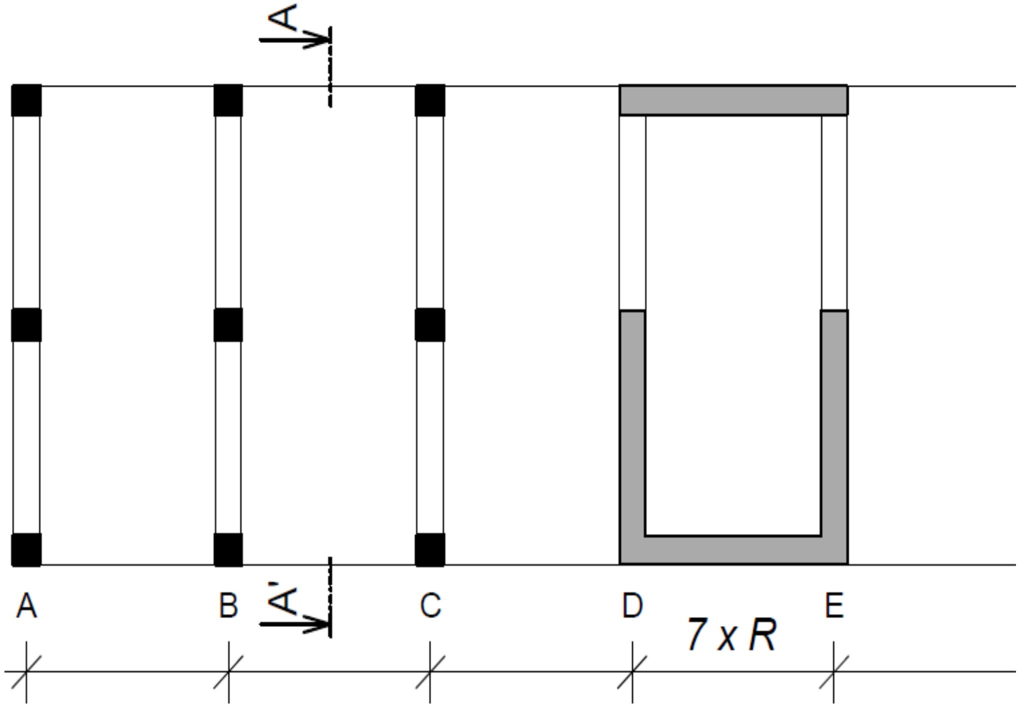
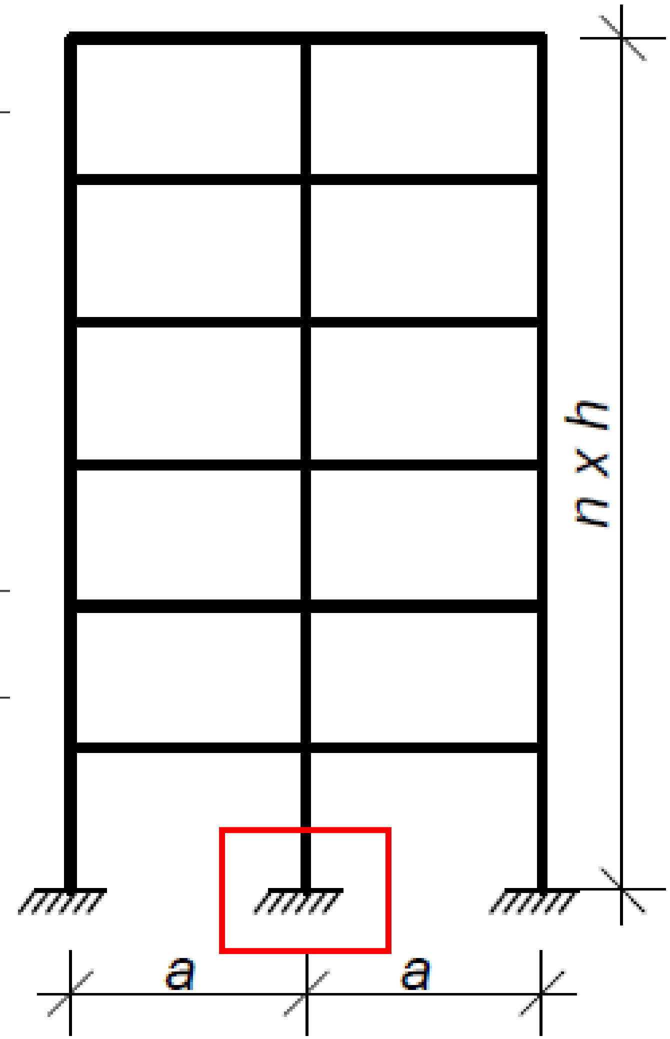
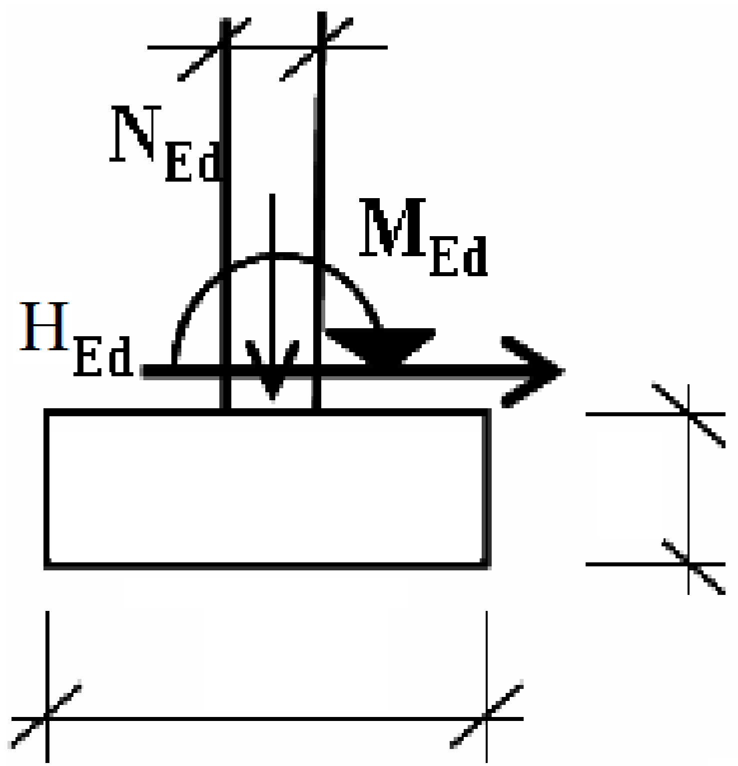
7th task:
Pad footing





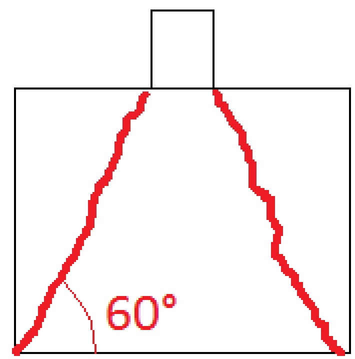
Pad footing

- Design of dimensions
- Design of plain concrete pad footing
- Design of reinforced concrete pad footing
- Drawings (shape and reinforcement of footings)

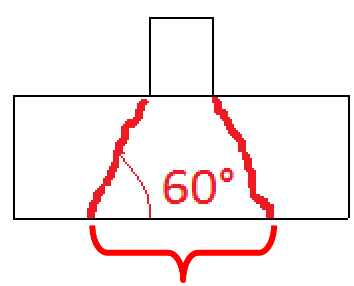


Difference between PC/RC footing

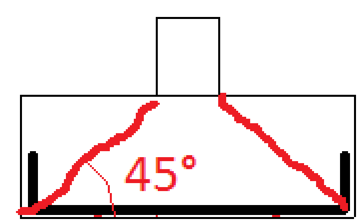
- Difference is in load-bearing angle
- For plain concrete, load-bearing angle is approximately 60°



- For reinforced concrete, the value is 30-45° => footing can be thinner, but you have to use the reinforcement



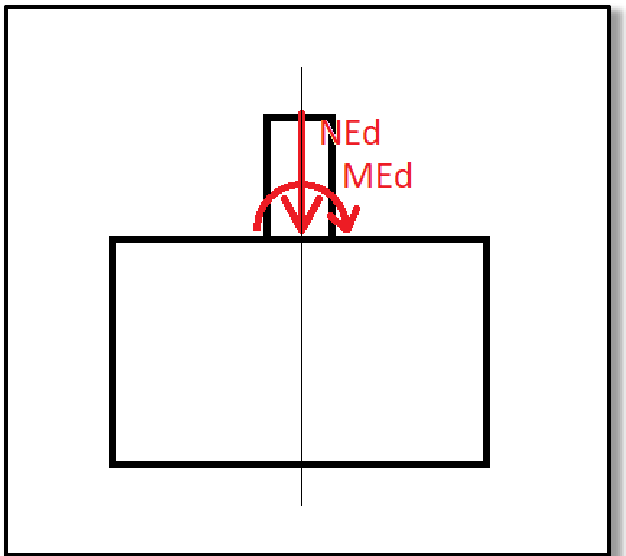
Without reinforcement, only this part is effective

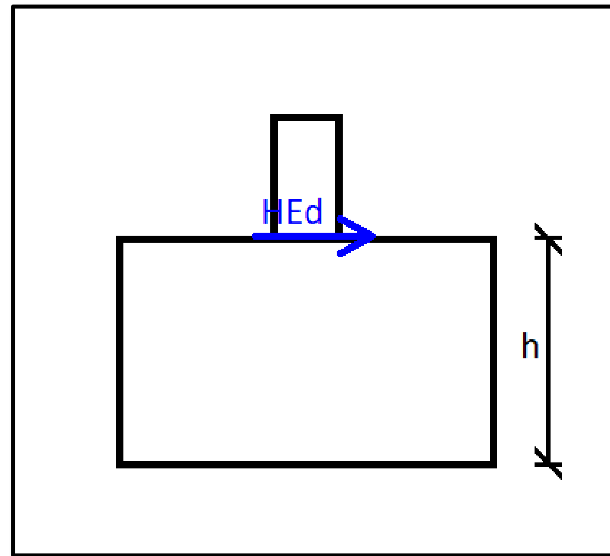


Reinforcement changes load-bearing angle

Loadings

- N_{Ed}, H_{Ed}, M_{Ed} – maximum values in the foot of inner column from 1st task





- Same for plain concrete and reinforced concrete footing

Loadings

- Self-weight of the footing can be estimated as

$$G_0 = 0.1 N_{\mathrm{Ed}}$$

- Design strength of subsoil (sandy gravel)

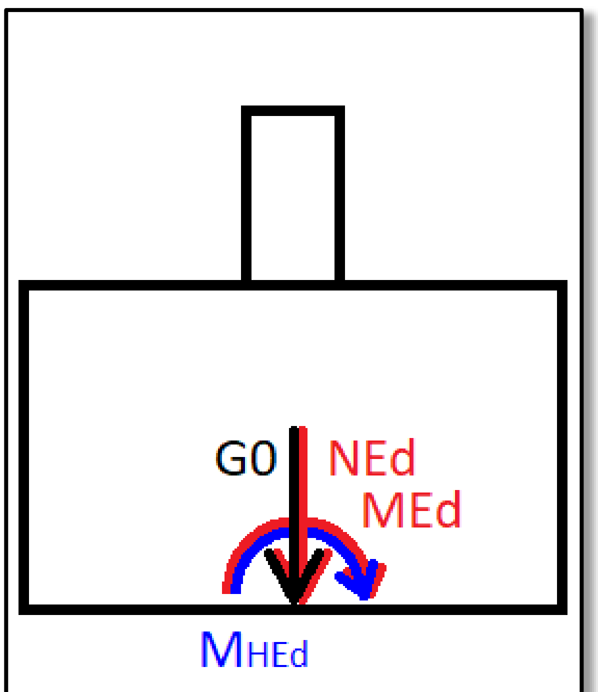
$$R_{\mathrm{d}} = 400 \text{ kPa}$$

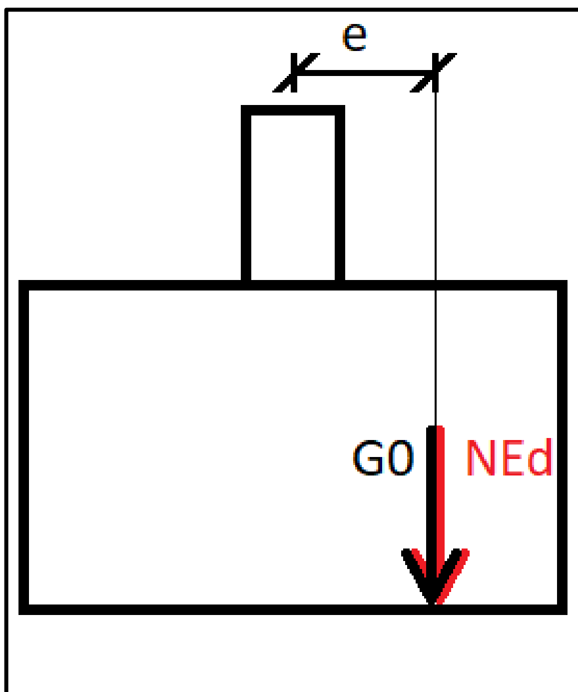
Loadings

- Eccentricity of loading

Height of the footing

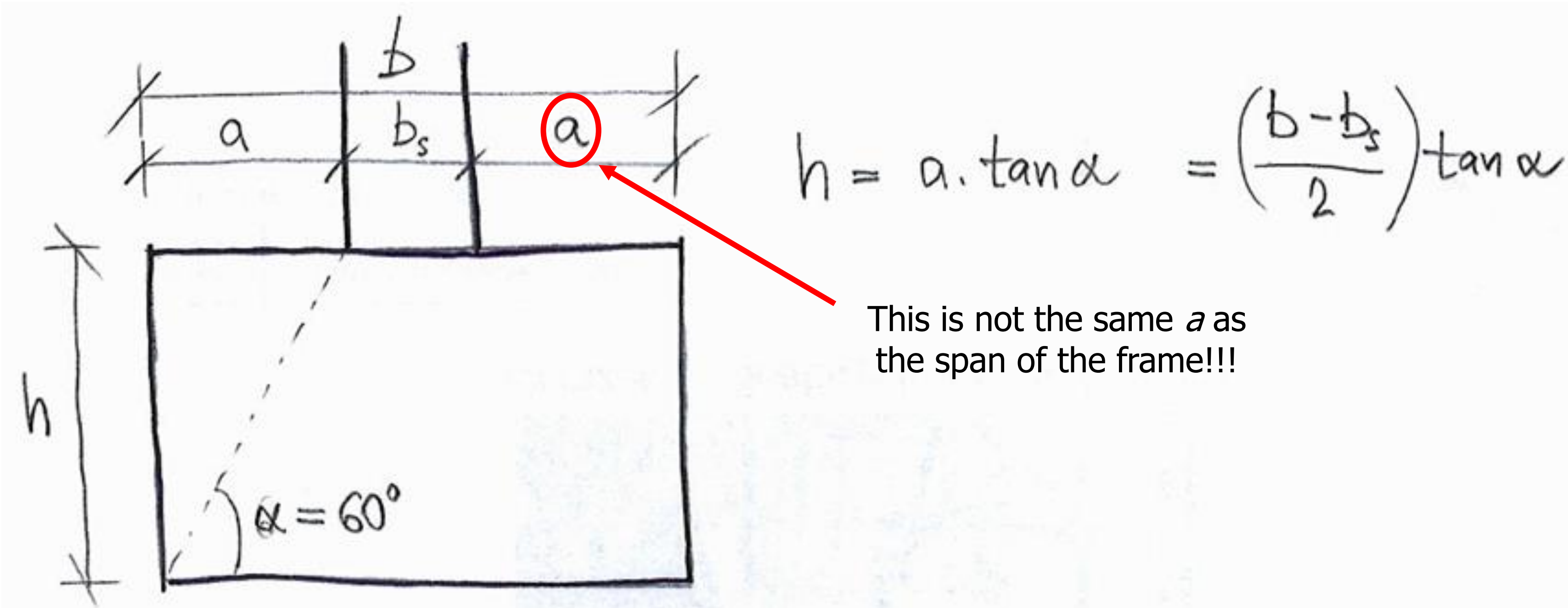
$$e = \frac{M_{\mathrm{Ed}} + H_{\mathrm{Ed}} \cdot h}{N_{\mathrm{Ed}} + G_0}$$





Horizontal dimensions (width)

- The height of the footing is unknown, but we can estimate it from the assumption α = 60 °



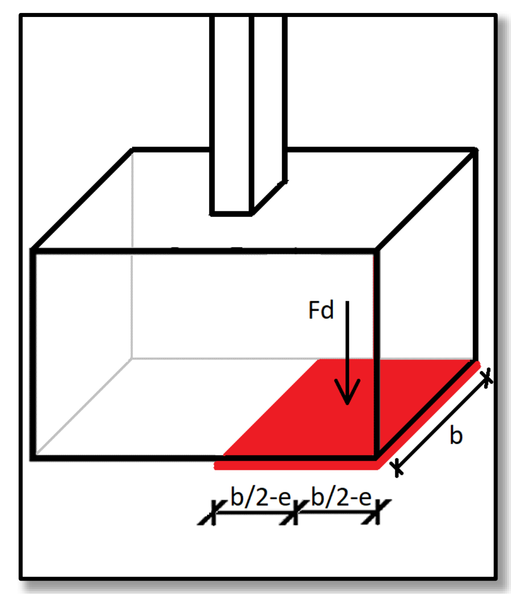
Horizontal dimensions

- Effective area of the footing (from eq. for soil load):

$$\sigma = \frac{N_{\mathrm{Ed}} + G_0}{A_{\mathrm{eff}}} \leq R_{\mathrm{d}} \quad \Rightarrow \quad A_{\mathrm{eff}} \geq \frac{N_{\mathrm{Ed}} + G_0}{R_{\mathrm{d}}}$$

- Width of the footing *b* is also given by quadratic equation from geometry:

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

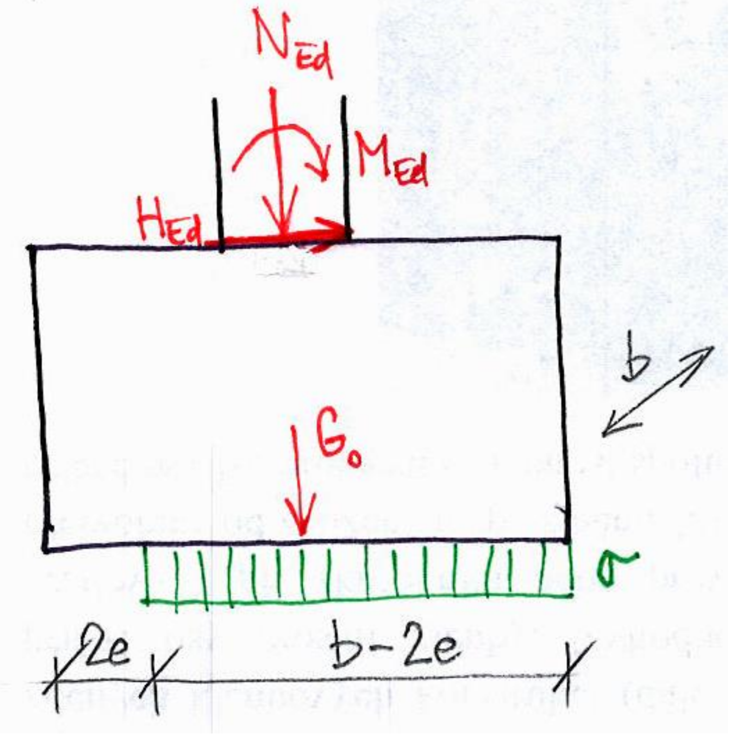


Horizontal dimensions

- From these two equations we can obtain a quadratic equation => two roots, only one of them will make physical sense

$$A_{\text{eff}} \geq \frac{N_{\text{Ed}} + G_0}{R_{\text{d}}}$$

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



Horizontal dimensions

- Calculate <u>real</u> value of *b* – round to 50 mm.

- For further calculations, calculate <u>estimations</u> of *h*, *e*, and A_{eff}

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

$$e = \frac{M_{Ed} + H_{Ed} \cdot h}{N_{Ed} + G_0}$$

$$G_{0,d} = 1.35 \cdot 25 \cdot b^2 h,$$

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

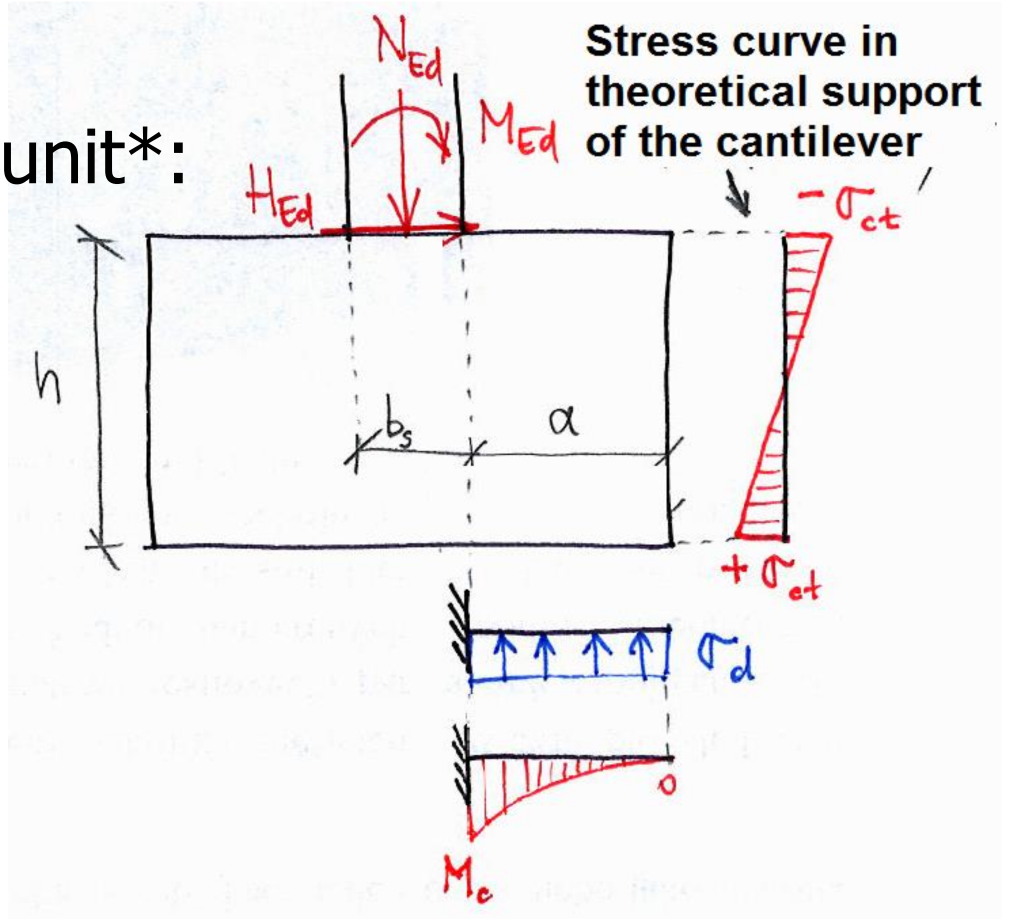
<u>Plain concrete</u> footing

- Footing can be modelled as cantilever of length *a*
- Design stress that bends the cantilever:

$$\sigma_d = \frac{N_{Ed}}{A_{eff}}$$

- Bending moment per unit*:

$$m_c = \frac{1}{2}\sigma_d a^2 \quad [\text{kNm/m}]$$



* We assume transversal width as 1 m.

Plain concrete footing

- <u>Tensile strength</u> of concrete:

Factor expressing the effect of additional shear stresses, 0.8

Characteristic tensile strength of concrete, see table (1st task)

$$f_{\mathrm{ctd}} = \frac{\alpha_{\mathrm{ct}}\, f_{\mathrm{ctk,0.05}}}{\gamma_{\mathrm{c}}}$$

Partial factor, 1.5

- <u>Real height</u> of the footing (round to 50 mm):

$$h \geq \frac{a}{0.85}\sqrt{\frac{3\sigma_{\mathrm{d}}}{f_{\mathrm{ctd}}}}$$

Effect of shear

Plain concrete footing

- Calculate real values of e and A_{eff}

$$h \geq \frac{a}{0.85}\sqrt{\frac{3\sigma_{\mathrm{d}}}{f_{\mathrm{ctd}}}}$$

$$e = \frac{M_{\mathrm{Ed}} + H_{\mathrm{Ed}} \cdot h}{N_{\mathrm{Ed}} + G_0}$$

$$\boldsymbol{G_{0,d} = 1.35 \cdot 25 \cdot b^2 h,}$$

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

Plain concrete footing

- Check of the footing – 2 conditions:
  1. Tensile stress < tensile strength of concrete

$$\sigma_{ct} = \frac{m_c}{W} = \frac{m_c}{\frac{1}{6}bh^2} \leq f_{ctd}$$

Here we take b = 1 m as we calculated m_c per 1 m

  2. Stress under the footing < strength of subsoil

$$\sigma = \frac{N_{Ed} + G}{A_{eff}} \leq R_d$$

Self-weight of the footing (NOT the estimated G_0,but calculated $G_{0,d}$ from real dimensions of your footing)

- If any of the conditions is not checked, the footing should be redesigned (in the homework, just propose the change, do not recalculate).

Reinforced concrete footing

- Choose $h = a$ (load-bearing angle 45°)
- Calculate e, A_{eff} and σ_d (different values than plain concrete footing)

$$h = a$$

$$e = \frac{M_{Ed} + H_{Ed} \cdot h}{N_{Ed} + G_0}$$

$$G_{0,d} = 1.35 \cdot 25 \cdot b^2 h,$$

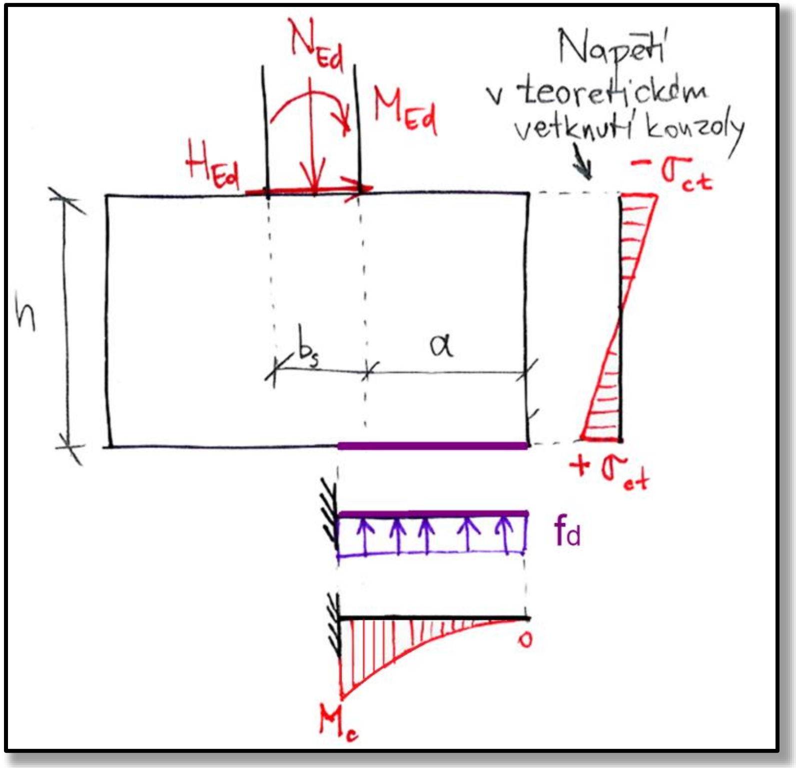
$$A_{eff} = b \cdot (b - 2e)$$

$$\sigma_d = \frac{N_{Ed}}{A_{eff}}$$

Reinforced concrete footing

- Reinforced concrete footing can be modelled as cantilever with the length of:

$$l_c = a + 0,15b_s$$



Reinforced concrete footing

- Calculate m_c (the same formula as for plain concrete footing, but use l_c instead of a)

$$m_c = \frac{1}{2}\sigma_d l_k^2$$

Reinforced concrete footing

- Design and check **bending reinforcement** – calculation procedure is the same as for slabs or beams ($a_{s,req} \rightarrow \emptyset \text{ per } y \text{ mm} \rightarrow a_{s,prov} \rightarrow x \rightarrow z \rightarrow m_{Rd}$).

- Value of m_c is in kNm/m => use b = 1 m in calculation of reinforcement !!!

- Use cover depth 50 mm, 14 – 20 mm rebars (use bigger diameters only if necessary)

Reinforced concrete footing

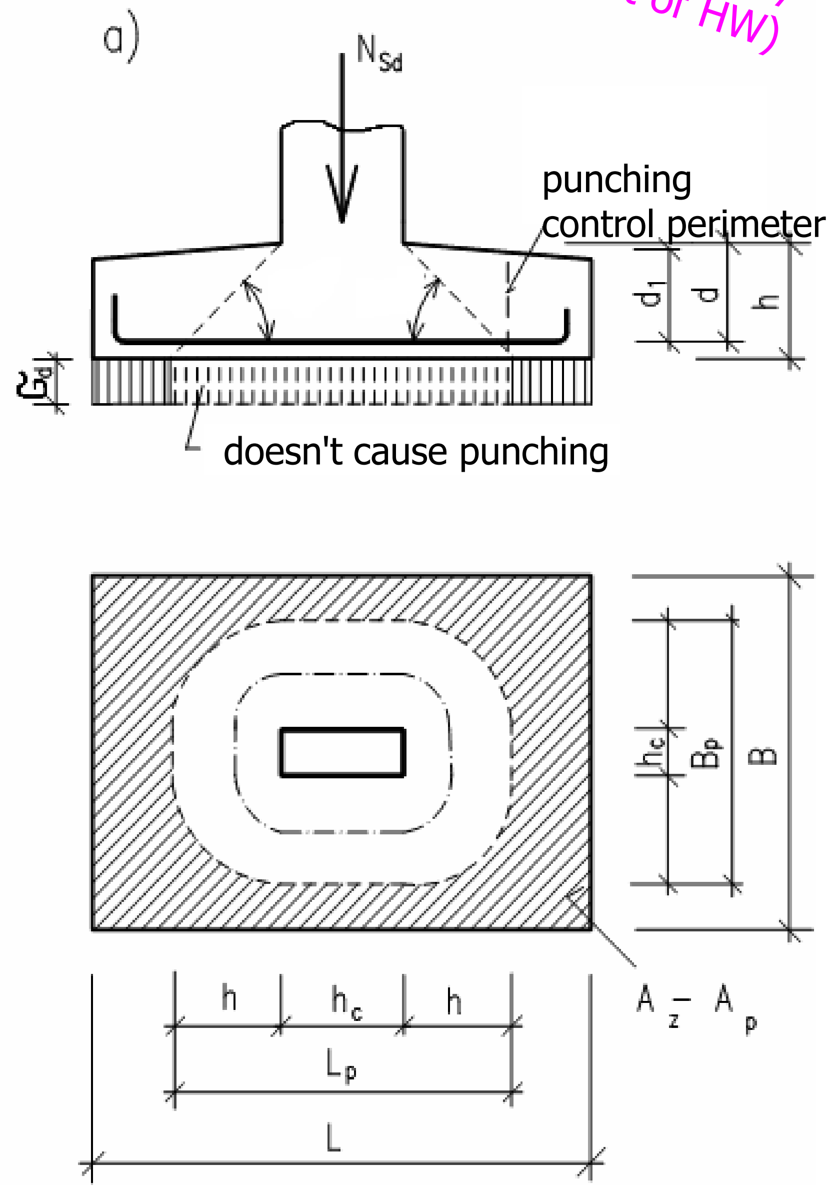
- **Check the stress under the footing** (2nd condition for plain concrete footing)

$$\sigma = \frac{N_{\mathrm{Ed}} + G}{A_{\mathrm{eff}}} \leq R_{\mathrm{d}}$$

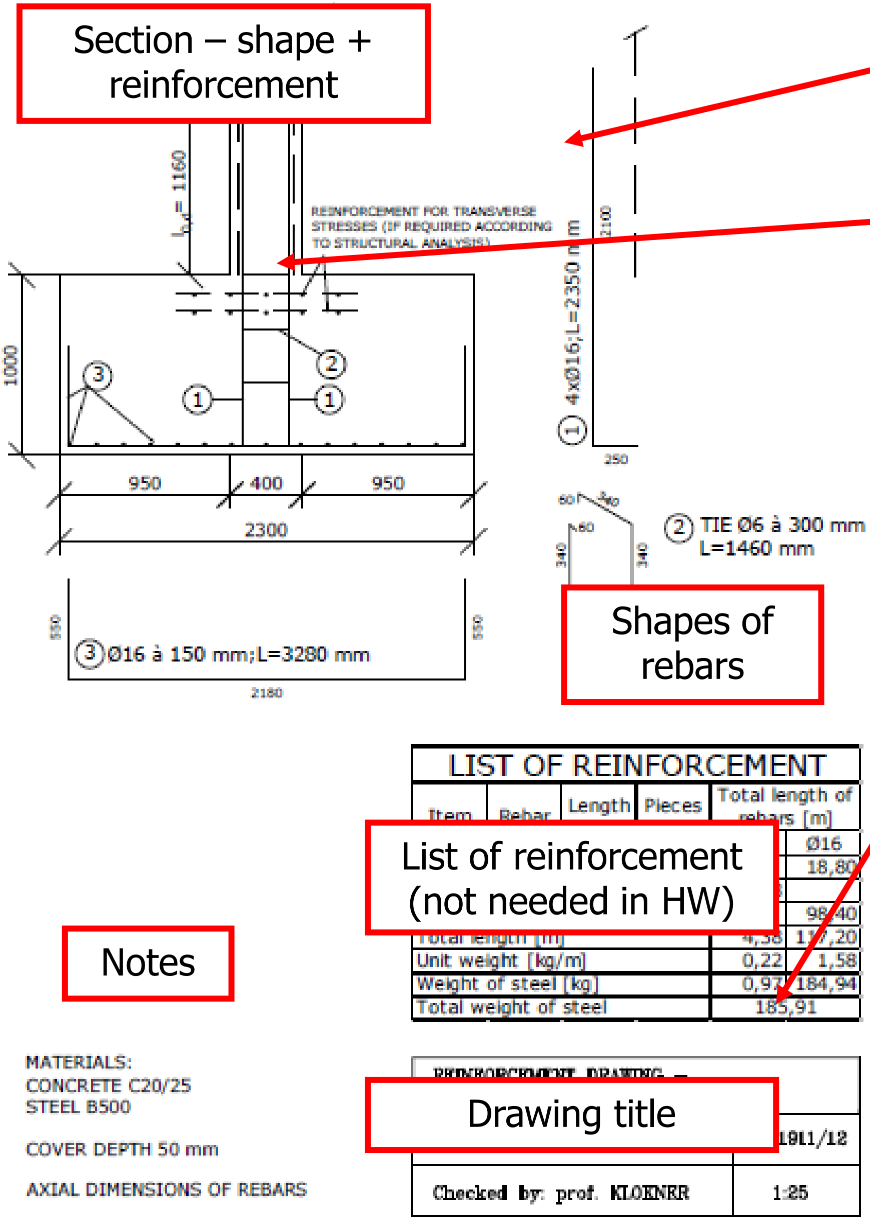
Reinforced concrete footing

Additional theory (not part of HW)

- If load-bearing angle is lower (close to 30°), punching reinforcement may be required
- One has to look for critical position of control perimeter $0{,}5d \le r_u \le 2d$ where $v_{Rd,i} - v_{Ed,i}$ is minimal (iteration)
- Eventually, punching reinforcement should be designed in this perimeter



Drawings



Starting reinforcement for columns (same as column reinforcement)

Ties – see column reinforcement, middle part

Calculate the amount of reinforcement. Bulk density of steel is 7850 kg/m^3

TWO DRAWINGS – one for plain concrete and one for reinforced concrete pad footing