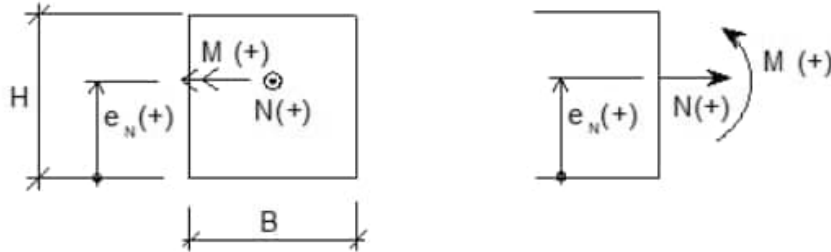


**Object:** Beam L1 - moment at bottom M(T)**PRINCIPLE SKETCH****INPUT****Concrete ( C30/37, C35/45, C40/50, C45/55 och C50/60 )**

BTG := "C30/37"

**Dimension rebars (  $\phi 10$ ,  $\phi 12$ ,  $\phi 16$ ,  $\phi 20$ ,  $\phi 25$  och  $\phi 32$  )** $\phi := 16 \cdot mm$ **Quality rebars ( B500 och Ks60 )**

TYP := "B500"

**Calculation of rebars at "bottom" reinforcement ( K = -1 ) or "top" reinforcement ( K = +1 )**

K := -1

**Concrete cover**TB :=  $50 \cdot mm + 16 \cdot mm = 66 \cdot mm$ **Permissible crack width** $w_{k, till} := 0.40 \cdot mm$ **Size largest ballast**stenmax :=  $32 \cdot mm$ **Minimal distance c/c rebars** $s_{min} := 125 \cdot mm$ **Location of centroid "compressed" rebars ( measured from compressed edge concrete )** $d_{tryck} := 50 \cdot mm$  .....

**Material concrete coefficients**

$\gamma_{c,U} := 1.50$  : ultimate state / ULS see EC2-1-1 table 2.1N

$\gamma_{c,S} := 1.00$  : service state / SLS

**Material rebar coefficients**

$\gamma_{s,U} := 1.15$  : ultimate state / ULS see EC2-1-1 table 3.1

$\gamma_{s,S} := 1.00$  : service state / SLS

**Correction factors of concrete resistance**

$\alpha_{cc} := 1.00$

$\alpha_{ct} := 1.00$

**Factors for tension-elongation determination of concrete resistance**

$\lambda := 0.80$  : see EC2-1 equation 3.19

$\eta := 1.00$  : see EC2-1 equation 3.20

**Factors for determination of crack width**

$k_1 := 0.80$  : see EC2-1 section 7.3.4

$k_2 := 0.50$  : see EC2-1 section 7.3.4

$k_3 := 7 \cdot \frac{\phi}{TB} = 1.697$  : see VVFS section 21.13

$k_4 := 0.425$

$k_t := 0.40$  : see EC2-1 section 7.3.4

$\phi_{ef} := 1.7$  : effective creep

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**Number of sections**

$$N := 9 \cdot pcs$$

**Spann length**

$$L := 6.0 \cdot m$$

**Geometry & forces**

x/L	B	H	M <sub>ULS</sub>	N <sub>ULS</sub>	M <sub>SLS</sub>	N <sub>SLS</sub>	e <sub>N</sub>
0,000	1000	750	1	0	1	0	375
0,125	1000	750	400	0	100	0	375
0,250	1000	750	500	0	200	0	375
0,375	1000	750	700	0	300	0	375
0,500	1000	750	900	0	400	0	375
0,625	1000	750	700	0	300	0	375
0,750	1000	750	500	0	200	0	375
0,875	1000	750	400	0	100	0	375
1,000	1000	750	1	0	1	0	375
-	mm	mm	kNm	kN	kNm	kN	mm

$$f_{ck} = 30.0 \text{ MPa} \quad f_{ctk_{0.05}} = 2.0 \text{ MPa} \quad f_{ctk_{0.95}} = 3.8 \text{ MPa} \quad \varepsilon_{cu} = 0.0035 \quad E_{cm} = 32.8 \text{ GPa}$$

$$\phi = 16 \text{ mm} \quad f_{yk} = 500 \text{ MPa} \quad E_{sk} = 200 \text{ GPa}$$

**CALCULATION****Concrete****Ultimate state (ULS):**

$$f_{cd,U} := \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_{c,U}} = 20 \text{ MPa} \quad : \text{ see EC2-1-1 equation 3.15}$$

$$f_{ctd} := \alpha_{ct} \cdot \frac{f_{ctk,0.05}}{\gamma_{c,U}} = 1.35 \text{ MPa} \quad : \text{ see EC2-1-1 equation 3.16}$$

**Service state (SLS):**

$$f_{cd,S} := \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_{c,S}} = 30.0 \text{ MPa} \quad : \text{ see EC2-1-1 equation 3.15}$$

$$f_{ctd} := \alpha_{ct} \cdot \frac{f_{ctk,0.05}}{\gamma_{c,S}} = 2.03 \text{ MPa} \quad : \text{ see EC2-1-1 equation 3.16}$$

**Reinforcement****Ultimate state (ULS):**

$$f_{yd,U} := \frac{f_{yk}}{\gamma_{s,U}} = 435 \text{ MPa}$$

$$E_{s,U} := E_{sk} = 200 \text{ GPa}$$

**Service state (SLS):**

$$f_{yd,S} := \frac{f_{yk}}{\gamma_{s,S}} = 500 \text{ MPa}$$

$$E_{s,S} := E_{sk} = 200 \text{ GPa}$$

**Elastic modulus**

Value  $\alpha$  is used to calculate location of neutral axis, while value  $\alpha_e$  is uses when applying EC2-1 equation 7.9.

$$\alpha := \frac{E_{s,S}}{E_{cm}} \cdot (1 + \phi_{ef}) = 16.4 \quad : \text{ including creep}$$

$$\alpha_e := \frac{E_{s,S}}{E_{cm}} = 6.1 \quad : \text{ excluding creep}$$

**Largest number of rebars per layer**

$$n_{max} := \text{floor} \left( \frac{B}{s_{min}} \right)$$

$$n_{max}^T = [8 \ 8 \ 8 \ 8 \ 8 \ 8 \ 8 \ 8 \ 8]$$

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**Largest amount of reinforcement per layer**

$$A_{max} := n_{max} \cdot \pi \cdot \left(\frac{\phi}{2}\right)^2$$

$$A_{max}^T = [1608 \ 1608 \ 1608 \ 1608 \ 1608 \ 1608 \ 1608 \ 1608 \ 1608] \text{ mm}^2$$

**Free distance between each layer**

$$FA := \max(1.5 \cdot \phi, \text{stenmax} + 5 \cdot \text{mm}) = 37 \text{ mm}$$

**Function - effective height**

$$d = \begin{cases} H - (TB + 0.5 \cdot \phi) & \text{if } Lag_{tot} = 1 \\ H - \frac{(TB + 0.5 \cdot \phi) \cdot A_{max} + (TB + 1.5 \cdot \phi + FA) \cdot (A_{tot} - A_{max})}{A_{tot}} & \text{if } Lag_{tot} = 2 \\ H - \frac{(2 \cdot TB + 2.0 \cdot \phi + FA) \cdot A_{max} + (TB + 2.5 \cdot \phi + 2 \cdot FA) \cdot (A_{tot} - 2 \cdot A_{max})}{A_{tot}} & \text{if } Lag_{tot} = 3 \\ H - \frac{(3 \cdot TB + 4.5 \cdot \phi + 3 \cdot FA) \cdot A_{max} + (TB + 3.5 \cdot \phi + 3 \cdot FA) \cdot (A_{tot} - 3 \cdot A_{max})}{A_{tot}} & \text{if } Lag_{tot} = 4 \end{cases}$$

**Function - number of layers**

$$Lag = \begin{cases} 1 & \text{if } \frac{A_{tot}}{A_{max}} \leq 1 \\ 2 & \text{if } 1 < \frac{A_{tot}}{A_{max}} \leq 2 \\ 3 & \text{if } 2 < \frac{A_{tot}}{A_{max}} \leq 3 \\ 4 & \text{if } 3 < \frac{A_{tot}}{A_{max}} \leq 4 \\ \text{break} & \text{if } \frac{A_{tot}}{A_{max}} > 4 \end{cases}$$

**Function - moment after moving normal force to level of reinforcement armering:**

$$M_s = \begin{cases} \text{if } K = -1 \\ \left| \begin{array}{l} M_s \leftarrow M_d - N_d \cdot [e_n - (h - d)] \text{ if } M_d > 0 \cdot \text{kNm} \\ M_s \leftarrow 0 \cdot \text{kNm} \text{ if } M_d \leq 0 \cdot \text{kNm} \end{array} \right. \\ \text{if } K = 1 \\ \left| \begin{array}{l} M_s \leftarrow -M_d - N_d \cdot (d - e_n) \text{ if } M_d \leq 0 \cdot \text{kNm} \\ M_s \leftarrow 0 \cdot \text{kNm} \text{ if } M_d > 0 \cdot \text{kNm} \end{array} \right. \end{cases}$$

**Limit values for balanced reinforcement**

$$\omega_{bal} := \frac{\lambda}{1 + \frac{f_{yd,U}}{\varepsilon_{cu} \cdot E_{s,U}}} = 0.493$$

$$m_{bal} := \omega_{bal} \cdot \left(1 - \frac{\omega_{bal}}{2}\right) = 0.372$$

**Function - distribution of total reinforcement per layer**

```

Lager = | if LagAnt= 1
        |   Lag ←  $\frac{As}{\left(\frac{\pi \phi^2}{4}\right)}$ 
        |   Lag2 ← 0
        |   Lag3 ← 0
        |   Lag4 ← 0
        | if LagAnt= 2
        |   Lag ← Nmax
        |   Lag2 ←  $\frac{As}{\left(\frac{\pi \phi^2}{4}\right)} - N_{max}$ 
        |   Lag3 ← 0
        |   Lag4 ← 0
        | if LagAnt= 3
        |   Lag ← Nmax
        |   Lag2 ← Nmax
        |   Lag3 ←  $\frac{As}{\left(\frac{\pi \phi^2}{4}\right)} - 2N_{max}$ 
        |   Lag4 ← 0
        | if LagAnt= 4
        |   Lag ← Nmax
        |   Lag2 ← Nmax
        |   Lag3 ← Nmax
        |   Lag4 ←  $\frac{As}{\left(\frac{\pi \phi^2}{4}\right)} - 3N_{max}$ 

```

**Function - algorithm for determination of ultimate moment (ULS)**

```

ABROTT = while Lag > LagAnt
  LagAnt ← LagAnt + 1
  dst ← d(Ast, LagAnt, H, Amax)
  Ms1 ← Ms(MU, NU, H, dst, eN)
  m1 ← min(  $\frac{M_{s1}}{d_{st}^2 \cdot B \cdot f_{cd,U}}$ , mbal )
  ω1 ← 1 - √(1 - 2 · m1)
  AI ← ω1 · B · dst ·  $\frac{f_{cd,U}}{f_{yd,U}}$ 
  Mbal ← mbal · B · dst2 · fcd,U
  if Ms1 > Mbal
    dec ← dst - dtryck
    AII ←  $\frac{M_{s1} - M_{bal}}{f_{yd,U} \cdot d_{ec}}$ 
  otherwise
    dec ← 0mm
    AII ← 0mm2
  Ast ← AI + AII +  $\frac{N_U}{f_{yd,U}}$ 
  Ast ← 0mm2 if Ast < 0mm2
  x1 ←  $\frac{d_{st} \cdot \omega_1}{\lambda}$ 

```

**Function - determination of neutral axis SLS**

$$\xi = \begin{cases} a \leftarrow 0.9 \\ \text{root} \left[ \frac{1}{2} \cdot \frac{a^2}{1-a} \left[ 1 - \left( 1 - \frac{a}{3} \right) \cdot \frac{-N_d \cdot d}{M_d} \right] - \frac{A_s \cdot \alpha}{b \cdot d} \cdot (1-a) \right], a \end{cases}$$

**Function - determination tension rebars SLS**

$$\sigma_s = \frac{M_d}{A_s \cdot d \cdot \left( 1 - \frac{\xi}{3} \right)} + \frac{N_d}{A_s}$$

**Function - algorithm determination SLS**

```

ABEUK = while wk ← wk,all + 0.1mm
  Ae ←  $\frac{\pi \phi^2}{4}$ 
  LagAnt ← Lag(Ae, Amax)
  d1 ← d(Ae, LagAnt H, Amax)
  while (wk > wk,all) ∧ (LagAnt ≤ 4)
    Ae ← Ae +  $\pi \frac{\phi^2}{4}$ 
    LagAnt ← Lag(Ae, Amax)
    d1 ← d(Ae, LagAnt H, Amax)
    σs1 ← σs(MSLS, NSLS, Ae, B, H, d1, eN)
    x ← d1 ξ(Ae, d1, MSLS, NSLS, B, H, eN)
    hef ← min[2.5(H - d1),  $\frac{(H-x)}{3}$ ,  $\frac{H}{2}$ ]
    Ac,eff ← hef · B
    ρp,eff ←  $\frac{A_e}{A_{c,eff}}$ 
    σr,max ← k3 · TB + k1 · k2 · k4 ·  $\frac{\phi}{\rho_{p,eff}}$ 
    Δε ←  $\frac{0.6 \cdot \sigma_{s1}}{E_{sS}}$  if  $\frac{\sigma_{s1} - k_t \cdot \frac{f_{cm}}{\rho_{p,eff}} \cdot (1 + \alpha_e \cdot \rho_{p,eff})}{E_{sS}} < \frac{0.6 \cdot \sigma_{s1}}{E_{sS}}$ 
    σs1 ← kt ·  $\frac{f_{cm}}{\rho_{p,eff}} \cdot (1 + \alpha_e \cdot \rho_{p,eff})$ 

```

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**RESULTS****Intermediate results - loadcombination SLS**

x	A <sub>s</sub>	w <sub>k</sub>	d	Δε	s <sub>r,max</sub>	ρ <sub>p,eff</sub>	σ <sub>s</sub>	x	h <sub>ef</sub>
0	402	0,02	676	0,00001	1363	0,002174	4	83	185
0,75	1005	0,29	676	0,00047	613	0,005434	157	122	185
1,50	1407	0,32	676	0,00068	470	0,007608	226	140	185
2,25	1608	0,38	676	0,00089	425	0,008695	298	148	185
3,00	2011	0,39	665	0,00102	378	0,010215	325	159	197
3,75	1608	0,38	676	0,00089	425	0,008695	298	148	185
4,50	1407	0,32	676	0,00068	470	0,007608	226	140	185
5,25	1005	0,29	676	0,00047	613	0,005434	157	122	185
6,00	402	0,02	676	0,00001	1363	0,002174	4	83	185
m	mm <sup>2</sup>	mm	mm	-	mm	-	MPa	mm	mm

**intermediate results - loadcombination ULS**

x	M <sub>u</sub>	A <sub>st</sub>	d <sub>st</sub>	A <sub>sc</sub>	d <sub>sc</sub>	m	m <sub>bal</sub>	X
0	1	3	676	0	0	0,000	0,372	0
0,75	400	1392	676	0	0	0,044	0,372	38
1,50	500	1762	672	0	0	0,055	0,372	48
2,25	700	2557	657	0	0	0,081	0,372	69
3,00	900	3400	646	0	0	0,108	0,372	92
3,75	700	2557	657	0	0	0,081	0,372	69
4,50	500	1762	672	0	0	0,055	0,372	48
5,25	400	1392	676	0	0	0,044	0,372	38
6,00	1	3	676	0	0	0,000	0,372	0
m	kNm	mm <sup>2</sup>	mm	mm <sup>2</sup>	mm	-	-	mm

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**Reinforcement SLS**

x	$A_s$	Layer 1	Layer 2	Layer 3	Layer 4
0	402	2	0	0	0
0,75	1005	5	0	0	0
1,50	1407	7	0	0	0
2,25	1608	8	0	0	0
3,00	2011	8	2	0	0
3,75	1608	8	0	0	0
4,50	1407	7	0	0	0
5,25	1005	5	0	0	0
6,00	402	2	0	0	0

**Reinforcement ULS**

x	$A_{st}$	Tension rebars				Compressive rebars	
		Lag 1	Lag 2	Lag 3	Lag 4	$A_{sc}$	Antal
0	3	0	0	0	0	0	0
0,75	1392	7	0	0	0	0	0
1,50	1762	8	1	0	0	0	0
2,25	2557	8	5	0	0	0	0
3,00	3400	8	8	1	0	0	0
3,75	2557	8	5	0	0	0	0
4,50	1762	8	1	0	0	0	0
5,25	1392	7	0	0	0	0	0
6,00	3	0	0	0	0	0	0
m	mm <sup>2</sup>	pcs	pcs	pcs	pcs	mm <sup>2</sup>	pcs

**The curtailment of longitudinal reinforcement according to EN 1992-1-1 section 9.2.3**

A simplified method according is used where  $a_l = d$  is assumed along entire beam.

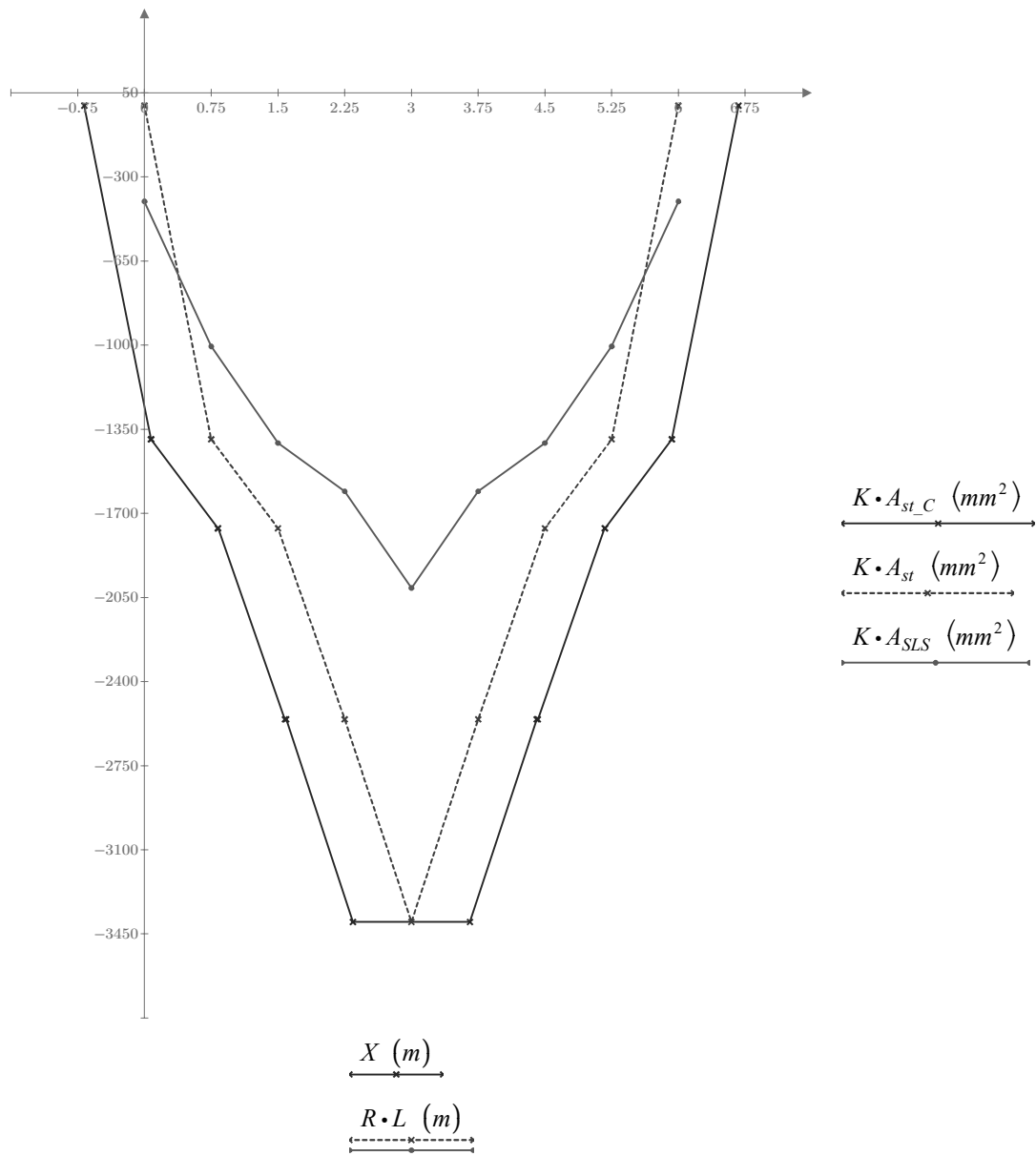
```

CurveC := for Area ∈ 1 .. (N - 1)
  a_l ← 1.0 • max (d_start, d_end)
  if A_st_C_Area > A_st_Area + 1
    X_start_Area ← R_Area • L + a_l
    A_st_C_start_Area ← A_st_Area
    X_end_Area ← R_Area + 1 • L + a_l
    A_st_C_end_Area ← A_st_Area + 1
  if A_st_Area ≤ A_st_Area + 1
    X_start_Area ← R_Area • L - a_l
    A_st_C_start_Area ← A_st_Area
    X_end_Area ← R_Area + 1 • L - a_l
    A_st_C_end_Area ← A_st_Area + 1

```

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**Diagram over required reinforcement**



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**Chosen reinforcement**

Table format:

Pos	$K_{rebar}$	Layer	$x_{start}$	$x_{end}$	$\phi$	$n_{rebar}$	$c_c$	$l_b$
1	-1	1	-1,0	7,0	16	4	250	800
2	-1	1	-1,0	7,0	16	4	250	800
3	-1	2	0	6,0	16	4	250	800
4	-1	2	1,0	5,0	16	4	250	800
5	-1	3	1,5	4,5	16	2	500	800
6	-1	x	0	0	0	0	0	0
7	-1	x	0	0	0	0	0	0
8	-1	x	0	0	0	0	0	0
9	-1	x	0	0	0	0	0	0
10	-1	x	0	0	0	0	0	0

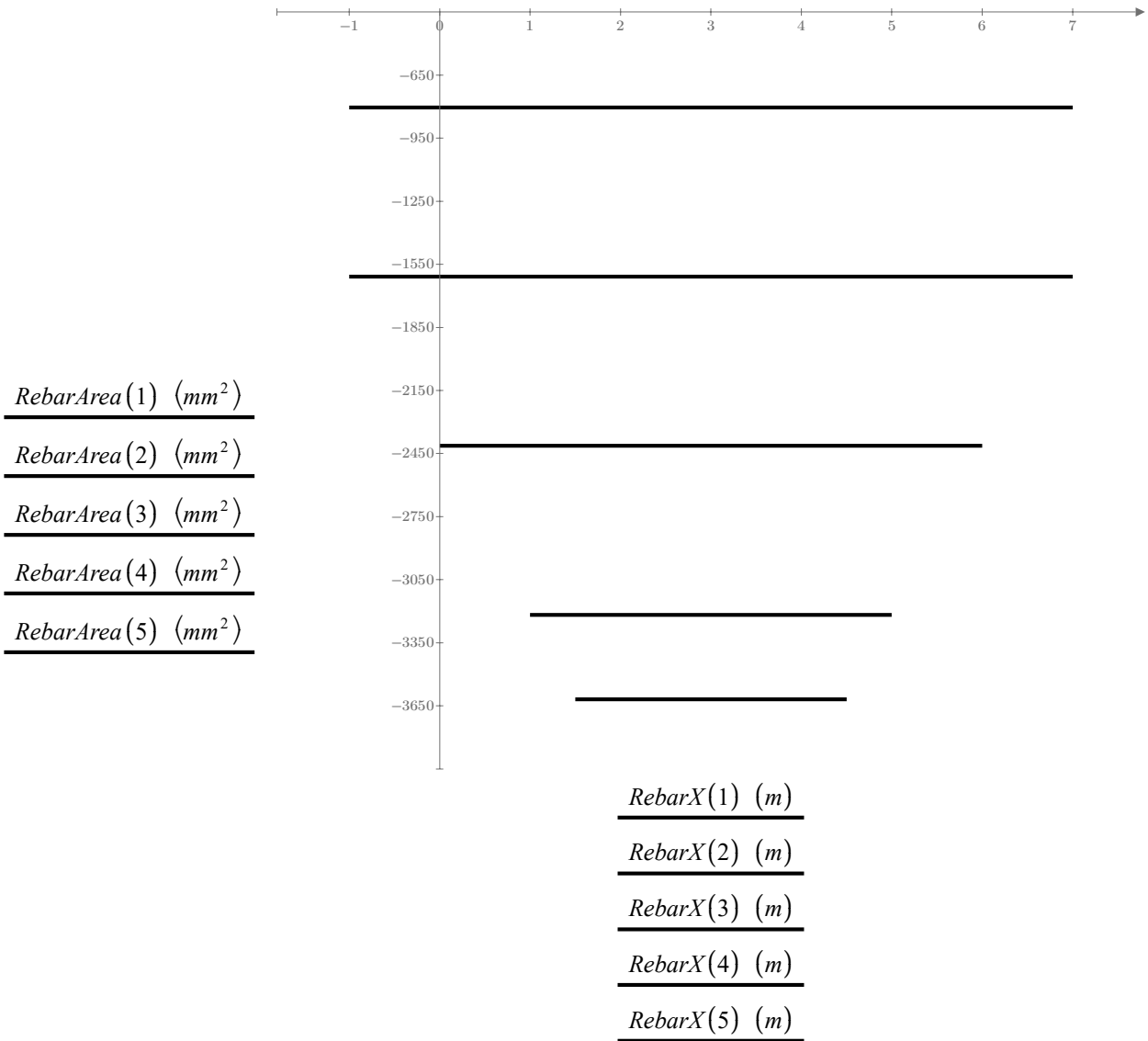
Function - graphic visualization:

```

RebarX(Pos) := || X_start_Pos
                || X_end_Pos

RebarArea(Pos) := || AS ← 0 m²
                  || for j ∈ 1 .. Pos
                  || || AS ← AS + n_rebar_j • π •  $\frac{\phi_j^2}{4}$ 
    
```

Diagram for graphic visualization:



**Diagram over required reinforcement**

Starting point and endpoint of diagram:

$$xR_{start} := -1.0 \text{ m}$$

$$xR_{end} := L + 1.0 \text{ m} = 7 \text{ m}$$

Function - create resistance curve for chosen rebars:

$$\Delta x_R := \frac{xR_{end} - xR_{start}}{99} \quad j := 1 \dots 100 \quad xR_j := xR_{start} + \Delta x_R \cdot (j - 1)$$

$\text{CurveR}(i) := \begin{cases} x_{R_1} \leftarrow x_{start_i} \\ x_{R_2} \leftarrow x_{start_i} + l_{b_i} \\ x_{R_3} \leftarrow x_{end_i} - l_{b_i} \\ x_{R_4} \leftarrow x_{end_i} \\ A_{R_1} \leftarrow 0 \text{ mm}^2 \\ A_{R_2} \leftarrow n_{rebar_i} \cdot \pi \cdot \frac{\phi_i^2}{4} \\ A_{R_3} \leftarrow n_{rebar_i} \cdot \pi \cdot \frac{\phi_i^2}{4} \\ A_{R_4} \leftarrow 0 \text{ mm}^2 \end{cases}$	$\text{CurveR}(i) := \begin{cases} x_{R_1} \leftarrow x_{start_i} \\ x_{R_2} \leftarrow x_{start_i} + l_{b_i} \\ x_{R_3} \leftarrow x_{end_i} - l_{b_i} \\ x_{R_4} \leftarrow x_{end_i} \\ A_{R_1} \leftarrow 0 \text{ mm}^2 \\ A_{R_2} \leftarrow n_{rebar_i} \cdot \pi \cdot \frac{\phi_i^2}{4} \\ A_{R_3} \leftarrow n_{rebar_i} \cdot \pi \cdot \frac{\phi_i^2}{4} \\ A_{R_4} \leftarrow 0 \text{ mm}^2 \end{cases}$
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

$$\text{RebarR}_j := \begin{cases} \text{for } Pos \in 1 \dots 10 \\ \quad \text{if } x_{start_{Pos}} < xR_j \leq x_{end_{Pos}} \\ \quad \quad AS \leftarrow AS + K_{rebar_{Pos}} \cdot \text{linterp} \left( \text{CurveR}(Pos)^{(1)}, \text{CurveR}(Pos)^{(2)}, xR_j \right) \end{cases}$$

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Diagram for graphic visualization:

