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FKAAS

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Durability and Serviceability

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With Wisdom We Explore

Introduction

- Durability requirement is to ensure that a structure has satisfactory durability and serviceability performance under normal circumstances throughout its lifetime.
- These requirements involve:
  a) aspects of design, such as concrete mix selection and determination of cover to reinforcing bars.
  b) selection of suitable materials for the exposure conditions.
- 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 Cl.4.4, 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 (i) the safe transmission of bond forces, (ii) the protection of steel against corrosion (durability), (iii) an adequate fire resistance.

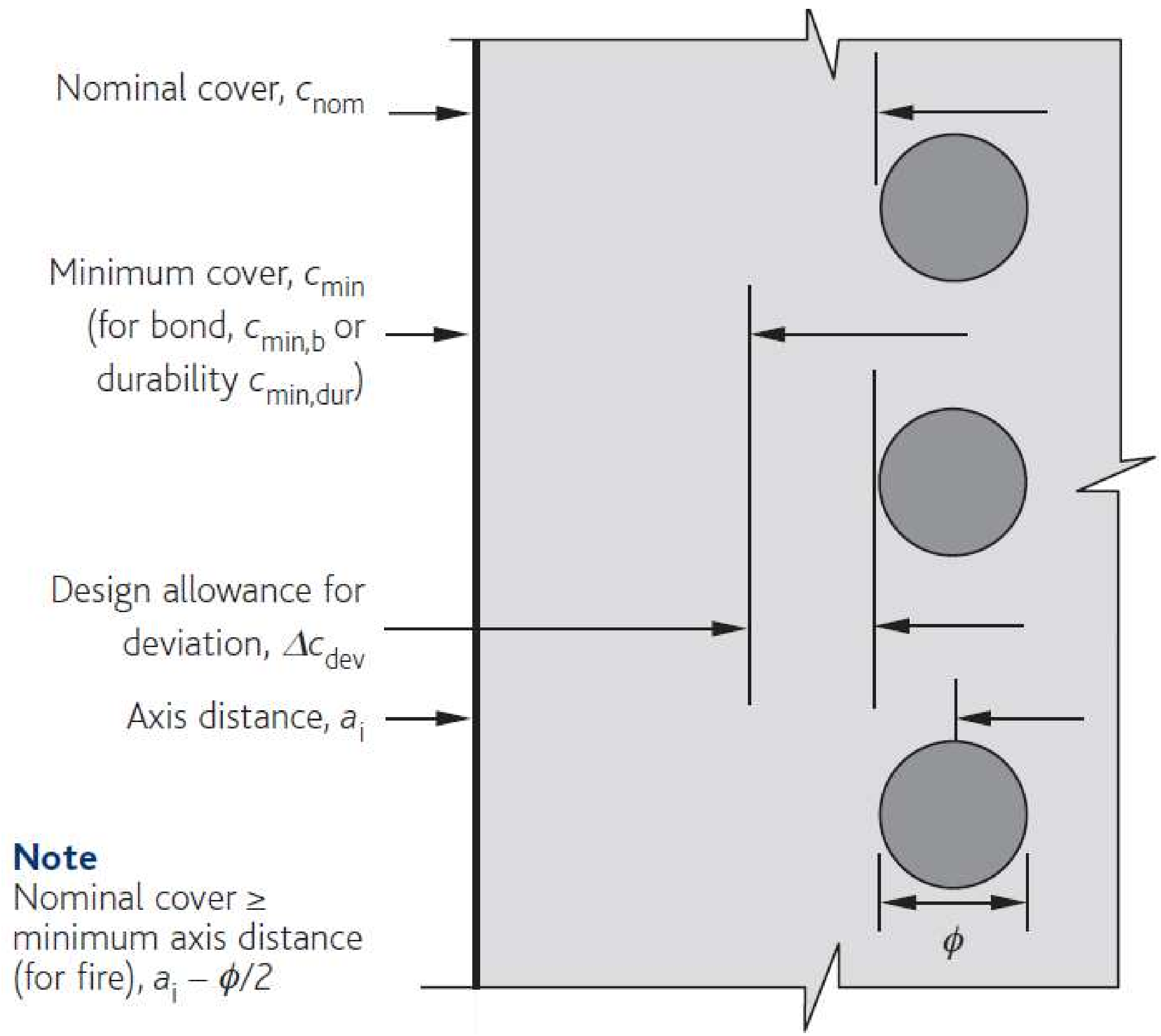
- The greater value for C_{min} satisfying the requirements for both bond and environmental conditions shall be used.

$$C_{\min} = \max\{C_{\min,bond}\ ;\ C_{\min,dur}\ ;\ C_{\min,fire}\ ;\ 10\text{mm}\}$$

- 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:



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Concrete Cover

- Minimum cover, $C_{min,b}$ requirement with regard to bond (Table 4.2, Cl.4.4.1).

Arrangement of Bars	Minimum Cover, $C_{min,b}$*
Separated	Diameter of bar
Bundle	Equivalent diameter $\Phi_n = Ø\sqrt{n_b} \leq 55$ 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 $n_b \geq 3$ for all other cases
* If the nominal maximum aggregate size is > 32 mm, $C_{min,b}$ should be increased by 5 mm	

Concrete Cover

- Minimum cover $C_{min,dur}$ requirement with regard to durability for reinforcement steel (Table 4.4N, Cl.4.4.1).
- 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	Exposure Class						
	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

Concrete Cover

- Exposure classes related to environmental condition

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
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surface exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Moderate humidity	Parts of bridges exposed to sprat containing chlorides Pavements Car park slabs

Concrete Cover

- Design working life and structural class

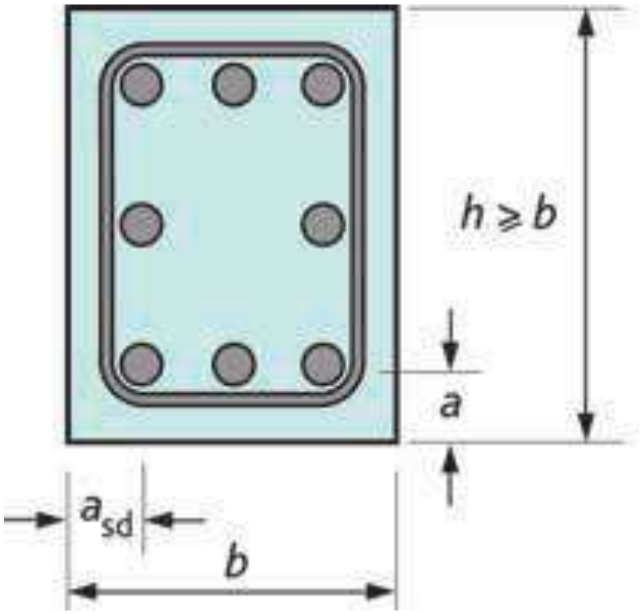
Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures
2	10 to 25	Replaceable structural parts, e.g. gantry girders, bearing
3	15 to 30	Agricultural and similar structures
4	50	Buildings structures and other common structures
5	100	Monumental building structures,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

Concrete Cover

- Minimum cover $C_{min,dur}$ for fire resistance
- It is based on nominal axis distance, a (the distance from the centre of the main reinforcement bar to the top or bottom surface of the member).

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

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



- The permissible combination of member dimension and axis distance of beam and slab are shown in Tables 5.5, 5.6 and 5.8.

Concrete Cover

- Minimum dimensions and axis distances for beams.

Standard Fire Resistance	Minimum Dimension (mm)						
	Possible combinations of a and b_{min} where a is the average axis distance and b_{min} is the width of beam				Web Thickness b_w		
					Class WA	Class WB	Class WC
1	2	3	4	5	6	7	8
R 30	b_{min} = 80 a = 25	120 20	160 15*	200 15*	80	80	80
R 60	b_{min} = 120 a = 40	160 35	200 30	300 25	100	80	100
R 90	b_{min} = 150 a = 55	200 45	300 40	400 35	110	100	100
R 120	b_{min} = 200 a = 65	240 60	300 55	500 50	130	120	120
R 180	b_{min} = 240 a = 80	300 70	400 65	600 60	150	150	140
R 240	b_{min} = 280 a = 90	350 80	500 75	700 70	170	170	160

Concrete Cover

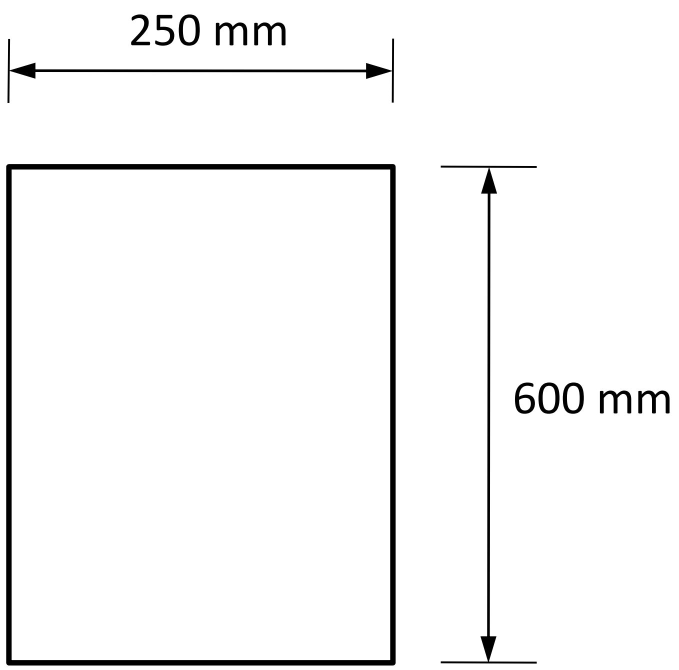
- Minimum dimensions and axis distances for one and two-way slabs.

Standard Fire Resistance	Minimum Dimension (mm)			
	Slab Thickness, h (mm)	Axis Distance, a		
		One-Way	Two-Way	
			$l_y/l_x \leq 1.5$	$1.5 < l_y/l_x < 2$
1	2	3	4	5
R 30	60	10*	10*	10*
R 60	80	20	10*	15*
R 90	100	30	15*	20
R 120	120	40	20	25
R 180	150	55	30	40
R 240	175	65	40	50

Example 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



Example 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,

$C_{min,fire} = a_{sd} – Ø_{link} - Ø_{bar}/2 = 40 – 8 – 20/2 =$ 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**

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.
- Based on Cl.7.3.2, the minimum area of reinforcement that must be provided within tensile zone is:

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

where: k_c is a coefficient to allow the stress distribution; k is a coefficient to allow the effect of non-uniform stresses; $f_{ct,eff}$ is mean tensile strength of concrete; A_{ct} is area of concrete in tension zone; and f_{yk} is the maximum stress permitted in the reinforcement

Area of Reinforcement

- The minimum area of reinforcement for beam also specified in Cl.9.2.1 as:

$$A_{s,\min} = 0.26(f_{ctm} / f_{yk})b_t d > 0.0013\mathrm{b}_t\mathrm{d}$$

where f_{ctm} is the mean value of axial tensile strength; b_t is mean width of the tension zone; and d is the effective depth.

- The maximum area of reinforcement (for both compression and tension) is specified in Cl.9.2.1 as:

$$A_{s,\max} = 0.04A_c = 0.04b_t h$$

where A_c is the cross section area; b_t is mean width of the tension zone; and h is the total depth.

Detailing 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 :
  a) the maximum bar size,
  b) the maximum aggregate size + 5 mm, or
  c) 20 mm, as specified in Cl.8.2.
- Other aspects related to the detailing of reinforcement that need serious attention are:
  a) Curtailment and anchorage of reinforcement (Cl.8.4)
  b) Lap in reinforcement (Cl.8.7)

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 Cl.7.4:
  a) Limiting span to depth ratios (Cl.7.4.2)
  b) Calculation of actual deflection (Cl.7.4.3)
- 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 as:

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

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

where:

l/d = limiting span/depth

K = *factor of structural system*

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

ρ = *required tension reinforcement ratio* = $A_{s,req} / bd$

ρ' = *required compression reinforcement ratio* = $A_{s',req} / bd$

Deflection

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

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	26
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:
  1) For flange section where the ratio of the flange width to the web width exceeds 3, the values should be multiplied by 0.8.
  2) 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*.
  3) 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.
- Therefore, the allowable *l/d* become:

$$\left(\frac{l}{d}\right)_{allow} = \frac{l}{d} \times MF_{span} \times MF_{area} < \left(\frac{l}{d}\right)_{actual}$$

Example 2

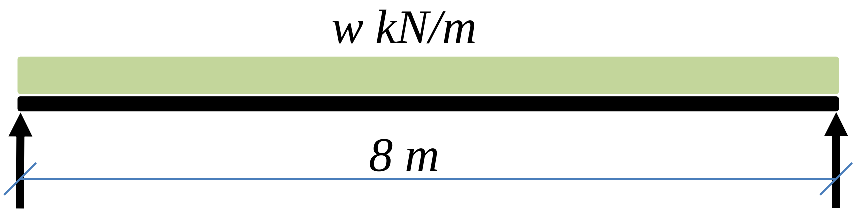
Check the deflection of simply supported beam. Given the following data:

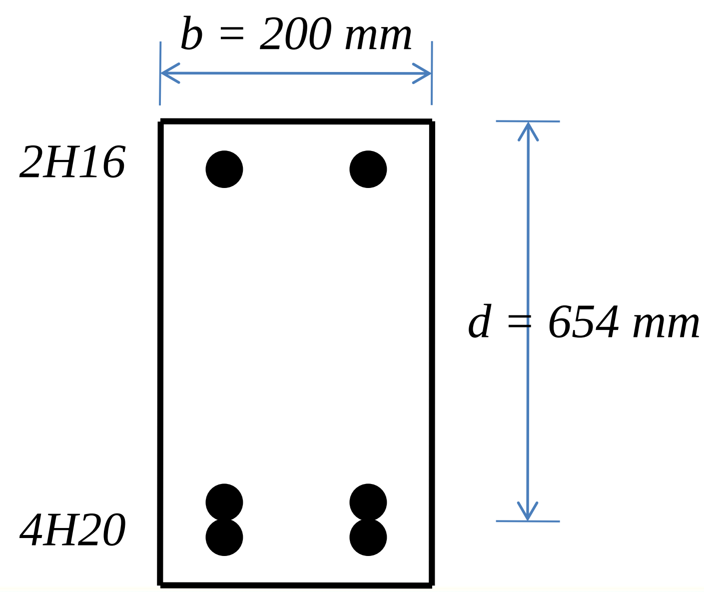
Char. strength of concrete, f_{ck} = 25 N/mm^2

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





Example 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)*

Example 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

MF_{span} = 7 / Span = 7/8 = 0.88

Modification factor for steel area provided

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

Allowable span-effective depth ratio, $\frac{l}{d}_{allow} = 17.08 \times 0.88 \times 1.03 = 15.48$

Actual span-effective depth ratio, $\frac{l}{d}_{actual} = \frac{8000}{654} = 12.23 < 15.48$

Cracking

- Cracks are induced in reinforced concrete elements as a result of:
  a) flexural tensile stress due to bending under applied loads;
  b) diagonal tension stress due to shear under applied load;
  c) volume changes due to shrinkage, creep, thermal and chemical effects; and
  d) splitting along reinforcement due to bond and anchorage failure.
- 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.

Cracking

- For control crack, two alternative methods are describe in Cl.7.3:
  1) control of cracking without direct calculation, (Cl.7.3.3)
  2) calculation of crack widths (Cl.7.3.4)
- Control of cracking without direct calculation:
  - For reinforced slabs in building subjected to bending without significant axial tension, specific measures to control cracking are not necessary where the overall depth does not exceed 200mm.
  - Principal reinforcement, $S_{max} \leq 3.0h$ or 400mm (which one smallest).
  - Secondary reinforcement, $S_{max} \leq 3.5h$ or 450 (which one smallest).

Cracking

- If h > 200mm, then the cracking is restricting by the bar diameter or spacing:
  1) Minimum reinforcement area, $A_{s,min}$ (Cl. 7.3.2)
  2) Maximum bar diameter (Table 7.2N)
  3) Maximum bar spacing (Table 7.3N)
- 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.

Cracking

- The steel stress should be calculated on the basis of a cracked section under the relevant combination of actions.
- It can be calculated using the following equations:

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

or

$$f_s = 435\left[\frac{G_k + 0.3Q_k}{1.35G_k + 1.5Q_k}\right]\left(\frac{A_{s,req}}{A_{s,prov}}\right)$$

where:

Gk and Qk are characteristics of permanent and variable actions respectively; fyk is characteristic strength of steel, δ is deflection.

Cracking

- Maximum bar diameter for crack control (Table 7.2N)

Steel Stress (N/mm2)	Maximum Bar Size (mm)		
	w_k = 0.4mm	w_k = 0.3mm	w_k = 0.2mm
160	40	32	25
200	32	25	16
240	20	16	12
280	16	12	8
320	12	10	6
360	10	8	5
400	8	6	4
450	6	5	-

Cracking

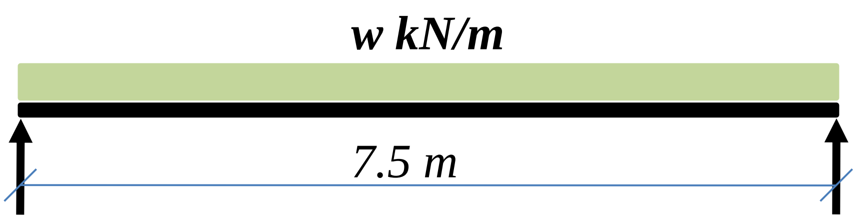
- Maximum bar spacing diameter for crack control (Table 7.3N)

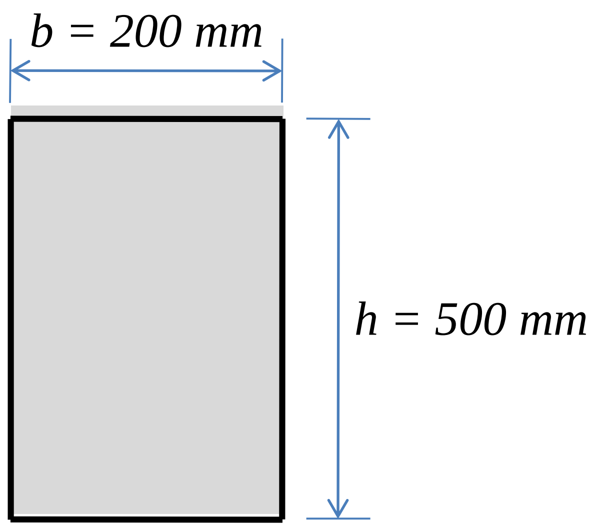
Steel Stress (N/mm2)	Maximum Bar Spacing (mm)		
	w_k = 0.4mm	w_k = 0.3mm	w_k = 0.2mm
160	300	300	200
200	300	250	150
240	250	200	100
280	200	150	50
320	150	100	-
360	100	50	-

Example 3

By using the stress block diagram, design the simply support beam and check the deflection and crack control. Given the following data:

Char. strength of concrete, f_{ck}	$= 25$ N/mm^2
Char. strength of reinforcement, f_{yk}	$= 500$ N/mm^2
Char. permanent action, G_k	$= 8.65$kN/m
Char. variable action, Q_k	$= 3.60$kN/m





*Use $Ø_{bar} = 16$mm, $Ø_{link} = 8$mm, C_{nom}=30mm