, Technical Innovation Consultancy</i>	
Structural Eurocodes – Frequently Asked Questions	1
View from the industry – benefits, threats and UK plc’s state of readiness	8
<i>Chris Hendy, Atkins plc</i>	
Complete Eurocode listing	17
Key aspects of the Eurocodes	24
Eurocode: Basis of structural design	25
<i>Professor Haig Gulvanessian CBE, Civil Engineering and Eurocode Consultant</i>	
Eurocode 1: Actions on structures	42
<i>Professor Haig Gulvanessian CBE, Civil Engineering and Eurocode Consultant</i>	
Eurocode 2: Design of concrete structures	80
<i>Owen Brooker, The Concrete Centre</i>	
Eurocode 3: Design of steel structures	90
<i>David Brown, Associate Director, Steel Construction Institute</i>	
Eurocode 4: Design of composite steel and concrete structures	105
<i>Dr Stephen Hicks, Manager Structural Systems, Heavy Engineering Research Association, New Zealand</i>	
Eurocode 5: Design of timber structures	123
<i>Arnold Page, BSc, BD, MIWSc. Structural timber engineering consultant</i>	

Eurocode 6: Design of masonry structures <i>Professor John Roberts, Principal, Technical Innovation Consultancy</i>	138
Eurocode 7: Geotechnical design <i>Andrew Harris, Director and Dr Andrew Bond, Director, Geomantix Ltd.</i>	151
Eurocode 8: Design of structures for earthquake resistance <i>Edmund Booth, Consulting Engineer</i>	171
Eurocode 9: Design of aluminium structures <i>Phil Tindall, UK Technical Director (Bridges), Hyder Consulting</i>	182
Annex A. Design of an LVL garage beam conforming to BS EN 1995-1 <i>Arnold Page, BSc, BD, MIWSc. Structural timber engineering consultant</i>	188
Web contact details for further information and training	198

Foreword

Professor John Roberts, Principal, Technical Innovation Consultancy

Welcome to the BSI *The essential guide to Eurocodes transition* Publication prepared to support the UK construction industry through one of the most significant developments in construction standardization. The withdrawal of conflicting national standards at the end of March 2010 presents the opportunity for designers to fully engage with the coherent set of modern design codes which the Eurocodes provide.

Structural Eurocodes are seen as leading the way in structural codes worldwide. Their flexibility enables adoption and use not only within Europe, but internationally. This feature has been recognized by several countries outside Europe and they are already committed to adopting Eurocodes.

The primary objectives of the Eurocodes are to:

- provide common design criteria and methods of meeting necessary requirements for mechanical resistance, stability and resistance to fire, including aspects of durability and economy;
- provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products;
- facilitate the marketing and use of structural components and kits in EU Member States;
- facilitate the marketing and use of materials and constituent products, the properties of which enter into design calculations;
- be a common basis for research and development, in the construction industry
- allow the preparation of common design aids and software;
- increase the competitiveness of the European civil engineering firms, contractors, designers and product manufacturers in their global activities.

It is a legal requirement from March 2010 that all European public-sector clients base their planning and building control applications on structural

designs that meet the requirements of the Eurocodes. In anticipation of this, changes are necessary to the Building Regulations.

Approved Document A for Building Regulations in England and Wales, which provides guidance on how to comply with Part A (structure) of the regulations, lists 22 of the national codes being withdrawn in 2010 but will not be revised by the Communities and Local Government (CLG) department until 2013. CLG have clarified the legal position through a circular letter dated the 29th January 2010 and available on their website <http://www.communities.gov.uk/corporate/publications/all/>.

The Scottish structural guidance is provided in section 1 of the Domestic Handbook and section 1 of the Non-Domestic Handbook. The Scottish Government plans to publish revised guidance incorporating Eurocodes that will come into effect in 2010.

In Northern Ireland, Technical Booklet D:1994, Structure will be revised to include references to Eurocodes alongside withdrawn British Standards.

The withdrawn British Standards may still be used to achieve compliance with UK building regulations for private sector work but they will no longer be maintained by BSI and will increasingly become out of date.

Each of the Eurocode parts is produced by a subcommittee under the guidance and co-ordination of a technical committee (CEN/TC 250). Delegates of the 29 Comité Européen de Normalisation (CEN) members are represented on CEN/TC 250 and its subcommittees.

Drafts of the Eurocode parts are elaborated by project teams, which are selected by the appropriate sub-committees. A project team consists of about six experts who represent the subcommittee. A vast majority of the project teams include a UK-based expert.

A Eurocode is subject to extensive consultation before it is adopted. Progressive drafts are discussed and commented on by CEN members and their appointed experts. A Eurocode part is adopted only after a positive vote by CEN Members.

This BSI Structural Eurocodes Transition Publication contains articles from leading academics and professionals to help you gain an understanding of the nature of the new codes and to ease your transition into using the new structural design codes.

Structural Eurocodes – Frequently Asked Questions

1 What are Eurocodes?

Structural Eurocodes are a set of harmonized European standards for the design of buildings and civil engineering structures. There are 10 Eurocodes made up of 58 parts that will be adopted in all EU Member states.

In the UK, they will replace over 50 existing British Standards that are due to be withdrawn on 31 March 2010 when full implementation of the Eurocodes will take place.

Eurocodes are a recommended means of giving a presumption of conformity to the essential requirements of the Construction Products Directive for products that bear CE Marking, as well as the preferred reference for technical specifications in public contracts.

Eurocodes cover the basis of structural design, actions on structures, the design of concrete, steel, composite steel and concrete, timber, masonry and aluminium structures, geotechnical design and the design of structures for earthquake resistance.

2 How do I use Eurocodes?

Eurocodes are designed to be used as a suite of documents, which means that for most projects more than one code will be needed e.g. BS EN 1990 Basis of Structural Design is always required.

In addition, Eurocodes are designed to be used with a national annex, which is available separately but is essential for compliance with the code.

Other documents required for using Eurocodes are the so-called Non-Contradictory Complementary Information (NCCI) documents. The status of these documents can vary. As the name suggests they provide supplementary material, that may be useful, but are not always essential for compliance with the Eurocodes.

Other documents include Execution Standards, which provide requirements for execution of structures that have been designed in accordance with Eurocodes.

3 What are national annexes and how do I use them?

In order to allow for the variety of climatic and other factors across the European Union each Member State may produce a national annex for each of the 58 Eurocode parts.

This will include

- Alternative values
- Country specific data (geographical, climatic, etc.)
- Alternative procedures.

It may also contain:

- Decisions on the application of informative annexes
- References to Non-Contradictory Complementary Information (NCCI).

Where a national annex is published it is essential to use it to comply with the Eurocode.

Where no national annex is available or no Nationally Determined Parameters (NDPs) are chosen the choice of the relevant values (e.g. the recommended value), classes or alternative method will be the responsibility of the designer, taking into account the conditions of the project and the National provisions.

NOTE: there will be no national annex to BS EN 1998-3 in the UK.

For information and to purchase national annexes applicable outside the UK contact BSI Distributor sales on 020 8996 7511 or email Distributor.Sales@bsigroup.com.

4 What are Nationally Determined Parameters?

The foreword of each Eurocode states that it recognizes the responsibilities of regulatory authorities in each Member State and protects their right to determine values related to regulatory safety matters at a national level where these continue to vary from State to State.

Accordingly, each Eurocode contains a number of parameters which are left open for national choice, called Nationally Determined Parameters (NDPs). The NDPs account for possible differences in geographical or climatic conditions, or in ways of life, as well as different levels of protection that may prevail at national, regional or local level. Recommended values for the NDPs are also provided in the Eurocodes.

5 What are NCCI and how do I use them?

Non-Contradictory Complementary Information (NCCI) are documents that the National committees consider useful for assisting the user to apply the Eurocode. They are not essential for compliance with the Eurocode but may provide background material or other guidance.

They have been approved by the BSI Committee and are usually listed in Clause NA.4 of the national annex.

This does not mean that all NCCI documents are produced by BSI however. They are not necessarily British Standards and may be published by other organisations.

6 What are Execution Standards and how do I use them?

These documents have been produced in support of the Eurocodes and are applicable to designs in accordance with the Eurocodes.

The Masonry Eurocode includes its own execution part (BS EN 1996-2) but other areas such as Concrete, Steel, and Geotechnics have separate documents, outside the Eurocodes suite, dealing with execution and workmanship.

7 How will Eurocodes be maintained and developed?

Eurocodes will be maintained and developed by the CEN/TC250 committee. Their responsibilities will include:

- Correction of errors
- Technical and editorial improvements
- Technical amendments with regard to urgent matters of health and safety
- Resolution of questions of interpretation
- Elimination of inconsistencies and misleading statements.

They will also approve any corrigendum (e.g. removal of printing and linguistic errors) or amendment (e.g. modification, addition or deletion of specific parts), as appropriate.

In addition, future editions of the Eurocodes, such as new annexes or parts and eventually new Eurocodes will be needed to include guidance reflecting new European Union policies, innovative design methods, construction techniques, new materials, products and the like.

8 What are the benefits of using the new Eurocodes?

- They will facilitate the acquisition of public sector contracts
- They will facilitate the acquisition of European contracts
- They are among the most advanced technical views prepared by the best informed groups of experts in their fields across Europe
- They are the most comprehensive treatment of subjects, with many aspects not previously codified now being covered by agreed procedures
- They provide a design framework and detailed implementation rules which are valid across Europe and likely to find significant usage worldwide
- They provide common design criteria and methods of meeting necessary requirements for mechanical resistance, stability and resistance to fire
- They provide a common understanding regarding the design of structures between owners, operators and users, designers, contractors and manufacturers of construction products
- They facilitate the marketing and use of structural components and kits in EU Member States
- They facilitate marketing and use of materials and constituent products, the properties of which enter into design calculations

- They enable the preparation of common design aids and software
- They increase competitiveness of European civil engineering firms, contractors, designers and product manufacturers in their global activities.

9 Have all of the Eurocodes been published?

Yes, BSI has now published all of the harmonized codes and national annexes.

The British Standards referred to in Part A of the Building Regulations will be withdrawn on the 31st of March 2010 and be replaced by a new, more technologically sophisticated set of British Standards – the Eurocodes.

10 What happens to the standards I currently use?

Following publication of a European standard, BSI is obliged to withdraw conflicting standards i.e. those within the same scope and field of application as the European standard. Where the national standard is not in a one-to-one relationship with the European standard, the national standard will be amended or revised to delete the conflicting requirements and to reflect the changed scope.

Withdrawn documents are still available and remain in the BSI catalogue for historical information purposes but a BSI committee no longer maintains withdrawn standards. That means that there is no 5-year review when a committee considers the currency of a standard and decides whether to confirm, revise or withdraw it.

11 What happens if I continue to use the old British Standards?

BSI committees have already stopped updating the British Standards to be withdrawn on the 31st of March 2010, so designers need to be mindful of insurance and liability issues if they continue to use them.

The new standards will become the preferred means of demonstrating compliance under the Public Contracts Regulations 2006 and the Construction Products Directive.

12 Is there a legal or insurance-related risk arising from continuing to use the old British Standards?

In any legal proceedings relating to structural design, the courts and other dispute-resolution forums will refer to Eurocodes – the state-of-the-art standards – to reach their decisions. Continuing to use withdrawn standards could put structural designers and their insurers at increasing risk.

There is a risk that with a dual system engineers will use codes to suit themselves and this could introduce further confusion and risk.

13 Which projects use Eurocodes?

The choice of which standards to use will be influenced by EU Directives such as those on public procurement and construction products, which are enacted in the UK as the Public Contracts Regulations 2006 and the Construction Products Regulations 1991 respectively. As such, most UK public sector organizations, utilities and product manufacturers intend to use Eurocodes for all new designs after April 2010.

The Highways Authority (England Wales and Northern Ireland) will expect new designs to be in accordance with Eurocodes after March 2010. The Highways Authority requirements will be described in an Advice Note (an IAN) which will be published shortly. The actual standards to be used on a project will be defined in the AIP (Approval in Principle) document for each contract.

Network Rail will require new work from March 2010 to be in accordance with Eurocodes.

14 Has Eurocode implementation been held up by the delay to the revision of Approved Document A?

A revision to Part A to update the referenced standards has been delayed for unrelated reasons and CLG remains fully supportive of the new British Standards.

There is nothing to stop designers using British Standards cited in the Regulations, it is 'legally permissible' to use them, though they should be aware of the comments in Q12.

15 Many engineers are not ready for the new British Standards, why does BSI not postpone withdrawal?

Both BSI and the Government have a legal obligation to meet the agreed date for Europe-wide implementation of the Eurocodes (i.e. 31 March 2010). The CEN agreement to create and apply harmonized standards is made between European governments and then delegated to their National Standards Bodies.

16 How can I purchase Eurocodes?

Eurocodes are published and sold in each country by the National Standards Body and in the United Kingdom can be purchased from BSI at <http://shop.bsigroup.com/eurocodes>.

17 What kind of guidance on Eurocodes is available from BSI?

Eurocode core documentation

BSI has published all 58 Eurocodes with national annexes, associated NCCI and PD. See the Eurocodes website for more information <http://shop.bsigroup.com/eurocodes>.

New online managed collection

BSI has recently made available a managed PDF collection of the full set of Eurocodes and national annexes. More information can be requested at <http://shop.bsigroup.com/eurocodesmanagedcollection>

Commentary, guidance, master classes, conferences

BSI has designed a series of master classes, publications and an annual conference on key Eurocode themes covering key design materials such as concrete, steel, timber.

Further information can be received from <http://shop.bsigroup.com/eurocodes>

View from the industry – benefits, threats and UK plc's state of readiness

Chris Hendy, Atkins plc

The Eurocodes are widely regarded as the most technically advanced suite of structural design codes available internationally. Why then is it often perceived that progress towards their adoption has been slow in the UK?

There is undoubtedly still some resistance from pockets of the UK structural community. Part of the inertia comes from the fact that the UK has extremely good British Standards already. For example, BS 5400-3 is widely considered to be the most *comprehensive* steel code of practice in the world but few would describe it as the most *economic*. Some in the UK argue that the Eurocode rules go too far and are, in some isolated cases, unsafe. There is however no evidence of this, particularly when the UK national annex has in a few places tightened up requirements. Arguments that the Eurocodes are unsafe because they give different answers to previous British codes are simply unsound and in places the British Standards are far too conservative and are increasingly being shown to be so.

Other resistance stems from the perceived effort involved in the changeover. The Eurocode awareness seminars that have been held over the last few years may potentially have been counter-productive. They have been intended to reassure, whilst at the same time demonstrate there is work to do. In some cases, pointing out a long list of differences in practice has made the process of adoption appear more daunting than perhaps it really is.

While there may be some resistance from within industry, BSI and the Highways Agency are actively driving implementation. The speed of production of national annexes has been on a par with or better than the progress made by much of mainland Europe. In addition, an increasing number of consultants

are using Eurocodes to form the basis of departures from standards in the assessment of existing structures because they can improve predicted load carrying resistance.

The state of readiness of industry bodies, software houses and institutions is also excellent by comparison with our other European counterparts. The Concrete Centre and Steel Construction Institute have produced, and continue to produce, much guidance and training material. Many of the big software houses are on top of software upgrades, waiting only for final national annexes to finalize releases. The ICE and IStructE are running seminars and training and publishing a comprehensive set of designers' guides to the various Eurocode parts.

Readiness amongst designers is however more patchy. Some of the big consultants have strategies in hand for helping their engineers to make the transition. Atkins for example has rolled out a series of four-day training courses to 60 'Champions' across the UK and ensured that all other staff have received the same training via a cascade from these Champions. Other companies are planning or have executed similar strategies. However, a significant number of companies are only just starting to consider the issue. There are good reasons to take the change seriously and act quickly. Some of these are discussed below. Most relate to the need to remain competitive.

Steel design

The rules given in the Eurocodes reflect modern research and bring together steel design practices from around Europe. Therefore, for bridges, for example, there is a significant change to the requirements set out in previous UK practice through BS 5400-3. Some typical examples include:

- *Class 4 beams with longitudinal stiffeners* – these are treated in the same way as beams without longitudinal stiffeners in EN 1993, unlike in BS 5400-3 where a completely different approach to calculation was employed involving checking individual panels and stiffeners for buckling in isolation. This allowed little load shedding between components and a single overstressed component could govern the design of the whole cross-section. In EN 1993-1-5, this does not happen and it is the strength of the whole cross-section which is important.
- *Shear-moment interaction* – EN 1993 produces a more economic check of shear and moment interaction than does BS 5400. There are various

reasons for the improvement in economy but the main gain relates to bridge girders for which recent non-linear parametric studies have shown little interaction between shear and bending for Class 3 and 4 cross-sections, and this is reflected in the shape of the interaction curve in EN 1993-1-5

- *Web transverse stiffeners* – The design requirements for web transverse stiffeners, provided to enhance shear resistance, are much less onerous than those of BS 5400 and themselves have still been shown to be conservative [1].

Various pilot studies were conducted for the UK Highways Agency to gauge the difference in resistances overall between BS 5400-3 and EN 1993 and hence measure the differences in expected materials costs. The conclusion was that if the simple application rules were followed, steel bridges with cross-sections in Class 1 and 2 throughout would require very similar quantities of materials for both codes. Where the bridge was more typical, with cross-sections in Class 3 or 4, a typical reduction in materials of around 10% was expected with EN 1993. However, if more advanced analysis techniques are used, such as non-linear analysis, much greater reductions can be achieved.

Concrete design

The rules developed for concrete design also reflect more modern research and reflect the modern use of higher grades of concrete. The formulae given in the Eurocodes use significantly higher concrete strengths than previous UK practice; C70/85 for bridges and C90/105 for buildings. The UK national annex however places a limit on cylinder strength in calculations of 50 MPa for shear due to concerns over the validity of the equations with high strength concrete, particularly those with limestone aggregates.

As with steel design, UK designers can expect to find some differences in resistances between codes. Some typical examples include:

- *Resistance to bending and axial force* – The use of a design reinforcement stress-strain curve allowing for strain hardening in EN 1992 can lead to around 7% greater bending resistance with Class B reinforcement than is obtained with BS 5400-4 where consideration of strain hardening is not permitted. Greater increase is obtained with Class C reinforcement which is more ductile.
- *Shear resistance* – Where there are shear links included in the design, the approach in EN 1992 differs from that in BS 5400-4 and leads to a

potential large increase in economy for reinforced concrete beams. Unlike the BS 5400 truss model employed which has a fixed truss angle of 45° , the truss angle in the Eurocodes can be varied between 45° and 21.8° resulting in up to 2.5 times more resistance provided by the links. This has to be balanced by a potential increase in longitudinal reinforcement where this reinforcement is curtailed, but the designer has far greater choice over where the reinforcement is to be provided and its total quantity.

- **Punching shear** – One significant additional requirement in the Eurocodes involves the calculation of punching shear resistance allowing for the interaction with coexistent bending moment transmitted at the same time as the shear load. A typical example is a pad foundation supporting a column. This is one area where Eurocode 2 produces a lower resistance typically than did BS 5400-4.

Increased use of finite element analysis

The use of finite element (FE) analysis will increase in the UK with the introduction of the Eurocodes as they provide codified rules for the use of both elastic and non-linear analysis which were not previously covered by UK codes; they were not prohibited but approval could be a long process with no guarantee of acceptance. Additionally, the format used in the Eurocodes (particularly steel) often facilitates the use of FE models and, in some situations, using an FE model is the most economic method both in terms of design cost and in terms of material costs.

Designers will need to embrace these analysis methods to remain competitive. FE analysis can give a very accurate representation of the true behaviour of the structure, but only if the assumptions made accurately represent this behaviour. As such, results can be either unsafe or overly safe if the assumptions are incorrect. Some examples of uses that are likely to become common are set out below, together with some discussion on possible pitfalls.

Linear elastic FE analysis is attractive because it permits the principle of superposition to be adopted; influence surfaces can be generated for the effect to be investigated and the results of different loadings may be combined. Elastic finite element modelling is appropriate for calculations on fatigue stress and serviceability where it is desirable for materials to remain elastic, but may be very conservative for predicting ultimate strength where plastic redistribution is possible after first yield. In the Eurocodes, particularly EN 1993, elastic

critical buckling analysis will be increasingly used to determine slendernesses for buckling directly from the computer.

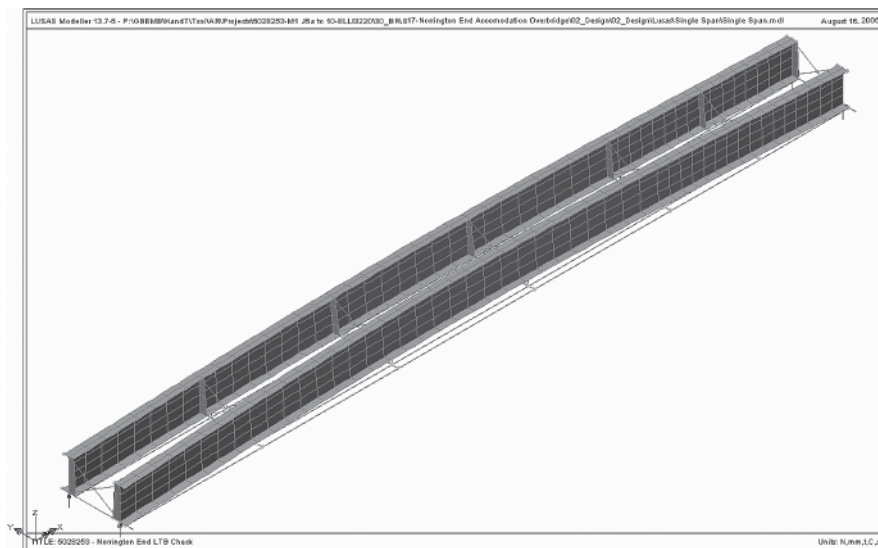
Elastic critical buckling analysis is particularly useful for analysing the construction condition of paired beams before the concrete is poured to make them composite. The slenderness can be determined directly from the elastic critical moment, M_{cr} according to

$$\bar{\lambda}_{LT} = \sqrt{W_y f_y / M_{cr}}$$

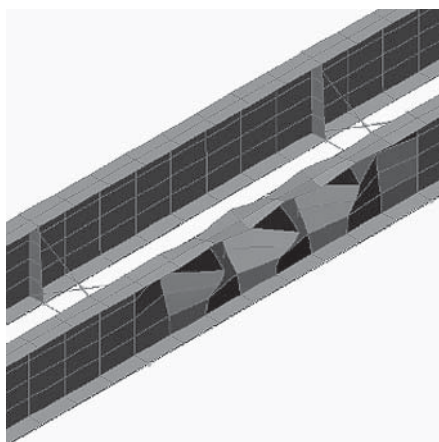
This is quick and easy to do and it is common for the Eurocodes to give significantly greater resistance than BS 5400. Figure 1a shows the critical mode representing global instability of a typical pair of cross-braced beams (the lateral buckling referred to in the code) but this was the twentieth mode produced by the computer; there were numerous lower local buckling modes of the form shown in Figure 1b which could safely be ignored as they were included elsewhere in the codified section properties for the beam. Reference [2] contains an example where a 53% greater ultimate resistance against buckling was produced using this EN 1993 approach rather than BS 5400-3. The analysis of arches also lends itself to the use of elastic critical buckling analysis in a similar manner where determination of the buckling slenderness via an effective length would otherwise be imprecise and necessarily conservative.

Non-linear analysis is the most advanced calculation procedure now permitted by Eurocodes. When performed correctly, non-linear analysis of structures can get very close to the true resistance. This is especially true of steel structures where the ultimate behaviour of steel can be very accurately represented in computer models – *Numerical validation of simplified theories for design rules of transversely stiffened plate girders* [1] covering transversely stiffened plate girders provides a good example. The accuracy of reinforced concrete models is less uniform; predominantly flexural behaviour (such as pier second order analysis shown as follows in Figure 2) is well modelled but more complex behaviour requiring prediction of reinforced concrete behaviour under general stress fields is less well understood and predictions show more scatter from test results.

The paired beams above provide an example of the further reserve of strength than can be obtained by using a non-linear model. For the same example, non-linear analysis gave 99% more ultimate resistance than did the simplified approach in BS 5400-3. The reasons for this increased resistance are discussed in *Lateral buckling of plate girders with lateral restraints* [2].



(a) Global buckling mode



(b) Typical local buckling mode

Figure 1. Elastic critical buckling analysis of paired steel beams

Buckling of slender piers by non-linear analysis can also bring significant savings in reinforcement compared to simplified code formulae, such as those in BS 5400-4. A typical example was the piers of the Medway Bridge [3]. The rules for non-linear analysis in EN 1992, including imperfections and material properties, were employed in the design after the initial reinforcement tonnage produced in accordance with BS 5400 was found to be excessive.

The pier shown in Figure 2 was analysed twice; once with 32 mm diameter reinforcement (T32) and again with 40 mm diameter (T40). The deflections shown were for:

- uncracked linear elastic analysis;
- second order uncracked elastic analysis;
- cracked second order analysis with T32 reinforcement;
- cracked second order analysis with T40 reinforcement.

The non-linear analysis resulted in a saving of reinforcement of approximately 60% compared to the UK design code.

There is little guidance available on the use of FE which makes experience in the field very important for successful modelling. The encouragement to use FE modelling by the Eurocodes is likely to lead to more inexperienced designers using it as a routine design tool. Engendering the need for checking strategies in these engineers is therefore extremely important and this can be difficult where the modelled behaviour is complex. Contrary to what many designers believe, the availability of software packages to perform these analyses requires a much greater degree of structural understanding, not a lesser degree, in order to check the model is performing satisfactorily. The example above of elastic critical buckling in paired beams is a case in point; the designer

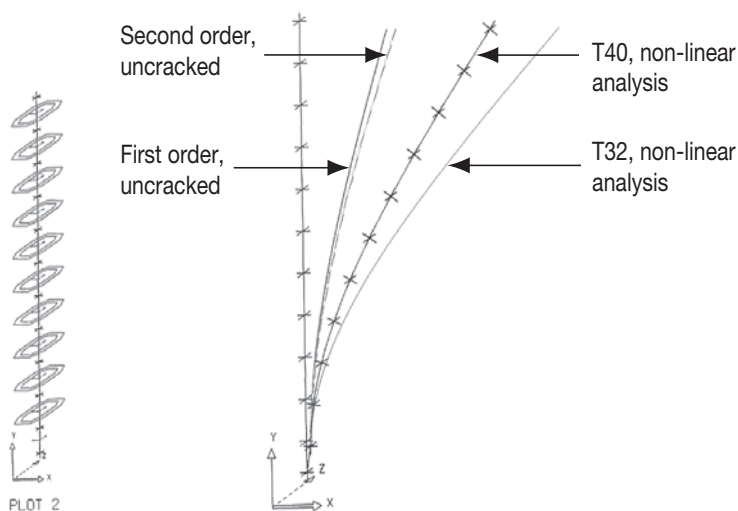


Figure 2. Second order analysis of slender piers

should have a strategy for verifying that the buckling modes produced are realistic and their eigenvalues are the right magnitudes. Standard textbook formulae could, for example, be used to approximate and check the critical stresses for the local buckling modes. A strategy for managing this change needs to be in place in design offices.

The above discussions set out some good reasons to embrace the change quickly. Designers who are not prepared face a risky transition period. The introduction of Eurocodes will provide a common set of design codes for use across Europe and, as considered below, in a number of countries outside Europe. Apart from a unique national annex (which can provide very limited information and will thus be very easy to assimilate by foreign competitors), a design done in the UK will follow the same set of rules as one done elsewhere in Europe. This will facilitate competition by UK designers across a wide range of countries but, of course, the reverse will also be true. If we are slow to adapt in the UK, others will not be and this brings potential threats to our industry.

The threats will not only come from within Europe. Countries with an existing reliance on, or close link to, British Standards are either already committed to adopting Eurocodes (e.g. Malaysia and Singapore) or are weighing up the benefits of adopting them (e.g. Hong Kong). In addition, training is starting in these countries. For example, the Institution of Engineers Malaysia commissioned Atkins to run a two-day Eurocode concrete bridge design training course for 85 delegates in Kuala Lumpur in September 2007, then commissioned another for steel design in March 2008 and has booked subsequent courses. At the time of writing there is no similar-scale external training taking place in the UK in bridge design. These countries may take a keen interest in UK opportunities.

The introduction of Eurocodes and the increased technical sophistication they bring is timely given the growing importance of the sustainability agenda and the drive for leaner construction. Many of the basic application rules in the Eurocodes lead to a modest but significant improvement in economy compared to existing British Standards. In many cases, this is derived from more recent research and testing. However, designers that follow the more complex methods of analysis permitted by the high level principles, such as non-linear analysis, may find very considerable improvements in economy. This will be the case, for example, for slender concrete piers or slender steel panels.

So to return to the original question, we shouldn't consider that the performance of UK plc in adopting Eurocodes has been sluggish. We should however recognize that the Eurocodes bring both opportunities and threats, and so to maximize the former and mitigate the latter now is the time to step up our preparation activities.

References

- [1] Presta F., Hendy C.R. *Numerical validation of simplified theories for design rules of transversely stiffened plate girders*, The Structural Engineer, Volume 86, Number 21, pp37–46 (4/11/2008)
- [2] Hendy C.R. and Jones R.P. *Lateral buckling of plate girders with lateral restraints*, ICE Bridge Engineering, March 2009
- [3] Hendy C.R. and Smith D.A. *Design of the New Medway Bridge, England*, ICE Bridge Engineering, 157, March 2004, Issue BE1, pp27–36

Complete Eurocode listing

The following tables show the constituent parts of the Eurocodes and their corresponding UK national annexes.

This listing is correct at the time of going to print. For the very latest information please go to www.bsigroup.com/eurocodes

NOTE All the Eurocodes listed have separate National Annexes with the following exceptions:

†Eurocodes which include National Annex information in the National Foreword of each Eurocode.

§Eurocodes which do not have National Annexes at all.

Eurocode. BS EN 1990 – Basis of structural design

Eurocode part	Title
BS EN 1990:2002	Basis of structural design
BS EN 1990:2002 Annex A2	Basis of structural design including Amendment A1 for Annex A2 for Bridges

Eurocode 1. BS EN 1991 – Actions on structures

Eurocode part	Title
BS EN 1991-1-1:2002	Actions on structures. General actions. Densities, self-weight, imposed loads for buildings
BS EN 1991-1-2:2002	Actions on structures. General actions. Actions on structures exposed to fire

Eurocode 1. BS EN 1991 – Actions on structures. (Contd)

Eurocode part	Title
BS EN 1991-1-3:2003	Actions on structures. General actions. Snow loads
BS EN 1991-1-4:2005	Actions on structures. General actions. Wind actions
BS EN 1991-1-5:2003	Actions on structures. General actions. Thermal actions
BS EN 1991-1-6:2005	Actions on structures. General actions. Actions during execution
BS EN 1991-1-7:2006	Actions on structures. General actions. Accidental actions
BS EN 1991-2:2003	Actions on structures. Traffic loads on bridges
BS EN 1991-3:2006	Actions on structures. Actions induced by cranes and machinery
BS EN 1991-4:2006	Actions on structures. Silos and tanks
PD 6688-1-1	Background paper to the UK National Annex to BS EN 1991-1-1
PD 6688-1-2:2007	Background paper to the UK National Annex to BS EN 1991-1-2
PD 6688-1-4	Background information to the National Annex to BS EN 1991-1-4 and additional guidance
PD 6688-1-5	Background paper to the UK National Annex to BS EN 1991-1-5
PD 6688-1-7	Recommendations for the design of structures to BS EN 1991-1-7
PD 6688-2	Recommendations for the design of structures to BS EN 1992-2

Eurocode 2. BS EN 1992 – Design of concrete structures

Eurocode part	Title
BS EN 1992-1-1:2004	Design of concrete structures. General rules and rules for buildings

BS EN 1992-1-2:2004	Design of concrete structures. Fire design
BS EN 1992-2:2005	Design of concrete structures. Concrete bridges. Design and detailing rules
BS EN 1992-3:2006	Design of concrete structures. Liquid retaining and containing structures
PD 6687:2006	Background paper to the UK National Annexes to BS EN 1992-1
PD 6687-1	Background paper to the UK National Annexes to BS EN 1992-1 and BS EN 1992-3 (supersedes PD 6687:2006)
PD 6687-2:2007	Recommendations for the design of structures to BS EN 1992-2

Eurocode 3. BS EN 1993 – Design of steel structures

Eurocode part	Title
BS EN 1993-1-1:2005	Design of steel structures. General rules and rules for buildings
BS EN 1993-1-2:2005	Design of steel structures. General rules. Structural fire design
BS EN 1993-1-3:2006	Design of steel structures. General rules. Supplementary rules for cold-formed members and sheeting
BS EN 1993-1-4:2006	Design of steel structures. General rules. Supplementary rules for stainless steels
BS EN 1993-1-5:2006	Design of steel structures. Plated structural elements
[†] BS EN 1993-1-6:2007	Design of steel structures. General. Strength and stability of shell structures
[†] BS EN 1993-1-7:2007	Design of steel structures. General. Plated structures subject to out of plane loading
BS EN 1993-1-8:2005	Design of steel structures. Design of joints
BS EN 1993-1-9:2005	Design of steel structures. Fatigue strength

Eurocode 3. BS EN 1993 – Design of steel structures. (Contd)

Eurocode part	Title
BS EN 1993-1-10:2005	Design of steel structures. Material toughness and through-thickness properties
BS EN 1993-1-11:2006	Design of steel structures. Design of structures with tension components
BS EN 1993-1-12:2007	Design of steel structures. Additional rules for the extension of EN 1993 up to steel grades S 700
BS EN 1993-2:2006	Design of steel structures. Steel bridges
BS EN 1993-3-1:2007	Design of steel structures. Towers, masts and chimneys. Towers and masts
§BS EN 1993-3-2:2008	Design of steel structures. Towers, masts and chimneys. Chimneys
†BS EN 1993-4-1:2007	Design of steel structures. Silos, tanks and pipelines. Silos
†BS EN 1993-4-2:2007	Design of steel structures. Silos, tanks and pipelines. Tanks
†BS EN 1993-4-3:2007	Design of steel structures. Silos, tanks and pipelines. Pipelines
BS EN 1993-5:2007	Design of steel structures. Piling
BS EN 1993-6:2007	Design of steel structures. Crane supporting structures
PD 6695-1-9	Recommendations for the design of structures to BS EN 1993-1-9
PD 6695-1-10	Recommendations for the design of structures to BS EN 1993-1-10
PD 6695-2	Recommendations for the design of bridges to BS EN 1993

Eurocode 4. BS EN 1994 – Design of composite steel and concrete structures

Eurocode part	Title
BS EN 1994-1-1:2004	Design of composite steel and concrete structures. General rules and rules for buildings
BS EN 1994-1-2:2005	Design of composite steel and concrete structures. General rules. Structural fire design
BS EN 1994-2:2005	Design of composite steel and concrete structures. General rules and rules for bridges
PD 6696-2:2007	Recommendations for the design of structures to BS EN 1994-2:2005

Eurocode 5. BS EN 1995 – Design of timber structures

Eurocode part	Title
BS EN 1995-1-1:2004	Design of timber structures. General. Common rules and rules for buildings
BS EN 1995-1-2:2004	Design of timber structures. General. Structural fire design
BS EN 1995-2:2004	Design of timber structures. Bridges

Eurocode 6. BS EN 1996 – Design of masonry structures

Eurocode part	Title
BS EN 1996-1-1:2005	Design of masonry structures. General rules for reinforced and unreinforced masonry structures
BS EN 1996-1-2:2005	Design of masonry structures. General rules. Structural fire design.
BS EN 1996-2:2006	Design of masonry structures. Design considerations, selection of materials and execution of masonry
BS EN 1996-3:2006	Design of masonry structures. Simplified calculation methods for unreinforced masonry structures

Eurocode 7. BS EN 1997 – Geotechnical design

Eurocode part	Title
BS EN 1997-1:2004	Geotechnical design. General rules
BS EN 1997-2:2007	Geotechnical design. Ground investigation and testing
PD 6694-1:2007	Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004

Eurocode 8. BS EN 1998 – Design of structures for earthquake resistance

Eurocode part	Title
BS EN 1998-1:2004	Design of structures for earthquake resistance. General rules, seismic actions and rules for buildings
BS EN 1998-2:2005	Design of structures for earthquake resistance. Bridges
§BS EN 1998-3:2005	Design of structures for earthquake resistance. Assessment and retrofitting of buildings
BS EN 1998-4:2006	Design of structures for earthquake resistance. Silos, tanks and pipelines
BS EN 1998-5:2004	Design of structures for earthquake resistance. Foundations, retaining structure and geotechnical aspects
BS EN 1998-6:2005	Design of structures for earthquake resistance. Towers, masts and chimneys
PD 6698:2009	Background paper to the UK National Annexes to BS EN 1998-1, BS EN 1998-2, BS EN 1998-4, BS EN 1998-5 and BS EN 1998-6

Eurocode 9. BS EN 1999 – Design of aluminium structures

Eurocode part	Title
BS EN 1999-1-1:2007	Design of aluminium structures. General structural rules
BS EN 1999-1-2:2007	Design of aluminium structures. Structural fire design
BS EN 1999-1-3:2007	Design of aluminium structures. Structures susceptible to fatigue
BS EN 1999-1-4:2007	Design of aluminium structures. Cold-formed structural sheeting
BS EN 1999-1-5:2007	Design of aluminium structures. Shell structures
PD 6702-1:2009	Structural use of aluminium. Recommendations for the design of aluminium structures to BS EN 1999
PD 6705-3:2009	Structural use of steel and aluminium. Recommendations for the execution of aluminium structures to BS EN 1090-3

Key aspects of the Eurocodes

- The Eurocodes support National Building Regulations and other national requirements for regulated work but remain subservient to them.
- National regulations set the appropriate level of safety through Nationally Determined Parameters (NDP). Certain other parameters can be set by individual countries.
- The clauses in the Eurocodes are divided into principles and application rules. Principles are identified by (P) after the clause number and cover items for which no alternative is permitted. Application rules are recommended methods of achieving the principles but alternative rules may also be used.
- There are two types of annex in the Eurocodes. Normative annexes are part of the requirements of the code.
- Informative annexes provide guidance that can be adopted or not on a country by country basis.
- The national annex is a special type of informative annex that contains the choices made by a particular country. Typically the national annex will state values and classes applicable to that country, provide value where only a symbol is given in the Eurocode and provide country specific data. The national annex also chooses when alternatives are given in the Eurocodes and indicates which informative annexes may be used. Finally it refers to Non-Contradictory Complementary Information (NCCI).
- An NCCI is a way of introducing additional guidance to supplement the Eurocodes without contradicting them.

Eurocode: Basis of structural design

*Professor Haig Gulvanessian CBE, Civil Engineering
and Eurocode Consultant*

Introduction

This chapter gives a brief introduction to EN 1990, describes its main innovative features, particularly the requirements, reliability differentiation, based on the consequences of failure, limit state and actions and the choice of load combination format and safety factors by the UK national annex considering consistency of safety for all materials.

EN 1990 (*Eurocode 0: Basis of structural design*) is the head key code for the harmonized Structural Eurocodes. EN 1990 establishes and provides comprehensive information and guidance for all the Structural Eurocodes, the principles and requirements for safety and serviceability, and provides the basis and general principles for the structural design and verification of buildings and civil engineering structures (including bridges, towers and masts, silos and tanks etc.). EN 1990 gives guidelines for related aspects of structural reliability, durability and quality control. It is based on the limit state concept and used in conjunction with the partial factor method. Comprehensive background information is given on EN 1990 by Gulvanessian, Calgaro and Holicky [1].

As shown in Figure 0.1, EN 1990 will be used with every Eurocode part for the design of new structures, together with:

- EN 1991 (*Eurocode 1: Actions on structures*); and
- EN 1992 to EN 1999 (design Eurocodes 2 to 9)

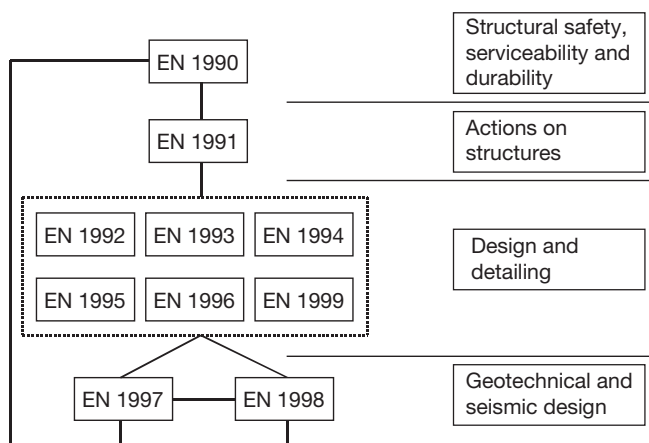


Figure 0.1. Links between Eurocodes

This is different to the situation adopted by the present British Standard codes of practice (e.g. BS 8110, BS 5950, BS 5628 etc.) because with the design Eurocodes the requirements for achieving safety, serviceability and durability and the expressions for action effects for the verification of ultimate and serviceability limit states and their associated factors of safety are only given in EN 1990. Unlike the equivalent British Standard codes of practice the material Eurocodes (EN 1992, EN 1993, EN 1994, EN 1995, EN 1996 and EN 1999) only include clauses for design and detailing in the appropriate material and require all the material independent information for the design (e.g. safety factors for actions, load combination expressions etc.) from EN 1990.

Furthermore, construction products requiring CE marking (e.g. pre-cast concrete products, metal frame domestic houses, timber frame housing etc.) all need to use the principles and rules in EN 1990 together with the appropriate Eurocodes, thus ensuring a level playing field, as do the execution standards.

As well as being the key Eurocode in setting recommended safety levels, EN 1990 also introduces innovative aspects described as follows which encourage the design engineer to consider the safety of people in the built environment together with the responsible consideration of economy by:

- allowing reliability differentiation based on the consequences of failure;
- introducing the concept of using the representative values of actions and not only the characteristic values as used for UK codes of practice. The

loads used in the EN 1990 load combinations recognize the appropriate cases where:

- rare
- frequent, or
- quasi-permanent

occurring events are being considered with the use of an appropriate reduction coefficient (ψ), applied to the characteristic load values as appropriate. The use of the representative values for actions in the load combination expressions for ultimate and serviceability limit state verifications are logical and give economies for particular design situations;

- an alternative load combination format, giving the choice to the designer of using either the expressions 6.10 or 6.10a/6.10b for the combination of actions for ultimate limit state verification. This choice provides opportunities for economy especially for the heavier materials, and can provide flexibility with regard to assessment;
- the use of lower factors of safety for loads compared to British Standards. Although the effects of actions according to the Eurocodes are lower than British Standards codes for ULS and SLS verification, this should not be a concern to the industry as the EN 1990 values are based on better science and better research;
- the use of advanced analytical techniques for the designer is encouraged and the use of probabilistic methods should the designer wish to use these for the more specialist design problems.

Principal objectives of EN 1990

EN 1990's principal objective is that this Eurocode sets out for every Eurocode part the *principles* and *requirements* for achieving:

- safety;
- serviceability;
- durability

of structures.

EN 1990 provides the information for safety factors for actions and the combination for action effects for the verification of both ultimate and serviceability limit states. Its rules are applicable for the design of building and civil engineering structures including bridges, masts, towers, silos, tanks, chimneys and geotechnical structures.

The requirements of EN 1990

To achieve safety, serviceability and durability for structures EN 1990 contains requirements to be adhered to by the complete Eurocode suite and construction product standards on

- fundamental requirements (safety, serviceability, resistance to fire and robustness);
- reliability management and differentiation;
- design working life;
- durability;
- quality assurance and quality control.

Each requirement is described as follows.

Fundamental requirements

The fundamental requirements stipulate that:

- a) a structure should be designed and executed in such a way that it will, during its intended life with appropriate degrees of reliability and in an economic way:
 - sustain all actions and influences likely to occur during execution and use (safety requirement); and
 - meet the specified serviceability requirements for a structure or a structural element (serviceability requirement); and
- b) in the case of fire, the structural resistance should be adequate for the required period of time;
- c) a structure should be designed and executed in such a way that it will not be damaged by events such as explosion, impact or consequences of human errors, to an extent disproportionate to the original cause (robustness requirement). EN 1990 provides methods of avoiding or limiting potential damage.

Reliability differentiation

Design and execution according to the suite of the Eurocodes, together with appropriate quality control measures, will ensure an appropriate degree of

reliability for the majority of structures. EN 1990 provides guidance for adopting a different level of reliability (reliability differentiation). Additional guidance is included in an informative annex to EN 1990 *Management of structural reliability for construction works*. Calgaro and Gulvanessian [2] describe the management of structural reliability in EN 1990, where the concept of the risk background of the Eurocodes is described more comprehensively.

EN 1990 gives recommended values of partial factors applicable to actions and provides a framework for the management, at national levels, of structural reliability. Embodied in the values of the partial factors are implicit 'acceptable' or 'accepted' risk levels, which relates to the consequences of the hazard and use of the structure. Risk may be defined as:

$$\text{Prob}(F) \times C$$

where:

$\text{Prob}(F)$ is the probability of the hazard occurring, and

C is the consequence in magnitude or extent, expressed, for example, in numbers of deaths, time or monetary units.

Partial factor design is based on the consideration of limit states which are, in most common cases, classified into ultimate and serviceability limit states idealizing undesirable phenomena. The design is such that their probability of occurrence in 50 years is less than an 'acceptable' value.

Figure 0.2 shows the ranges of values for probabilities for the ultimate and serviceability limit states, obtained when using EN 1990.

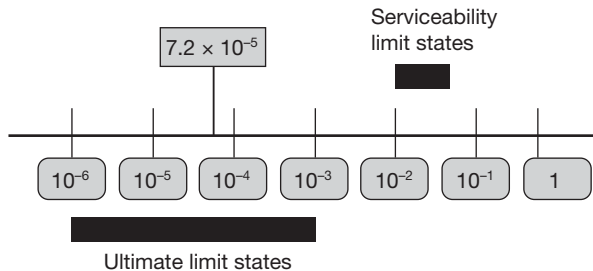


Figure 0.2. Probabilities associated with limit states

Table 0.1. Design working life classification

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures
2	10–25	Replaceable structural parts, e.g. gantry girders, bearings
3	15–25	Agricultural and similar buildings
4	50	Buildings and other common structures
5	120	Monumental buildings, bridges and other civil engineering structures

Design working life

In EN 1990 the design working life is the assumed period for which a structure is to be used for its intended purpose with anticipated maintenance but without major repair being necessary. Table 0.1 taken from the UK national annex to EN 1990 gives a design working life classification.

Durability

EN 1990 stipulates that the structure should be designed such that deterioration over its design working life does not impair the performance of the structure.

The durability of a structure is its ability to remain fit for use during the design working life given appropriate maintenance. The structure should be designed in such a way, and/or provided with protection so that no significant deterioration is likely to occur within the period between successive inspections. The need for critical parts of the structure to be available for inspection without complicated dismantling should be considered in the design. Other interrelated factors that should be considered to ensure an adequately durable structure are listed in EN 1990 and each is considered and given as follows:

- a) the intended and future use of the structure;
- b) the required performance criteria;

- c) the expected environmental influences;
- d) the composition, properties and performance of materials;
- e) the choice of a structural system;
- f) the shape of members and structural detailing, and buildability;
- g) the quality of workmanship and level of control;
- h) the particular protective measures;
- i) the maintenance during the intended life.

Quality assurance and quality control

EN 1990 stipulates that appropriate quality assurance measures should be taken in order to provide a structure that corresponds to the requirements and to the assumptions made in the design by:

- definition of the reliability requirements;
- organizational measures;
- controls at the stages of design, execution, use and maintenance.

Principles of limit state design

Ultimate and serviceability limit states

EN 1990 is based on the limit state concept used in conjunction with the partial safety factor method where limit states are the states beyond which the structure no longer fulfils the relevant design criteria. Two different types of limit state are considered, namely ultimate limit state and serviceability limit state.

Based on the use of structural and load models, it has to be verified that no limit state is exceeded when relevant design values for actions, material and product properties, and geometrical data are used. This is achieved by the partial factor method.

In the partial factor method the basic variables (i.e. actions, resistances and geometrical properties) are given design values through the use of partial factors, ψ , and reduction coefficients, γ , of the characteristic values of variable actions (see Figure 0.3).

Design may also be based on a combination of tests and calculations, provided that the required level of reliability is achieved. Alternatively, EN 1990 allows for design directly based on probabilistic methods (see Figure 0.4).

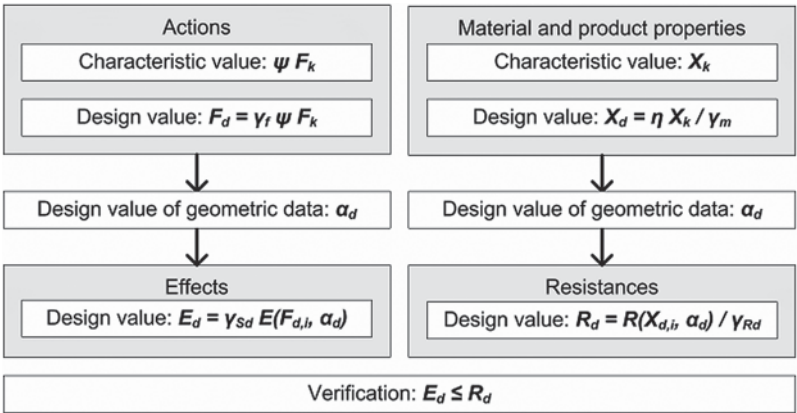


Figure 0.3. Verification by the partial factor method

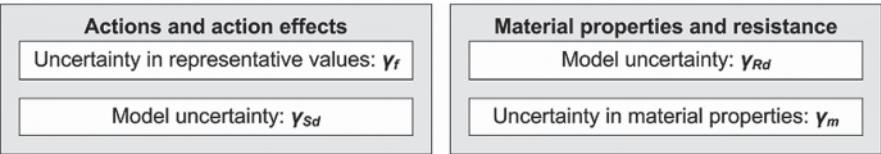


Figure 0.4. Individual partial safety factors

Design situations

Design situations are sets of physical conditions representing the real conditions occurring during the execution and use of the structure, for which the design will demonstrate that relevant limit states are not exceeded.

EN 1990 stipulates that a relevant design situation needs to be selected to take account of the circumstances in which the structure may be required to fulfil its function.

Ultimate limit state verification design situations

EN 1990 classifies design situations for ultimate limit state verification as follows:

- persistent situations (conditions of normal use);
- transient situations (temporary conditions, e.g. during execution);

- accidental situations; and
- seismic situations.

Serviceability limit state verification design situations

Serviceability limit states correspond to conditions beyond which specified service requirements for a structure or structural element are no longer met and the design situations concern:

- the functioning of the construction works or parts of them;
- the comfort of people; and
- the appearance.

EN 1990 recommends that the serviceability requirements should be determined in contracts and/or in the design. EN 1990 distinguishes between reversible and irreversible serviceability limit states. EN 1990 gives three expressions for serviceability design: characteristic, frequent and quasi-permanent.

Actions

Actions are sets of forces, imposed displacements or accelerations. They are classified by their variation in time as follows:

- permanent actions, G , e.g. self-weight of structures, fixed equipment and road surfacing, and indirect actions caused by shrinkage and uneven settlements;
- variable actions, Q , e.g. imposed loads on building floors, beams and roofs, wind actions or snow loads;
- accidental actions, A , e.g. explosions or impact from vehicles.

A variable action has four representative values. In decreasing order of magnitude, they are:

- characteristic value Q_k ;
- combination value $\psi_0 Q_k$;
- frequent value $\psi_1 Q_k$;
- quasi-permanent value $\psi_2 Q_k$.

The reduction coefficients, ψ , are applied to the characteristic load values which are appropriate to cases where

- combination (or Rare)
- frequent, or
- quasi-permanent

occurring events are being considered.

Verification by the partial factor method

Ultimate limit states

For the ultimate limit state verification, EN 1990 stipulates that the effects of design actions do not exceed the design resistance of the structure at the ultimate limit state; and the following ultimate limit states need to be verified.

Ultimate limit states concern the safety of people and/or the safety of structures and, in special circumstances, the protection of the contents. They are associated with collapse or with other similar forms of structural failure.

In EN 1990 the following ultimate limit states are verified, where relevant.

- **EQU.** Loss of static equilibrium of the structure or any part of it considered as a rigid body, where:
 - minor variations in the value or the spatial distribution of actions from a single source are significant;
 - the strengths of construction materials or ground are generally not governing.
- **STR.** Internal failure or excessive deformation of the structure or structural members, including footings, piles and basement walls, etc., where the strength of construction materials of the structure governs.
- **GEO.** Failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance.
- **FAT.** Fatigue failure of the structure or structural members. The combinations apply:
 - persistent or transient design situation (fundamental combination);
 - accidental design situation;
 - seismic design situation.

For a limit state of static equilibrium (EQU), it is verified that:

$$E_{d,dst} \leq E_{d,stab}$$

where

$E_{d,dst}$ is the design value of the effect of destabilizing actions, and

$E_{d,stab}$ is the design value of the effect of stabilizing actions.

When considering a limit state of rupture or excessive deformation of a section, member or connection (STR and/or GEO), it is verified that:

$$E_d \leq R_d$$

where

E_d is the design value of the effect of actions, and

R_d is the design value of the corresponding resistance.

Specific rules for FAT limit states are given in the design Eurocodes EN 1992 to EN 1999.

For the ultimate limit state verification, EN 1990 stipulates that the effects of design actions do not exceed the design resistance of the structure at the ultimate limit state; and the following ultimate limit states need to be verified.

Alternative load combination expressions in EN 1990 for the persistent and transient design situations

EN 1990 specifies three sets of alternative combination expressions for the determination of action effects, expressions 6.10, 6.10a and 6.10b, and 6.10a modified and 6.10b (see the following) for the persistent and transient design situations to be used by EN 1991 and the design Eurocodes for ultimate limit state verification, as follows:

$$a) \sum_{j \geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_P P \text{ "+" } \gamma_{Q,1} Q_{k,1} \text{ "+" } \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \quad (6.10)$$

The procedure using expression 6.10 is denoted as case A in this paper.

For this case the combination of actions is governed by a leading variable action $Q_{k,1}$ represented by its characteristic value and multiplied by its appropriate safety factor γ_Q . Other variable actions $Q_{k,i}$ for $i > 1$ which may act simultaneously with the leading variable action $Q_{k,1}$ are taken into account as accompanying variable actions and are represented by their combination value, i.e. their characteristic value reduced by the relevant combination

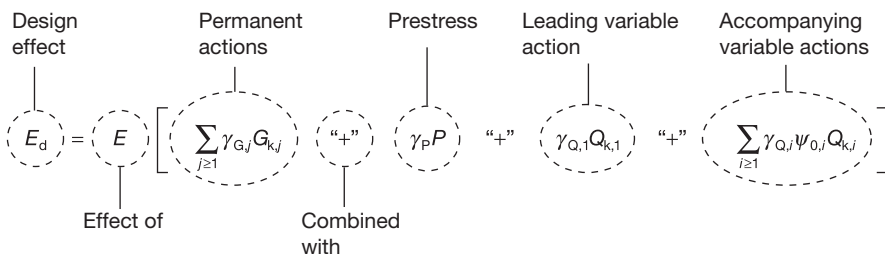


Figure 0.5. ULS verification (persistent and transient design situation) expression 6.10

factor, ψ_0 , and are multiplied by the appropriate safety factor to obtain the design values.

The permanent actions are taken into account with their characteristic values, and are multiplied by the load factor γ_G . Depending on whether the permanent actions act favourably or unfavourably they have different design values.

This is explained in Figure 0.5.

b) or the less favourable of the two following expressions:

$$\sum_{j \geq 1} \gamma_{G,j} G_{k,j} + \gamma_P P + \gamma_{Q,1} \psi_{0,1} Q_{k,1} + \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \quad (6.10a)$$

$$\sum_{j \geq 1} \xi_j \gamma_{G,j} G_{k,j} + \gamma_P P + \gamma_{Q,1} Q_{k,1} + \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \quad (6.10b)$$

The procedure using expressions 6.10a and 6.10b is denoted as case B.

In expression 6.10a, there is no leading variable action: all the variable actions are taken into account with their combination value, i.e. their value is reduced by the relevant combination factor ψ_0 . The permanent actions are taken into account as in expression 6.10, and the unfavourable permanent actions may be considered as the leading action in the combination of actions. All the actions are multiplied by the appropriate safety factors, γ_G or γ_Q .

In expression 6.10b the combination of actions is governed by a leading variable action represented by its characteristic value as in expression 6.10 with the other variable actions being taken into account as accompanying variable actions and are represented by their combination value, i.e. their characteristic value is reduced by the appropriate combination coefficient of a variable action ψ_0 . But the unfavourable permanent actions are taken into account

with a characteristic value reduced by a reduction factor, ξ , which may be considered as a combination factor.

All the actions are multiplied by the appropriate load factors, γ_G or γ_Q . When the envelope of the two expressions showing the less favourable effects of expressions 6.10a and 6.10b is determined, generally expression 6.10a applies to members where the ratio of variable action to total action is low, i.e. for heavier structural materials, and 6.10b applies where the same ratio is high, i.e. for lighter structural materials.

- c) or expression 6.10a modified to include self-weight only and expression 6.10b, as shown as follows:

$$\sum_{j \geq 1} \gamma_{G,j} G_{k,j} \text{ “+” } \gamma_P P \quad (6.10a, \text{ modified})$$

$$\sum_{j \geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{ “+” } \gamma_P P \text{ “+” } \gamma_{Q,1} Q_{k,1} \text{ “+” } \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \quad (6.10b)$$

The procedure using expressions 6.10a modified and 6.10b is denoted as case C. This case is very similar to case B but the first of pair expressions includes only permanent actions.

In the preceding text:

“+” implies ‘to be combined with’

Σ implies ‘the combined effect of’

ξ is a reduction factor for unfavorable permanent actions G

EN 1990 allows through NDPs and the national annexes for

- the choice of which of the three combination expressions given in EN 1990 to use; and
- the specification of appropriate safety factors, γ , and combination coefficients, ψ and ξ , for actions

which should be used nationally.

Comparison of expressions for the combination of the effects of actions between BSI structural codes of practice and EN 1990 (note that the factors of safety for permanent and variable actions are lower in EN 1990) using expression 6.10, are shown as follows.

For one variable action (imposed or wind)

- BSI: $1.4G_k + (1.4 \text{ or } 1.6)Q_k$
- EN 1990: $1.35G_k + 1.5Q_k$

For two or more variable actions (imposed + wind)

- BSI: $1.2G_k + 1.2Q_{k1} + 1.2Q_{k2}$
- EN 1990: $1.35G_k + 1.5Q_{k1} + 0.75Q_{k2}$

where

G_k is the characteristic value for permanent actions, and

Q_k is the characteristic value for variable actions

Choice of load combination expressions for the UK national annex to EN 1990

Based on an investigation by Gulvanessian and Holický [3], the following two combinations have been adopted in the UK national annex for EN 1990 for buildings.

- Expression 6.10 with $\gamma_G = 1.35$ and $\gamma_Q = 1.5$
- Expressions 6.10a and 6.10b with $\gamma_G = 1.35$, $\gamma_Q = 1.5$ and $\xi = 0.925$

All recommended γ and ψ (except ψ_0 for wind actions, where in the UK national annex $\psi_0 = 0.5$) values have been adopted by the UK national annex for EN 1990, and are generally being adopted by most CEN Member States.

For bridges only the use of expression 6.10 is permitted.

Load combination expressions in EN 1990 for accidental design situations

For the ultimate limit states verification for accidental design situations, EN 1990 requires the following combination expression to be investigated:

$$\sum_{j \geq 1} G_{k,j} \text{ “+” } P \text{ “+” } A_d \text{ “+” } (\psi_{1,1} \text{ or } \psi_{2,1})Q_{k,1} \text{ “+” } \sum_{i > 1} \psi_{2,i}Q_{k,i}$$

The choice between $\psi_{1,1}Q_{k,1}$ or $\psi_{2,1}Q_{k,1}$ should be related to the relevant accidental design situation (impact, fire or survival after an accidental event or situation). In the UK national annex to EN 1990, $\psi_{1,1}Q_{k,1}$ is chosen.

The combinations of actions for accidental design situations should either

- involve an explicit accidental action A (fire or impact); or
- refer to a situation after an accidental event ($A = 0$).

For fire situations, apart from the temperature effect on the material properties, A_d should represent the design value of the indirect thermal action due to fire.

The expression for the accidental design situation specifies factors of safety of unity both for the self-weight and the accidental action A_d and a frequent or quasi-permanent value for the leading variable action. The philosophy behind this is the recognition that an accident on a building or construction works is a very rare event (although when it does occur the consequences may be severe) and hence EN 1990 provides an economic solution.

Serviceability limit states

For the serviceability limit states verification, EN 1990 stipulates that:

$$E_d \leq C_d \quad (6.13)$$

where

C_d is the limiting design value of the relevant serviceability criterion, and
 E_d is the design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination.

Combination of actions for the serviceability limit states

For the serviceability limit states verification, EN 1990 requires the three following combinations to be investigated:

- The characteristic (rare) combination used mainly in those cases when exceedance of a limit state causes a permanent local damage or permanent unacceptable deformation.

$$\sum_{j \geq 1} G_{k,j} \text{ "+" } P_k \text{ "+" } Q_{k,1} \text{ "+" } \sum_{i > 1} \psi_{0,i} Q_{k,i} \quad (6.14b)$$

- b) The frequent combinations used mainly in those cases when exceedance of a limit state causes local damage, large deformations or vibrations which are temporary.

$$\sum_{j \geq 1} G_{k,j} \text{ "+" } P \text{ "+" } \psi_{1,1} Q_{k,1} \text{ "+" } \sum_{i > 1} \psi_{2,i} Q_{k,i} \quad (6.15b)$$

- c) The quasi-permanent combinations used mainly when long term effects are of importance.

$$\sum_{j \geq 1} G_{k,j} \text{ "+" } P \text{ "+" } \sum_{i \geq 1} \psi_{2,i} Q_{k,i} \quad (6.16b)$$

Partial factors for serviceability limit states

Unless otherwise stated (e.g. in EN 1991 to 1999), the partial factors for serviceability limit states are equal to 1.0. ψ factors are given in Table 1.3 in the chapter on Eurocode 1 in this book.

Conclusions

EN 1990 is a fully operative code and the concept of a fully operative material-independent code is new to the European design engineer. It is certainly not a code that should be read once and then placed on the book-shelf. It is the key Eurocode that sets the requirements for design, material, product and execution standards. EN 1990 needs to be fully understood as it is key to designing structures that have an acceptable level of safety and economy, with opportunities for innovation.

A course and a designers guide for EN 1990 are available in the UK through Thomas Telford Ltd. of the Institution of Civil Engineers.

Regarding implementation of EN 1990 in the UK, EN 1990 was published in April 2002 and the UK national annex for buildings was published in 2004. The UK national annex for bridges is due in 2009.

References

- [1] Gulvanessian H., Calgaro J.A, Holický M. *Designers' Guide to EN 1990: Eurocode: Basis of Structural Design*, Thomas Telford, London, 2002

- [2] Calgaro J.A., Gulvanessian H. Management of reliability and risk in the Eurocode system. Conference – Safety, Risk and Reliability, Malta – Trends in Engineering, IABSE 2001.
- [3] Gulvanessian H., Holický M. *Eurocodes: Using reliability analysis to combine action effects. Proceedings of the Institution of Civil Engineers, Structures and Buildings*, Thomas Telford, London, 2005