Designers' Guide to EN 1994-1-1:2026

Eurocode 4: Design of Composite Steel and Concrete Structures Part 1.1: General rules and rules for buildings

Third edition

Roger P. Johnson and Stephen J. Hicks

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Eurocode 4 Design of composite steel and concrete structures

Part 1.1: General rules and rules for buildings

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Preface to the third edition

EN 1994-1-1, 'General rules and rules for buildings' is a part of Eurocode 4, 'Design of composite steel and concrete structures' which is one of the standards that comprise the current system of Eurocodes. Details are given in Chapter 0, 'Introduction', which corresponds to *Clause 0* of EN 1994-1-1.

Objectives of this guide

This book provides guidance on the interpretation and use of EN 1994-1-1, with comment and worked examples. It explains the relationship with the other Eurocode parts to which Eurocode 4 refers and with other standards and regulations. It also provides references and background information on the origin of the provisions of EN 1994-1-1.

Layout of this guide

EN 1994-1-1 has a foreword, twelve main Clauses, numbered 0 to 11, and ten Annexes, numbered A to J. This guide has twelve chapters, numbered 0 to 11, which correspond to the Clauses; chapters numbered 12 to 20, which correspond to Annexes A, B and D to J; Appendices A and B which provide background theory for lateral-torsional buckling and columns, respectively, and Appendix C on the new technical specification for composite dowel shear connectors. Annex C does not need comment and so has no chapter here.

The numbering and titles of the sections in this guide also correspond to those of the level 2 clauses (e.g. 1.1) of EN 1994-1-1. Some sub-sections are also numbered (e.g. 1.1.2). This implies correspondence with the subclause in EN 1994-1-1 of the same number. Their titles also correspond. There are extensive references to lower-level clause and paragraph numbers. The first significant reference to a clause is in ***bold italic*** type (e.g. ***clause 1.1.1(2)***). These are in strict numerical sequence throughout the book, and appear in the adjacent outer margin to help readers to find comments on particular provisions of the code. Some comments on clauses are necessarily out of sequence, but use of the index should enable these to be found.

In worked examples, results are calculated that may appear as numbers in arithmetical work pages later. To enable readers to find the source of the number, it and its symbol are printed in **bold** type at first appearance; for example: $\boldsymbol{f_{ctm}}$**=** 0.89 × 2.6 **= 2.31 MPa.**

All cross-references in this guide to clauses, paragraphs, annexes, figures, tables and formulae of EN 1994-1-1 are in *italic* type, which is also used where text from EN 1994-1-1 has been directly reproduced (conversely, cross-references to and quotations from other sources, including other Eurocodes, are in roman type). Figures, formulae and tables repeated from EN 1994-1-1 retain their number. They are distinguished from new material by the use of *italic* type when referring to them. The word 'formula' in Eurocode 4 includes equations and inequalities.

References to EN 1994, EN 1994-1-1 and so on should be deemed to refer to BS EN 1994-1-1:2026.

Formulae not in Eurocode 4 are referred to as 'equations' and have numbers prefixed by X (e.g. Equation X6.1 in Chapter 6).

The following abbreviations are widely used in this book.

BS EN, British and European standard

CEN, European Committee for Standardization

EAD, European Assessment Document

ETA, European Technical Assessment

ETPS, European Technical Product Specification

IABSE, International Association for Bridge and Structural Engineering

NCCI, non-contradictory complementary information

NDP, nationally determined parameter

TS, technical specification

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Roger P. Johnson and *Stephen J. Hicks*

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CHAPTER 0
Introduction

This clause is preceded by a short 'European foreword', which refers to the preparation of this revision of EN 1994-1-1, gives some reminders to users and refers to the purpose and use of national annexes.

0.1 Introduction to the Eurocodes

Clause 0.1

Of the Eurocodes listed in ***clause 0.1***, EN 1994-1-1 cross-refers extensively only to EN 1992, 'Design of concrete structures' and EN 1993, 'Design of steel structures'. There are a few references to EN 1990, 'Basis of structural and geotechnical design', with which it has to be consistent.

The way in which Eurocodes are used in practice depends to some extent on the laws and regulations of the country concerned, as explained in this clause. The Eurocodes recognise the responsibility of relevant authorities and have safeguarded their right to determine values related to safety matters at a national level.

The governments of the UK and its devolved regions publish documents that provide guidance on the means by which compliance with the Building Regulations in force can be achieved. For the structure and its safety these are: Approved Document A (England); Approved Document A (Wales); Scottish Technical Handbook; and Technical Booklet D in Northern Ireland.

Approved Document A (England) currently references the Eurocodes. It states: '*…British Standards for structural design based on the Eurocodes were…implemented by the British Standards Institution on 1st April 2010 and it is these standards with their corresponding UK National Annexes which are now referenced in this Approved Document as practical guidance on meeting Part A requirements*.' It further states: '*There may be alternative ways of achieving compliance with the requirements and there may be cases where it can be demonstrated that the use of withdrawn standards no longer maintained by the British Standards Institution continues to meet Part A requirements*.' The Scottish Technical Handbook, the Welsh Approved Document and the Northern Ireland Technical Booklet have been updated in a similar way.

0.2 and 0.3 Introduction to EN 1994 (all parts) and to EN 1994-1-1

No definition is given of the 'steel and concrete composite structures' to which EN 1994 applies. Composite members, beams, columns and slabs are defined in *clause 3.1*. The titles of its Parts include the well-understood words 'building' and 'bridge'. It will usually be obvious where the code applies; it is where composite behaviour, defined in *clause 3.1.4*, is being relied on in design.

EN 1994-2 has a new title, 'Bridges'. The previous EN 1994-2 included all the general rules of EN 1994-1-1. There were some provisions that were in theory 'general', but given only in EN 1994-2 because they were in practice not used for buildings, where simpler methods are preferred. They have now been moved into EN 1994-1-1, which unfortunately increases its length and complexity. EN 1994-2 is, of course, much shorter than before.

EN 1994-1-2 covers 'Structural fire design'. It is outside the scope of this guide.

The following further Parts of Eurocode 4 are also outside the scope, except for Appendix C on composite dowels.

- CEN/TS 1994-1-101: Double and single skin steel concrete composite (SC) structures (in preparation).
- CEN/TS 1994-1-102: Composite dowels (publication expected in 2026).
- CEN/TS 1994-1-103: Composite columns comprising high performance columns (in preparation).

0.4 Verbal forms used in the Eurocodes

Provisions are of two main types: Principles, which use the verb 'shall', and Application Rules, which use 'should'. In the first set of Eurocodes, the clause number of a principle ended in P. This is no longer done. If a design method deviates from a clause in some way, the verb used is important, because if 'shall' is used, that design does not comply with the Eurocodes, which may have legal implications. The situation with deviation from a 'should' clause is more complex, as explained below.

0.5 National Annex for EN 1994-1-1

Each national standards body is required to publish each Eurocode part as a national standard. It comprises, without any alterations, the full text of the Eurocode and its annexes as published by the Comité Européen de Normalisation (CEN), usually preceded by a National Title Page and a National Foreword, and followed by a National Annex.

Each Eurocode recognises the right of national regulatory authorities to determine values related to safety matters. Values, classes or methods to be chosen or determined at national level are referred to as Nationally Determined Parameters (NDPs). A recommended value for each one is given in a Note that follows the relevant clause. Those clauses are listed in this clause. The values are usually those assumed during drafting and used for calibration work.

In EN 1994-1-1 the NDPs are principally the partial factors for material or product properties peculiar to this standard – for example, relating to shear connectors or profiled sheeting. A new method for the resistance of composite slabs to vertical shear was sufficiently controversial to need three NDPs. Each national annex gives or cross-refers to the values to be used for the NDPs in its country. For the five annexes that are Informative (optional), each country has these options: to permit its use; to mandate its use (i.e. treat it as Normative, with the same status as the rest of the Eurocode); to prohibit its use in full or in part; or to provide alternative provisions in full or in part.

Complementary information (formerly referred to as non-contradictory complementary information or 'NCCI' in the first-generation Eurocodes) may be directly included within the national annex (NA) or by reference, provided that it does not alter or contradict any provisions of the Eurocode. In practice, questions on interpretation of code clauses always arise. Any organisation can publish material claimed to be 'complementary information', and particular industries may have a vested interest in doing so.

Each national annex will have been approved by the relevant national standards body (BSI for the UK), which in effect gives complementary information to which it refers a status close to that of a national standard. However, much complementary information will appear after the national annex has been published. Before using such material for work claimed to be in accordance with Eurocodes, the designer should be satisfied that it does not alter or contradict any provisions of the Eurocode.

The UK's National Annex to EN 1994-1-1 was not complete at the time of writing (April 2025), so this book uses the 'recommended' data given in Notes in Eurocode 4. The comments given on the 'expected' content of the Annex are mainly based on the NA to the 2004 Eurocode 4, and should not be relied on.

Drafting errors in codes and some questions of interpretation are resolved by the official corrigenda and amendments that appear in its lifetime. Proposals for these are classified as 'editorial' or 'technical'. As they would apply in all Member States, technical changes have to be approved by the CEN Committee TC 250/SC 4.

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CHAPTER 1
Scope

- Scope of EN 1994-1-1 *Clause 1.1*
- Assumptions *Clause 1.2*

1.1 Scope of EN 1994-1-1

Clause 1.1 refers to 'basic rules for the design of composite structures' for 'buildings' and 'bridges'. The Eurocodes are concerned with structural behaviour. Other requirements – for example, thermal and acoustic insulation, are not considered. *Clause 1.1*

In EN 1994-1-1, all rules that are for buildings only are preceded by a heading that includes the word 'buildings' or, if an isolated paragraph, are placed at the end of the relevant clause – for example, *clause 7.4.2.3(5)*. All other provisions are 'general' – for example, most of the rules for resistance to bending apply for a composite beam in a building as in a bridge, so those rules are 'general' and appear in EN 1994-1-1, even for rules where most applications occur in bridges.

The coverage in this guide of the 'general' clauses of Part 1-1 is relevant to both buildings and bridges, except where noted otherwise. However, guidance provided by or related to the worked examples may be relevant only to applications in buildings.

The provisions of Part 1-1 cover the design of the common composite members

- beams in which a steel section acts compositely with concrete
- composite slabs formed with profiled steel sheeting
- concrete-encased and concrete-filled composite columns
- joints between composite beams and steel or composite columns.

Clauses 7 and *11* concern connected members. *Clause 7*, 'Structural analysis', is needed particularly for framed structures. Unbraced frames and sway frames are within its scope. The provisions include definitions of imperfections and the use of second-order global analysis and prestress by imposed deformations.

The scope of Part 1-1 extends to steel I-sections where the web is encased by reinforced concrete and shear connection is provided between the concrete and the steel ('partially encased' composite members). The primary reason for its choice is improved resistance in fire. Fully-encased composite beams are not included because

- no satisfactory model has been found for the ultimate strength in longitudinal shear of a beam without shear connectors
- it is not known to what extent some design rules (e.g. for moment-shear interaction and redistribution of moments) are applicable.

A fully encased beam with shear connectors can usually be designed as if partly encased or uncased, provided that care is taken to prevent premature spalling of encasement in compression.

Part 2, *Bridges*, includes further application rules that may on occasion be useful for buildings, such as those on

- composite plates (where the steel member is a flat steel plate, not a profiled section)
- composite plate girders and box girders
- tapered or non-uniform composite members.

The omission of application rules for a type of member or structure should not prevent its use, where appropriate. Some omissions are deliberate, to encourage the use of innovative design based on specialised literature, the properties of materials and the fundamentals of equilibrium and compatibility, and follow the principles given in the relevant Eurocodes. This applies, for example, to

- base plates beneath composite columns
- shear heads in reinforced concrete framed structures (Piel and Hanswille, 2006)
- many aspects of 'mixed' structures, as used in tall buildings (Henderson, 2017).

1.2 Assumptions

Clause 1.2

Clause 1.2 consists only of cross-references to assumptions made in other European standards. It does not repeat the further assumptions found in appropriate clauses of all Parts of EN 1994. Assumptions, in general, relate to the types of structures and the level of technical management of their design and execution that the authors of the standard had in mind. Their applicability to an unusual structure or type of technical management should always be considered.

The Eurocodes are concerned with design and not execution, but minimum standards of workmanship are required to ensure that the design assumptions are valid. For this reason, EN 1090 Parts 1, 2 and 4 on execution of steel structures (BS EN 1090) and EN 13670 for concrete structures (BS EN 13670) are included in ***clause 1.2(3)***. All Eurocodes prefer 'execution' to the familiar term 'construction'.

Clause 1.2(3)

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CHAPTER 2
Normative references

This chapter corresponds to *clause 2* of EN 1994-1-1, 'Normative references'. References in Eurocode 4 to clauses in the documents listed here have the same status, concerning requirement, as if they were in Eurocode 4.

The Bibliography at the end of EN 1994-1-1 provides a longer list of standards that are not 'Normative', and explains the several types of reference to them that are used in the Parts of EN 1994. It includes designated standards that businesses can use to show their construction products, services or processes comply with essential requirements of legislation (e.g. EN 10025 for hot rolled structural steel products).

References in this *clause 2* are given only to other European standards, all of which are intended to be used as a package. Formally, the standards of the International Organization for Standardization (ISO) apply only if given an EN ISO designation. However, in cases when suitable EN standards do not exist, reference may be made to European Technical Specifications (TS) or assessments that comply with all of the requirements given within European Assessment Documents (EAD).

National standards for design and for products that conflict with a relevant EN standard have been (or are being) 'withdrawn' by the British Standards Institution (BSI). They will become increasingly out-of-date, but remain important references for work on existing structures that were designed using them.

In its application to buildings, EN 1994-1-1 is based on the concept of the initial erection of a steel frame, which may include prefabricated concrete or composite members. The placing of precast concrete or profiled steel sheeting for floors, reinforcement and formwork for columns and so on then follow. The addition of in situ concrete completes the composite structure. The presentation and content of EN 1994-1-1 therefore relate more closely to EN 1993-1-1 than to EN 1992-1-1.

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CHAPTER 3
Terms, definitions and symbols

3.1 Terms and definitions

Where a term is used in another Eurocode to which EN 1994-1-1 refers, its definition will be found in that code, not in *clause 3.1*. The care taken during drafting to avoid defining the same term in more than one code has, generally, been successful. Reference to the definitions in other codes can be helpful. For example, 'non-linear resistance' is in EN 1994-1-1, and 'non-linear analysis' is in EN 1993-1-1, neither giving the other term. Words like 'action' are not found in *clause 3.1* because it is defined in EN 1990. It means a load and/or an imposed deformation.

Where there is doubt, the definition in the code being used takes priority. For example, the text of EN 1994-1-1 refers to 'solid slabs' and EN 1992-1-1 has a definition 'slab, solid'. The definition 'solid composite slab' in *clause 3.1.38* is obviously applicable here.

In pre-Eurocode practice in the UK, and continuing in verbal usage, the meanings of 'resistance', 'capacity' and 'strength' lacked clear definition. In Eurocode 4, 'resistance' is used for a property of a cross-section or member that includes the dimension of force (e.g. buckling resistance), and 'capacity' is used where it does not (e.g. rotation capacity, slip capacity). 'Strength' is used for a property of a material or connector that includes the dimension of force. The term 'capacity design', defined in EN 1993-1-1, does not follow this convention. It is not used in Eurocode 4.

Many of the definitions in ***clause 3.1*** include the word 'composite', which implies shear connection, defined in *clause 3.1.2.* Its main function (*clause 3.1.1*) is to *limit* longitudinal slip and separation between the steel and concrete components of a member. They cannot be eliminated. Separation is always assumed to be negligible but explicit allowance may need to be made for effects of slip – for example, as in *clauses 5.4.2.1, 8.6.1(12)* and *A.4(1).* *Clause 3.1*

The definition 'composite frame' (***clause 3.1.12***) does not refer to concrete members. Where the behaviour is essentially that of a reinforced or prestressed concrete structure, with only a few composite members, global analysis should be generally in accordance with Eurocode 2 and specialised guidance (Plumier and Degée, 2023). *Clause 3.1.12*

The definition of 'prestress' in ***clause 3.1.18*** refers to the use of prestressing by 'controlled imposed deformations', usually by jacking at supports, which is within the scope of Eurocode 4. Clause 3 of EN 1992-1-1, which defines prestress as an action caused by the stressing of tendons, applies to EN 1994-2 but not to EN 1994-1-1, as this is outside its scope. *Clause 3.1.18*

The term 'plastic neutral axis' is not included in the definitions in *clause 3* of EN 1994-1-1. EN 1992-1-1 does not use it. Its rules for stress distribution in compression zones (clause 8.1.2) include a rectangular ('plastic') distribution of concrete stress, but the neutral axis is *not* at one edge of the stress block. In Eurocode 4 it is at one edge, so care is needed in verifications where the code refers to Eurocode 2 (e.g. for bending resistance of a concrete flange).

3.2 Symbols

This clause lists over 500 symbols, about twice the number in the previous Eurocode 4, some of which had two meanings. The increase is mostly in the subscripts used, partly to cover the seven additional annexes and to avoid double meanings. Most of the annexes have a separate list, giving the symbols that are not in the main list. Hence, it may be necessary to look at both lists to find a symbol in an annex. There is no list of subscripts. A few can have more than one meaning – for example, $_{m}$ can mean either 'measured' or 'mean'.

This book uses the Eurocode symbols. They are defined near the start of each section in which they appear, except in some worked examples.

Some subscripts are separated by commas, which indicate a different meaning – for example, $A_{c,eff}$ (concrete, effective). This does not always apply, notably in the important group of subscripts $_{Rd}$, $_{Rk}$, $_{Ed}$ and $_{Ek}$, with R for resistance, E for effect of action, d for design and k for characteristic. For a complex design method, such as that for beams with web openings, the distinction between say, M_{Ed} and M_{Rd}, is important.

The subscripts for the three main materials used in composite structures in symbols for strength are $_{c}$ (concrete), $_{y}$ (structural steel) and $_{s}$ (reinforcing steel). For structural steel, $_{a}$ is also used, as in $M_{a,Ed}$, from the French 'acier'.

There are a few changes from the previous Eurocode 4 in the definitions of symbols, including the following.

- f_{ck} is now the characteristic cylinder strength of concrete at age t_{ref}, with t_{ref} a 'reference time', given in EN 1992-1-1: 5.1.3(2). The previous 28 days remains the 'general' value, and an option to specify other times has been added.
- For profiled sheeting, the words 'excluding longitudinal stiffener' have been added to the definition of h_p, the 'overall depth of profiled sheeting'. There is a new symbol, h_{pg}, for the depth including a stiffener.