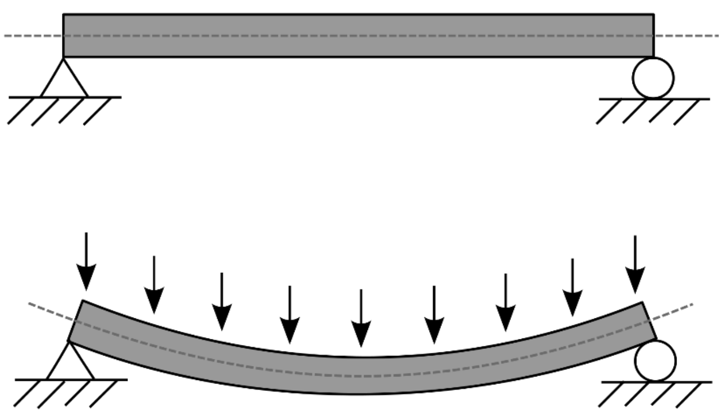
Application



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SLS deflection - general

The control of deflection can be done:

- by calculation
- by tabulated values

SLS = quasi-permanent load condition

$$G + \psi_2 Q_k$$

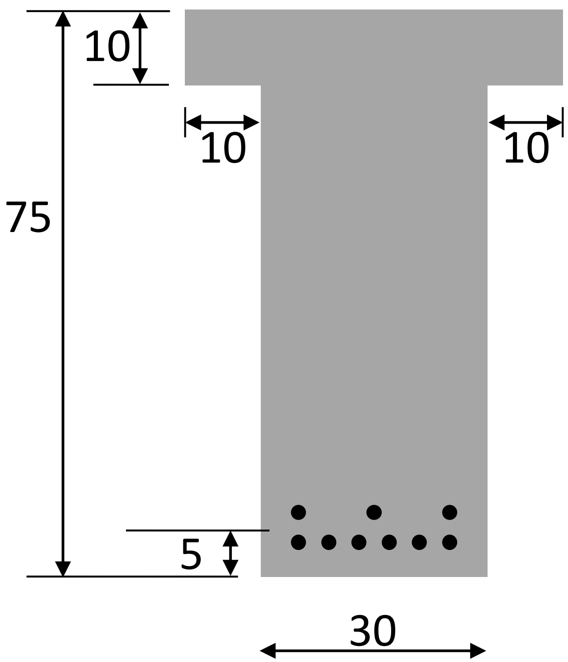
SLS deflection - general

1. DEFLECTION CONTROL BY CALCULATION

2. DEFLECTION CONTROL WITHOUT CALCULATION

Deflection control by calculation

Simple supported RC beam deflection calculus



$9\phi 20 = 28.26\ cm^2$

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

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

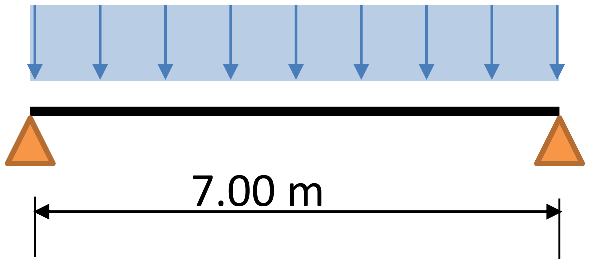
$\rightarrow E_{cm} = 31000\ N/mm^2$

$PC52$

$c_{nom} = 25\ mm$

SLS = quasi-permanent load condition

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



$t_0 = 28\ days$

$t = 57\ years = 20805\ days$

Deflection control by calculation

An adequate prediction of behaviour is given by:

$$\alpha = (1 - \zeta)\alpha_I + \zeta\alpha_{II}$$

α - the deformation parameter considered which may be strain, curvature or rotation; α **may also be taken as a deflection**

α_I, α_{II} - parameter value corresponding to the **stage I (un-cracked) or II (fully cracked)**

ζ - distribution coefficient, allowing for tensioning stiffening at a section (ζ = 0 for un-cracked elements)

$$\zeta = 1 - \beta\left(\frac{\sigma_{sr}}{\sigma_s}\right)^2$$

Deflection control by calculation

ζ - distribution coefficient, allowing for tensioning stiffening at a section (ζ = 0 for un-cracked elements)

$$\zeta = 1 - \beta \left(\frac{\sigma_{sr}}{\sigma_s} \right)^2$$

β - coefficient taking account of the influence of the duration of the loading or of repeated loading on the average strain

$= 1.0$ for a single short-term loading

$= 0.5$ for sustained loads or many cycles of repeated loading

σ_s - stress in the tension reinforcement calculated on the basis of a cracked section

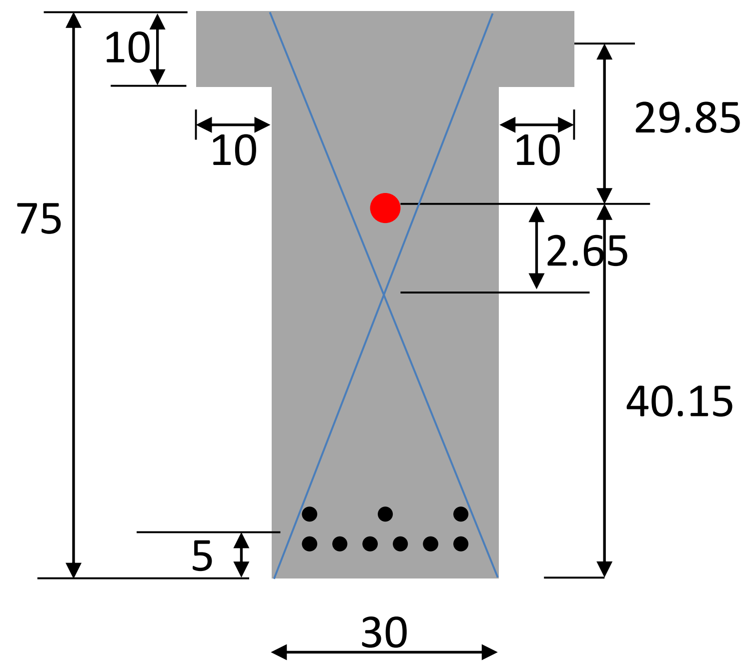
σ_{sr} - stress in the tension reinforcement calculated on the basis of a cracked section under the loading conditions causing first cracking;

NOTE: $\boldsymbol{\sigma_{sr}/\sigma_s}$ **may be replaced by** $\boldsymbol{M_{cr}/M_{Eqp}}$ **for bending**

Deflection control by calculation

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

$$M_{cr} = f_{ctm} \cdot W_1 = f_{ctm} \frac{I_I}{(h - y_G)} =$$

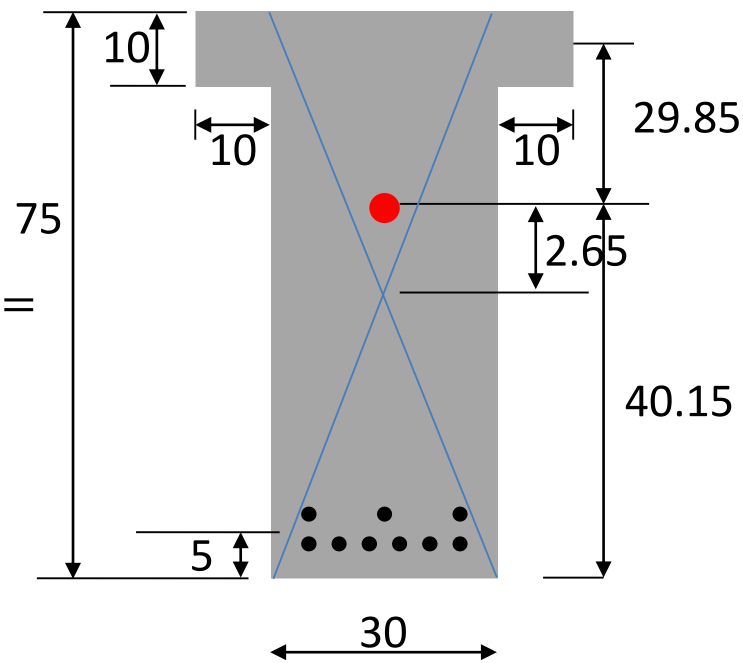


$$I_I = \frac{30 \cdot 75^3}{12} + 30 \cdot 75 \cdot 2.65^2 + \frac{20 \cdot 10^3}{12} + 20 \cdot 10 \cdot 29.85^2 = 1250359\ cm^4 = 1250359 \cdot 10^4\ mm^4$$

I_I - second moment of area of the un-cracked concrete section (stage I)

Deflection control by calculation

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



$$M_{cr} = f_{ctm} \cdot W_1 = f_{ctm} \frac{I_I}{(h - y_G)} = 2.6 \frac{1250359 \cdot 10^4}{401.5} =$$

$$M_{cr} = 81.0\ kNm$$

$$I_I = \frac{30 \cdot 75^3}{12} + 30 \cdot 75 \cdot 2.65^2 + \frac{20 \cdot 10^3}{12} + 20 \cdot 10 \cdot 29.85^2 = 1250359\ cm^4 = 1250359 \cdot 10^4\ mm^4$$

I_I - second moment of area of the un-cracked concrete section (stage I)

Deflection control by calculation

ζ - distribution coefficient, allowing for tensioning stiffening at a section (ζ = 0 for un-cracked elements)

$$\zeta = 1 - \beta \left(\frac{\sigma_{sr}}{\sigma_s} \right)^2$$

β - coefficient taking account of the influence of the duration of the loading or of repeated loading on the average strain

$= 1.0$ for a single short-term loading

$= 0.5$ for sustained loads or many cycles of repeated loading

$$\zeta = 1 - \beta \left(\frac{M_{cr}}{M_{Eqp}} \right)^2 =$$

Deflection control by calculation

ζ - distribution coefficient, allowing for tensioning stiffening at a section (ζ = 0 for un-cracked elements)

$$\zeta = 1 - \beta \left(\frac{\sigma_{sr}}{\sigma_s} \right)^2$$

β - coefficient taking account of the influence of the duration of the loading or of repeated loading on the average strain

$= 1.0$ for a single short-term loading

$= 0.5$ for sustained loads or many cycles of repeated loading

$$\zeta = 1 - \beta \left(\frac{M_{cr}}{M_{Eqp}} \right)^2 = 1 - 0.5 \left(\frac{81.0}{325} \right)^2 = 0.97$$

Deflection control by calculation

Curvature due to loads

Un-cracked stage I

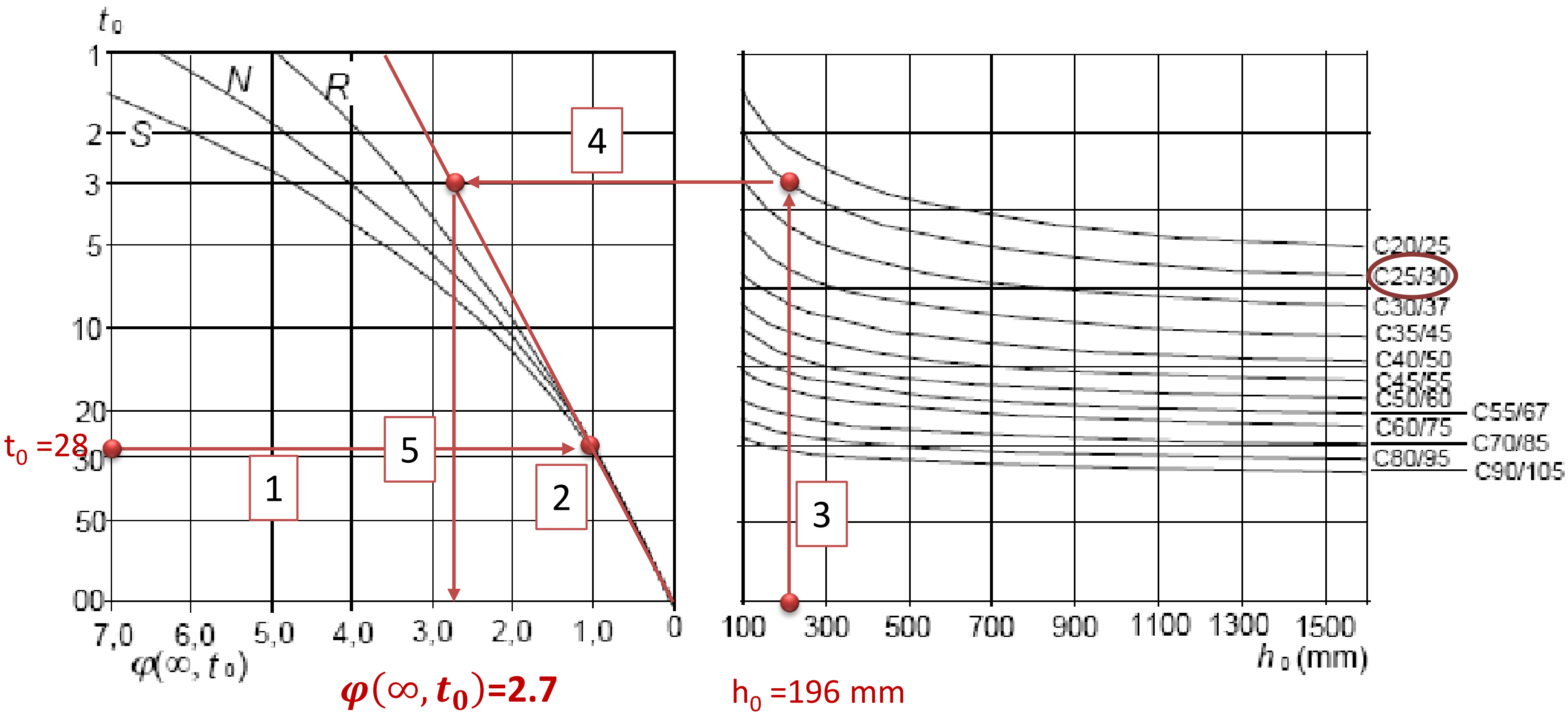
$$\frac{1}{r_I} = \frac{M_{Eqp}}{E_{c,eff} I_I}$$

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(\infty, t_0)}$$

Deflection control by calculation

Determination of creep coefficient

$$h_0 = \frac{2A_c}{u} = \frac{2(2 \cdot 10 \cdot 10 + 30 \cdot 75)}{30 + 2 \cdot 65 + 2 \cdot 10 + 2 \cdot 10 + 50} = 196\,mm$$



inside conditions - RH = 50%

Deflection control by calculation

Curvature due to loads

Un-cracked stage I

$$\frac{1}{r_I} = \frac{M_{Eqp}}{E_{c,eff} I_I}$$

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(\infty, t_0)} =$$

Deflection control by calculation

Curvature due to loads

Un-cracked stage I

$$\frac{1}{r_I} = \frac{M_{Eqp}}{E_{c,eff} I_I} =$$

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(\infty, t_0)} = \frac{31000}{1 + 2.7} = 8378\ MPa$$

Deflection control by calculation

Curvature due to loads

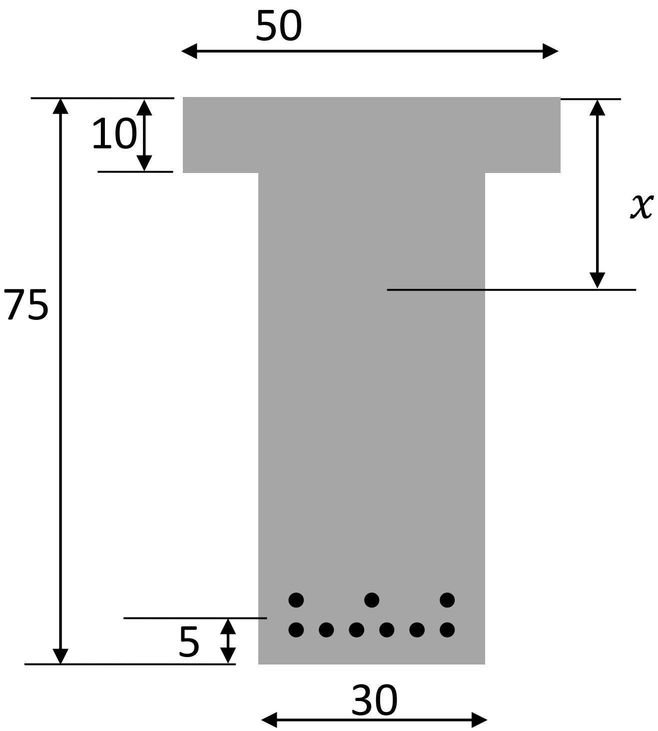
Un-cracked stage I

$$\frac{1}{r_I} = \frac{M_{Eqp}}{E_{c,eff} I_I} = \frac{325 \cdot 10^6}{8378 \cdot 1250359 \cdot 10^4} = 3.10 \cdot 10^{-6}$$

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(\infty, t_0)} = \frac{31000}{1 + 2.7} = 8378\ MPa$$

Deflection control by calculation

Curvature due to loads



Fully cracked stage II

$$\frac{1}{r_{II}} = \frac{M_{Eqp}}{E_{c,eff} \cdot I_{II}}$$

I_{II} - inertia of the cracked section

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

I_{cc} - inertia of compressed concrete area about neutral axis
- inertia of reinforcement area about own axis is negligible

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

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

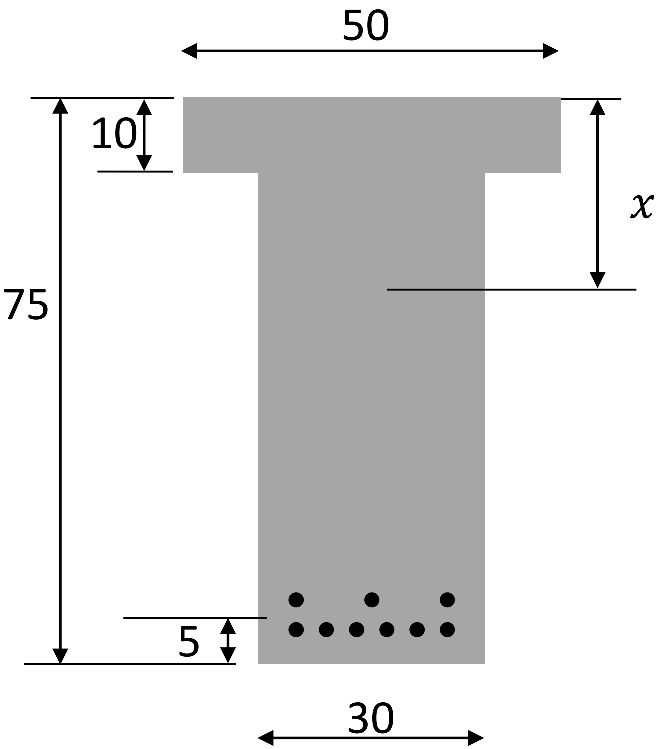
Deflection control by calculation

Curvature due to loads

x can be computed from>

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

$$\alpha_e = \frac{E_s}{E_c} =$$

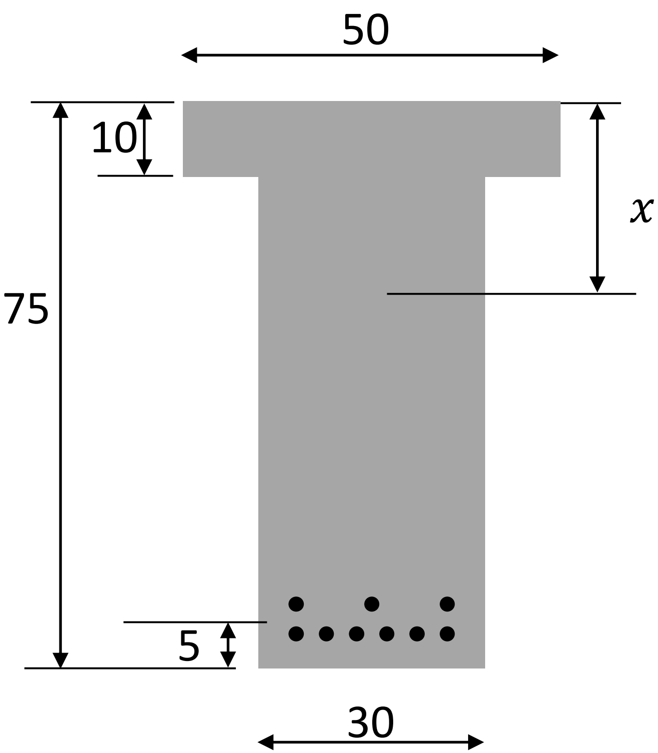


$$0.5 \cdot 50 \cdot x^2 - 0.5(50 - 30)(x - 10)^2 - 25.1 \cdot 28.26(70 - x) = 0$$

$$x =$$

Deflection control by calculation

Curvature due to loads



x can be computed from>

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

$$\alpha_e = \frac{E_s}{E_c} = \frac{210000}{8378} = 25.1$$

$$0.5 \cdot 50 \cdot x^2 - 0.5(50-30)(x-10)^2 - 25.1 \cdot 28.26(70-x) = 0$$

$x =$

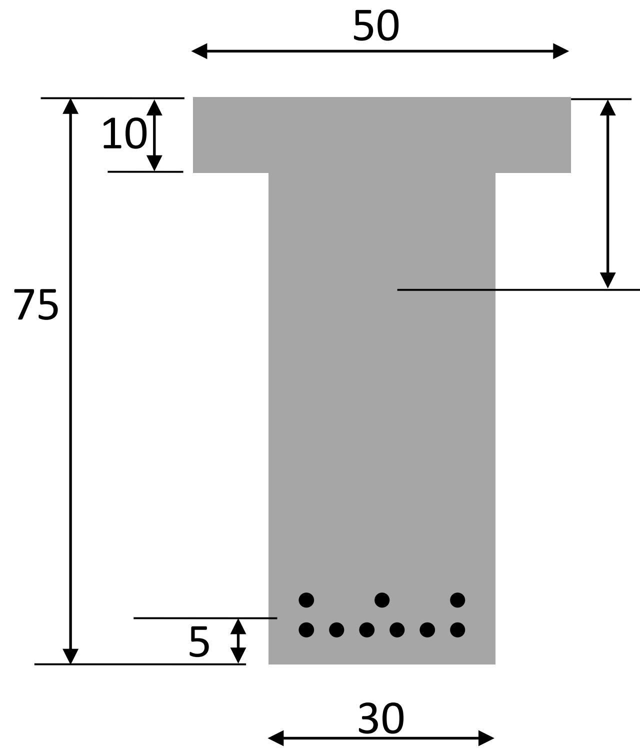
Deflection control by calculation

Curvature due to loads

x can be computed from>

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

$$\alpha_e = \frac{E_s}{E_c} = \frac{210000}{8378} = 25.1$$



$$0.5 \cdot 50 \cdot x^2 - 0.5(50 - 30)(x - 10)^2 - 25.1 \cdot 28.26(70 - x) = 0$$

$$x = 35.2 \text{ cm} = 352 \text{ mm}$$

Deflection control by calculation

Curvature due to loads

Fully cracked stage II

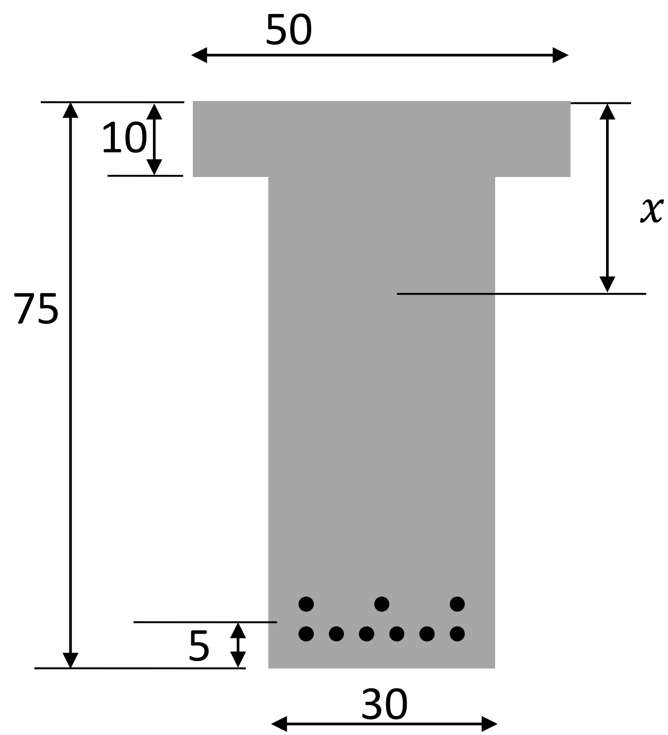
$$\frac{1}{r_{II}} = \frac{M_{Eqp}}{E_{c,eff} \cdot I_{II}}$$

I_{II} - inertia of the cracked section

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

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

$$I_{II} =$$

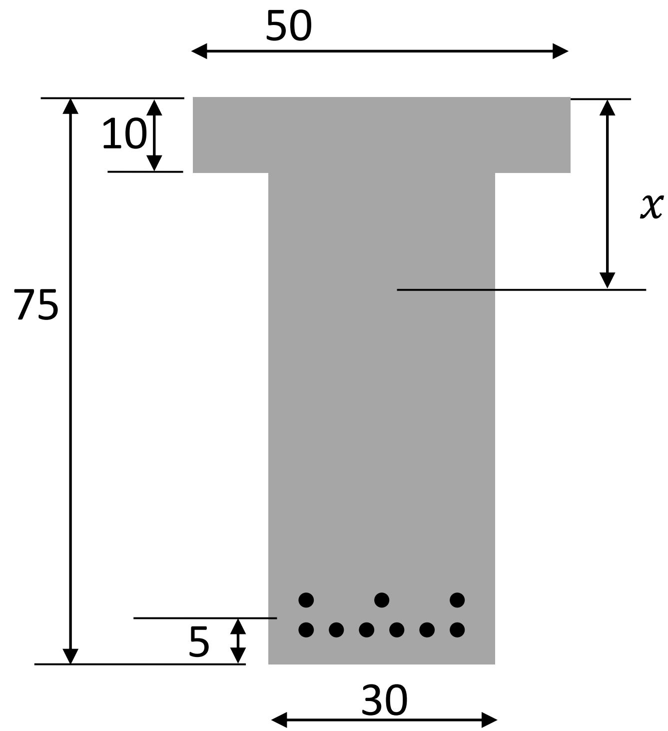


Deflection control by calculation

Curvature due to loads

Fully cracked stage II

$$\frac{1}{r_{II}} = \frac{M_{Eqp}}{E_{c,eff} \cdot I_{II}}$$



I_{II} - inertia of the cracked section

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

$$I_{cc} = \frac{bx^3}{3} - (b - b_w)\frac{\left(x - h_f\right)^3}{3} = \frac{50 \cdot 35.2^3}{3} - (50 - 30)\frac{(35.2 - 10)^3}{3} = 620217\ cm^4$$

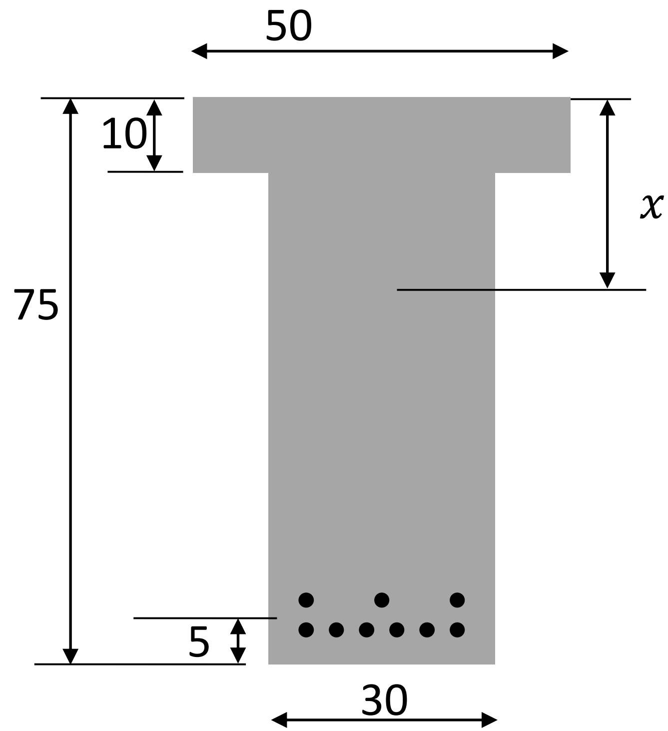
$I_{II} =$

Deflection control by calculation

Curvature due to loads

Fully cracked stage II

$$\frac{1}{r_{II}} = \frac{M_{Eqp}}{E_{c,eff} \cdot I_{II}} =$$



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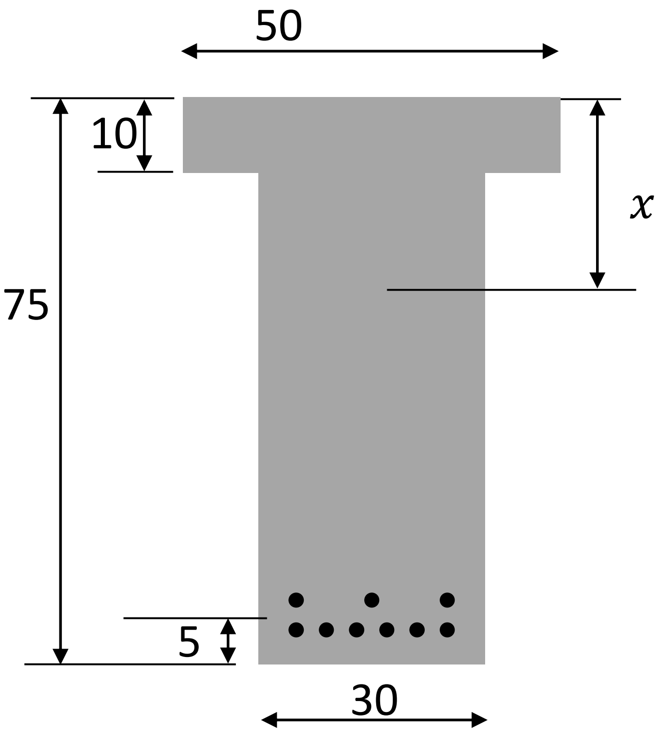
$$I_{II} = 620217 + 25.1 \cdot 28.26(70 - 35.2)^2 = 1479239\ cm^4 = 1479239 \cdot 10^4\ mm^4$$

Deflection control by calculation

Curvature due to loads

Fully cracked stage II

$$\frac{1}{r_{II}} = \frac{M_{Eqp}}{E_{c,eff} \cdot I_{II}} = \frac{325 \cdot 10^6}{8378 \cdot 1479239 \cdot 10^4} = 2.62 \cdot 10^{-6}$$



I_{II} - inertia of the cracked section

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

$$I_{cc} = \frac{bx^3}{3} - (b - b_w)\frac{\left(x - h_f\right)^3}{3} = \frac{50 \cdot 35.2^3}{3} - (50 - 30)\frac{(35.2 - 10)^3}{3} = 620217\ cm^4$$

$$I_{II} = 620217 + 25.1 \cdot 28.26(70 - 35.2)^2 = 1479239\ cm^4 = 1479239 \cdot 10^4\ mm^4$$

Deflection control by calculation

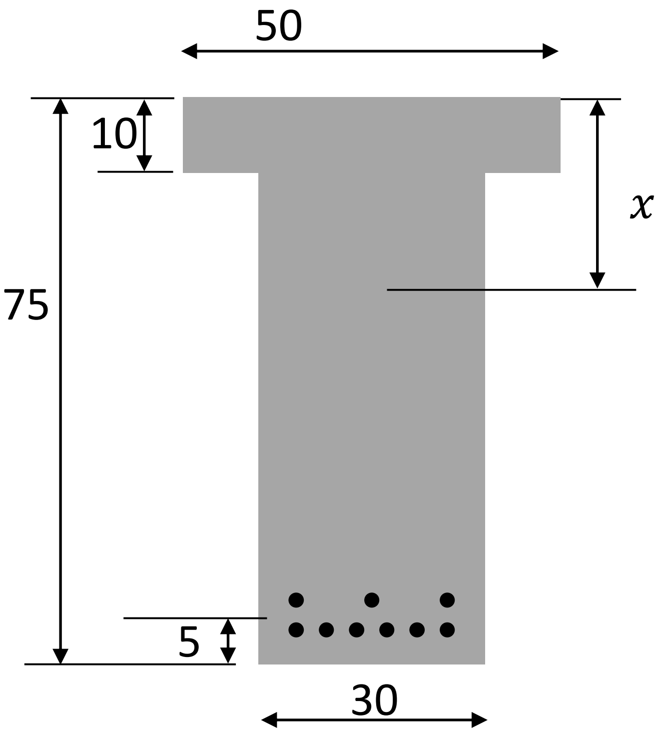
From the expression of

$$\alpha = (1-\zeta)\alpha_I + \zeta\alpha_{II}$$

Curvature interpolated value due to loads

$$\frac{1}{r} = (1-\zeta)\frac{1}{r_I} + \zeta\frac{1}{r_{II}}$$

$$\frac{1}{r} =$$



Deflection control by calculation

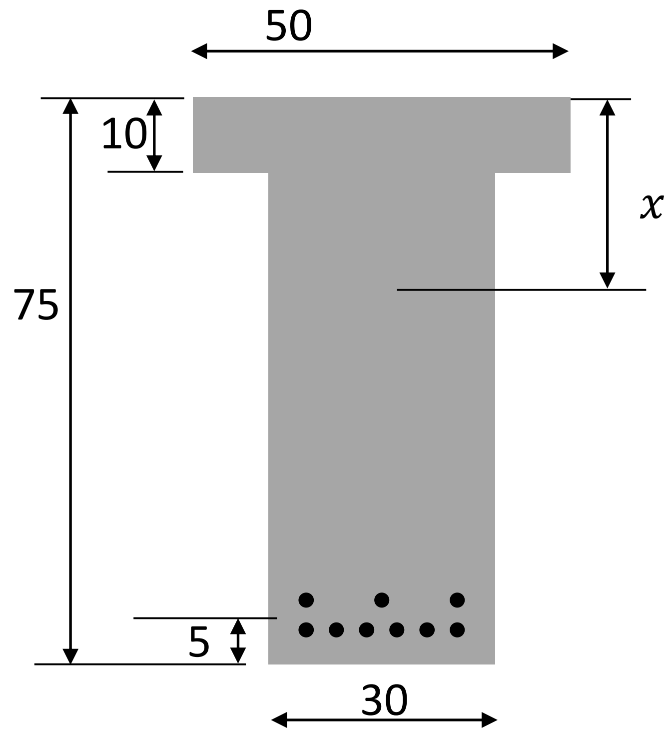
From the expression of

$$\alpha = (1-\zeta)\alpha_I + \zeta\alpha_{II}$$

Curvature interpolated value due to loads

$$\frac{1}{r} = (1-\zeta)\frac{1}{r_I} + \zeta\frac{1}{r_{II}}$$

$$\frac{1}{r} = (1-0.97)\cdot 3.10\cdot 10^{-6} + 0.97\cdot 2.62\cdot 10^{-6} = 2.63\cdot 10^{-6}$$

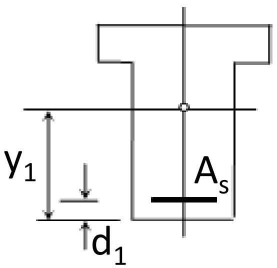


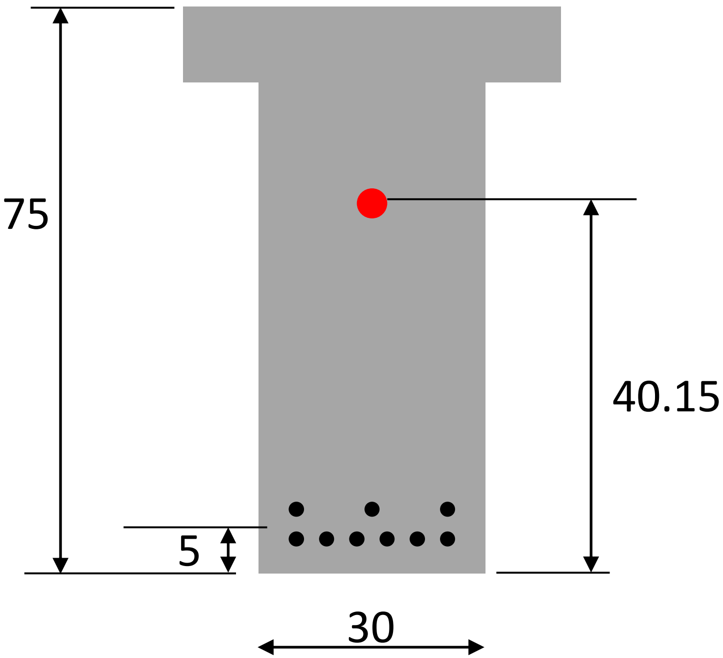
Deflection control by calculation

Curvature due to shrinkage

Un–cracked stage I

$$\frac{1}{r_{csI}} = \varepsilon_{cs}\alpha_e \frac{S_{sI}}{I_I}$$





ε_{cs} - free shrinkage strain

S_{sI} - first moment of area of the reinforcement (A_s) about the centroid of the section

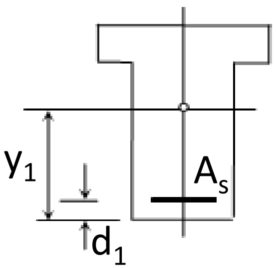
$$S_{sI} = A_s(y_1 - d_1) =$$

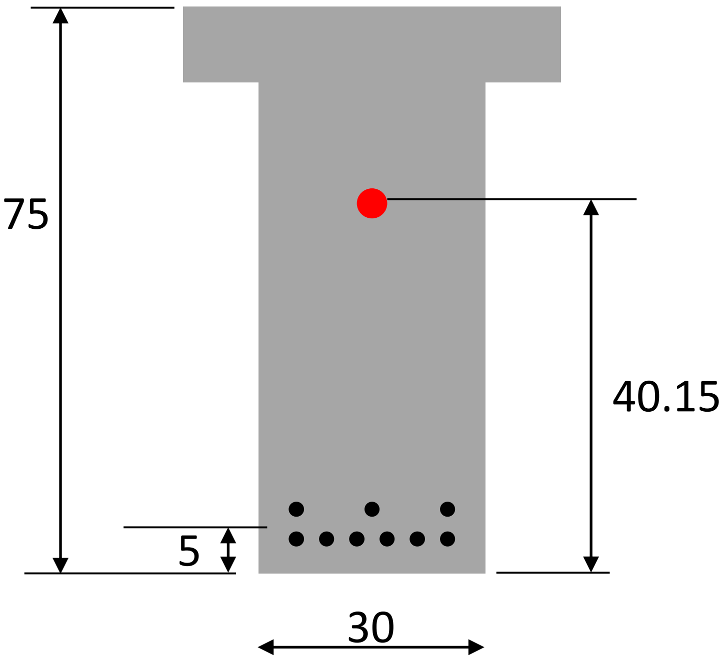
Deflection control by calculation

Curvature due to shrinkage

Un–cracked stage I

$$\frac{1}{r_{csI}} = \varepsilon_{cs}\alpha_e \frac{S_{sI}}{I_I}$$





ε_{cs} - free shrinkage strain

S_{sI} - first moment of area of the reinforcement (A_s) about the centroid of the section

$$S_{sI} = A_s(y_1 - d_1) = 28.26(40.15 - 5) = 993.3cm^3$$

Deflection control by calculation

ε_{cs} - free shrinkage strain

$$\boldsymbol{\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}}$$

ε_{cd} - drying shrinkage
ε_{ca} - autogenous shrinkage

Deflection control by calculation

The final value of drying shrinkage strain

$$\varepsilon_{cd,\infty} = k_h \cdot \varepsilon_{cd,0} =$$

$$h_0 = 2A_c/u = 196\ mm$$

Table 3.3 Values for k_h in Expression (3.9)

h_0	k_h
100	1.0
200	0.85
300	0.75
≥ 500	0.70

$$k_h = 0{,}856$$

Table 3.2 Nominal unrestrained drying shrinkage values $\varepsilon_{cd,0}$ (in $^0/_{00}$) for concrete with cement CEM Class N

$f_{ck}/f_{ck,cube}$ (MPa)	Relative Humidity (in $^0/_0$)					
	20	40	60	80	90	100
20/25	0.62	0.58	0.49	0.30	0.17	0.00
40/50	0.48	0.46	0.38	0.24	0.13	0.00
60/75	0.38	0.36	0.30	0.19	0.10	0.00
80/95	0.30	0.28	0.24	0.15	0.08	0.00
90/105	0.27	0.25	0.21	0.13	0.07	0.00

$$\varepsilon_{cd,0} = 0.463‰$$

Deflection control by calculation

The final value of drying shrinkage strain

$$\varepsilon_{cd,\infty} = k_h \cdot \varepsilon_{cd,0} = 0.856 \cdot 0.463 = 0.396$$

$$h_0 = 2A_c/u = 196\,mm$$

Table 3.3 Values for k_h in Expression (3.9)

h_0	k_h
100	1.0
200	0.85
300	0.75
≥ 500	0.70

$$k_h = 0{,}856$$

Table 3.2 Nominal unrestrained drying shrinkage values $\varepsilon_{cd,0}$ (in ‰) for concrete with cement CEM Class N

$f_{ck}/f_{ck,cube}$ (MPa)	Relative Humidity (in %)					
	20	40	60	80	90	100
20/25	0.62	0.58	0.49	0.30	0.17	0.00
40/50	0.48	0.46	0.38	0.24	0.13	0.00
60/75	0.38	0.36	0.30	0.19	0.10	0.00
80/95	0.30	0.28	0.24	0.15	0.08	0.00
90/105	0.27	0.25	0.21	0.13	0.07	0.00

$$\varepsilon_{cd,0} = 0.463‰$$

Deflection control by calculation

The value of drying shrinkage at 57 years :

$$\varepsilon_{cd}(57\ years) = \beta_{ds}(t,t_s) \cdot k_h \cdot \varepsilon_{cd,0} =$$

$$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s) + 0{,}04\sqrt{{h_0}^3}} =$$

$t_0 = 28\ days$ -the age of the concrete (days) at the beginning of drying shrinkage (or swelling). Normally this is at the end of curing;

$t = 57\ years = 20805\ days$ - the age of the concrete at the moment considered, in days

Deflection control by calculation

The value of drying shrinkage at 57 years :

$$\varepsilon_{cd}(57\ years) = \beta_{ds}(t,t_s) \cdot k_h \cdot \varepsilon_{cd,0} =$$

$$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0{,}04\sqrt{{h_0}^3}} = \frac{(20805-28)}{(20805-28)+0{,}04\sqrt{196^3}} = 0.995$$

$t_0 = 28\ days$ -the age of the concrete (days) at the beginning of drying shrinkage (or swelling). Normally this is at the end of curing;

$t = 57\ years = 20805\ days$ - the age of the concrete at the moment considered, in days

Deflection control by calculation

The value of drying shrinkage at 57 years :

$$\varepsilon_{cd}(57\ years) = \beta_{ds}(t,t_s) \cdot k_h \cdot \varepsilon_{cd,0} = 0.995 \cdot 0.856 \cdot 0.463 = 0.394‰$$

$$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0{,}04\sqrt{{h_0}^3}} = \frac{(20805-28)}{(20805-28)+0{,}04\sqrt{196^3}} = 0.995$$

$t_0 = 28\ days$ -the age of the concrete (days) at the beginning of drying shrinkage (or swelling). Normally this is at the end of curing;

$t = 57\ years = 20805\ days$ - the age of the concrete at the moment considered, in days

Deflection control by calculation

The final value of autogenous shrinkage strain

$$\varepsilon_{ca,\infty} = 2{,}5(f_{ck} - 10) \cdot 10^{-6} =$$

The value of autogenous shrinkage at 57 years:

$$\varepsilon_{ca}(57\ years) = \beta_{as}(57\ years) \cdot \varepsilon_{ca,\infty} =$$

$$\beta_{as}(57\ years) = 1 - e^{-0{,}2t^{0{,}5}}$$

Deflection control by calculation

The final value of autogenous shrinkage strain

$$\varepsilon_{ca,\infty} = 2{,}5(f_{ck} - 10) \cdot 10^{-6} = 2.5(25 - 10) \cdot 10^{-6} = 0.037‰$$

The value of autogenous shrinkage at 57 years:

$$\varepsilon_{ca}(57\ years) = \beta_{as}(57\ years) \cdot \varepsilon_{ca,\infty} =$$

$$\beta_{as}(57\ years) = 1 - e^{-0{,}2t^{0{,}5}} = 1 - e^{-0{,}2 \cdot 20805^{0{,}5}} = 1$$

Deflection control by calculation

The final value of autogenous shrinkage strain

$$\varepsilon_{ca,\infty} = 2{,}5(f_{ck} - 10) \cdot 10^{-6} = 2.5(25 - 10) \cdot 10^{-6} = 0.037‰$$

The value of autogenous shrinkage at 57 years:

$$\varepsilon_{ca}(57\ years) = \beta_{as}(57\ years) \cdot \varepsilon_{ca,\infty} = 0.037‰$$

$$\beta_{as}(57\ years) = 1 - e^{-0{,}2t^{0{,}5}} = 1 - e^{-0{,}2 \cdot 20805^{0{,}5}} = 1$$

The total shrinkage strain:

$$\boldsymbol{\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}} =$$

Deflection control by calculation

The final value of autogenous shrinkage strain

$$\varepsilon_{ca,\infty} = 2{,}5(f_{ck} - 10) \cdot 10^{-6} = 2.5(25 - 10) \cdot 10^{-6} = 0.037‰$$

The value of autogenous shrinkage at 57 years:

$$\varepsilon_{ca}(57\ years) = \beta_{as}(57\ years) \cdot \varepsilon_{ca,\infty} = 0.037‰$$

$$\beta_{as}(57\ years) = 1 - e^{-0{,}2t^{0{,}5}} = 1 - e^{-0{,}2 \cdot 20805^{0{,}5}} = 1$$

The total shrinkage strain:

$$\boldsymbol{\varepsilon_{cs}} = \boldsymbol{\varepsilon_{cd}} + \boldsymbol{\varepsilon_{ca}} = 0.394 + 0.037 = 0.431‰$$

Deflection control by calculation

Curvature due to shrinkage

Un–cracked stage I

$$\frac{1}{r_{csI}} = \varepsilon_{cs} \alpha_e \frac{S_{sI}}{I_I} =$$

Deflection control by calculation

Curvature due to shrinkage

Un–cracked stage I

$$\frac{1}{r_{csI}} = \varepsilon_{cs}\alpha_e \frac{S_{sI}}{I_I} = \frac{0.431}{1000} \cdot 25.1 \frac{993.3 \cdot 10^3}{1250359 \cdot 10^4} = 0.859 \cdot 10^{-6}$$

Deflection control by calculation

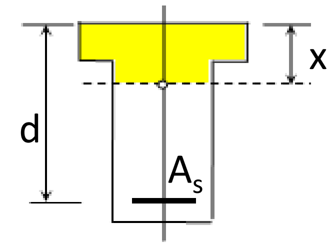
Curvature due to shrinkage

Fully cracked stage II

$$\frac{1}{r_{csII}} = \varepsilon_{cs}\alpha_e \frac{S_{sII}}{I_{II}}$$

I_{II} – inertia of the cracked section

S_{sII} - 1st moment of A_s about cracked section centroid



$$S_{sI} = A_s(d - x) =$$

Deflection control by calculation

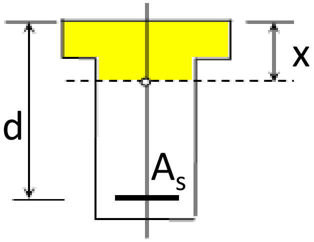
Curvature due to shrinkage

Fully cracked stage II

$$\frac{1}{r_{csII}} = \varepsilon_{cs}\alpha_e \frac{S_{sII}}{I_{II}}$$

I_{II} – inertia of the cracked section

S_{sII} - 1st moment of A_s about cracked section centroid



$$S_{sI} = A_s(d - x) = 28.26(70 - 35.2) = 983.5\ cm^3$$

Deflection control by calculation

Curvature due to shrinkage

Fully cracked stage II

$$\frac{1}{r_{csII}} = \varepsilon_{cs}\alpha_e \frac{S_{sII}}{I_{II}} =$$

Deflection control by calculation

Curvature due to shrinkage

Fully cracked stage II

$$\frac{1}{r_{csII}} = \varepsilon_{cs}\alpha_e \frac{S_{sII}}{I_{II}} = \frac{0.431}{1000} \cdot 25.1 \frac{983.5 \cdot 10^3}{1479239 \cdot 10^4} = 0.719 \cdot 10^{-6}$$

Deflection control by calculation

Curvature interpolated value due to shrinkage

$$\frac{1}{r_{cs}} = (1-\zeta)\frac{1}{r_{csI}} + \zeta\frac{1}{r_{csII}} =$$

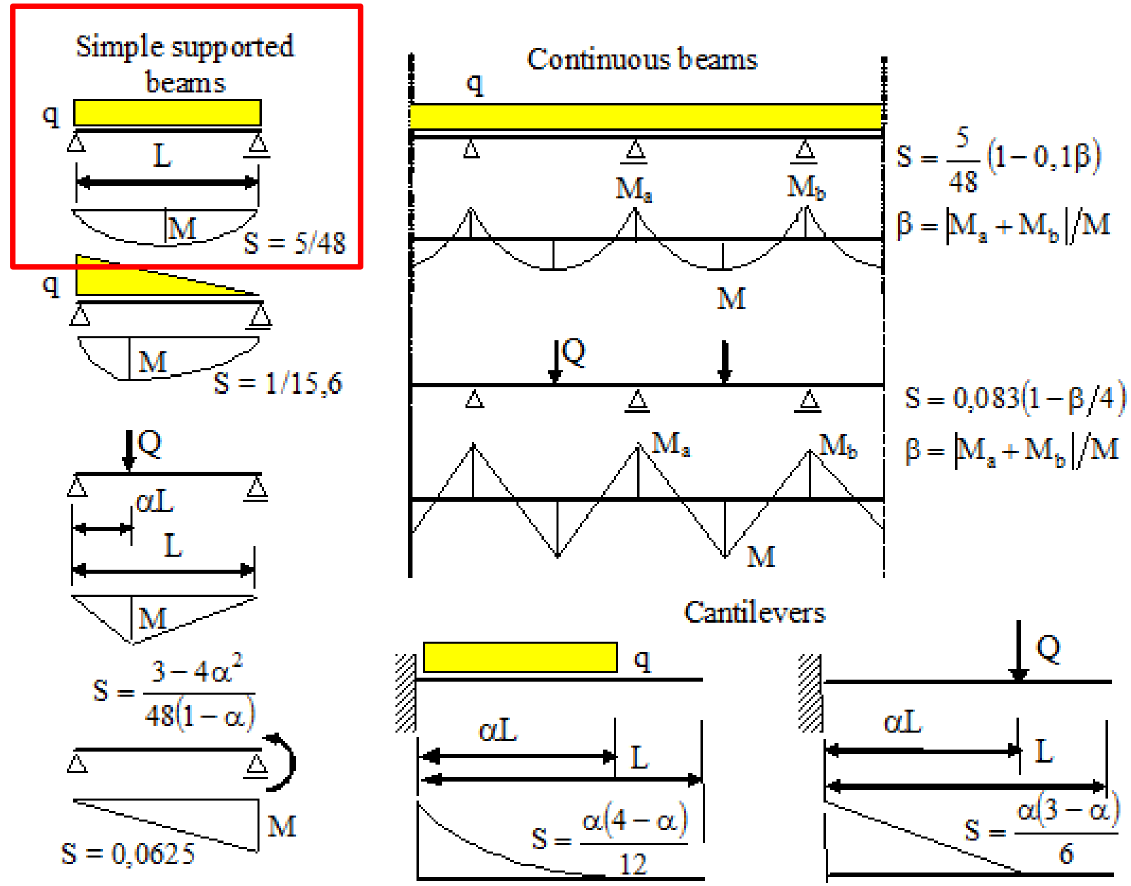
Deflection control by calculation

Curvature interpolated value due to shrinkage

$$\frac{1}{r_{cs}} = (1-\zeta)\frac{1}{r_{csI}} + \zeta\frac{1}{r_{csII}} = (1-0.97)\cdot 0.859\cdot 10^{-6} + 0.97\cdot 0.719\cdot 10^{-6} = 0.723\cdot 10^{-6}$$

Deflection control by calculation

Deflection of bent elements:



$$f = SL^2\left(\frac{1}{r} + \frac{1}{r_{cs}}\right) =$$

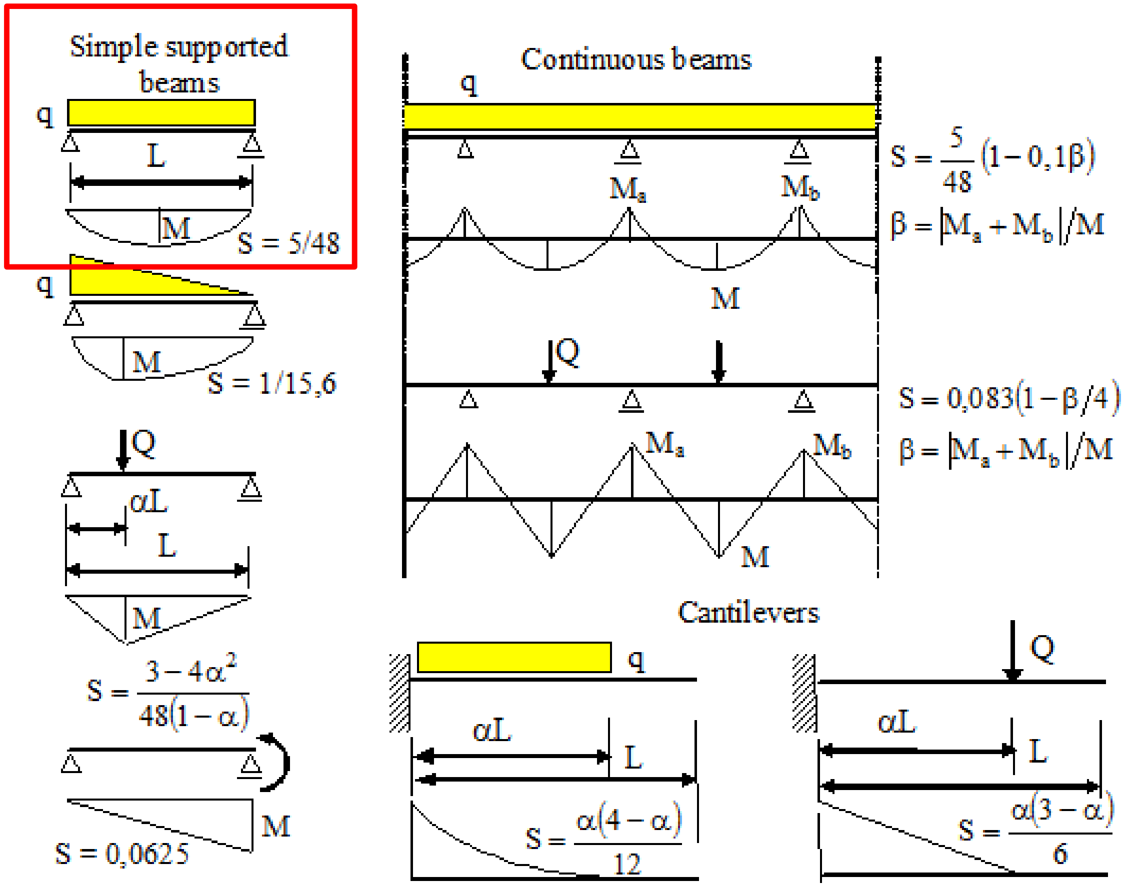
L - design span

$1/r$ - curvature due to loads

$1/r_{cs}$ - curvature due to shrinkage

Deflection control by calculation

Deflection of bent elements:



$$f = SL^2\left(\frac{1}{r}+\frac{1}{r_{cs}}\right) = \frac{5}{48}7000^2(2.63\cdot 10^{-6}+0.723\cdot 10^{-6}) = \mathbf{17.1\ mm} < \frac{\boldsymbol{L}}{\mathbf{250}} = \mathbf{28}\ \boldsymbol{mm}$$

1. DEFLECTION CONTROL BY CALCULATION

2. DEFLECTION CONTROL WITHOUT CALCULATION

Deflection control without calculation

For span-depth ratios below 7,5 m no further checks are needed if $\left(\frac{L}{d}\right) \leq \left(\frac{L}{d}\right)_{lim}$

$$\left(\frac{L}{d}\right)_{lim} = K\left[11 + 1{,}5\sqrt{f_{ck}}\frac{\rho_0}{\rho} + 3{,}2\sqrt{f_{ck}}\left(\frac{\rho_0}{\rho} - 1\right)^{3/2}\right] \qquad \text{if } \rho \leq \rho_0$$

$$\left(\frac{L}{d}\right)_{lim} = K\left[11 + 1{,}5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}\frac{\rho'}{\rho_0}}\right] \qquad \text{if } \rho > \rho_0$$

where:

$\left(\frac{L}{d}\right)_{lim}$ is the limit span/depth

K is the factor to take into account the different structural systems

$\rho_0 = \sqrt{f_{ck}} \cdot 10^{-3}$ is the reference reinforcement ratio

ρ is the required tension reinforcement ratio at mid-span from design loads

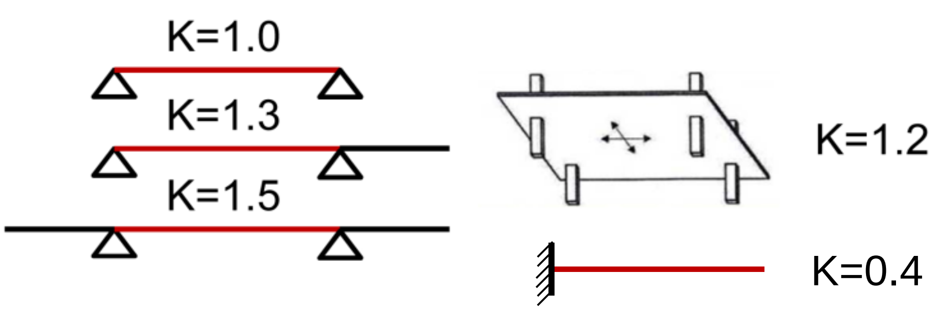
ρ' is the required compression reinforcement ratio at mid-span from design loads

The expressions have been derived for an assumed stress in the reinforcing steel at mid span stress σ_s = 310 N/mm² (corresponding roughly to $f_{yk} = 500\ MPa$)

Deflection control by calculation

Table 3.3.1 Tabulated values for *l / d*

Structural system	Factor *K*	*l / d*	
		ρ = 1,5 %	ρ = 0,5 %
Simply supported slab/beam	1,0	14	20
End span	1,3	18	26
Interior span	1,5	20	30
Flat slab	1,2	17	24
Cantilever	0,4	6	8



Deflection control by calculation

a) Correction for σ_s

If another stress level is applied or if more reinforcement than minimum required is provided, the values obtained for $\left(\frac{L}{d}\right)_{lim}$ should be multiplied by $\frac{310}{\sigma_s}$.

It will normally be conservative to assume that

$$\frac{310}{\sigma_s} = \frac{500}{f_{yk}} \frac{A_{s,req}}{A_{s,prov}}$$

Where

σ_s is the tensile steel stress at mid-span under the design load at SLS

$A_{s,req}$ is the area of steel required at this section for ultimate limit state

$A_{s,prov}$ is the area of steel provided at this section

$$\sigma_s = \alpha_e \sigma_{c,s} = \alpha_e \frac{M}{I_{II}}(d - x) = 25.1 \frac{325 \cdot 10^6}{1479239 \cdot 10^4}(700 - 352) = 192\ MPa$$

$$\rightarrow \qquad \frac{310}{\sigma_s} = \frac{310}{192} = \mathbf{1.56}$$

Deflection control by calculation

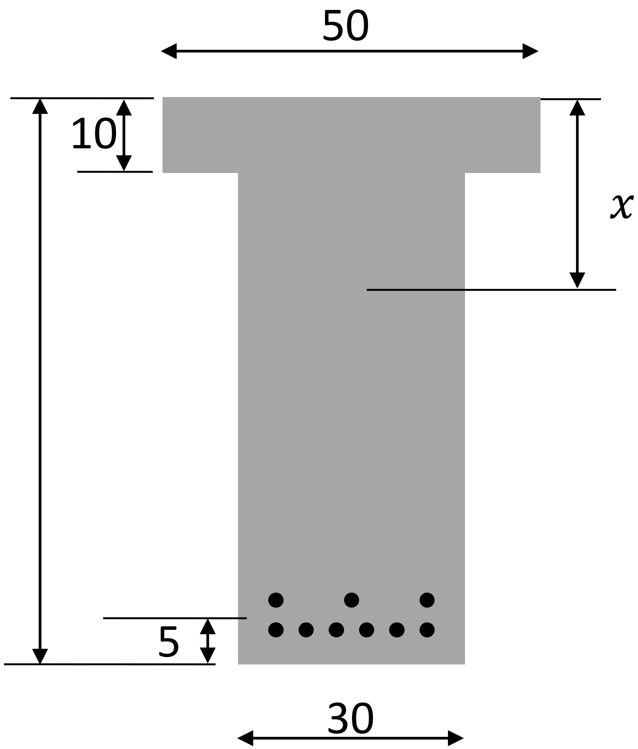
b) Correction for flanged section

For flanged sections if

$$b/b_w \geq 3$$

$\left(\frac{L}{d}\right)_{lim}$ values should be multiplied by 0,8.

$\frac{50}{30} = 1.67 \ < 3$ → No correction needed



c) Corrections for beams and slabs (no flat slabs) with spans larger than 7 *m*

It is not the case → No correction needed

Deflection control without calculation

$$\rho_0 = \sqrt{f_{ck}} \cdot 10^{-3} = 0.005$$

$$\rho = \frac{A_s}{bd} = \frac{2826}{300 \cdot 700} = 0.013$$

Table 3.3.1 Tabulated values for *l / d*

Structural system	Factor *K*	*l / d*	
		ρ = 1,5 %	ρ = 0,5 %
Simply supported slab/beam	1,0	14	20
End span	1,3	18	26
Interior span	1,5	20	30
Flat slab	1,2	17	24
Cantilever	0,4	6	8

$$\rightarrow \rho > \rho_0$$

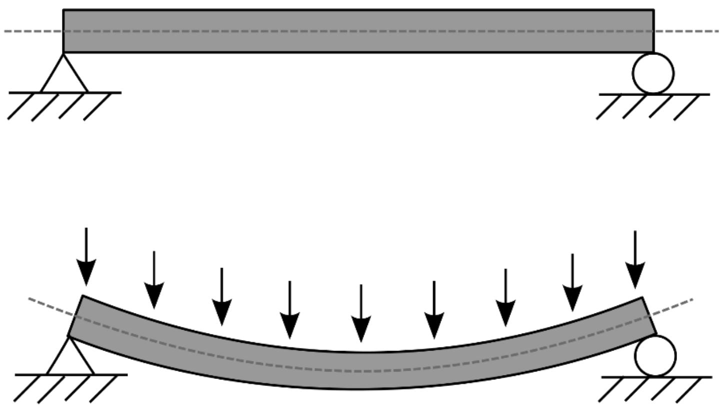
$$\left(\frac{L}{d}\right) = K\left[11 + 1{,}5\sqrt{f_{ck}}\frac{\rho_0}{\rho - \rho'} + \frac{1}{12}\sqrt{f_{ck}\frac{\rho'}{\rho_0}}\right] = 1\left[11 + 1.5\sqrt{25}\frac{0.005}{0.013 - 0} + \frac{1}{12}\sqrt{25}\sqrt{\frac{0}{0.005}}\right]$$

$$= 13.9$$

$$\left(\frac{L}{d}\right)_{lim} = 1.56 * 13.9 = 21.7\ mm$$

$$\rightarrow \left(\frac{L}{d}\right) \leq \left(\frac{L}{d}\right)_{lim}$$

$$\left(\frac{L}{d}\right) = \frac{7.00}{0.70} = 10$$



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THANK YOU FOR YOUR ATTENTION!