Practical Design to Eurocode 2

The webinar will start at 12.30

(I'm happy to field individual questions beforehand - Use 'Questions' on the shown Control Panel)

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

EC2 Background, Materials, Cover and Effective Spans

Lecture 2

28th September 2017

Model Answers to

Week 1

Reminder: last week: Exercise: Load Arrangements

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 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).



Exercise: Load Arrangements (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	$\gamma_G G_k$ or $\xi\gamma_G G_k$	$\gamma_Q Q_k$ or $\gamma_Q \Psi_0 Q_k$	n
(6.10)			
(6.10a)			
(6.10b)			



Load Arrangement Solution

Q1	Span $\gamma_G G_k + \gamma_Q Q_k$	Cant $\gamma_G G_k + \gamma_Q Q_k$
EQU	$0.9\ G_k$	$1.10\ G_k + 1.5Q_k$
STR	$1.35^{\#}\ G_k$	$1.35^{\#}G_k + 1.5Q_k$
STR	$1.35^{\#}\ G_k + 1.5Q_k$	$1.35^{\#}G_k$

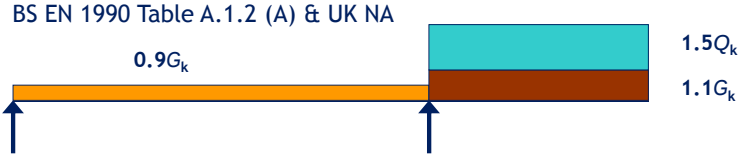
or 1.0 G_k in each case



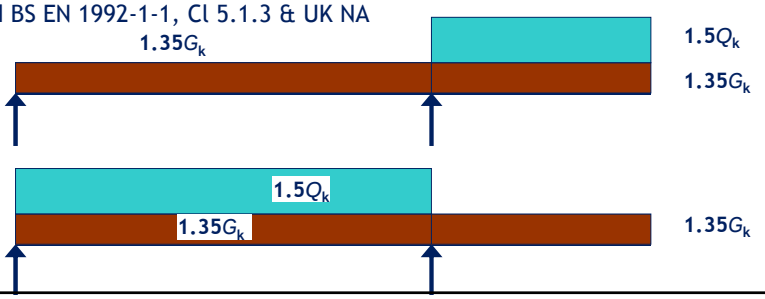
Load Arrangement Exercise Solution

1. Overhanging cantilever beam

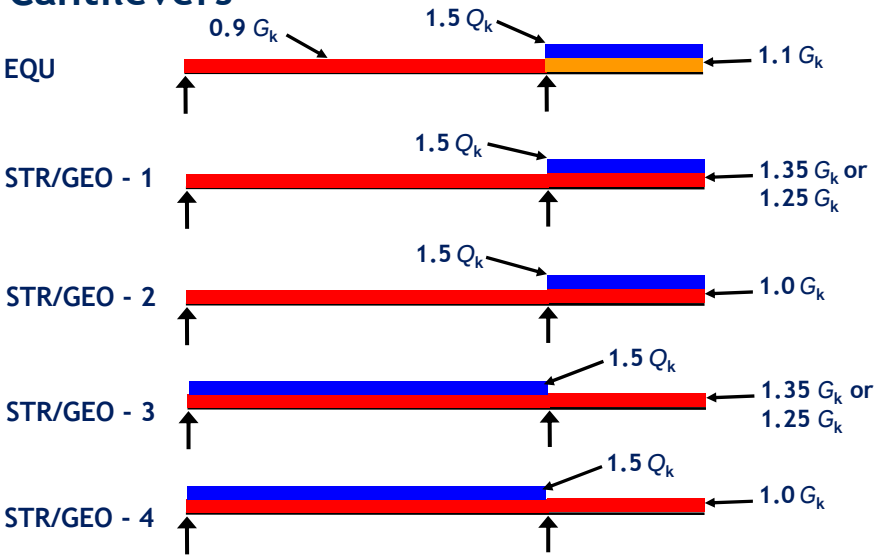
a) Combination for equilibrium (EQU)
BS EN 1990 Table A.1.2 (A) & UK NA



b) Combination for structural strength (STR) BS EN 1990 Table A.1.2 (B) & UK NA and BS EN 1992-1-1, Cl 5.1.3 & UK NA



UK NA Load Arrangements: Cantilevers



Pattern Loading

Reminder

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.

Load Arrangement Solution

Continuous single-way slab

(using BS EN 1990 and UK NA and BS 1992-1-2 Cl 5.1.3 & UK NA)



a) Value using Combination from BS EN 1990 Expression (6.10)
$\gamma_G G_k + \gamma_Q Q_k$ 1.35 x 6 + 1.5 x 4 = **14.1 kN/m²**

b1) Value using Combination from BS EN 1990 Expression (6.10a) and UK National Annex
$\gamma_G G_k + \gamma_Q \psi_0 Q_k$ 1.35 x 6 + 1.5 x 0.7 x 4 = **12.3 kN/m²**

b2) Value using Combination from BS EN 1990 Expression (6.10b) and UK National Annex
$\gamma_G \xi G_k + \gamma_Q Q_k$ 1.35 x 0.925 x 6 + 1.5 x 4 = **13.5 kN/m²**

Expression (6.10b) gives the more economic design

Load Arrangements: Model Answers

Q1	Span $\gamma_G G_k + \gamma_Q Q_k$	Cant $\gamma_G G_k + \gamma_Q Q_k$
EQU	0.9 G_k	1.10 G_k + 1.5Q_k
STR	1.35# G_k	1.35#G_k + 1.5Q_k
STR	1.35# G_k + 1.5Q_k	1.35#G_k

or 1.0 G_k in each case



Q2	$\gamma_G G_k$ or $\xi\gamma_G G_k$	$\gamma_Q Q_k$ or $\gamma_Q \psi_0 Q_k$	n
(6.10)	1.35 x 6	+ 1.5 x 4	= **14.1 kN/m²**
(6.10a)	1.35 x 6	+ 1.5 x 0.7 x 4	= **12.3 kN/m²**
(6.10b)	1.35 x 0.925 x 6	+ 1.5 x 4	= **13.5 kN/m²**

ULS (GEO/STR) for UK Buildings

Clarification

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

1.5.2.3 transient design situation

design situation that is relevant during a period much shorter than the design working life of the structure and which has a high probability of occurrence.

NOTE A transient design situation refers to temporary conditions of the structure, of use, or exposure, *e.g.* during construction or repair.

1.5.2.4 persistent design situation

design situation that is relevant during a period of the same order as the design working life of the structure

NOTE Generally it refers to conditions of normal use.

Summary: Lecture 2

- Background & Basics
- Concrete
- Reinforcement
- Durability and Cover
- A Few Definitions
- Exercises

Background to Eurocode 2

BS EN 1992

Design of concrete structures

Materials

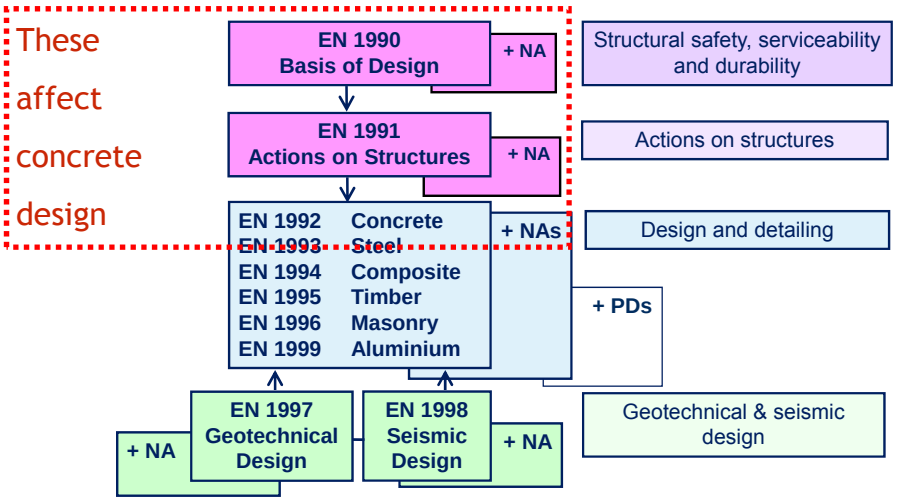
Eurocode 2: Context

	UK	CEB/*fib*	Eurocode 2
1968	CP114 (CP110 draft)	Blue Book (Limit state design)	
1972	**CP110** (Limit state design)	Red Book	
1975			**Treaty of Rome**
1978		**Model Code 78**	
1985	**BS8110**		Eurocode 2 *(EC)*
1990		**Model Code 90**	
1993			EC2: Part 1-1(ENV) *(CEN)*
2004			**EC2: Part 1-1 (EN)**
2005			UK Nat. Annex.
2006	BS8110/EC2		PD 6687
2010	**EC2** BS8110 'withdrawn'	Model Code 2010	
2013		(final) MC2010	WG and 10 TGs
2016			Project Team redrafting. WG and 10 TGs
2023?	EC2 v2?		EC2 v2?

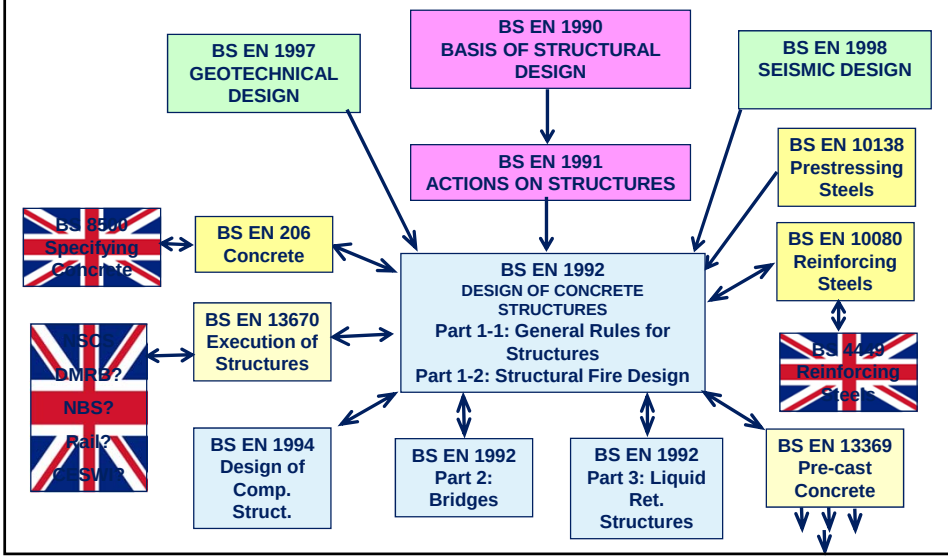
Eurocode 2: Design of Concrete Structures

- BS EN 1992-1-1: General Rules and Rules For Buildings
- BS EN 1992-1-2: Fire Resistance of Concrete Structures
- BS EN 1992-2: Reinforced and Prestressed Concrete Bridges
- BS EN 1992-3: Liquid Retaining Structures

Eurocode Hierarchy



Eurocode 2: relationships

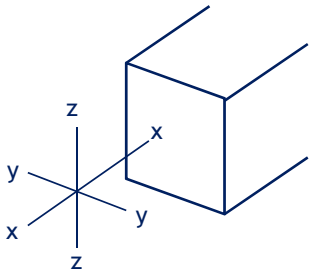


General notes on Eurocode 2

1. Code deals with phenomena, rather than element types so bending, shear, torsion, punching, crack control, deflection control (not beams, slabs, columns)
2. Design is based on characteristic cylinder strength
3. No derived formulae (e.g. only the details of the stress block are given, not the flexural design formulae)
4. No 'tips' (e.g. concentrated loads, column loads,)
5. Unit of stress in MPa
6. Applicable for ribbed reinforcement f_y 400MPa - 600MPa (Plain or mild steel not covered but info on plain and mild steel given in PD 6687)
7. Notional horizontal loads considered in *addition* to lateral loads
8. High strength, up to C90/105 covered
9. No materials or workmanship section (refer to various ENs)

General notes on Eurocode 2

10. Cover related to requirements for durability, fire and bond also subject to allowance for deviations due to variations in execution
11. Variable strut inclination method for shear
12. Punching shear checks at 2d from support
13. 1/1000 expressed as ‰
14. Major axis y and minor axis z



EN1992-1-1: Contents

1. General
2. Basis of design
3. Materials
4. Durability and cover to reinforcement
5. Structural analysis
6. Ultimate limit states
7. Serviceability states
8. Detailing of reinforcement and prestressing tendons – General
9. Detailing of members and particular rules
10. Additional rules for precast and concrete elements and structures
11. Lightweight aggregated concrete structures
12. Plain and lightly reinforced concrete structures

EN1992-1-1: 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 pre-stressing steel relaxation losses
E.	(Informative)	Indicative Strength Classes for durability Use BS8500
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 (Detailing rules for particular situations) Alternative Annex J in PD 6687

Basis of design

Basis of design (2.0)

- Use EN 1990
- Use EN 1991
- Partial material factors, γ_M Table 2.1N and NA

Design situation	γ_c for concrete	γ_s for reinforcing steel	γ_s for prestressing steel
Persistent and transient	1.50	1.15	1.15
Accidental	1.20	1.00	1.00

NB. alternative γ_Ms in EC 7

- Fastenings should be subject to an ETA
- (NB. EN 1992-4, Fasteners out soon!)

Concrete

Eurocode 2

Concrete properties (Table 3.1)

Strength classes for concrete														
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98
f_{ctm} (MPa)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44

f_{ck} = Concrete cylinder strength
f_{cm} = Mean concrete strength
E_{cm} = Mean value of elastic modulus
$f_{ck,cube}$ = Concrete cube strength
f_{ctm} = Mean concrete tensile strength

- BS 8500 includes C28/35 & C32/40
- For shear design, max shear strength as for C50/60

Design Strength Values (3.1.6)

- Design compressive strength, f_{cd}
  $f_{cd} = \alpha_{cc} f_{ck} / \gamma_c$
- Design tensile strength, f_{ctd}
  $f_{ctd} = \alpha_{ct} f_{ctk,0.05} / \gamma_c$

α_{cc} (= 0.85 (flexure) and 1.0 (shear)) and α_{ct} (= 1.0) are coefficients to take account of long term effects on the compressive and tensile strengths and of unfavourable effects resulting from the way the load is applied

$f_{ctk,0.05} = 0.7 f_{ctm}$

Poll:
Design compressive strength, f_{cd}

For a C30/37 concrete what is f_{cd}?

a	17.0 MPa
b	20.0 MPa
c	21.0 MPa
d	22.2 MPa
e	23.5 MPa
f	24.7 MPa

Poll:
Design tensile strength, f_{ctd}

For a C30/37 concrete what is f_{ctd}?

a	1.08 MPa
b	1.15 MPa
c	1.35 MPa
d	1.50 MPa
e	1.64 MPa
f	1.93 MPa

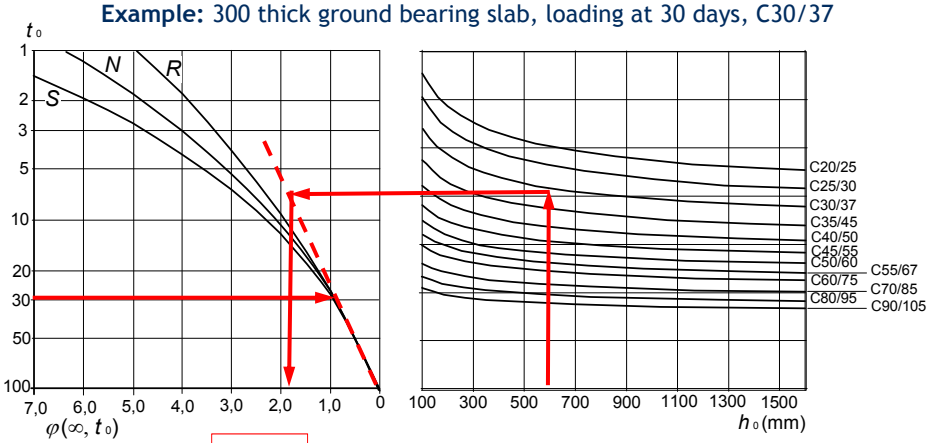
Elastic Deformation (3.1.3)

- Values given in EC2 are indicative and vary according to type of aggregate.
  - quartzite aggregates factor 1.0,
  - limestone factor 0.9,
  - sandstone factor 0.7,
  - Basalt factor 1.20,
- $E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0,3}E_{cm}$
- Tangent modulus, E_c , may be taken as 1.05 E_{cm}
- Poisson's ratio
  - for uncracked concrete = 0.2
  - for cracked concrete = 0
- Linear coeff. of thermal expansion = 10 x 10^{-6} K^{-1}

Creep (3.1.4)

Inside conditions – RH = 50%

Example: 300 thick ground bearing slab, loading at 30 days, C30/37



φ = 1.8

$h_0 = 2A_c/u$ where A_c is the cross-section area and u is perimeter of the member in contact with the atmosphere

Shrinkage (3.1.4)

Shrinkage Strain, ε_{cs}, is composed of two components:

- Drying Shrinkage Strain, ε_{cd}, develops slowly
- Autogenous Shrinkage Strain, ε_{ca}, develops during the hardening of the concrete.

Drying shrinkage, ε_{cd}

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s)\cdot k_h \cdot \varepsilon_{cd,0}$ (EC2, Exp (3.9)

Autogenous shrinkage, ε_{ca}

$\varepsilon_{ca}(t) = \beta_{as}(t)\cdot\varepsilon_{ca}(\infty)$ (EC2, Exp (3.11)

(There is more information on creep and shrinkage in Annex B)

Creep and Shrinkage Annex B

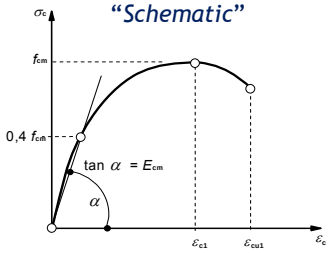
- **Creep**
  - φ_0 is the notional creep coefficient (in Figure 3.1 the notation used is $\varphi(\infty,t_0)$)
  - $\varphi(t,t_0)$ is the creep at any time, t after time of loading, t_0
- **Shrinkage**
  - $\varepsilon_{cd,0}$ is the basic drying shrinkage strain
  - $\varepsilon_{cd,}(t) = \beta_{ds}(t,t_s)k_h\ \varepsilon_{cd,0}$ (Section 3)

Concrete Stress Blocks (3.1.5 and 3.1.7)

For structural analysis

For section analysis

"Schematic"



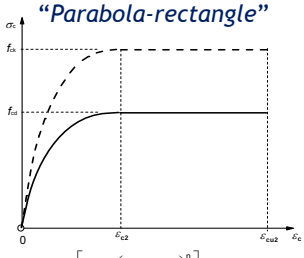
$\varepsilon_{c1}\,(^0/_{00}) = 0{,}7\, f_{cm}^{0.31}$

$\varepsilon_{cu1}\,(^0/_{00}) =$

$2.8 + 27[(98\text{-}f_{cm})/100]^4\ f_{cm})/100]^4$

for $f_{ck} \geq 50$ MPa otherwise 3.5

"Parabola-rectangle"



$$\sigma_c = f_{cd}\left[1 - \left(1 - \frac{\varepsilon_c}{\varepsilon_{c2}}\right)^n\right] \text{ for } 0 \leq \varepsilon_c < \varepsilon_{c2}$$

$\sigma_c = f_{cd}$ for $\varepsilon_{c2} \leq \varepsilon_c \leq \varepsilon_{cu2}$

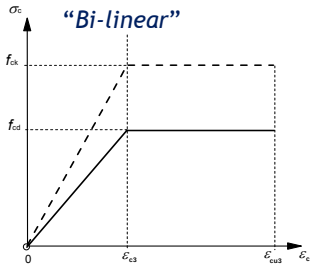
$n = 1.4 + 23.4\ [(90\text{-}\ f_{ck})/100]^4$
for $f_{ck} \geq 50$ MPa otherwise 2.0

$\varepsilon_{c2}\,(^0/_{00}) = 2.0 + 0.085(f_{ck}\text{-}50)^{0,53}$

for $f_{ck} \geq 50$ MPa otherwise 2,0

$\varepsilon_{cu2}\,(^0/_{00}) = 2.6 + 35\ [(90\text{-}f_{ck})/100]^4$
for $f_{ck} \geq 50$ MPa otherwise 3.5

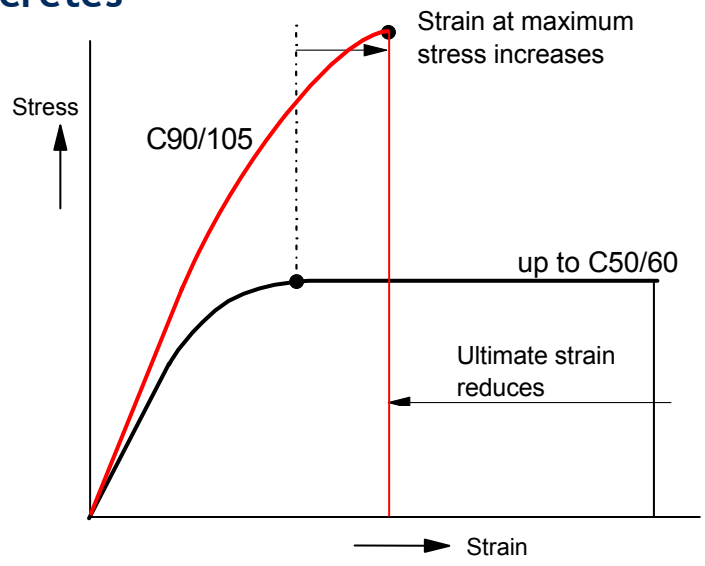
"Bi-linear"



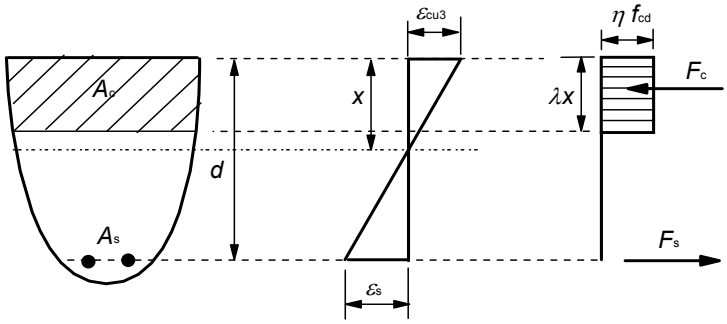
$\varepsilon_{c3}\,(^0/_{00}) = 1.75 + 0.55\ [(f_{ck}\text{-}50)/40]$
for $f_{ck} \geq 50$ MPa otherwise 1.75

$\varepsilon_{cu3}\,(^0/_{00}) = 2.6 + 35[(90\text{-}f_{ck})/100]^4$
for $f_{ck} \geq 50$ MPa otherwise 3.5

Change in Shape of Concrete Stress Block for high strength concretes



Rectangular Concrete Stress Block (3.1.7, Figure 3.5)



$\lambda = 0.8$ for $f_{ck} \le 50$ MPa

$= 0.8 - \frac{(f_{ck} - 50)}{400}$ for $50 < f_{ck} \le 90$ MPa

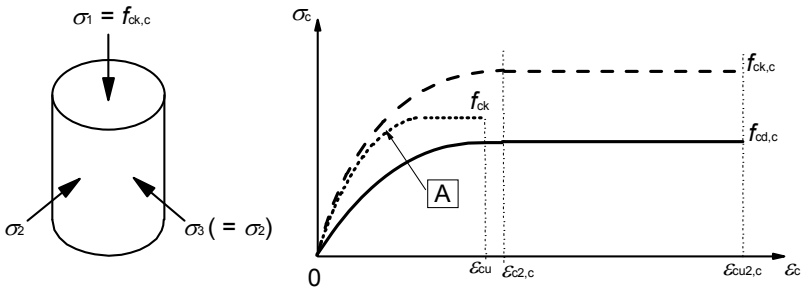
$\eta = 1.0$ for $f_{ck} \le 50$ MPa

$= 1.0 - (f_{ck} - 50)/200$ for $50 < f_{ck} \le 90$ MPa

Flexural Tensile Strength (3.1.8)

- The mean tensile strength, $f_{ctm,fl}$, (only used in does-it-crack-or-not? checks) depends on the mean axial strength and the depth of the cross section
  $f_{ctm,fl} = \max\{(1.6 - h/1000)f_{ctm}; f_{ctm}\}$
- This relationship also applies to the characteristic tensile values
- For Serviceability calculations care should be taken in using $f_{ctm,fl}$ (See Section 7)

Confined Concrete (3.1.9)



$f_{ck,c} = f_{ck}\,(1.000 + 5.0\,\sigma_2/f_{ck})$ for $\sigma_2 \le 0.05 f_{ck}$

$= f_{ck}\,(1.125 + 2.50\,\sigma_2/f_{ck})$ for $\sigma_2 > 0.05 f_{ck}$

$\varepsilon_{c2,c} = \varepsilon_{c2}\,(f_{ck,c}/f_{ck})^2$

$\varepsilon_{cu2,c} = \varepsilon_{cu2} + 0.2\,\sigma_2/f_{ck}$

Reinforcement

Reinforcement (1) (3.2.1 and 3.2.2)

- Principles and Rules are given for deformed bars, decoiled rods, welded fabric and lattice girders.
- EC2 does not cover the use of plain reinforcement
- Material properties are given in Annex C of EC2.
  BS 4449 aligns with Annex C.
  (When finally published EN 10080 should provide the performance characteristics and testing methods but will not specify the material properties.)

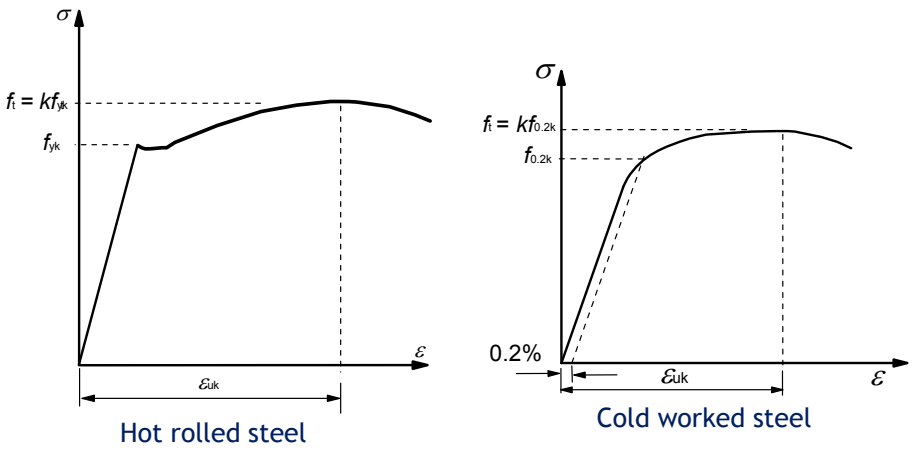
Reinforcement (Annex C)

Product form	Bars and de-coiled rods			Wire Fabrics		
Class	A	B	C	A	B	C
Characteristic yield strength f_{yk} or $f_{0,2k}$ (MPa)	400 to 600					
$k = (f_t/f_y)_k$	≥1,05	≥1,08	≥1,15 <1,35	≥1,05	≥1,08	≥1,15 <1,35
Characteristic strain at maximum force, ε_{uk} (%)	≥2,5	≥5,0	≥7,5	≥2,5	≥5,0	≥7,5
Fatigue stress range ($N = 2 \times 10^6$) (MPa) with an upper limit of $0.6f_{yk}$	150			100		

cold worked *hot rolled* *seismic*

The UK has chosen a maximum value of characteristic yield strength, f_{yk} = 600 MPa, but 500 MPa is the value assumed in BS 4449 and BS 4483 for normal supply.

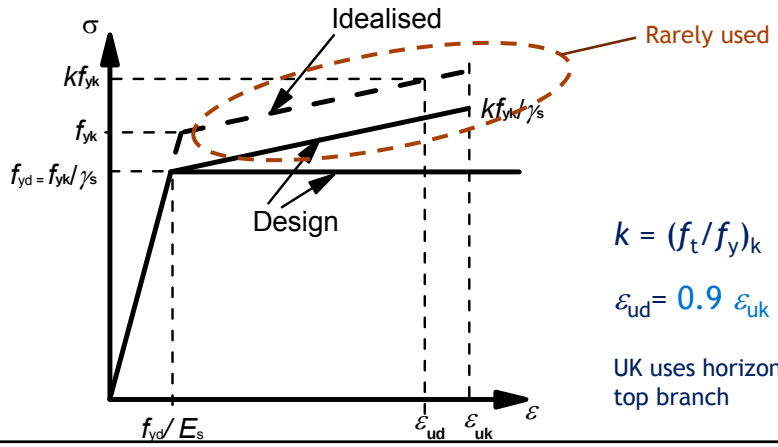
Reinforcement
(3.2.4, figure 3.7)



- The design value for E_s may be assumed to be 200 GPa

Reinforcement - Design Stress/Strain Curve (3.2.7, Figure 3.8)

Alternative design stress/strain relationships are permitted:
- inclined top branch with a limit to the ultimate strain horizontal
- horizontal top branch with no strain limit



$k = (f_t/f_y)_k$

$\varepsilon_{ud} = 0.9\ \varepsilon_{uk}$

UK uses horizontal top branch

Extract from BS 8666

Table 1 — Notation of steel reinforcement

Type of steel reinforcement	Notation
For diameters ⩽ 12mm, Grade B500A, Grade B500B or Grade B500C conforming to BS 4449:2005 For diameters >12mm, Grade B500B or Grade B500C conforming to BS 4449:2005	H
Grade B500A conforming to BS 4449:2005	A
Grade B500B or Grade B500C conforming to BS 4449:2005	B
Grade B500C conforming to BS 4449:2005	C
A specified grade and type of ribbed stainless steel conforming to BS 6744:2001	S
Reinforcement of a type not included in the above list having material properties that are defined in the design or contract specification.	X
NOTE 1 In the Grade description B500A, etc., "B" indicates reinforcing steel. NOTE 2 Within the ranges given, the grades(s) supplied for notations H and B are at the supplier's discretion.	

Prestressing Steel (1)
(3.3.1 and 3.3.2)

- Pending release of EN 10138, BS 5896 is being used.
  (Unlike EN 10080 the harmonised standard for prestressing steel, EN10138, is likely to provide all the mechanical properties. The reason given is that there are only a few types of prestressing steel and they can all be included within the Standard.)
  - Adequate ductility is assumed if $f_{pk}/f_{p0,1k} \geq 1.1$
  - Prestressing steel losses are defined for:
    - Class 1: wire or strand - ordinary relaxation
    - Class 2: wire or strand - low relaxation
    - Class 3: hot rolled and processed bars

Pre-stressing Strands Commonly Used in the UK (BS 5896)

Strand type	Steel Number	Nominal tensile strength (MPa)	Nominal diameter (mm)	Cross-sectional area (mm^2)	Nominal mass (kg/m)	Charact-eristic value of maximum force (kN)	Maximum value of maximum force (kN)	Charact-eristic value of 0.1% proof force (kN)
12.9 'Super'	1.1373	1860	12.9	100	0,781	186	213	160
12.7 'Super'	1.1372	1860	12.7	112	0.875	209	238	180
15.7 'Super'	1.1375	1770	15.7	150	1.17	265	302	228
15.7 Euro'	1.1373	1860	15.7	150	1.17	279	319	240
15.2 'Drawn'	1.1371	1820	15.2	165	1.290	300	342	258

Prestressing Devices (3.4)

- Anchorages and Couplers should be in accordance with the relevant European Technical Approval.
- NB. new BS 8597 on couplers.
- External non-bonded tendons situated outside the original section and connected to the structure by anchorages and deviators only, should be in accordance with the relevant European Technical Approval.

Durability and Cover

Durability of Structures

To avoid durability issues:

We:

- Specify cover,
- Control the maximum water/cement ratio
- Control the cement content.



Informative Annex E (strength classes for durability) does not apply in the UK. The UK has its own methodology – refer to BS 8500.

Cover (4.4.1)

Nominal cover, $c_{nom} = c_{min} + \Delta c_{dev}$

Nominal cover, c_{nom}

Minimum cover, c_{min}

$c_{min} = \max \{c_{min,dur}; c_{min,b}; 10\ mm\}$

Durability as per BS 8500

Bond ≡ ϕ

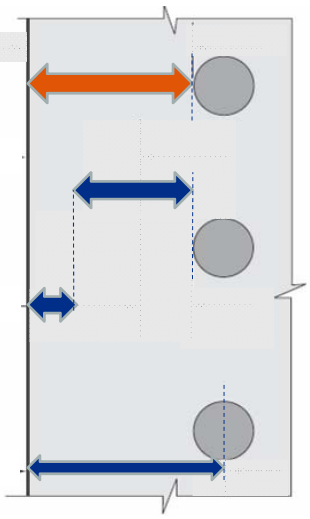
Allowance for deviation, Δc_{dev}

10 mm recommended

Axis distance, *a*

Fire protection

Tables in Section 5 of part 1-2 (etc.)



Cover, $c_{min,dur}$, (4.4.1.2(5))

$c_{min,dur}$, minimum cover for durability

The UK National Annex decision for $c_{min,dur}$ is: use BS 8500, viz:

Subclause	Nationally Determined Parameter	Eurocode Recommendation	UK Decision
4.4.1.2 (5)	Structural classification and values of minimum cover due to environmental conditions $c_{min,dur}$	Table 4.3N for structural classification Tables 4.4N and 4.5N for values of $c_{min,dur}$	**Use BS 8500-1:2006**, Tables A.3, A.4, A.5 and A.9 for recommendations for concrete quality for a particular exposure class and cover reinforcement *c*.

In EC2, $c_{min,dur}$ can be modified by further factors, but in the UK these factors are all 0.

i.e: Values of $c_{dur,\gamma}$, $\Delta c_{dur,st}$ and $\Delta c_{dur,add}$ are taken as 0 in the UK unless reference is made to specialist literature.

Cover, $c_{min,dur}$

In order to use Tables in BS 8500, one needs to establish relevant Exposure Class.

Exposure Classes.

Table 4.1 (based on EN 206-1) provides the definitions for different environmental conditions.

- XO – no risk of corrosion or attack
- XC – risk of carbonation-induced corrosion
- XS – risk of chloride-induced corrosion (sea water)
- XD - risk of chloride-induced corrosion
- XF – risk of freeze/thaw attack
- XA (DC - BS8500) – risk of chemical attack in ground

Cover, $c_{min,dur}$

Table 4.1 (based on EN 206-1)

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs

Cover, $c_{min,dur}$

Table 4.1 (cont. based on EN 206-1)

4 Corrosion induced by chlorides from sea water		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5. Freeze/Thaw Attack		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation with de-icing agents or sea water	Road and bridge decks exposed to de-icing agents Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing
6. Chemical attack		
XA1	Slightly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA2	Moderately aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA3	Highly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water

Car Park Exposure Classes

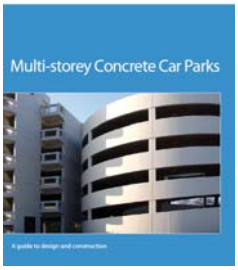


Table 5: Proposed exposure classes for car parks

Element type and location	Recommended exposure class	Recommended exposure class in coastal areas
Top surface of decks and ramps at the entry level of car park	XD3 (XC3/4)[a] & XM1[b]	XD3(XC3/4)[a], XS1[c] & XM1[b]
Top surface of decks and ramps exposed to freezing e.g. roof level	XF2 & XD1(XC3/4)[a] Optional - XM1[b]	XF2, XS1(XC3/4)[a] & XD1[d] Optional - XM1[b]
Top surface of decks and ramps in other locations	XD1 (XC3/4)[a] Optional - XM1[b]	XS1 (XC3/4)[a] & XD1[d] Optional - XM1[b]
Soffits of decks and ramps	XC3/4	XSI (XC3/4)[a]
Vertical elements	XC3/4	XSI (XC3/4)[a]
Vertical elements exposed to freezing	XC3/4 XFI	XSI (XC3/4)[a] XFI
Elements protected from rainfall e.g. internal area such as stair enclosures	XCI	XCI

Key:
a Exposure classes given in brackets denote classes which are less critical and assumed in BS 8500 to occur simultaneously with the main exposure class.
b BS EN1992-1-1 Cl 4.4.1.2(13) advises that for abrasion class XM1 (moderate) a sacrificial layer of 5mm of concrete may be used. This is appropriate for use at the entry level to the car park, which will be subject to the most severe conditions and may also be adopted for other situations.
c XD3 condition is more critical.
d XSI condition is more critical.

Cover, $c_{min,dur}$,

(from BS 8500 for a 50 year life.)

Table A.4 **Durability [A] recommendations for reinforced or prestressed elements with an intended working life of at least 50 years**

Nominal cover [B]	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete [C] with 20 mm maximum aggregate size [D]								Cement/combination types
mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	
Corrosion induced by carbonation (XC exposure classes)									
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*									
XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	C45/55 [E] 0.35 [F] 380	C35/45 [E] 0.45 360	C32/40 [E] 0.50 340	C32/40 [E] 0.50 340	C32/40 [E] 0.50 340	CEM I, IIA, IIB-S, SRPC
	—	—	—	C40/50 [E] 0.35 [F] 380	C32/40 [E] 0.45 360	C28/35 0.50 340			
	—	—	—	C32/40 [E] 0.40 380	C25/30 0.50 340	C25/30 0.50 340			
	—	—	—	C32/40 [E] 0.40 380	C28/35 0.50 340	C25/30 0.50 340			
XD2 or XS2	—	—	—	C40/50 [E] 0.40 380	C32/40 [E] 0.50 340	C28/35 0.55 320			
	—	—	—	C35/45 [E] 0.40 380	C28/35 0.50 340	C25/30 0.55 320			
	—	—	—	C32/40 [E] 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

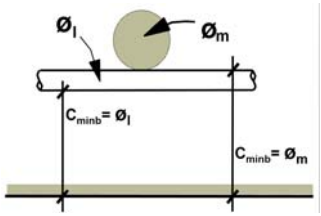
For the relevant Exposure Class, choose a preferred concrete strength and $c_{min,dur}$
Note restrictions on w/c ratio, cement content and type

Cover, $c_{min,b}$ (4.4.1.2(3))

$c_{min,b}$ minimum cover for bond,

For bars:

$c_{min,b}$ = bar diameter



For Post-tensioned tendons:

- Circular ducts: Duct diameter
- Rectangular ducts: The greater of:
  - the smaller dimension or
  - half the greater dimension

For pre-tensioned tendons:

- 1.5 x diameter of strand or wire
- 2.5 x diameter of indented wire

Cover, Δc_{dev}, (4.4.1.3)

Δc_{dev}, allowance for deviation = 10mm

- A reduction in Δc_{dev} may be permitted:
  - quality assurance system, which includes measuring concrete cover, $10 \text{ mm} \geq \Delta c_{dev} \geq 5 \text{ mm}$
  - where very accurate measurements are taken and non conforming members are rejected (e.g. precast elements), $10 \text{ mm} \geq \Delta c_{dev} \geq 0 \text{ mm}$

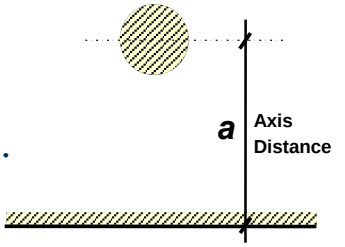
- *RECAP* : $c_{nom} = c_{min} + \Delta c_{dev}$

. . . . . subject to considerations of fire

Fire: axis distance, a

(EN1992-1-2 Cl 1.6.1 & Fig 5.2 etc.)

Axis Distance, a, is specified as the distance from the face to the *centre* of the *main* bar (not cover).



So:

$c_{nom} \geq a - \phi_{link} - \phi_{main\ bar}/2$

Axis Distance, a, is usually derived from Tabular Data for various elements in section 5 of BS EN 1992-1-2, Structural fire design

Axis Distance, a, may also be derived from various fire design methods in BS EN 1992-1-2.

(NB: No Δ_{cdev}: Fire will be covered in Lecture 8)

Cover: Summary

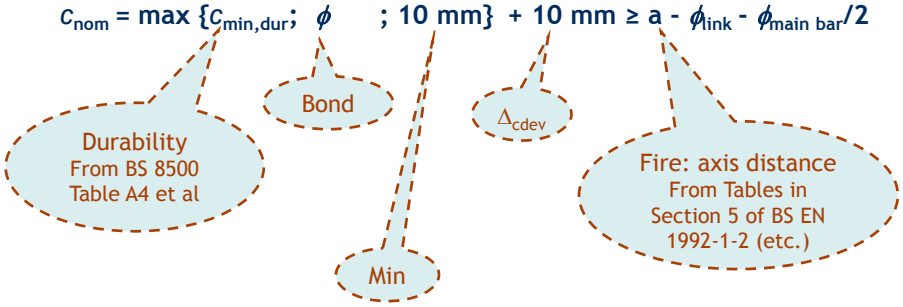
The Nominal Cover, c_{nom}, is the cover specified on the drawings.

It is defined as:

$c_{nom} = \max \{c_{min,dur};\ c_{min,b};\ 10\ mm\} + \Delta c_{dev} \geq a - \phi_{link} - \phi_{main\ bar}/2$

Usually:

$c_{nom} = \max \{c_{min,dur};\ \phi\ ;\ 10\ mm\} + 10\ mm \geq a - \phi_{link} - \phi_{main\ bar}/2$

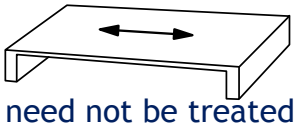


A few definitions

In time for next week

Idealisation of the structure (5.3)

- Beam: Span ≥ 3*h* otherwise it is a deep beam
- Slab: Minimum panel dimension ≥ 5*h*
  - One-way spanning

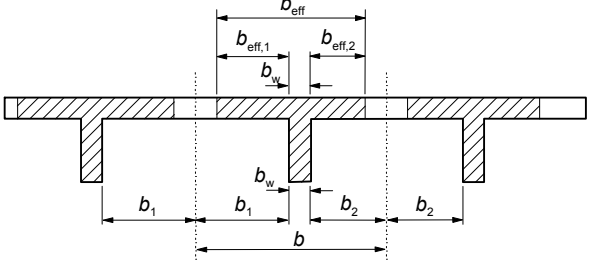


- Ribbed or waffle slabs: these need not be treated as discrete elements provided that:
  - rib spacing ≤ 1500mm
  - rib depth below flange ≤ 4*b*
  - flange depth ≥ 1/10 clear distance between ribs or 50mm - transverse ribs are provided with a clear spacing ≤ 10 *h*
- Column: *h* ≤ 4*b* and *L* ≥ 3*h* otherwise it should be considered as a wall

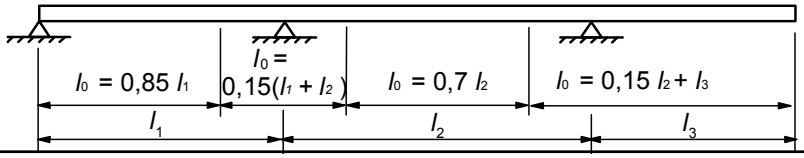
Effective Flange Width (5.3.2.1)

$b_{eff} = \Sigma\, b_{eff,i} + b_w \le b$

Where $b_{eff,i} = 0{,}2b_i + 0{,}1l_0 \le 0{,}2l_0$ and $b_{eff,i} \le b_i$

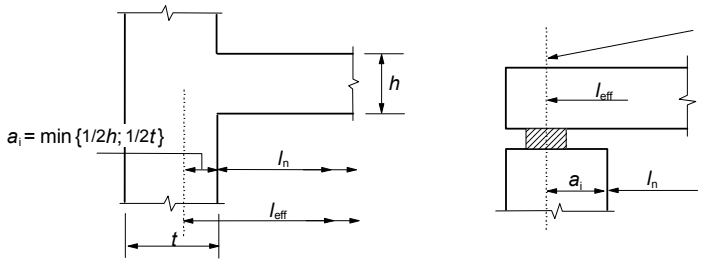


l_0, is the distance between points of zero moment.
It may be taken as:



Effective Length of Beam or Slab (5.3.2.2)

$$l_{eff} = l_n + a_1 + a_2$$



- The design moment and reaction for monolithic support should generally be taken as the greater of the elastic and redistributed values (≥ 0.65 the full fixed moment).
- Permitted reduction, $\Delta M_{Ed} = F_{Ed.sup} t/8$

Exercise

Cover Exercise (Fire and Durability)

What is the nominal cover for a car park one-way slab with one hour fire resistance (i.e. REI = 60)?

- Use *Concise Eurocode 2*
- Assume the max bar size in the slab is 25mm.
- Assume the concrete is C32/40 with cement type IIIB
- Assume design life 50 years and in-situ construction

Cover Example (pro forma)

See Concise

BOND	
EC2-1-1 Table 4.2 (Section 4.2)	$c_{min,b}$ =.....
DURABILITY	
EC2-1-1 Table 4.1 (Table 4.1)	Durability Class ……. . .
UK NA & BS 8500 (Table 4.2)	$c_{min,dur}$ = ...
DEVIATION	
EC2-1-1Cl. 4.4.1.3 (Section 4.5)	Δc_{dev} =.....
FIRE	
EC2-1-2 Table 5.8 (Table 4.7)	Min axis distance a=…..

Nominal Cover governed by ……= ……..mm

Working space

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

End of Lecture 2