DURABILITY AND SERVICEABILITY

Introduction of Durability

- Durability requirements are to ensure that a structure has satisfactory durability and serviceability performance under normal circumstances throughout its lifetime.

- These requirements will involve aspects of design, such as concrete mix selection and determination of cover to reinforcing bars, as well as selection of suitable materials for the exposure conditions which are expected.

- EC2 recommends simple rules concerning the **concrete mix and cover to reinforcement**, **minimum member dimension**, and limits to **reinforcement quantities and spacing** which must be taken into account at the member sizing and reinforcement detailing stage.

Introduction of Serviceability

- In order to serves its intended purpose, a structure must be safe and serviceable.
- A structure is safe, if it is able to resist without distress and with sufficient margin of safety, all forces which are likely to act on it during its life time.
- Serviceability, implies that deformation of structures such as **deflections**, **cracking** and other distortions under load shall not be excessive

Concrete Cover

- Based on Sec. 4.4 EC2, the nominal cover can be assessed as follows:

$$C_{nom} = C_{\min} + \Delta C_{dev}$$

- Where C_{min} shall be provided in order to ensure (Sec. 4.4.1.2 EC2):
  - The safe transmission of **bond** forces
  - The protection of steel against corrosion (**Durability**)
  - An adequate **fire resistance**
- The greater value for C_{min} satisfying the requirements for both bond and environmental conditions shall be used.

$$C_{\min} = \max\{C_{\min,b*}; C_{\min,dur} + \Delta C_{dur,\gamma} - \Delta C_{dur,st} - \Delta C_{dur,add}; 10mm\}$$

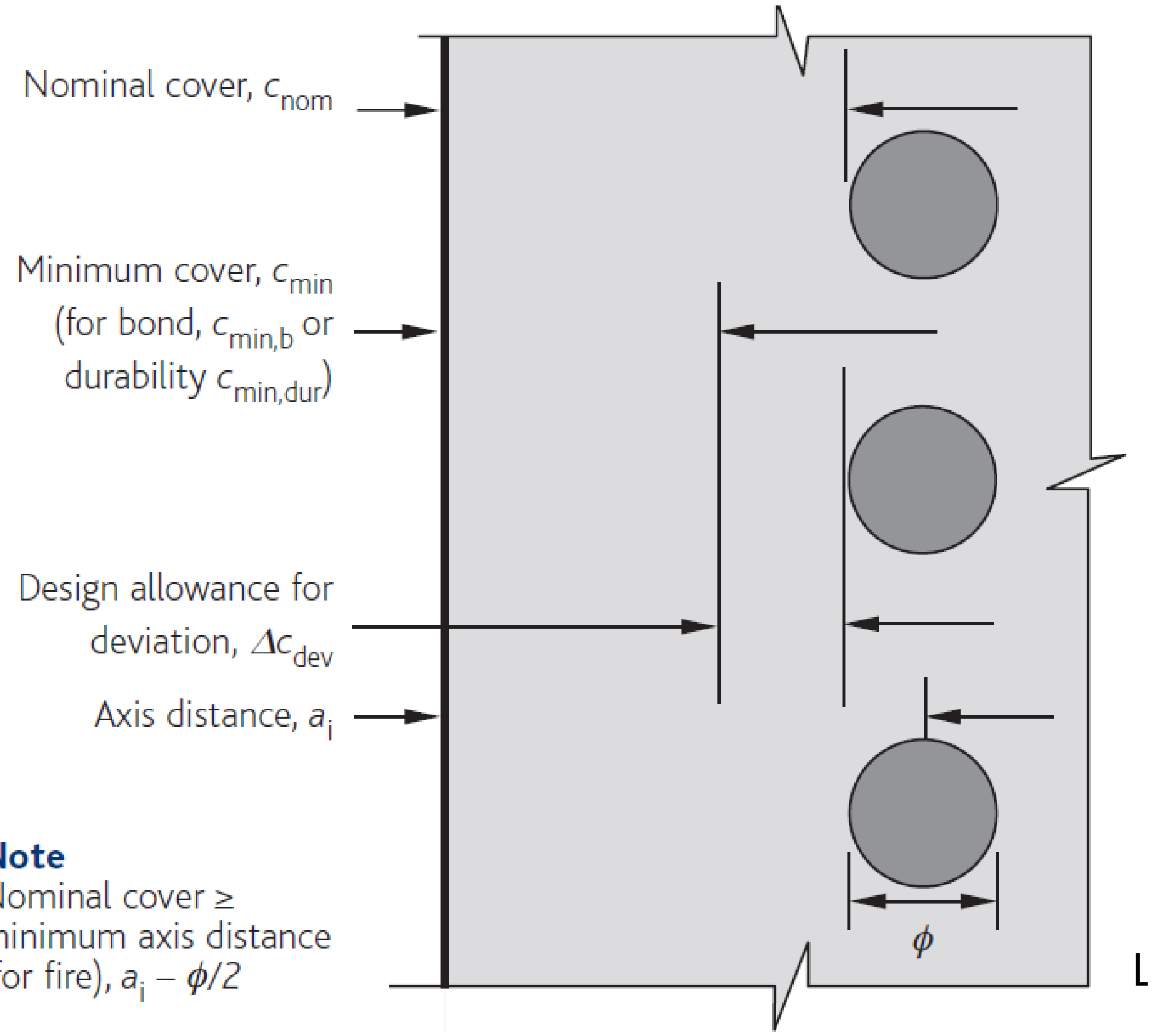
Concrete Cover

$C_{min,b}$	minimum cover due to bond requirement
$C_{min,dur}$	minimum cover due to environmental condition
$\Delta_{Cdur,\gamma}$	additive safety element
$\Delta C_{dur,st}$	reduction of minimum cover for use of stainless steel
$\Delta C_{dur, add}$	reduction of minimum cover for use of additional protection

- ΔC_{dev} is and allowance which should be made in the design for deviation from the minimum cover. It should be taken as **10 mm**. It is permitted to reduce to **5 mm** if the fabrication subjected to a quality assurance system.

Concrete Cover

- **Cover**



Note
Nominal cover ≥ minimum axis distance (for fire), $a_i - \phi/2$

Concrete Cover

- **Minimum cover, $C_{min,b}$ requirement with regard to bond**

Arrangement of bars	Minimum cover $c_{min,b}$*
Separated	Diameter of bar
Bundle	Equivalent diameter $\phi_n = \phi \sqrt{n_b} \leq 55$ mm Where n_b is the number of bars in the bundle, which is limited to $n_b \leq 4$ for vertical bars in compression $n_b \leq 3$ for all other cases
* If the nominal maximum aggregate size is > 32 mm, $c_{min,b}$ should be increased by 5 mm	

Table 4.2; EN 1992-1-1

Concrete Cover

- **Minimum cover $C_{min,dur}$ requirement with regard to durability for reinforcement steel.**

Structural Class	Exposure Class according to Table 4.1 EC 2						
	X0	XC1	XC2/XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Table 4.4N; EN 1992-1-1

Concrete Cover

- **Minimum cover $C_{min,dur}$:**

Exposure conditions			Cement/ combination designations[b]	Strength class[c], maximum w/c ratio, minimum cement or combination content (kg/m³), and equivalent designated concrete (where applicable)							
Typical example	Primary	Secondary		Nominal cover to reinforcement[d]							
				$15 + \Delta c_{dev}$	$20 + \Delta c_{dev}$	$25 + \Delta c_{dev}$	$30 + \Delta c_{dev}$	$35 + \Delta c_{dev}$	$40 + \Delta c_{dev}$	$45 + \Delta c_{dev}$	$50 + \Delta c_{dev}$
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	<<<	<<<	<<<

Concrete Cover

- **Exposure classes related to environmental condition**

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

Table 4.1; EN 1992-1-1

Concrete Cover

- **Design working life and structural class**

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearing
3	15 to 30	Agricultural and similar structures
4	50	Buildings structures and other common structures
5	100	Monumental building structures, bridges, and other civil engineering structures

Concrete Cover

- Structural classification and values of $C_{min,dur}$ for use in a Country may be found in its National Annex. The recommended Structural Class (design working life of 50 years) is S4 for the indicative concrete strengths given in Annex E and the recommended modifications to the structural class is given in Table 4.3N.

Structural Class							
Criterion	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1	XD2 / XS1	XD3 / XS2 / XS3
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2
Strength Class 1) 2)	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1
Special Quality Control of the concrete production ensured	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1

Concrete Cover

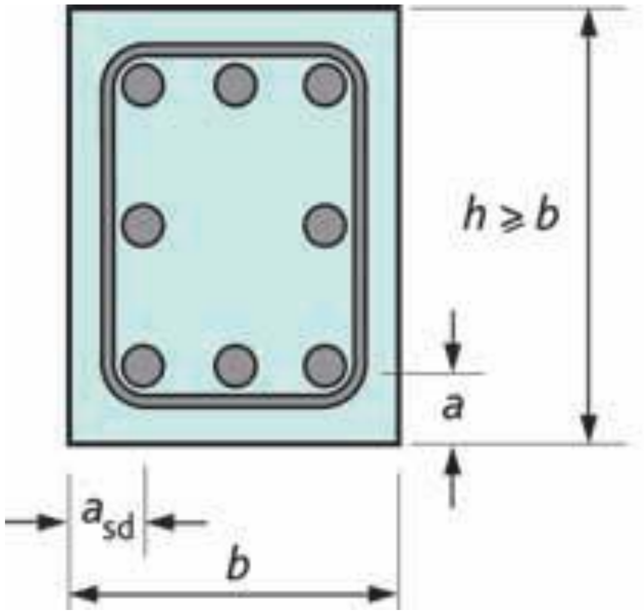
Minimum cover for fire resistance

- The recommendation for structural fire design is considered in EC2: Part 1-2. Rather than giving a minimum cover, the method used is based on nominal axis distance, a. The axis distance is the distance from the centre of the main reinforcement bar to the top or bottom surface of the member.

$$a \geq C_{nom} + \phi_{link} + \phi_{bar} / 2$$

$$a_{sd} = a + 10$$

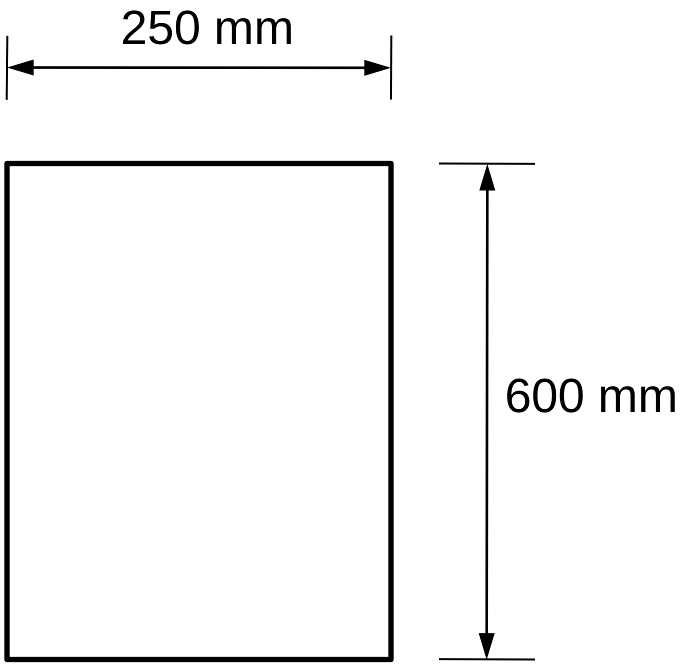
The permissible combination of member dimension and axis distance, a of beam and slab are shown in Table 5.5, 5.6 and 5.8 EC2 : Part 1-2.



Example 4.1

Determine concrete cover of the beam as shown below. Given the following data.

Design life	= 50 years
Fire resistance	= R60
Exposure classes	= XC1
Bar diameter	= 20mm
Link diameter	= 8 mm



Solution of Example 4.1

Min. concrete cover regard to bond, $C_{min,b}$ = 20 mm

Min. concrete cover regard to durability, $C_{min, dur}$ = 15 mm

Min. required axis distance, a for R60 fire resistance = 30 mm

a_{sd} = 30 + 10 = 40 mm

Min. concrete cover regard to fire,

$C_{min} = a_{sd} – Ø_{link} - Ø_{bar}/2 = 40 – 8 – 20/2 = 22$ mm

Allowance in design for deviation, ΔC_{dev} = 10 mm

Nominal concrete cover;

$C_{nom} = C_{min} + \Delta C_{dev} = 22 + 10 =$ **32 mm**

Solution of Example 4.1

Minimum dimensions and axis distances for beams made with reinforced concrete for fire resistance (EN 1992–1–2 Tables 5.5 and 5.6).

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 beam							
		Simply supported beams				Continuous beams			
		A	B	C	D	E	F	G	H
R60	b_{min} = a =	120 40	160 35	200 30	300 25	120 25	200 12[a]		
R90	b_{min} = a =	150 55	200 45	300 40	400 35	150 35	250 25		
R120	b_{min} = a =	200 65	240 60	300 55	500 50	200 45	300 35	450 35	500 30
R240	b_{min} = a =	280 90	350 80	500 75	700 70	280 75	500 60	650 60	700 50

Min. & Max. Area of Reinforcement

- The minimum area of reinforcement is to **control thermal** and **shrinkage cracking** within acceptable limits.
- This ensures that the reinforcement does not yield when concrete in tension zone cracks due to sudden transfer of stress to the reinforcement.
- The minimum area of reinforcement that must be provided within tensile zone is

$$A_{s,\min} = k_c k f_{ct,eff} A_{ct} / f_{yk}$$

- Refer to Sec. 7.3.2 EN 1992-1-1.

Min. & Max. Area of Reinforcement

$$A_{s,\min} = k_c k f_{ct,eff} A_{ct} / f_{yk}$$

- k_c: a coefficient to allow the stress distribution within the section immediately prior to cracking (1.0 for pure tension and 0.4 for pure bending).
- k: a coefficient to allow for the effect of non-uniform stresses.
- $f_{ct,eff}$: mean value of the tensile strength of concrete effective at the time cracks may be first expected to occur at the appropriate age.
- A_{ct}: area of concrete in that part of the section which is calculated to be in the tension zone.
- f_{yk}: absolute value of the maximum stress permitted in the reinforcement

Min. & Max. Area of Reinforcement

- The minimum area of reinforcement for beam also specified in Section 9.2.1 as follows:

$$A_{s,\min} = 0.26(f_{ctm} / f_{yk})b_t d$$ But not less than $0.0013b_t d$

f_{ctm}: *mean value of axial tensile strength*

b_t: *mean width of the tension zone*

d: *effective depth*

- The limits $A_{s,max}$ specified by EC2 in Section 9.2.1 is $0.04A_c$ (0.04 of cross section of area) for tension or compression reinforcement.

Spacing of Reinforcement

- The minimum distance between bars is to permit concrete flows around reinforcement during construction and to ensure that concrete can be compacted satisfactorily for the development of adequate bond.

- The clear distance between bars should not be less than the maximum of

  (i) the maximum bar size,

  (ii) the maximum aggregate size + 5 mm, or

  (iii) 20 mm. (Specified in section 8.2 EC2).

Spacing of Reinforcement

- Maximum bar size or spacing to limit width crack (w).

Steel stress (σ_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

Curtailment and Anchorage of Reinforcement

- It is a common practice to cut off bars where they are no longer required to resist moment.
- Each curtailed bar should extend a full anchorage length beyond the point at which it is no longer needed.
- The basic required anchorage length given in section 8.4.3 EC2 is as follows;

$$l_{bd,rqd} = (\phi/4)(\sigma_{sd}/f_{bd}) = (\phi/4)(f_{yk}/1.15)/f_{bd}$$
$$= (f_{yk}/4.6f_{bd})\phi$$

Where; f_{yk} = Characteristic strength of reinforcement

f_{bd} = Ultimate anchorage bond stress (section 8.4.2 EC2)

- The basic anchorage length discussed above must be further modified to give the minimum design anchorage length taking into account several factors.
- The design anchorage length (l_{bd}) is given by

$$l_{bd} = \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5 l_{b,rqd} \geq l_{b,\min}$$

Where;

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ = Coefficient given in Table 8.2 EC2

$l_{b,\ min}$ = Minimum anchorage length

for tension bars : max $\{0.3\ l_{bd,rqd};\ 10Ø;\ 100\ mm\}$

for compression bars : max $\{0.6\ l_{bd,rqd};\ 10Ø;\ 100\ mm\}$

Table 8.2 EC2

Value of α	α allows for the effect of	Type of anchorage	Reinforcement in Tension	Reinforcement in Compression
α_1	The shape of the bars	Straight	1.0	1.0
		Other than straight	0.7 if $c_d > 3.0\phi$ or 1.0 if not	1.0
α_2	Concrete cover to reinforcement	Straight	$1.0 - 0.15(c_d - \phi)/\phi$ but ≥ 0.7 and ≤ 1.0	1.0
		Other than straight	$1.0 - 0.15(c_d - 3\phi)/\phi$ but ≥ 0.7 and ≤ 1.0	1.0
α_3	Confinement of transverse reinforcement not welded to the main reinforcement	All types of reinforcement	$1 - K\lambda$, but ≥ 0.7 and ≤ 1.0	1.0
α_4	Confinement of transverse reinforcement welded to the main reinforcement	All types, position and sizes of reinforcement	0.7	0.7
α_5	Confinement by transverse pressure	All types of reinforcement	$1 - 0.04p$ but ≥ 0.7 and ≤ 1.0	-

Lap in Reinforcement

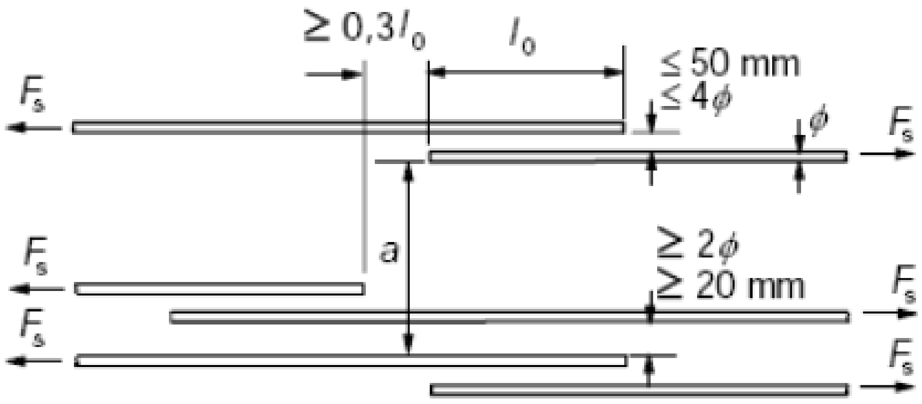
- Laps are required when bars placed short of their required length need to be extended.

- Laps are also required when the bar diameter has to be changed along the length.

- The purpose of lapping is to transfer effectively the axial force from the terminating bar to the connecting bar with the same line of action at the junction.

Lap in Reinforcement

- Requirements for laps are discussed in Section 8.7 EC2. The code recommends that;
  - Laps between bars should be staggered and should not occur in regions of high stress.
  - The arrangement of lapped bars should comply with figure below.



Lap in Reinforcement

- The length of laps should be based on the minimum anchorage length modified to take into account factors such as cover, etc. The design lap length required is given by,

$$l_o = \alpha_1, \alpha_2, \alpha_3, \alpha_5, \alpha_6 l_{b,rqd} \geq l_{o,\min}$$

where

α_1, α_2 , α_3 and α_5 = coefficient given in Table 8.2 EC2

For the calculation of α_3 , Ast,min should be taken as 1.0As(sd/fyd), with As= area of one lapped bar

$\alpha_6 = (\rho_1/25)^{0.5}$ but not exceeding 1.5 nor less than 1.0 and ρ_1 is the percentage of reinforcement lapped within $0.65 l_o$ from the centre of the lap length being considered. Value of α_6 are given in Table 8.3 EC2

$l_{o,min}$= the absolute minimum lap length = max {0.36 $l_{bd,rqd}$; 15Ø; 200 mm}

Lap in Reinforcement

- Transverse reinforcement must be provided around laps unless lapped bars are less than 20 mm diameter or the percentage of lapped bars in any section is less than 25%.

- In these cases minimum transverse reinforcement provided for other purposes such as shear links will be adequate.

- Otherwise transverse reinforcement must be provided, as shown in figure below, having a total area of not less than the area of one lapped bar.

Lap in Reinforcement

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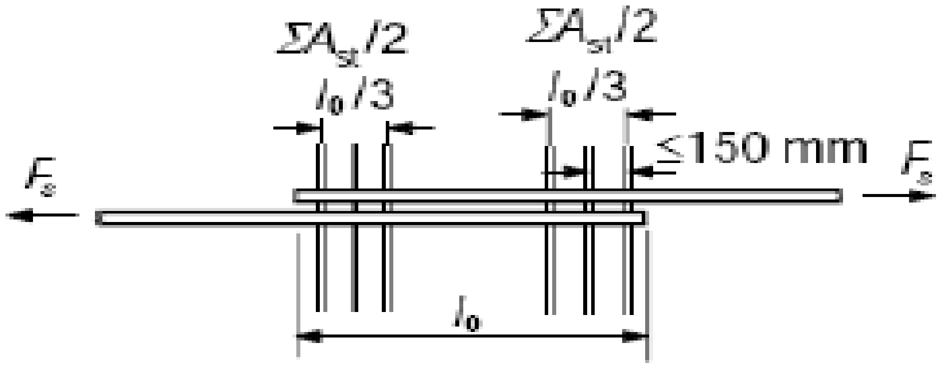
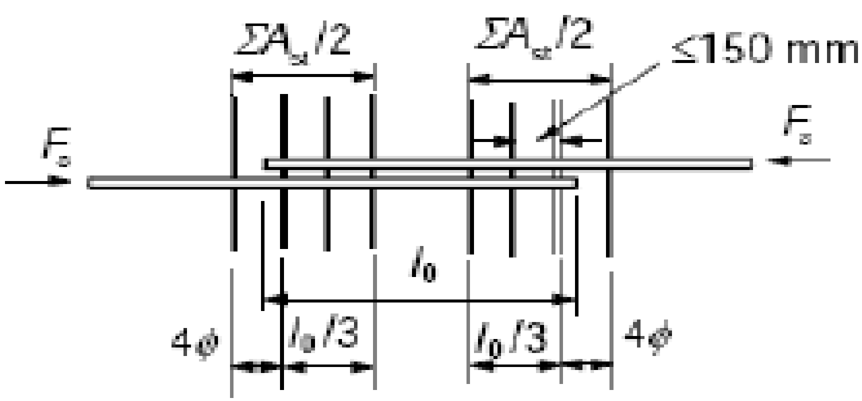


Tension lap



Compression lap

Deflection

- Excessive deflection lead to sagging of floor, crushing of partitions, buckling of glass enclosures, ill lifting doors and windows, poor drainage, misalignment of machinery and excessive vibration.

- For control of deflection, two alternative methods are described in EC2 clause 7.4:
  - Limiting span to depth ratios (Clause 7.4.2)
  - Calculation of actual deflection (Clause 7.4.3)

Deflection

- Deflection limit:
  - final deflection of a beam, slab or cantilever subjected to quasi-permanent loads should not exceed span/250
  - for the deflection which takes place after the application of finishes or fixing of partition should not exceed span/500 to avoid damage to fixtures and fittings.

Deflection

- The basic span-effective depth ratios, to control deflection to a maximum of span/250 are given in EC2 as;

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_o}{\rho} + 3.2\sqrt{f_{ck}}\left(\frac{\rho_o}{\rho} - 1\right)^{3/2}\right] \quad \text{if } \rho \leq \rho_o$$

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\frac{\rho_o}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho}}\right] \quad \text{if } \rho > \rho_o.$$

where:

l/d = limiting span/depth

K = factor to take into account the different in structural system

ρ_o = reference reinforcement ratio = $\sqrt{f_{ck}}\, 10^{-3}$

ρ = required tension reinforcement ratio = $100_{As,req}$ / bd

ρ' = required compression reinforcement ratio = $100_{As',req}$ / bd

Deflection

Table 7.4N (EC2): Basic ratio of span/effective depth for reinforced concrete members without axial compression

Structural System	K	Basic span-effective depth ratio	
		Concrete highly stressed, ρ = 1.5%	Concrete lightly stressed, ρ = 0.5%
1. Simply supported beam, one/two way simply supported slab	1.0	14	20
2. End span of continuous beam or one-way continuous slab or two way spanning slab continuous over one long side	1.3	18	26
3. Interior span of beam or one way or two way spanning slab	1.5	20	30
4. Slab supported on columns without beam (flat slab) based on longer span	1.2	17	24
5. Cantilever	0.4	6	8

Deflection

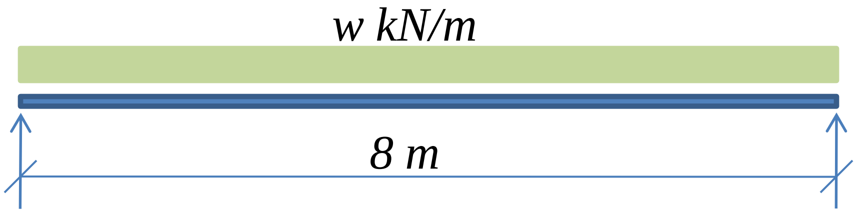
The basic ratios are modified in particular cases as follows:

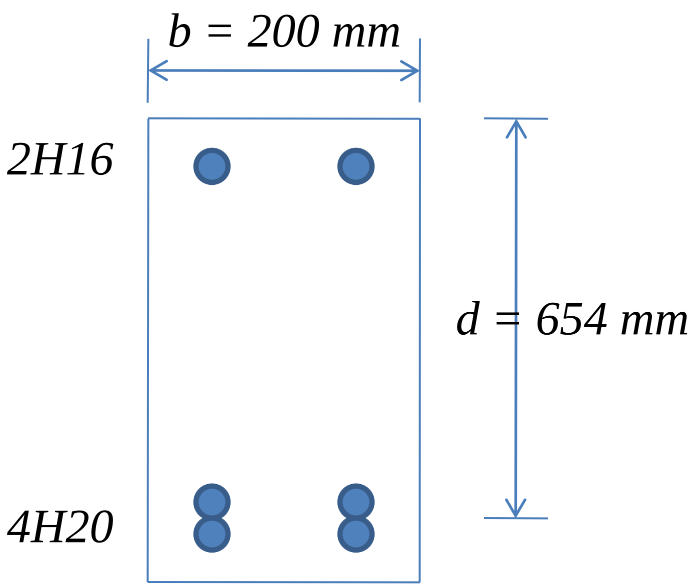
- For flange section where the ratio of the flange width to the web width exceeds 3, the values should be multiplied by 0.8.

- For beam and slabs, other than flat slab, with spans exceeding 7 m, which support partitions liable to be damaged by excessive deflection, the values should be multiplied by 7/span.

- Where more tension reinforcement is provided ($A_{s,prov}$) than that required ($A_{s,\ req}$), multiply the values by $A_{s,prov}/A_{s,req.}$ but should not greater than 1.5.

Example 4.2





Char. strength of concrete, f_{ck} = 25 N/mm^2
Char. Strength of reinforcement, f_{yk} = 500 N/mm^2

Tension steel, $A_{s,req.}$ = 1220 mm^2 $A_{s,prov.}$ = 1257 mm^2
Compression steel, $A_{s'req}$ = 356 mm^2 $A_{s'prov.}$ = 402 mm^2

Check the deflection of the beam.

Solution of Example 4.2

Percentage of required tension reinforcement, ρ

$$\rho = \frac{A_{s,req}}{bd} = \frac{(1220)}{200(654)} = 0.009$$

Percentage of required compression reinforcement, ρ'

$$\rho' = \frac{A_{s',req}}{bd} = \frac{(356)}{200(654)} = 0.0027$$

Reference reinforcement ratio, ρ_o

$$\rho_o = \sqrt{f_{ck}} \times 10^{-3} = \sqrt{25} \times 10^{-3} = 0.005$$

Structural system factor, K = 1.0 (Table 7.4N)

Since, $\rho > \rho_o$ *(Use Eq. 7.16b EC2)*

Solution of Example 4.2

Basic span – effective depth ratio, *l/d*

$$\frac{l}{d} = K\left[11 + 1.5\sqrt{f_{ck}}\,\frac{\rho_o}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{\rho'}{\rho}}\right]$$

$$\frac{l}{d} = 1.0\left[11 + 1.5\sqrt{25}\,\frac{0.005}{0.009 - 0.0027} + \frac{1}{12}\sqrt{25}\sqrt{\frac{0.0027}{0.009}}\right] = 17.08$$

Modification factor for span greater than 7m

$= 7 / (Span\ (m)) = 7/8 = 0.88$

Modification factor for steel area provided

$= A_{s,prov.} / A_{s,req.} = 1257 / 1220 = 1.03 < 1.5$

Allowable span-effective depth ratio

$$l / d_{allow} = 17.08 \times 0.88 \times 1.03 = 15.48$$

Actual span-effective depth ratio

$$l / d_{actual} = \frac{8000}{654} = 12.23 < 15.48$$

Cracking

Cracks are induced in reinforced concrete elements as a result of:

- flexural tensile stress due to bending under applied loads;
- diagonal tension stress due to shear under applied load;
- volume changes due to shrinkage, creep, thermal and chemical effects; and
- splitting along reinforcement due to bond and anchorage failure.

Cracking

- The primary objective of crack control is to limit the width of individual cracks.

- This is required not only for aesthetic reasons, but more importantly, for durability and particularly for corrosion protection of reinforcement.

- For control crack, two alternative methods are describe in EC2 section 7.3
  1. Control of cracking without direct calculation, (Clause7.3.3)
  2. Calculation of crack widths (Clause7.3.4)

Cracking

Limiting crack width :

- In the absence of specific requirements (e.g. water tightness) the crack width may be limited to 0.3 mm in all exposure classes under quasi-permanent combination of loads.

- In the absence of requirements for appearance, this limit may be relaxed to 0.4 mm for exposure classes X0 and XC1. **(Table 7.1N EC2)**

Cracking

Control of cracking without direction calculation.

- Minimum reinforcement area, A_{smin}

$$A_{s,\min} = k_c k f_{ct,eff} A_{ct} / f_{yk}$$

- Maximum spacing of reinforcement (Given in Table 7.3N EC2)

- Maximum bar size (Given in Table 7.2N EC2)

Cracking

Table 7.3N EC2: Maximum bar spacing for crack control

Steel stress (N/mm^2)	Maximum bar spacing (mm)	
	$w_k = 0.4$ mm	$w_k = 0.3$ mm
160	300	300
200	300	250
240	250	200
280	200	150
320	150	100
360	100	50

$$f_s = \frac{f_{yk}}{1.15}\left[\frac{G_k + 0.3Q_k}{1.35G_k + 1.5Q_k}\right]\frac{1}{\delta}$$

Cracking

Table 7.2N EC2: Maximum bar diameter for crack control

Steel stress (N/mm^2)	Maximum bar size (mm)	
	w_k = 0.4 mm	w_k = 0.3 mm
160	40	32
200	32	25
240	20	16
280	16	12
320	12	10
360	10	8
400	8	6
450	6	5