Universitatea Politehnica Timişoara
Facultatea de Construcţii
Departamentul de Căi de Comunicație Terestre, Fundații și Cadastru

FOUNDATIONS

- CURS 9 -

Design of shallow foundations

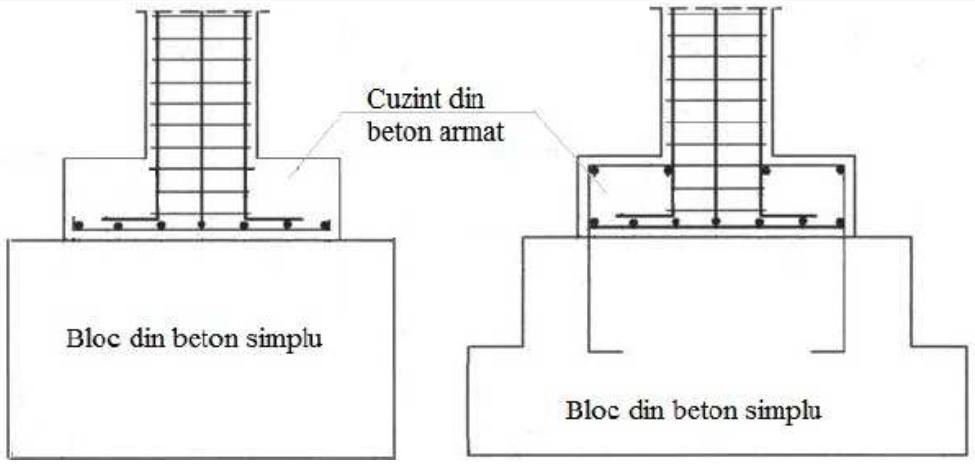
Prof.dr.ing Adrian CIUTINA

CHAPTER VI – SHALLOW FOUNDATIONS

§ 6.6 Design of base and RC pillow foundation

- The **Base and reinforced concrete pillow foundation** (also known as **rigid foundation**) is realized from a plain concrete base and a reinforced concrete pillow under cast-concrete columns.
- The purpose of the base is to increase the area of transmission of pressure between structure and soil.
- The design of Base & Pillow foundation requires two steps:
  - design of the pillow
  - design of the base.

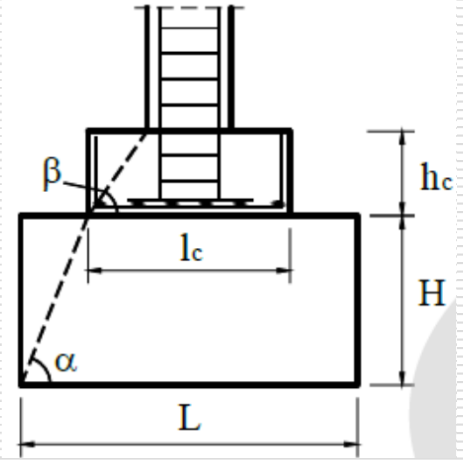
Obs: The plain concrete base could have 1 to 3 steps.

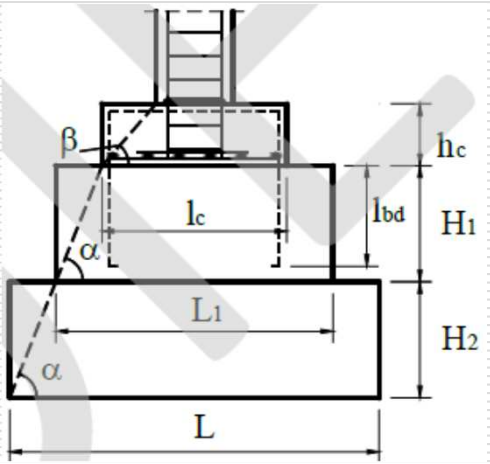


Obs: In order to obtain a horizontal footing level, a 5 to 10 cm equalizing concrete layer is cast (C8/10).

§ 6.6 Design of base and RC pillow foundation
- Pillow design -

- The main purpose of the pillow is to fix the column in the foundation and to spread the concentrated load on a larger contact area.
- In usual cases the pillow has a prismatic form.
- Geometrical requirements (proportioning):
  - l_c/L; b_c/B=*0.50…0.65* for single tread;
  - l_c/L; b_c/B=*0.40…0.50* for multiple treads;
  - $h_c \geq 300mm$ *but* $h_c/L \geq 0.25$;
  - *tanβ≥0.65.* If *tanβ≥1.00* then the check to shear force is not required. Otherwise, the check to shear force should be performed according to Eurcode 2.
  - Concrete class: min C12/15



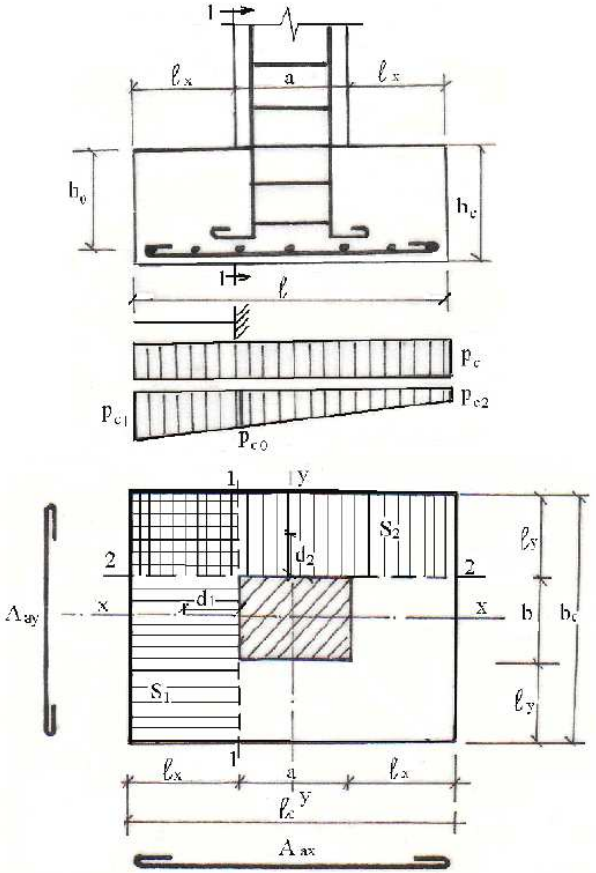


with: l_c, b_c – length and width of the pillow

L, B – length an width of the foundation base

Obs: The final dimensions of the pillow will be found by design checks (pressure and section checking).

§ 6.6 Design of base and RC pillow foundation
- Pillow design -



☐ Pillow reinforcement:

☐ **Sole reinforcement**:

Results from the design to bending moment of the foundation.

Minimum requirements: p_{min}=0.1%, Φ_{min}=10mm, d_{min}=100mm, d_{max}=250mm, anchoring hooks of minimum height (*d*).

☐ **Superior reinforcement**:

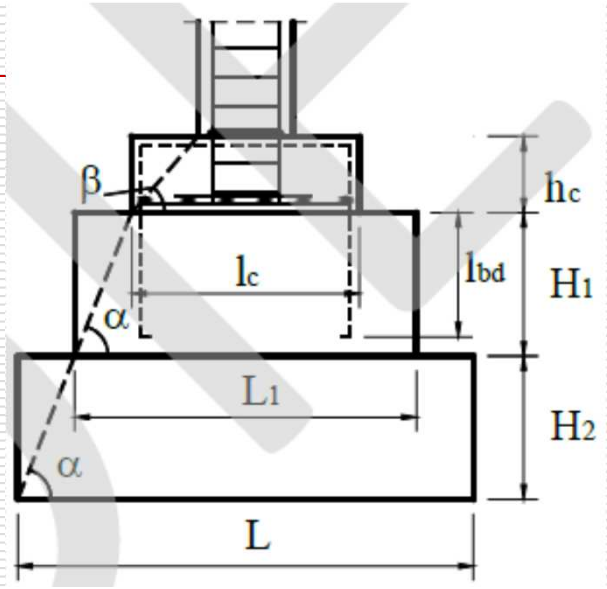
Disposed when the pillow has detachments:

- check of eccentric compression between the pillow and base;
- need of tension forces in the case in which the pillow active area $<0.7 l_c \cdot b_c$;
- check of negative bending of the pillow, loaded by reinforcement forces;

Minimum requirements: Φ_{min}=10mm, d_{min}=100mm, d_{max}=250mm, disposed as a grid.

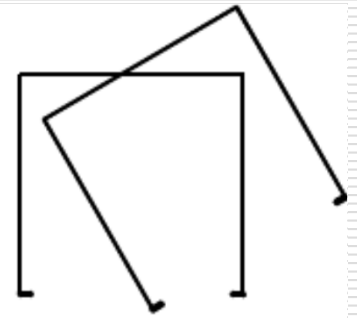
§ 6.6 Design of base and RC pillow foundation
- Pillow design -

☐ Pillow reinforcement:



☐ **Superior reinforcement**:

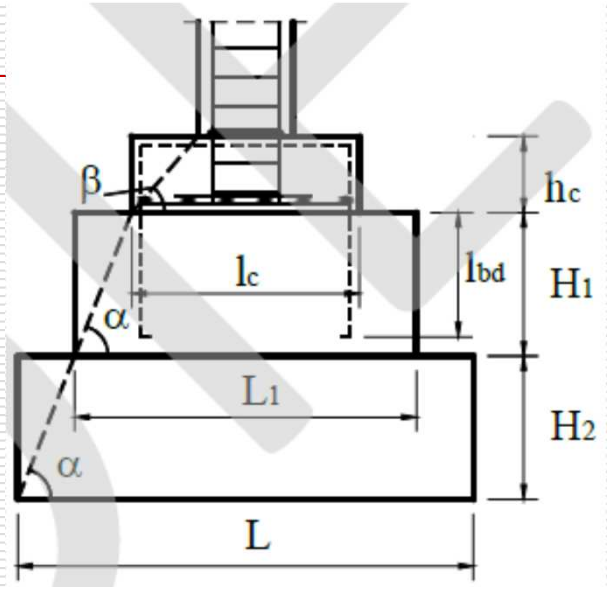
- constructive for pillows working in compression;
- resulting from bending check of the foundation block, considered as a cantilever and loaded by base pressure;



- check of eccentric compression between the pillow and base (need of tension forces in when the pillow active area < $0.7 l_c \cdot b_c$);
- check of the pillow in negative bending, loaded by reinforcement forces;

Minimum requirements: $\boldsymbol{\Phi_{min}=10mm}$, $\boldsymbol{d_{min}=100mm}$, $\boldsymbol{d_{max}=250mm}$, disposed as a grid.

§ 6.6 Design of base and RC pillow foundation
- Pillow design -



☐ Pillow reinforcement:

☐ **Column reinforcement**:

Identical to the column reinforcements. Their design results from the column design.

- the reinforcing bars are extended beyond the length of column plastic hinge;

- over this zone, the bars are driven over anchoring length $l_{bd}=30\Phi$

- stirrups: disposed to confine the column reinforcement. They are identical to column stirrups. Minimum requirements: at least two stirrups.

☐ **Transversal reinforcement**:

Needed to overtake the shear foundation forces when $tan\beta \geq 1.00$.

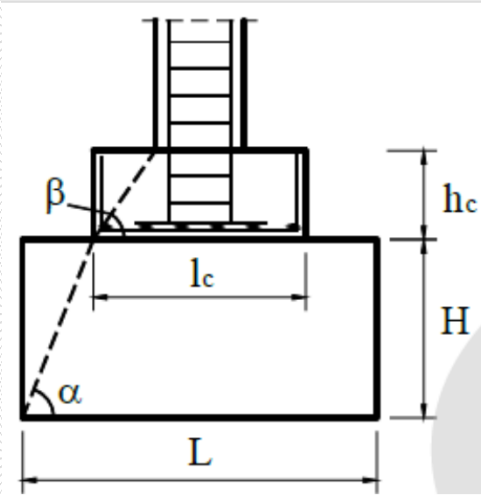
Are realized as inclined bars under the column.

Design is done in accordance with the Eurocode 2 requirements

§ 6.6 Design of base and RC pillow foundation - Pillow design -

- The contact pressure between the pillow and the base are found by (in cases in which there are no detachment of the pillow from the base):

$$p_{c1,c2} = \frac{N_c}{l_c \cdot b_c} \pm \frac{6M_{c(x)}}{l_c^2 \cdot b_c} \quad \text{or} \quad p_{c1,c2} = \frac{N_c}{b_c \cdot l_c} \pm \frac{6M_{c(y)}}{b_c^2 \cdot l_c}$$

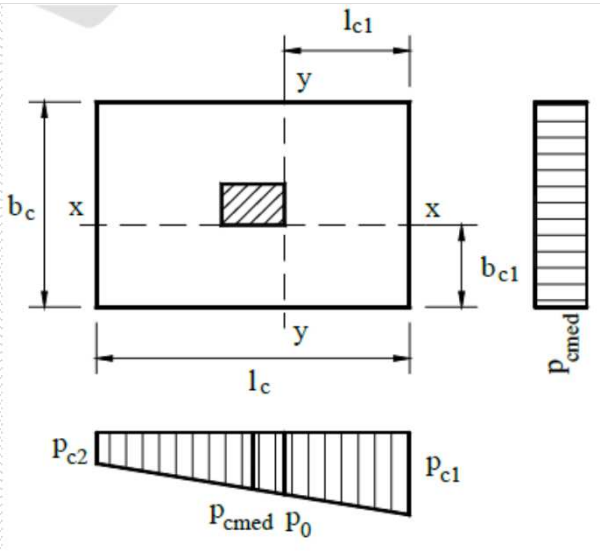


- If $p_2<0$ (detachment of pillow), then the length of the effective (compressed) zone is:

$$A_x = 3\left(\frac{l_c}{2} - \frac{M_{c(x)}}{N_c}\right) \quad \text{or} \quad A_y = 3\left(\frac{b_c}{2} - \frac{M_{c(y)}}{N_c}\right)$$

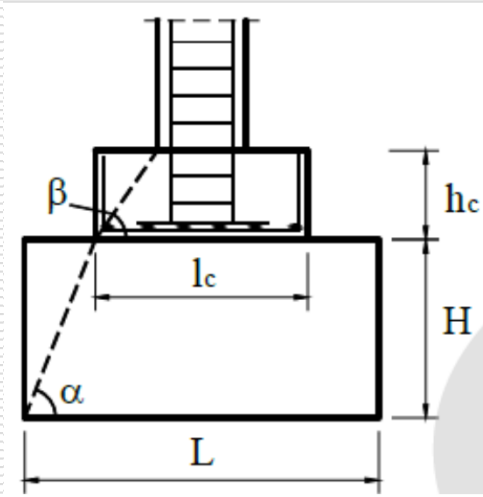
- In these cases, the contact pressures are computed by:

$$p_{c1} = \frac{2N_c}{3b_c\left(\frac{l_c}{2} - \frac{M_{c(x)}}{N_c}\right)} \quad \text{or} \quad p_{c1} = \frac{2N_c}{3l_c\left(\frac{b_c}{2} - \frac{M_{c(y)}}{N_c}\right)}$$



§ 6.6 Design of base and RC pillow foundation - Pillow design -

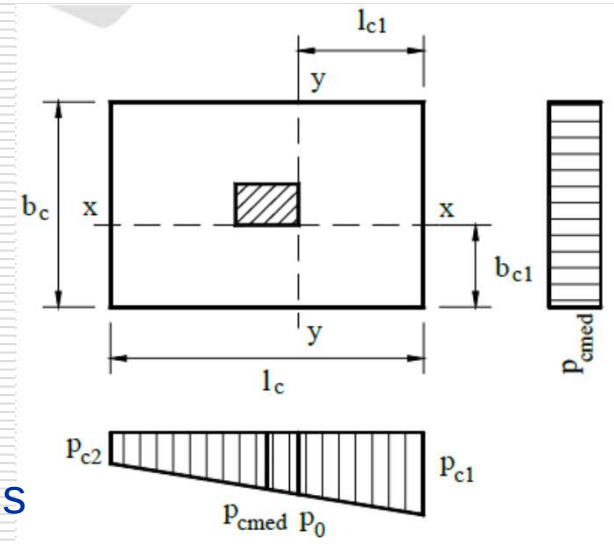
In the above formulae: N_c, M_{cx}, M_{cy} are the axial load and the bending moments computed at the base of the pillow.



- Pressure check under pillow:

$$p_{c1}(p_{c2}) < f_{cd,b}$$

where $f_{cd,b}=0.85 \cdot f_{ck}/\gamma_c$ is the design strength of base concrete



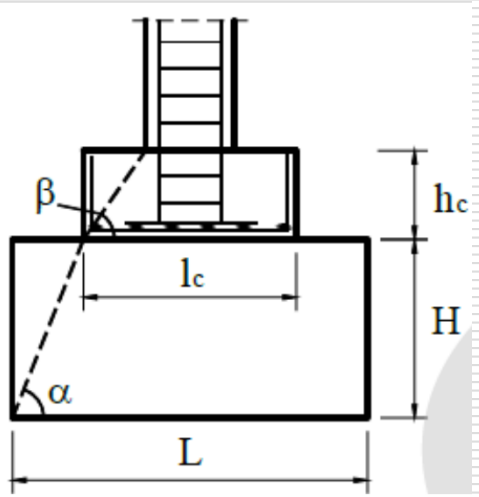
Obs: Usually the concrete class of the pillow (min C12/15) is greater than the concrete class of the base (min C8/10).

§ 6.6 Design of base and RC pillow foundation - Pillow design -

- The bending moments, computed at the edge of the column (sections x-x and y-y) are determined by:

$$M_x = b_c \cdot \left[p_{c0} \frac{l_{c1}^2}{2} + (p_{c1} - p_{c0}) \frac{l_{c1}^2}{3} \right]$$

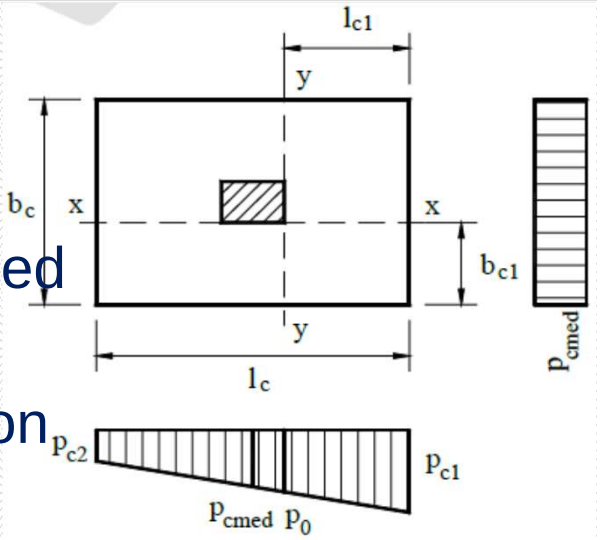
$$M_y = l_c \cdot p_{cmed} \frac{b_{c1}^2}{2}, \quad p_{cmed} = \frac{p_{c1} + p_{c2}}{2}$$



- The bending moments, computed as above will lead to the design of sole reinforcing bars.

- If the effective area is smaller than 70% of the pillow area ($l_c \cdot b_c$) then the pillow should be anchored (by reinforcing bars) in the foundation base.

- The condition in this case require that the tension forces will equilibrate the compression forces by considering an uniform pressure distribution.

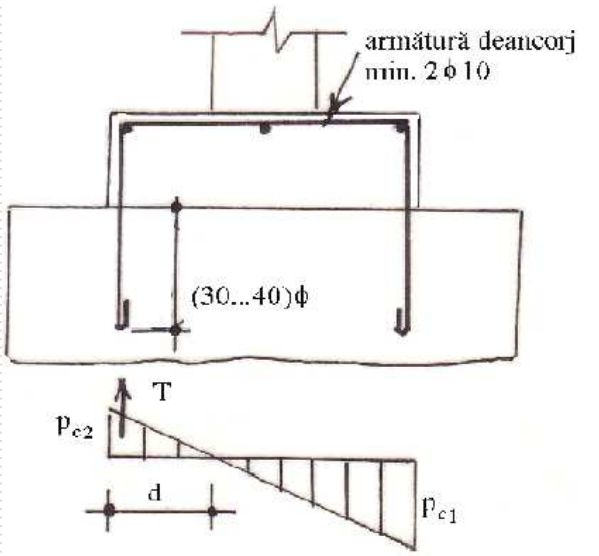


§ 6.6 Design of base and RC pillow foundation - Pillow design -

- The design of vertical reinforcement results from:

$$A_{nec} = \frac{c \cdot T}{R_a} = \frac{c \cdot b \cdot d \cdot p_{c2}}{2 \cdot R_a \left(f_{yd} \right)}$$

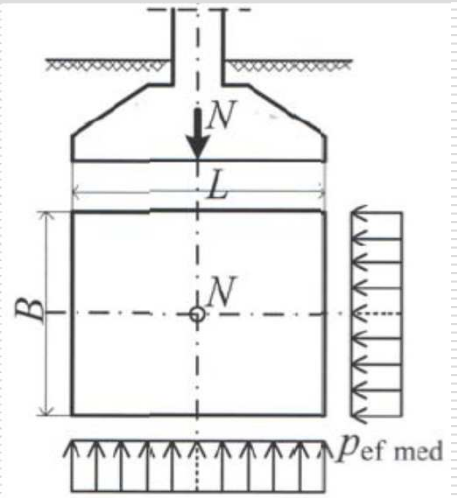
Where $R_a(f_{yd})$ is the design resistance of the reinforcement



§ 6.6 Design of base and RC pillow foundation
- Check of soil pressure -

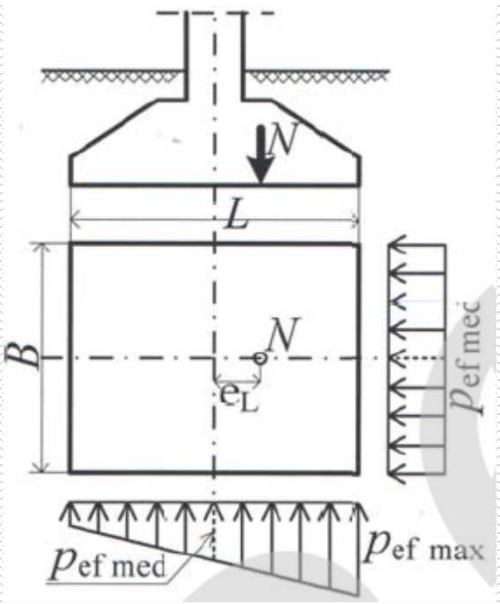
- **Check of soil pressure** :
- Centric loading:

$$p_{\text{ef med}} = N_F / A \leq p_{\text{conv}}$$



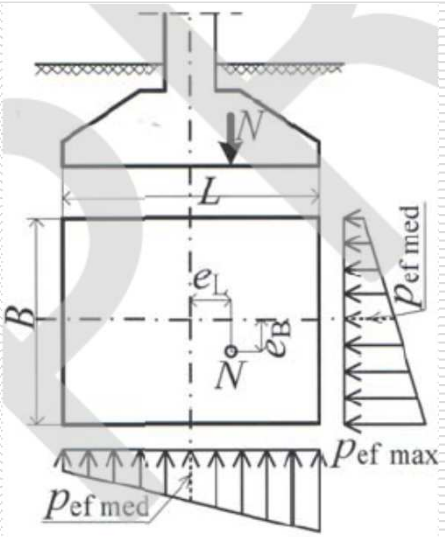
- Uni-axial eccentric loading:

$$p_{ef\,\max} = \omega \frac{N_F}{L \cdot B} \leq 1{,}2\, p_{\text{conv}}$$



- Bi-axial eccentric loading:

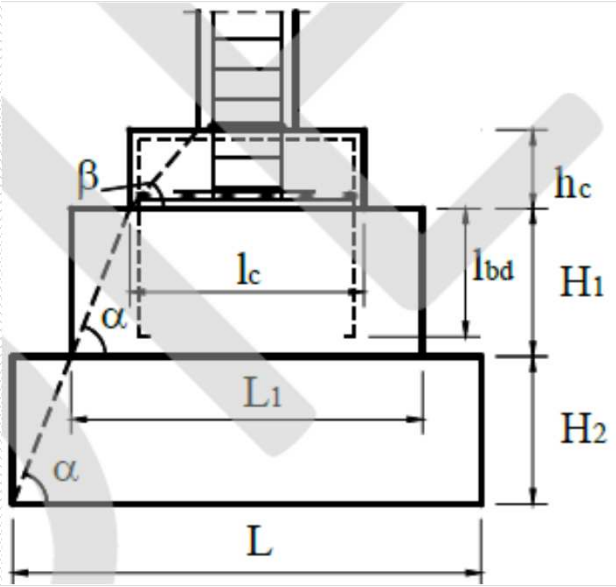
$$p_{ef\,\max} = \omega \frac{N_F}{L \cdot B} \leq 1{,}4\, p_{\text{conv}}$$



Obs: From these formulae is excluded the seismic (special) combination of actions.

§ 6.6 Design of base and RC pillow foundation
- Design of foundation base -

- The **foundation base (foundation block)** is realized by plain concrete of one to three steps.



- The foundation base steps are made by respecting the following conditions:
  - the minimum height of a single step base is 400 mm;
  - the concrete base could be realized by maximum three steps each having a minimum height of 300mm. The bottom step height should be of minimum 400mm.
  - concrete class: minimum C8/10 but should be adjusted in function of durability conditions.

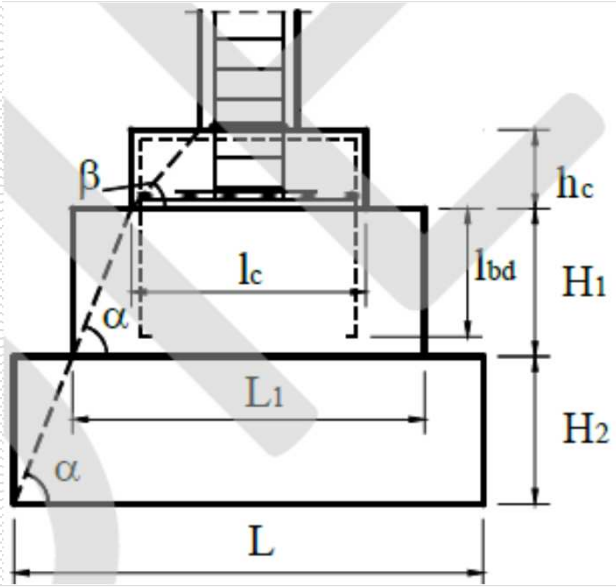
Obs: Obviously, the foundation could be realised by only one step. However, in order to make this costly efficient, the volume of concrete is minimised by means of the foundation steps.

§ 6.6 Design of base and RC pillow foundation
- Design of foundation base -

- The **foundation base (foundation block)** is realized by plain concrete of one to three steps.

- The final height of the base should satisfy condition:

$$tan\ \alpha > tan\ \alpha_{min}$$

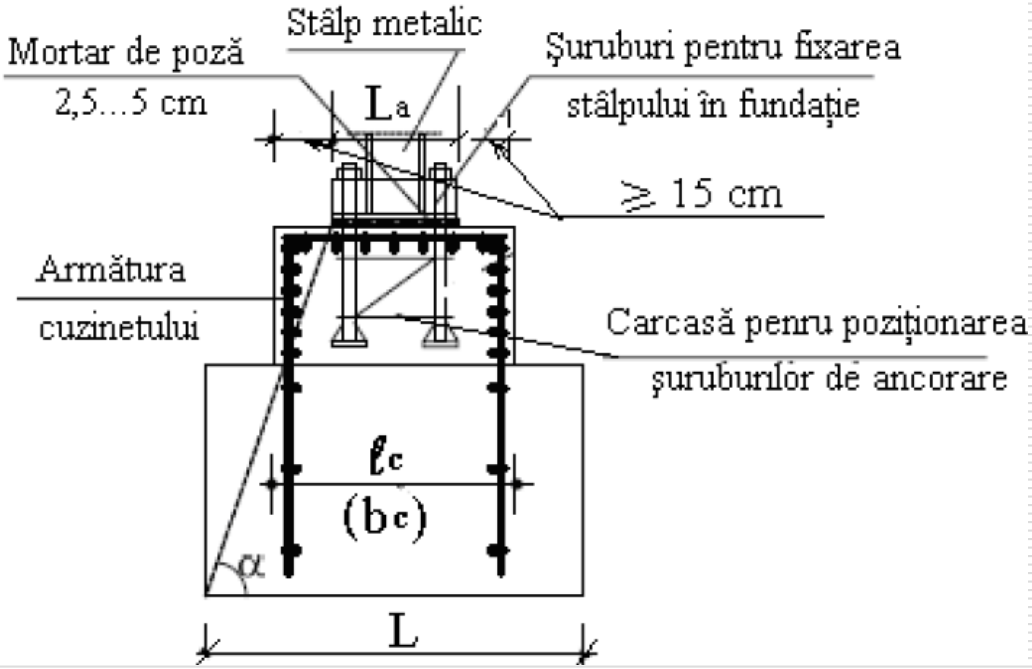


Presiunea efectivă pe teren (kPa)	Valori minime tg α funcție de clasa betonului	
	$C_{4/5}$	$C_{8/10}$ sau mai mare
200	1,15	1,05
250	1,30	1,15
300	1,40	1,30
350	1,50	1,40
400	1,60	1,50
600	2,00	1,85

- This condition will be fulfilled for each foundation step.
- Between the horizontal layers of concrete (including the pillow) joints must assure a friction coefficient μ of minimum 0.7.
- This could be achieved by realizing rough grooves of min 3mm height, distanced at 40mm.

§ 6.7 Design of foundations under steel columns

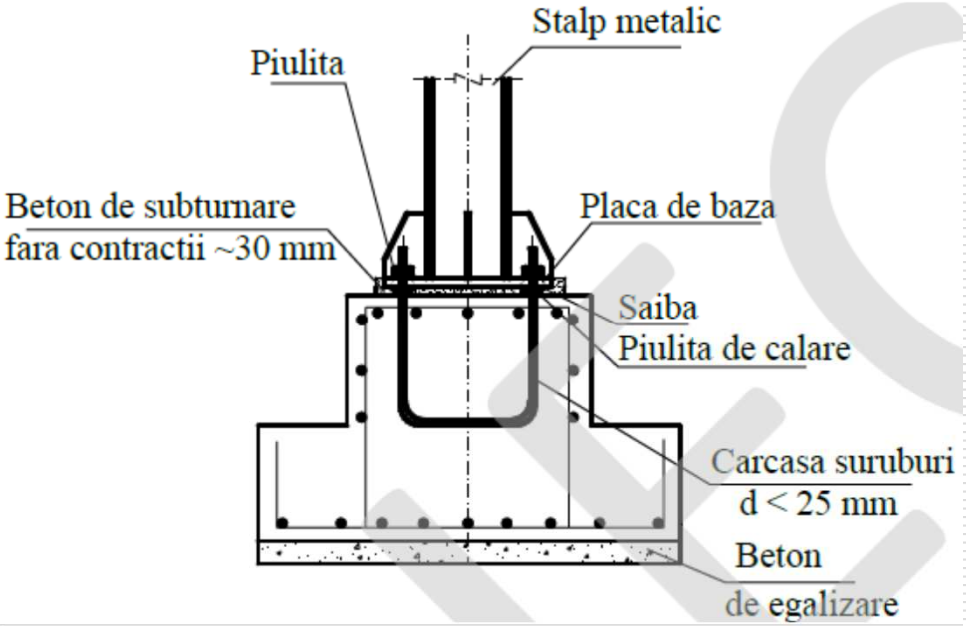
- The reinforced concrete foundations under steel columns are considered as **rigid foundations** and could be realized in one or more steps.
- The column base is haunched in order to offer a larger base at the contact with foundation concrete:
  - vertical stiffeners are provided to increase the bottom cross-section;
  - column base-plate offers a rigid means for transmission of forces;
  - the anchoring bolts offer fixing and transmission of traction forces to column.



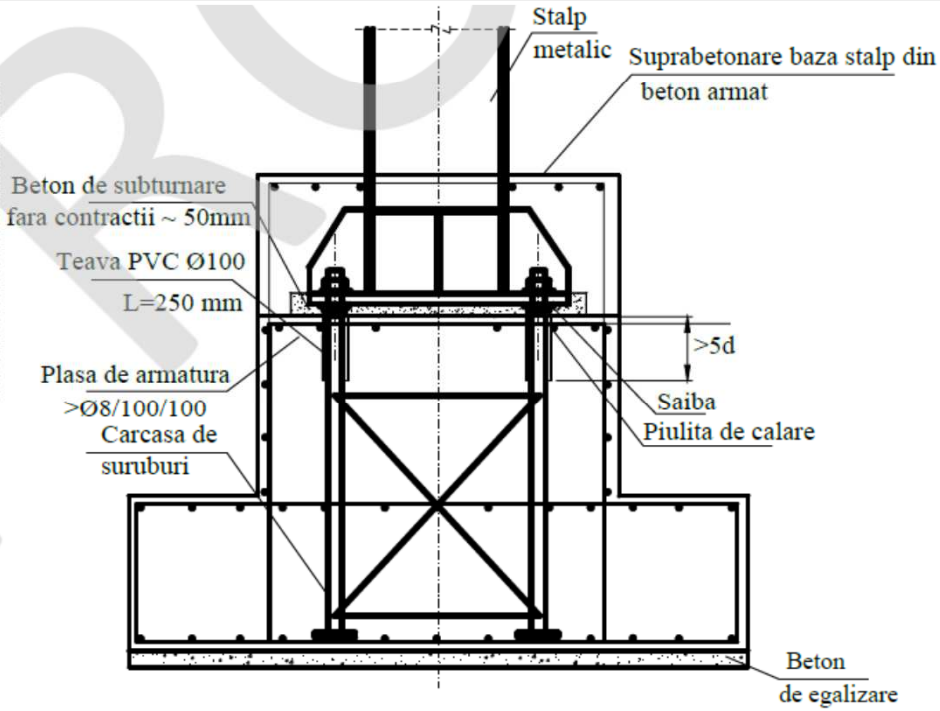
- anchoring bolts (high diameter rods) are embedded in concrete, where they act as special reinforcements.

§ 6.7 Design of foundations under steel columns

- For columns transmitting small forces, conducting to small diameters of anchoring bolts (d<25mm), the below detail could be used:



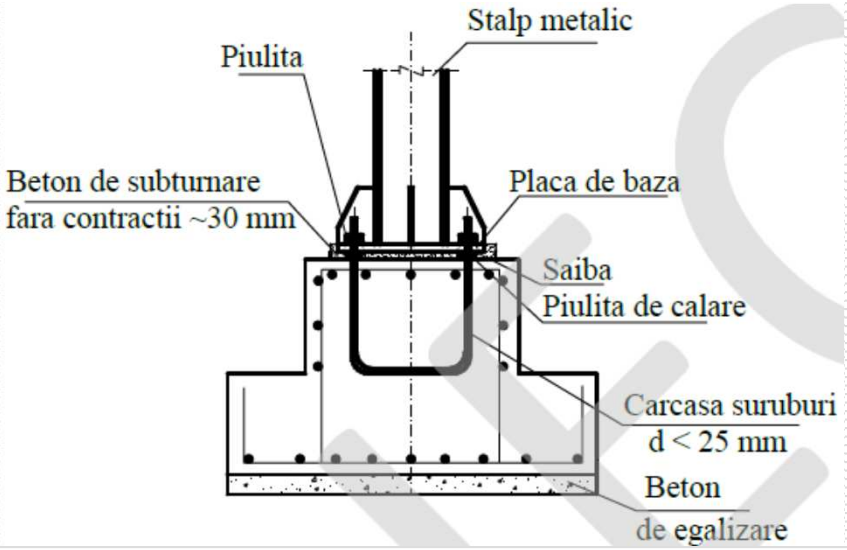
- For higher loads, the anchoring bolts should be extended to bottom step:



- The design of anchoring bolts results from steel column design
- Special design conditions must be assured for base-plate and foundation reinforcement.

§ 6.7 Design of foundations under steel columns - anchoring bolts and base plate -

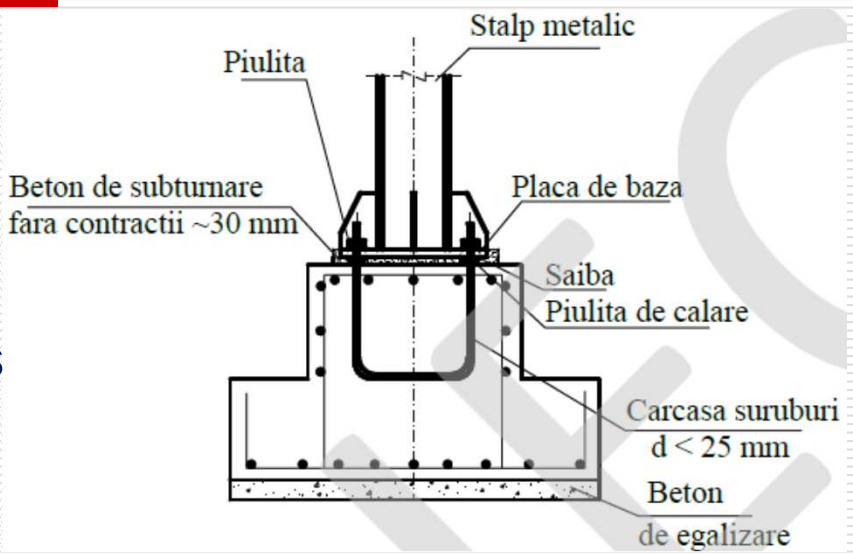
- Conditions for anchoring bolts:
  - The proper design of anchoring bolts will be according to EN 1993 (steel structure design) and EN 1998 (seismic design);
  - in order to avoid a brittle fracture of the bolts, a height of $5d_s$ should be out of concrete contact;



- It is recommended that the horizontal shear forces will not be transmitted via anchoring bolts. This could be assured by:
  - over-concreting of the column base for a height of at least 400mm, or
  - welding additional steel elements under the column base , thus transmitting shear directly to reinforced concrete pillow or
  - embedding the column in the infrastructure for a height assuring direct anchoring.

§ 6.7 Design of foundations under steel columns - anchoring bolts and base plate -

- The minimum length of the anchoring bolts results from the conditions:
  - length of the base plate (L_a) + anchoring length (*30d*) if ribbed bolts are used;
  - length of the base plate (L_a) + half of the anchoring length (*15d*) for smooth anchoring bolts with welded end-plate.



- The minimum area of the base plate results from the condition:

$$A_p = \frac{N_s}{0,4R_c\left(f_{cd}\right)}$$

where N_s is the tension force in the anchoring bolts

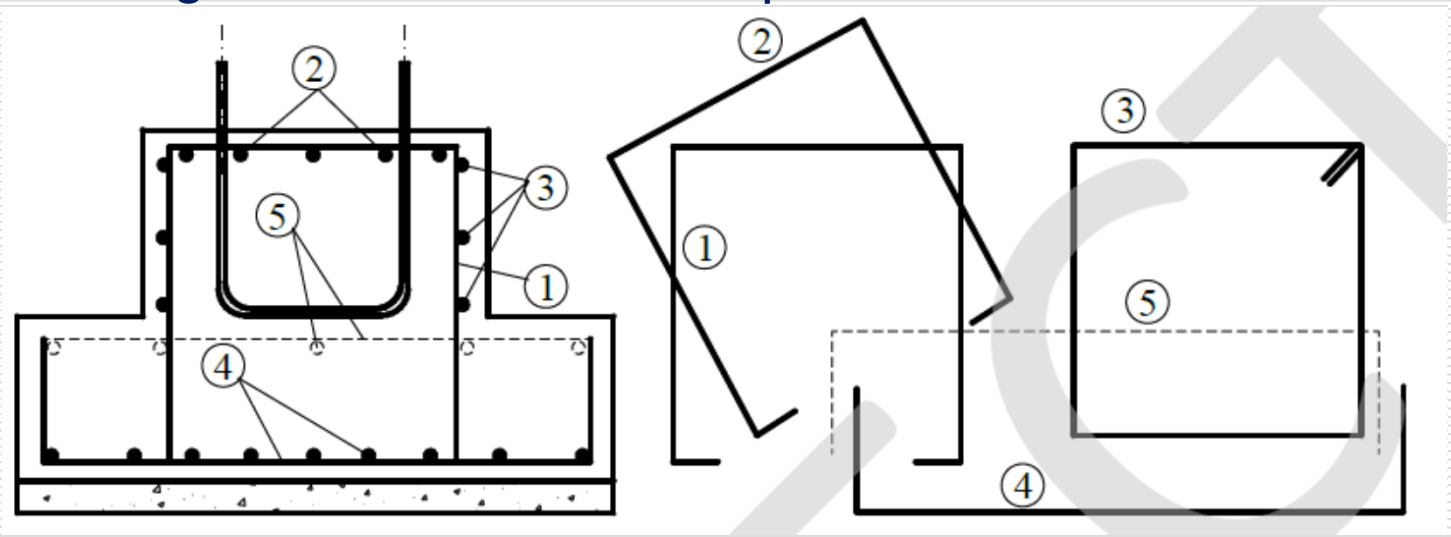
f_{cd} is the design resistance of the concrete in the pillow

§ 6.7 Design of foundations under steel columns - Pillow design -

- The main purpose of the pillow is to fix the column in the foundation and to spread the concentrated load on a larger contact area.
- In usual cases the pillow has a prismatic form.
- Geometrical requirements (proportioning):
  - l_c/L; $b_c/B=0.50…0.65$ for single tread;
  - l_c/L; $b_c/B=0.40…0.50$ for multiple treads;
  - $h_c \geq 300mm$ *but* $h_c/L \geq 0.25$;
  - $tan\beta \geq 0.65$. If $tan\beta \geq 1.00$ then the check to shear force is not required. Otherwise the check to shear force is performed according to Eurcode 2.
  - concrete class: min C12/15
- The pillow plan dimensions results from the pressure condition at contact with the foundation base. The last could be cast from a lower concrete class.
- Also, the pillow dimensions should overpass the steel base-plate by at least 150 mm in each side.

§ 6.7 Design of foundations under steel columns - Pillow design -

- The pillow reinforcing could be realized as presented in below picture:

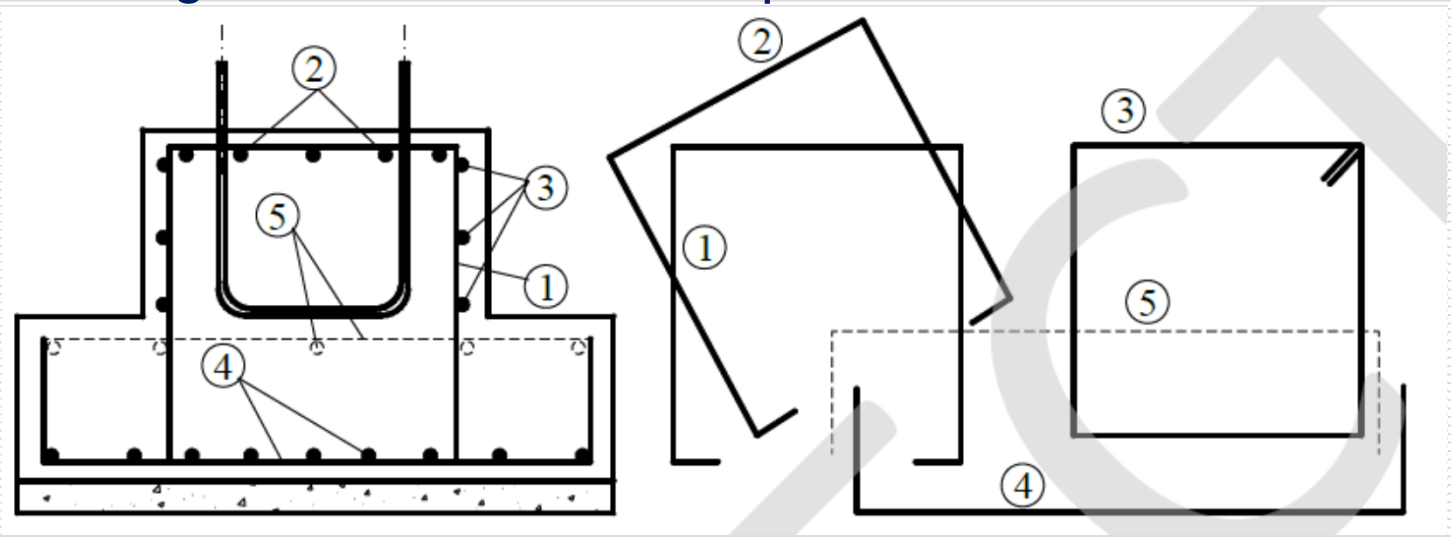


- the **vertical reinforcement** (1 and 2 in the figure) results from eccentric axial check between the pillow and the foundation base;
- the design forces in section are derived from the associated capacity moments of the reinforcing bolts;
- the superior horizontal reinforcement (1 and 2) could be supplemented with one or two bar meshes if necessary;

Minimum requirements: Φ_{min}=10mm, d_{min}=100mm, d_{max}=200mm, disposed as a grid.

§ 6.7 Design of foundations under steel columns - Pillow design -

- The pillow reinforcing could be realized as presented in below picture:

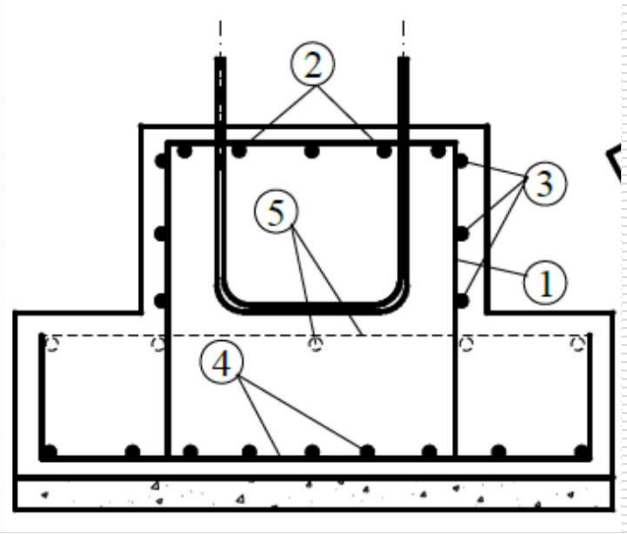


- the **horizontal reinforcement** (no 3 in the figure) are disposed on the perimeter of the pillow;
- the area of the reinforcement should be 0.25 of the vertical reinforcing area;

Minimum requirements: Φ_{min}=8mm, d_{max}=200mm, disposed as stirrups.

§ 6.7 Design of foundations under steel columns - Design of foundation base -

- Design of foundation base is performed in a similar manner as in case of base and RC pillow foundation:



- The final height of the base should satisfy condition:

$$tan\ \alpha > tan\ \alpha_{min}$$

- This condition will be fulfilled for each foundation step.

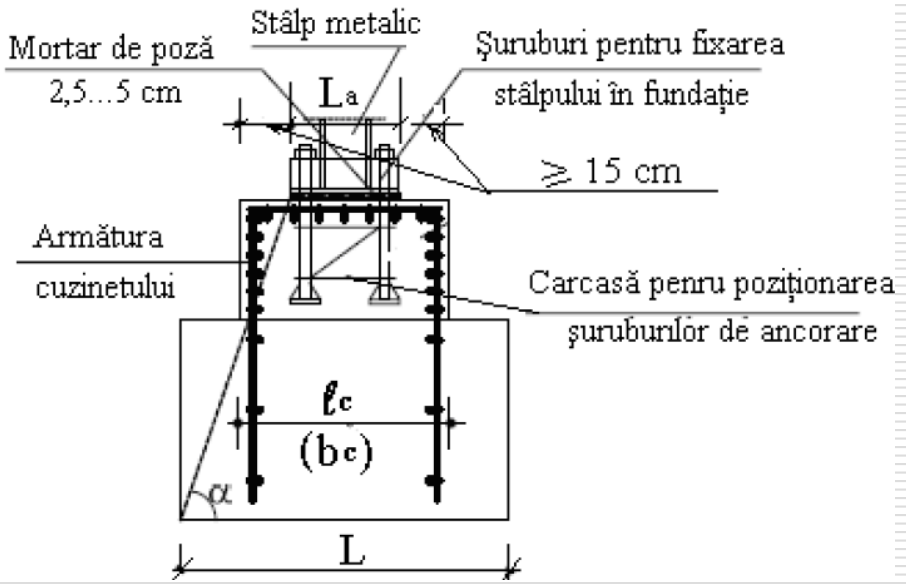
- Between the horizontal layers of concrete (including the pillow) joints must assure a friction coefficient μ of minimum 0.7.
- This could be achieved by realizing rough grooves of min 3mm height, distanced at 40mm.
- Bottom reinforcement (no. 4 in the figure) is not mandatory.

§ 6.7 Design of foundations under steel columns

- Review of design checks in case of foundations under steel columns:

- Check of contact pressure between the base plate and the concrete (pillow).

- Check of contact pressure between the pillow and the foundation base **(as in case of base and RC pillow foundation).**



- Check of contact pressure between the foundation base and the foundation soil **(as in case of base and RC pillow foundation).**
- Design of pillow reinforcement: similar to base and RC pillow foundation design but additional check the moment capacity of the anchoring bolts.