

Eurocode 2: Design of concrete structures —

**Part 1.4 General rules —
Lightweight aggregate concrete with
closed structure —**

**(together with United Kingdom
National Application Document)**

ICS 91.040; 91.080.40

Committees responsible for this Draft for Development

The preparation of this Draft for Development was entrusted by Technical Committee B/525, to Subcommittee B/525/2, Structural use of concrete, upon which the following bodies were represented:

- Association of Consulting Engineers
- British Cement Association
- British Precast Concrete Federation Ltd.
- Department of the Environment (Property and Buildings Directorate)
- Department of Transport (Highways Agency)
- Federation of Civil Engineering Contractors
- Institution of Civil Engineers
- Institution of Structural Engineers
- Steel Reinforcement Commission

This Draft for Development, having been prepared under the direction of the Sector Board for Building and Civil Engineering, was published under the authority of the Standards Board and comes into effect on 15 September 1996

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The following BSI reference relates to the work on this Draft for Development:
Committee reference B/525/2

ISBN 0 580 25819 X

Amendments issued since publication

Amd. No.	Date	Comments

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National foreword

This Draft for Development was prepared by Subcommittee B/525/2 and is the English language version of ENV 1992-1-4:1994 *Eurocode 2: Design of concrete structures Part 1.4: General rules — Lightweight aggregate concrete with closed structure*, as published by the European Committee for Standardization (CEN). This Draft for Development also includes the United Kingdom (UK) National Application Document (NAD) to be used with the ENV in the design of buildings to be constructed in the UK.

ENV 1992-1-4 results from a programme of work sponsored by the European commission to make available a common set of rules for the structural and geotechnical design of building and civil engineering works.

This publication is not to be regarded as a British Standard.

An ENV is made available for provisional application, but does not have the status of a European Standard. The aim is to use the experience gained to modify the ENV so that it can be adopted as a European Standard. The publication of this ENV and its National Application Document should be considered to supersede any reference to a British Standard in previous DD ENV Eurocodes concerning the subject covered by these documents.

The values for certain parameters in the ENV Eurocodes may be set by individual CEN Members so as to meet the requirements of national regulations. These parameters are designated by |_| in the ENV.

During the ENV period of validity, reference should be made to the supporting documents listed in the National Application Document (NAD).

The purpose of the NAD is to provide essential information, particularly in relation to safety, to enable the ENV to be used for buildings constructed in the UK. The NAD takes precedence over corresponding provisions in the ENV.

The Building Regulations 1991, Approved Document A 1992, draws attention to the potential use of ENV Eurocodes as an alternative approach to Building Regulation compliance. ENV 1992-1-4 is considered to offer such an alternative approach, when used in conjunction with its NAD.

Users of this document are invited to comment on its technical content, ease of use and any ambiguities or anomalies. These comments will be taken into account when preparing the UK national response to CEN on the question of whether the ENV can be converted to an EN.

Comments should be sent in writing to the Secretary of Subcommittee B/525/2, BSI, 389 Chiswick High Road, London W4 4AL, quoting the document reference, the relevant clause and, where possible, a proposed revision, by 31 October 1996.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to vi, the ENV title page, pages 2 to 17 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

National Application Document for use in the UK with ENV 1992-1-4:1994

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Introduction

This National Application Document (NAD) has been prepared by Subcommittee B/525/2. It has been developed from the following.

- a) A textual examination of ENV 1992-1-4.
- b) A parametric calibration against BS 8110, supporting standards and test data.
- c) Trial calculations.

1 Scope

This NAD provides information to enable ENV 1992-1-4 (hereafter referred to as EC2-1.4) to be used for the design of buildings to be constructed in the UK. It will be assumed that it will be used in conjunction with DD ENV 1992-1-1, the NAD of which refers to BSI publications for values of actions.

2 Partial factors, combination factors and other values

- a) The values for combination coefficients (ψ) should be those given in Table 1 of the NAD for EC2-1.1.
- b) The values for partial factors for normal temperature design should be those given in EC2-1.1, except where modified by the NAD for that code.
- c) Other values should be those given in EC2-1.1, except where modified by the NAD for that code, and EC2-1.4, except for those given in Table 1 of this NAD.

Table 1 — Values to be used in referenced clauses instead of boxed values

Reference in EC2-1.4	Definition	UK values
4.4.3.2 (106)	Basic ratios of span/effective depth	0.85 times Table 7 of the NAD to EC2-1.1:1991. [Note the value 38 in Table 7 should be 47]
5.2.1.2 (104)	Minimum diameters of mandrel	0 % not 30 %, but use Table 8 of the NAD to EC2-1.1:1991

3 Reference standards

Supporting standards including materials specifications and standards for construction are listed in Table 2 of this NAD.

Table 2 — Reference in EC2-1.4 to other codes and standards

Reference in EC2-1.4	Document referred to	Document title or subject area	Status	UK document
Various	ENV 1992-1-1	Design of concrete	Published	DD ENV 1992-1-1
1.1.2 P (106)	ENV 206	Concrete: Performance, production, placing and compliance	Published 1990	DD ENV 206:1992
1.1.2 P (106)	ENV 1992-1-6	Plain concrete structures	Published 1994	DD ENV 1992-1-6:1996
1.4.2 P (103)	ENV 206	Concrete: Performance, production, placing and compliance	Published 1990	DD ENV 206:1992
2.5.5.1 (113)	ENV 1992-1-1 Appendix 1	Effects of time-dependent deformation of concrete	Published 1990	DD ENV 1992-1-1:1992
3.1.2.1 P (102)	ENV 206	Concrete: Performance, production, placing and compliance	Published 1990	DD ENV 206:1992
3.1.2.1 (103)	ENV 206	Concrete: Performance, production, placing and compliance	Published 1990	DD ENV 206:1992
3.1.2.5.2 (105)	ISO 6784	Concrete — Determination of static modulus of elasticity in compression	Published 1982	—
3.1.2.5.5 (107)	ENV 1992-1-1 Appendix 1	Effects of time-dependent deformation of concrete	Published 1990	DD ENV 1992-1-1:1992
4.2.1.3.3 (103)	ENV 1992-1-1 Appendix 2 & 3	Non-linear analysis and supplementary information on the ultimate limit state induced by structural deformations	Published 1990	DD ENV 1992-1-1:1992
4.2.1.3.3 (104)	ENV 1992-1-1 Appendix 3	Supplementary information on the ultimate limit state induced by structural deformations	Published 1990	DD ENV 1992-1-1:1992
4.3.5.2 P (106)	ENV 1992-1-1 Appendix 3	Supplementary information on the ultimate limit state induced by structural deformations	Published 1990	DD ENV 1992-1-1:1992

4 Additional recommendations

4.1 Chapter 3. Material Properties

a) *Clause 3.1.2.3 (105)*

Equation (3.106) should be replaced by:

$$\eta_1 = 0.4 + 0.6\rho/2400$$

b) *Clause 3.1.2.5.2 (105)*

Equation (3.107) should be replaced by:

$$\eta_E = (\rho/2400)^2$$

ICS 91.040.00; 91.100.30

Descriptors: Buildings, concrete structure, computation, building codes, rules of calculation

English version

**Eurocode 2: Design of concrete structures —
Part 1-4: General rules —
Lightweight aggregate concrete with closed structure**

Eurocode 2: Calcul des structures en béton —
Partie 1-4: Règles générales —
Béton de granulats à structure fermée

Eurocode 2: Planung von Stahlbeton-und
Spannbetontragwerken —
Teil 1-4: Allgemeine Regeln —
Leichtbeton mit geschlossenem Gefüge

This European Prestandard (ENV) was approved by CEN on 1993-06-25 as a prospective standard for provisional application. The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard (EN).

CEN members are required to announce the existence of this ENV in the same way as for an EN and to make the ENV available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the (ENV) until the final decision about the possible conversion of the ENV into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Foreword

Objectives of the Eurocodes

- (1) The “Structural Eurocodes” comprise a group of standards for the structural and geotechnical design of buildings and civil engineering works.
- (2) They cover execution and control only to the extent that is necessary to indicate the quality of the construction products, and the standard of the workmanship needed to comply with the assumptions of the design rules.
- (3) Until the necessary set of harmonized technical specifications for products and for the methods of testing their performance are available, some of the Structural Eurocodes cover some of these aspects in informative Annexes.

Background of the Eurocode programme

- (4) The Commission of the European Communities (CEC) initiated the work of establishing a set of harmonized technical rules for the design of building and civil engineering works which would initially serve as an alternative to the different rules in force in the various Member States and would ultimately replace them. These technical rules became known as the “Structural Eurocodes”.
- (5) In 1990, after consulting their respective Member States, the CEC transferred the work of further development, issue and updating of the Structural Eurocodes to CEN, and the EFTA Secretariat agreed to support the CEN work.
- (6) CEN Technical Committee CEN/TC250 is responsible for all Structural Eurocodes

Eurocode programme

- (7) Work is in hand on the following Structural Eurocodes, each generally consisting of a number of parts:
 - EN 1991, Eurocode 1: Basis of design and actions on structures.
 - EN 1992, Eurocode 2: Design of concrete structures.
 - EN 1993, Eurocode 3: Design of steel structures.
 - EN 1994, Eurocode 4: Design of composite steel and concrete structures.
 - EN 1995, Eurocode 5: Design of timber structures.
 - EN 1996, Eurocode 6: Design of masonry structures.
 - EN 1997, Eurocode 7: Geotechnical design.

EN 1998, Eurocode 8: Design provisions for earthquake resistance of structures.

EN 1999, Eurocode 9: Design of aluminium alloy structures.

- (8) Separate sub-committees have been formed by CEN/TC250 for the various Eurocodes listed above.
- (9) This Part 1-4 of Eurocode 2 is being published as a European Prestandard (ENV) with an initial life of three years.
- (10) This Prestandard is intended for experimental application and for the submission of comments.
- (11) After approximately two years CEN members will be invited to submit formal comments to be taken into account in determining future actions.
- (12) Meanwhile feedback and comments on this Prestandard should be sent to the Secretariat of CEN/TC250/SC2 at the following address:

Deutsches Institut für Normung e.V. (DIN)
Burggrafenstrasse 6
D – 10787 Berlin
phone: (+ 49) 30 – 26 01 – 25 01
fax: (+ 49) 30 – 26 01 – 12 31

or to your national standards organization.

National application documents (NAD'S)

- (13) In view of the responsibilities of authorities in member countries for safety, health and other matters covered by the essential requirements of the Construction Products Directive (CPD), certain safety elements in this ENV have been assigned indicative values which are identified by [] (“boxed values”). The authorities in each member country are expected to assign definitive values to these safety elements.
- (14) Some of the supporting European or International Standards may not be available by the time this Prestandard is issued. It is therefore anticipated that a National Application Document (NAD) giving definitive values for safety elements, referencing compatible supporting standards and providing national guidance on the application of this Prestandard, will be issued by each member country or its Standards Organization.
- (15) It is intended that this Prestandard is used in conjunction with the NAD valid in the country where the building or civil engineering works is located.

Matters specific to this prestandard

(16) The scope of Eurocode 2 is defined in 1.1.1 of ENV 1992-1-1 and the scope of this Part of Eurocode 2 is defined in 1.1.2. Additional Parts of Eurocode 2 which are planned are indicated in 1.1.3 of ENV 1992-1-1; these will cover additional technologies or applications, and will complement and supplement this Part.

(17) In using this Prestandard in practice, particular regard should be paid to the underlying assumptions and conditions given in 1.3 of ENV 1992-1-1.

(18) The seven chapters of this Prestandard are complemented by four Appendices which have the same normative status as the chapters to which they relate. These Appendices have been introduced by moving some of the more detailed Principles/Application Rules, which are needed in particular cases, out of the main part of the text to aid its clarity.

(19) As indicated in paragraph (14) of this Foreword, reference should be made to National Application Documents which will give details of compatible supporting standards to be used. For this Part of Eurocode 2, particular attention is drawn to the approved Prestandard ENV 206 (Concrete — performance, production, placing and compliance criteria), and the durability requirements given in 4.1 of this Prestandard.

(20) The provisions of this Prestandard are based substantially on the 1978 edition of the CEB Model Code and other more recent CEB and FIP documents.

(21) In developing this Prestandard, background documents have been prepared, which give commentaries on and justifications for some of the provisions in this Prestandard.

For ENV 1992-1-4, the following additional sub-clauses apply:

(22) This Part 1-4 of Eurocode 2 complements ENV 1992-1-1 for the particular aspects of lightweight aggregate concrete with closed structure.

(23) The framework and structure of this Part 1-4 correspond to ENV 1992-1-1. However, Part 1-4 contains Principles and Application Rules which are specific to structure made with lightweight aggregate concrete with closed structure.

(24) Where a particular sub-clause of ENV 1992-1-1 is not mentioned in this ENV 1992-1-4, that sub-clause of ENV 1992-1-1 applies as far as deemed appropriate in each case.

Some Principles and Application Rules of ENV 1992-1-1 are modified or replaced in this Part, in which case they are superseded.

Where a Principle or Application Rule in ENV 1992-1-1 is modified or replaced, the new number is identified by the addition of 100 to the original number. Where a new Principle or Application Rule is added, it is identified by a number which follows the last number of ENV 1992-1-1 with 100 added to it.

A subject not covered by ENV 1992-1-1 is introduced in this Part by a new sub-clause. The sub-clause number for this follows the most appropriate clause number in ENV 1992-1-1.

(25) The numbering of equations, figures, footnotes and tables in this Part follow the same principles as the clause numbering in (24) above.

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1 Introduction

This clause of ENV 1992-1-1 is applicable except as follows:

1.1 Scope

1.1.2 Scope of part 1-4 of Eurocode 2

Addition after Principle P(5):

- P(106) Part 1-4 of Eurocode 2 gives a general basis for the design of buildings and civil engineering works in reinforced and prestressed concrete made with lightweight aggregate concrete with closed structure as defined in ENV 206.
- For plain concrete structures made with lightweight aggregate concrete with closed structure, Part 1-6 of ENV 1992 and this Part 1-4 shall be applied analogously.
- P(107) All clauses of ENV 1992-1-1 are generally applicable, unless they are substituted by special clauses of this Part 1-4.
- P(108) This Part 1-4 applies to all concretes with closed structure made with natural or artificial mineral lightweight aggregates, unless reliable experience indicates that provisions different from those given can be adopted safely.
- (109) This Part 1-4 does not apply to aerated concrete either autoclaved or normally cured nor to lightweight aggregate concrete with open structure.

1.4 Definitions

1.4.2 Special terms used in part 1-4 of Eurocode 2

Addition after Principle P(2):

- P(103) Lightweight aggregate concrete: concrete having a closed structure^a and an oven-dry density of not more than 2 000 kg/m³ consisting of or containing a proportion of artificial or natural lightweight aggregates having a particle density of less than 2 000 kg/m³.

^a according to ENV 206, 5.2, so made and compacted as to retain no appreciable amount of entrapped air other than entrained air.

1.7 Special symbols used in this part 1-4 of Eurocode 2

1.7.2 Latin upper case symbols

Addition:

LC The strength classes of lightweight aggregate concrete are preceded by the symbol LC.

1.7.4 Greek symbols

Addition:

$\eta_E, \eta_1, \eta_2, \eta_3, \eta_4$: conversion coefficient or ratio.

1.7.5 Subscripts

Addition:

lc Material properties of lightweight aggregate concrete are indicated by the subscript lc.

2 Basis of design

This clause of ENV 1992-1-1 is applicable except as follows:

2.5 Analysis

2.5.5 Determination of the effects of time dependent deformation of concrete

2.5.5.1 General

Replacement of Application Rule (13) by:

- (113) Appendix 1 in Part 1-1 of ENV 1992 does not apply to lightweight aggregate concrete with closed structure.

Addition after Application Rule (13):

- (114) When the influence of the time dependent deformation of concrete is considered to be of particular significance so that its evaluation requires the use of rigorous calculation procedures, reference should be made to appropriate documents in complying with P(1), P(2) and (5) in ENV 1992-1-1. In performing such calculations, a knowledge of environmental conditions and of material composition and properties is important for accurate prediction.

3 Material properties

This clause of ENV 1992-1-1 is applicable except as follows:

3.1 Concrete

3.1.0 Notation (see also 1.7)

Addition:

- η_E Conversion factor for the calculation of the modulus of elasticity
 η_1 Coefficient for the determination of the tensile strength
 η_2 Ratio of the moduli of elasticity of lightweight aggregate concrete with closed structure and normal weight concrete
 ρ Oven-dry density of lightweight aggregate concrete in kg/m³

3.1.2 Lightweight aggregate concrete

3.1.2.1 Definitions

Replacement of Principles P(1) and P(2) by:

- P(101) The density of lightweight aggregate concrete is defined as the mass per unit volume after oven-drying (105 °C).
P(102) The density shall be determined in accordance with ENV 206.

Addition after Principle P(2):

- (103) In ENV 206, Clause 7.3.2, lightweight aggregate concrete is classified according to its density as shown in lines 1 and 2 of Table 3.105 on page 9. In addition, Table 3.105 gives corresponding densities for plain and reinforced concrete with normal percentages of reinforcement which may be used for design purposes in calculating self-weight or imposed permanent loading.
(104) The contribution of the reinforcement to the density may alternatively be determined by calculation.

Table 3.105 — Density classes and corresponding design densities of lightweight aggregate concrete according to ENV 206

Density class		1.0	1.2	1.4	1.6	1.8	2.0
Oven-dry density ρ (kg/m ³)		901 – 1 000	1 001 – 1 200	1 201 – 1 400	1 401 – 1 600	1 601 – 1 800	1 801 – 2 000
Density (kg/m ³)	plain concrete	1 050	1 250	1 450	1 650	1 850	2 050
	reinforced concrete	1 150	1 350	1 550	1 750	1 950	2 150

3.1.2.3 Tensile strength

Addition after Application Rule (4):

- (105) In the absence of more accurate data, an estimate of the tensile strength can be obtained by multiplying the f_{ct} -values calculated from equations (3.2) to (3.4), or obtained from Table 3.1 in Clause 3.1.2.4 of ENV 1992-1-1 by a coefficient

$$\eta_1 = 0.40 + 0.60 \frac{\rho}{2200} \quad (3.106)$$

where ρ denotes the upper limit of the oven-dry density in line 2 of Table 3.105 (kg/m³).

3.1.2.4 Strength classes of lightweight aggregate concrete

Replacement of Principle P(1) and Application Rules (2) and (3) by:

- P(101) Design shall be based on a strength class of concrete which corresponds to a specified value of the characteristic compressive strength.
For lightweight aggregate concrete the same strength classes apply as for normal weight concrete.
- (102) The compressive strength of concrete is classified by concrete strength classes which relate to the cylinder strength, f_{ck} , or the cube strength $f_{ck, cube}$, in accordance with ENV 206, Clauses 7.3.1.1 and 11.3.5.
The strength classes of lightweight aggregate concrete are preceded by the symbol LC.
- (103) For design calculations, the concrete strength classes and the characteristic compressive strength can be obtained from Table 3.106.

Table 3.106 — Strength classes and characteristic compressive strengths f_{lck} of lightweight aggregate concrete (in N/mm²)

Strength	LC 12/15	LC 16/20	LC 20/25	LC 25/30	LC 30/37	LC 35/45	LC 40/50	LC 45/55	LC 50/60
f_{lck}	12	16	20	25	30	35	40	45	50

Addition after Application Rule (3):

- (104) Concrete of strength classes LC 12/15 or less, and concrete of classes higher than LC 50/60 should not be used unless their use is appropriately justified. For prestressed concrete, classes lower than LC 30/37 should not be used for pre-tensioned and lower than LC 25/30 not for post-tensioned work.

3.1.2.5 Deformation properties

3.1.2.5.2 Modulus of elasticity

Addition after Application Rule (4):

- (105) An estimate of the mean values of the secant modulus E_{lcm} for lightweight aggregate concrete can be obtained by multiplying the values in Table 3.2 or acc. to equation (3.5) in ENV 1992-1-1 by a coefficient

$$\eta_E = (\rho/2200)^2 \quad (3.107)$$

where:

ρ denotes the upper limit of the oven-dry density in line 2 of Table 3.105 (kg/m^3).

The values so obtained are approximate. Where accurate data are needed, e.g. where deflections are of great importance, tests should be carried out to determine the E_{lcm} -values in accordance with ISO 6784. In other cases, experience with a particular aggregate backed by general test data, will often provide a reliable value for E_{lcm} , but with unknown aggregates, it would be advisable to consider a range of values.

3.1.2.5.4 Coefficient of thermal expansion

Replacement of Principle P(1) by:

- (101) The coefficient of thermal expansion depends mainly on the type of aggregates used and varies over a wide range.

Addition after Principle P(1):

- (102) For design purposes where thermal expansion is of no great importance, the coefficient may be taken as $8 \cdot 10^{-6}/^\circ\text{C}$. However, the actual value may be significantly higher.
- (103) The difference between the coefficients of thermal expansion of steel and of lightweight aggregate concrete need not be considered in design.

3.1.2.5.5 Creep and shrinkage

Addition after Application Rule (5):

- (106) In the absence of test results, Tables 3.3 and 3.4 in 3.1.2.5.5 of Part 1-1 of ENV 1992 can be taken as a basis for calculation, subject to the following modifications:

The final values for the creep coefficient $\phi(\infty, t_0)$ can be reduced by the ratio:

$$\eta_2 = \frac{E_{lcm}}{E_{cm}} \quad (3.108)$$

The creep strain so derived and the basic shrinkage strains should be multiplied by the factors η_3 and η_4 respectively given in Table 3.107 below.

- (107) Appendix 1 of ENV 1992-1-1 is not applicable (see 2.5.5.1(113) of this Part 1-4).

Table 3.107 — Factors for the evaluation of the creep coefficients and shrinkage strains of lightweight aggregate concrete

Concrete strength class	Factors for	
	Creep η_3	Shrinkage η_4
LC 12/15, LC 16/20	1.3	1.5
LC 20/25 to LC 50/60	1.0	1.2

4 Section and member design

This clause of ENV 1992-1-1 is applicable except as follows:

4.1 Durability requirements

4.1.3 Design

4.1.3.3 Concrete cover

Replacement of Principle P(3) by:

- P(103) The protection of reinforcement against corrosion depends upon the continuing presence of a surrounding alkaline environment provided by an adequate thickness of good quality, well-cured concrete. The thickness of cover required depends both upon the exposure conditions and on the concrete quality.
- The quality of cover in lightweight aggregate concrete is more sensitive to poor workmanship than in normal weight concrete and, for this reason, special care is necessary to ensure the required standards of workmanship are achieved.

4.2 Design

4.2.1 Lightweight aggregate concrete

4.2.1.2 Physical properties

Replacement of this clause by:

- a) Density
See section 3.1.2.1, Table 3.105, of this Part 1-4.
- b) Poisson's ratio
Section 3.1.2.5.3 of Part 1-1 of ENV 1992 applies.
- c) Coefficient of thermal expansion
Section 3.1.2.5.4 of this Part 1-4 applies.

4.2.1.3 Mechanical properties

4.2.1.3.1 Strength

Replacement of Application Rules (1) and (2) by:

- (101) Characteristic values of the compressive strength for defined strength classes of concrete may be taken from Table 3.106 above (see 3.1.2.4 of this Part 1-4).
- (102) For each strength class of concrete three values of concrete tensile strength are to be distinguished. They should be applied appropriately, depending on the problem being considered. They can be derived by applying 3.1.2.3(105) in this Part 1-4.

4.2.1.3.2 Modulus of elasticity

Replacement of Application Rules (1) by:

- (101) Clause 3.1.2.5.2 of this Part 1-4 applies.

4.2.1.3.3 Stress-strain diagrams

Replacement of Application Rules (3) to (12) by:

- a) Diagrams for structural analysis
- (103) For non-linear or plastic analysis (see Appendix 2 of ENV 1992-1-1), or for the calculation of second order effects (Appendix 3 of Part 1-1), stress-strain diagrams for short term loads as shown schematically in Figure 4.101 may be used. They are characterized by the modulus of elasticity $E_{lc,nom}$, the concrete compressive strength f_{lc} , and the strain ϵ_{lcl} at the peak stress f_{lc} (compressive stress σ_{lc} and strain ϵ_{lc} are both taken as negative).

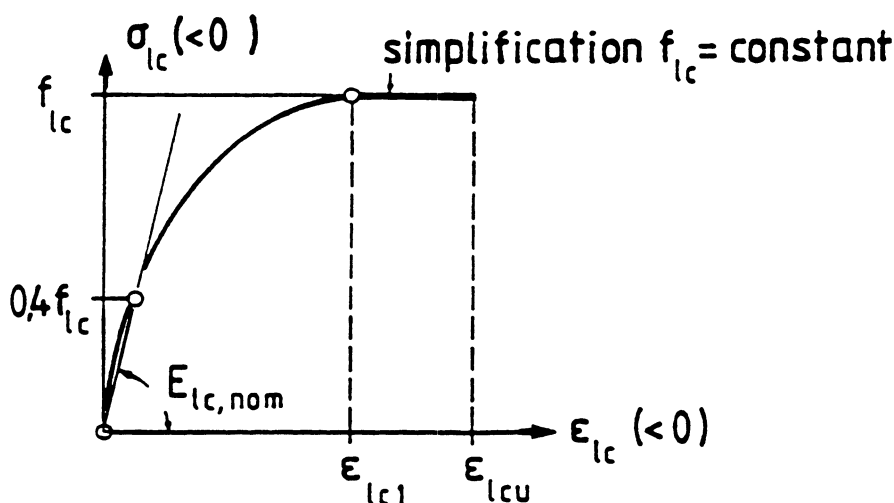


Figure 4.101 — Schematic stress-strain diagram of lightweight aggregate concrete for structural analysis

- (104) For the relevant values of the modulus of elasticity $E_{lc,nom}$ and the compressive strength f_{lc} , either
- mean values of E_{lcm} (see 3.1.2.5.2) and f_{lcm} [see equation (4.103)]
 - or
 - design values, respectively given by

$$E_{lcd} = E_{lcm}/\gamma_c \text{ and } f_{lcd} = \frac{f_{lck}}{\gamma_c} \quad (4.101)$$

are applicable according to the relevant clauses in sections 2.5.3 and 4.3.5 of ENV 1992-1-1. γ_c is the partial safety factor for concrete (see 2.3.3.2 and Appendix 3, A3.1, of Part 1-1).

- (105) The $\sigma_{lc} - \epsilon_{lc}$ relationship given in Figure 4.101 for short-term loading, can be expressed by the following function:

$$\frac{\sigma_{lc}}{f_{lc}} = \frac{k \cdot \eta - \eta^2}{1 + (k-2) \cdot \eta} \quad (4.102)$$

where:

$$\eta = \epsilon_{lc}/\epsilon_{lc1} \quad (\epsilon_{lc} \text{ and } \epsilon_{lc1} \text{ are both } < 0)$$

$$\epsilon_{lc1} = -0.0022 \quad (\text{strain at the peak compressive stress } f_{lc})$$

$$k = (1.1 \cdot E_{lc,nom}) \cdot \epsilon_{lc1}/f_{lc} \\ (f_{lc} \text{ introduced as } -f_{lc})$$

$E_{lc,nom}$ denotes either the mean value E_{lcm} of the longitudinal modulus of deformation or the corresponding design value E_{lcd} [see paragraph (104) above].

Equation (4.102) is valid for $k \geq 1.0$ and $0 \leq \eta \leq 1$.

The mean value of the concrete compressive strength may be assumed as

$$f_{lcm} = f_{lck} + |\delta| \text{ (N/mm}^2\text{)} \quad (4.103)$$

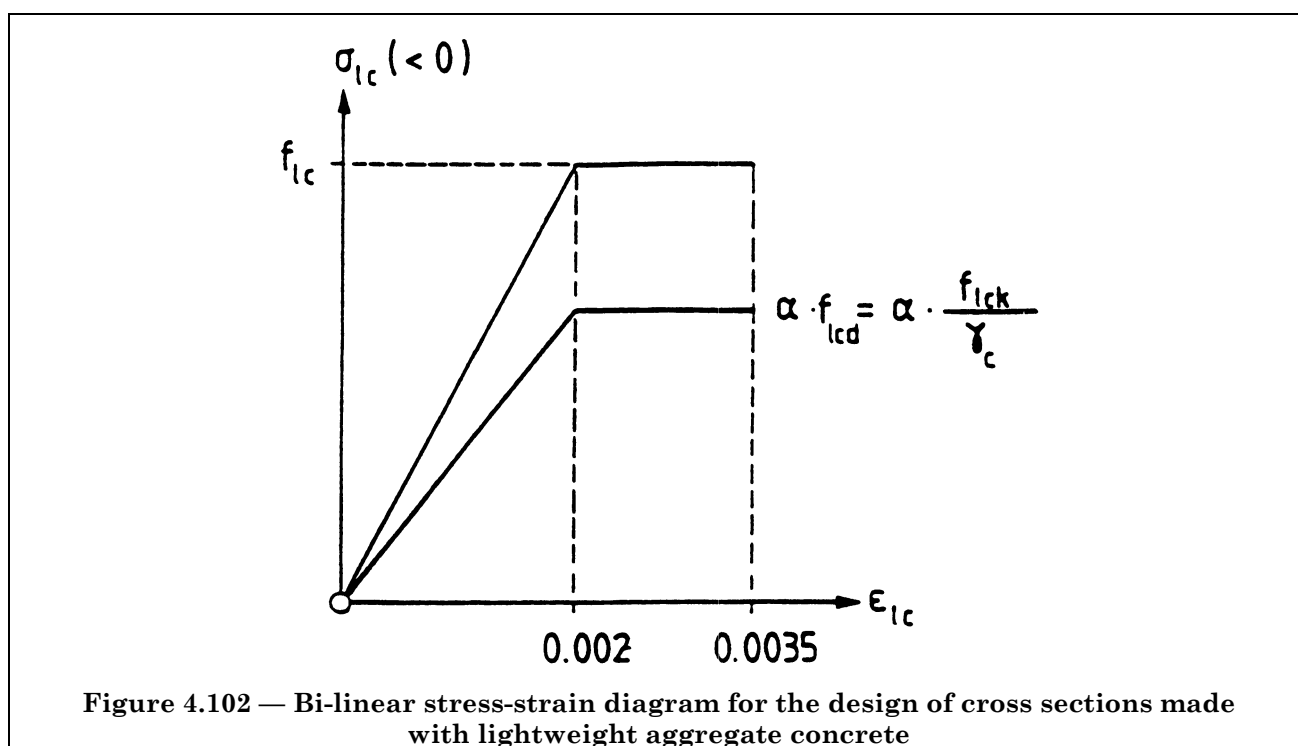
- (106) For simplification, the strain ϵ_{lc} beyond ϵ_{lc1} may be ignored (e.g. $\epsilon_{lcu} = \epsilon_{lc1}$).
- (107) Otherwise, a constant value $\sigma_{lc} = f_{lc}$ may be adopted for $\epsilon_{lc1} \geq \epsilon_{lc} \geq \epsilon_{lcu}$; in this case it should be assumed that $\epsilon_{lcu} = -0.0035$.

(108) Other idealized stress-strain diagrams may be used, e.g. a bi-linear diagram. Assuming $k = 1.0$ in expression (4.102) and applying paragraph (107) above, the diagram in Figure 4.101 yields to a bi-linear one with $\epsilon_{lc1} = -0.0022$ and $\epsilon_{lcu} = -0.0035$. This bi-linear diagram may be used for $k \leq 1.0$.

b) Stress distribution for cross-section design

(109) The idealized parabolic-rectangular stress-strain diagram in Figure 4.2 of ENV 1992-1-1 may be used.

(110) However, for lightweight aggregate concrete the preferred idealization for cross-section design is the bi-linear diagram in Figure 4.102.



(111) The design concrete strength is defined by

$$f_{lcd} = \frac{f_{lck}}{\gamma_c} \quad (4.104)$$

The design diagram is derived from the chosen idealized diagram by means of a reduction of the stress ordinate of the idealized diagram by a factor α/γ_c , in which

γ_c is the partial coefficient for concrete (see 2.3.3.2 in ENV 1992-1-1)

α is a coefficient taking account of long term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied.

The additional reduction factor α for sustained compression may generally be assumed to be $|0.77|$ for the parabolic-rectangular diagram and $|0.80|$ for the bi-linear diagram.

When using the parabolic-rectangular diagram for the application of paragraphs (3) to (5) in 2.5.3.4.2 of Part 1-1 of ENV 1992 (e.g. approximate check of rotation capacity), the coefficient $\alpha = |0.77|$ should be replaced by $\alpha = |0.72|$ for the calculation of the ratio x/d .

(112) A rectangular stress distribution as given in Figure 4.4 in ENV 1992-1-1 may be assumed. The factor $\alpha = |0.77|$ given for the idealized parabolic-rectangular diagram is valid, except that it should be reduced to $|0.72|$ when the compression zone decreases in width in the direction of the extreme compression fibre.

4.2.3 Prestressed concrete

4.2.3.5 *Design of members in prestressed concrete*

4.2.3.5.6 *Anchorage zones of pre-tensioned members*

Addition after Application Rule (9):

- (110) Sub-clause 4.2.3.5.6 3) of ENV 1992-1-1 applies with the provision that equation (4.12) is replaced by

$$l_{bp} = \frac{1}{\eta_1} \beta_b \phi \quad (4.112)$$

in which η_1 is given by clause 3.1.2.3 of this Part 1-4.

4.3 Ultimate limit states

4.3.2 Shear

4.3.2.3 *Elements not requiring design shear reinforcement* ($V_{sd} \leq V_{Rd1}$)

Addition after Application Rule (3):

- (104) This section of ENV 1992-1-1 applies with the provisions that:
- Table 4.8 of Part 1-1 should not be used.
 - in equation (4.18) in Part 1-1, the basic design shear strength τ_{Rd} should be taken as

$$\tau_{Rd} = \frac{0.25 \cdot f_{lct,k0.05}}{\gamma_c}$$

with $f_{lct,k0.05}$ according to 3.1.2.3 of this Part 1-4.

- c) Equation (4.20) in ENV 1992-1-1 is replaced by

$$v = 0.6 - \frac{f_{lck}}{235} \geq 0.425 \quad (f_{lck} \text{ in N/mm}^2) \quad (4.120)$$

4.3.4 Punching

4.3.4.5 *Shear resistance*

4.3.4.5.1 *Slabs or foundations without punching shear reinforcement*

Addition after Application Rule (2):

- (103) In equation (4.56) in ENV 1992-1-1, τ_{Rd} should be calculated according to 4.3.2.3 (104) of this Part 1-4.

4.3.5 Ultimate limit states induced by structural deformation (buckling)

4.3.5.2 *Design procedures*

Addition after Application Rule (5):

- P(106) Clauses 4.3.5.2 to 4.3.5.7 and Appendix 3 of ENV 1992-1-1 apply subject to the conditions set out below.
- (107) Values appropriate to lightweight aggregate concrete for E_{lc} and the creep effect should be considered (see 3.1.2.5.2 and 3.1.2.5.5 of this Part 1-4 respectively).
- (108) Bi-linear stress strain diagrams (see 4.2.1.3.3 of this Part 1-4) may be taken into consideration.

4.4 Serviceability limit states

4.4.2 Limit states of cracking

4.4.2.2 Minimum reinforcement areas

Addition after Application Rule (8):

- (109) This clause of ENV 1992-1-1 applies with the provision that in equation (4.78) $f_{ct,eff}$ should be replaced by $f_{lct,eff}$, with

$f_{lct,eff}$ = the tensile strength of the concrete effective at the time when the cracks may first be expected to occur. In many cases, such as where the dominant imposed deformation arises from dissipation of the heat of hydration, this may be within 3–5 days from casting depending on the environmental conditions, the shape of the member and the nature of the form-work. Values of $f_{lct,eff}$ may be obtained according to clause 3.1.2.3 of this Part 1-4, by taking as the class the strength at the time cracking is expected to occur. When the time of cracking cannot be established with confidence as being less than 28 days, it is suggested that a minimum tensile strength of |2.5| N/mm² be adopted.

4.4.3 Limit states of deformation

4.4.3.2 Cases where calculations may be omitted

Addition after Application Rule (5):

- (106) Sub-clause 4.4.3.2 2) in ENV 1992-1-1 applies except that Table 4.14 is replaced by Table 4.114 below.

Table 4.114 — Basic ratios of span/effective depth for reinforced lightweight aggregate concrete members without axial compression

Structural system	Concrete highly stressed	Concrete lightly stressed
1. Simply supported beam, one or two-way spanning simply supported slab	15	21
2. End span of continuous beam or one way continuous slab or two-way spanning slab continuous over one long side	20	27
3. Interior span of beam or one-way or two-way spanning slab	21	30
4. Slab supported on columns without beams (Flat slab) (based on longer span)	18	25
5. Cantilever	6	8

5 Detailing provisions

This clause of ENV 1992-1-1 is applicable except as follows:

5.0 Notation

Addition:

η_1 Coefficient for determination of the tensile strength.

5.1 General

Addition after Principle P(4):

- P(105) The rules given in this sub-clause are the supplementary rules for lightweight aggregate concrete as referred to in 5.1 2) of ENV 1992-1-1.

- (106) The diameter of bars embedded in lightweight aggregate concrete should not normally exceed |32| mm (see 5.2.6 of ENV 1992-1-1).

5.2 Steel for reinforced concrete

5.2.1 General detailing arrangements

5.2.1.2 Permissible curvatures

Addition after Application Rule (3):

- (104) This clause of ENV 1992-1-1 applies with the provision that the minimum diameters of mandrels given in Tables 5.1 and 5.2 of ENV 1992-1-1 should be increased by |30| %.

5.2.2 Bond

5.2.2.2 *Ultimate bond stress*

Addition after Application Rule (3):

- (104) This clause of ENV 1992-1-1 applies with the provision that the design values f_{bd} given in Table 5.3 of Part 1-1 are multiplied by η_1 in which η_1 is given by equation (3.106) in clause 3.1.2.3 of this Part 1-4.

5.2.2.3 *Basic anchorage length*

Replacement of Application Rule (2) by:

- (102) The basic anchorage length required for the anchorage of a bar of diameter ϕ is:

$$l_b = (\phi/4) * (f_{yd}/f_{bd}) \quad (5.103)$$

Values for f_{bd} are according to clause 5.2.2.2 of this Part 1-4.

5.2.3 Anchorage

5.2.3.2 *Anchorage methods*

Replacement of Application Rule (4) by:

- (104) Spalling or splitting may be prevented by complying with clause 5.2.1.2 of this Part 1-4.

5.2.3.4 *Required anchorage length*

5.2.3.4.1 *Bars and wires*

Addition after Application Rule (1):

- (102) Application Rule (1) of ENV 1992-1-1 applies with the provision that l_b is derived according to clause 5.2.2.3 of this Part 1-4.

5.2.6 Additional rules for high bond bars exceeding |32| mm in diameter

Additional clause:

5.2.6.0 *General*

- P(101) This section applies only if the use of such bars can be justified by experience or test data.

5.2.6.2 *Bond*

Replacement of Principle P(1) by:

- P(101) For bar diameters $\phi > |32|$ mm, the values f_{bd} in Table 5.3 of ENV 1992-1-1 should be multiplied by $\eta_1 * (132 - \phi)/100$ (ϕ in mm). For η_1 , see 3.1.2.3(105) of this Part 1-4.

5.2.7 Bundled high bond bars

5.2.7.1 *General*

Replacement of Principle P(1) by:

- P(101) Bundles of bars should not be used unless their use is justified by experience or test data. In that case, Section 5.2.7 of ENV 1992-1-1 applies, however with the limitation $\phi \leq |20|$ mm.

6. Construction and workmanship

This clause of ENV 1992-1-1 is applicable.

7. Quality control

This clause of ENV 1992-1-1 is applicable.

Appendix 1 Additional provisions for the determination of the effects of time-dependent deformation of concrete

Appendix 1 of ENV 1992-1-1 does not apply for lightweight aggregate concrete with closed structure.

Appendix 2 Non-linear analysis

Appendix 2 of ENV 1992-1-1 applies.

Appendix 3 Supplementary information on the ultimate limit states induced by structural deformation

Appendix 3 in Part 1-1 of ENV 1992 applies as far as deemed appropriate in each case.

Appendix 4 Checking deflections by calculation

Appendix 4 in ENV 1992-1-1 applies.

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