

DESIGNERS' GUIDES TO THE EUROCODES

**DESIGNERS' GUIDE TO EN 1994-2
EUROCODE 4: DESIGN OF STEEL AND
COMPOSITE STRUCTURES**

PART 2: GENERAL RULES AND RULES FOR BRIDGES

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C. R. HENDY and R. P. JOHNSON



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Preface

EN 1994, also known as Eurocode 4 or EC4, is one standard of the Eurocode suite and describes the principles and requirements for safety, serviceability and durability of composite steel and concrete structures. It is subdivided into three parts:

- *Part 1.1: General Rules and Rules for Buildings*
- *Part 1.2: Structural Fire Design*
- *Part 2: General Rules and Rules for Bridges.*

It is used in conjunction with EN 1990, *Basis of Structural Design*; EN 1991, *Actions on Structures*; and the other design Eurocodes.

Aims and objectives of this guide

The principal aim of this book is to provide the user with guidance on the interpretation and use of EN 1994-2 and to present worked examples. It covers topics that will be encountered in typical steel and concrete composite bridge designs, and explains the relationship between EN 1994-1-1, EN 1994-2 and the other Eurocodes. It refers extensively to EN 1992 (*Design of Concrete Structures*) and EN 1993 (*Design of Steel Structures*), and includes the application of their provisions in composite structures. Further guidance on these and other Eurocodes will be found in other Guides in this series.¹⁻⁷ This book also provides background information and references to enable users of Eurocode 4 to understand the origin and objectives of its provisions.

The need to use many Eurocode parts can initially make it a daunting task to locate information in the sequence required for a real design. To assist with this process, flow charts are provided for selected topics. They are not intended to give detailed procedural information for a specific design.

Layout of this guide

EN 1994-2 has a foreword, nine sections, and an annex. This guide has an introduction which corresponds to the foreword of EN 1994-2, Chapters 1 to 9 which correspond to Sections 1 to 9 of the Eurocode, and Chapter 10 which refers to Annexes A and B of EN 1994-1-1 and covers *Annex C* of EN 1994-2. Commentary on Annexes A and B is given in the Guide by Johnson and Anderson.⁵

The numbering and titles of the sections and second-level clauses in this guide also correspond to those of the clauses of EN 1994-2. Some third-level clauses are also numbered (for example, 1.1.2). This implies correspondence with the sub-clause in EN 1994-2 of the same number. Their titles also correspond. There are extensive references to lower-level clause and paragraph numbers. The first significant reference is in ***clause 1.1.1(2)***.

These are in strict numerical sequence throughout the book, to help readers 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.

All cross-references in this guide to sections, clauses, sub-clauses, paragraphs, annexes, figures, tables and expressions of EN 1994-2 are in *italic* type, and do not include 'EN 1994-2'. Italic is also used where text from a clause in EN 1994-2 has been directly reproduced.

Cross-references to, and quotations and expressions from, other Eurocodes are in roman type. Clause references include the EN number; for example, 'clause 3.1.4 of EN 1992-1-1' (a reference in *clause 5.4.2.2(2)*). All other quotations are in roman type. Expressions repeated from EN 1994-2 retain their number. The authors' expressions have numbers prefixed by D (for Designers' Guide); for example, equation (D6.1) in Chapter 6.

Abbreviated terms are sometimes used for parts of Eurocodes (e.g. EC4-1-1 for EN 1994-1-1⁸) and for limit states (e.g. ULS for ultimate limit state).

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The second author is deeply indebted to the other members of the project and editorial teams for Eurocode 4 on which he has worked: David Anderson, Gerhard Hanswille, Bernt Johansson, Basil Koliass, Jean-Paul Lebet, Henri Mathieu, Michel Mele, Joel Raoul, Karl-Heinz Roik and Jan Stark; and also to the Liaison Engineers, National Technical Contacts, and others who prepared national comments. He thanks the University of Warwick for facilities provided for Eurocode work, and, especially, his wife Diana for her unfailing support.

Chris Hendy
Roger Johnson

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CHAPTER 4

Durability

This chapter corresponds to *Section 4*, which has the following clauses:

- General *Clause 4.1*
- Corrosion protection at the steel–concrete interface in bridges *Clause 4.2*

4.1. General

Almost all aspects of the durability of composite structures are covered by cross-references in *clause 4.1(1)* to ENs 1990, 1992 and 1993. Bridges must be sufficiently durable to remain serviceable throughout their design life. Clause 2.4 of EN 1990 lists ten factors to be taken into account, and gives the following general requirement:

Clause 4.1(1)

‘The structure shall be designed such that deterioration over its design working life does not impair the performance of the structure below that intended, having due regard to its environment and the anticipated level of maintenance.’

The specific provisions given in EN 1992 and EN 1993 focus on corrosion protection to reinforcement, tendons and structural steel.

Reinforced concrete

The main durability provision in EN 1992 is the specification of concrete cover as a defence against corrosion of reinforcement and tendons. The following outline of the procedure is for reinforcement only. In addition to the durability aspect, adequate concrete cover is essential for the transmission of bond forces and for providing sufficient fire resistance (which is of less significance for bridge design). The minimum cover c_{\min} to satisfy the durability requirements is defined in clause 4.4.1.2 of EN 1992-1-1 by the following expression:

$$c_{\min} = \max\{c_{\min,b}; c_{\min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add}; 10 \text{ mm}\} \quad (\text{D4.1})$$

where: $c_{\min,b}$ is the minimum cover due to bond requirements and is defined in Table 4.2 of EN 1992-1-1. For aggregate sizes up to 32 mm it is equal to the bar diameter (or equivalent bar diameter for bundled bars),
 $c_{\min,dur}$ is the minimum cover required for the environmental conditions,
 $\Delta c_{dur,\gamma}$ is an additional safety element which EC2 recommends to be 0 mm,
 $\Delta c_{dur,st}$ is a reduction of minimum cover for the use of stainless steel, which, if adopted, should be applied to all design calculations, including bond. The recommended value in EC2 without further specification is 0 mm,
 $\Delta c_{dur,add}$ is a reduction of minimum cover for the use of additional protection. This could cover coatings to the concrete surface or reinforcement (such as epoxy coating). EC2 recommends taking a value of 0 mm.

Table 4.1. Minimum cover $c_{\min, \text{dur}}$ for reinforcement. (Source: based on Table 4.4N of EN 1992-1-1¹⁵)

Environmental Requirements for c_{\min} (mm)		Exposure Class (from Table 4.1 of EN 1992-1-1)					
Structural Class	X0	XC1	XC2/XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
1	10	10	10	15	20	25	30
2	10	10	15	20	25	30	35
3	10	10	20	25	30	35	40
4	10	15	25	30	35	40	45
5	15	20	30	35	40	45	50
6	20	25	35	40	45	50	55

The minimum cover for durability requirements, $c_{\min, \text{dur}}$, depends on the relevant 'exposure class' taken from Table 4.1 of EN 1992-1-1.

There are 18 exposure classes, ranging from X0, 'no risk of corrosion', to XA3, 'highly aggressive chemical environment'. It should be noted that a particular element may have more than one exposure class, e.g. XD3 and XF4. The XF and XA designations affect the minimum required concrete grade (via EN 1992-1-1 Annex E) and the chemical composition of the concrete. The XC and XD designations affect minimum cover and crack width requirements, and XD, XF and XS affect a stress limit for concrete under the characteristic combination, from clause 7.2(102) of EN 1992-2. The exposure classes most likely to be appropriate for composite bridge decks are:

- XC3 for a deck slab protected by waterproofing (recommended in clause 4.2(105) of EN 1992-2)
- XC3 for a deck slab soffit protected from the rain by adjacent girders
- XC4 for other parts of the deck slab exposed to cyclic wetting and drying
- XD3 for parapet edge beams in the splash zone of water contaminated with de-icing salts; and also XF2 or XF4 if exposed to both freeze-thaw and de-icing agents (recommended in clause 4.2(106) of EN 1992-2).

Informative Annex E of EN 1992-1-1 gives 'indicative strength classes' (e.g. C30/37) for each exposure class, for corrosion of reinforcement and for damage to concrete.

The cover $c_{\min, \text{dur}}$ is given in Table 4.4N of EN 1992-1-1 in terms of the exposure class and the structural class, and the structural class is found from Table 4.3N. These are reproduced here as Tables 4.1 and 4.2, respectively. Table 4.2 gives modifications to the initial structural class, which is recommended (in a Note to clause 4.4.1.2(5) of EN 1992-1-1) to be class 4, assuming a service life of 50 years and concrete of the indicative strength.

Taking exposure class XC4 as an example, the indicative strength class is C30/37. Starting with Structural Class 4, and using Tables 4.1 and 4.2:

- for 100-year life, increase by 2 to Class 6
- for use of C40/50 concrete, reduce by 1 to Class 5
- where the position of the reinforcement is not affected by the construction process, reduce by 1 to Class 4.

'Special quality control' (Table 4.2) is not defined, but clues are given in the Notes to Table 4.3N of EN 1992-1-1. Assuming that it will not be provided, the Class is 4, and Table 4.1 gives $c_{\min, \text{dur}} = 30$ mm. Using the recommendations that follow equation (D4.1),

$$c_{\min} = 30 \text{ mm}$$

The cover to be specified on the drawings, c_{nom} , shall include a further allowance for deviation (Δc_{dev}) according to clause 4.4.1.3(1)P of EN 1992-1-1, such that:

$$c_{\text{nom}} = c_{\min} + \Delta c_{\text{dev}}$$

Table 4.2. Recommended structural classification. (Source: based on Table 4.3N of EN 1992-1-1¹⁵)

Criterion	Structural Class						
	Exposure Class (from Table 4.1 of EN 1992-1-1)						
	X0	XC1	XC2/XC3	XC4	XD1	XD2/XS1	XD3/XS2/XS3
Service life of 100 years	Increase class by 2	Increase class by 2	Increase class by 2	Increase class by 2	Increase class by 2	Increase class by 2	Increase class by 2
Strength Class (see notes 1 and 2)	≥C30/37 Reduce class by 1	≥C30/37 Reduce class by 1	≥C35/45 Reduce class by 1	≥C40/50 Reduce class by 1	≥C40/50 Reduce class by 1	≥C40/50 Reduce class by 1	≥C45/55 Reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1
Special Quality Control of the concrete ensured	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1	Reduce class by 1

Note 1: The strength class and water/cement ratio are considered to be related values. The relationship is subject to a national code. A special composition (type of cement, w/c value, fine fillers) with the intent to produce low permeability may be considered.

Note 2: The limit may be reduced by one strength class if air entrainment of more than 4% is applied.

The value of Δc_{dev} for buildings and bridges is defined in the National Annex and is recommended in clause 4.4.1.3(2) of EN 1992-1-1 to be taken as 10 mm. This value may be reduced in situations where accurate measurements of cover achieved can be taken and non-conforming elements rejected. This could apply to precast units.

Almost all the provisions on cover, but not the process to be followed, can be modified in the National Annex to EN 1992-1-1.

Structural steel

The rules in Section 4 of EN 1993-1-1 cover the need for access for in-service inspection, maintenance, and possible reconstruction of parts susceptible to corrosion, wear or fatigue. Further provisions relevant to fatigue are given in Section 4 of EN 1993-2, and a list is given of parts that may need to be replaceable. Corrosion allowances for inaccessible surfaces may be given in the National Annex. Further discussion on durability of structural steel is presented in the *Designers' Guide to EN 1993-2*.⁴

Access to shear connectors is not possible, so they must be protected from corrosion. **Clause 4.1(2)** refers to *clause 6.6.5*, which includes relevant detailing rules, for cover and for haunches.

Clause 4.1(2)

4.2. Corrosion protection at the steel–concrete interface in bridges

The side cover to stud connectors must be at least 50 mm (*clause 6.6.5.4(2)*). **Clause 4.2(1)** requires provision of a minimum of 50 mm of corrosion protection to each edge of a steel flange at an interface with concrete. This does not imply that the connectors must be protected.

Clause 4.2(1)

For precast deck slabs, the reference to *Section 8* is to *clause 8.4.2*, which requires greater corrosion protection to a steel flange that supports a precast slab without bedding. Normal UK practice when using 'Omnia' planks has been to extend the corrosion protection a minimum of 25 mm beyond the plank edge and its seating material, with due allowance

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