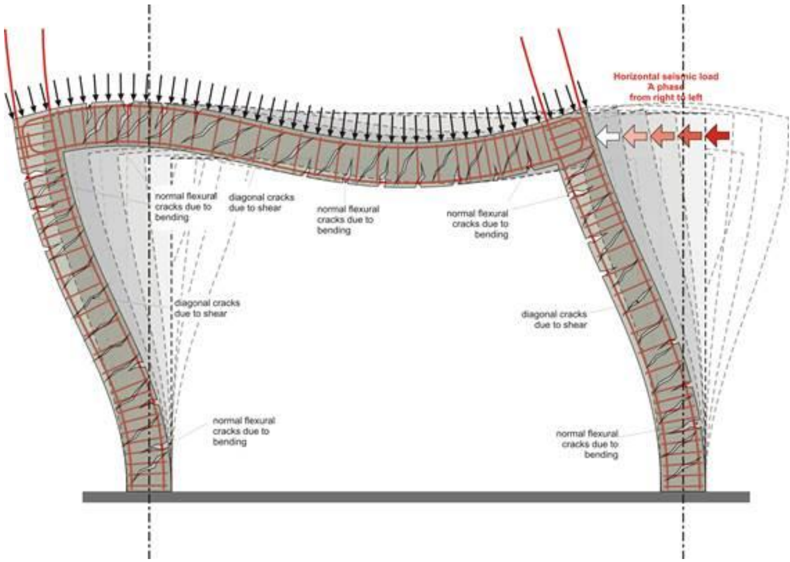
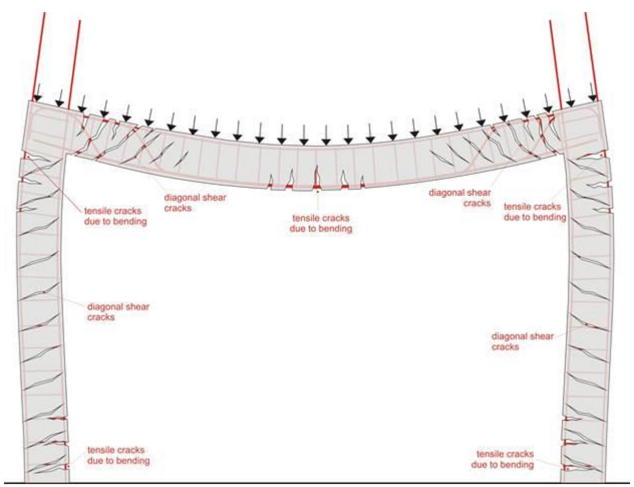
Application





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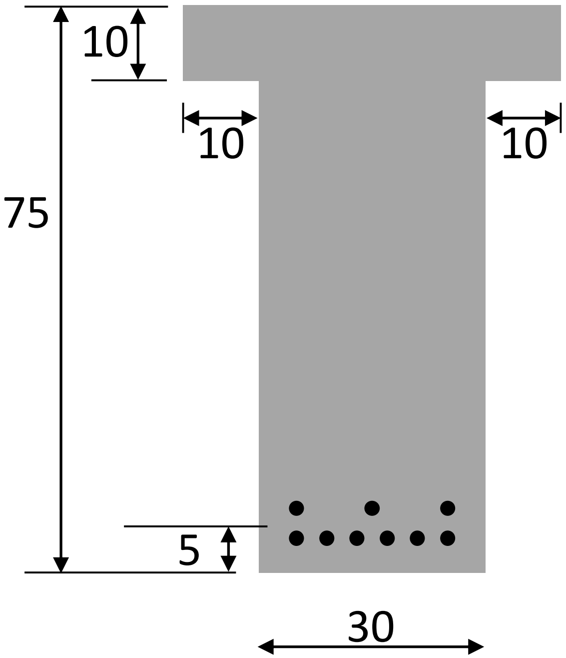
Crack control by calculation

Simple supported RC beam crack control



$$9\text{Ø}20 = 28.26\ cm^2$$

$$C25/30 \rightarrow f_{ck} = 25\ N/mm^2$$

$$\rightarrow f_{ctm} = 2.6\ N/mm^2$$

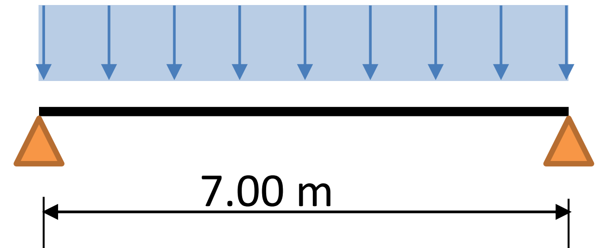
$$\rightarrow E_{cm} = 31000\ N/mm^2$$

$$PC52 \rightarrow f_{yk} = 345\ N/mm^2$$

$$c_{nom} = 25\ mm$$

SLS = quasi-permanent load condition

$G + \psi_2 Q_k = 5.3$ t/m



Crack control by calculation

Maximum crack spacing

a) Distance between bars $\leq 5(c + \phi/2)$ – usual situation

$$s_{r,max} = 3{,}4c + 0{,}425 k_1 k_2 \frac{\phi}{\rho_{p,eff}}$$

b) Distance between bars $> 5(c + \phi/2)$ – slabs, massive elements

$$s_{r,max} = 1{,}3(h - x)$$

$5\left(c + \frac{\phi}{2}\right) =$

Distance between bars = → **case …**

c = concrete cover

Crack control by calculation

Maximum crack spacing

a) Distance between bars $\leq 5(c + \phi/2)$ – usual situation

$$s_{r,max} = 3{,}4c + 0{,}425k_1k_2\frac{\phi}{\rho_{p,eff}}$$

b) Distance between bars $> 5(c + \phi/2)$ – slabs, massive elements

$$s_{r,max} = 1{,}3(h - x)$$

$$5\left(c + \frac{\phi}{2}\right) = 5 * \left(25 + \frac{20}{2}\right) = 175\ mm$$

Distance between bars = 16 mm → **case a)**

Crack control by calculation

1. Maximum crack spacing

$$s_{r,max} = 3{,}4c + 0{,}425 k_1 k_2 \frac{\phi}{\rho_{p,eff}}$$

where

c is the concrete cover

ϕ is the bar diameter

k_1 bond factor

= 0,8 for high bond bars,

= 1,6 for bars with an effectively plain surface

k_1 strain distribution coefficient

= 1,0 for tension

= 0,5 for bending

= $(\varepsilon_1 + \varepsilon_2)/2\varepsilon_1$ for cases of eccentric tension, where ε_1 is the greater and ε_2 is the lesser tensile strain at the boundaries of the section considered, assessed on the basis of a cracked section

$\rho_{p,eff} = A_s/A_{c,eff}$

$A_{c,eff}$ effective area of concrete in tension surrounding the reinforcement of depth $h_{c,ef}$

$h_{c,ef} = \min[2{,}5(h-d); (h-x)/3\,; h/2]$

Crack control by calculation

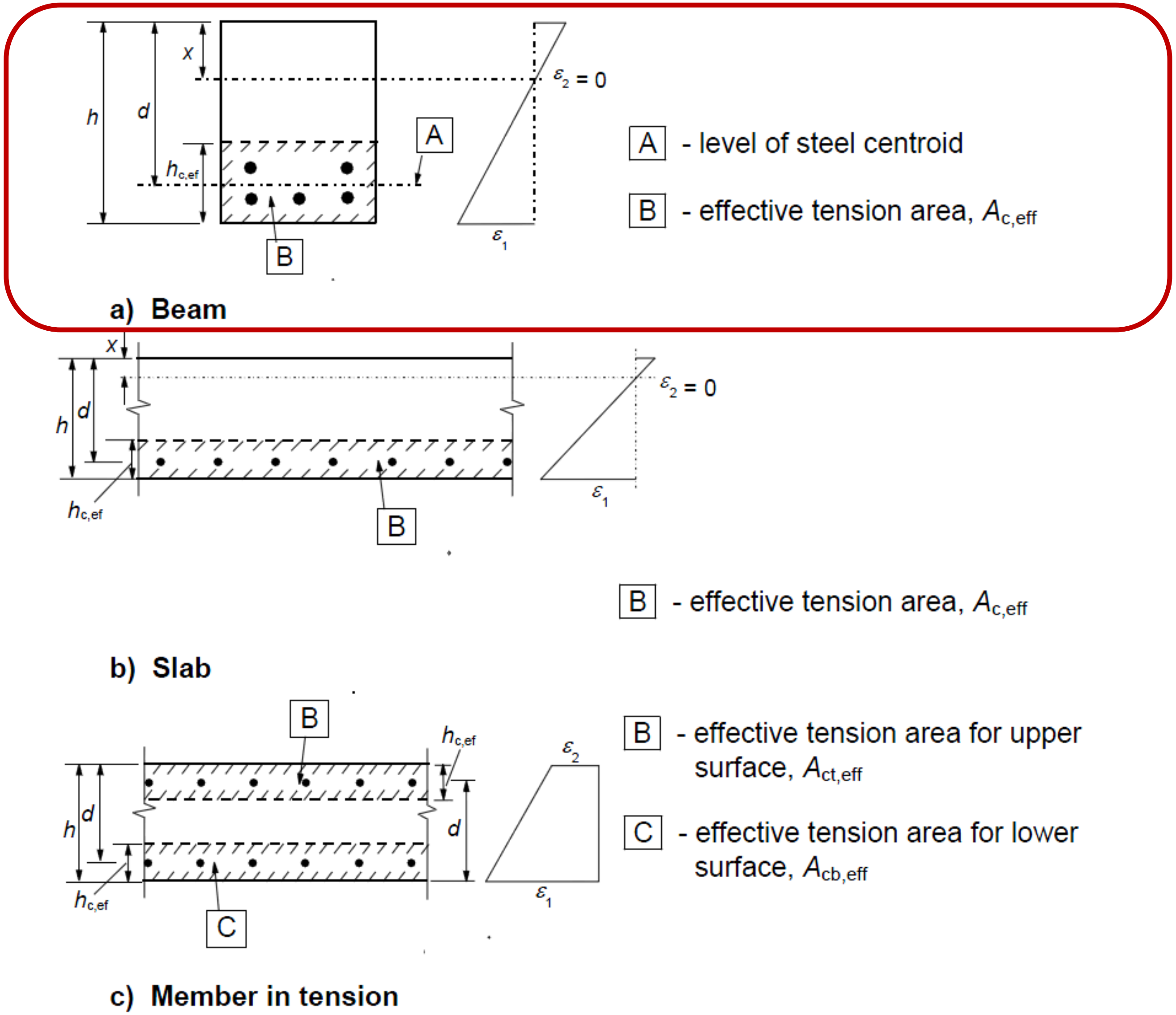


Figure 7.1: Effective tension area (typical cases)

Crack control by calculation

$$h_{c,ef} = \min[2{,}5(h-d); (h-x)/3\,; h/2]$$

x can be computed from:

$$0.5bx^2 - 0.5(b-b_w)\left(x-h_f\right)^2 - \alpha_e A_{s1}(d-x) = 0$$

$\alpha_e = \frac{E_s}{E_c} =$ - coefficient of equivalence

$$0.5 \cdot 50 \cdot x^2 - 0.5(50-30)(x-10)^2 - 6.77 \cdot 28.26(70-x) = 0$$

$x =$

$$ax^2+bx+c=0$$

$$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

Crack control by calculation

$$h_{c,ef} = \min[2{,}5(h-d);\,(h-x)/3\,;\,h/2]$$

x can be computed from:

$$0.5bx^2 - 0.5(b-b_w)(x-h_f)^2 - \alpha_e A_{s1}(d-x) = 0$$

$\alpha_e = \frac{E_s}{E_c} = \frac{210000}{31000} = 6.77$ - coefficient of equivalence

$$0.5 \cdot 50 \cdot x^2 - 0.5(50-30)(x-10)^2 - 6.77 \cdot 28.26(70-x) = 0$$

$$x = 20.6\ \text{cm} = \mathbf{206\ mm}$$

$$ax^2+bx+c=0$$

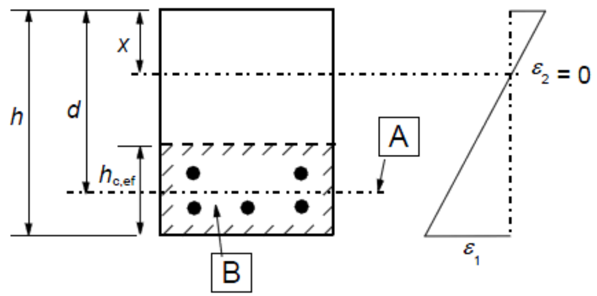
$$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

Crack control by calculation

$$h_{c,ef} = \min[2{,}5(h-d); (h-x)/3\,; h/2]$$

$$h_{c,ef} =$$

$$A_{c,eff} = h_{c,ef} \cdot b =$$



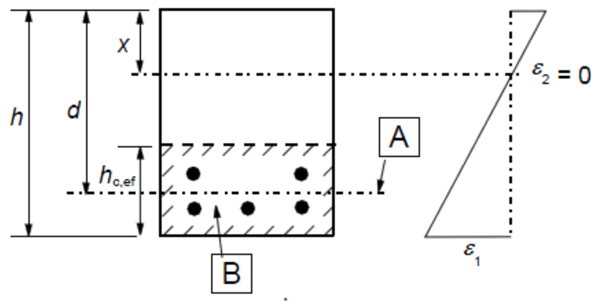
a) Beam

Crack control by calculation

$$h_{c,ef} = \min[2{,}5(h-d); (h-x)/3\,; h/2] = \min[2{,}5(750-700); (750-206)/3\,; 750/2]$$

$$h_{c,ef} = \min[125; 181; 375] = \mathbf{125\ mm}$$

$$A_{c,eff} = h_{c,ef} \cdot b = 125 \cdot 300 = 37500\ mm^2$$



a) Beam

$$\rho_{p,eff} = \frac{A_s}{A_{c,eff}} =$$

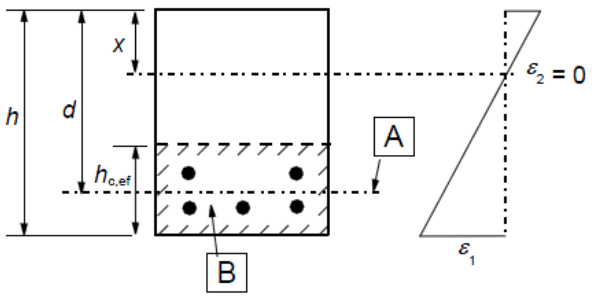
$$s_{r,max} = 3{,}4c + 0{,}425 k_1 k_2 \frac{\phi}{\rho_{p,eff}} =$$

Crack control by calculation

$$h_{c,ef} = \min[2{,}5(h-d); (h-x)/3\,; h/2] = \min[2{,}5(750-700); (750-206)/3\,; 750/2]$$

$$h_{c,ef} = \min[125; 181; 375] = \mathbf{125\,mm}$$

$$A_{c,eff} = h_{c,ef} \cdot b = 125 \cdot 300 = 37500\,mm^2$$



a) Beam

$$\rho_{p,eff} = \frac{A_s}{A_{c,eff}} = \frac{2826}{37500} = 0.07536$$

$$s_{r,max} = 3{,}4c + 0{,}425 k_1 k_2 \frac{\phi}{\rho_{p,eff}} = 3.4 \cdot 25 + 0.425 \cdot 0.8 \cdot 0.5 \cdot \frac{20}{0.07536} = \mathbf{130mm}$$

Crack control by calculation

2. Crack width calculation

$$w_k = s_{r,max}(\varepsilon_{sm} - \varepsilon_{cm})$$

where

ε_{sm} is the mean strain in the reinforcement under the relevant combination of loads, including the effect of imposed deformations and taking into account the effects of tension stiffening.

ε_{cm} is the mean strain in the concrete between cracks

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t \frac{f_{ct,eff}}{\rho_{p,eff}}\left(1 + \alpha_e \rho_{p,eff}\right)}{E_s} \geq 0.6 \frac{\sigma_s}{E_s}$$

$\sigma_s = \alpha_e \frac{M}{I_{II}}(d - x)$ Navier's formula applied for cracked RC section in bending

k_t factor dependent on the duration of the load
= 0,6 for short term loading
= 0,4 for long term loading

$f_{ct,eff}$ is the mean value of the tensile strength of the concrete effective at the time when the cracks may first be expected to occur: $f_{ct,eff} = f_{ctm}$ or lower, $f_{ctm}(t)$, if cracking is expected earlier than 28 days

Crack control by calculation

$\sigma_s = \alpha_e \frac{M}{I_{II}}(d - x)$ Navier's formula applied for cracked RC section in bending

$I_{II} = I_{cc} + \cancel{(\alpha_e - 1)A_{s2}(x - d_2)^2} + \alpha_e A_{s1}(d - x)^2$ - inertia of the cracked section

$I_{cc} = \frac{bx^3}{3} - (b - b_w)\frac{(x-h_f)^3}{3}$ - inertia of compressed concrete area about neutral axis

$$I_{cc} = \frac{bx^3}{3} - (b - b_w)\frac{\left(x - h_f\right)^3}{3} =$$

$$I_{II} =$$

$$M_{Eqp} = \frac{Load \cdot Span^2}{8} =$$

Crack control by calculation

$\sigma_s = \alpha_e \frac{M}{I_{II}}(d-x)$ Navier's formula applied for cracked RC section in bending

$I_{II} = I_{cc} + (\alpha_e - 1)A_{s2}(x-d_2)^2 + \alpha_e A_{s1}(d-x)^2$ - inertia of the cracked section

$I_{cc} = \frac{bx^3}{3} - (b-b_w)\frac{(x-h_f)^3}{3}$ - inertia of compressed concrete area about neutral axis

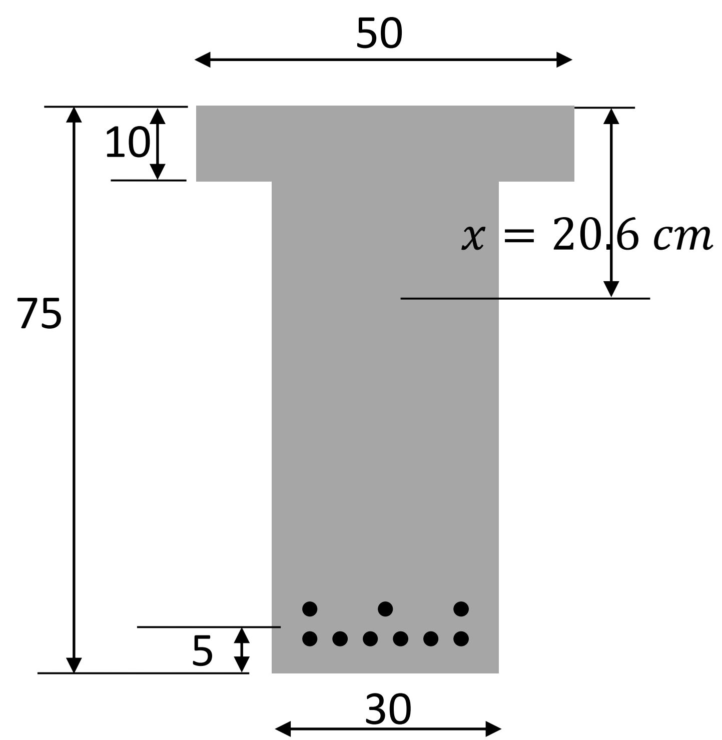
$$I_{cc} = \frac{bx^3}{3} - (b-b_w)\frac{\left(x-h_f\right)^3}{3} = \frac{50 \cdot 20{,}6^3}{3} - (50-30)\frac{(20{,}6-10)^3}{3} = 137757\ cm^4$$

$$I_{II} = 137757 + 6.77 \cdot 28.26(70-20.6)^2 = 604647\ cm^4 = 604647 \cdot 10^4\ mm^4$$

$$M_{Eqp} = \frac{Load \cdot Span^2}{8} = \frac{53 \cdot 7.0^2}{8} = 325\ kNm$$

Crack control by calculation

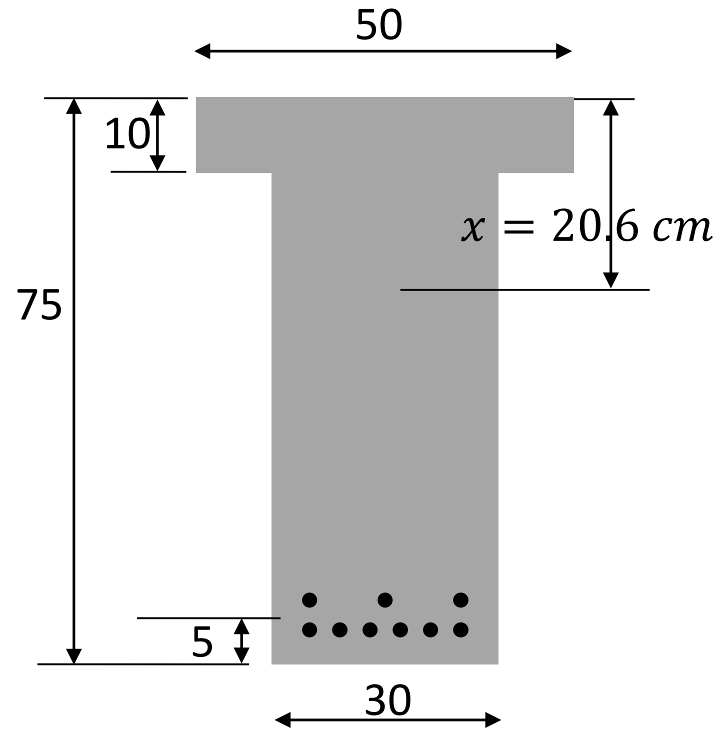
$$\sigma_s = \alpha_e \frac{M}{I_{II}}(d - x) =$$



Crack control by calculation

$$\sigma_s = \alpha_e \frac{M}{I_{II}}(d - x) = 6.77\,\frac{325 \cdot 10^6}{604647 \cdot 10^4}(700 - 206) =$$

$$\sigma_s = 180\ N/mm^2$$



Crack control by calculation

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t \frac{f_{ct,eff}}{\rho_{p,eff}}\left(1 + \alpha_e \rho_{p,eff}\right)}{E_s}$$

$$\varepsilon_{sm} - \varepsilon_{cm} =$$

Crack control by calculation

$$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t \frac{f_{ct,eff}}{\rho_{p,eff}}\left(1 + \alpha_e \rho_{p,eff}\right)}{E_s} = \frac{180 - 0.4 \frac{2.6}{0.07536}(1 + 6.77 \cdot 0.07536)}{210000}$$

$$\varepsilon_{sm} - \varepsilon_{cm} = 0.758 \cdot 10^{-3}$$

$\Rightarrow$

$$\boldsymbol{w_k = s_{r,max}(\varepsilon_{sm} - \varepsilon_{cm}) =}$$

Crack control by calculation

$$\varepsilon_{sm}-\varepsilon_{cm}=\frac{\sigma_s-k_t\dfrac{f_{ct,eff}}{\rho_{p,eff}}\left(1+\alpha_e\rho_{p,eff}\right)}{E_s}=\frac{180-0.4\dfrac{2.6}{0.07536}(1+6.77\cdot 0.07536)}{210000}$$

$$\varepsilon_{sm}-\varepsilon_{cm}=0.758\cdot 10^{-3}$$

$$\Rightarrow$$

$$\boldsymbol{w_k}=\boldsymbol{s_{r,max}}(\boldsymbol{\varepsilon_{sm}}-\boldsymbol{\varepsilon_{cm}})=130\cdot 0.758\cdot 10^{-3}=0.098mm=0.1\,mm$$

$$\boldsymbol{w_k=0.1\,mm}$$

Crack control by calculation

Table 7.1N Recommended values of w_{max} (mm)

Exposure Class	Reinforced members and prestressed members with unbonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0,4[1]	0,2
XC2, XC3, XC4	0,3	0,2[2]
XD1, XD2, XS1, XS2, XS3		Decompression

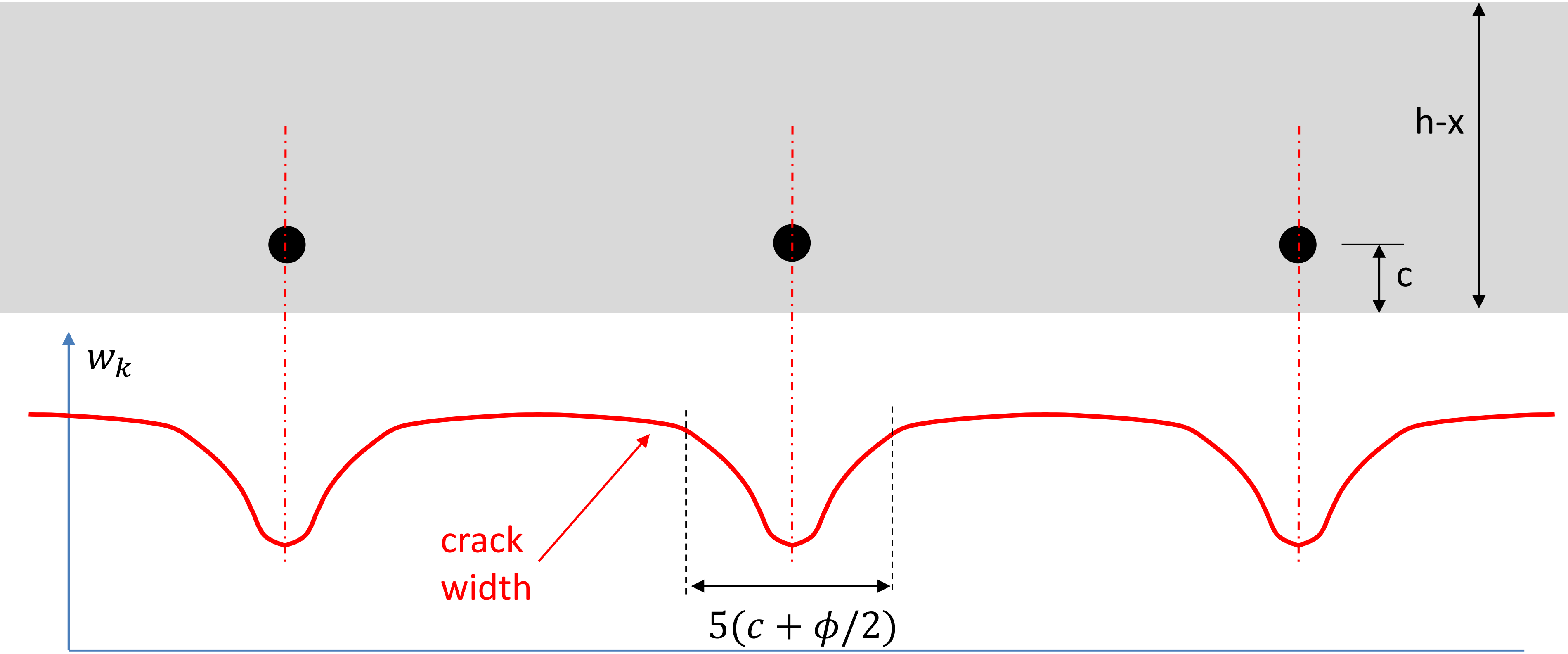
Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed.

Note 2: For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.

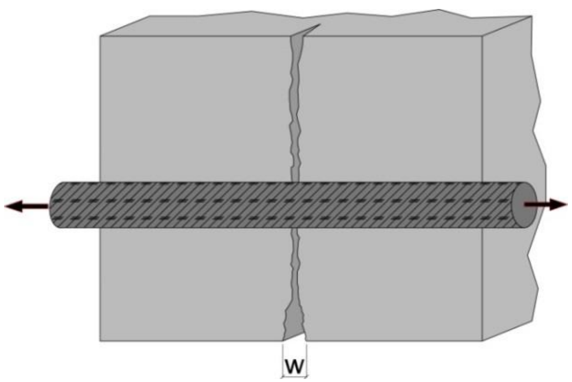
Under the relevant combination of loads there is necessary to have

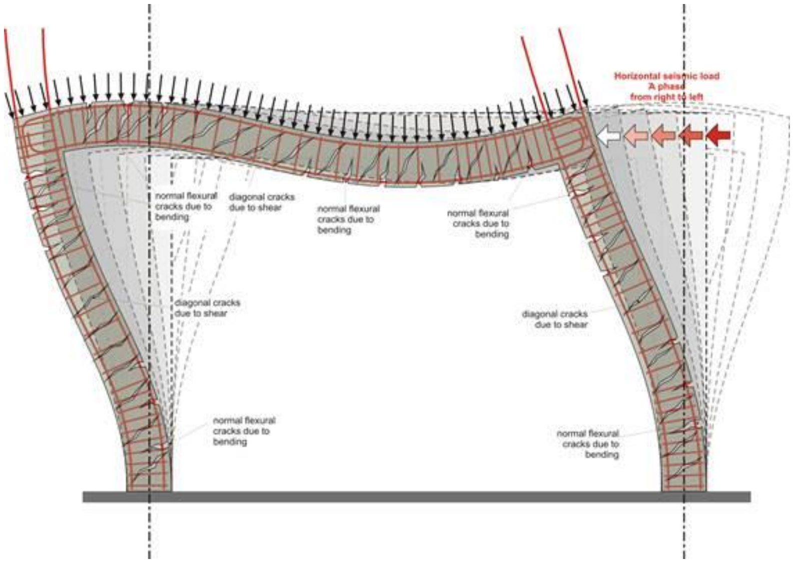
$$w_k \leq w_{max}$$

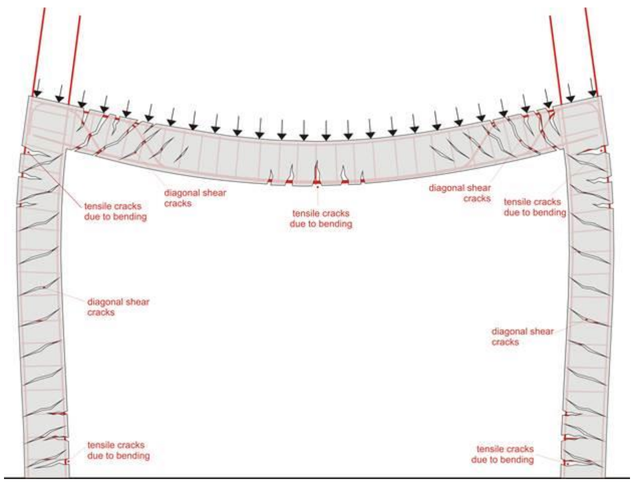
Crack control by calculation



Cracks are always measured at the surface of the structure !







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THANK YOU FOR YOUR ATTENTION!