Assignment 7

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$a = 5,4\ m$

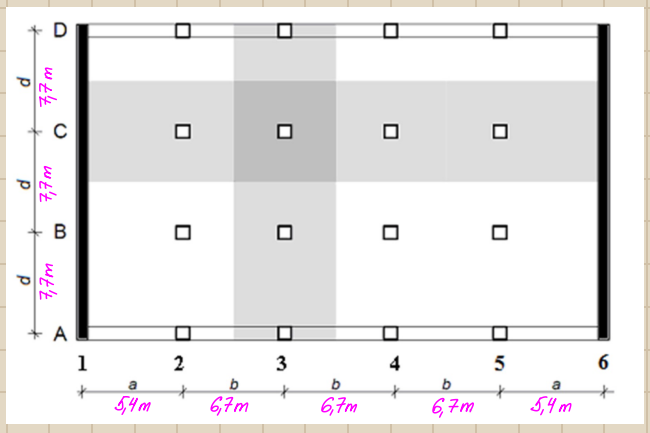
$b = 6,7\ m$

$d = 7,7\ m$

C 25/30

$(g - g_0)_{floor,k} = 1,4\ kN/m^2$

$q_{floor,k} = 4,9\ kN/m^2$



1. Design of dimensions

1.1 Slab thickness

$$h_{d,1} = \frac{L_{n,max}}{30} = \frac{7700 - 2 \cdot 200}{30} = 243\ mm \text{ (assume column } 400 \times 400)$$

$$h_{d,2} = c + \frac{\phi_s}{2} + \frac{L_{max}}{k_{c1} \cdot k_{c2} \cdot k_{c3} \cdot \lambda_{d,tab}}$$

For concrete C25/30 $\lambda_{d,tab} = 22,2$

Preliminarily take ϕ 12 mm => $c = 25\ mm$ (from task 1)

$$h_{d,2} = 25 + 6 + \frac{7700}{1,2 \cdot 22,2} = 320\ mm$$

=> choose $h_s = 300\ mm$

Span - depth ratio:

$$\lambda = \frac{L_s}{\cancel{h_s}\ d} = \frac{7700}{300} = 25,67$$

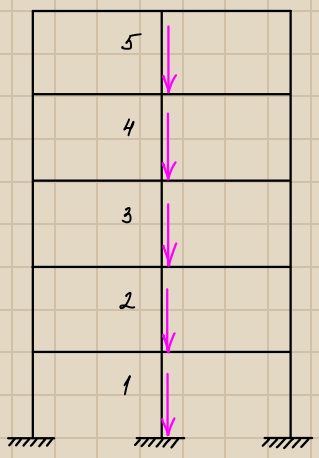
$\lambda_d = 1,2 \cdot 22,2 = 26,64$

$\lambda \neq \lambda_d$ ✓

* must be d instead of h_s, we agreed that I don't have to change it

1.2 Wall thickness

$a = 5,4m < 6m$ => $b_w = 200\ mm$



1.3 Perimeter beam dimensions

$h_b = 950\ mm$

$b_b = 200\ mm$

1.4 Column dimensions

Loading of the slab

Load type	k-value [kN/m²]	ɣ	design value [kN/m²]
Self-weight	$25\ kN/m^3 \cdot 0{,}3\ m = 7{,}5$	1,35	10,125
Dead load	1,4	1,35	1,89
Live load	4,9	1,5	7,35
Total	13,8		19,4

Tributing area of column:

$6{,}7 \cdot 7{,}7 = 51{,}6\ m^2$

Self-weight of the column (preliminarily take 400×400 mm)

$0{,}25 \cdot \cancel{0{,}4}\ 0{,}5^2 \cdot (3{,}5 - 0{,}3) = \cancel{0{,}128}\ 0{,}2\ kN$

1st floor:

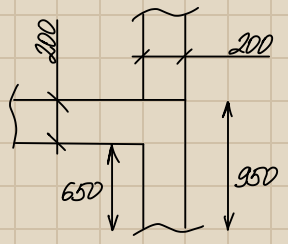
$N_{Ed} = (19{,}4 \cdot 51{,}6 + \cancel{0{,}128}\ 0{,}2) \cdot 5 = \cancel{5005{,}8}\ 5006{,}2\ kN$

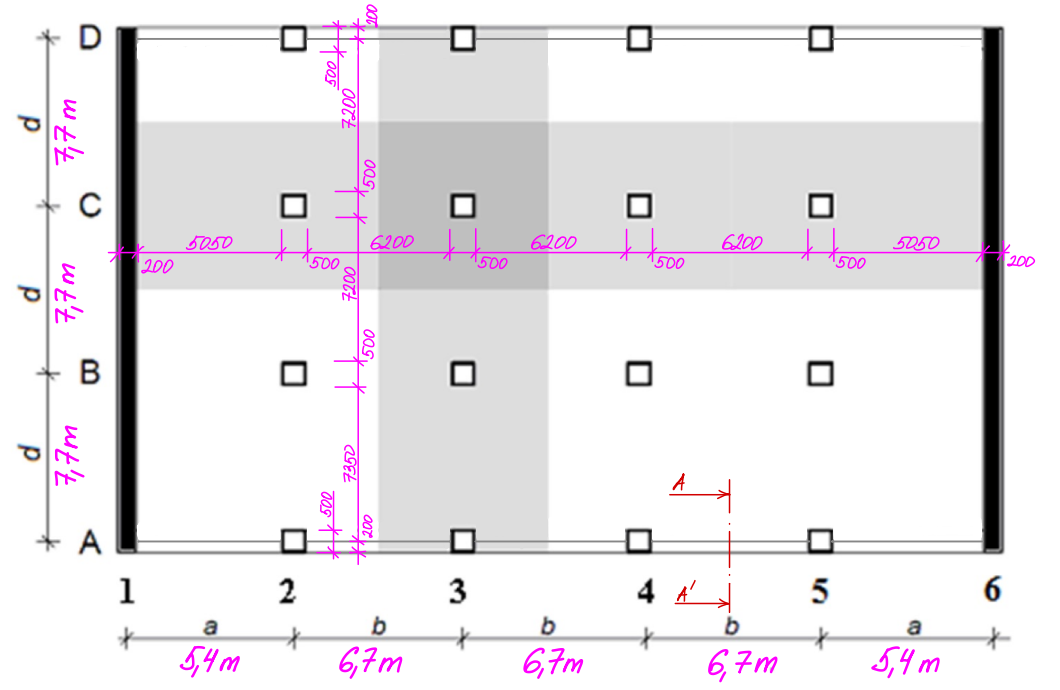
$$A_{c,rqd} = \frac{N_{Ed}}{0{,}8 f_{cd} + 0{,}02 \cdot 400\ MPa} = \frac{\cancel{5{,}0058}\ 5{,}0062}{0{,}8 \cdot 16{,}67 + 0{,}02 \cdot 400} = 0{,}2346\ m^2 \checkmark$$

$A_c = 0{,}4^2 = 0{,}16\ m^2$ – doesn't suffice

Take $A_c = 0{,}5^2 = 0{,}25\ m^2$ ✓

Section A – A'





2. Preliminary check of slab punching

$u_0 = 4a = 4 \cdot 0,5 = 2\ m$ – face of the column

$d = 300 - 25 - 6 = 269\ mm$

$u_1 = 4a + 2\pi \cdot 2d = 2 + 4 \cdot 0,269\pi = 5,38\ m$ – 2d from u_0

Failure of compressed concrete at u_0:

$$V_{Ed,0} = \frac{\beta V_{Ed}}{u_0 \cdot d} \leq V_{Rd,max} = 0,4\nu \cdot f_{cd}$$

$$\nu = 0,6\left(1 - \frac{f_{ck}}{250}\right) = 0,6\left(1 - \frac{25}{250}\right) = 0,54$$

$$\Rightarrow V_{Rd,max} = 0,4 \cdot 0,54 \cdot 16,67 \cdot 10^3 = 3600,7\ kPa$$

$\beta = 1,15$

V_{Ed} (1 floor) $= 19,4 \cdot 51,6 + 0,2 = 1001,24\ kN$

$$\Rightarrow V_{Ed,0} = \frac{1,15 \cdot 1001,24}{2 \cdot 0,269} = 2140,2\ kPa$$

$2140,2 < 3600,7$ ✓

Condition is satisfied, so no caps

Failure of punching reinforcement at u_1:

Checking if it could be anchored:

$$v_{Ed,1} = \frac{\beta V_{Ed}}{u_1 \cdot d} \leq k_{max} \cdot v_{Rd,c} = k_{max} \cdot C_{Rd,c} \cdot k \cdot \sqrt[3]{100 \rho_1 \cdot f_{ck}}$$

$$v_{Ed,1} = \frac{1,15 \cdot 1001,24}{5,38 \cdot 0,269} = 795,6 \text{ kPa}$$

Coefficient of max. resistance $k_{max} = 1,8$ (for double-headed studs)

Reduction factor $C_{Rd,c} = 0,12$

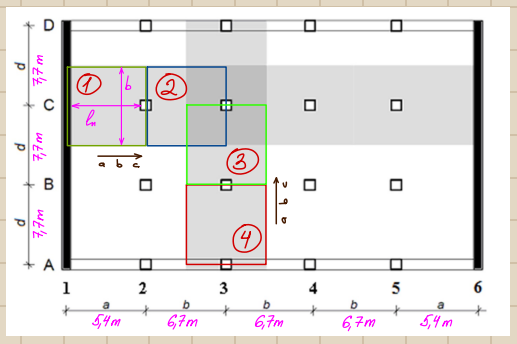
Effect of depth:

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{269}} = 1,86 \leq 2$$

$$\rho_1 = 0,005$$

$$\Rightarrow k_{max} \cdot v_{Rd,c} = 1,8 \cdot 0,12 \cdot 1,86 \sqrt[3]{100 \cdot 0,005 \cdot 25} = 0,9324 \text{ MPa}$$

$795,6 \text{ kPa} < 932,4 \text{ kPa}$ ✓



3. Bending moments

Total bending moment in a panel:

$f_d = 19,4 \text{ kN/m}^2$

$$M_{tot} = \frac{1}{8} f_d \cdot b \cdot l_n^2$$

Panel 1) $M_{tot}^1 = \frac{1}{8} \cdot 19,4 \cdot 7,7 \cdot (5,4 - 0,25 - 0,1)^2 = 476,2 \text{ kNm}$

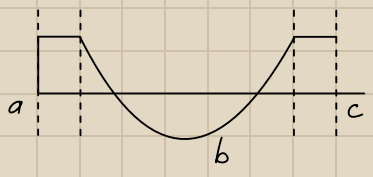
Panel 2) $M_{tot}^2 = \frac{1}{8} \cdot 19,4 \cdot 7,7 \cdot (6,7 - 0,25 \cdot 2)^2 = 717,8 \text{ kNm}$

Panel 3) $M_{tot}^3 = \frac{1}{8} \cdot 19,4 \cdot 6,7 \cdot (7,7 - 0,25 \cdot 2)^2 = 842,3 \text{ kNm}$

Panel 4) $M_{tot}^4 = \frac{1}{8} \cdot 19,4 \cdot 6,7 \cdot (7,7 - 0,25 \cdot 2)^2 = 842,3 \text{ kNm}$

Support and mid-span moments:

$M = f_i \cdot M_{tot}^i$



Panel 1) $f_a = 0,65$

$f_b = 0,35$

$f_c = 0,65$

$M_a^1 = 0,65 \cdot 476,2 = 309,5$ kNm

$M_b^1 = 0,35 \cdot 476,2 = 166,7$ kNm

$M_c^1 = 0,65 \cdot 476,2 = 309,5$ kNm

Panel 2) $f_a = 0,65$

$f_b = 0,35$

$f_c = 0,65$

$M_a^2 = 0,65 \cdot 717,8 = 466,6$ kNm

$M_b^2 = 0,35 \cdot 717,8 = 251,2$ kNm

$M_c^2 = 0,65 \cdot 717,8 = 466,6$ kNm

Panel 3) $f_a = 0,65$

$f_b = 0,35$

$f_c = 0,65$

$M_a^3 = 0,65 \cdot 842,3 = 547,5$ kNm

$M_b^3 = 0,35 \cdot 842,3 = 294,8$ kNm

$M_c^3 = 0,65 \cdot 842,3 = 547,5$ kNm

Panel 4) $f_a = 0,3$

$f_b = 0,5$

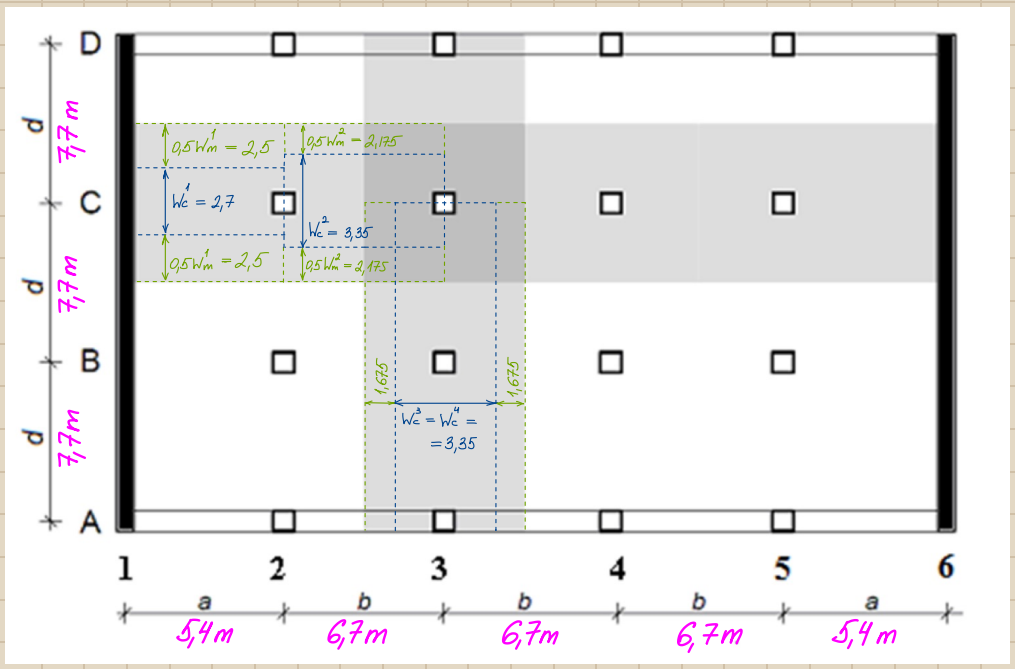
$f_c = 0,7$

$M_a^4 = 0,3 \cdot 842,3 = 252,7\ kNm$

$M_b^4 = 0,5 \cdot 842,3 = 421,2\ kNm$

$M_c^4 = 0,7 \cdot 842,3 = 589,6\ kNm$

Moments in column and middle strips



Panel 1)

$W_c^1 = 2 \cdot 0,25 \cdot 5,4 = 2,7\ m$

$W_m^1 = 7,7 - 2,7 = 5\ m \Rightarrow 0,5 W_m^1 = 2,5\ m$

Panel 2)

$W_c^2 = 2 \cdot 0,25 \cdot 6,7 = 3,35\ m$

$W_m^2 = 7,7 - 3,35 = 4,35\ m \Rightarrow 0,5\ W_m^2 = 2,175\ m$

Panel 3)

$W_c^3 = 2 \cdot 0,25 \cdot 6,7 = 3,35\ m$

$W_m^3 = 6,7 - 3,35 = 3,35\ m \Rightarrow 0,5\ W_m^3 = 1,675\ m$

Panel 4)

same as for panel 4

We must split the moments into column and middle strip moments

$M_c = w(j_i \cdot M_{tot})$

$M_m = (1-w)(j_1 \cdot M_{tot})$

mid-span: $w = 0{,}6$

inner support: $w = 0{,}75$

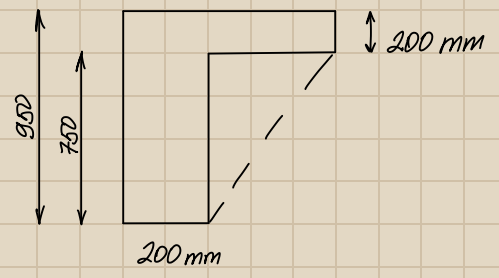
edge beam: $w = \min(\max(1 - \frac{\beta_t}{10}; 0{,}75); 1)$

$\beta_t = \frac{I_t}{2I_s}$

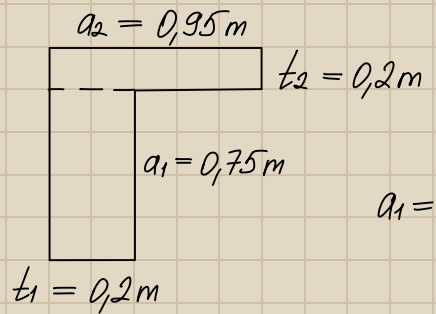
$I_s = \frac{1}{12} b h_s^3 = \frac{1}{12} \cdot 6{,}7 \cdot 0{,}3^2 = 0{,}015\ m^4$

$I_t = \sum_{i=1}^{n} \left(1 - 0{,}63 \cdot \frac{t_i}{a_i}\right) \cdot \frac{t_i^3 \cdot a_i}{3}$

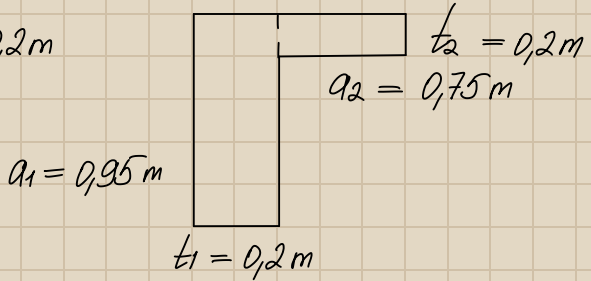
750 $\quad h_v \leq 4h_s \Rightarrow h_v \leq 800\ mm$



a)



b)



$I_t^a = \left(1 - 0{,}63 \cdot \frac{0{,}2}{0{,}75}\right) \cdot \frac{0{,}2^3 \cdot 0{,}75}{3} + \left(1 - 0{,}63 \cdot \frac{0{,}2}{0{,}95}\right) \frac{0{,}2^3 \cdot 0{,}95}{3} =$

$= 0{,}00386\ m^4$

$I_t^b = \left(1 - 0{,}63 \cdot \frac{0{,}2}{0{,}95}\right) \cdot \frac{0{,}2^3 \cdot 0{,}95}{3} + \left(1 - 0{,}63 \cdot \frac{0{,}2}{0{,}75}\right) \frac{0{,}2^3 \cdot 0{,}75}{3} =$

$= 0{,}00386\ m^4$

$$\beta_t = \frac{0{,}00386}{2 \cdot 0{,}015} = 0{,}12$$

$$\psi = \min\left(\max\left(1 - \frac{\frac{0{,}12}{10}}{}, 0{,}75\right); 1\right) = \min\left(\max\left(0{,}988; 0{,}75\right); 1\right) =$$

$$= \min(0{,}988; 1) = 0{,}988$$

$$M_c = \psi (j_i \cdot M_{tot})$$

$$M_m = (1 - \psi)(j_i \cdot M_{tot})$$

mid-span: $\psi = 0{,}6$

inner support: $\psi = 0{,}75$

edge beam: $\psi = 0{,}988$

Panel 1)

(wall) $m_w^1 = \frac{309{,}5}{7{,}7} = 40{,}2$ kNm/m

$M_a^1 = 0{,}65 \cdot 476{,}2 = 309{,}5$ kNm
$M_b^1 = 0{,}35 \cdot 476{,}2 = 166{,}7$ kNm
$M_c^1 = 0{,}65 \cdot 476{,}2 = 309{,}5$ kNm

$m_m^{1b} = \frac{(1 - 0{,}6) \cdot 166{,}7}{5} = 13{,}4$ kNm/m

$m_c^{1b} = \frac{0{,}6 \cdot 166{,}7}{2{,}7} = 37{,}0$ kNm/m

$w_c^1 = 2 \cdot 0{,}25 \cdot 5{,}4 = 2{,}7$ m
$w_m^1 = 7{,}7 - 2{,}7 = 5$ m

$m_m^{1c} = \frac{(1 - 0{,}75) \cdot 309{,}5}{5} = 15{,}5$ kNm/m

$m_c^{1c} = \frac{0{,}75 \cdot 309{,}5}{2{,}7} = 86{,}0$ kNm/m

Panel 2)

$M_a^2 = 0{,}65 \cdot 717{,}8 = 466{,}6$ kNm
$M_b^2 = 0{,}35 \cdot 717{,}8 = 251{,}2$ kNm
$M_c^2 = 0{,}65 \cdot 717{,}8 = 466{,}6$ kNm

$m_m^{2a} = \frac{(1 - 0{,}75) \cdot 466{,}6}{4{,}35} = 26{,}8$ kNm/m

$m_c^{2a} = \frac{0{,}75 \cdot 466{,}6}{3{,}35} = 104{,}5$ kNm/m

$w_c^2 = 2 \cdot 0{,}25 \cdot 6{,}7 = 3{,}35$ m
$w_m^2 = 7{,}7 - 3{,}35 = 4{,}35$ m

$$m_m^{2b} = \frac{(1-0,6)\cdot 251,2}{4,35} = 23,1 \text{ kNm/m}$$

$$m_c^{2b} = \frac{0,6\cdot 251,2}{3,35} = 45,0 \text{ kNm/m}$$

$$m_m^{2c} = \frac{(1-0,75)\cdot 466,6}{4,35} = 26,8 \text{ kNm/m}$$

$$m_c^{2c} = \frac{0,75\cdot 466,6}{3,35} = 104,5 \text{ kNm/m}$$

Panel 3)

$M_a^3 = 0,65\cdot 842,3 = 547,5$ kNm
$M_b^3 = 0,35\cdot 842,3 = 294,8$ kNm
$M_c^3 = 0,65\cdot 842,3 = 547,5$ kNm

$$m_m^{3a} = \frac{(1-0,75)\cdot 547,5}{3,35} = 40,9 \text{ kNm/m}$$

$W_c^3 = 2\cdot 0,25\cdot 6,7 = 3,35$ m
$W_m^3 = 6,7 - 3,35 = 3,35$ m

$$m_c^{3a} = \frac{0,75\cdot 547,5}{3,35} = 122,6 \text{ kNm/m}$$

$$m_m^{3b} = \frac{(1-0,6)\cdot 294,8}{3,35} = 35,2 \text{ kNm/m}$$

$$m_c^{3b} = \frac{0,6\cdot 294,8}{3,35} = 52,8 \text{ kNm/m}$$

$$m_m^{3c} = \frac{(1-0,75)\cdot 547,5}{3,35} = 40,9 \text{ kNm/m}$$

$$m_c^{3c} = \frac{0,75\cdot 547,5}{3,35} = 122,6 \text{ kNm/m}$$

Panel 4)

$M_a^4 = 0,3\cdot 842,3 = 252,7$ kNm
$M_b^4 = 0,5\cdot 842,3 = 421,2$ kNm
$M_c^4 = 0,7\cdot 842,3 = 589,6$ kNm

$$m_m^{3a} = \frac{(1-0,988)\cdot 252,7}{3,35} = 0,9 \text{ kNm/m}$$

$$m_c^{3a} = \frac{0,988\cdot 252,7}{3,35} = 74,5 \text{ kNm/m}$$

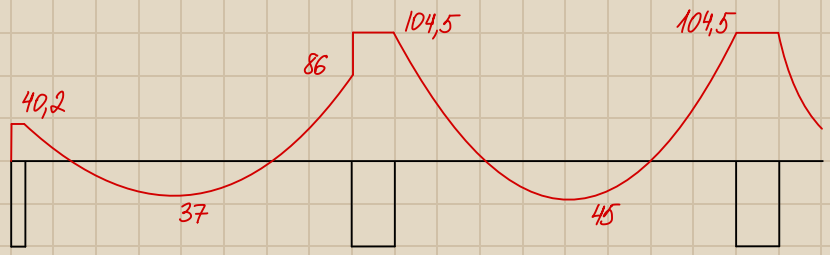
$$m_m^{3b} = \frac{(1-0,6)\cdot 421,2}{3,35} = 50,3 \text{ kNm/m}$$

$$m_c^{3b} = \frac{0,6\cdot 421,2}{3,35} = 75,4 \text{ kNm/m}$$

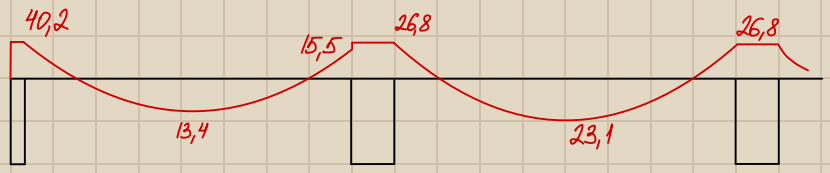
$$m_m^{3c} = \frac{(1-0,75)\cdot 589,6}{3,35} = 44,0 \text{ kNm/m}$$

$$m_c^{3c} = \frac{0,75\cdot 589,6}{3,35} = 132,0 \text{ kNm/m}$$

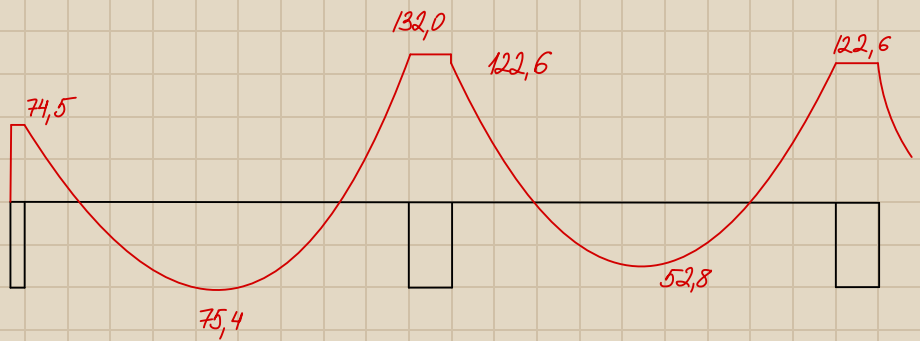
Belt C – column strip



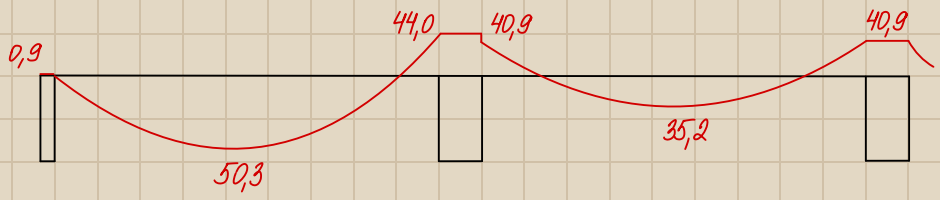
Belt C – middle strip



Belt 3 – column strip



Belt 3 – middle strip



Moments in middle and column strip							
Panel	Cross-section	Positive/negative moment M_i [kNm]	Strip	w	Moment in middle/ column strip M_j [kNm]	Width of the strip s_j [m]	Moment per 1m of the slab m_j [kNm/m]
1	a (left support)	309,5	no division	1	309,5	7,7	40,2
	b (midspan)	166,7	middle	0,6	66,7	5	13,3
			column		100,0	2,7	37,0
	c (right support)	309,5	middle	0,75	77,4	5	15,5
			column		232,1	2,7	86,0
2	a (left support)	466,6	middle	0,75	116,7	4,35	26,8
			column		350,0	3,35	104,5
	b (midspan)	251,2	middle	0,6	100,5	4,35	23,1
			column		150,7	3,35	45,0
	c (right support)	466,6	middle	0,75	116,7	4,35	26,8
			column		350,0	3,35	104,5
3	a (left support)	547,5	middle	0,75	136,9	3,35	40,9
			column		410,6	3,35	122,6
	b (midspan)	294,8	middle	0,6	117,9	3,35	35,2
			column		176,9	3,35	52,8
	c (right support)	547,5	middle	0,75	136,9	3,35	40,9
			column		410,6	3,35	122,6
4	a (left support)	252,7	middle	0,988	3,0	3,35	0,9
			column		249,7	3,35	74,5
	b (midspan)	421,2	middle	0,6	168,5	3,35	50,3
			column		252,7	3,35	75,4
	c (right support)	589,6	middle	0,75	147,4	3,35	44,0
			column		442,2	3,35	132,0