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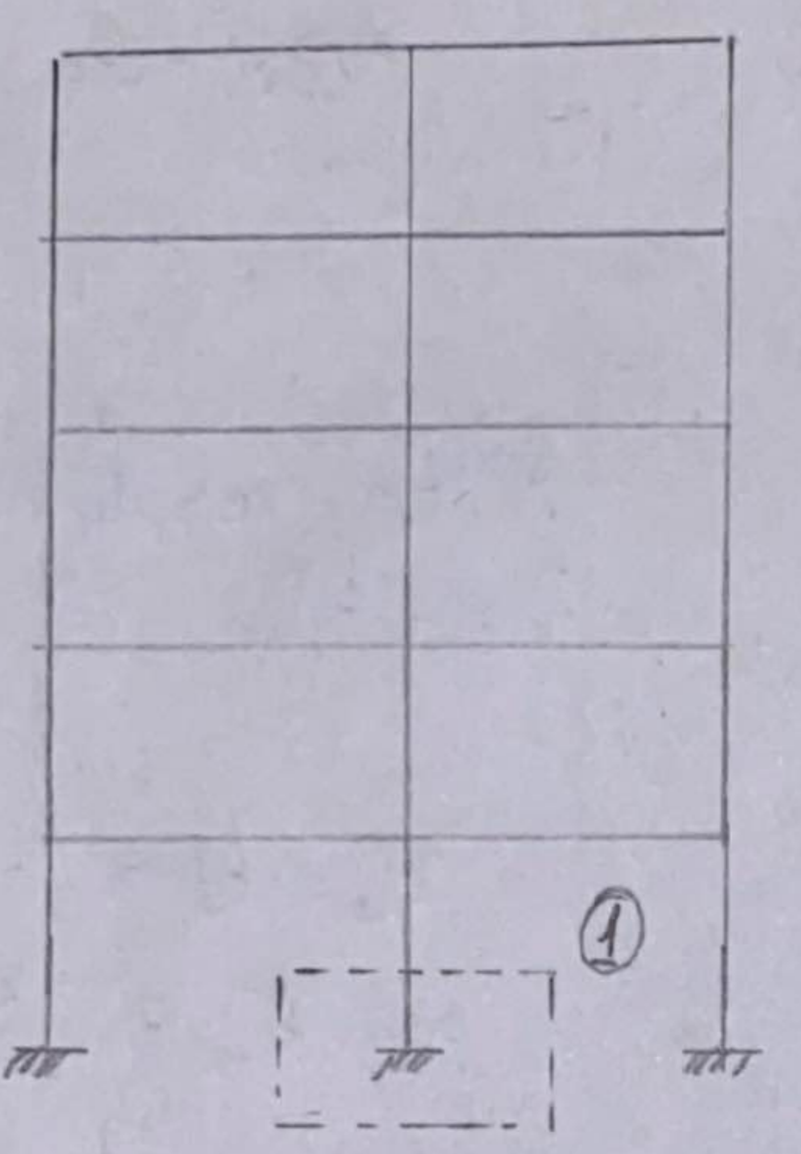
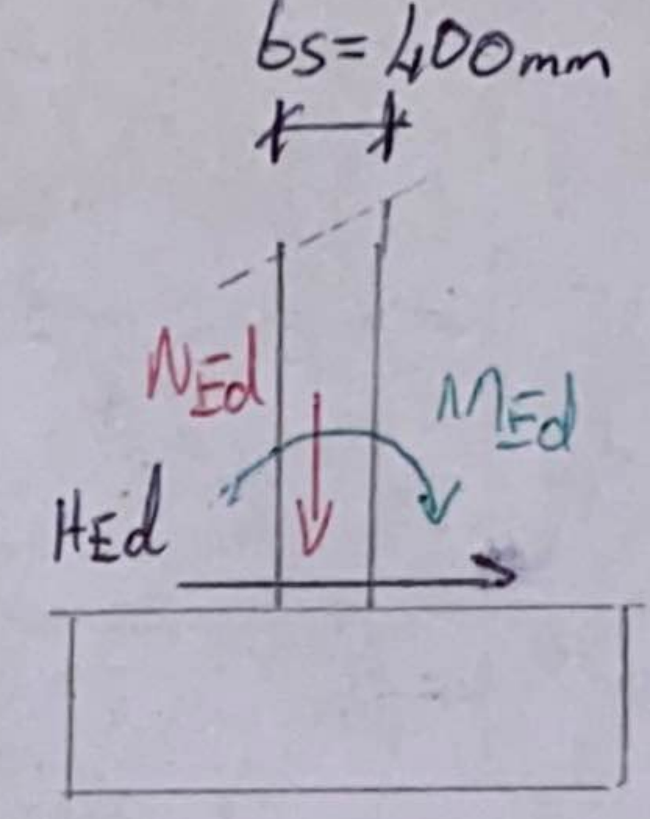
TASK 7: PAD FOOTING

1) Design of dimensions





* $H_{Ed} = V_{Ed}$

From IDEASTATICA

* $N_{Ed} = 3867{,}9$ kN
* $H_{Ed} = V_{Ed} = 29{,}5$ kN
* $M_{Ed} = 69{,}7$ kNm

Self-weight of the footing can be estimated as:

$G_o = 0{,}1\, N_{Ed}$

$G_o = 0{,}1 \times 3867{,}9 = \underline{386{,}79 \text{ kN}}$

Width of the footing b can be obtained:

$\rightarrow A_{eff} = b \cdot (b - 2e)$

$\rightarrow 0 = b^2 - 2be - A_{eff}$

$\rightarrow 0 = b^2 - 2be - \dfrac{N_{Ed} + G_o}{R_d}$ ①

$A_{eff} \geq \dfrac{N_{Ed} + G_o}{R_d}$

AND $e = \dfrac{M_{Ed} + H_{Ed} \cdot h}{N_{Ed} + G_o}$

$h = \left(\dfrac{b}{2} - \dfrac{b_s}{2}\right) \tan \alpha$

$$e = \frac{M_{Ed} + H_{Ed} \cdot \left(\frac{b}{2} - \frac{b_s}{2}\right) \tan\alpha}{N_{Ed} + G_o}$$

$$e = \frac{M_{Ed} + \frac{H_{Ed} \cdot \tan\alpha \cdot b}{2} - \frac{H_{Ed} \cdot \tan\alpha \cdot b_s}{2}}{N_{Ed} + G_o} \quad ②$$

We insert equation (2) in equation (1)

$$0 = b^2 - \frac{2M_{Ed}.b + H_{Ed}.\tan\alpha.b^2 - H_{Ed}.\tan\alpha.b_s.b}{N_{Ed}+G_0} - \frac{N_{Ed}+G_0}{R_d}$$

$$\Leftrightarrow 0 = b^2 - \frac{H_{Ed}.\tan\alpha.b^2}{N_{Ed}+G_0} - \frac{(2M_{Ed} - H_{Ed}.\tan\alpha.b_s)}{N_{Ed}+G_0}b - \frac{N_{Ed}+G_0}{R_d}$$

$$\Leftrightarrow 0 = \underbrace{\left(1 - \frac{H_{Ed}.\tan\alpha}{N_{Ed}+G_0}\right)}_{a} b^2 - \underbrace{\frac{(2M_{Ed} - H_{Ed}.\tan\alpha.b_s)}{N_{Ed}+G_0}}_{b} b - \underbrace{\frac{N_{Ed}+G_0}{R_d}}_{c}$$

$$\Leftrightarrow \boxed{ax^2 + bx + c}$$

$H_{Ed} = 29,5$ kN
$\alpha = 60°$
$N_{Ed} = 3867,9$ kN
$G_0 = 386,79$ kN
$M_{Ed} = 69,7$ kN
$b_s = 0,40$ m
$R_d = 400$ kPa

With resolution of quadratic equation in calculator, we obtain:

$x_1 = b_1 = -3,27$ m
$x_2 = b_2 = 3,29$ m

b_1 hasn't physical sense. So $\boxed{b = 3,29 \text{ m}}$

Design b value = 3,30 m

Estimations:

- The height of the footing:

$$h = \left(\frac{b - b_s}{2}\right)\tan\alpha = \left(\frac{3,30 - 0,4}{2}\right)\tan(60) \simeq 2,51 \text{ m}$$

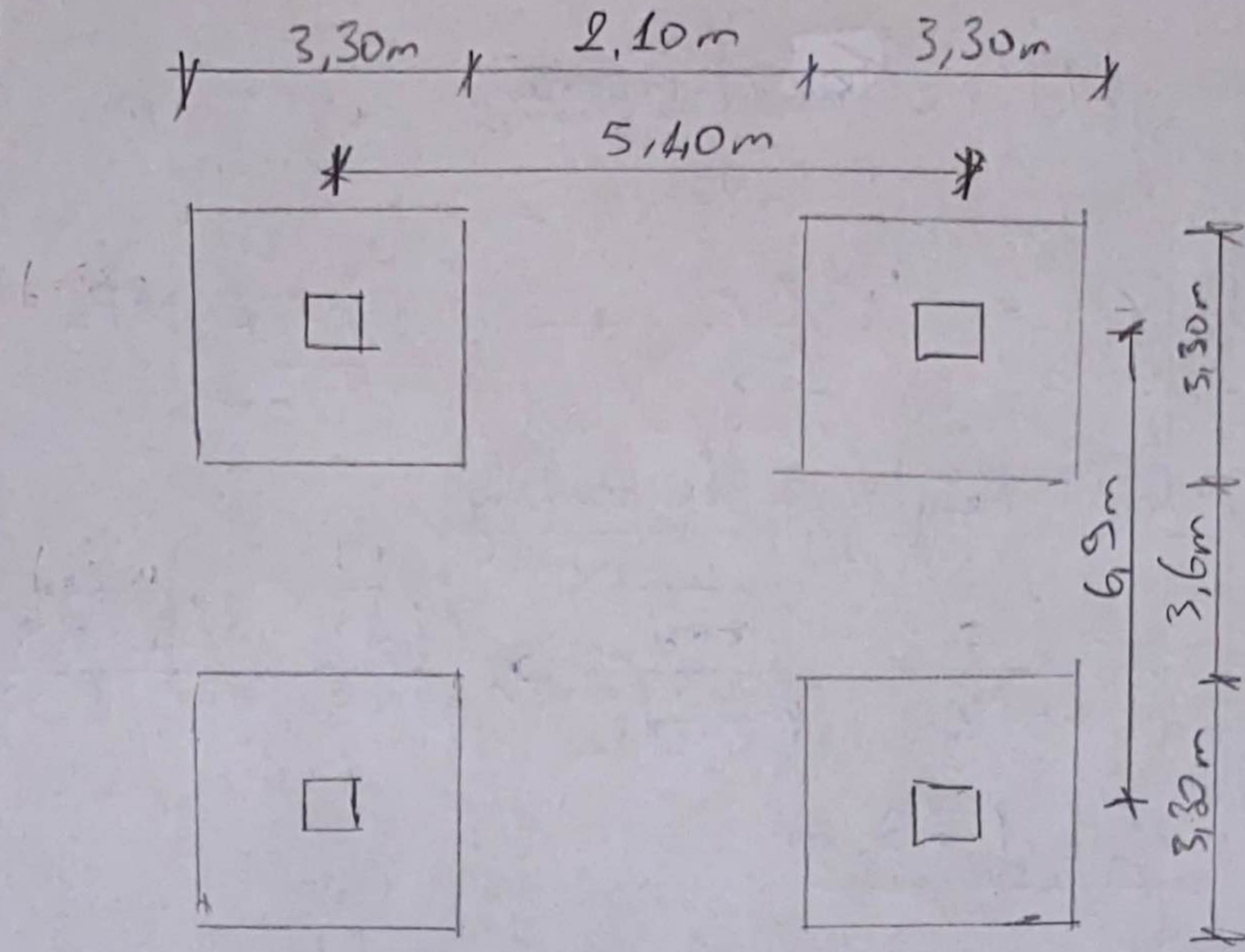
- $$e = \frac{M_{Ed} + H_{Ed}.h}{N_{Ed} + G_0} = \frac{69,7\times10^3 + 29,5\times10^3\times2,51}{3867,9\times10^3 + 386,79\times10^3} \simeq 0,0337$$

33,8 mm

- $$A_{eff} \geq \frac{N_{Ed}+G_0}{R_d} = \frac{3867,9\times10^3 + 386,79\times10^3}{400\times10^3} = 10,64 \text{ m}^2$$

$A_{eff} \geq 10,64$ m^2

Check of clear distance

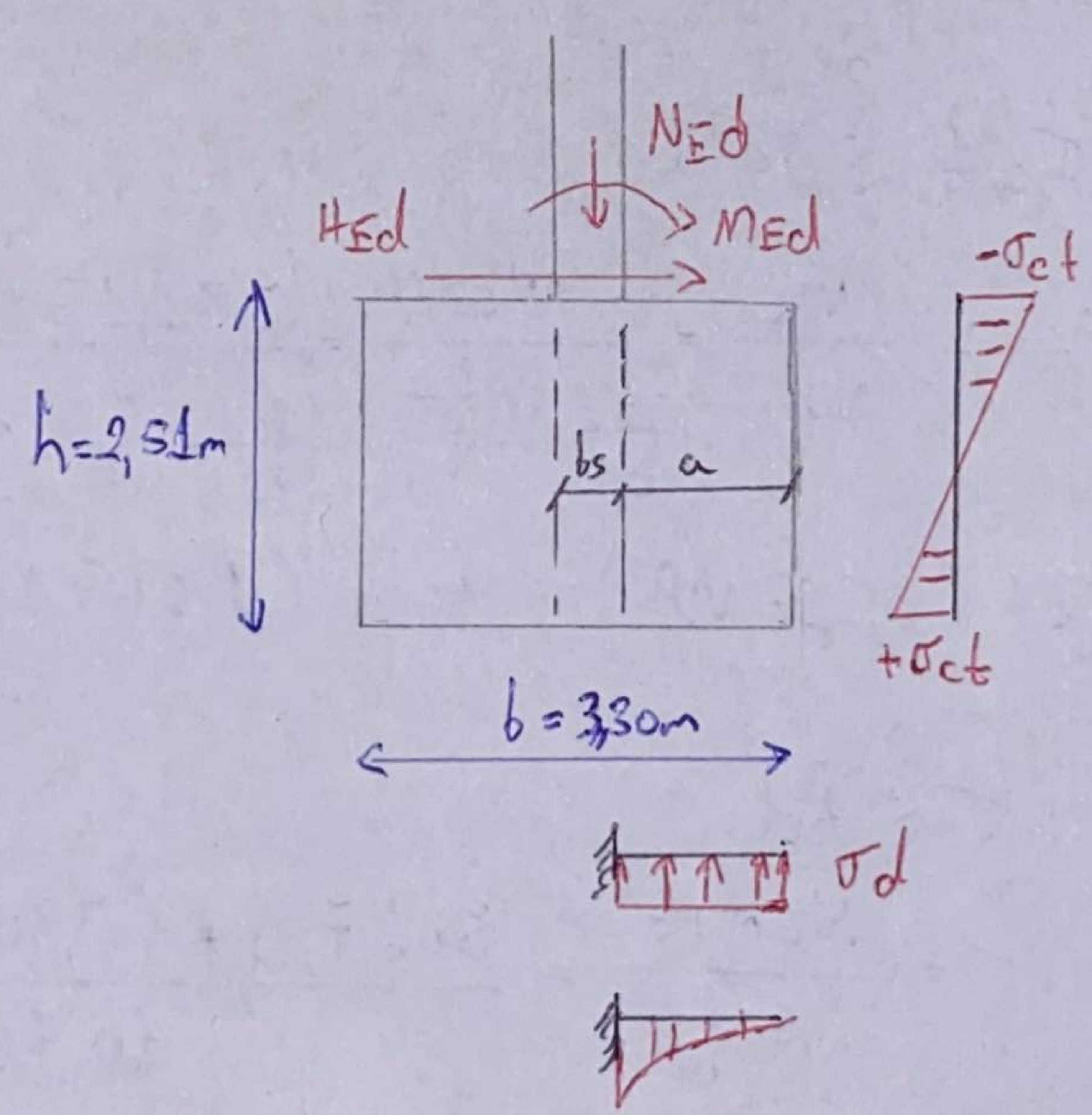


In horizontal direction 2,10m < b (3,30m) not checked!
In vertical direction 3,60m > b (3,30m) checked.
We should change pad footing by strip footing in horizontal direction.

2) Design of plain concrete pad footing

$b_s = 0,40$ m

$a = \frac{b - b_s}{2} = \frac{3,30 - 0,40}{2} = 1,45$ m



Stress in cantilever:

$$\sigma d = \frac{N_{Ed}}{A_{eff}} = \left(\frac{3867,9 \times 10^3}{10,64}\right) \times 10^{-3} \simeq 363,52 \text{ kPa}$$

Bending moment in cantilever

$$M_c = \frac{1}{2} \sigma d\, a^2 = \frac{1}{2} \times 363,52 \times 1,45^2 \simeq 382,15 \text{ kNm/m}$$

- **Tensile strength of concrete**

$$f_{ctd} = \frac{\alpha_{ct} \cdot f_{ctk,0,05}}{\gamma_c}$$

for C30/37
$f_{ctk,0,05} = 2,0$

$$= \frac{0,8 \times 2}{1,5} \simeq 1,067 \text{ MPa}$$

- **Real height of the footing**

$$h \geq \frac{a}{0,85} \cdot \sqrt{\frac{3\sigma_d}{f_{ctd}}} \geq \frac{1,45}{0,85} \cdot \sqrt{\frac{3 \times 363,52 \times 10^{-3}}{1,067}} \simeq 1,72 \text{ m}$$

$h = 1,75$ m

- Real value of e: $\frac{M_{Ed} + H_{Ed} \cdot h}{N_{Ed} + G_o} = \frac{69,7 \times 10^3 + 29,5 \times 10^3 \times 1,75}{3867,9 \times 10^3 + 386,79 \times 10^3}$

$\simeq 0,0285 \text{ m} = 28,5 \text{ mm}$

- Real value of $A_{eff} = b \cdot (b - 2e)$

$= 3,30 \cdot (3,30 - 2 \times 0,0285) \simeq 10,70 \text{ m}^2$

2.1) Check of the footing

* $\sigma_{ct} \overset{?}{\leq} f_{ctd}$

$$\sigma_{ct} = \frac{M_c}{W} = \frac{M_c}{\frac{1}{6} \cdot b \cdot h^2} = \left(\frac{382,15 \times 10^3}{\frac{1}{6} \cdot 3,30 \times 1,75^2} \right) \times 10^{-6} \simeq 0,227 \text{ MPa}$$

σ_{ct} (0,227 MPa) < f_{ctd} (1,067 MPa) checked!

* $\sigma \overset{?}{\leq} R_d$

$$\sigma = \frac{N_{Ed} + G}{A_{eff}} = \frac{3867,9 + (3,30^2 \times 1,75 \times 25)}{10,70} \simeq 406 \text{ kPa}$$

σ (406 kPa) > R_d (400 kPa) NOT CHECKED!

The second condition isn't checked. We can try to resolve the problem by increasing A_{eff}. As $A_{eff} = b \cdot (b - 2e)$, we should increase the width of the foundation b.

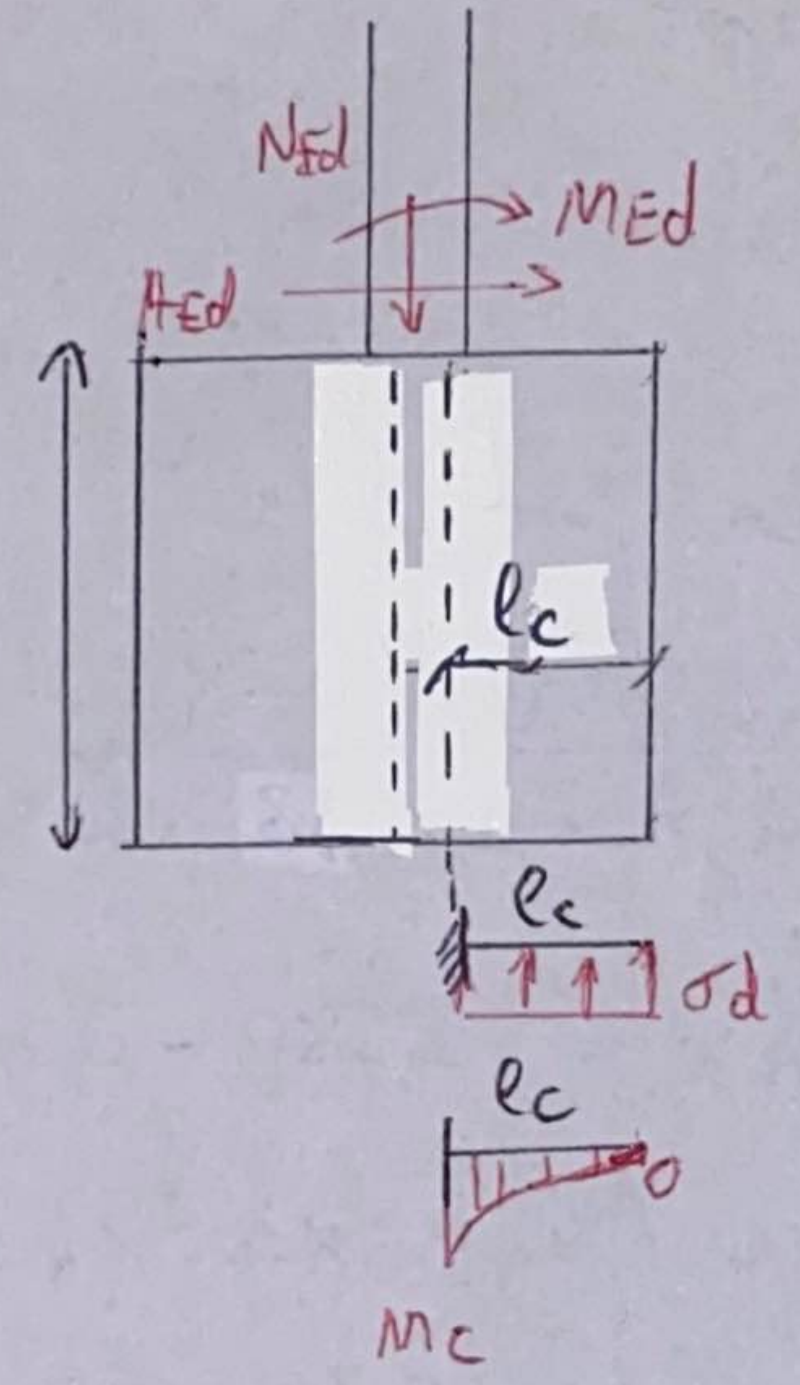
3) Design of reinforced concrete pad footing

• $h = a \Rightarrow a = 1{,}45\,m$; $h = 1{,}45\,m$

• $e = \dfrac{M_{Ed} + H_{Ed} \cdot h}{N_{Ed} + G} = \dfrac{69{,}7 \times 10^3 + 29{,}5 \times 10^3 \times 1{,}45}{3867{,}9 \times 10^3 + (3{,}30^2 \times 1{,}45 \times 25 \times 10^3)}$

$\simeq 0{,}0263 \simeq 26{,}4\ mm$

• $A_{eff} = b \cdot (b - 2e) = 3{,}30 \cdot (3{,}30 - 2 \times 0{,}0263) \simeq 10{,}72\,m^2$



$\sigma_d = \dfrac{N_{Ed}}{A_{eff}} = \dfrac{3867{,}9}{10{,}72} \simeq 360{,}81\ kPa$

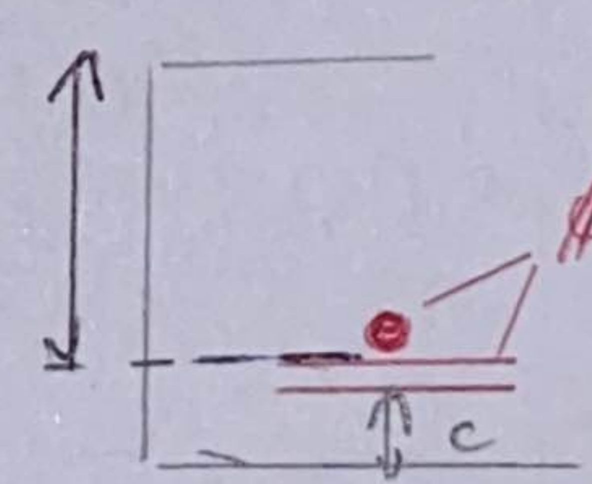
$l_c = a + 0{,}15\,b_s$

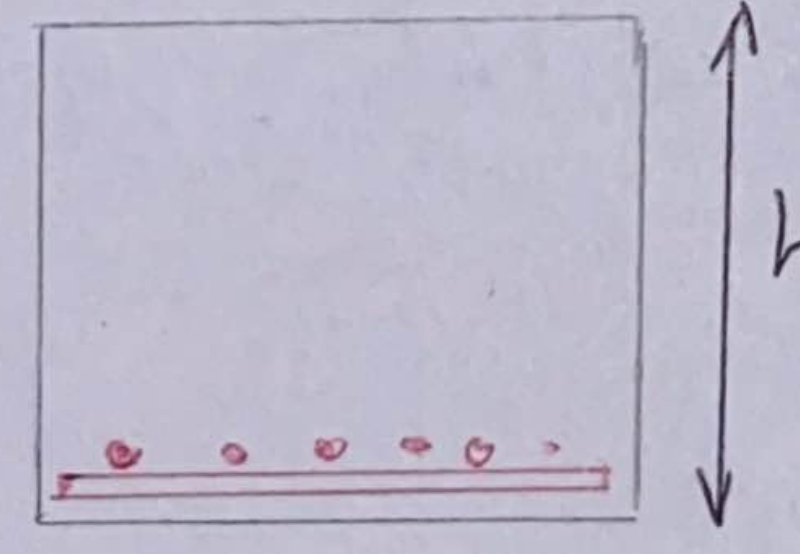
$l_c = 1{,}45 + 0{,}15 \times 0{,}4 = 1{,}51\,m$

$M_c = \dfrac{1}{2}\sigma_d \cdot l_c^2$

$= \dfrac{1}{2}\, 360{,}81 \times 1{,}51^2 \simeq 411\ kNm/m$

Effective depth d





$d = h - c - Ø_{rebar}$

$d = 1450 - 50 - 20$

$= 1380\ mm$

Reinforcement required : $a_{s,rqd} = \dfrac{M_c}{Z \cdot f_{yd}} = \dfrac{M_c}{0{,}9 \cdot d \cdot f_{yd}}$

$= \left(\dfrac{411 \times 10^3}{0{,}9 \times 1{,}380 \times 435 \times 10^6}\right) \times 10^4$

$= 7{,}61\ cm^2/m$

Minimum required reinforcement

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

$$\max\left(0,26 \cdot \frac{2,9}{500} \cdot 1,00 \cdot 1,380 \, ; \, 0,0013 \times 1 \times 1,380\right) \times 10^4$$

$$\max\left(20,81 \ cm^2/m \, ; \, 17,94 \ cm^2/m\right)$$

$a_{s,min} = 20,81 \ cm^2/m > a_{s,rqd}$

DESIGN $\phi 20 - 150$ mm $\Rightarrow a_{s,prov} = \left(\frac{1000}{150} \times 3,14\right)$

$\phi 20 = 3,14 \ cm^2$

$= 20,93 \ cm^2/m > a_{s,min}$

Check of the design

- The height of compressed part:

$$x = \frac{a_{s,prov} \cdot f_{yd}}{0,8 \cdot b \cdot f_{cd}} = \frac{20,93 \times 10^2 \times 435}{0,8 \times 1 \times 20 \times 10^6} \times 10^3 \cong 56,90 \ mm$$

- level arm $z = d - 0,4x = 1380 - 0,4 \times 56,90 = 1357,24$ mm

$M_{Rd} = a_{s,prov} \cdot f_{yd} \cdot z = (20,93 \times 10^2 \times 435 \times 1,35724) \times 10^{-3}$

$M_{Rd}(1235,70 \ kNm/m) > M_c \ (411 \ kNm/m)$

checked!

3.1) Detailling rules

$$\xi = \frac{x}{d} = \frac{56,90}{1380} \simeq 0,041 < 0,45$$ checked!

Spacing of rebars

$s \leq \min(2h; 250 \ mm)$

$s \leq \min(2 \times 1,45; 250 \ mm)$

$s(150 \ mm) < 250$ mm checked!

Check of stress under the footing.

$$\sigma \overset{?}{<} R_d \ ; \ \sigma = \frac{N_{Ed} + G}{A_{eff}} = \frac{3867,9 + (3,30^2 \times 1,45 \times 25)}{10,72}$$

$\sigma = 397,64$ kPa $< R_d = 400$ kPa checked!