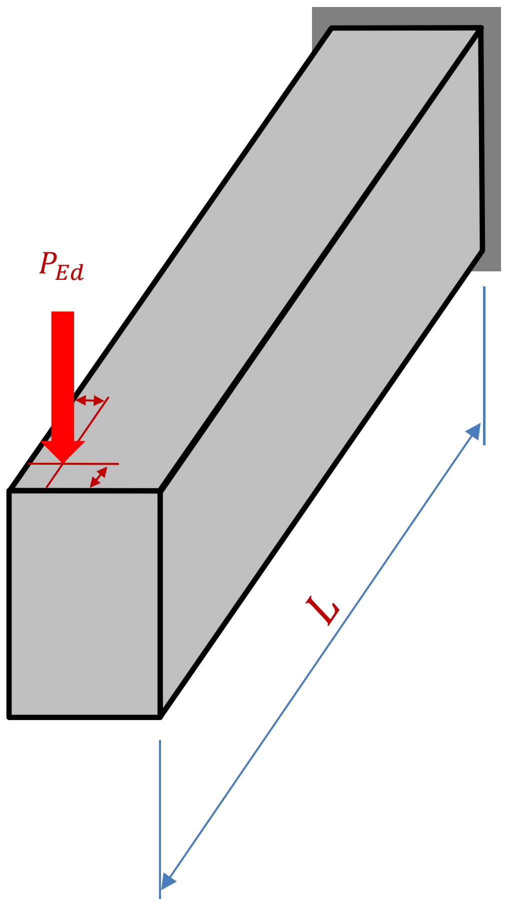

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Initial data

RC beam

$$h = 600\ mm$$
$$b = 400\ mm$$
$$L = 1100\ mm$$

Load $P_{Ed} = 400\ kN$

Load eccentricity $e_x = 50\ mm$

$e_y = 50\ mm$

Concrete class $C30/37$

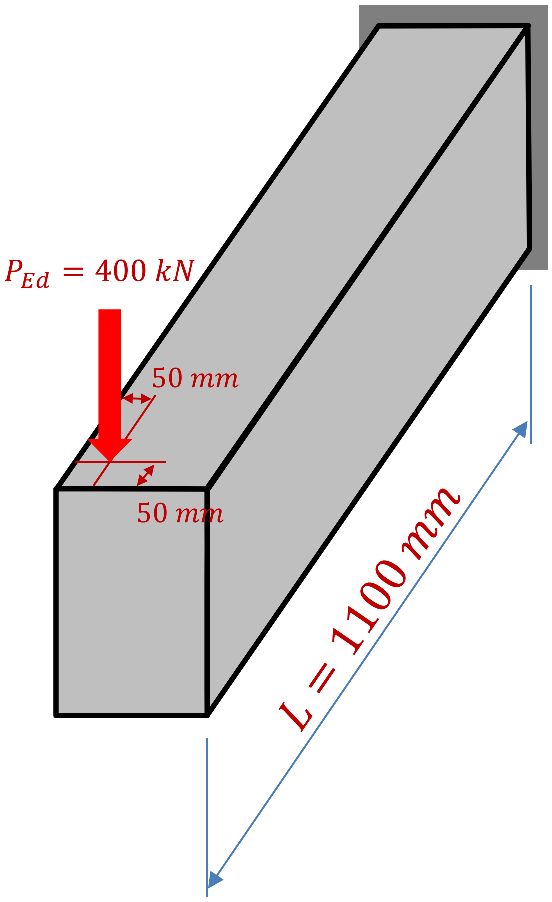
$f_{ctk,0.05} = 2.00\ MPa$

Reinforcement $A_l \rightarrow \emptyset 20$

$A_w \rightarrow \emptyset 10$

Reinforcement strength $f_{yk} = 500\ MPa$

Exposure class XC3



Material properties

$f_{cd} = ?\, MPa$

$f_{ctd} = ?\ MPa$

$f_{yd} = ?\ MPa$

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

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

$c_{min,dur} = ?\, mm$

Table 4.4N: Values of minimum cover, $c_{min,dur}$, requirements with regard to durability for reinforcement steel in accordance with EN 10080.

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	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

Material properties

$$f_{cd} = 20\ MPa$$
$$f_{ctd} = 1.33\ MPa$$

$$f_{yd} = 434.8\ MPa$$

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

$$c_{min} = max\ \{c_{min,b}; c_{min,dur};\ 10\ mm\}$$
$$c_{min,dur} = 25\ mm$$

Table 4.4N: Values of minimum cover, $c_{min,dur}$, requirements with regard to durability for reinforcement steel in accordance with EN 10080.

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	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

Material properties

$$f_{cd} = 20\ MPa$$
$$f_{ctd} = 1.33\ MPa$$

$$f_{yd} = 434.8\ MPa$$

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

$$c_{min} = max\ \{c_{min,b}; c_{min,dur};\ 10\ mm\}$$
$$c_{min,dur} = 25\ mm$$

Table 4.3N: Recommended structural classification

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

Material properties

$$f_{cd} = 20\ MPa$$
$$f_{ctd} = 1.33\ MPa$$

$$f_{yd} = 434.8\ MPa$$

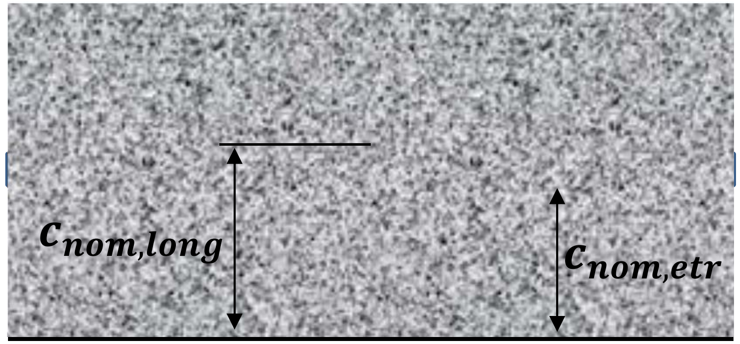
$$c_{nom} = c_{min} + \Delta c_{dev}$$

$$c_{min} = max\,\{c_{min,b}; c_{min,dur};\ 10\ mm\}$$
$$c_{min,dur} = 25\ mm$$

Cerință de mediu pentru $c_{min,dur}$ (mm)							
Clasa structurală	Clasa de expunere conform tabelul 4.1						
	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

Material properties

LONGITUDINAL REINFORCEMENT	TRANSVERSAL REINF. (stirrup)
$c_{min} = max\left\{c_{min,b}; c_{min,dur}; \ 10\ mm\right\}$	
$= \ max\{20\ mm; 25\ mm; 10\ mm\}$	$= \ max\{10\ mm; 25\ mm; 10\ mm\}$
$c_{min,long} = 25\ \text{mm}$	$c_{min,etr} = 25\ \text{mm}$
$\Delta c_{dev} = 10\ mm$ (A.N.)	$\Delta c_{dev} = 10\ mm$ (A.N.)
$\boldsymbol{c_{nom,long} = 35\ mm}$	$\boldsymbol{c_{nom,etr} = 35\ mm}$
$\Rightarrow c_{nom,etr} = c_{nom,long} - \phi_{etr} = 25\ mm$	$\Rightarrow c_{nom,long} = c_{nom,etr} + \phi_{etr} = 45\ mm$
$c_{nom,etr} = 22mm < c_{nom,etr}^{nec} = 35\ mm$	$c_{nom,long} = 45\ mm > c_{nom,long}^{nec} = 35\ mm$
$\Rightarrow \boldsymbol{c_{nom,long} = 45\ mm}$ **OK!!!**	



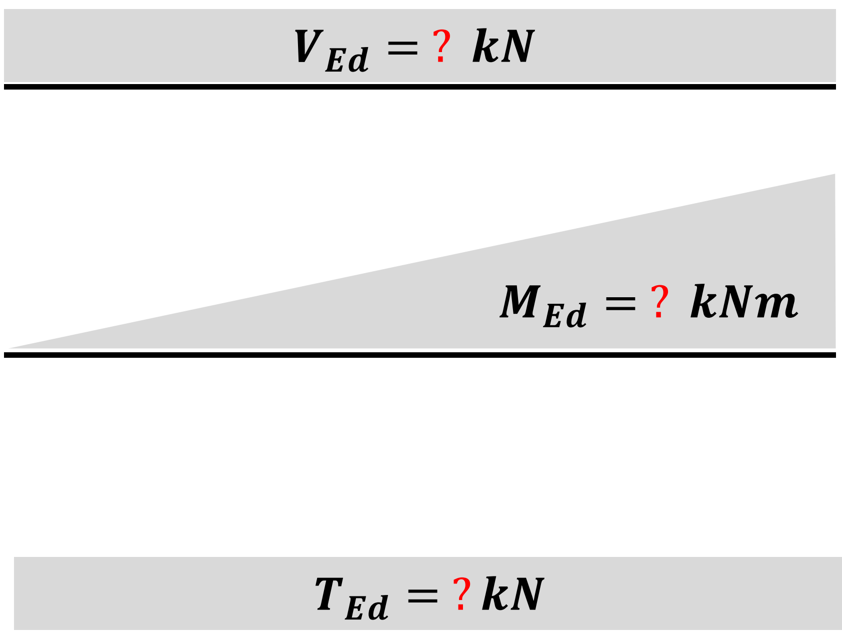
Material properties

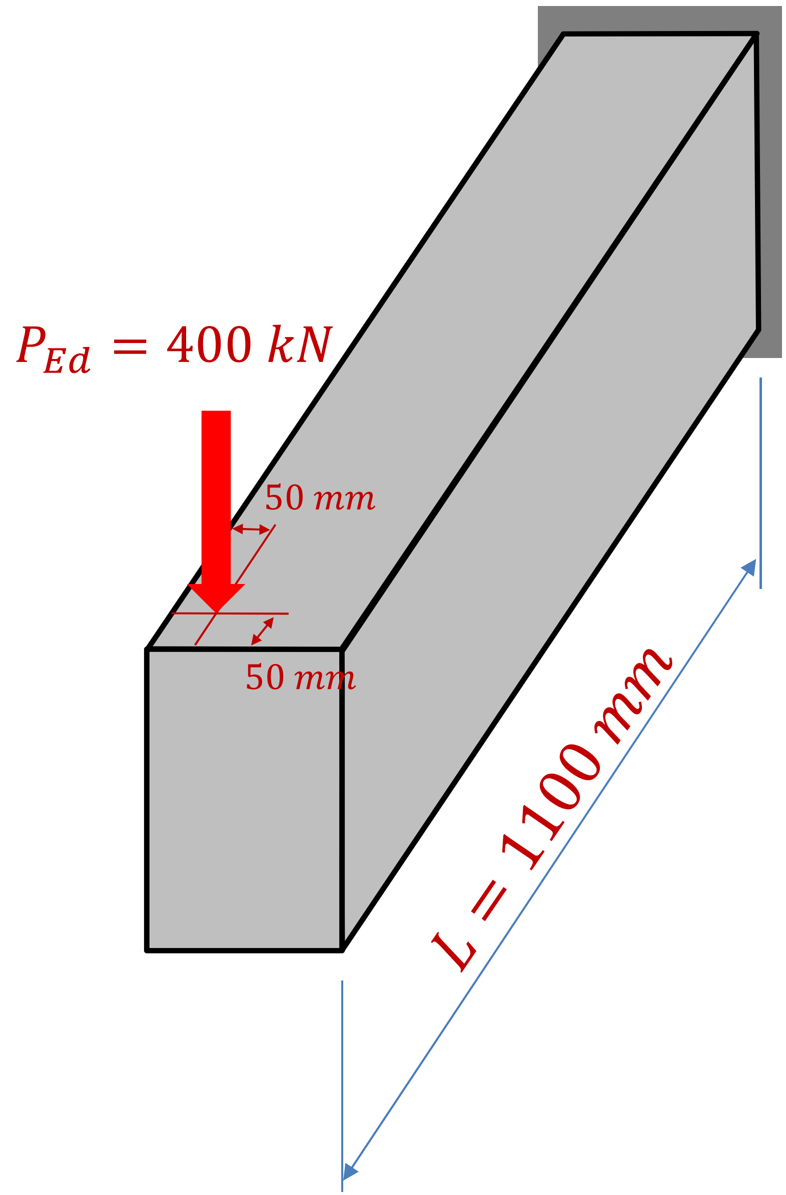
$$f_{cd} = 20\ MPa$$
$$f_{ctd} = 1.33\ MPa$$

$$f_{yd} = 434.8\ MPa$$

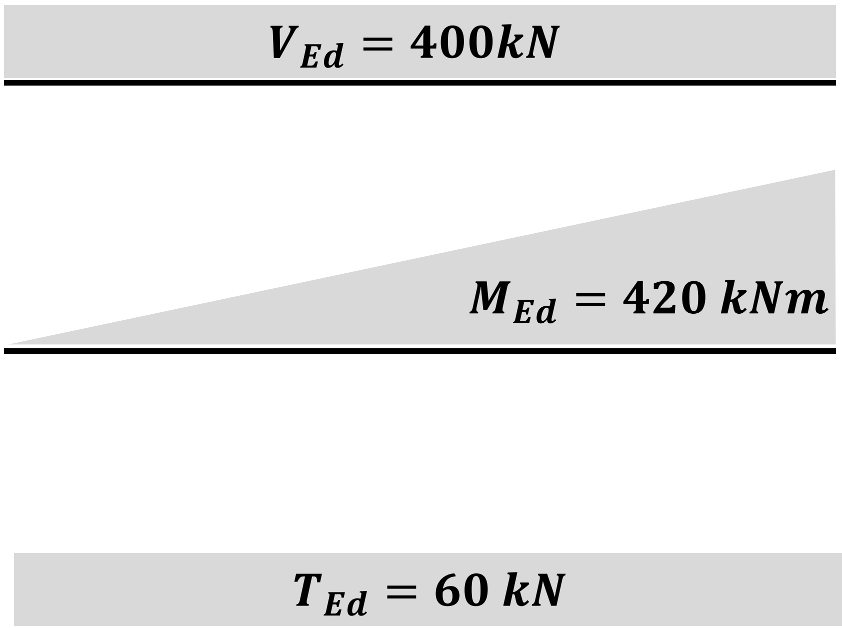
$$c_{nom,l} = 45\ mm$$

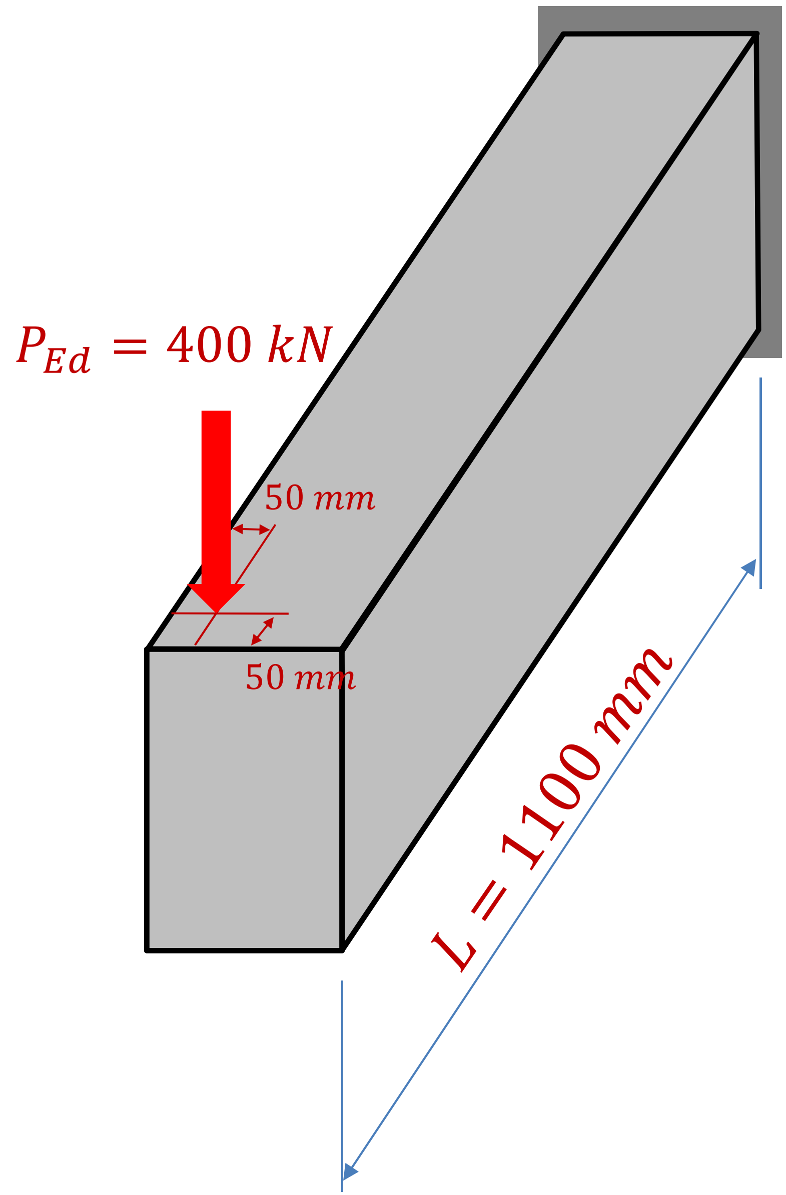
Design values of the loads





Design values of the loads





Computation of the design thin-walled cross section

$$t_{ef} = \frac{A}{u} \geq t_{ef,min} = 2t_s$$

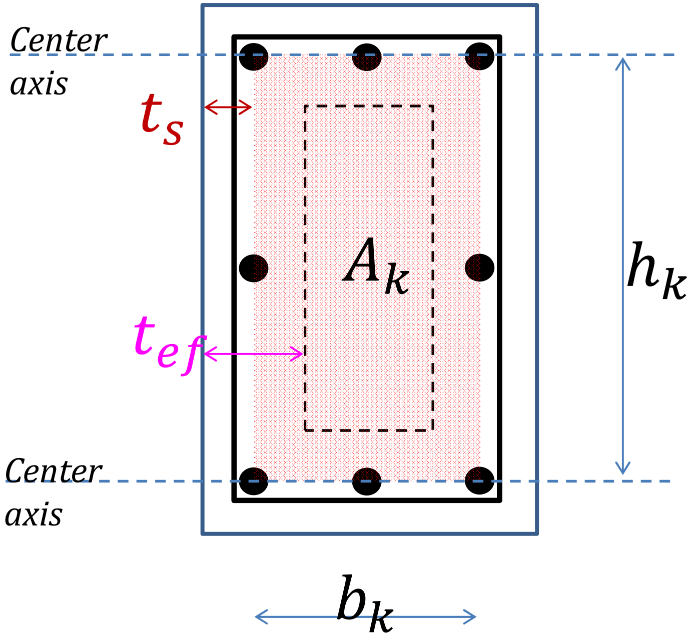
$$t_s = ?\ mm$$

$$t_{ef,min} = 2t_s = ?\ mm$$

$$A = ?\ mm^2$$

$$u = ?\ mm$$

$$t_{ef} = \frac{A}{u} = ?\ mm$$



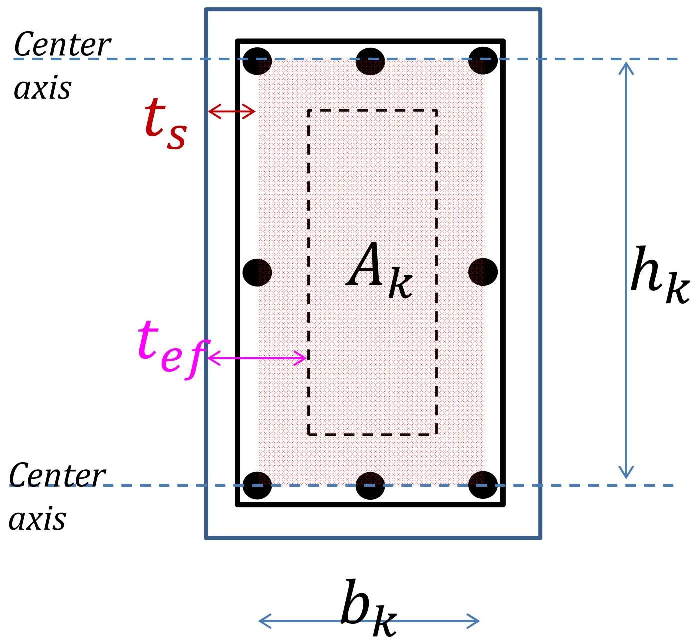
Computation of the design thin-walled cross section

$$t_{ef} = \frac{A}{u} \geq t_{ef,min} = 2t_s$$

$$t_s = 55\ mm$$
$$t_{ef,min} = 2t_s = 110\ mm$$

$$A = 240000\ mm^2$$
$$u = 2000\ mm$$

$$t_{ef} = \frac{A}{u} = 120\ mm$$



Computation of the design thin-walled cross section

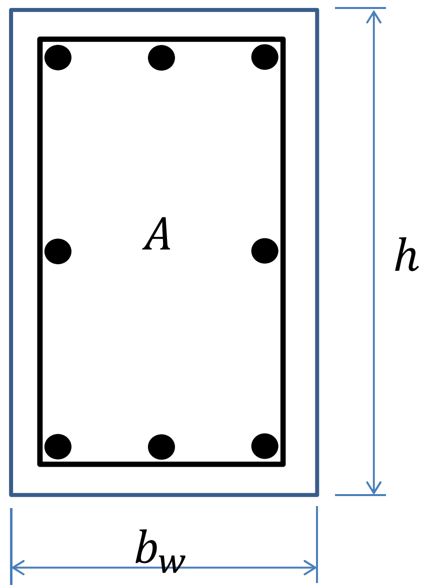
$$t_{ef} = \frac{A}{u} \geq t_{ef,min} = 2t_s$$

$$t_s = 55\ mm$$
$$t_{ef,min} = 2t_s = 110\ mm$$

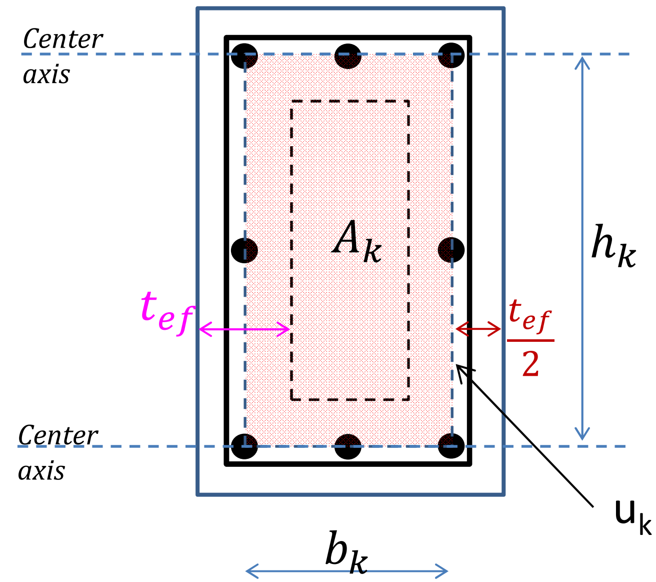
$$A = 240000\ mm^2$$
$$u = 2000\ mm$$

$$t_{ef} = \frac{A}{u} = 120\ mm$$

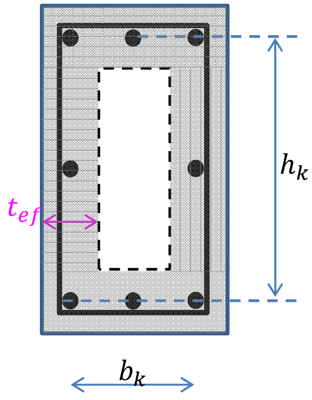
$$b_k = ?\ mm$$
$$h_k = ?\ mm$$
$$u_k = ?\ mm$$
$$A_k = ?\ mm^2$$



$$A = b_w h$$
$$u = 2(b_w + h)$$



$$A_k = b_k h_k$$
$$u_k = 2(b_k + h_k)$$



Computation of the design thin-walled cross section

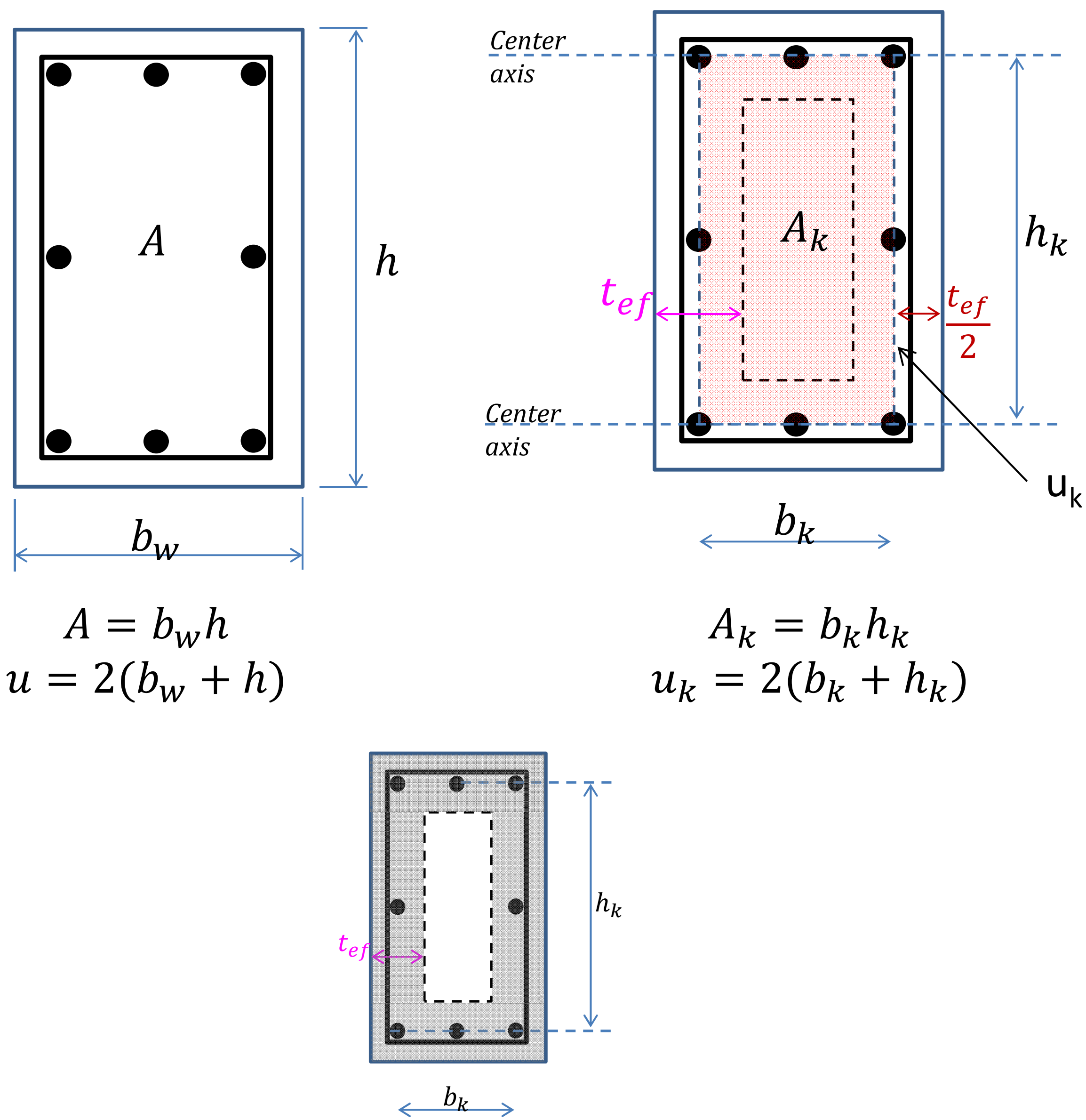
$$t_{ef} = \frac{A}{u} \geq t_{ef,min} = 2t_s$$

$$t_s = 55\ mm$$
$$t_{ef,min} = 2t_s = 110\ mm$$

$$A = 240000\ mm^2$$
$$u = 2000\ mm$$

$$t_{ef} = \frac{A}{u} = 120\ mm$$

$$b_k = 280\ mm$$
$$h_k = 480\ mm$$
$$u_k = 1520\ mm$$
$$A_k = 134400\ mm^2$$



$$A = b_w h$$
$$u = 2(b_w + h)$$

$$A_k = b_k h_k$$
$$u_k = 2(b_k + h_k)$$

Design for bending

$$\mu = \frac{M_{Ed}}{bd^2 f_{cd}} = ? \overset{?}{<} \mu_{lim} = 0.8\xi_{lim}(1 - 0.4\xi_{lim}) = ?$$

Where

$$\xi_{lim} = \frac{3.5}{3.5 + 1000 f_{yd}/E_s} = ?$$

$$d = h - d_s = ?\ mm$$

$$\omega_s = 1 - \sqrt{1 - 2\mu} = ?$$

$$A_{sl,nec} = \omega_s bd \frac{f_{cd}}{f_{yd}} = ?\ mm^2$$

$$A_{sl,eff} = ?\ \phi 20 = ?\, mm^2$$

$$b_{nec} = ?\ mm \overset{?}{<} b_{eff} = 400\ mm$$

Design for bending

$$\mu = \frac{M_{Ed}}{bd^2 f_{cd}} = 0.177 < \mu_{lim} = 0.8\xi_{lim}(1 - 0.4\xi_{lim}) = 0.372$$

Where

$$\xi_{lim} = \frac{3.5}{3.5 + 1000 f_{yd}/E_s} = 0.617$$

$$d = h - d_s = 545\ mm$$

$$\omega_s = 1 - \sqrt{1 - 2\mu} = 0.196$$

$$A_{sl,nec} = \omega_s bd \frac{f_{cd}}{f_{yd}} = 1965\ mm^2$$

$$A_{sl,eff} = 7\phi 20 = 2199\ mm^2$$

$$b_{nec} = 360\ mm < b_{eff} = 400\ mm$$

Design for shear

$$V_{Rd,c} = \max\begin{pmatrix}[C_{Rd,c}k(100\rho_l f_{ck})^{1/3} + k_1\sigma_{cp}]b_w d \\ (v_{min} + k_1\sigma_{cp})b_w d\end{pmatrix} = ?$$

Where

$$C_{Rd,c} = \frac{0,18}{\gamma_c} = ?$$

$$k = 1 + \sqrt{\frac{200}{d}} = ? \leq 2$$

$$\rho_l = \frac{A_{sl}}{b_w d} = ? \leq 0.02$$

$$v_{min} = 0,035k^{3/2} \cdot f_{ck}^{1/2} = ?$$

Design for shear

$$V_{Rd,c} = \max\begin{pmatrix} [C_{Rd,c}k(100\rho_l f_{ck})^{1/3} + \cancel{k_1\sigma_{cp}}]b_w d \\ (v_{min} + \cancel{k_1\sigma_{cp}})b_w d \end{pmatrix} = \max\begin{pmatrix} 130.9\ kN \\ 85.0\ kN \end{pmatrix} = 130.9kN$$

Where

$$C_{Rd,c} = 0{,}18/\gamma_c = 0.12$$

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2 = 1.61$$

$$\rho_l = \frac{A_{sl}}{b_w d} = 0.010 \leq 0.02$$

$$v_{min} = 0{,}035k^{3/2} \cdot f_{ck}^{1/2} = 0.390$$

Design for shear

$V_{Rd,c} = 130.9kN$ < $V_{Ed} = 400\ kN$

→ ?

Design for shear

$V_{Rd,c} = 130.9kN$ < $V_{Ed} = 400\ kN$

→ **shear reinforcement is required**

Design for shear

$V_{Rd,c} = 130.9kN$ < $V_{Ed} = 400\ kN$

→ **shear reinforcement is required**

→ **Computation of**

$$V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot \nu_1 \cdot f_{cd} sin\theta cos\theta = ?$$

Where

$\alpha_{cw} = 1$ for non-prestressed structures

$$\nu_1 = \nu = 0{,}6\left(1 - \frac{f_{ck}}{250}\right) = ?$$

$\theta = 45°$

Design for shear

$$V_{Rd,max} = \alpha_{cw} b_w \cdot z \cdot v_1 \cdot f_{cd} sin\theta cos\theta = 1035.9\ kN$$

Where

$\alpha_{cw} = 1$ for non-prestressed structures

$$v_1 = v = 0{,}6\left(1 - \frac{f_{ck}}{250}\right) = 0.528$$

$\theta = 45°$

Design for shear

$V_{Rd,max} = 1035.9\ kN$ > $V_{Ed} = 400\ kN$

→ ?

Design for shear

$V_{Rd,max} = 1035.9\ kN \quad > \quad V_{Ed} = 400\ kN$

→ **cross section could be reinforced for shear**

TORSIONAL CRACKING MOMENTS

$$T_{Rd,c} = 2A_k t_{ef} f_{ctd} = ?\ kNm$$

with $\tau_t = f_{ctd}$

TORSIONAL CRACKING MOMENTS

$$T_{Rd,c} = 2A_k t_{ef} f_{ctd} = 43.0\ kNm$$

with $\tau_t = f_{ctd}$

TORSIONAL CRACKING MOMENTS

$T_{Rd,c} = 2A_k t_{ef} f_{ctd} = 43.0\ kNm$ < $T_{Ed} = 60\ kNm$

→ ?

Design for torsion

Torsional cracking moments

TORSIONAL CRACKING MOMENTS

$T_{Rd,c} = 2A_k t_{ef} f_{ctd} = 43.0\ kNm$ **<** $T_{Ed} = 60\ kNm$

→ reinforcement for torsion is required

FOR APPROXIMATELY RECTANGULAR SOLID SECTIONS

Calculation for combined shear and torsion is required ← **NO**

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} \leq 1$$

YES → no reinforcement calculation required

Design for torsion

Torsional cracking moments

FOR APPROXIMATELY RECTANGULAR SOLID SECTIONS

Calculation for combined shear and torsion is required ← **NO**

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} \leq 1$$

YES → no reinforcement calculation required

$$\frac{60}{43.0} + \frac{400}{130.9} \leq ?$$

Design for torsion

Torsional cracking moments

FOR APPROXIMATELY RECTANGULAR SOLID SECTIONS

Calculation for combined shear and torsion is required ← **NO**

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} \leq 1$$

YES → no reinforcement calculation required

$$\frac{60}{43.0} + \frac{400}{130.9} \leq 4.45 > 1$$

CAPACITY OF COMPRESSED STRUTS

$$T_{Rd,max} = 2\alpha_{cw} \nu f_{cd} A_k t_{ef} sin\theta cos\theta = ?\ kNm$$

$\alpha_{cw} = 1$ for non-prestressed structures

$$\nu_1 = \nu = 0,6\left(1 - \frac{f_{ck}}{250}\right) = ?$$

$\theta = 45°$

Design for torsion

Maximum resistance of concrete struts

CAPACITY OF COMPRESSED STRUTS

$$T_{Rd,max} = 2\alpha_{cw}\nu f_{cd}A_k t_{ef} sin\theta cos\theta = 170.3\ kNm$$

$\alpha_{cw} = 1$ for non-prestressed structures

$$\nu_1 = \nu = 0,6\left(1 - \frac{f_{ck}}{250}\right) = 0.528$$

$$\theta = 45°$$

Design for torsion

Maximum resistance of concrete struts

CAPACITY OF COMPRESSED STRUTS

$$T_{Rd,max} = 2\alpha_{cw}\nu f_{cd}A_k t_{ef} sin\theta cos\theta = 170.3\ kNm \quad > \quad T_{Ed} = 60\ kNm$$

→ ?

Design for torsion

Maximum resistance of concrete struts

CAPACITY OF COMPRESSED STRUTS

$$T_{Rd,max} = 2\alpha_{cw}\nu f_{cd}A_k t_{ef} sin\theta cos\theta = 170.3\ kNm \quad > \quad T_{Ed} = 60\ kNm$$

→ **cross section could be reinforced for torsion**

Design for torsion

THE MAXIMUM RESISTANCE OF A MEMBER SUBJECTED TO TORSION AND SHEAR IS LIMITED BY THE CAPACITY OF THE CONCRETE STRUTS

reconsider of the cross section ← **NO**

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

YES → next step = reinforcement calculation

Notes about $V_{Rd,max}$

- in solid cross sections the full width of the web may be used
- for non-solid sections replace b_w by t_{ef}

Design for torsion

Maximum resistance of concrete struts

THE MAXIMUM RESISTANCE OF A MEMBER SUBJECTED TO TORSION AND SHEAR IS LIMITED BY THE CAPACITY OF THE CONCRETE STRUTS

reconsider of the cross section ← **NO**

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

YES → next step = reinforcement calculation

$$\frac{60}{170.3} + \frac{400}{1035.9} \leq ?$$

→ ?

Design for torsion

Maximum resistance of concrete struts

THE MAXIMUM RESISTANCE OF A MEMBER SUBJECTED TO TORSION AND SHEAR IS LIMITED BY THE CAPACITY OF THE CONCRETE STRUTS

reconsider of the cross section ← **NO**

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} \leq 1$$

YES → next step = reinforcement calculation

$$\frac{60}{170.3} + \frac{400}{1035.9} \leq 0.738 < 1$$

→ cross section could be reinforced for combined shear and torsion

Design of shear reinforcement

The condition of rational use of stirrups $V_{Rd,s} = V_{Ed}$

With $\theta = 45°$
and $\alpha = 90°$

$$\left(\frac{A_{sw}}{s}\right)_{nec} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot ctg\theta} = ?$$

Design of shear reinforcement

The condition of rational use of stirrups $V_{Rd,s} = V_{Ed}$

With $\theta = 45°$
and $\alpha = 90°$

$$\left(\frac{A_{sw}}{s}\right)_{nec} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot ctg\theta} = 1.876$$

Design of torsional reinforcement

Transversal torsional reinforcement

The condition of rational use of stirrups $T_{Rd,sw} = T_{Ed}$

With $\theta = 45°$

$$\left(\frac{A_{sw}}{s}\right)_{nec} = \frac{T_{Ed}}{2A_k f_{ywd}} \, tan\theta = ?$$

Design of torsional reinforcement

Transversal torsional reinforcement

The condition of rational use of stirrups $T_{Rd,sw} = T_{Ed}$

With $\theta = 45°$

$$\left(\frac{A_{sw}}{s}\right)_{nec} = \frac{T_{Ed}}{2A_k f_{ywd}} \, tan\theta = 0.513$$

Design of torsional reinforcement

Longitudinal torsional reinforcement

Required area of the longitudinal bars is obtained from $T_{Rd,sl} = T_{Ed}$

With $\theta = 45°$

$$A_{sl} = \frac{T_{Ed} u_k}{2A_k f_{yd}} cot\theta = ?\ mm^2$$

Proposals $?\ \phi\ 6$
or $?\ \phi\ 8$
or $?\ \phi\ 10$
or $?\ \phi\ 12$
or $?\ \phi\ 14$

Design of torsional reinforcement

Longitudinal torsional reinforcement

Required area of the longitudinal bars is obtained from $T_{Rd,sl} = T_{Ed}$

With $\theta = 45°$

$$A_{sl} = \frac{T_{Ed} u_k}{2 A_k f_{yd}} cot\theta = 780\ mm^2$$

Proposals $16\ \phi\ 8 = 804\ mm^2$

or $10\ \phi\ 10 = 785\ mm^2$

or $7\ \phi\ 12 = 792\ mm^2$

or $6\ \phi\ 14 = 924\ mm^2$

or $4\ \phi\ 16 = 804\ mm^2$

Detailing of reinforcement

Structural elements are subjected to $M_{Ed} + V_{Ed} + T_{Ed}$

→ should take account of superposition of the effects of all the effects

M_{Ed}	V_{Ed}	T_{Ed}	Σ
A_s	-	A_{sl}	$A_s + A_{sl}$
-	$(A_{sw}/s)_V$	$(A_{sw}/s)_T$	$(A_{sw}/s)_{V+T}$

→ $\mathbf{A_s + A_{sl} = 7\phi20 + 6\phi14}$

→ $\mathbf{\left(\frac{A_{sw}}{s}\right)_{V+T} = 1.876 + 0.513 = 2.389\ \frac{mm^2}{mm}}$

Detailing of reinforcement

Structural elements are subjected to $M_{Ed} + V_{Ed} + T_{Ed}$

→ $\left(\frac{A_{sw}}{s}\right)_{V+T} = 1.876 + 0.513 = 2.389$

For n = 2 $A_{sw} = 2 \cdot A_{\phi ?} = ?\ mm^2$

→ $s_{nec} = ?\ mm$

→ $s_{eff} = ?\ mm < s_{min} = 80\ mm$

Detailing of reinforcement

Structural elements are subjected to $M_{Ed} + V_{Ed} + T_{Ed}$

→ $\left(\frac{A_{sw}}{s}\right)_{V+T} = 1.876 + 0.513 = 2.389$

For n = 2 $A_{sw} = 2 \cdot A_{\phi 10} = 157\ mm^2$

→ $s_{nec} = 65.8\ mm$

→ $s_{eff} = 60\ mm < s_{min} = 80\ mm$

Detailing of reinforcement

Structural elements are subjected to $M_{Ed} + V_{Ed} + T_{Ed}$

→ $\left(\frac{A_{sw}}{s}\right)_{V+T} = 1.876 + 0.513 = 2.389$

For n = 4 $A_{sw} = 4 \cdot A_{\phi 10} = ?\ mm^2$

→ $s_{nec} = ?\ mm$

→ $s_{eff} = ?\ mm$ $> s_{min} = 80\ mm$

$< s_{max} = \min(0.75d, u/8, b) = 400\ mm$

Detailing of reinforcement

Structural elements are subjected to $M_{Ed} + V_{Ed} + T_{Ed}$

→ $\left(\frac{A_{sw}}{s}\right)_{V+T} = 1.876 + 0.513 = 2.389$

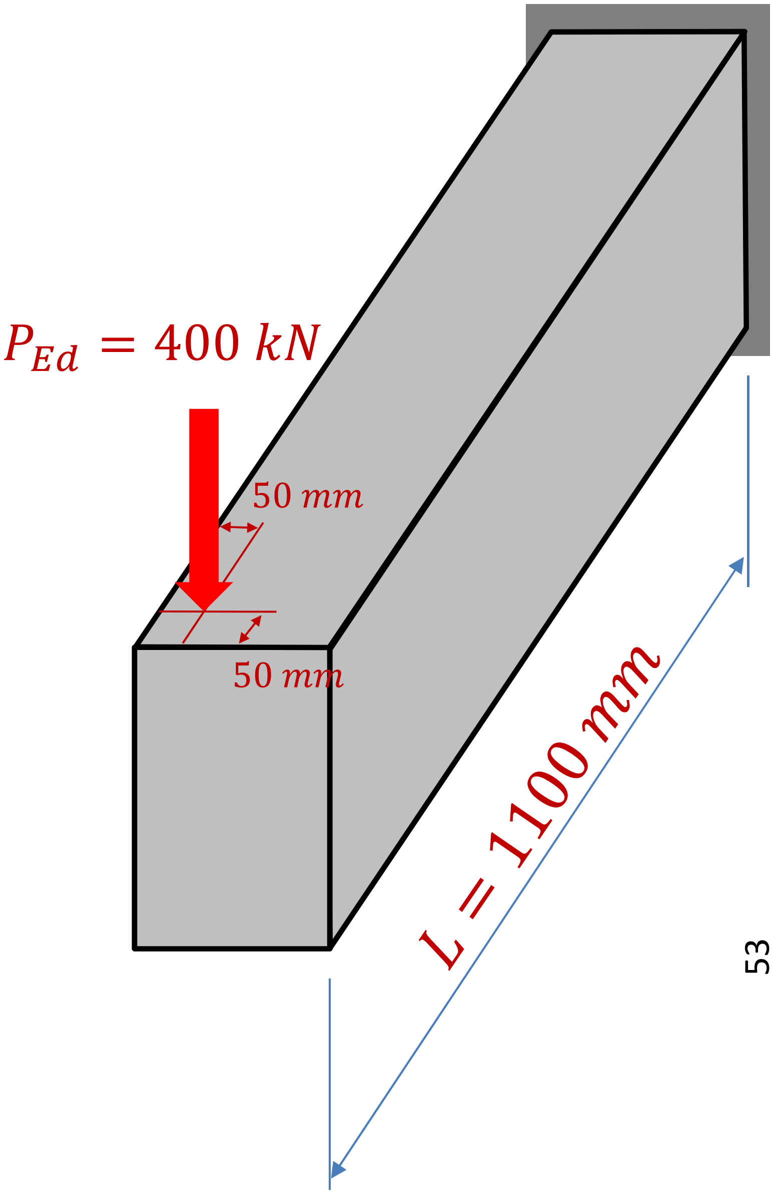
For n = 4 $A_{sw} = 4 \cdot A_{\phi 10} = 314\, mm^2$

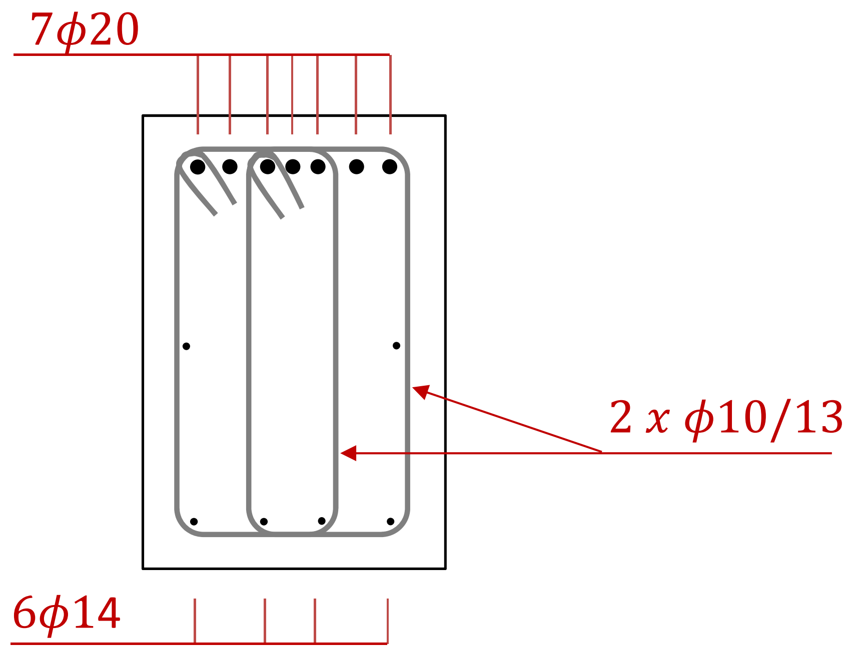
→ $s_{nec} = 131.5\, mm$

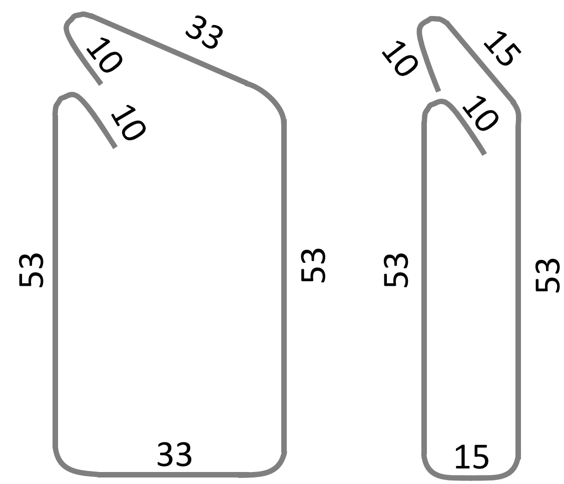
→ $\boldsymbol{s_{eff} = 130\, mm}$ $> s_{min} = 80\, mm$

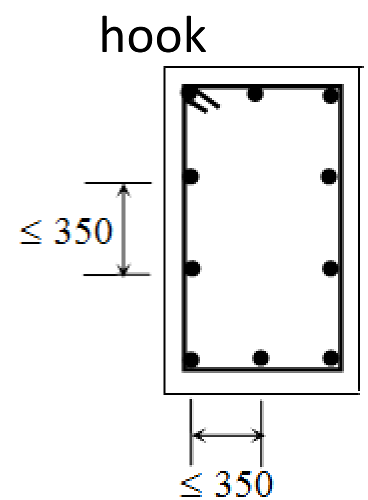
$< s_{max} = \min(0.75d, u/8\,, b) = 400\, mm$

Detailing of reinforcement

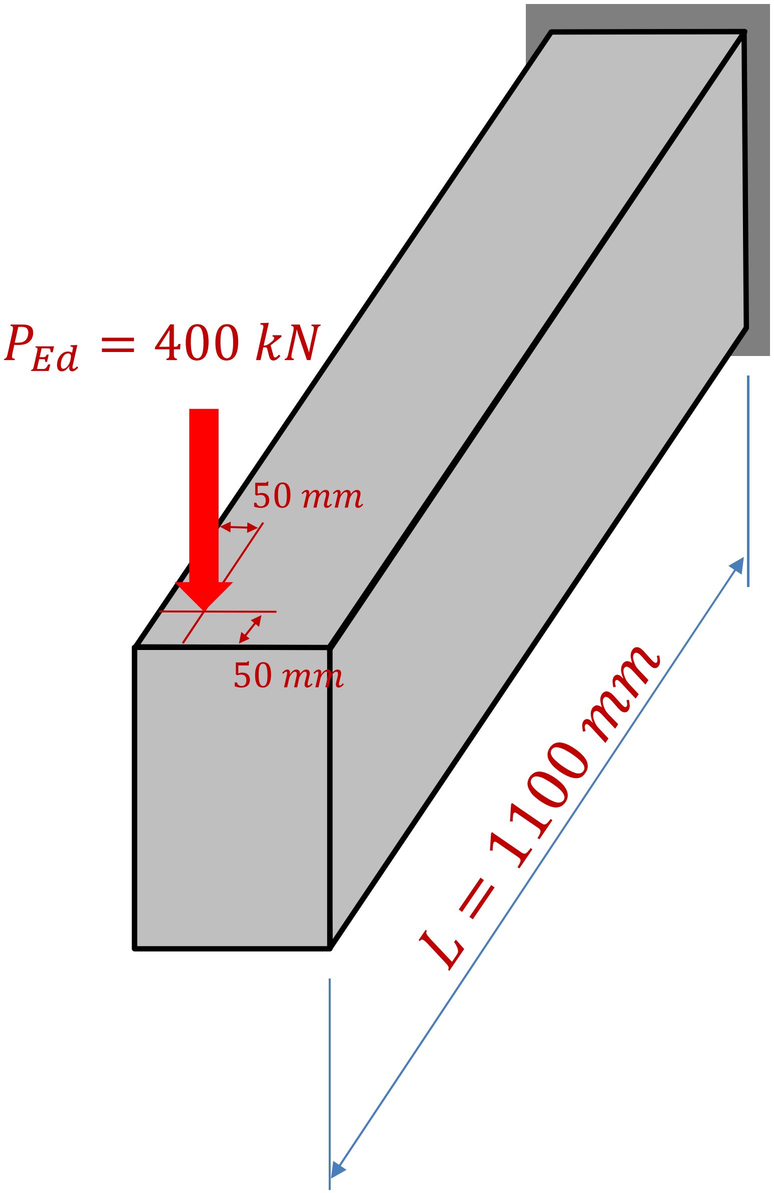








THANK YOU FOR YOUR ATTENTION!



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