Communities and Local Government

Companion Document

EN 1992-1-1: Eurocode 2: Design of Concrete Structures – Part 1: General rules and rules for buildings

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Final Research Report: BD 2403

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August 2007
Department for Communities and Local Government: London

The support of The Concrete Centre in finalising this report is acknowledged.

Whilst this document provides practical guidance on the use of Eurocode BS EN 1992-1-1 and BS EN 1992-1-2 for the design of buildings, it shall only be applied in conjunction with both the Eurocode and its National Annex published by the British Standards Institution.

It should be noted that this guidance has been based on the published Eurocode, BS EN 1992-1-1:2004 and EN 1992-1-2: 2004 together with the draft of the respective National Annexes, as available at the time of writing (January 2005).

Department for Communities and Local Government
Eland House
Bressenden Place
London
SW1E 5DU
Telephone: 020 7944 4400
Website: www.communities.gov.uk

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Communities and Local Government Publications
PO Box 236
Wetherby
West Yorkshire
LS23 7NB
Tel: 08701 226 236
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FOREWORD, SCOPE AND OBJECTIVES OF THE COMPANION GUIDE

0.1 Current status of Eurocodes

The complete suite of the CEN Structural Eurocodes will be converted to full EN (European Standard) by 2005. This will include the package of codes relating to the design of buildings in concrete. Following a period of co-existence between the Eurocodes and the present National Codes, the National Codes will cease to be maintained; this period is expected to be about 5 years after conversion. The European Commission, in close co-operation with representatives of Member States has prepared a document "Application and Use of the Eurocodes" [1], and Recommendations for the use of the Eurocodes [2].

0.2 Scope and objectives of *Companion Document* to EN1992-1-1: Eurocode 2: Design of Concrete Structures – Part 1: General rules and rules for buildings

This companion guide is intended to be a "high level" document, whose target audience are principally senior members of the profession. The document is likely to have a limited life and serve as an aid to introduce EN1992-1-1 [3] during the period of co-existence (see 0.1). This guide should not be used directly for design purposes. It follows the format of EN1992-1, with Chapters 1 to 7 covering Sections 1 to 7 of EN 1992-1-1 and with Chapter 8 covering Sections 9 to 12. The Companion Document seeks to identify and discuss where appropriate

- The main differences between EN 1992-1-1 and BS 8110
- Philosophical similarities between EN 1992-1-1 and BS 8110
- Changes in design principles
- Process change/design impact
- Information on handbooks, worked examples and other guidance on EN 1992-1-1.
- Application within the UK together with the BSI National Annex.

For an explanation of the symbols used in this companion document, the reader should refer to EN 1991-1-1 or BS 8100 as appropriate

The editorial style of EN 1992-1-1 (see 0.3.2) is different from UK practice. BS 8110 gives direct guidance for the design of different member types, whereas EC2 concentrates on design principles. In this context the additional guidance produced by different organisations should prove invaluable to the UK profession; in particular the EN 1992-1-1 "How to design leaflets" (see 9.1.2(2)), explaining the basic design concepts for structural elements.

0.3 Features of EN 1992–1–1

EN 1992-1-1 gives general rules for all structures and comprehensive rules for the design of buildings in plain, reinforced and prestressed concrete. Both normal weight and lightweight concrete are included.

The Sections in EN 1992-1-1 explain the basis of different phenomena (e.g. bending, shear, bond) rather than member types (e.g. beams, slabs, columns).

All Eurocodes use the limit state approach and the partial factor method of verification.

0.4 The Eurocodes, background, objectives and their status

The Commission of the European Community decided on an action programme in the field of construction based on article 95 of the Treaty of Rome. Within this action programme the Commission took the initiative to establish a set of harmonised technical rules for the structural design of construction works, with the following European Commission objective:

"The Eurocodes to establish a set of common technical rules for the design of buildings and civil engineering works which will ultimately replace the differing rules in the various Member States".

The Commission established in the mid 1970's, a Steering Committee containing representatives of Member States, whose work on the Eurocodes programme, led to the publication of a set of first generation Eurocodes after fifteen years.

In 1989 a Special Agreement was made between CEN and the European Commission bringing the responsibility of producing the structural Eurocodes to CEN. The agreement also specified that the Eurocodes are to serve as reference documents to be recognised by authorities of the Member States for the following purposes:

a) as a means of compliance of building and civil engineering works with the Essential Requirements as set out in Council Directive 89/106/EEC (The Construction Products Directive), particularly Essential Requirement No 1 –

Mechanical resistance and stability and Essential Requirement No 2 – Safety *in case of fire.* The use of EN Eurocodes in technical specifications for products is described in the Commissions Guidance paper, 'Application and Use of Eurocodes'. [1]

b) as a basis for specifying contracts for the execution of construction works and related engineering services in the area of public works. This relates to Council Procurement Directives for:

- Works, which covers procurement by public authorities of civil engineering and building works, with a current (2004) threshold of about 5m Euros for an individual project, and

- Services, which covers procurement of services by public authorities, with current (2004) thresholds for Government Departments of 130k Euros and others, including local authorities of 200k Euros.

c) as a framework for drawing up harmonised technical specifications for construction products

0.5 Relationship between the Eurocodes and National Regulations/Public Authority Requirements

There is a clear and vital distinction between design codes and National Regulations/Public Authority Requirements. Harmonisation of National requirements is outside the scope of Eurocode development. It is the objective however that the Eurocodes, together with their appropriate National Annexes, should be recognised in National Regulations as one of the routes for meeting compliance. The legal status of the Eurocodes under the Building Regulations will be exactly the same as that of the current National Codes of Practice. In accordance with normal rules following the introduction of European Standards, Eurocodes will be called up in public procurement specifications, and to be used for the design of products for the purpose of obtaining a CE (Conformité Européen) mark. See 0.4.

CHAPTER 1
Introduction

1.1 The Eurocode System

1.1.1 EUROCODE PROGRAMME AND THE RELATIONSHIP BETWEEN VARIOUS EUROCODES

The Structural Eurocodes are shown in Table 1.1. Each, generally consists of a number of parts, which cover the technical aspects of the structural and fire design of buildings and civil engineering structures, with specific parts relating bridges. A list of the various parts and the date each EN is due will be continuously updated on the Thomas Telford website www.eurocodes.co.uk.

Table 1.1 The Structural Eurocodes

EN Number	The Structural Eurocodes
EN 1990	Eurocode: Basis of Structural Design
EN 1991	Eurocode 1: 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 of structures for earthquake resistance
EN 1999	Eurocode 9: Design of aluminium structures

The Eurocodes are a harmonised set of documents that have to be used together. Their relationship is shown in Figure 1.1.

EN 1992 includes the following four parts:

EN 1992-1-1: Common Rules for Buildings and Civil Engineering Structures

EN 1992-1-2: Structural Fire Design

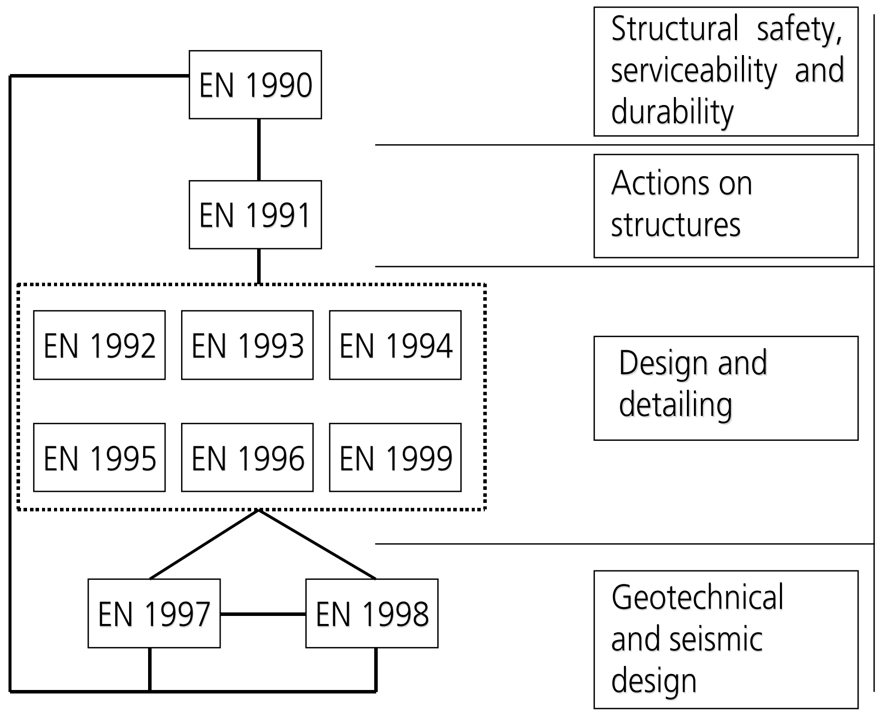
EN 1992-2: Bridges

EN 1992-3: Liquid Retaining and Containment Structures

1.1.2 LINKS WITH EN1990 AND EN1991 AND LOAD COMBINATIONS

In accordance with Figure 1.1, EN 1992-1-1 has to be used with EN 1990 [4] the head key Eurocode, the appropriate parts of EN 1991: Actions on structures and EN 1997: Geotechnical design. EN 1992-1-1 scope covers design and detailing unlike BS 8110 which also provides material independent information (i.e. partial factors for loads, load combination expressions etc). In the Eurocode system, all the material independent information to be used with all Eurocode parts is in EN 1990 for which a brief description is given in Chapter 2.

Figure 1.1 Links between the Eurocodes



1.2 Differences in philosophy between existing British Standards and Eurocodes

The principal differences relate to the guidance in EN 1990 (i.e. the requirements, the concept of design situations, representative values of actions and verification formats). These are explained in Chapter 2.

For EN 1992-1-1, its Sections explain the basis of different phenomena (e.g. bending, shear, bond) rather than member types (e.g. beams, slabs, columns) as in BS 8110.

1.3 Supporting and related documents (product standards etc): Required and available

The following standards are required for the use of EN 1992-1-1

1.3.1 GENERAL REFERENCE STANDARDS

EN 1990: Eurocode: Basis of structural design

EN 1991-1-5: Eurocode 1: Part 1-5: General actions: Thermal actions

EN 1991-1-6: Eurocode 1: Part 1-6: General actions: Actions during execution

1.3.2 OTHER REFERENCE STANDARDS

EN 1991: Eurocode 1: Actions on structures: all parts

EN 1997: Eurocode 7 Geotechnical design

EN 1998: Eurocode 8: Design of structures for earthquake resistance

EN 197-1: Cement: Composition, specification and conformity criteria for common cements

EN 206-1: Concrete: Specification, performance, production and conformity

EN 12390: testing hardened concrete

EN 10080: Steel for the reinforcement of concrete

EN 10138: Prestressing steels

EN ISO 17760: Permitted welding process for reinforcement

ENV 13670: Execution of concrete structures

EN 13791: Testing concrete

EN ISO 15630: Steel for the reinforcement and prestressing of concrete: Test methods

hENs: Construction products relevant for concrete structures

1.4 Eurocode terminology and symbols

1.4.1 TERMINOLOGY

Most of the definitions given in the Eurocodes derive from ISO 2394[R], ISO 3898[R], and ISO 8930[R]. In addition reference should be made to EN 1990 which provides a basic list of terms and definitions which are applicable to EN 1990 to EN 1999, thus ensuring a common basis for the Eurocode suite.

For the structural Eurocode suite, attention is drawn to the following key definitions, which may be different from current national practices:

- "*Action*" means a load, or an imposed deformation (e.g. temperature effects or settlement)
- "*Effects of Actions*" or "*Action effects*" are internal moments and forces, bending moments, shear forces and deformations caused by actions
- "*Strength*" is a mechanical property of a material, in units of stress
- "*Resistance*" is a mechanical property of a cross-section of a member, or a member or structure.

1.4.2 SYMBOLS

The notation in the Eurocodes is based on ISO 3898[R].

There are a few important changes from previous practice in the UK. For example, an *x-x* axis is along a member, a *y-y* axis is parallel to the flanges of a section, and z-z is the perpendicular to the flanges of a section.

Characteristic values of any parameter are distinguished by a subscript "k". Design values have the subscript "d".

1.5 The use of EN1992-1-1 for structural concrete design

1.5.1 DISTINCTION BETWEEN PRINCIPLES AND APPLICATION RULES

The clauses in the EN 1991-1-2 are set out as either Principles or Application Rules. They are set out, as below, in EN 1990 and referred to by the other Eurocode parts.

- *"Principles comprise general statements and definitions for which there is no alternative, as well as requirements and analytical models for which no alternative is permitted unless specifically stated"*

- *"The Principles are identified by the letter P following the paragraph number"*. The word **shall** is always used in the Principle clauses

- *"The Application Rules are generally recognised rules which comply with the Principles and satisfy their requirements"*

- *"It is permissible to use alternative design rules different from the Application Rules given in EN 1991-1-1 for works, provided that it is shown that the alternative rules accord with the relevant Principles and are at least equivalent with regard to the structural safety, serviceability and durability which would be expected when using the Eurocodes"*. (i.e. the safety coefficient β as defined in EN 1990 [4] should be the same or greater than that of the application rule considered)

EN 1990 through a note to this point states

If an alternative design rule is substituted for an Application Rule, the resulting design cannot be claimed to be wholly in accordance with EN 1991-1-1 although the design will remain in accordance with the Principles of EN 1991-1-1. When EN 1991-1-1 is used in respect of a property listed in an Annex Z of a product standard or an ETAG, the use of an alternative design rule may not be acceptable for CE marking.

With regard to the note to, the European Commission guidance paper L, Application and Use of the Eurocodes [1] states:

National Provisions should avoid replacing any EN Eurocode provisions, e.g. Application Rules, by national rules (codes, standards, regulatory provisions, etc).

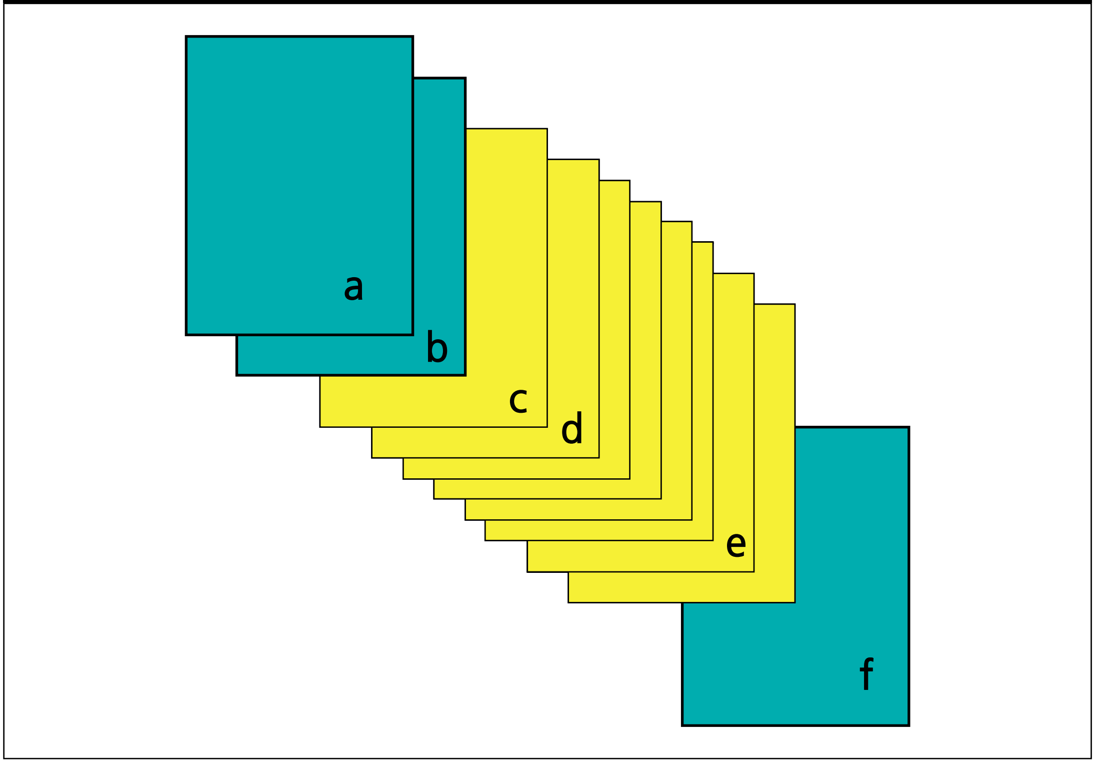
When, however, National Provisions do provide that the designer may – even after the end of the co-existence period – deviate from or not apply the EN Eurocodes or certain provisions thereof (e.g. Application Rules), then the design will not be called "a design according to EN Eurocodes".

- *"Application Rules are identified by a number in brackets"* (only). The verb **should** is normally used for application rules. The verb **may** is also used for example as an alternative application rule. The verbs **is** and **can** are used for a definitive statement or as an assumption.

1.6 Role of National Annex – Using EN Eurocode at a National level

It is the responsibility of each national standards body (e.g. British Standards Institute (BSI) in the UK) to implement Eurocodes as national standards.

Figure 1.2 National Standards Implementing Eurocodes



Key
a: National Title Page; b: Foreword; c: EN Title page; d: EN Text; e: EN Annexes; f: National Annex

The national standard implementing each Eurocode part – will comprise, without any alterations, the full text of the Eurocode and its annexes as published by the CEN (Figure 1.2, *boxes c, d and e*). This may be preceded by a national title page (*box a*) and national foreword (*box b*), and may be followed by a national annex (*box f*). (See 1.6.1).

1.6.1 RULES AND CONTENTS OF NATIONAL ANNEXES FOR EUROCODES

The European Commission recognising the responsibility of regulatory and national competent authorities in each EU Member State has safeguarded their right to determine values related to safety matters at national level through a national annex. These safety matters include different levels of protection that may prevail at national, regional or local level, and ways of life.

A National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, (see 1.6.2) to be used for the design of buildings and civil engineering works to be constructed in the country concerned. Where a Eurocode Clause allows choice, a recommended value or method is given.

1.6.2 NATIONALLY DETERMINED PARAMETERS (NDPs)

NDPs will allow Member States to choose the level of safety, applicable to their territory. The values, classes or methods to be chosen or determined at national level, are:

- Values and/or classes where alternatives are given in the Eurocode (e.g. levels of safety)

- Values to be used where only a symbol is given in the Eurocode (e.g. partial factors)

- Country-specific data (geographical, climatic, etc) (e.g. snow maps)

- Procedures to be used where alternative procedures are given in the Eurocodes.

1.6.3 NATIONAL ANNEXES

The National Standards Bodies (i.e. BSI in the UK) should publish the NDPs in a National Annex. A National Annex is not required if a Eurocode part is not relevant for the Member State (e.g. seismic design for some countries).

In addition to NDPs a National Annex may also contain:

- Decisions on the application of informative annexes

- References to non-contradictory complementary information *(NCCI)* to assist the user in applying the Eurocode.

It should be noted that in EN 1992-1-1, NDPs are used for other situations than just to safeguard Member States' rights to define safety. They have been used to cover situations where there is no possibility of a consensus view being reached on an issue (e.g. for most of the serviceability section and the sections on detailing rules in EN 1992-1-1). It is hoped that in the first revision of EN 1992-1-1 many of these NDPs will be rationalised.

CHAPTER 2

Basis of Structural Design

2.1 The use of EN1990 for structural concrete design

2.1.1 DIFFERENCES BETWEEN EN 1990: EUROCODE BASIS OF STRUCTURAL DESIGN AND UK PRACTICE

This Chapter briefly describes the objectives of EN 1990, lists the requirements and provides information on the representative values of the loads to be used in the combination of actions for use with the design and detailing clauses of EN 1992-1-1. It also gives the values adopted by the BSI national annex to EN 1990.

There are some differences between EN 1990 and UK practice (i.e. the material independent clauses from Chapter 2 of BS 8110 and Chapter 2 of BS 5950 etc). The principal differences that will be explained here are:

- The requirements of EN 1990 (see 2.1.3)
- The design situations to consider for both the ultimate and serviceability limit states (see 2.1.3 c)
- The representative values of the actions to use for the different design situations (see 2.1.5)
- The expressions for combining the effects of actions (see 2.1.6)
- The factors of safety to use for the appropriate design situations (see 2.1.6.3 and 2.1.7.2)
- Choices made in the UK National Annex to EN 1990 (see 2.1.8).

Gulvanessian, Calgaro and Holicky provide a comprehensive description, background and commentary to EN 1990 [5]. Chapter 2 of the BRE Handbook on Actions on Structures also provides guidance on EN 1990 [6], which describes the background to the selections made in the BSI National Annex to EN 1990.

2.1.2 OBJECTIVES AND FUNCTION AND REQUIREMENTS OF EN 1990

EN 1990 [4] is the head key Eurocode for the harmonised Structural Eurocodes. EN 1990 establishes and provides comprehensive information and guidance for all the Eurocodes, on the principles and requirements for safety, serviceability, describes the basis of their design and verification, and gives guidelines for related aspects of structural reliability and durability of structures. It is based on the limit state concept and used in conjunction with the partial factor method. EN 1992 *does not give* the material-independent clauses required for design. These are only included in EN 1990. Hence very importantly EN 1990 has to be used with all the Eurocode parts and it provides the information for safety factors for actions and combination for action effects for the verification of both ultimate and serviceability limit states.

2.1.3 REQUIREMENTS

The requirements of EN 1990 which need to be adhered to by EC2 are

(i) Fundamental Requirements: These relate to safety, serviceability and robustness requirements

(ii) Reliability Differentiation

(iii) Design Situations: EN 1990 stipulates that a relevant design situation is selected taking account of the circumstances in which the structure may be required to fulfil its function. 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.

(iv) Design Working Life: For buildings and other common structures the recommended design working life (i.e. the assumed period for which a structure is to be used for its intended purpose with anticipated maintenance but without major repair being necessary) is 50 years. For concrete, design working life needs to be considered for material property deterioration, life cycle costing and evolving maintenance strategies.

(v) Durability

(vi) Quality Assurance

The above requirements are discussed comprehensively in [5] and [6]

2.1.4 PRINCIPLES OF LIMIT STATE DESIGN

2.1.4.1 Ultimate and Serviceability Limit States

(a) Ultimate limit states are those associated with collapse or with other forms of structural failure and concern:

- The safety of people in or about the structure and
- The safety of the structure and its contents.

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

- The functioning of the construction works or parts of them
- The comfort of people in or about the structure and
- The appearance.

2.1.4.2 Limit State Design

Limit state design is carried out by:

- Setting up structural and load models for relevant ultimate and serviceability limit states (i.e. the design situations, see 2.1.3(iii) and 2.1.4.1(b)) to be considered in the various design situations and load cases and
- Verifying that the criteria for a limit state is not exceeded when the design values for actions, material properties and geometrical data are used in the models.

There are differences between the concept of design situations approach in EN 1990 and approach of the BSI codes. In the verification of serviceability limit states in EN 1990, separate load combination expressions are used depending on the design situation being considered. For each of the particular design situations an appropriate representative value for an action is used, (see 2.1.7).

2.1.5 THE REPRESENTATIVE VALUES OF THE ACTIONS TO USED FOR THE DIFFERENT DESIGN SITUATIONS

2.1.5.1 The representative values of the actions

In addition to the characteristic values of actions which are similar to the BSI definition, other representative values are specified in EN 1990 for variable and accidental actions. Three representative values commonly used for variable actions are the combination value $\psi_0 Q_k$, the frequent value $\psi_1 Q_k$ and the quasi-permanent value $\psi_2 Q_k$. The factors ψ_0, ψ_1 and ψ_2 are reduction factors of the characteristic values of variable actions.

The combination value $\psi_0 Q_k$, the frequent value $\psi_1 Q_k$, and the quasi-permanent value $\psi_2 Q_k$ are explained below.

The combination value $\psi_0 Q_k$ is associated with the combination of actions for ultimate and irreversible serviceability limit states (the serviceability limit states where some consequences of actions exceeding the specified service requirements will remain when the actions are removed) in order to take account of the reduced probability of simultaneous occurrence of the most unfavourable values of several independent actions.

The frequent value $\psi_1 Q_k$ is primarily associated with the frequent combination in the serviceability limit states and it is also assumed to be appropriate for verification of the accidental design situation of the ultimate limit states. In both cases the reduction factor ψ_1 is applied as a multiplier of the leading variable action.

The main use of **quasi-permanent values $\psi_2 Q_k$** is the assessment of long-term effects, for example in checking cracking or deflection. But they are also used for the representation of variable actions in accidental and seismic combinations of actions (ultimate limit states) and for verification of frequent and quasi-permanent combinations (long term effects) of serviceability limit states.

Values for all the three coefficients ψ_0, ψ_1 and ψ_2 for buildings are given in the BSI National Annex A to EN 1990. [4]

2.1.6 VERIFICATION BY THE PARTIAL FACTOR METHOD

Note: The expression numbers given in the Chapter are those given in EN 1990.

2.1.6.1 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.

a) For the limit state verification for static equilibrium (EQU)

$$E_{d,dst} \leq E_{d,stb} \qquad (6.7)$$

where :

$E_{d,dst}$ is the design value of the effect of destabilising actions;

$E_{d,stb}$ is the design value of the effect of stabilising actions.

b) For internal failure or excessive deformation of the structure or structural members, including footings, piles, basement walls, etc., where the strength of construction materials of the structure governs (STR); and for failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance (GEO);

$$E_d \leq R_d \qquad (6.8)$$

where :

E_d is the design value of the effect of actions such as internal force, moment or a vector representing several internal forces or moments;

R_d is the design value of the corresponding resistance.

2.1.6.2 Combination of Actions for Ultimate Limit States

a) The fundamental (persistent and transient) design situations for ultimate limit state verifications, other than those relating to fatigue, are symbolically represented as follows:

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

This combination assumes that a number of variable actions are acting simultaneously, Q_{k1} is the *dominant* variable action and this is combined with the combination value of the *accompanying* variable actions Q_{ki}.

P is a relevant representative value for prestressing actions.

Alternatively EN 1990 allows the use of the following equations together.

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

where ξ is a reduction factor for γ_{Gj} within the range 0.85 to 1.

In the case of (6.10a) and (6.10b) the National Annex may additionally modify expression 6.10a to include permanent actions only. (i.e. The variable actions are not included in (6.10a)).

The more unfavourable of expressions (6.10a) and (6.10b) may be applied instead of expression 6.10, but only under conditions defined by the National Annex.

EN 1990 also provides expressions for verifying both the accidental and seismic design situations.

2.1.6.3 Partial factors for the ultimate limit states

For buildings, the recommended partial factors for the persistent and transient situation in EN 1990 are $\gamma_G = 1.35$ and $\gamma_Q = 1.5$, but these may be altered by the National Annex. Values of combination coefficient ψ are given in EN 1990.

2.1.7 SERVICEABILITY LIMIT STATES

For the serviceability limit states verification EN 1990 stipulates that:

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

where :

C_{d} is the limiting design value of the relevant serviceability criterion.

E_{d} is the design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination.

2.1.7.1 Combination of Actions for the Serviceability Limit States

For serviceability limit states verification, EN 1990 requires the three combinations below to be investigated: EN 1990 gives three expressions for serviceability design: characteristic, frequent and quasi-permanent.

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

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

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.

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

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

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

2.1.7.1 Partial factors for Serviceability Limit states

Unless otherwise stated (e.g. in EN1991 to EN1999), the partial factors for serviceability limit states are equal to 1.0. ψ factors are given in EN 1990.

2.1.8 RECOMMENDATIONS FOR COMBINATION AND PARTIAL FACTORS TO BE ADOPTED IN THE BSI NATIONAL ANNEX

2.1.8.1 Choice of NDPs for the BSI National Annex to EN 1990 for serviceability limit state verification

Based on the considerations of:

- Levels of reliability “enjoyed” in the UK and
- Usability, both for the super-structure and the sub-structure.

The UK national Annex has adopted the use of either:

- **Expression 6.10 with γ_G = 1,35 and γ_Q = 1,5, or**
- **Expression 6.10a and 6.10b with γ_G = 1,35 and γ_Q = 1,5 and ξ = 0,925.**

for the persistent and transient design situations with the EN 1990 recommended Ψ values, except the ψ_0 values for wind is reduced from 0,6 to 0,5.

For the accidental design situations Expression (6.11b) of EN 1990 is adopted in the BSI National Annex and $\psi_{1,1}$ is chosen for the loading variable action.

2.1.8.2 Choice of NDPs for the BSI National Annex to EN 1990 for serviceability limit state verification

The BSI National Annex adopts the expression (6.14b) and (6.15b) and (6.16b) with γ =1, and the ψ values as for the ultimate limit state verifications.

2.2 Resistance partial factors

The material partial safety factors γ_c and γ_s are given in Chapter 6, Clause 6.6 for ultimate limit state verifications and Chapter 7, Clause 7.3 for serviceability limit state verifications.

CHAPTER 3
Materials

3.1 Concrete – Comparison between EN 1992-1-1 and BS 8110

3.1.1 CYLINDER/CUBE STRENGTH

The cylinder strength of concrete is used in all expressions in EN 1992-1-1.

EN 1992-1-1 gives the relationship between cube and cylinder strengths. Throughout EN 1992-1-1, reference to concrete strength class uses both the cube and cylinder strengths (e.g. C 30/37, in which 30 is the cylinder strength in MPa (N/mm^2) and 37 is the corresponding cube strength).

Note: The cylinder strength is approximately 80% of the cube strength.

3.1.2 STRENGTH CLASSES

EN 1992-1-1 provides guidance for design using certain high strength concretes, which BS8110 does not. The maximum characteristic cylinder strength f_{ck} permitted is 90N/mm^2, which corresponds to a characteristic cube strength of 105N/mm^2 (i.e. C90/105).

EN 1992-1-1 provides guidance values, which may be used in the absence of better data, for the consideration of creep, shrinkage and elastic modulus.

3.1.3 NON-LINEAR CREEP

When the concrete compressive service stress at loading exceeds 0.45 f_{ck}, creep should be considered as being non-linear. This will normally only come into effect where there are high levels of pre-stress.

3.1.4 DESIGN COMPRESSIVE AND TENSILE STRENGTHS

In determining the value of the design compressive strength EN 1992-1-1 recommends a value for α_{cc} equal to 1,0.

Note: EN 1992-1-1 defines α_{cc} as follows.

"α_{cc} *coefficient taking account of long term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied*."

Using a value of 1,0 in the UK will have an identical effect on design as changing the partial safety factor, γ_c, from 1.5 to 1.275 for the design of sections for flexure or flexure combined with axial load.

In the absence of a clear justification for such a reduction in safety the BSI National Annex to EN 1992-1-1 has adopted a value for α_{cc} equal to 0.85.

Note: The value of 0.85 was first explicitly given in the 1970 CEB/FIP "Recommendations for an international code of practice for reinforced concrete" Though the definitions of α_{cc} have changed from document to document, the value of 0.85 has remained unchanged and is included in the CEB 1990 Model Code.

3.1.5 STRESS BLOCK

The forms of stress block and comparisons between EN 1992-1-1 and BS 8110 are given in Chapter 6.

3.1.6 PRODUCTION OF CONCRETE

The production of concrete should comply with the provisions of EN 206[7] and BS 8500 Part 2 [11].

3.1.7 DENSITIES FOR CONCRETE

In EN 1991-1-1 [9] a value of 25kN/m^3 is given for the density of normal weight concrete compared to the value of 23.6 kN/m^3 given in BS 8110.

3.2 Reinforcement and prestressing steel – Comparisons between EN 1992-1-1 and BS 8110

3.2.1 REINFORCING STEEL

The reinforcement specified when using EN 1992-1-1 generally needs to comply with EN 10080, and the Annex C (Normative) of EN 1992-1-1 for the mechanical properties. Information is given only for ribbed reinforcement.

Note: The true characteristic strength of reinforcement currently used in the UK is 500 MPa and the partial factor of 1.15 should be applied to this strength.

3.3 Ductility requirements

EC2 specifies three levels of ductility for reinforcing steel. If class **A** reinforcement is used, the maximum amount of redistribution permitted is 20% otherwise the upper 30% limit applies. Class **C** reinforcement needs only be specifically specified for seismic designs or in other situations requiring high ductility such as in cold climates, though its use in other circumstances is acceptable.

3.3.1 PRESTRESSING STEEL

Prestressing steel should comply with EN 10138.

CHAPTER 4

Durability and cover to reinforcement

4.1 Comparison between EN 1992-1-1 and BS 8110

Comparisons between EN 1992-1-1 and BS 8110 made in this companion document have assumed that the required covers to be provided are essentially unaltered. Simplified guidance to enable engineers to determine the required cover to be provided in different circumstances is in course of preparation and will be included within the BSI National Annex to EN 1992-1-1.

Cover for durability and bond requirements is specified as a minimum value in EN 1992-1-1 whereas BS8110 specifies cover as a nominal value.

Compared to BS 8110, durability considerations are considered in a more explicit manner in EN 1992-1-1. For example EN 1992-1-1 has classifications based around potential deterioration mechanisms. The concept of an explicitly defined design life is included and the designer is required to identify the most severe environmental conditions for each particular case, rather than assessing the environmental exposure as for BS 8110.

The concept of an explicitly defined design life and the recognition of the need to take additional measures if this design life is required to be significantly exceeded must be seen as a positive step forward.

4.2 Determination of required cover and link to design working life and exposure class

EN 206 [7] defines six exposure classes and these are repeated in EN 1992-1-1. EN 1992-1-1 recommends concrete grades and cover to reinforcement for design working life of 50 and 100 years.

The BSI National Annex will provide its own values. Covers to be shown on the drawings are nominal values, which are the sum of the minimum value required for durability and the construction/production tolerance, $\Delta_{c,dev}$.

CHAPTER 5

Structural analysis

5.1 Load cases and combinations

5.1.1 COMPARISON BETWEEN EN 1992-1-1 AND BS 8110

a) Expressions for the combination of action effects, and values for partial factors

Chapter 2 describes the two basic approaches given in EN 1990 for combining action effects (e.g. expression (6.10), or expressions (6.10a) and (6.10b) acting together). Expression (6.10) is similar in concept to BS 8110 expressions. However when two variable actions are being considered there are large differences between EN 1990 and the BSI recommendations, as EN 1990 more logically uses the representative value of the action (See 2.1.5).

Table 5.1 Comparison of partial safety factors for actions for the ultimate limit state verification for unfavourable actions

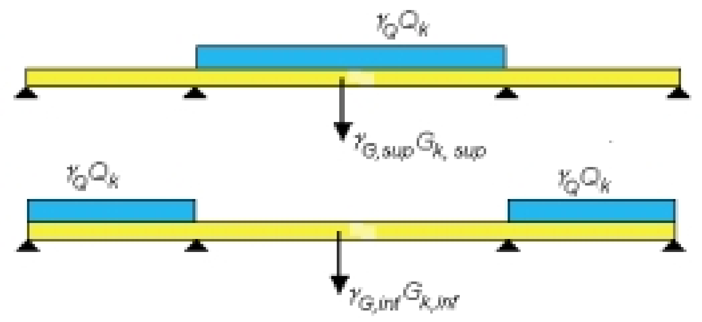
Condition	EN 1990 (expression 6.10)			BS 8110		
	$\gamma_{G,sup}$	γ_Q leading	γ_Q accompanying	$\gamma_{G,sup}$	γ_Q leading	γ_Q accompanying
One Variable Action	1,35	1,5	N/A	1,4	1,4 or 1,6	N/A
≥ Two Variable Actions	1,35	1,5	$\psi_0$1,5	1,2	1,2	1,2

b) Explanation of $\gamma_{G,sup}$ and $\gamma_{G,inf}$

EN 1990 differentiates between unfavourable ($\gamma_{G,sup}$) favourable ($\gamma_{G,inf}$) effects of an action. Table 5.1 applies for unfavourable effects. When the effects of the action are favourable on the member then for EN 1990 $\gamma_{G,inf} = 1,0$ and $\gamma_Q = 0$.

Considering the differences in resistance partial factors γ_M, the results for one variable action agree closely between EN 1990 and the BSI codes. For more than one variable action the level of safety offered by EN 1990 is appreciably higher, as described by Gulvanessian and Holicky [9].

Figure 5.1 Treatment of alternate spans by EN 1990/EN 1992-1- 1



c) Treatment of loading for alternate spans

A major difference between EN 1990 and the BSI system is the partial safety factor appropriate to the permanent actions for unloaded spans.

Considering verification using expression 6.10, the use of $\gamma_{G,sup}$ or $\gamma_{G,inf}$ and the load arrangements for permanent and variable actions are illustrated in Figure 5.1. (Note: In the top diagram all three spans are loaded with $\gamma_{G,sup}$, and in the lower diagram all three spans are loaded with $\gamma_{G,inf}$). The top diagram will give the maximum sagging moment in the central span and the lower diagram will give the hogging moment in the central span. The top diagram with $\gamma_{G,inf}$ instead of $\gamma_{G,sup}$ will give the hogging moment in the end spans and the lower diagram with $\gamma_{G,sup}$ instead $\gamma_{G,inf}$ will give the hogging moment in the end spans.

When using Expression 6.10 the values of $\gamma_{G,sup}$ and $\gamma_{G,inf}$ are 1,35 and 1,00 respectively with γ_Q = 1,5. When using expressions 6.10a and 6.10b**,** $\gamma_{G,sup}$ is multiplied by the reduction factor ξ = 0,925 becoming 1,25. The other values are not altered.

Note: The proposed BSI National Annex is also permitting the simplified load combinations of all spans and alternate spans loaded according to the guidance given in BS8110 to be considered sufficient, in the majority of cases.
For slabs the proposed BSI National Annex is permitting the “all spans loaded condition” to be considered sufficient, subject to the same restrictions as in BS 8110.

5.2 Geometric Imperfections

In EN 1992-1-1, The unfavourable effects of possible deviations in the geometry of the structure and the position of loads need to be taken into account, in ultimate limit states in persistent and accidental design situations only. The imperfections need to be taken into account together with other actions (e.g. lateral loads such as wind loads). The structure is assumed to be out of plumb with a recommended value of 1/200 for the basic inclination. The effects of the inclination may be represented by an equivalent horizontal loads (inclination × the vertical loads) are applied to the structure.

In BS 8110 only the more critical effect is used in design.

5.3 Idealisation of structures

5.3.1 DEFINITIONS OF MEMBER TYPES ACCORDING TO GEOMETRY

IN EN 1992-1-1 the elements of a structure are classified, by consideration of their nature and function, as beams, columns, slabs, walls etc. EN 1992-1-1 provides rules for the commoner elements and of structures consisting of a combination of these.

EN 1992-1-1 defines particular members as follows

- A *beam* where its span is not less than 3 times the overall depth
- A *slab* where its minimum panel dimension is not less than 5 times the overall slab thickness
- A *column* where its section depth does not exceed 4 times its width and its height is at least 3 times the section depth. Otherwise it should be considered as a *wall.*

EN 1992-2-1 gives guidance on determining the effective flange width in T and L beams, and the effective span of beams and slabs in buildings. Unlike BS 8110, effective widths of tension flanges are also given (*used for stiffness estimation when checking cracking and deflection*).

5.4 Redistribution

As in BS 8110 limited redistribution of moments without an explicit check on the rotation capacity of sections is permitted by EN 1992-1-1. As the strength of concrete increases it becomes more brittle. Therefore different formulae are given for $f_{ck} \leq$ 50N/mm^2 and for $f_{ck} > 50$ N/mm^2.

5.5 Slenderness and effective length of isolated members

To decide whether a column needs to be considered as slender and to determine its slenderness ratios, the effective lengths of a column in both directions need to be determined. The effective lengths are dependent on whether the column may be assumed to be braced or unbraced (“non-sway” or “sway” in Eurocode terminology).

For determining effective lengths,

- BS8110 provides tables of values of β with assessment of the end conditions that are appropriate. β can range from 0.75 to 2.2

- The EN 1992-1-1 procedure appears more complicated, as an assessment needs to be made of the relative flexibilities of the rotational restraints at each end of the column. However this process can be simplified by making conservative assumptions.

For determining slenderness ratios.

- In BS8110 the limits on slenderness ratio l_{ex}/h and l_{ey}/h are 15 (braced) and 10 (unbraced) for stocky columns

- In EN 1992-1-1 the slenderness ratio λ is calculated from l_0/i where l_0 is the effective length and i is the radius of gyration of the uncracked cross section. For a rectangular section ignoring the reinforcement, this simplifies to $\lambda = 3.464\ l_0/h$. The slenderness should be checked in both directions.

Note: There is no value of λ specified as a cut-off between short and slender columns, but in practice, second order effects (*slenderness*) need to be considered above an l_0/h ratio of about 15.

For columns designed to EN 1992-1-1, using the nominal curvature method which it is probably the more straightforward of the three alternative methods given, the final design moment is increased by the additional moment to account for second order effects. Once this adjustment has been made the N-M interaction charts may be used as before. The same approach is used for BS8110 except that the second order moments are calculated differently.

5.6 Biaxial bending

With EN 1992-1-1 a separate design may initially be carried out in each principal direction. Imperfections need be taken into account only in the direction where they will have the most unfavourable effect.

No further check is necessary if:

$\lambda_y/\lambda_x \leq 2$ and $\lambda_x/\lambda_y \leq 2$

and $(e_y/h)/(e_x/b) \leq 0.2$ or $(e_x/b)/(e_y/h) \leq 0.2$

e_x and e_y are the effective total eccentricities including second order effects.

If the above conclusions are not fulfilled and biaxial bending needs to be considered, the following simplified criterion may be used:

$(M_{Edx}/M_{Rdx})^a + (M_{Edy}/M_{Rdy})^a \leq 1.0$

$M_{Edx,y}$ = Design moment of resistance in the respective direction including second order effects

$M_{Rdx,y}$ = Moment of resistance in the respective direction

a = exponent dependent on geometry

For biaxial bending, BS8110 states that symmetrically reinforced rectangular sections may be designed to withstand an increased moment about one axis. It is known that this approach can be unsafe in extreme circumstances, so the introduction of the above the methods of EN 1992-1-1 are welcomed.

CHAPTER 6

Ultimate limit states

Note: The Sections in the EN 1992-1-1 explain the basis of different phenomena (e.g. bending, shear, bond) rather than member types (e.g. beams, slabs, columns). The more common phenomena (bending, shear, punching shear and members in compression) are discussed in this Chapter.

6.1 Design of flexural elements at the ultimate limit state

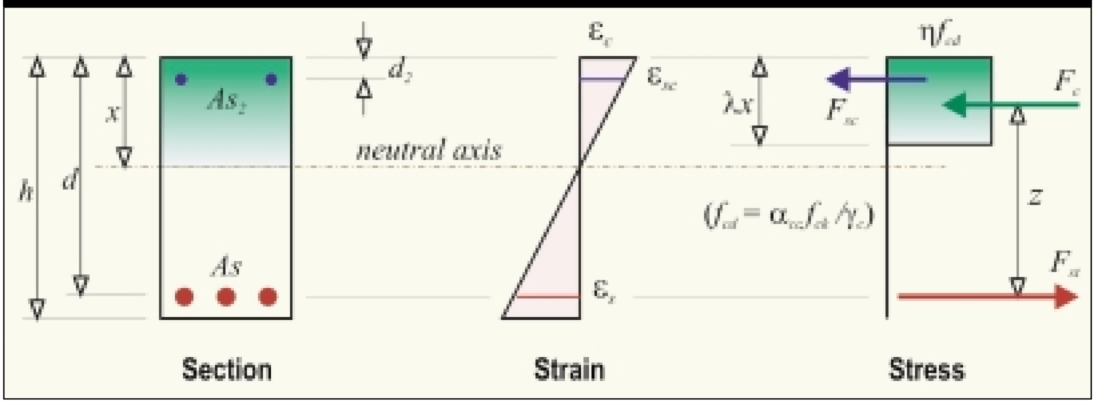
The design of flexural elements to EN 1992-1-1 is very similar to that of BS8110. Where EN 1991-1-2 differs, is that it does not generally give element specific design guidance like BS 8110. The Eurocode provides the general principles to be applied. This approach is less restrictive and should encourage innovative design methods.

Several options are given in the Eurocode for the type of stress-strain relationship that may be assumed for concrete design. In many cases the designer is likely to opt for the simple rectangular stress block.

6.1.1 COMPARISON OF STRESS BLOCKS OF EN 1992-1-1 BS8110

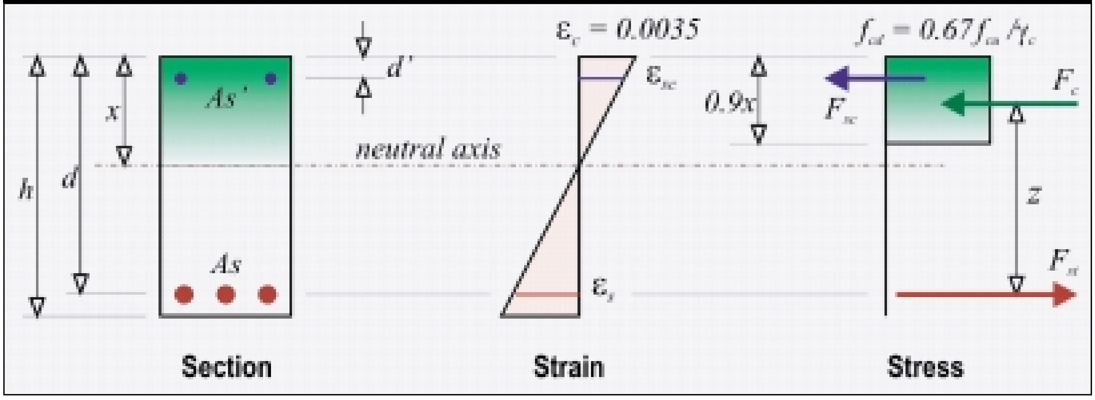
The stress block from EN 1992-1-1 is shown in Figure 6.1

Figure 6.1 EN 1992-1-1 stress block



The stress block from BS 8110 is shown in Figure 6.2

Figure 6.2 BS8110 stress block



For bending with or without axial force, the basic assumptions of the Eurocode are similar to those of BS 8110. A simplified rectangular stress block is permitted as shown in Figure 6.1. For EN 1992-1-1, see Figure 6.1 a value of 0.85 for α_{cc} has been adopted in the BSI National Annex . The EN 1992-1-1 parameters η (defining the effective strength) and λ (defining the effective height of the compression zone), together have the effect of reducing the allowable concrete force for higher strength concretes (above C50/60).

Up to C50/60 λ=0.8 and η=1.0 are used. Above C50/60 expressions are introduced in EN 1992-1-1, where the value of the stress and the depth of the stress block become a function of concrete strength.

Note: According to parametric studies considering the impact of the different stress block on the design of rectangular beams using linear elastic analysis with limited redistribution there is very little practical difference between EN 1992-1-1 and BS 8110. This conclusion can also be assumed for solid slabs designed using linear elastic analysis with limited redistribution.

6.2 Shear

In EN 1992-1-1 as in BS8110 the design shear resistance depends on concrete strength, effective depth and tension steel ratio. EN 1992-1-1 requires the tension in the longitudinal reinforcement implicit in the shear model to be taken into account in addition to that caused by bending moment.

6.2.1 MEMBERS NOT REQUIRING DESIGN SHEAR REINFORCEMENT

Calculated shear reinforcement need not be provided when the design value of the applied shear force is less than the design shear resistance of the member without shear reinforcement. As with BS 8110 most members will however require *minimum* shear reinforcement, in accordance with EN 1992 detailing requirements.

The recommended design shear resistance of a member considering concrete alone, is determined below using EN 1992:

$$v_{Rd,c} = \frac{0.18}{\gamma_c} k \left(100 \rho_l f_{ck}\right)^{1/3} \geq v\min = 0.035 k^{3/2} \sqrt{f_{ck}} \text{ for } \sigma_{cp} = 0$$

Where k = 1 + √(200/d) ≤ 2

$\rho_l = A_s/(bd) \leq 0.02$

The value $0.18/\gamma_c$ and the expression for the minimum concrete shear stress v_{min} are recommended values which may be altered in the National Annex.

With γ_c = 1.5, comparison with the values of v_c given in Table 3.8 of BS8110 indicates that, BS 8110 generally allows a higher design shear resistance before shear reinforcement is required. EN 1992 can however allow higher design shear resistance for low reinforcement percentages, and this effect is accentuated the higher the strength of the concrete.

6.2.2 MEMBERS REQUIRING DESIGN SHEAR REINFORCEMENT

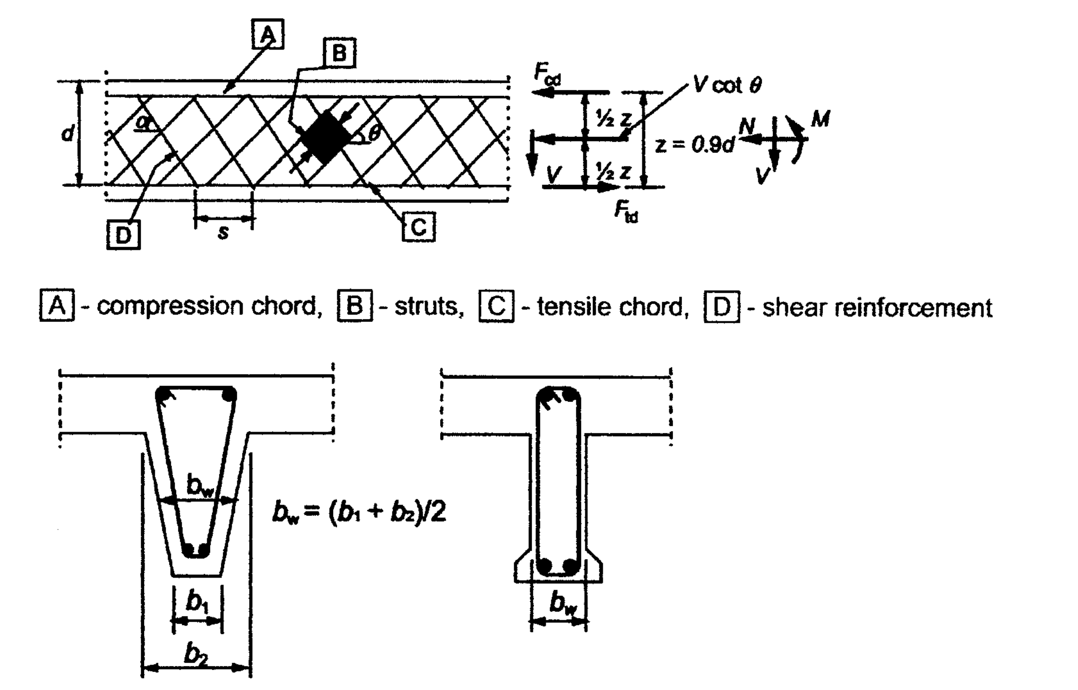
Calculated shear reinforcement needs to be provided when the design value of the applied shear force is greater than the design shear resistance of the member without shear reinforcement.

EN 1992 differs from BS8110 in that above the limit at which the concrete alone provides sufficient capacity, the designed shear steel to be provided is determined ignoring the contribution from the concrete.

6.2.2.1 The truss model

The design method used in EN 1992-1-1 is known as the variable strut inclination method and is based on a truss model.

Figure 6.3 Truss model and notation for shear reinforced members



α angle between shear reinforcement and the main tension chord.
θ angle between concrete compression struts and the main tension chord.
F_{td} design value of the tensile force in the longitudinal reinforcement
F_{cd} design value of the concrete compression force in the direction of the longitudinal member axis.
b_w design web width.
z denotes, for a member with constant depth, the inner lever arm corresponding to the maximum bending moment in the element under consideration, in the shear analysis, the approximate value z = 0.9d can be normally used.

For members not subjected to axial forces the required area of shear reinforcement needed in the form of links, calculated at a distance *d* from the support face, is according to EN 1992 given by:

$$A_{sw}/s = V_{Ed}/(0.9d\,f_{ywd}\cot\theta)$$

The BS8110 expression gives:

$$A_{sv}/s_v = b_v(v-v_c)/f_y v_d$$

6.2.2.2 Choice of Cot θ

The National Annex to EN 1992 may choose an appropriate angle θ (i.e. the angle between the assumed concrete compression strut and the main tension chord). θ should be chosen between 22 and 45 degrees so that

$$1 \leq \cot\theta \leq 2{,}5$$

The largest possible value of cotθ should normally be used to minimise the number stirrups required. Both EN 1992-1-1 and BS8110 specify a maximum shear capacity that cannot be exceeded.

In BS8110 this limit is $0.8\sqrt{f_{cu}} \leq 5$ N/mm^2.

For members with vertical shear reinforcement, the maximum possible shear resistance V_{Rd} is given by:

$V_{Rdmax}=\alpha_{cw} b_w z \nu f_{cd}/(\cot\theta+\tan\theta)$ (expression 6.9 of EN 1992-1-1)

where $\nu = 0.6(1-f_{ck}/250)$

$f_{cd} = \alpha_{cc} f_{ck}/\gamma_c$ (expression (3.15) of EN 1992-1-1

and $\alpha_{cw}=1$ for non-prestressed structures

For a given required shear capacity the amount of shear reinforcement to be provided when designing to EN 1992-1-1 is dependent upon cot θ which should be maximised by equating the design shear force to the maximum possible shear force V_{Rdmax} if $\cot\theta<2.5$. The maximum allowable value of $\cot\theta$ is found by equating the design shear force V_{Ed} to V_{Rdmax}.which leads to the following inequality:

$$1 \leq \cot\theta = \frac{\omega + \sqrt{\omega^2 - 4}}{2} \leq 2.5$$

where $\omega = \cot\theta + \tan\theta = \dfrac{0.9 b_w d \nu f_{cd}}{V_{Ed}}$

Therefore the concrete strength influences the amount of shear reinforcement provided, if cot θ needs to be less than 2.5 to satisfy the criterion on maximum shear capacity. The maximum possible shear stress corresponds to $\cot\theta=1$ and is given by:

$V_{Rdmax}/b_w d=0.45\,\nu$

If the design stress of the shear reinforcement is below 80% of the characteristic yield stress f_{yk}, ν may be taken as:

$\nu = 0.6$ up to C60

$\nu = 0.9 - f_{ck}/200 > 0.5$ for grades above C60

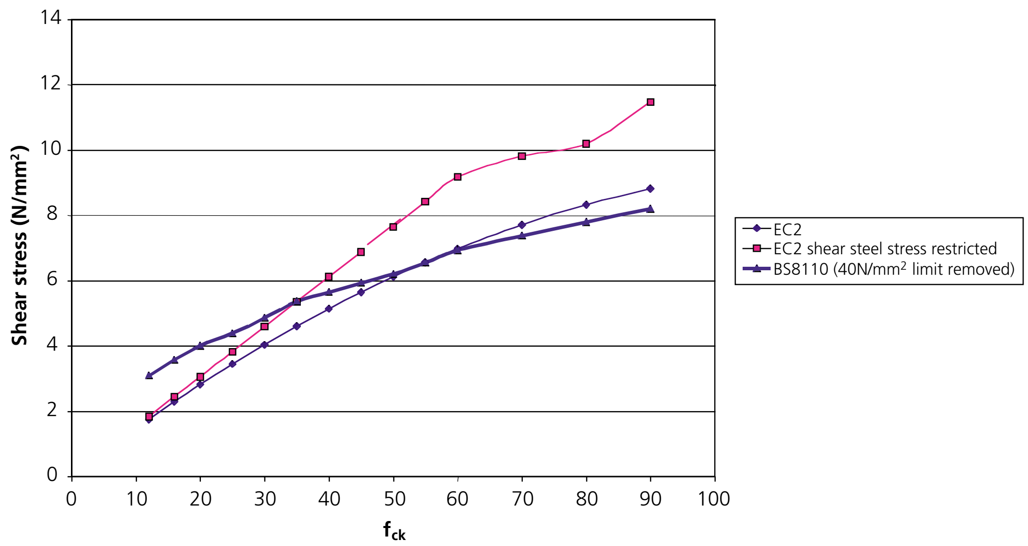
EN 1992-1-1 and BS 8110 have been compared with

- *$\alpha_{cc} = 0.85$ and $\gamma_c = 1.5$ and*
- *ignoring the increase allowable for ν if the stress in the shear steel is restricted.*

EN 1992-1-1 allows a smaller maximum shear capacity at low strengths, but a higher capacity at higher strengths principally arising from the cut off of 5 N/mm^2 in BS8110.

The increase in the allowable shear stress becomes quite significant when increased values of ν are permitted even ignoring the cut-off in BS8110 as illustrated in Figure 6.4.

Figure 6.4 Comparison of maximum permissible shear stresses



The additional tensile force ΔF_{td} in the longitudinal reinforcement due to shear is given by

$\Delta F_{td} = 0.5 V_{Ed} \cot\theta$ for vertical stirrups.

$(M_{Ed}/z) + \Delta F_{td}$ should not be taken greater than M_{Edmax}/z where M_{Edmax} is the maximum moment along the beam.

The additional force only effects the curtailment of longitudinal reinforcement and can be taken into account using a shift rule as shown in Figure 9.2 of EN 1992-1-1.

where $\omega = \cot\theta + \tan\theta = \dfrac{0.9 b_w d \nu f_{cd}}{V_{Ed}}$

6.2.2.3 Shear at the interface between concretes cast at different times

A model to calculate the shear at the interface between concrete cast at different times is given in EN 1992-1-1. It incorporates the shear strength of concrete, friction due to any forces normal to the interface and the effect of reinforcement that crosses the joint.

6.2.3 GENERAL CONCLUSION FOR BEAM SHEAR

EN 1992-1-1 and BS 8110 can in general be expected to give similar results in terms of the number and spacing of links to be provided.

6.3 Torsion

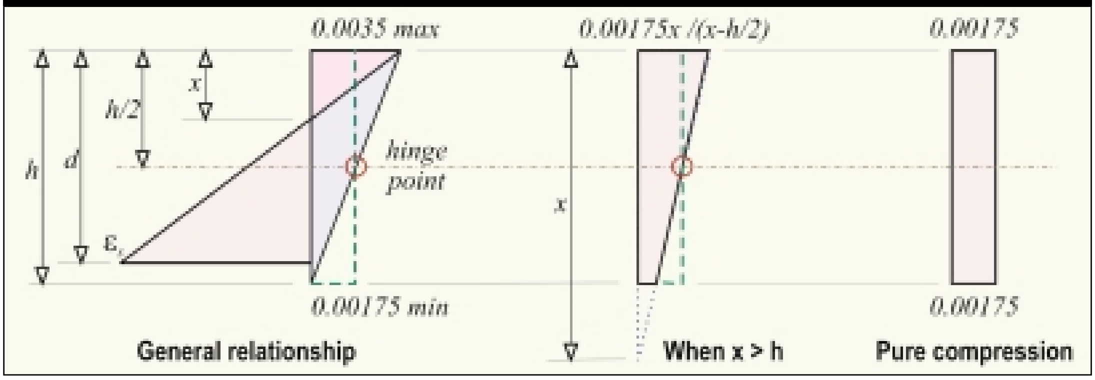
Torsion resistance is calculated using thin wall section theory, and in the case of a solid section, the section is converted into an equivalent hollow section from which the resistance is calculated.

6.4 Design of compression elements at the ultimate limit state

As stated in 6.1 EN 1992-1-1, unlike BS 8110, does not give separate guidance for designing a column for a known combination of moment and axial force.

In EN 1991-1-2, similar to BS8110, the rectangular stress block used for the design of beams (see 6.1) can also be used for the design of columns. However, unlike BS8110, the maximum compressive strain for concrete when designing to EN 1992-1-1 has to be less than 0.0035 (for $f_{ck} \leq$ 50N/mm^2). When the whole section is in pure compression (see Figure 6.5) the strain will fall to half this value. This will affect the strains for the reinforcement and hence forces which the reinforcement can carry.

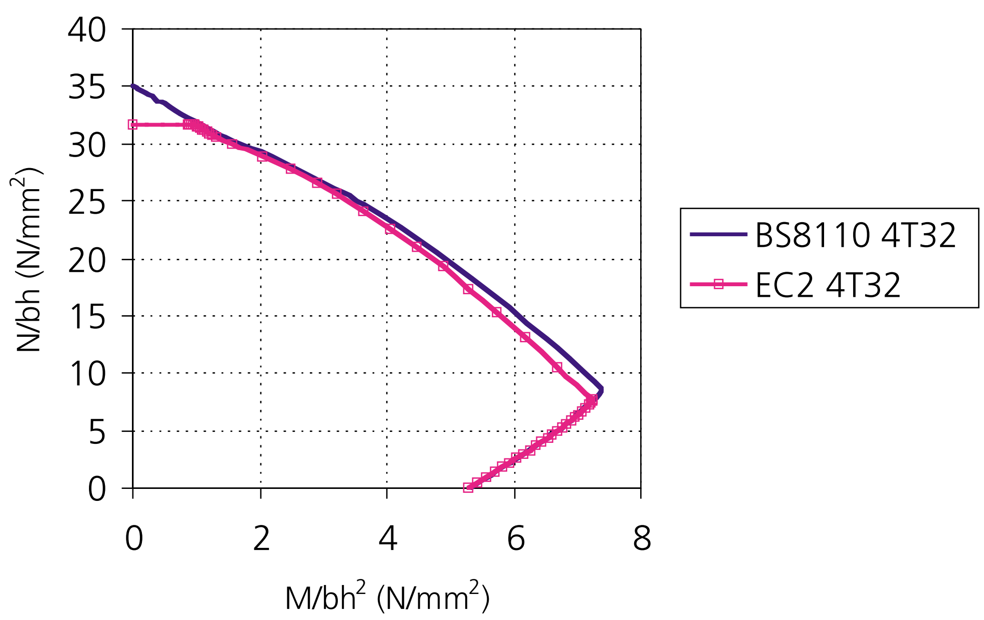
Figure 6.5 Design of compression element at ultimate limit state – EN 1992-1-1 stress block



Note to Figure 6.5: The limitation of the strain of 0,00175 applies when the bi-linear stress block in Figure 3,4 of EN 1991-1-1 is used.

N-M interaction charts (see Figure 6.6) for a 300mmx300mm section with the above assumptions, and using a value of α_{cc}= 0.85, give close agreement between EN 1992-1-1 and BS8110. The horizontal cut-off line on the EN 1992-1-1 curve, has minimal practical effect, as it will normally fall within the zone of minimum applied moment.

Figure 6.6 N-M interaction charts



6.5 Flat slabs and design for punching shear

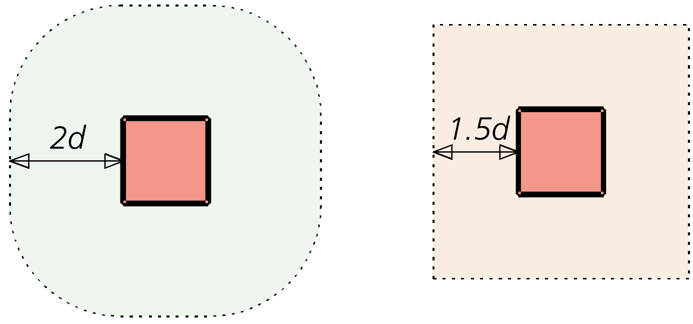
6.5.1 ANALYSIS OF FLAT SLABS

The analysis of flat slabs is within the scope of EN 1992-1-1, through an informative annex. The widths of column and middle strips may be the same as in BS8110. The percentages of moments carried by these strips are given as ranges but the BS8110 values fall within these ranges and hence may still be used, based on the rules of using informative Annexes with the Eurocode system.

6.5.2 PUNCHING

The other major issue when designing flat slabs is punching shear, which is dealt with in the normative part of EN 1992-1-1. The calculation of punching shear is basically similar to BS 8110, except that the control perimeter is at $2d$, rather than $1.5d$ from the column face, and follows a locus from the column face, rather than being rectangular in shape. See Figure 6.7. In EN 1992 it is only necessary to calculate the area of shear reinforcement at the first control perimeter. The next stage is to calculate the perimeter at which no shear reinforcement is provided. It is assumed that the same calculated shear reinforcement is provided at all perimeters.

Figure 6.7 Typical basis control parameter for rectangular member



	EC2	**BS 8110**
Basic control perimeter:	*At 2d*	*at 1.5d*
Control perimeter shape:	*Rounded corners*	*Rectangular*

The effective shear force V_{Ed} may be determined using simple enhancement factors similar to those in BS8110 subject to certain conditions* and the corresponding values are given below.

Note
* *These are nominal values for braced structures. Calculation of shear enhancement factors from expressions given in EC2 or BS 8110 may result in less conservative values.*

6.5.2.1 Flat slab shear enhancement factors

Internal:	*1.15*	*1.15*
Edges:	*1.4*	*1.4 or 1.25*
Corners:	*1.5*	*1.25*

When links are required, EN 1992-1-1 allows a contribution of 75% of the concrete shear resistance (*unlike beam shear*), and a radial distribution of links is assumed. The shape of the outer perimeter, at which no further links are required, is related to the link arrangement, unlike the basic control perimeter.

The higher enhancement factor of 1.5 for corner columns may prove critical in some circumstances, when sizing flat slabs for shear. A method for determining the effective shear force taking into account the moment transfer at the slab/column junction is given in EN 1992-1-1 as an alternative to using the above factors. This method may give lower effective shear forces than the simplified enhancement factors

6.6 Material Partial Safety factors

As with BS8110, EN 1992-1-1 uses a basic material partial factor γ_m for concrete of 1.5. Several years ago the material partial factor for reinforcing steel in BS8110 was reduced from 1.15 to 1.05. EN 1992-1-1 uses a value of 1.15 although this is a recommended value that may be altered by the BSI National

Annex. This is unlikely to have any practical impact however as steel intended to meet the existing yield strength of 460N/mm^2 assumed by BS8110 is likely to be able to meet the 500N/mm^2 assumption made by EN 1992-1-1, so that the design yield strength f_{yd} will be virtually identical. BS8110 is being revised to be in line with EN 1992 i.e. fy=500N/mm^2 and for reinforcement γ_m=1.15.

For Ultimate limit states.

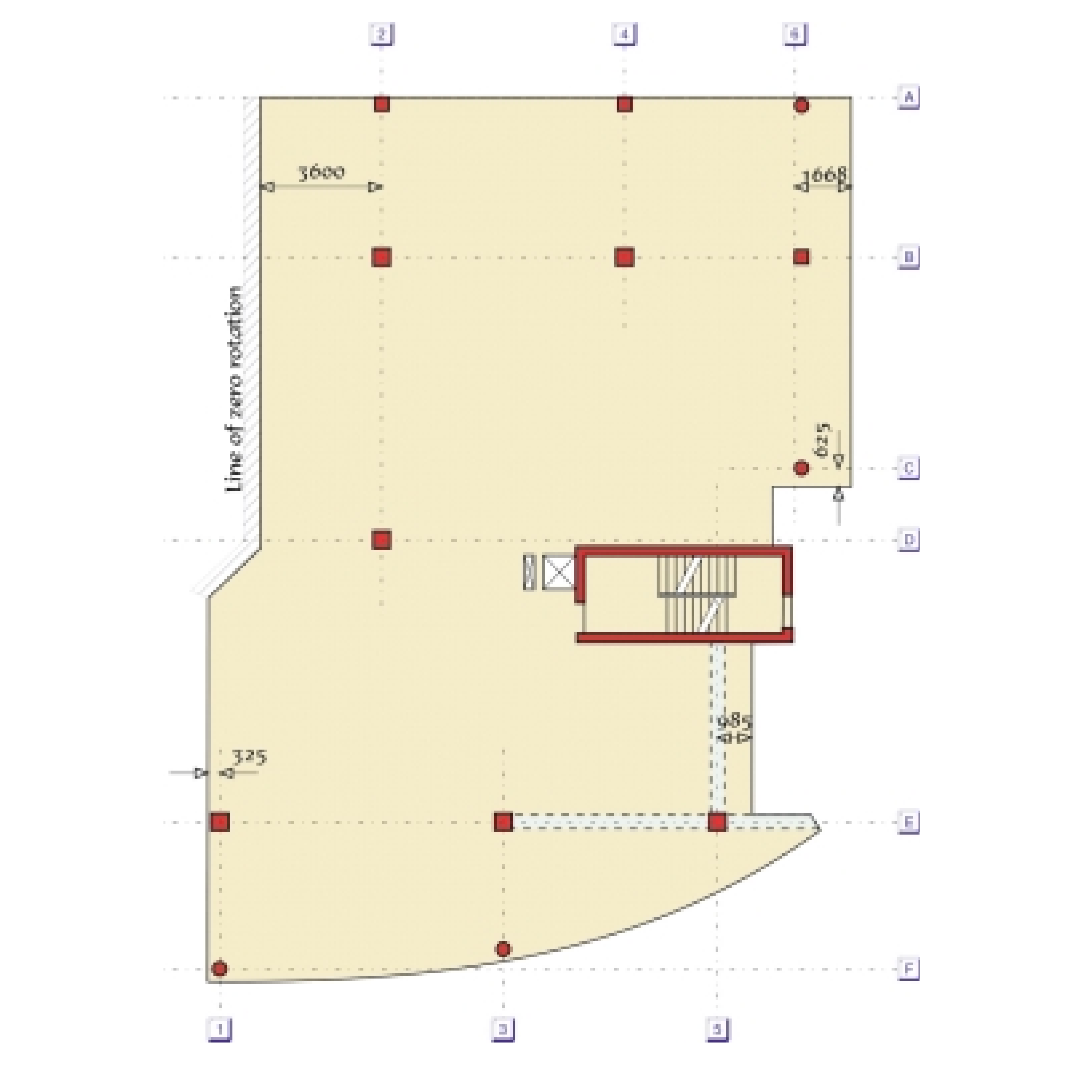
Persistent and transient situations	$\gamma_c = 1.5$	$\gamma_s = 1.15$
Accidental situations	$\gamma_c = 1.2$	$\gamma_s = 1.00$

6.7 Comparative design study

In this section the results of a separate design study undertaken on a typical flat slab building are reviewed.

The floor plan chosen for the study was based on a structure already designed to BS8110. It had a slightly irregular layout with fairly typical spans of 8.4 and 7.2 m (Figure 6.8).

Figure 6.8 Floor plan for building design study



A finite element analysis (iterative, cracked section) was used for the design of the slabs, because of the irregular column layout. The deflections affecting the perimeter cladding proved to be critical in determining slab thickness.

The determined depth of the slab, required to satisfy the perimeter deflection limit, is 260mm for EN 1992-1-1 and 280 mm for BS 8110. There are several reasons for this difference; the principal reasons being:

- *For a specified concrete grade a higher instantaneous modulus of elasticity E_C is given by EN 1992-1-1*
- *The cracking stress is much higher to EN 1992-1-1 and increases with concrete strength, but is limited to only 1.0 N/mm^2 in BS8110.*

The above effects tend to predict smaller displacements with EN 1992-1-1, although these effects are partially offset by a greater density for concrete (25 kN/m^3 in the Eurocodes as opposed to 23.6 for BS 8110), 5 mm more bottom cover required for EN 1992-1-1, and the slightly different relationship between support and span steel.

In everyday practice, the above selected slab depths may have been rounded up to the nearest 25mm, giving 275mm and 300mm respectively.

The column load reduction factors given in EN 1992-1-1 were found not to be as generous as in BS6399. However the National Annex for EN 1991-1-1 may adopt the BSI factors.

Column sizes were determined by the maximum amount of vertical reinforcement permitted by each code. In BS 8110 this is 6% (10% at laps) and to EN 1992-1-1, 4% (8% at laps). This resulted in actual column sizes being very similar. EN 1992-1-1 does however permit the 4% limit to be exceeded where the concrete can still be placed and compacted successfully.

Considering the costs of concrete reinforcement, formwork and excavation, overall construction costs were found to be quite similar between EN 1992-1-1 and BS8110. The study [11] used Expressions 6.10a and 6.10b in EN 1990. Using Expression 6.10 the construction costs using EN 1992-1-1 would have been slightly higher (of the order of 2-3%), than for BS 8110.

CHAPTER 7
Serviceability limit states

7.1 Serviceability design and checks

Design for serviceability is largely concerned with ensuring that the design function of the structure is not impaired by the performance of the structure. Serviceability criteria will therefore depend upon the actual planned function of the structure and since all design functions cannot be envisaged by a code, the designer and his client have the ultimate responsibility for choosing appropriate limits. The limitations given in EN 1992-1-1 are applicable in most normal circumstances but it is the responsibility of the designer to check that they are appropriate for the particular structure considered and choose other limits if they are deemed more appropriate.

Serviceability checks in EN 1992-1-1comprise stress limitation, crack control and deflection control.

Regarding *stress limitation* BSI Codes of Practice on concrete design have not required stress checks in reinforced members for over 30 years.

For *crack control* EN 1992-1-1 gives two methods. Either the bar diameter and/or spacing is limited to the values given for the different stress levels in the reinforcement and crack widths, or detailed calculations are undertaken to demonstrate compliance with acceptance criteria.

For *deflection control* three methods are available in EN 1992-1-1:

a) span/effective depth limits similar to those in BS 8110;

b) simple calculations based on extensive parametric studies;

c) detailed calculations of deflections taking into account

   – concrete tensile strength

   – concrete modulus of elasticity

   – creep and shrinkage

7.2 Span/depth ratios

In both BS8110 and EN 1992-1-1 the allowable span/depth ratio depends on concrete strength and tension and compression reinforcement ratios.

Flowcharts that may be downloaded free from www.eurocode2.info show how the permissible span/depth ratio is arrived at.

A detailed parametric study on span/depth ratios has been carried out comparing the provisions of the EN 1992-1-1 and BS 8110 in relation to the minimum permitted depth of rectangular beams for a given span. The influence of increasing the allowable tension steel was considered by allowing a maximum increase of 100% (i.e. double) than that required for the ultimate limit state, although there is no upper limit stated in EN 1992-1-1 since it was not envisaged that designers would increase the area of tension reinforcement to reduce slab thickness. The BSI National Annex limits the increase to 50%. The reduction in slab thickness allowed by the span-to-depth rules by increasing the area of tension steel provided over that required, cannot be justified by calculation for more than marginal increases in reinforcement. The 20% redistribution was assumed for all continuous spans.

The study showed that EN 1992-1-1 tended to be more conservative at low concrete strengths. However EN 1992-1-1 tends to permit much higher span/depth ratios for low reinforcement percentages, even when restricting the maximum enhancement in steel area. In practice however, economic rather than minimum permissible depth designs will generally be used, and these provide very similar results for both EN 1992-1-1 and BS 8110, depending on the assumptions made**. It may not be possible to justify by deflection calculation some slab thicknesses given by the EC2 span to depth rules for very low reinforcement percentages. The span to depth rules in EC2 do not fully account for the effects of either early age striking or loading from slabs above during construction which may control long-term slab deflections.**

7.3 Partial factors for material properties for serviceability limit state verifications

The partial factors are as follows:

Serviceability limit states. $\gamma_c = 1.00$, $\gamma_s = 1.00$

CHAPTER 8

Additional guidance in EN 1992-1-1 (Sections 8–12 and Annexes)

8.1 Section 8 Detailing of reinforcement – general and Section 9 Detailing of members and particular rules

EN 1992-1-1 provides two comprehensive Sections for detailing, and only a few particular aspects will be discussed here.

8.1.1 BOND AND ANCHORAGE

The basic bond stress used for the calculation of anchorage and lap lengths is in EN 1992-1-1 depending upon the quality of bond for the position of the reinforcement during concreting, which is also dependent upon the depth of the member. The design anchorage length is determined by applying a number of factors to the basic length, including the shape of the bar, concrete cover and confinement offered by transverse pressure and reinforcement.

Additional rules apply to large diameter bars (≥ 32mm) where in particular the bond stress is reduced. It is recommended that large diameter bars are anchored using mechanical devices or as straight bars with confining reinforcement in the form of links.

8.1.2 DETAILING RULES

EN 1992-1-1 gives detailing rules for various member types. Maximum and minimum percentages of reinforcement, spacing rules etc are given for slabs, beams, columns, walls, deep beams and flat slabs.

8.1.3 ROBUSTNESS AND TYING REQUIREMENTS

Tying requirements for robustness in EN 1992-1-1 are given and these are similar to those in BS 8110, with requirements for peripheral, internal and horizontal column or wall ties but vertical ties are required only in panel buildings of 5 storeys or more. These particular rules are however superseded by the Approved Document A guidance on disproportionate collapse. EN 1992-1-1 allows for the provisions to ensure robustness to be altered by the National Annex.

8.1.4 ADDITIONAL REQUIREMENTS

a) The spacing rules in EN 1992-1-1 may lead to more and smaller bars, unless crack widths are checked, than for BS 8110.

b) There is a requirement in EN 1992-1-1 that beam top steel should be distributed across flanges (both tension and compression).

8.2 Section 10 Precast concrete elements and structures

EN 1992-1-1 permits reduced partial factors for materials γ_c and γ_s provided this is justified by adequate control procedures.

8.3 Section 11 Lightweight aggregate concrete structures

EN 1992-1-1 gives clear guidance on density and material properties.

The design methods for lightweight concrete are the same as the design methods for dense concrete although EN 1992-1-1 gives modified recommended values for many factors, including α_{cc} and α_{ct}

8.4 Section 12 Plain and lightly reinforced concrete structures

This Section provides simplified design equations for plain and lightly reinforced concrete structures, such as strip footings or walls.

8.5 Materials and Workmanship

EN 1992-1-1 does not cover materials and workmanship and a separate Execution Standard has been prepared. This is currently in ENV form and a national document based on the existing National Structural Concrete Specification [10] is in preparation.

One issue, which however is specifically referred to in EN 1992-1-1, is the tolerance on cover. Cover to meet durability and bond requirements is specified as a *minimum value* with a tolerance of up to 10mm to be added on top. This is in contrast to BS8110 where cover is specified as a *nominal value* and a tolerance of 5mm accepted. In situations where good quality control is exercised (e.g. factory produced precast beams) there is scope for reducing the tolerance.

8.6 Annexes to EN 1992-1-1

EN 1992-1-1 has the following Annexes.

A (Informative)	Modification of partial factors for materials
B (Informative)	Creep and shrinkage strain
C (Normative)	Reinforcement properties
D (Informative)	Detailed calculation method for prestressing steel relaxation losses
E (Informative)	Indicative strength classes for durability
F (Informative)	Reinforcement expressions for in-plane stress conditions
G (Informative)	Soil structure interaction
H (Informative)	Global second order effects in structures
I (Informative)	Analysis of flat slabs and shear walls
J (Informative)	Examples of regions with discontinuity in geometry or action

CHAPTER 9
Conclusions

9.1 Availability of Guidance for EN 1992-1-1

9.1.1 HANDBOOKS, MANUALS, AND CONCISE EUROCODES

H Gulvanessian, J-A Calgaro and M Holiky: Designers Guide to EN 1990: Eurocode: Basis of Structural Design, Thomas Telford Publications 2002.

A W Beeby and R S Narayanan: Designers Handbook to Eurocode 2 Part 1.1, Design of Concrete Structures, Thomas Telford, London, 1995

These two handbooks produced as part of the Eurocode Design Handbooks series published by Thomas Telford is aimed at designers, at all professional levels, involved in the design of reinforced or prestressed concrete using the ENV version of the Eurocode. It provides advice to designers through an explanation of the background to and the intention of the clauses of the particular Eurocode.

Institution of Structural Engineers, Manual for the Design of Reinforced Concrete Building Structures to EC2

The manual will use the format of the green book (Manual for BS8110). As with the green book the scope of the manual covers the majority of concrete building structures and has now been extended to cover slender columns and prestressed concrete. An appendix for the structural design of foundations using limit state philosophy has also been included.

9.1.2 AVAILABILITY OF OTHER DESIGN AIDS

A suite of practical design aids to assist practising engineers to become familiar with and apply the code is currently in course of preparation. These include:

1. A set of Excel based spreadsheets, to complement the existing highly popular set of spreadsheets to BS8110 produced by the Concrete Centre (TCC)

2. A series of How to Design Leaflets explaining the basic design concepts for primary structural elements available on-line and to be freely distributed.

3. A concise code summarising the key information within the code required for everyday use and appropriate values from and references to other supporting codes

4. Worked Examples for the Design of Concrete Buildings

A helpline facility is planned to be set up so that frequently asked questions can be answered and a dedicated website www.eurocode2.info is now on-line and will be expanded to provide links to available sources of information. This will complement other activities such as the RCC's Concrete Computer Aided Learning package.

9.1.3 EUROCODE EXPERT AND THE INSTITUTION OF CIVIL ENGINEERS

Eurocode expert with its comprehensive website www.eurocodes.co.uk provides up to date information on the latest situation with regard to the development and implementation of the Eurocodes, with information on guidance documents, training courses etc. See also the special Eurocodes issue published by the Institution of Civil Engineers [12].

9.2 Impact on the profession

The implementation of the Eurocodes in the UK will provide opportunities to the UK profession, as they are foreseen to

- Improve the functioning of the single market for products and engineering services, by removing obstacles arising from different nationally codified practices for the assessment of structural reliability

- Improve the competitiveness of the European construction industry, and the professionals and industries connected to it, in Countries outside the European Union.

Calibration studies have shown that the differences in cost between structures and members designed to EN 1992 and BS 8110 is neutral. With regard to the use of EN 1992 there are differences between the Eurocodes and current UK practice that could increase the cost of design during the initial learning curve. In particular, EN 1992-1-1 explain the basis of different phenomena (e.g. bending, shear, bond) rather than member types (e.g. beams, slabs, columns) explained in BS 8110.

Differences in practice (e.g. specifying a cylinder strength) may necessitate better communication between the designer and the contractor.

9.3 Concluding remarks

1. The implementation of the Eurocodes including EN 1992-1-1 for the design of all types of structures will have a big impact on the UK profession. There

will be a learning curve associated with training, gaining familiarity and using the new codes.

2. Design aids and information will assist the profession during implementation.

3. In general EN 1992-1-1, used with the National Annex, gives similar solutions to BS 8110 and additionally offers scope for more economic structures.

4. Overall EN 1992-1-1 is less prescriptive and its scope is more extensive than BS8110 for example in permitting higher concrete strengths. In this sense the new code will permit designs not currently permitted in the UK, and thus give designers the opportunity to derive benefit from the considerable advances in concrete technology over recent years. It is considered that, after an initial acclimatisation period, the implementation of EN 1992-1-1 will be generally regarded as a very good code and a step in the right direction.

5. Some of the main differences between the EN 1992-1-1 and BS 8110 described in this document are summarised below:

   - EN 1992-1-1 allows for the use of high strength concretes, which BS8110 does not

   - Concrete strengths are classified by cylinder strengths which are typically 10-20% less than the corresponding cube strength

   - In EN 1992-1-1 cover for durability and bond requirements is specified as a minimum value whereas BS8110 specifies a nominal value

   - Durability considerations are considered in a more explicit manner in the EN 1992-1-1. The concept of an explicitly defined design life is included and the designer is required to identify the most severe environmental conditions for each particular case

   - The material partial safety factor for concrete will remain the same as the BS 8110 value ($\gamma_{m,conc}$ = 1.5). Although there is a small change in the material factor for reinforcing steel this will have little practical impact and the recommended EN 1992-1-1 value of $\gamma_{m,steel}$ = 1.15 is likely to be adopted in the UK National Annex

   - Load combination expressions and values for partial factors for loading are given in EN 1990

   - A slightly higher value for the density of normal weight concrete is assumed. Preliminary studies[1] indicate that the overall impact of using EN 1992-1-1 in this area will be minimal

   - The Sections in the EN 1992-1-1 explain the basis of different phenomena (e.g. bending, shear, bond) rather than member types (e.g. beams, slabs, columns) as in BS 8110

- For the design of flexural elements at the ultimate limit state preliminary studies indicate that there is very little practical difference between EN 1992-1-1 and BS8110

- In terms of shear resistance of beams EN 1992-1-1 differs from BS8110 in that above the limit at which concrete alone has sufficient capacity, the designed shear steel to be provided is determined ignoring the contribution from the concrete.

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