Practical Design to Eurocode 2

The webinar will start at 12.30

Course Outline

Lecture	Date	Speaker	Title
1	21 Sep	Jenny Burridge	Introduction, Background and Codes
2	28 Sep	Charles Goodchild	EC2 Background, Materials, Cover and effective spans
3	5 Oct	Paul Gregory	Bending and Shear in Beams
4	12 Oct	Charles Goodchild	Analysis
5	19 Oct	Paul Gregory	Slabs and Flat Slabs
6	26 Oct	Charles Goodchild	Deflection and Crack Control
7	2 Nov	Jaylina Rana	Columns
8	9 Nov	Jenny Burridge	Fire
9	16 Nov	Paul Gregory	Detailing
10	23 Nov	Jenny Burridge	Foundations

Introduction, Background and Codes

Lecture 1

21st September 2017

Summary: Lecture 1

- Introduction
- Background & Basics
- Eurocode (Eurocode 0)
- Eurocode Load Combinations
- Eurocode 2 Load Cases
- Eurocode 1 Loads/Actions
- Exercise

Introduction

Practical Design to Eurocode 2

Objectives:

Starting on 21st September 2017, this ten-week (Thursday lunchtime) online course will cover the relevant sections of Eurocode 2, etc ; considering the practical application of the code with worked examples and hands-on polls and workshops on design.

The most common structural elements will be covered. The course is designed for practising UK engineers so will use the UK's Nationally Determined Parameters.

Following this course delegates will:

- Know your way around Eurocode 2: Parts 1-1 & 1-2, General design rules and fire design.
- Understand the context for the code, and the essential differences between Eurocode 2 and BS 8110 in practice.
- Have experience in design to Eurocode 2 requirements.
- Have experience using the code through worked examples

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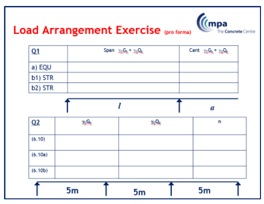
Course Resources (soft copies)

Course notes

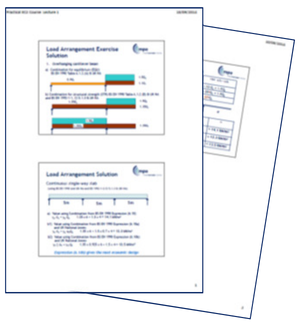
Pro formas

for exercises (as and when)



Model answers

(as and when)



Course Resources (soft copy)

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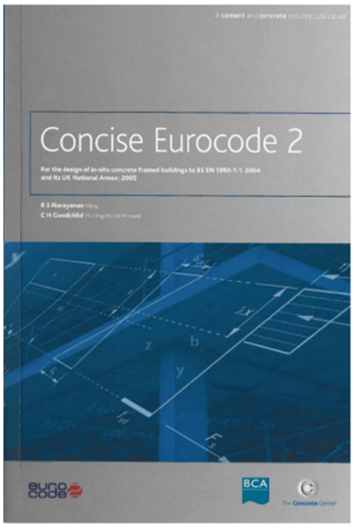


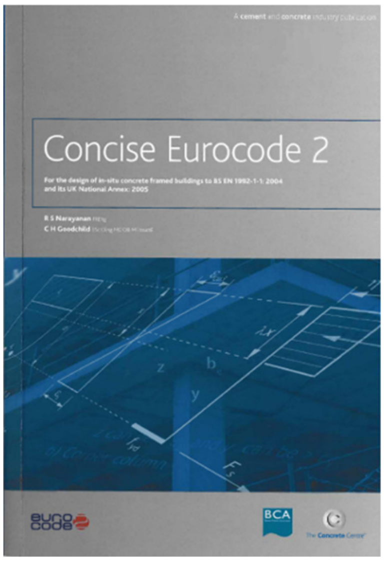
Concise Eurocode 2

- Introduction Basis of Design
- Materials
- Durability and Cover
- Structural Analysis
- Bending and Axial Force
- Shear
- Punching Shear
- Torsion
- Serviceability
- Detailing – general
- Detailing – particular
- Tying systems
- Plain concrete
- Design Aids

Print this one out (or buy a copy!)
Lots of references to it later.

Course Resources (soft copies)

mpa The Concrete Centre



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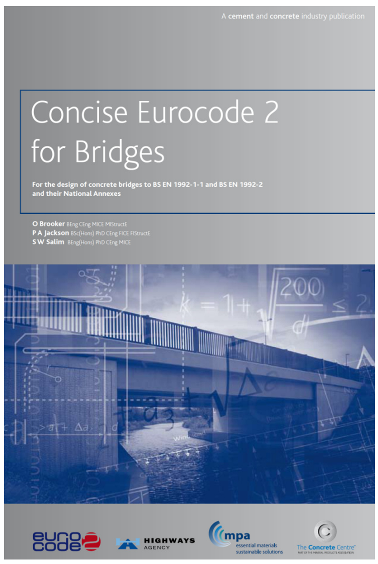
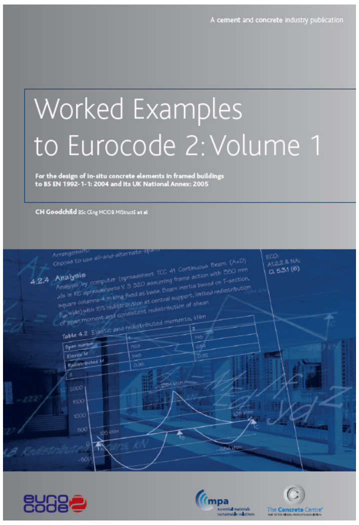


Course Resources (soft copy)



Worked Examples

- Introduction
- Analysis, actions and load arrangements
- Slabs (one-way and flat slabs)
- Beams
- Columns
- Walls
- Annex A: Derived Formulae
- Annex B: Serviceability Limit State
- Annex C: Design Aids

Course Resources (soft copy)

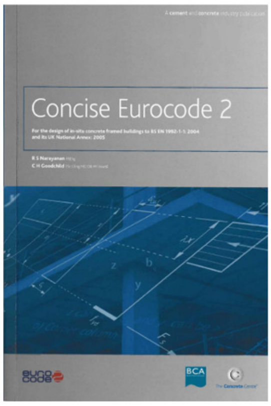
How to…Compendium

- Introduction to Eurocodes
- Getting started
- Slabs
- Beams
- Columns
- Foundations
- Flat slabs
- Deflections
- Retaining walls
- Detailing
- BS 8500
- Structural fire design

Revised Edition January 2011

Go To Training - Control Panel

Course Resources (soft copy)



Concise Eurocode 2

- Introduction Basis of Desig
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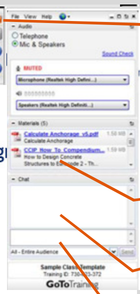


Show/Hide control panel

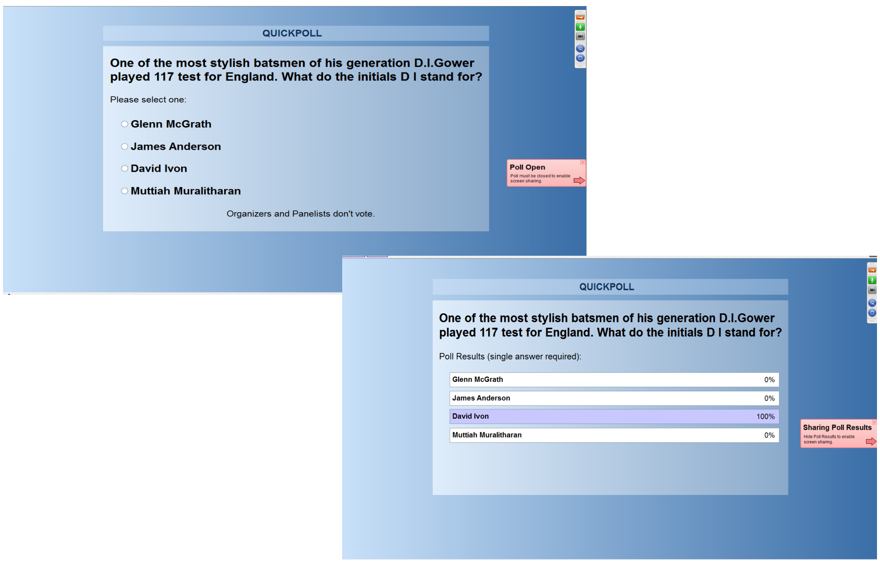
Materials

Chat: ask questions here

Chat

Session recordings will be sent after about 2 hours. Other issues: email Patience.

Go To Training - Polls



Conventions:

From EN1992-1-1

From UK NA

TCC Comment

Subscripts:

- $_E$ effects of actions
- $_R$ resistance
- $_d$ design value
- $_k$ characteristic value
- $_w$ shear

Warning: Eurocode-speak!

letter	name	capita
α	Alpha	Α
β	Beta	Β
γ	Gamma	Γ
δ	Delta	Δ
ε	Epsilon	Ε
ζ	Zeta	Ζ
η	Eta	Η
θ	Theta	Θ
ι	Iota	Ι
κ	Kappa	Κ
λ	Lambda	Λ
μ	Mu	Μ
ν	Nu	Ν
ξ	Xi	Ξ
ο	Omicron	Ο
π	Pi	Π
ρ	Rho	Ρ
σ ς	Sigma	Σ
τ	Tau	Τ
υ	Upsilon	Υ
φ	Phi	Φ
χ	Chi	Χ
ψ	Psi	Ψ
ω	Omega	Ω

Greek Alphabet

Eurospeak

e.g:
Verify (check)
Action (load)
Variable action (live load)
Permanent action (dead load)
Frequent value (for SLS checks)
Quasi-permanent value (for long term SLS)
Annex (appendix)

Background & Basics

Setting the scene

CEN National Members

Austria Belgium
Cyprus
Czech Republic
Denmark
Estonia Finland
France
Germany
Greece Hungary
Iceland Ireland
Italy Latvia
Lithuania
Luxembourg
Malta
The Netherlands
Norway Poland
Portugal
Romania
Slovakia
Slovenia Spain
Sweden
Switzerland
United Kingdom

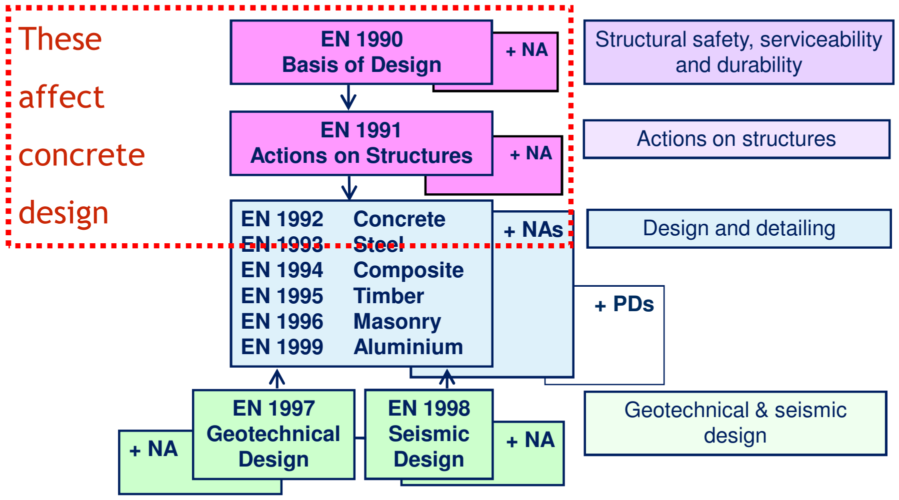
Eurocodes are being/ will be used in:

- EU countries
- EFTA Countries
- Malaysia
- Singapore
- Vietnam
- Sri Lanka
- Others?

The Eurocodes

- **BS EN 1990 (EC0) :** Basis of structural design
- **BS EN 1991 (EC1) :** Actions on Structures
- **BS EN 1992 (EC2) :** Design of concrete structures
- **BS EN 1993 (EC3) :** Design of steel structures
- **BS EN 1994 (EC4) :** Design of composite steel and concrete structures
- **BS EN 1995 (EC5) :** Design of timber structures
- **BS EN 1996 (EC6) :** Design of masonry structures
- **BS EN 1997 (EC7) :** Geotechnical design
- **BS EN 1998 (EC8) :** Design of structures for earthquake resistance
- **BS EN 1999 (EC9) :** Design of aluminium structures

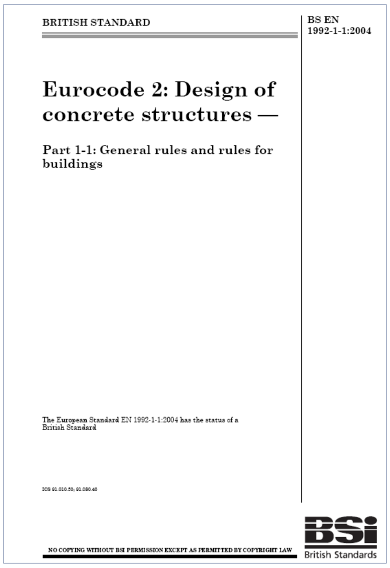
Eurocode Hierarchy



Format of the Eurocodes

Each Eurocode Contains:

- National front cover



BRITISH STANDARD

BS EN 1992-1-1:2004

Eurocode 2: Design of concrete structures —

Part 1-1: General rules and rules for buildings

The European Standard EN 1992-1-1:2004 has the status of a British Standard

ICS 91.010.30; 91.080.40

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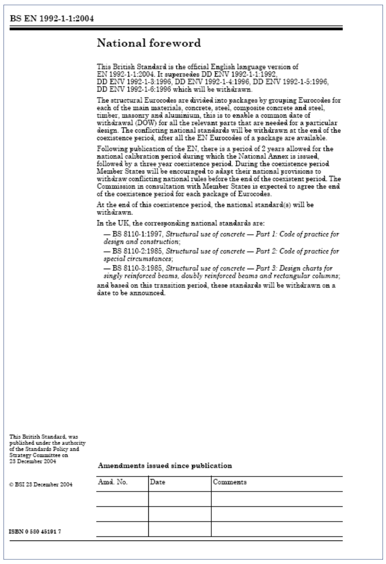
British Standards

Format of the Eurocodes

Each Eurocode Contains:

- National front cover
- National foreword



BS EN 1992-1-1:2004

National foreword

This British Standard is the official English language version of EN 1992-1-1:2004. It supersedes DD ENV 1992-1-1:1992, DD ENV 1992-1-3:1996, DD ENV 1992-1-4:1996, DD ENV 1992-1-5:1996, DD ENV 1992-1-6:1996 which will be withdrawn.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials, concrete, steel, composite concrete and steel, timber, masonry and aluminium, this is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the coexistence period, after all the EN Eurocodes of a package are available.

Following publication of the EN, there is a period of 2 years allowed for the national calibration period during which the National Annex is issued, followed by a three year coexistence period. During the coexistence period Member States will be encouraged to adapt their national provisions to withdraw conflicting national rules before the end of the coexistent period. The Commission in consultation with Member States is expected to agree the end of the coexistence period for each package of Eurocodes.

At the end of this coexistence period, the national standard(s) will be withdrawn.

In the UK, the corresponding national standards are:

— BS 8110-1:1997, *Structural use of concrete — Part 1: Code of practice for design and construction*;

— BS 8110-2:1985, *Structural use of concrete — Part 2: Code of practice for special circumstances*;

— BS 8110-3:1985, *Structural use of concrete — Part 3: Design charts for singly reinforced beams, doubly reinforced beams and rectangular columns*;

and based on this transition period, these standards will be withdrawn on a date to be announced.

This British Standard, was published under the authority of the Standards Policy and Strategy Committee on 23 December 2004

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ISBN 0 580 45191 7

Amendments issued since publication

Amd. No.	Date	Comments

Format of the Eurocodes

mpa The Concrete Centre

Each Eurocode Contains:

- National front cover
- National foreword
- CEN front cover

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1992-1-1

December 2004

ICS 91.010.30; 91.080.40

Supersedes ENV 1992-1-1:1991, ENV 1992-1-3:1994, ENV 1992-1-4:1994, ENV 1992-1-5:1994, ENV 1992-1-6:1994, ENV 1992-3:1998

English version

Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

Eurocode 2: Calcul des structures en béton - Partie 1-1 : Règles générales et règles pour les bâtiments

Eurocode 2: Bemessung und konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau

This European Standard was approved by CEN on 16 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
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EUROPÄISCHES KOMITEE FÜR NORMUNG

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Ref. No. EN 1992-1-1:2004: E

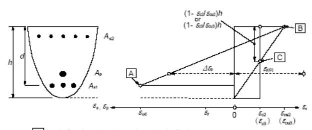
Format of the Eurocodes

mpa The Concrete Centre

Each Eurocode Contains:

- National front cover
- National foreword
- CEN front cover
- Main text and annexes (which must be as produced by CEN)

EN 1992-1-1:2004 (E)



A - reinforcing steel tension strain limit

B - concrete compression strain limit

C - concrete pure compression strain limit

Figure 6.1: Possible strain distributions in the ultimate limit state

6.2 Shear

6.2.1 General verification procedure

(1)P For the verification of the shear resistance the following symbols are defined:

$V_{Rd,c}$ is the design shear resistance of the member without shear reinforcement.
$V_{Rd,s}$ is the design value of the shear force which can be sustained by the yielding shear reinforcement.
$V_{Rd,max}$ is the design value of the maximum shear force which can be sustained by the member, limited by crushing of the compression struts.

In members with inclined chords the following additional values are defined (see Figure 6.2):

V_{ccd} is the design value of the shear component of the force in the compression area, in the case of an inclined compression chord.
V_{td} is the design value of the shear component of the force in the tensile reinforcement, in the case of an inclined tensile chord.

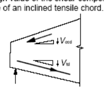


Figure 6.2: Shear component for members with inclined chords

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Format of the Eurocodes

Each Eurocode Contains:

- National front cover
- National foreword
- CEN front cover
- Main text and annexes (which must be as produced by CEN)
- Annexes - can by normative and/or informative

EN 1992-1-1:2004 (E)

ANNEX C (Normative)

Properties of reinforcement suitable for use with this Eurocode

C.1 General

(1) Table C.1 gives the properties of reinforcement suitable for use with this Eurocode. The properties are valid for temperatures between -40ºC and 100ºC for the reinforcement in the finished structure. Any bending and welding of reinforcement carried out on site should be further restricted to the temperature range as permitted by EN 13670.

Table C.1: Properties of reinforcement

Product form	Bars and de-coiled rods			Wire Fabrics			Requirement or quantile value (%)
Class	A	B	C	A	B	C	-
Characteristic yield strength f_{yk} or $f_{0,2k}$ (MPa)	400 to 600						5,0
Minimum value of $k = (f_t/f_y)_k$	≥1,05	≥1,08	≥1,15 <1,35	≥1,05	≥1,08	≥1,15 <1,35	10,0
Characteristic strain at maximum force, ε_{uk} (%)	≥2,5	≥5,0	≥7,5	≥2,5	≥5,0	≥7,5	10,0
Bendability	Bend/Rebend test			-			
Shear strength	-			0,3 $A f_{yk}$ (A is area of wire)			Minimum
Maximum deviation from nominal mass (individual bar or wire) (%) — Nominal bar size (mm) ≤ 8 / > 8	± 6,0 / ± 4,5						5,0

Note: The values for the fatigue stress range with an upper limit of βf_{yk} and for the Minimum relative rib area for use in a Country may be found in its National Annex. The recommended values are given in Table C.2N. The value of β for use in a Country may be found in its National Annex. The recommended value is 0,6.

Table C.2N: Properties of reinforcement

Product form	Bars and de-coiled rods			Wire Fabrics			Requirement or quantile value (%)
Class	A	B	C	A	B	C	-
Fatigue stress range (MPa) (for N ≥ 2 x 10^6 cycles) with an upper limit of βf_{yk}	≥150			≥100			10,0
Bond: Minimum relative rib area, $f_{R,min}$ — Nominal bar size (mm) 5 - 6 / 6,5 to 12 / > 12	0,035 / 0,040 / 0,056						5,0

Fatigue: Exceptions to the fatigue rules for use in a Country may be found in its National Annex. The

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Format of the Eurocodes

National Annex (NA)

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Table NA.1 — UK decisions for Nationally Determined Parameters described in BS EN 1992-1-1:2004 (continued)

Subclause	Nationally Determined Parameter	Eurocode recommendation	UK decision
6.8.6 (3)	Value of k_5	0,9	1,0
6.8.7 (1)	Fatigue: values for N and k_1	$N = 10^6$ cycles $k_1 = 0,85$	Use the recommended value
7.2 (2)	Value of k_1	0,6	Use the recommended value
7.2 (3)	Value of k_2	0,45	Use the recommended value
7.2 (5)	Value of k_3, k_4, k_5	$k_3 = 0,8$ $k_4 = 1,0$ $k_5 = 0,75$	Use the recommended value
7.3.1 (5)	Limitations of crack width w_{max}	Table 7.1N	Use Table NA.4
7.3.2 (4)	Value of $\sigma_{ct,p}$	$f_{ct,eff}$ in accordance with 7.3.2 (2)	Use the recommended value
7.3.4 (3)	Maximum crack spacing in Expression (7.11): values for k_3 and k_4	$k_3 = 3,4$ $k_4 = 0,425$	Use the recommended value
7.4.2 (2)	Values of basic span/depth ratios	Table 7.4N	Use Table NA.5
8.2 (2)	Values of k_1 and k_2	$k_1 = 1$ mm $k_2 = 5$ mm	Use the recommended value
8.3 (2)	Minimum mandrel diameter $\phi_{m,min}$	Table 8.1N	Use in Table NA.6a) and Table NA.6b)
8.6 (2)	Anchorage capacity of a welded [illegible]	$F_{btd} = l_{td}\phi_t\sigma_{td} \le F_{wd}$	Use the recommended value
8.8 (1)	Additional rules for large diameter bars: limiting bar size	$\phi_{large} > 32$ mm	$\phi_{large} > 40$ mm
[illegible]	[illegible] reinforcement areas	[illegible]	[illegible]

6

BS EN 1992-1-1:2004

National Annex

The National Annex provides:

- Values of Nationally Determined Parameters (NDPs)

  (NDPs have been allowed for reasons of safety, economy and durability)

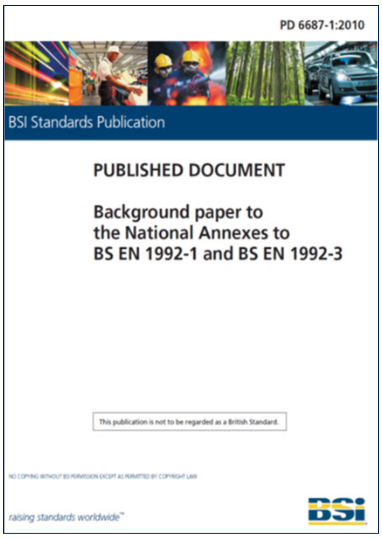
  – Example: Min *diameter* for longitudinal steel in columns

    ϕ_{min} = 8 mm in text ϕ_{min} = 12 mm in N.A.

- The decision where main text allows alternatives
  – Example: Load arrangements in Cl. 5.1.3 (1) P
- The choice to adopt informative annexes
  – Example: Annexes E and J are not used in the UK
- Non-contradictory complementary information (NCCI)
  – Example: PD 6687 *Background paper to UK National Annexes*

In these course notes UK Nationally Determined Parameters (NDPs) are shown in blue!

NCCI


PD 6687-1:2010

BSI Standards Publication

PUBLISHED DOCUMENT

Background paper to the National Annexes to BS EN 1992-1 and BS EN 1992-3

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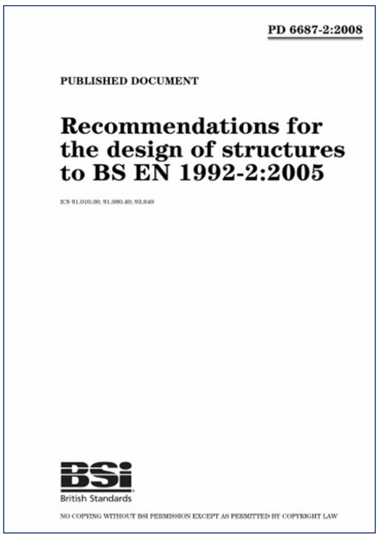
PD 6687-2:2008

PUBLISHED DOCUMENT

Recommendations for the design of structures to BS EN 1992-2:2005

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Features of the Eurocodes

- The Eurocodes contain Principles (P) which comprise:
  - General statements and definitions for which there is no alternative, as well as:
  - Requirements and analytical models for which no alternative is permitted
- They also contain Application Rules, which are generally rules which comply with the Principles
- The Eurocodes also use a comma (,) as the decimal marker

  (in these course notes and conventionally in the UK, the decimal marker is normally the decimal point)
- Along with all BS ENs, the Eurocodes will continue to be used during and after Brexit: no change.

Eurocode
(aka Eurocode 0 or EC0)

BS EN 1990:2002

Basis of structural design

Eurocode (EC0)

EN 1990 provides comprehensive information and guidance for all the Eurocodes, on the **principles and requirements for safety and serviceability.**

It gives the **partial safety factors** for actions and combinations of action for the verification of both **ultimate and serviceability limit states.**

e.g. EC0 - Ultimate load can be $1.35\ G_k + 1.5\ Q_k$

Limit State Design

Limit states are conditions beyond which some design criterion is violated.

Generally the structure shall be verified at:

– **Ultimate Limit State:**
  Any condition that concerns the safety of people or structure

– **Serviceability Limit State:**
  Corresponds to conditions in use of the structure. The limit state could be related to cracking, deformation or vibration.

Limit State Design

Ultimate Limit States:

Internal failure or excessive structural deformation (**STR**)

$E_d \leq R_d$;

Loss of equilibrium (**EQU**)

$E_{d,dst} \leq R_{d,stb}$

Failure or excessive deformation of ground (**GEO**)

Failure through time dependent effects e.g. fatigue (**FAT**)

Limit State Design

Serviceability Limit States:

Include:-
– the functioning of the structure or structural members under normal use;
– the comfort of people ;
– the appearance of the construction works,

Generally:

a) Deformations that affect the appearance, the comfort of users, or the functioning of the structure (including the functioning of machines or services), or that cause damage to finishes or non-structural members ;
b) Vibrations that cause discomfort to people, or – that limit the functional effectiveness of the structure ;
c) Damage that is likely to adversely affect the appearance, the durability, or the functioning of the structure.

Basis of Design

Durability:

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

Verification by Partial Safety Factor Method

Principle:

When using the partial factor method, it shall be verified that, in all relevant design situations, no relevant limit state is exceeded when design values for actions or effects of actions and resistances are used in the design models.

i.e. $E_d \leq R_d$

E_d is the design value of the effect of actions.

R_d is the design value of the corresponding resistance.

Actions

Actions:

G_k = characteristic *permanent* action

Q_k = characteristic *variable* action

Design Value of Action

$$F_d = \gamma_f \cdot F_{rep}$$

Where: γ_f = **partial factor for actions**
See NA to BS EN 1990: Table NA.A1.2

F_{rep} = ***representative* value** of action

= $\psi \cdot F_k$

And:

ψ **converts** the **characteristic value** of (a variable) action to the ***representative*** **value**.

Representative Values of *Variable* Actions

Each *variable* action may take one of four representative values, the main one being the characteristic value.

Other representative values are obtained by the application of ψ factors, which can take one of four values, namely, 1.00 or ψ_0 or ψ_1 or ψ_2.

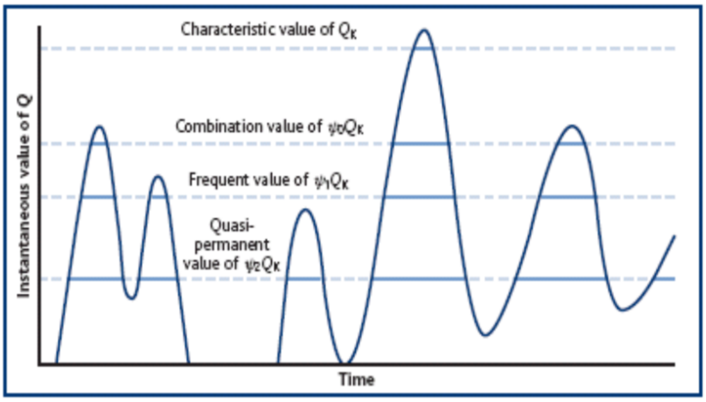
ψ = 1.0 when only one variable action is present in a combination.

$\psi_0 \cdot Q_k$ is the **combination value** of a variable action.

$\psi_1 \cdot Q_k$ is the **frequent value**.

$\psi_2 \cdot Q_k$ is the **quasi-permanent value**.

Representative Values of Variable Actions



Ref: Gulvanessian, H ICE Proceedings, Civil Engineering 144 November 2001 pp.8-13

UK Values of ψ Factor

Table NA.A1.1 UK National Annex of BS EN 1990

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings,			
Category A : domestic, residential	0.7	0.5	0.3
Category B : office areas	0.7	0.5	0.3
Category C : congregation areas	0.7	0.7	0.6
Category D : shopping areas	0.7	0.7	0.6
Category E : storage areas	1.0	0.9	0.8
Category F : traffic area, < 30kN	0.7	0.7	0.6
Category G : traffic area, 30 – 160kN	0.7	0.5	0.3
Category H : roofs	0.7	0	0
Snow load: H ≤ 1000 m a.s.l.	0.5	0.2	0
Wind loads on buildings	0.5	0.2	0

Combination of Actions

For each critical load case design values of the effects of actions are determined by combining the effects of actions that are considered to act simultaneously

Either

$\Sigma \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \Sigma \gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i}$ Exp. (6.10)

Or (for STR and GEO) the more adverse of

$\Sigma \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot \psi_{0,1} \cdot Q_{k,1} + \Sigma \gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i}$ Exp. (6.10 a)

or

$\Sigma \xi \cdot \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \Sigma \gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i}$ Exp. (6.10 b)

The value for ξ for the UK is 0.925

ULS (GEO/STR) for Buildings

Design values of actions, ultimate limit state - persistent and transient design situations (Table A1.2(B) Eurocode)					
Comb'tion expression reference	Permanent actions		Leading variable action	Accompanying variable actions	
	Unfavourable	Favourable		Main(if any)	Others
Eqn (6.10)	$\gamma_{G,j,sup}\ G_{k,j,sup}$	$\gamma_{G,j,inf}\ G_{k,j,inf}$	$\gamma_{Q,1}\ Q_{k,1}$		$\gamma_{Q,i}\ \Psi_{0,i}\ Q_{k,i}$
Eqn (6.10a)	$\gamma_{G,j,sup}\ G_{k,j,sup}$	$\gamma_{G,j,inf}\ G_{k,j,inf}$		$\gamma_{Q,1}\Psi_{0,1}Q_{k,1}$	$\gamma_{Q,i}\ \Psi_{0,i}\ Q_{k,i}$
Eqn (6.10b)	$\xi\ \gamma_{G,j,sup}G_{k,j,sup}$	$\gamma_{G,j,inf}\ G_{k,j,inf}$	$\gamma_{Q,1}\ Q_{k,1}$		$\gamma_{Q,i}\ \Psi_{0,i}\ Q_{k,i}$

ULS (GEO/STR) for UK Buildings

Design values of actions, ultimate limit state - persistent and transient design situations (Table A1.2(B) Eurocode)					
Comb'tion expression reference	Permanent actions		Leading variable action	Accompanying variable actions	
	Unfavourable	Favourable		Main(if any)	Others
Eqn (6.10)	1.35 G_k	1.0 G_k	1.5 $Q_{k,1}$		1.5 $\Psi_{0,i}\ Q_{k,i}$
Eqn (6.10a)	1.35 G_k	1.0 G_k		1.5 $\Psi_{0,1}\ Q_k$	1.5 $\Psi_{0,i}\ Q_{k,i}$
Eqn (6.10b)	0.925x1.35G_k	1.0 G_k	1.5 $Q_{k,1}$		1.5 $\Psi_{0,i}\ Q_{k,i}$

For buildings Exp (6.10) is usually used: $1.35\ G_k + 1.5\ Q_k$

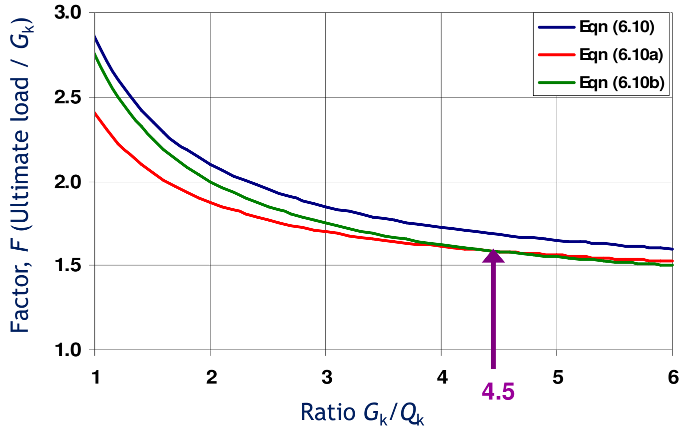
But Exp (6.10b) could be used and for one variable action: $1.25\ G_k + 1.5\ Q_k$

Provided:

1. Permanent actions < 4.5 x variable actions
2. Excludes storage loads

ULS (GEO/STR) for UK Buildings

Should you use Exp (6.10), (6.10a) or (6.10b)?



Poll:
ULS Load Combinations (STR)

For an office slab,

- Dead load = 6.25 kN/m^2,
- Superimposed dead load = 1.5 kN/m^2 and
- Imposed load = 5.0 kN/m^2.

What is n (ultimate load) in kN/m^2 ?

a	15.7 kN/m^2
b	15.9 kN/m^2
c	17.2 kN/m^2
d	18.0 kN/m^2
e	18.9 kN/m^2
f	19.1 kN/m^2

Poll:
ULS Load Combinations (STR)

For an office slab,

- DL = 6.25 kN/m²,
- SDL = 1.5 kN/m² and
- IL = 5.0 kN/m².

What is n (ultimate load) in kN/m² ?

a	15.7 kN/m²
b	15.9 kN/m²
c	17.2 kN/m²
d	18.0 kN/m²
e	18.9 kN/m²
f	19.1 kN/m²

Poll: ANSWER
ULS Load Combinations (STR)

For an office slab,
What is n (ultimate load in kN/m²)?

d	Exp(6.10)				
	DL	6.25	1.35	8.44	
	SDL	1.50	1.35	2.03	
	IL	5.00	1.50	7.50	18.0
a	Exp(6.10a)				
	DL	6.25	1.35	8.44	
	SDL	1.50	1.35	2.03	
	IL	5.00	1.05	5.25	15.7
					worse case
c	Exp(6.10b)				
	DL	6.25	1.25	7.81	
	SDL	1.50	1.25	1.88	
	IL	5.00	1.50	7.50	17.2

f	Wrong 1				
	DL	6.25	1.50	9.38	
	SDL	1.50	1.50	2.25	
	IL	5.00	1.50	7.50	19.1
b	Wrong 2				
	DL	6.25	1.25	7.81	
	SDL	1.50	1.25	1.88	
	IL	5.00	1.25	6.25	15.9
e	Wrong 3 (BS8110!)				
	DL	6.25	1.40	8.75	
	SDL	1.50	1.40	2.10	
	IL	5.00	1.60	8.00	18.9

Example:
ULS Combination of Actions (STR)

e.g: Perm. action + leading variable action + accompanying action

e.g: Dead + Imposed load (Office) + wind

The ultimate (STR) design load is either:

$\Sigma\gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \Sigma\gamma_{Q,I} \cdot \psi_{0,I} \cdot Q_{k,I}$ Exp. (6.10)

or the more adverse of:

$\Sigma\gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot \psi_{0,1} \cdot Q_{k,1} + \Sigma\gamma_{Q,I} \cdot \psi_{0,I} \cdot Q_{k,I}$ Exp. (6.10 a)

or

$\Sigma\, \xi \cdot \gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \Sigma\, \gamma_{Q,I} \cdot \psi_{0,I} \cdot Q_{k,I}$ Exp. (6.10 b)

Example:
ULS Combination of Actions (STR)

Partial Factors for Actions (ULS)

$\gamma_G = 1.35$ (NA 2.2.3.3 and Table NA.A1.2)

$\gamma_Q = 1.5$ (NA 2.2.3.3 and Table NA.A1.2)

Relevant ψ factors

ψ_0 - office areas = 0.7 (Table NA.A.A1.1)

ψ_0 - wind = 0.5 (Table NA.A.A1.1)

The value for ξ for the UK is 0.925

ULS Combination of Actions (STR) Summary

The ultimate (STR) design load is either:

$\Sigma\gamma_{G,J}\,G_{k,j} + \gamma_{Q,1}\,Q_{k,1} + \Sigma\gamma_{Q,I}\cdot\psi_{0,I}\,Q_{k,i}$ Exp. (6.10)

$= 1.35\,G_k + 1.5\,Q_{k,1} + 1.5 \times 0.5\,Q_{k,w}$ Exp. (6.10)

$= 1.35\,G_k + 1.5\,Q_{k,1} + 0.75\,Q_{k,w}$ Exp. (6.10)

Or the more adverse of

$\Sigma\gamma_{G,j}\,G_{k,j} + \gamma_{Q,1}\cdot\psi_{0,1}\,Q_{k,1} + \Sigma\gamma_{Q,I}\,\psi_{0,I}\,Q_{k,i}$ Exp. (6.10 a)

$= 1.35\,G_k + 1.5 \times 0.7\,Q_{k,1} + 1.5 \times 0.5\,Q_{k,w}$ Exp. (6.10 a)

$= 1.35G_k + 1.05\,Q_{k,1} + 0.75Q_{k,w}$ Exp. (6.10 a)

or

$\Sigma\,\xi\cdot\gamma_{G,j}\cdot G_{k,j} + \gamma_{Q,1}\cdot Q_{k,1} + \Sigma\,\gamma_{Q,I}\cdot\psi_{0,I}\cdot Q_{k,I}$ Exp. (6.10 b)

$= 0.925 \times 1.35G_k + 1.5\,Q_{k,1} + 1.5 \times 0.5\,Q_{k,w}$ Exp. (6.10 b)

$= 1.25G_k + 1.5\,Q_{k,1} + 0.75\,Q_{k,w}$ Exp. (6.10 b)

ULS Equilibrium (EQU)

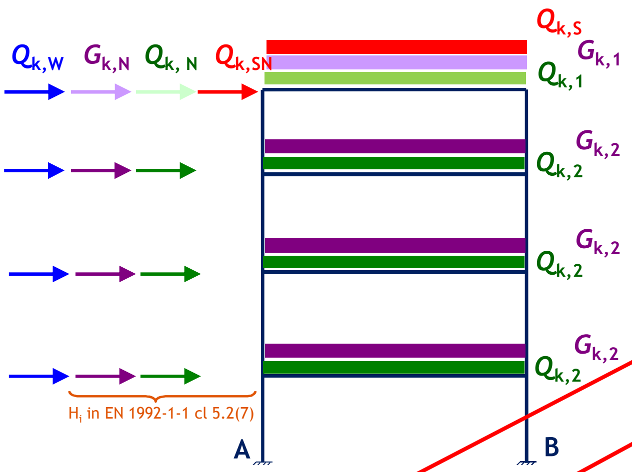
Eurocode:

Design values of actions, ultimate limit state - persistent and transient design situations (Table A1.2(B) Eurocode)					
Comb'tion expression reference	Permanent actions		Leading variable action	Accompanying variable actions	
	Unfavourable	Favourable		Main(if any)	Others
Eqn (6.10)	$\gamma_{G,j,sup}\,G_{k,j,sup}$	$\gamma_{G,j,inf}\,G_{k,j,inf}$	$\gamma_{Q,1}\,Q_{k,1}$		$\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}$

UK:

Eqn (6.10)	$1.10\,G_k$	$0.9\,G_k$	$1.5\,Q_{k,1}$		$1.5\,\psi_{0,i}\,Q_{k,i}$

Frames and EQU



ψ_0 = 0.7 for $Q_{k,2}$

ψ_0 = 0.7 for $Q_{k,1}$

ψ_0 = 0.5 for $Q_{k,W}$

ψ_0 = 0.7 for $Q_{k,S}$

Wind as leading variable action

Wind as accompanying variable action

Check uplift at A

① $0.9\ G_{k,1} + 0.9\ \Sigma G_{k,2} - 1.5\ Q_{k,W} - 1.5 \times 0.7\ Q_{k,SN} - 1.10^{\#}\ G_{k,N} - 1.5 \times 0.7\ Q_{k,N}$

② $0.9\ G_{k,1} + 0.9\ \Sigma G_{k,2} - 1.5 \times 0.5\ Q_{k,W} + 1.5\ Q_{k,SN} - 1.10^{\#}\ G_{k,N} - 1.5 \times 0.7\ Q_{k,N}$

Note # According to note in BS EN 1990 Table A.1.2 (A) & UK NA, as an alternative $\gamma_{G,sup} = 1.35$

SLS: Serviceability Limit State
BS EN 1990 (6.5.3)

Partial Factors for Actions (SLS)

$\gamma_G = 1.00$

$\gamma_Q = 1.00$ . . . . Subject to

ψ_0 - combination value

ψ_1 - frequent value.

ψ_2 - quasi-permanent value.

So: Combinations of Actions (SLS)

Characteristic combination (typically irreversible limit states)	$G_{k,j} + Q_{k,1} + \Sigma \psi_{0,i} \cdot Q_{k,i}$
Frequent combination (typically reversible limit states)	$G_{k,j} + \psi_{1,1} \cdot Q_{k,1} + \Sigma\ \psi_{2,i} \cdot Q_{k,i}$
Quasi permanent combination (typically long term effects and appearance of the structure)	$G_{k,j} + \Sigma\ \psi_{2,i} \cdot Q_{k,i}$

UK Values of ψ Factors (again)

Table NA.A1.1 UK National Annex of BS EN 1990

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings,			
Category A : domestic, residential	0.7	0.5	0.3
Category B : office areas	0.7	0.5	0.3
Category C : congregation areas	0.7	0.7	0.6
Category D : shopping areas	0.7	0.7	0.6
Category E : storage areas	1.0	0.9	0.8
Category F : traffic area, < 30kN	0.7	0.7	0.6
Category G : traffic area, 30 – 160kN	0.7	0.5	0.3
Category H : roofs	0.7	0	0
Snow load: H ≤ 1000 m a.s.l.	0.5	0.2	0
Wind loads on buildings	0.5	0.2	0

Poll:
SLS Load Combination

For an office slab,

- DL = 6.25 kN/m^2,
- SDL = 1.5 kN/m^2 and
- IL = 5.0 kN/m^2.

What is the quasi permanent load?
in kN/m^2 ?

a	9.3 kN/m^2
b	10.3 kN/m^2
c	11.3 kN/m^2
d	12.8 kN/m^2
e	15.3 kN/m^2

Poll:
SLS Load Combination

For an office slab,

- DL = 6.25 kN/m²,
- SDL = 1.5 kN/m² and
- IL = 5.0 kN/m².

What is the quasi permanent load? in kN/m² ?

= γ_G * DL + γ_G* SDL + ψ_2*IL

= 1.0 * 6.25 + 1.0 * 1.5 + 0.3 * 5.0

= 9.25 kN/m²

ψ_2	a	9.3 kN/m²
ψ_1 (freq.)	b	10.3 kN/m²
ψ_0 (??)	c	11.3 kN/m²
Char.	d	12.8 kN/m²
Wrong	e	15.3 kN/m²

Load cases
BS EN 1990 3.5(3)

"The verifications shall be carried out for all relevant design situations and load cases."

Simplified load arrangements for beams and slabs are in EC2 and the NA

NB:

There are also Partial Factors in EC7 - Geotechnical design

The UK National Annex to EC7 refers only to Design Approach 1. Two combinations of partial load and partial soil factors need consideration.

	Partial load factor		Partial material factor, γ_m		
	γ_{Gk}	γ_{Qk}	tan ϕ'	c'	c_u
Combination 1	1.35	1.5	1.0	1.0	1.0
Combination 2	1.0	1.3	1.25	1.25	1.4

Note: where variable action is favourable $\gamma_Q = 0$

ϕ' angle of shearing resistance (in terms of effective stress)
c' cohesion intercept (in terms of effective stress)
c_u undrained shear strength

These will be covered in Lecture 10

Eurocode 2 Loads Cases

BS EN 1992

Concrete Structures

EC2: Load cases & combinations

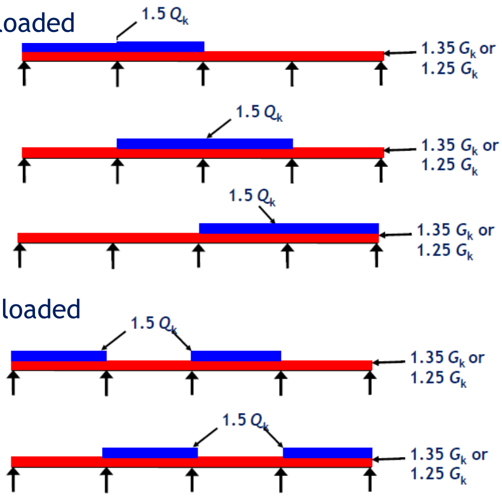
EC2: Cl 5.1.3 gives one 'simplified' option:

Concise: 5.4.2

Adjacent spans loaded

and

Alternate spans loaded



UK NA to EN 1992-1-1:
Simplified load arrangements

Table NA.1 — UK decisions for Nationally Determined Parameters described in BS EN 1992-1-1:2004 *(continued)*

Subclause	Nationally Determined Parameter	Eurocode[a] recommendation	UK decision
4.4.1.3 (4)	Values of k_1 and k_2	k_1 = 40 mm k_2 = 75 mm	Use the recommended values
5.1.3 (1)P	Simplified load arrangements	The following load arrangements should be considered: a) alternate spans carrying the design variable and permanent load ($\gamma_Q Q_k + \gamma_G G_k + P_m$), other spans carrying only the design permanent load $\gamma_G G_k + P_m$; b) any two adjacent spans carrying the design variable and permanent loads ($\gamma_Q Q_k + \gamma_G G_k + P_m$); all other spans carrying only the design permanent load, $\gamma_G G_k + P_m$.	Use any of the following three options. a) Consider the two load arrangements recommended in the Eurocode for alternate and adjacent spans. b) Consider the two following arrangements for all spans and alternate spans: 1) all spans carrying the design variable and permanent load ($\gamma_Q Q_k + \gamma_G G_k + P_m$); 2) alternate spans carrying the design variable and permanent load ($\gamma_Q Q_k + \gamma_G G_k + P_m$), other spans carrying only the design permanent load $\gamma_G G_k + P_m$; the same value of γ_G should be used throughout the structure; c) For slabs, use the all spans loaded arrangement described in b)1) if: 1) in a one-way spanning slab the area of each bay exceeds 30 m²; 2) the ratio of the variable load Q_k to the permanent load G_k does not exceed 1,25; and 3) the variable load Q_k does not exceed 5 kN/m² excluding partitions. In option c), when analysis is carried out using the load arrangement described in b)1), the resulting support moments except those at the supports of cantilevers should be reduced by 20%, with a consequential increase in the span moments. In this context a bay means a strip across the full width of a structure bounded on the other two sides by lines of support. The load arrangements in a), b) and c) are drafted using BS EN 1990:2002, Expression (6.10). Although not shown here, they can also be drafted using BS EN 1990:2002, Expressions (6.10a) and (6.10b).
5.2 (5)	Value of θ_0	1/200	Use the recommended value

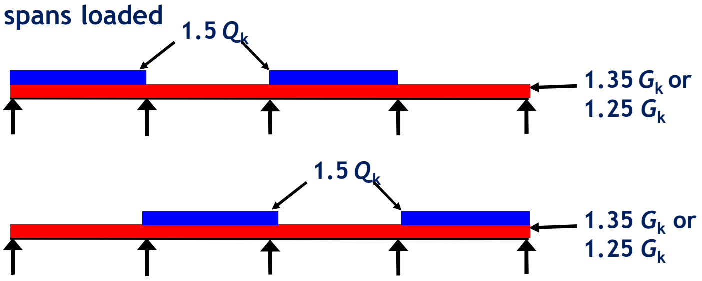
[a] Table NA.1 relates to BS EN 1992-1-1 incorporating Corrigendum No. 1 (January 2008).

UK NA: Simplified load arrangements

NA gives additional options, either:

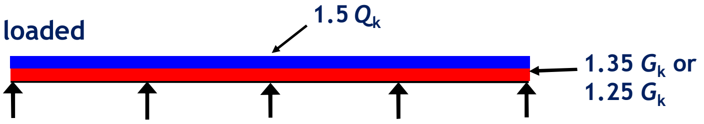
Concise: 5.4.2

Alternate spans loaded



and

All spans loaded

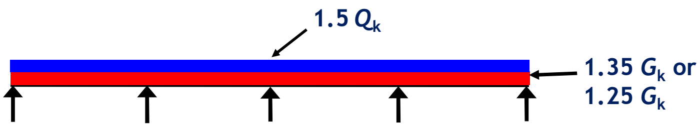


UK NA: Arrangement of Actions

Or, for some slabs, the NA gives a 3rd option :

Concise: 5.4.2

Option 3 is all spans loaded:



You can use this option for slabs if:

1. In a one-way spanning slab the area of each bay exceeds 30m^2;
2. the ratio of the variable load Q_k to the permanent load G_k does not exceed 1.25; and
3. the variable load Q_k does not exceed 5 kN/m^2 excluding partions.

Note: the resulting support moments except those at the supports of cantilevers should be reduced by 20%, with a consequential increase in the span moments.

Pattern Loading

From EN1990:

Table A1.2(B) - Design values of actions (STR/GEO) (Set B)

NOTE 3 The characteristic values of all permanent actions from one source are multiplied by $\gamma_{G,sup}$ if the total resulting action effect is unfavourable and $\gamma_{G,inf}$ if the total resulting action effect is favourable. For example, all actions originating from the self weight of the structure may be considered as coming from one source; this also applies if different materials are involved.

There is no such note for **Table A1.2(A) - Design values of actions (EQU) (Set A)**

Therefore there should be **no pattern loading on permanent actions for STR and GEO** verifications but there should be pattern loading on permanent actions for EQU.

Eurocode 1 - Loads/Actions

BS EN 1991

Actions on structures

Eurocode 1

Eurocode 1 has ten parts:

- **1991-1-1** Densities, self-weight and imposed loads
- **1991-1-2** Actions on structures exposed to fire
- **1991-1-3** Snow loads
- **1991-1-4** Wind actions
- **1991-1-5** Thermal actions
- **1991-1-6** Actions during execution
- **1991-1-7** Accidental actions due to impact and explosions
- **1991-2** Traffic loads on bridges
- **1991-3** Actions induced by cranes and machinery
- **1991-4** Actions in silos and tanks

EN 1991-1-1

Densities, self-weight and imposed loads

- Bulk density of mass concrete is 24 kN/m^3
- Bulk density of *reinforced* concrete is 25 kN/m^3
  - This represents 1.84% reinforcement
- Add 1 kN/m^3 for wet concrete
- The UK NA uses the same loads as BS 6399
- Plant loading not given

EN 1991-1-1: extracts from UK NA

Category	Example Use	q_k (kN/m^2) Char. value of udl	Q_k (kN) Char. value of pt load
A1	All uses within self-contained dwelling units	1.5	2.0
A2	Bedrooms and dormitories	1.5	2.0
A3	Bedrooms in hotels and motels, hospital wards and toilets	2.0	2.0
A5	Balconies in single family dwelling units	2.5	2.0
A7	Balconies in hotels and motels	4.0 min	2.0
B1	Offices for general use	2.5	2.7
C5	Assembly area without fixed seating, concert halls, bars, places of worship	5.0	3.6
D1/2	Shopping areas	4.0	3.6
E12	General storage	2.4 per m ht	7.0
E17	Dense mobile stacking in warehouses	4.8 per m ht (min 15.0)	7.0
F	Gross vehicle weight ≤ 30 kN	2.5	10.0

EN 1991-1-1

Imposed load reductions:

Cl 6.3.1.2 (10 & 11)

EC1 allows imposed load reductions for large floor areas and several storeys. The NA modifies the equation in EC1: use either:

$\alpha_A = 1.0 - A/1000 \geq 0.75$ (NA.1)

where A is the area (m^2) supported

or

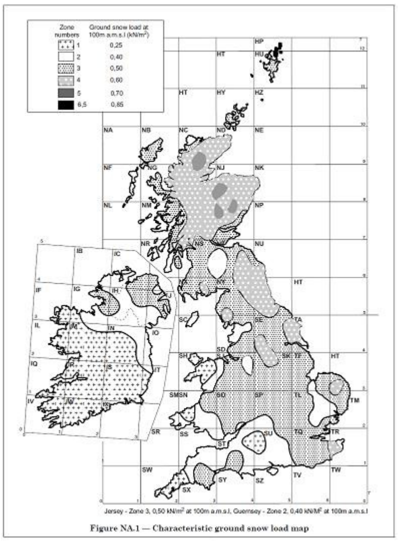
$\alpha_n = 1.1 - n/10$ $1 \leq n \leq 5$

$\alpha_n = 0.6$ $6 \leq n \leq 10$

$\alpha_n = 0.5$ $n > 10$ (NA.2)

where n is the number of storeys supported

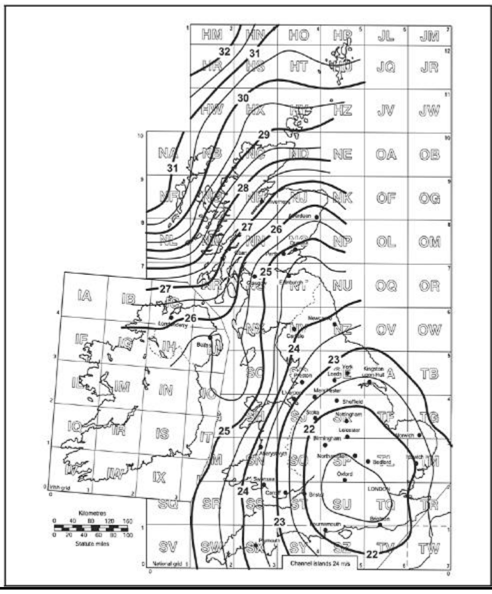
BS EN 1991-3 (NA) Snow



Zone numbers	Ground snow load at 100m a.m.s.l (kN/m^2)
1	0,25
2	0,40
3	0,50
4	0,60
5	0,70
6,5	0,85

Snow loads

BS EN 1991 1-4 (NA) Wind



Wind speeds

$v_{b,map}$

$F_w = c_s c_d \Sigma w_k A_{ref}$

c_s = size factor

c_d= dynamic factor

$w_k = q_{p(z)} c_f$

- $q_{p(z)}$ = peak wind pressure $= c_{e(z)} q_b$
  - $c_{e(z)}$ = exposure factor town or country
  - $q_b = 0.5\rho(c_{dir} c_{season} c_{prob} c_{alt} v_{b,map})^2$
    - $\rho = 1.226 kg/m^3$
- c_f= force coefficient

A_{ref} = area of structure

Exercise

Lecture 1

Load Arrangement Exercise

Q1. Overhanging cantilever beam. Determine the γ_F factors that should be applied to G_k and Q_k:-

a) for equilibrium (EQU) (BS EN 1990, Table A1.2(A) & UK NA)

b) for structural strength (STR) (BS EN 1990, Exp (6.10) & UK NA)

Q2. Continuous single-way slab. Assuming permanent actions = 6 kN/m^2 and variable actions = 4 kN/m^2, calculate the most economic value of ULS total loading (kN/m^2) using Exps (6.10), (6.10a) and (6.10b) (see BS EN 1990 Table A1.2(B) & UK NA).

Load Arrangement Exercise (pro forma)

Q1	Span $\gamma_G G_k + \gamma_Q Q_k$	Cant $\gamma_G G_k + \gamma_Q Q_k$
a) EQU		
b1) STR		
b2) STR		

Q2	$\gamma_G G_k$	$\gamma_Q Q_k$	n
(6.10)			
(6.10a)			
(6.10b)			

We will go through the answers to the exercise at the beginning of next week's lecture

End of Lecture 1

- Introduction
- Background & Basics
- Eurocode (Eurocode 0)
- Eurocode Load Combinations
- Eurocode 2 Load Cases
- Eurocode 1 Loads/Actions
- Exercise