HOW TO DESIGN

CONCRETE STRUCTURES

Getting Started

EUROPEAN CONCRETE PLATFORM

Instructions for the Members of BIBM, CEMBUREAU, EFCA and ERMCO:

"All or part of the information contained herein may be used, translated and adapted at national level with reference and credit to the original publication issued by the European Concrete Platform". (See guidelines)
It is the responsibility of the Members (national associations) of BIBM, CEMBUREAU, EFCA and ERMCO to translate and/or adapt this publication within their national framework, to publish it under their own name and logo and to disseminate it to their contacts at national level. The logo of the European Concrete Platform cannot be used at national level.

It is the responsibility of the Members (national associations) of BIBM, CEMBUREAU, EFCA and ERMCO to submit for authorisation the national version of the Concise Eurocode 2 and the "How to leaflets" to their respective national standardisation committee responsible for the Eurocodes.

Acknowledgements to the European Concrete Platform ASBL

To be adapted at national level:

Acknowledgements to the European Concrete Platform ASBL

Published by *Name of national concrete platform or National member*
Editor: ...
address
country

Layout & Printing by *Name of national concrete platform or National member*

2. Getting started

Introduction

This to be redrafted as appropriate in each country.

The design process

This guide is intended to assist the designer determine all the design information required prior to embarking on detailed element design. It covers design life, actions on structures, load arrangements, combinations of actions, method of analysis, material properties, stability and imperfections, minimum concrete cover and maximum crack widths.

Where NDPs occur in the text in this publication, recommended values in EN 1992 are used and highlighted in yellow. The UK values have been used for NDPs embedded in figures and charts and the relevant NDPs are scheduled separately to assist other users in adapting the figures and charts.

The process of designing elements will not be revolutionised as a result of using Eurocode 2[1], although much of the detail may change – as described in subsequent guides in this series.

Detailing is not covered in these guides, but the process will not vary significantly from current practice. With regard to specification, advice can be found in the guide *Introduction to Eurocodes*[2].
In the long-term it is anticipated that Eurocode 2 will lead to more economic structures.

Design life

The design life for a structure is given in Eurocode: *Basis of structural design*[3]. These are noted in Table 1 (overleaf). These should be used to determine the durability requirements for the design of reinforced concrete structures.

Actions on structures

Eurocode 1: *Actions on structures*[4] consists of 10 parts giving details of a wide variety of actions. Further information on the individual codes can be found in the first guide in this series, *How to design concrete structures using Eurocode 2: Introduction to Eurocodes*.

Eurocode 1, Part 1–1: General actions – *Densities, self-weight, imposed loads for buildings*[5] gives the densities and self-weights of building materials (see Table 2 overleaf). It should be noted that there is no advice given for loading in plant rooms.

At the time of writing not all the parts of Eurocode 1 and their National Annexes are available. Advice on the use of current national standards in conjunction with EC2 should be determined by the relevant authorities in a country.

Table 1
Indicative design working life (from UK National Annex to Eurocode)

Design life (years)	Examples
10	Temporary structures
10–30	Replaceable structural parts
15–25	Agricultural and similar structures
50	Buildings and other common structures
120	Monumental buildings, bridges and other civil engineering structures

Table 2
Selected bulk density of materials (from Eurocode 1, Part 1–1)

Material	Bulk density (kN/m³)
Normal weight concrete	24.0
Reinforced normal weight concrete	25.0
Wet normal weight reinforced concrete	26.0

Figure 1
Alternate spans loaded

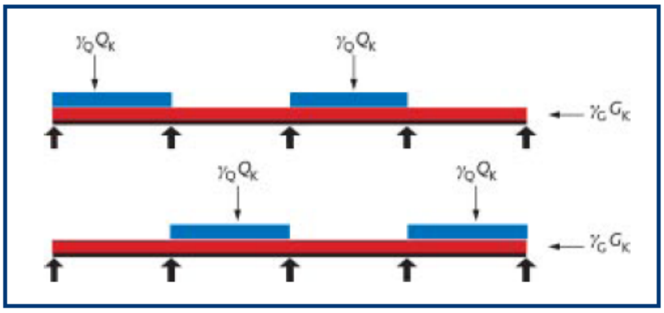


Figure 2
Adjacent spans loaded

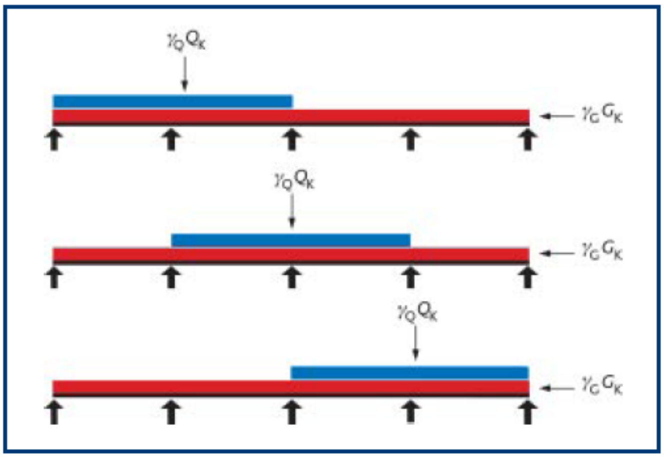
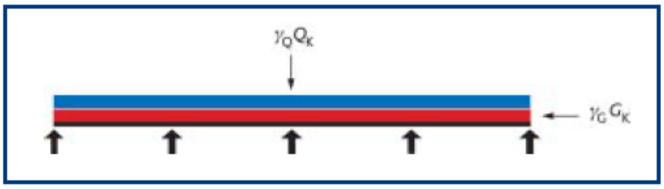


Figure 3
All spans loaded



Load arrangements

The term load arrangements refers to the arranging of variable actions(e.g. imposed and wind loads) to give the most onerous forces in a member or structure and are given in Eurocode 2 and National Annexes are allowed to provide simplifications.

For building structures Eurocode 2 Part 1–1 recommends the following load arrangements for both the ultimate limit state and serviceability limit state:

Alternate or adjacent spans loaded

The design values should be obtained from the more critical of:

- Alternate spans carrying the design variable and permanent loads with other spans loaded with only the design permanent load (seeFigure 1). The value of γ_G should be the same throughout.
- Any two adjacent spans carrying the design variable and permanent loads with other spans loaded with only the design permanent load (see Figure 2). The value of γ_G should be the same throughout.

Combination of actions

The term combination of actions refers to the value of actions to be used when a limit state is under the influence of different actions.

The numerical values of the partial factors for the ULS combination canbe obtained by referring to Eurocode: *Basis of structural design or the guide Introduction to Eurocodes*[2].

There are three SLS combinations of actions – characteristic, frequent and quasi-permanent. The numerical values are given in Eurocode: *Basis of structural design*.

Material properties

Concrete

In Eurocode 2 the design of reinforced concrete is based on thecharacteristic cylinder strength rather than cube strength and should be specified according to *EN 206–1*[7](e.g. for class C28/35 concrete the cylinderstrength is 28 MPa, whereas the cube strength is 35 MPa).Typical concrete properties are given in Table 4.

Concrete up to class C90/105 can be designed using Eurocode 2. For classes above C50/60, however, there are additional rules and variations. For this reason, the design of these higher classes is not considered in this series of guides.

Reinforcing steel

Eurocode 2 can be used with reinforcement of characteristic strengths ranging from 400 to 600 MPa. The properties of steel reinforcement are summarised in Table 5 (on page 4). There are three classes of reinforcement, A, B and C, which provide increasing ductility. Class A is not suitable where redistribution of 20% and above has been assumed in the design.There is no provision for the use of plain bar or mild steel reinforcement.

Table 3

Selected imposed loads for buildings (from draft UK National Annex to Eurocode 1, Part 1–1)

Category	Example use	q_k (kN/m²)	Q_k (kN)
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 at outer edge
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 height	7.0
E17	Dense mobile stacking in warehouses	4.8 per m height (min. 15.0)	7.0
F	Gross vehicle weight ≤ 30kN	2.5	10.0

Table 4

Selected concrete properties based on Table 3.1 of Eurocode 2, Part 1–1

Symbol	Description	Properties										
f_{ck} (MPa)	Characteristic cylinder strength	12	16	20	25	30	35	40	45	50	28[a]	32[a]
$f_{ck,cube}$ (MPa)	Characteristic cube strength	15	20	25	30	37	45	50	55	60	35	40
f_{ctm} (MPa)	Mean tensile strength	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	2.8	3.0
E_{cm}[b] (GPa)	Secant modulus of elasticity	27	29	30	31	33	34	35	36	37	32	34

Key

a Concrete class not cited in Table 3.1, Eurocode 2, Part 1–1

b Mean secant modulus of elasticity at 28 days for concrete with quartzite aggregates. For concretes with other aggregates refer to Cl 3.1.3 (2)

Table 5
Characteristic tensile properties of reinforcement

Class (BS 4449) and designation (BS 8666)	A	B	C
Characteristic yield strength f_{yk} or $f_{0.2k}$ (MPa)	500	500	500
Minimum value of $k = (f_t/f_y)_k$	≥ 1.05	≥ 1.08	≥ 1.15 < 1.35
Characteristic strain at maximum force ε_{uk} (%)	≥ 2.5	≥ 5.0	≥ 7.5

Notes
1 Table derived from BS EN 1992–1–1 Annex C, BS 4449: 2005 and BS EN 10080[10].
2 The nomenclature used in BS 4449: 2005 differs from that used in BS EN 1992–1–1 Annex C and used here.
3 In accordance with BS 8666, class H may be specified, in which case class A, B or C may be supplied.

Table 6
Bending moment and shear co-efficients for beams

	Moment	Shear
Outer support	25% of span moment	$0.45\ (G + Q)$
Near middle of end span	$0.900\ Gl + 0.100\ Ql$	
At first interior support	$-0.094\ (G + Q)\ l$	$0.63\ (G + Q)^{a}$
At middle of interior spans	$0.066\ Gl + 0.086\ Ql$	
At interior supports	$-0.075\ (G + Q)\ l$	$0.50\ (G + Q)$

Key
a $0.55\ (G + Q)$ may be used adjacent to the interior span.

Notes
1 Redistribution of support moments by 15% has been included.
2 Applicable to 3 or more spans only and where $Q_k \leq G_k$.
3 Minimum span ≥ 0.85 longest span.
4 l is the effective length, G is the total of the ULS permanent actions, Q is the total of the ULS variable actions.

Table 7
Exposure classes

Class	Description
No risk of corrosion or attack	
X0	For concrete without reinforcement or embedded metal where there is no significant freeze/thaw, abrasion or chemical attack.
Corrosion induced by carbonation	
XC1	Dry or permanently wet
XC2	Wet, rarely dry
XC3/4	Moderate humidity or cyclic wet and dry
Corrosion induced by chlorides other than from seawater	
XD1	Moderate humidity
XD2	Wet, rarely dry
XD3	Cyclic wet and dry
Corrosion induced by chlorides from seawater	
XS1	Exposed to airborne salt but not in direct contact with sea water
XS2	Permanently submerged
XS3	Tidal, splash and spray zones
Freeze/thaw with or without de-icing agents	
XF1	Moderate water saturation without de-icing agent
XF2	Moderate water saturation with de-icing agent
XF3	High water saturation without de-icing agent
XF4	High water saturation with de-icing agent or sea water
Chemical attack (ACEC classes)	
Refer to BS 8500–1 and Special Digest 1[11]	

Structural analysis

The primary purpose of structural analysis in building structures is to establish the distribution of internal forces and moments over the whole or part of a structure and to identify the critical design conditions at all sections. The geometry is commonly idealised by considering the structure to be made up of linear elements and plane two-dimensional elements.

The type of analysis should be appropriate to the problem being considered. The following may be used: linear elastic analysis, linear elastic analysis with limited redistribution, and plastic analysis. Linear elastic analysis may be carried out assuming cross sections are uncracked (i.e. concrete section properties); using linear stress-strain relationships, and assuming mean values of elastic modulus.

For the ultimate limit state only, the moments derived from elastic analysis may be redistributed (up to a maximum of 30%) provided that the resulting distribution of moments remains in equilibrium with the applied loads and subject to certain limits and design criteria (e.g. limitations of depth to neutral axis).

Regardless of the method of analysis used, the following principles apply:

- **Where a beam or slab is monolithic with its supports, the critical design hogging moment may be taken as that at the face of the support, but should not be taken as less than 0.65 times the full fixed end moment.**
- **Where a beam or slab is continuous over a support that may be considered not to provide rotational restraint, the moment calculated at the centre line of the support may be reduced by ($F_{Ed,sup}\ t/8$),where $F_{Ed,sup}$ is the support reaction and t is the breadth of the support.**
- **For the design of columns the elastic moments from the frame action should be used without any redistribution.**

Bending moment and shear force co-efficients for beams are given in Table 6; these are suitable where spans are of similar length and the other notes to the table are observed.

Minimum concrete cover

The nominal cover can be assessed as follows:

$$c_{nom} = c_{min} + \Delta c_{dev} \qquad \text{Exp. (4.1)}$$

Where c_{min} should be set to satisfy the requirements below:

- **safe transmission of bond forces**
- **durability**
- **fire resistance**

and Δc_{dev} is an allowance which should be made in the design for deviations from the minimum cover. It should be taken as 10 mm, unless fabrication (i.e. construction) is subjected to a quality assurance system, in which case it is permitted to reduce Δc_{dev} to between 10 mm and 5 mm.

Figure 4
Sections through structural members, showing nominal axis distance, *a*

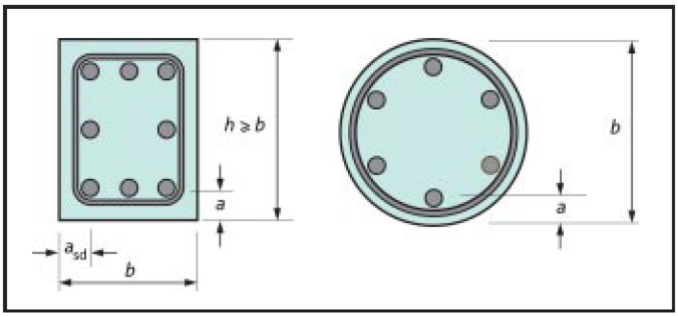


Table 9
Minimum column dimensions and axis distances for columns with rectangular or circular section – method A

Standard fire resistance	Minimum dimensions (mm) Column width (b_{min})/axis distance *(a)* of the main bars	
	Column exposed on more than one side (μ_{fi} = 0.7)	Exposed on one side (μ_{fi} = 0.7)
R 60	250/46 350/40	155/25
R 120	350/57* 450/51*	175/35
R 240	†	295/70

Notes
1 Refer to BS EN 1992–1–2 for design limitations.
2 μ_{fi} is the ratio of the design axial load under fire conditions to the design resistance of the column at normal temperature conditions. Conservatively μ_{fi} may be taken as 0.7.
* Minimum 8 bars.
† Method B indicates 600/70 for R 240 and μ_{fi} = 0.7 and may be used. See EN 1992–1–2 Table 5.2b.

Minimum cover for bond

The minimum cover to ensure adequate bond should not be less than the bar diameter, or equivalent bar diameter for bundled bars, unless the aggregate size is over 32 mm.

Minimum cover for durability

The recommendations for durability in Eurocode 2 are based on BS EN 206–112. In the UK the requirements of BS EN 206 –1 are applied through the complementary standard BS 8500.

Table 10
Minimum dimensions and axis distances for reinforced concrete slabs

Standard fire resistance		Minimum dimensions (mm) Possible combinations of *a* and b_{min} where *a* is the average axis distance and b_{min} is the width of the rib							
		One-way spanning slab	Two-way spanning slab $l_y/l_x \le 1.5$	Two-way spanning slab $1.5 < l_y/l_x \le 2$	Flat slab	Ribs in a two-way spanning ribbed slab			
REI 60	h_s = a =	80 20	80 10	80 15	180 15	b_{min} = a =	100 25	120 15	≥200 10
REI 120	h_s = a =	120 40	120 20	120 25	200 35	b_{min} = a =	160 45	190 40	≥300 30
REI 240	h_s = a =	175 65	175 40	175 50	200 50	b_{min} = a =	450 70	700 60	—

Note
Refer to BS EN 1992–1–2 for design limitations.

Design for fire resistance

Eurocode 2 Part 1–2: *Structural fire design*[8], gives several methods for determining the fire resistance of concrete elements; further guidance can be obtained from specialist literature. Design for fire resistance may still be carried out by referring to tables to determine the minimum cover and dimensions for various elements, as set out below.

Rather than giving the minimum cover, the tabular method is based on nominal axis distance, a (see Figure 4). This is the distance from the centre of the main reinforcing bar to the surface of the member. It is a nominal (not minimum) dimension. The designer should ensure that

$$a \ge c_{nom} + \phi_{link} + \phi_{bar}/2.$$

There are three standard fire exposure conditions that may be satisfied:

R **Mechanical resistance for load bearing**
E **Integrity of separation**
I **Insulation**

Tables 9 and 10 give the minimum dimensions for columns and slabs to meet the above conditions. Further information is given in Eurocode 2 and subsequent guides in this series, including design limitations and data for walls and beams.

Table 8

Selected[a] recommendations for normal-weight reinforced concrete quality for combined exposure classes and cover to reinforcement for at least a 50-year intended working life and 20 mm maximum aggregate size

Exposure conditions (Refer to Table 7)			Cement/ combination designations[b]	Strength class[c], maximum w/c ratio, minimum cement or combination content (kg/m³), and equivalent designated concrete (where applicable)							
				Nominal cover to reinforcement[d]							
Typical example	**Primary**	**Secondary**		15 + Δc_{dev}	20 + Δc_{dev}	25 + Δc_{dev}	30 + Δc_{dev}	35 + Δc_{dev}	40 + Δc_{dev}	45 + Δc_{dev}	50 + Δc_{dev}
Internal mass concrete	**X0**		All	Recommended that this exposure is not applied to reinforced concrete							
Internal elements (except humid locations)	**XC1**		All	C20/25, 0.70, 240 or RC25	<<<	<<<	<<<	<<<	<<<	<<<	<<<
Buried concrete in AC-1 ground conditions[e]	**XC2**	**AC-1**	All	—	—	C25/30, 0.65, 260 or RC30	<<<	<<<	<<<	<<<	<<<
Vertical surface protected from direct rainfall	**XC3 & XC4**		All except IVB	—	C40/50, 0.45, 340 or RC50	C32/40, 0.55, 300 or RC40	C28/35, 0.60, 280 or RC35	C25/30, 0.65, 260 or RC30	<<<	<<<	<<<
Exposed vertical surfaces		**XF1**	All except IVB	—	C40/50, 0.45, 340 or RC50	C32/40, 0.55, 300 or RC40	C28/35, 0.60, 280 or RC35	<<<	<<<	<<<	<<<
Exposed horizontal surfaces		**XF3**	All except IVB	—	C40/50, 0.45, 340[f] or RC50XF[f]	<<<	<<<	<<<	<<<	<<<	<<<
		XF3 (air entrained)	All except IVB	—	—	C32/40, 0.55, 300 plus air[f,g]	C28/35, 0.60, 280 plus air[f,g] or PAV2	C25/30, 0.60, 280 plus air[f,g,h] or PAV1	<<<	<<<	<<<
Car park elements subject to airborne chlorides only	**XD1**	**XC3/4**	All except IVB	—	—	C40/50, 0.45, 360	C32/40, 0.55, 320	C28/35, 0.60, 300	<<<	<<<	<<<
Car park decks and areas subject to de-icing spray	**XD3**	**XC3/4**	IIB-V, IIIA	—	—	—	—	—	C35/45, 0.40, 380	C32/40, 0.45, 360	C28/35, 0.50, 340
			CEM I, IIA, IIB-S, SRPC	—	—	—	—	—	C45/55, 0.35, 380	C40/50, 0.40, 380	C35/45, 0.45, 360
			IIIB	—	—	—	—	—	C32/40, 0.40, 380	C28/35, 0.45, 360	C25/30, 0.50, 340
Vertical elements subject to de-icing spray and freezing		**XC3/4 +XF2**	IIB-V, IIIA	—	—	—	—	—	C35/45, 0.40, 380	C32/40, 0.45, 360	C32/40, 0.50, 340
			CEM I, IIA, IIB-S, SRPC	—	—	—	—	—	C45/55, 0.35, 380	C40/50, 0.40, 380	C35/45, 0.45, 360
			IIIB	—	—	—	—	—	C32/40, 0.40, 380	C32/40 0.45, 360	C32/40, 0.50, 340
Car park decks, ramps and external areas subject to freezing and de-icing salts		**XC3/4 +XF4**	CEM I, IIA, IIB-S, SRPC	—	—	—	—	—	C45/55, 0.35, 380[f]	C40/50, 0.40, 380[f]	<<<
		XC3/4 +XF4 (air entrained)	IIIB	—	—	—	—	—	—	C28/35 0.45, 360[f,g]	C28/35, 0.50, 340[f,g]
Exposed vertical surfaces near coast	**XS1**	**XC3/4 +XF2**	IIB-V, IIIA	—	—	—	C45/55, 0.35, 380	C35/45, 0.45, 360	C32/40, 0.50, 340	<<<	<<<
			CEM I, IIA, IIB-S, SRPC	—	—	—	C50/60, 0.35, 380	C40/50, 0.45, 360	C35/45, 0.50, 340	<<<	<<<
			IIIB	—	—	—	C35/45, 0.40, 380	C32/40, 0.50, 340	C32/40, 0.55, 320	<<<	<<<
Exposed horizontal surfaces near coast		**XC3/4 +XF4**	CEM I, IIA, IIB-S, SRPC	—	—	—	C50/60, 0.35, 380[f]	C40/50, 0.45, 360[f]	<<<	<<<	<<<

Key

a This table comprises a selection of common exposure class combinations. Requirements for other sets of exposure classes eg XD2, XS2 and XS3 should be derived from BS 8500-1: 2002, Annex A.

b See BS 8500-2, Table 1. (CEM I is Portland cement, IIA to IVB are cement combinations.)

c For prestressed concrete the minimum strength class should be C28/35.

d Δc_{dev} is an allowance for deviations.

e For sections less than 140 mm thick refer to BS 8500.

f Freeze/thaw resisting aggregates should be specified.

g Air entrained concrete is required.

h This option may not be suitable for areas subject to severe abrasion.

— Not recommended

<<< Indicates that concrete quality in cell to the left should not be reduced

Stability and imperfections

The effects of geometric imperfections should be considered in combination with the effects of wind loads (i.e. not as an alternative load combination). For global analysis, the imperfections may be represented by an inclination θ_i.

θ_i = (1/200) x a_h x a_m

where

a_h = (2/√l), to be taken as not less than 2/3 nor greater than 1.0

a_m = $[0.5 (1 + 1/m)]^{0.5}$

l is the height of the building in metres

m is the number of vertical members contributing to the horizontal force in the bracing system.

The effect of the inclination may be represented by transverse forces at each level and included in the analysis with other actions (see Figure 5):

Effect on bracing system: Hi = θ_i (N_b – N_a)

Effect on floor diaphragm: Hi = θ_i (N_b + N_a)/2

Effect on roof diaphragm: Hi = θ_i N_a

where N_a and N_b are longitudinal forces contributing to H_i.

In most cases, an allowance for imperfections is made in the partial factors used in the design of elements. However for columns, the effect of imperfections, which is similar in principle to the above, must be considered (see *How to design concrete structures using Eurocode 2: Columns*[9]).

Crack control

Crack widths should be limited to ensure appearance and durability are satisfactory.In the absence of specific durability requirements (e.g. water tightness) the crack widths in reinforced members may be limited to 0.3 mm in all exposure classes under the quasi-permanent combination. In the absence of requirements for appearance, this limit may be relaxed (to say 0.4 mm) for exposure classes X0 and XC1 (refer to Table 7). The theoretical size of the crack can be calculated using the expressions given in Cl 7.3.4 from Eurocode 2–1–1 or from the 'deemed to satisfy' requirements that can be obtained from Table 11, which is based on tables 7.2N and 7.3N of the Eurocode. The limits apply to either the bar size or the bar spacing, not both.

Figure 5

Examples of the effect of geometric imperfections

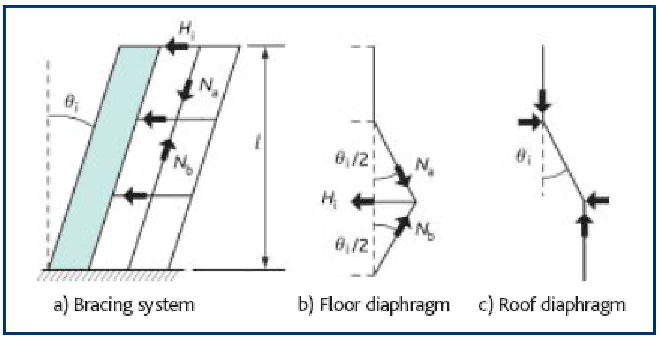


Table 11

Maximum bar size or spacing to limit crack width

Steel stress (σ_s) MPa	w_{max} = 0.4 mm Maximum bar size (mm)		w_{max} = 0.4 mm Maximum bar spacing (mm)	w_{ma} = 0.3 mm Maximum bar size (mm)		w_{ma} = 0.3 mm Maximum bar spacing (mm)
160	40		300	32		300
200	32	OR	300	25	OR	250
240	20		250	16		200
280	16		200	12		150
320	12		150	10		100
360	10		100	8		50

Note

The steel stress may be estimated from the expression below (or see Figure 6):

$$\sigma_s = \frac{f_{yk}\, m\, A_{s,req}}{\gamma_{ms}\, n\, A_{s,prov}\, \delta}$$

where:

f_{yk} is the characteristic reinforcement yield stress

γ_{ms} is the partial factor for reinforcing steel

m is the total load from quasi-permanent combination

n is the total load from ULS combination

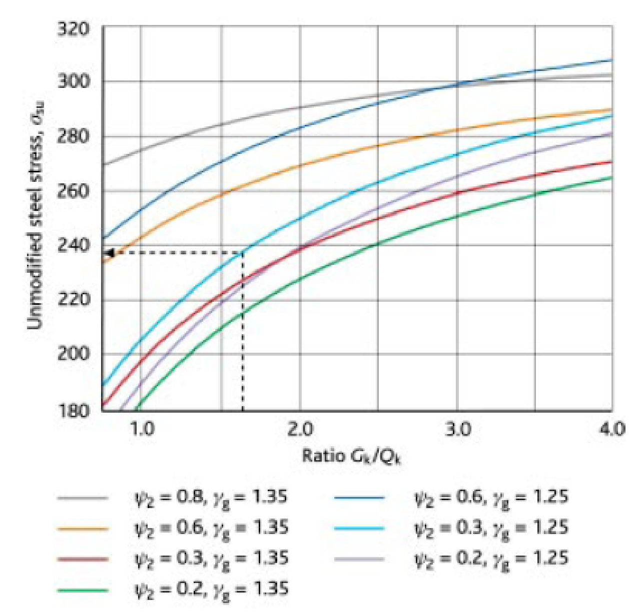
$A_{s,req}$ is the area of reinforcement at the ULS

$A_{s,prov}$ is the area of reinforcement provided

δ is the ratio of redistributed moment to elastic moment

Figure 6

Determination of steel stress for crack width control



To determine stress in the reinforcement (σ_s), calculate the ratio G_k/Q_k, read up the graph to the appropriate curve and read across to determine σ_{su}.

σ_s can be calculated from the expression: $\sigma_s = \sigma_{su} \left(\frac{A_{s,req}}{A_{s,prov}}\right)\left(\frac{1}{\delta}\right)$

References

1 Eurocode 2: *Design of concrete structures*. BSI (4 parts).
2 NARAYANAN, R S & BROOKER, O. *How to design concrete structures using Eurocode 2: Introduction to Eurocodes* (TCC/03/16). The Concrete Centre, 2005.
3 EN 1991, Eurocode: *Basis of structural design*. 2002.
4 EN 1991, Eurocode 1: *Actions on structures*. (10 parts).
5 EN 1990, Eurocode 1: *Actions on structures Part 1–1: General actions – Densities, self-weight, imposed loads for buildings*2002.
6 EN 10080: *Steel for the reinforcement of concrete – Weldable reinforcing steel – General*. 2005.
7 EN 206–1: *Concrete – Part: Specification, performance, production and conformity*. 2000.
8 EN 1992–1–2, Eurocode 2: *Design of concrete structures. General rules – structural fire design*, BSI, 2004.
9 MOSS, R M & BROOKER, O. *How to design concrete structures using Eurocode 2: Columns*, (TCC/03/20). The Concrete Centre, 2006.

Additional references for precast construction

1. EN 13369-Common rules for precast concrete products
2. NARAYANAN, RS - Precast Eurocode 2 - Design Manual. British precast, 2006

Further guidance and advice

- Guides in this series cover: Introduction to Eurocodes, Getting started, Slabs, Beams, Columns, Foundations, Flat slabs and Deflection. For free downloads, details of other publications and more information on Eurocode 2 visit www.eurocode2.info
- This guide is taken from The Concrete Centre's publication, How to design concrete structures using Eurocode 2 (Ref.CCIP-006)
- For information on all the new Eurocodes visit www.eurocodes.co.uk

Acknowledgements

This guide was originally published by BCA and The Concrete Centre in the UK. The author of the original publication was O Brooker BEng, Ceng, MICE, MIStructE.

Tables & Charts: Word versions (corrected text highlighted in green)

Table 1 Indicative design working life

Design life (years)	Examples
10	Temporary structures
10-25	Replaceable structural parts
15-30	Agricultural and similar structures
50	Buildings and other common structures
100	Monumental buildings, bridges and other civil engineering structures.

Table 2 Selected bulk density of materials (from Eurocode 1, Part 1–1)

Material	Bulk density (kN/m^3)
Normal weight concrete	24.0
Reinforced normal weight concrete	25.0
Wet normal weight reinforced concrete	26.0

Table 3 Selected imposed loads for buildings (recommended values in EN 1991-1-1)

Category	Example use	q_k (kN/m^2)	Q_k (kN)
A	Floors	2.0	2.0
A	Stairs	2.0	2.0
A	Balconies in single family dwelling units	2.5	2.0
B	Office areas	3.0	4.5
C5	Areas susceptible to large crowds (e.g.) in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms	5.0	4.5
D1	Areas in general retail shops	4.0	4.0
D2	Areas in department stores	5.0	7.0
E1	Areas of storage use including storage of books and other documents	7.5	7.0
F	Gross vehicle weight ≤ 30 kN	2.5	20.0

Table 4 Selected concrete properties based on Table 3.1 of EN 1992- 1–1

Symbol	Description	Properties										
f_{ck} (MPa)	Characteristic cylinder strength	12	16	20	25	30	35	40	45	50	28[a]	32[a]
$f_{ck,cube}$ (MPa)	Characteristic cube strength	15	20	25	30	37	45	50	55	60	35	40
f_{ctm} (MPa)	Mean tensile strength	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	2.8	3.0
E_{cm}[b] (GPa)	Secant modulus of elasticity	27	29	30	31	33	34	35	36	37	32	34

Key
a Concrete class not cited in Table 3.1, EN 1992- 1-1
b Mean secant modulus of elasticity at 28 days for concrete with quartzite aggregates. For concretes with other aggregates refer to Cl 3.1.3 (2) of EN 1992-1-1

Table 5 Characteristic tensile properties of reinforcement

Ductility class	A	B	C
Characteristic yield strength f_{yk} or $f_{0.2k}$ (MPa)	**400 - 600**	**400 - 600**	**400 - 600**
Minimum value of $k = (f_t/f_y)_k$	**≥ 1.05**	**≥ 1.08**	**≥ 1.15 < 1.35**
Characteristic strain at maximum force ε_{uk} (%)	**≥ 2.5**	**≥ 5.0**	**≥ 7.5**

Notes
1 **Table derived from EN 1992-1-1 Annex C and EN 10080[10].**

Table 6 Bending moment and shear coefficients for beams

	Moment	Shear
Outer support	**25% of span moment**	**0.45 (G + Q)**
Near middle of end span	**0.090 Gl + 0.100 Ql**	
At first interior support	**-0.094 (G + Q)l**	**0.63 (G + Q)[a]**
At middle of interior spans	**0.066 Gl + 0.086 Ql**	
At interior supports	**-0.075 (G + Q)l**	**0.50 (G + Q)**

Key
a **0.55 (G + Q) may be used adjacent to the interior span.**
Notes:
1 **Redistribution of support moments by 15% has been included.**
2 **Applicable to 3 or more spans only and where $Q_k \leq G_k$.**
3 **Minimum span ≥ 0.85 longest span.**
4 **l is the effective length, G is the total of the ULS permanent actions, Q is the total of the ULS variable actions.**

Table 7 Exposure Classes (in accordance with EN 206-1)

Class	Description
No risk of corrosion or attack	
XO	**For concrete without reinforcement or embedded metal where there is no significant freeze/thaw, abrasion or chemical attack**
Corrosion induced by carbonation	
XC1	**Dry or permanently wet**
XC2	**Wet, rarely dry**
XC3/4	**Moderate humidity or cyclic wet and dry**
Corrosion induced by chlorides other than from seawater	
XD1	**Moderate humidity**
XD2	**Wet, rarely dry**
XD3	**Cyclic wet and dry**
Corrosion induced by chlorides from seawater	
XS1	**Exposed to airborne salt but not in direct contact with sea water**
XS2	**Permanently submerged**
XS3	**Tidal, splash and spray zones**
Freeze/thaw with or without de-icing agents	
XF1	**Moderate water saturation without de-icing agent**
XF2	**Moderate water saturation with de-icing agent**
XF3	**High water saturation without de-icing agent**
XF4	**High water saturation with de-icing agent or sea water**
Chemical attack	
XA1	**Slightly aggressive chemical environment (EN 206 -1, Table 2)**
XA2	**Moderately aggressive chemical environment (EN 206 -1, Table 2)**
XA3	**Highly aggressive chemical environment (EN 206 -1, Table 2)**

Table 8 Selected[a] recommendations for normal-weight reinforced concrete quality for combined exposure classes and cover to reinforcement for at least a 50-year intended working life and 20 mm maximum aggregate size.

(Note: Any country adapting this Table should substitute data applicable in the country)

Exposure conditions			Cement/ combination designations[b]	Strength class[c], maximum w/c ratio, minimum cement or combination content (kg/m^3) or equivalent designated concrete (where applicable)							
Typical example	Primary	Secondary		Nominal cover to reinforcement[d]							
				15 + Δc_{dev}	20 + Δc_{dev}	25 + Δc_{dev}	30 + Δc_{dev}	35 + Δc_{dev}	40 + Δc_{dev}	45 + Δc_{dev}	50 + Δc_{dev}
Internal mass concrete	**X0**	—	**All**	**Recommended that this exposure is not applied to reinforced concrete**							
Internal elements (except humid locations)	**XC1**	—	**All**	**C20/25, 0.70, 240 or RC20/25**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**
Buried concrete in AC-1 ground conditions[e]	**XC2**	**AC-1**	**All**	—	—	**C25/30, 0.65, 260 or RC25/30**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**
Vertical surface protected from direct rainfall	**XC3 & XC4**	—	**All except IVB**	—	**C40/50, 0.45, 340 or RC40/50**	**C30/37, 0.55, 300 or RC30/37**	**C28/35, 0.60, 280 or RC28/35**	**C25/30, 0.65, 260 or RC25/30**	**<<<**	**<<<**	**<<<**
Exposed vertical surfaces		**XF1**	**All except IVB**	—	**C40/50, 0.45, 340 or RC40/50**	**C30/37, 0.55, 300 or RC30/37**	**C28/35, 0.60, 280 or RC28/35**	**<<<**	**<<<**	**<<<**	**<<<**
Exposed horizontal surfaces		**XF3**	**All except IVB**	—	**C40/50, 0.45, 340[g] or RC40/50XF[g]**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**	**<<<**
		XF3 (air entrained)	**All except IVB**	—	—	**C32/40, 0.55, 300 plus air[g,h]**	**C28/35, 0.60, 280 plus air[g,h] or PAV2**	**C25/30, 0.60, 280 plus air[g,h,j] or PAV1**	**<<<**	**<<<**	**<<<**
Elements subject to airborne chlorides	**XD1[f]**	—	**All**	—	—	**C40/50, 0.45, 360**	**C32/40, 0.55, 320**	**C28/35, 0.60, 300**	**<<<**	**<<<**	**<<<**
Car park decks and areas subject to de-icing spray	**XD3[f]**	—	**IIB-V, IIIA**	—	—	—	—	—	**C35/45, 0.40, 380**	**C32/40, 0.45, 360**	**C28/35, 0.50, 340**
			CEM I, IIA, IIB-S, SRPC	—	—	—	—	—	**See BS 8500**	**C40/50, 0.40, 380**	**C35/45, 0.45, 360**
			IIIB, IVB-V	—	—	—	—	—	**C32/40, 0.40, 380**	**C28/35, 0.45, 360**	**C25/30, 0.50, 340**
Vertical elements subject to de-icing spray and freezing		**XF2**	**IIB-V, IIIA**	—	—	—	—	—	**C35/45, 0.40, 380**	**C32/40, 0.45, 360**	**C32/40, 0.50, 340**
			CEM I, IIA, IIB-S, SRPC	—	—	—	—	—	**See BS 8500**	**C40/50, 0.40, 380**	**C35/45, 0.45, 360**
			IIIB, IVB-V	—	—	—	—	—	**C32/40, 0.40, 380**	**C32/40, 0.45, 360**	**C32/40, 0.50, 340**
Car park decks, ramps and external areas subject to freezing and de-icing salts		**XF4**	**CEM I, IIA, IIB-S, SRPC**	—	—	—	—	—	**See BS 8500**	**C40/50, 0.40, 380[g]**	**<<<**
		XF4 (air entrained)	**IIB-V, IIIA, IIIB**	—	—	—	—	—	**C28/35, 0.40, 380[g,h]**	**C28/35, 0.45, 360[g,h]**	**C28/35, 0.50, 340[g,h]**

Table 8 continued

Exposed vertical surfaces near coast	XS1	XF1	CEM I, IIA, IIB-S, SRPC	—	—	—	See BS 8500	C35/45, 0.45, 360	C32/40, 0.50, 340	<<<	<<<
			IIB-V, IIIA	—	—	—	See BS 8500	C32/40, 0.45, 360	C28/35, 0.50, 340	C25/30, 0.55, 320	<<<
			IIIB	—	—	—	C32/40, 0.40, 380	C25/30, 0.50, 340	C25/30, 0.50, 340	C25/30, 0.55, 320	<<<
Exposed horizontal surfaces near coast		XF4	CEM I, IIA, IIB-S, SRPC	—	—	—	See BS 8500	C40/50, 0.40, 380[g]	<<<	<<<	<<<

Key
a **This table comprises a selection of common exposure class combinations. Requirements for other sets of exposure classes, e.g. XD2, XS2 and XS3 should be derived from BS 8500-1: 2002. Annex A.**
b **See BS 8500-2, Table 1. (CEM I is Portland cement, IIA to IVB are cement combinations.)**
c **For prestressed concrete the minimum strength class should be C28/35.**
d Δc_{dev} **is an allowance for deviations.**
e **For sections less than 140 mm thick refer to BS 8500.**
f **Also adequate for exposure class XC3/4.**
g **Freeze/thaw resisting aggregates should be specified.**
h **Air entrained concrete is required.**
j **This option may not be suitable for areas subject to severe abrasion.**
— **Not recommended**
<<< Indicates that concrete quality in cell to the left should not be reduced

Table 9 Minimum column dimensions and axis distances for columns with rectangular or circular section – Method A

Standard fire resistance	Minimum dimensions (mm) Column width (b_{min})/axis distance (a) of the main bars	
	Column exposed on more than one side (μ_{fi} = 0.7)	Exposed on one side (μ_{fi} = 0.7)
R 60	**250/46** **350/40**	**155/25**
R 120	**350/57*** **450/51***	**175/35**
R 240	**†**	**295/70**

Notes
1 **Refer to EN 1992-1-2 for design limitations.**
2 μ_{fi} **is the ratio of the design axial load under fire conditions to the design resistance of the column at normal temperature conditions. Conservatively** μ_{fi} **may be taken as 0.7.**
*** Minimum 8 bars**
† Method B indicates 600/70 for R 240 and μ_{fi} **= 0.7 and may be used. See EN 1992-1-2 Table 5.2b**

Table 10 Minimum dimensions and axis distances for reinforced concrete slabs

Standard fire resistance		Minimum dimensions(mm)							
		One-way spanning slab	Two-way spanning slab $l_y/l_x \leq 1.5$	Two-way spanning slab $1.5 < l_y/l_x \leq 2$	Flat slab	Ribs in two-way spanning ribbed slab b_{min} is the width of the rib			
REI 60	h_s = a =	**80** **20**	**80** **10**	**80** **15**	**180** **15**	b_{min} = a =	**100** **25**	**20** **15**	**≥200** **10**
REI 120	h_s = a =	**120** **40**	**120** **20**	**120** **25**	**200** **35**	b_{min} = a =	**160** **45**	**190** **40**	**≥300** **30**
REI 240	h_s = a =	**175** **65**	**175** **40**	**175** **50**	**200** **50**	b_{min} = a =	**450** **70**	**700** **60**	**—**

Note
1 **Refer to EN 1992-1-2 for design limitations.**
2 a **is the axis distance (see Figure 4).**
3 h_s **is the slab thickness, including any non-combustible flooring.**

Table 11 Maximum bar size or spacing to limit crack width

Steel stress ($_s$) MPa	w_{max} = 0.4 mm			w_{max} = 0.3 mm		
	Maximum bar size (mm)		Maximum bar spacing (mm)	Maximum bar size (mm)		Maximum bar spacing (mm)
160	**40**	OR	**300**	**32**	OR	**300**
200	**32**		**300**	**25**		**250**
240	**20**		**250**	**16**		**200**
280	**16**		**200**	**12**		**150**
320	**12**		**150**	**10**		**100**
360	**10**		**100**	**8**		**50**

Note

When the cracking is load induced, the steel stress may be estimated from the expression below (or see Figure 6):

$$_s = \frac{f_{yk}\, m\, A_{s,req}}{\gamma_{ms}\, n\, A_{s,prov}}$$

where

- f_{yk} **= characteristic reinforcement yield stress**
- γ_{ms} **= partial factor for reinforcing steel**
- m **= total load from quasi-permanent combination**
- n **= total load from ULS combination**
- $A_{s,req}$ **= area of reinforcement at the ULS**
- $A_{s,prov}$ **= area of reinforcement provided**
- **= ratio of redistributed moment to elastic moment**

When the cracking is caused by restraint, steel stress immediately after cracking should be calculated for the chosen bar diameter. An iterative process will be required.Bar spacing rule does not apply to this condition