Engin Aydeniz
Erasmus Student

HOMEWORK 8 - CM01

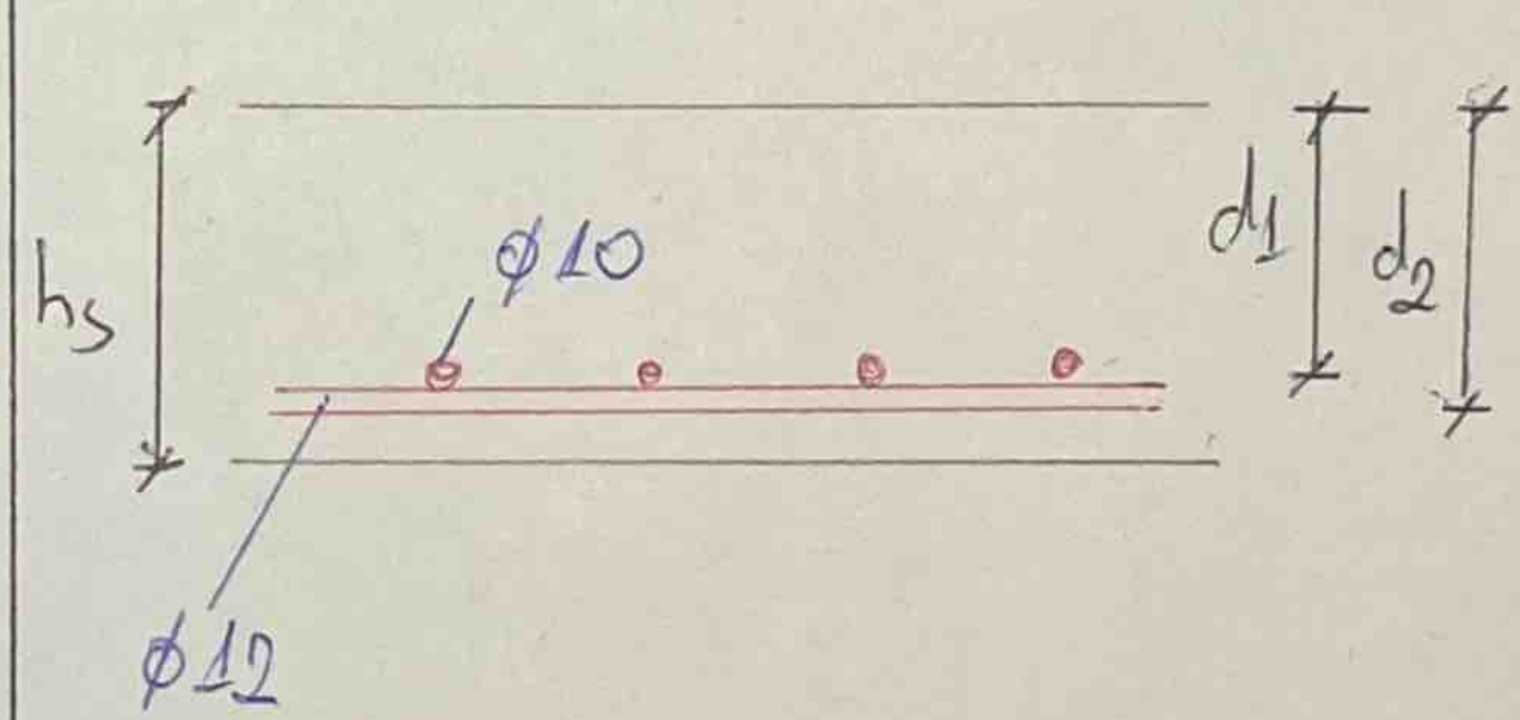
TASK 3: Two-way slab supported on colums

3. Structural analysis of the slab

1). Design slab reinforcement (rebars) for calculated moments

• Effective depth

The highest bending moment occurs in the strip "3" with 101,24 kNm/m. Therefore, we should place rebars firstly in this direction to get more effective depth.



$h_s = 280$ mm

$c = 25$ mm

$$d_2 = h_s - c - \frac{\phi_{12}}{2} = 280 - 25 - \frac{12}{2} = \underline{269 \text{ mm}}$$

$$d_1 = h_s - c - \phi_{12} - \frac{\phi_{10}}{2} = 280 - 25 - 12 - \frac{10}{2} = \underline{238 \text{ mm}}$$

• Level arm

$z = 0,9\, d$ → see exeel

• Cross-sectional area of reinforcement required

$$a_{s,rqd} = \frac{M_{Ed}}{z \cdot f_{yd}} \rightarrow \text{see excel}$$

f_{yd} ↓ 435 MPa

• Minimum reinforcement

• Brittle failure precaution

For "C" strip

$$a_{s,min_1} = \max\left(0{,}26\ \frac{f_{ctm}}{f_{yk}}\ b\, d\ ;\ 0{,}0013\, b\, d\right)$$

| $f_{ctm} = 2{,}9$ MPa for C 30/37

$$= \max\left(0{,}26 \cdot \frac{2{,}9}{500} \cdot 1000 \cdot 239\ ;\ 0{,}0013 \cdot 1000 \cdot 239\right)$$

$$= \max(360\ ;\ 311)\ mm^2 = 360\ mm^2$$

- Excessive cracking precaution

$$a_{s,min_2} = \frac{k_c \cdot k \cdot f_{ct,eff} \cdot A_{ct}}{\sigma_s}$$

| $A_{ct} = 0{,}5 \cdot b \cdot d$

$$= \frac{0{,}4 \cdot 1 \cdot 2{,}9 \cdot 0{,}5 \cdot 1000 \cdot 239}{500} = 277\ mm^2$$

Therefore, for C strip $a_{s_{min}} = 360\ mm^2$

For "3" strip ($d = 249$ mm)

$$a_{s,min_1} = \max\left(0{,}26\ \frac{2{,}9}{500} \cdot 1000 \cdot 249\ ;\ 0{,}0013 \cdot 1000 \cdot 249\right)$$

$$= \max(376\ ;\ 324)\ mm^2 = 376\ mm^2$$

$$a_{s_{min},2} = \frac{0{,}4 \cdot 1 \cdot 2{,}9 \cdot 0{,}5 \cdot 1000 \cdot 249}{500} = 289\ mm^2$$

Therefore for "3" strip $a_{s_{min}} = 376\ mm^2$

• Height of compressed zone of concrete cross-section

$$x = \frac{a_{s\,prov} \cdot f_{yd}}{0{,}8 \cdot b \cdot f_{cd}} \rightarrow \text{see excel}$$

(f_{cd} = 20 MPa)

- Spacing of rebars

$s \leq \min(2h_s ; 250 \text{ mm})$

$s \leq \min(2 \times 28 ; 250) = 58 \text{ mm}$ but recommended minimum value is 100 mm

This rule has met for all rebars designed.

3.1.1. Upper reinforcement

$\frac{1}{3} l_n$ - column strip

$\frac{1}{4} l_n$ - middle strip

Panel C0 ($l_n = 6575 \text{ mm}$)

$L_{bar} = \frac{1}{3} l_n = \frac{1}{3} \times 6575 = 2192 \text{ mm}$

- Anchorage length

$l_{b,rqd} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}}$

$\sigma_{sd} = f_{yd} = 435 \text{ MPa}$

$f_{ctd} = \frac{f_{ct,k,0,05}}{1,5}$

For C30/37 $f_{ct,k0,05} = 2 \text{ MPa}$

$f_{ctd} = \frac{2}{1,5} = 1,33 \text{ MPa}$

$f_{bd} = 2,25 \cdot \alpha_1 \cdot \alpha_2 \cdot f_{ctd}$
$= 2,25 \cdot 1 \cdot 1 \cdot 1,33$
$\simeq 3,00 \text{ MPa}$

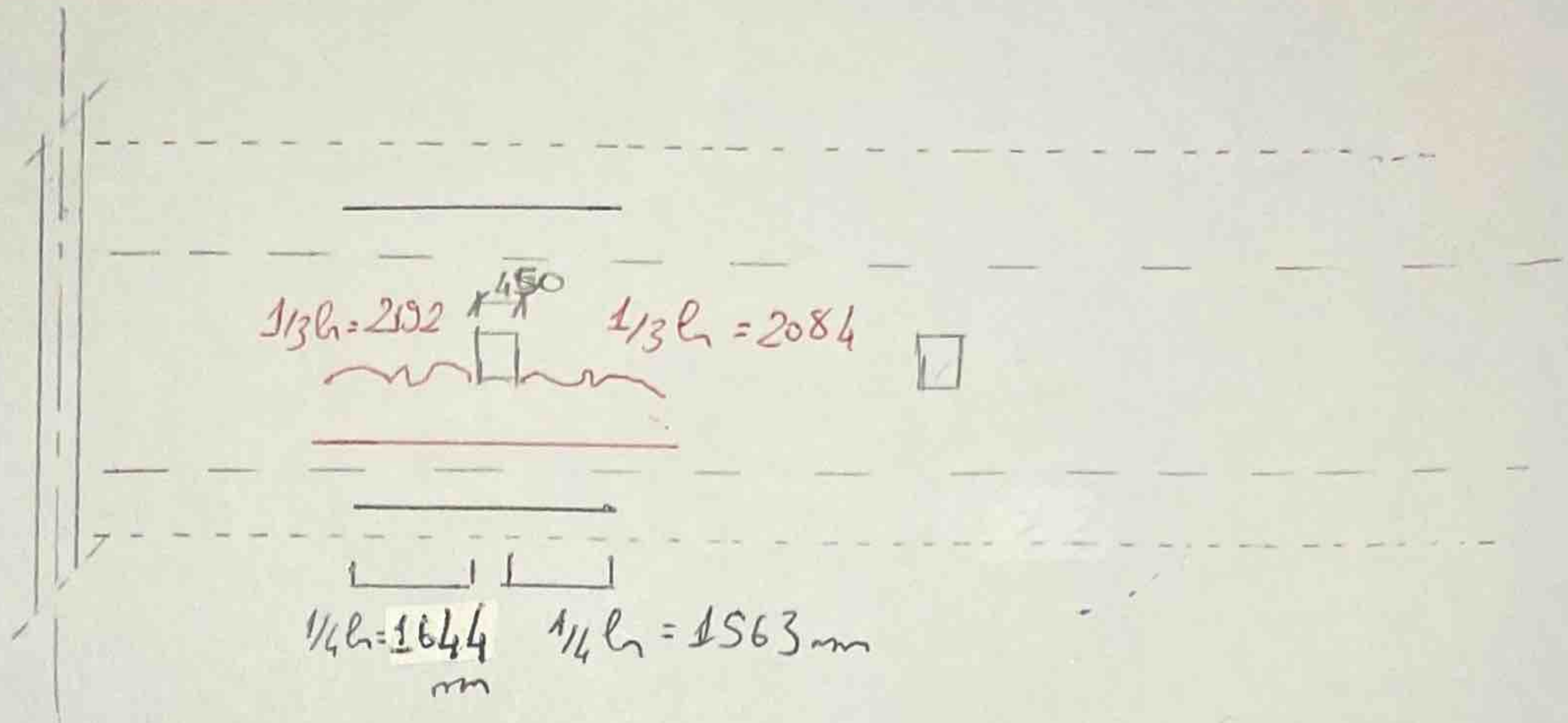
For $\phi 12 \text{ mm}$

$l_{b,rqd} = \frac{12}{4} \cdot \frac{435}{3} = 435 \text{ mm}$; $l_{bd} = \underbrace{\alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5}_{=1} \cdot l_{b,rqd}$
$= 435 \text{ mm}$

$l_{b,min} = \max(0,3 \cdot l_{b,rqd} ; 10\phi ; 100 \text{ mm})$
$= \max(0,3 \cdot 435 ; 10 \times 12 ; 100) = 130,5 \text{ mm}$

$l_{bd} > l_{b,min}$ OK

Panel C6



Panel 3

Anchorage length

For φ12

$l_{bd} = 435\ mm$

For φ10

$$l_{b,rqd} = \frac{\phi}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} = \frac{10}{4} \cdot \frac{435}{3} \simeq 363\ mm$$

$$l_{bd} = \underbrace{\alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4}_{=1} \cdot \alpha_5 \cdot l_{b,rqd} = 363\ mm$$

$$l_{b,min} = max(0{,}3\ l_{b,rqd};\ 10\phi;\ 100\ mm)$$

$$max(109;\ 100;\ 100) = 109\ mm$$

$l_{bd} > l_{b,min}$ OK

4. Punching in colom C3

4.1. Resistance without reinforcement

Column with caps

* $v_{Ed,1} = \frac{\beta . V_{Ed}}{u_1 . d}$

$= \frac{1,15 \times 842 \times 10^3}{5370 \times 243,5}$

$\simeq$ 0,74 MPa

$\beta = 1,15$
$V_{Ed} = 842$ kN
$u_1 = 5370$ mm
} From Homework 7

$d = \frac{d_c + d_3}{2} = \frac{238 + 249}{2} = 243,5$ mm

$d_c = 238$ mm ; $d_3 = 249$ mm

* $v_{Rd,c} = \max\left[C_{Rd,c} \cdot k \cdot \sqrt[3]{(100\, \rho_1 \cdot f_{ck})} ; 0,035\sqrt{k^3 f_{ck}}\right]$

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

$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{243,5}} \simeq 1,91 < 2$ OK!

* $\rho_1 = \sqrt{\rho_{lc} \cdot \rho_{l3}}$; $\rho_{lc} = \frac{a_{sc}}{1000 d_c} = \frac{1131}{1000 . 238}$

$\simeq 0,00475$

$\rho_{l3} = \frac{a_{s3}}{1000 d_3} = \frac{1131}{1000 . 249}$

$\simeq 0,00454$

$\rho_l = \sqrt{\rho_{lc} \cdot \rho_{l3}} = \sqrt{0,00475 \cdot 0,00454} = 0,00464$

* $f_{ck} = 30$ MPa

$\rightarrow v_{Rd,c} = \max\left[0,12 \cdot 1,91 \cdot \sqrt[3]{100 \cdot 0,00464 \cdot 30} ; 0,0035\sqrt{1,91^3 \cdot 30}\right]$

$= \max[0,55 ; 0,050] = 0,55$ MPa

$v_{Ed,1} > v_{Rd,c}$ → we need to design punching reinforcement.
(0,74 MPa) (0,55 MPa)

4.2. Design of punching reinforcement

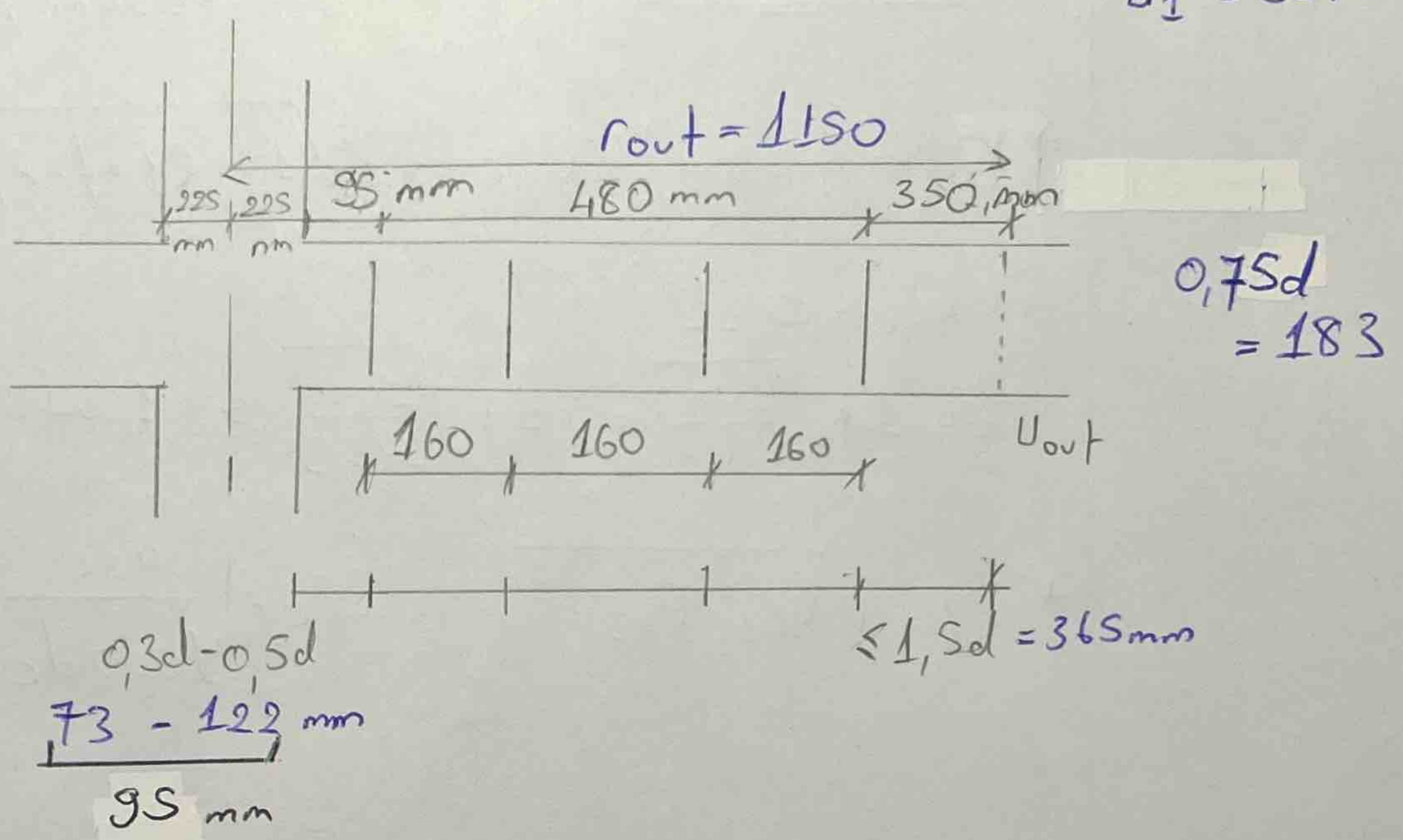
- $u_{out} = \frac{\beta \cdot V_{Ed}}{v_{Rd,c} \cdot d} = \frac{1,15 \cdot 842 \times 10^3}{0,55 \times 243,5} = 7230 \text{ mm}$

- $r_{out} = \frac{u_{out}}{2\pi} = \frac{7230}{2\pi} \approx 1150 \text{ mm}$

Layout of punching reinforcement

$d = 243,5 \text{ mm}$

$u_1 = 3370 \text{ mm}$



- Number of rails

$n \geq \max\left(\frac{2\pi(r_{out} - 1,5d)}{2d} ; \frac{u_1}{1,5d}\right)$

$\geq \max\left(\frac{2\pi(1150 - 1,5 \cdot 243,5)}{2 \times 243,5} ; \frac{3370}{1,5 \cdot 243,5}\right)$

$\geq \max(10,12 ; 14,7) = 15 \text{ rails}$

- Cross-sectional area of studs

Let's use $\phi 10$ for studs $A_{sw1,\phi 10} = 79 \text{ mm}^2$

$A_{sw} = n \cdot A_{sw,1}$

$= 15 \cdot 79 = 1185 \text{ mm}^2$

$$* v_{Ed,1} = \frac{\beta \cdot V_{Ed}}{u_1 \, d} = 0,74 \text{ MPa}$$

$$v_{Rd,cs} = 0,75 \cdot v_{Rd,c} + 1,5 \frac{d}{s_r} \cdot A_{sw} \cdot f_{yw,ef} \cdot \frac{1}{u_1 \cdot d} \cdot \sin\alpha \leq k_{max} \cdot v_{Rd,c}$$

$\rightarrow f_{ywd,ef} = 250 + 0,25d \leq f_{ywd}$

$= 250 + 0,25 \cdot 243,5$

$\simeq 311$ MPa < 435 MPa OK!

$$v_{Rd,cs} = 0,75 \cdot 0,55 + 1,5 \cdot \frac{243,5}{160} \cdot 1185 \cdot \frac{1}{5370 \cdot 243,5} \times 311 \cdot \sin(90) \leq 1,80 \cdot 0,55$$

$1,05$ MPa $\overset{?}{<}$ $0,99$ MPa

Therefore $v_{Rd,cs} = 0,99$ MPa

$v_{Ed,1} < v_{Rd,cs}$ CHECKED!

(0,74 MPa) (0,99 MPa)

4.3. Check of punching reinforcement ratio

$$\rho_{sw} = 1,5 \cdot \frac{A_{sw,1}}{s_r \cdot s_t} \geq \rho_{sw,min}$$

$$1,5 \cdot \frac{79}{160 \cdot 335} = 0,0022$$

$$\rho_{sw,min} = 0,08 \cdot \frac{\sqrt{30}}{500} = 0,00088$$

$\rho_{sw} > \rho_{sw,min}$ CHECKED!

$s_r = 160$ mm

$$s_{t,real} = \frac{2\pi \cdot (r_{out} - 350)}{n} = \frac{2\pi(1150 - 350)}{15} = 335 \text{ mm}$$