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

FOUNDATIONS

- CURS 7b -

Design of shallow foundations

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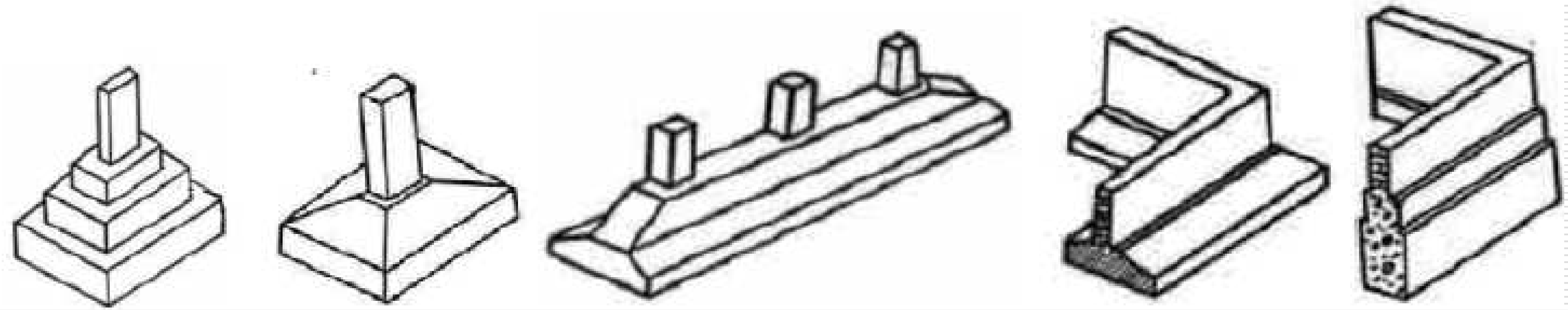
CHAPTER VI – SHALLOW FOUNDATIONS

§ 6.1 Introduction

- **Shallow foundations** are those executed near the ground surface or at shallow depths, and the load transfer is assured by direct contact between the foundation and the soil.
- Shallow foundations are used when subsoil exploration proves that all soil strata affected by the building could resist the superimposed stresses without causing excessive settlements.



§ 6.1 Introduction

- The materials used should be adapted to the contact with the foundation soils (of reduced resistance) and affected by humidity:
  - Stone masonry;
  - Plain concrete;
  - Reinforced concrete

Obs: The foundations are hidden works and hard to follow by direct inspection.

- Stone masonry is a rather old material used for shallow foundations, usually in places in which stone is a local material (river or pit broken stone) and the binder is lime or cement mortar.
- Plain concrete is used for compressed elements stress such as massive foundation blocks, plinths, concrete fills.

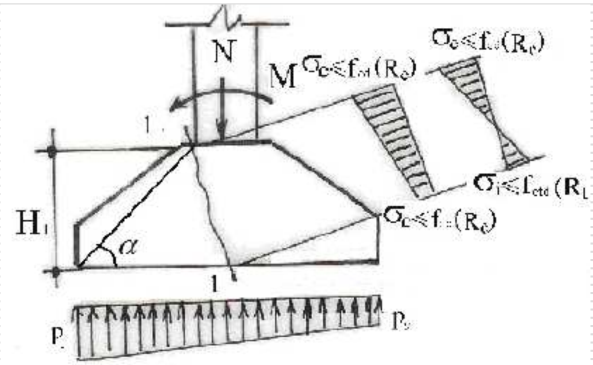
Minimum concrete class: C8/10 (concrete fills, plints), C12/15 for foundation blocks.

- Reinforced concrete is used for single or continuous foundation pillows, mat foundations, elastic foundations, as well as precast foundation units.

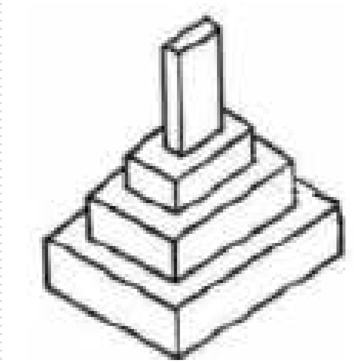
Minimum concrete class: C12/15 (single foundations), C16/20 for precast units.

§ 6.2 Types of shallow foundations

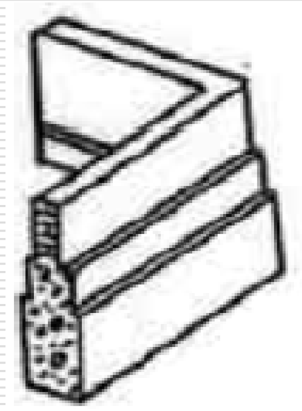
- The main types of shallow foundations are differentiated in function of the way in which they transmit the stresses and internal forces:
  - **Rigid foundations:** They are subjected to compression and could be made of plain concrete. Internal deformations are neglected;
  - Rigid foundations could be realized for:
    - Single foundations under columns
    - Strip foundations under bearing walls



Stresses in rigid foundation



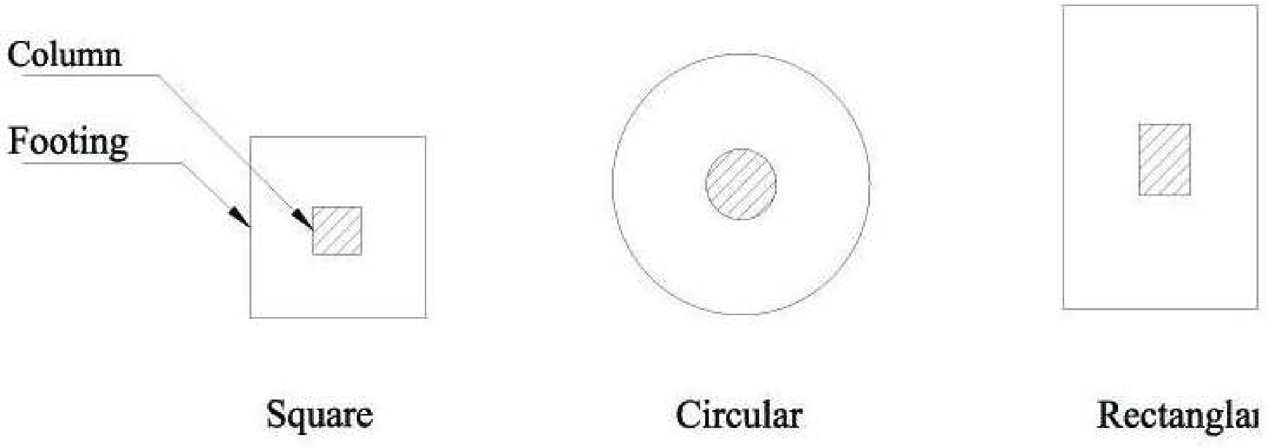
Single foundation



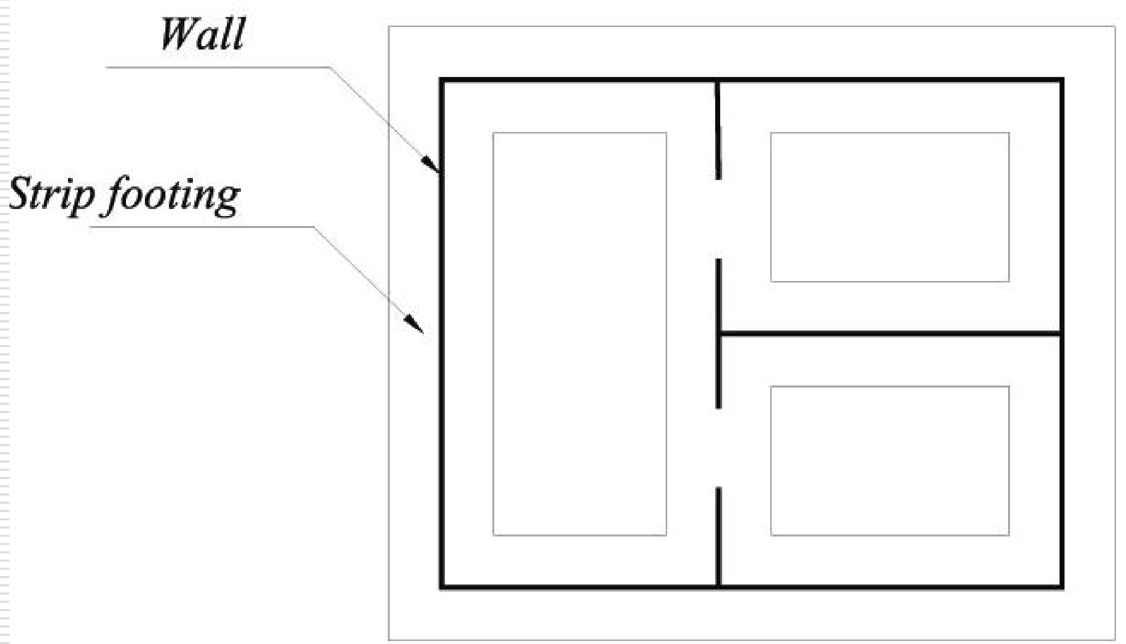
Strip foundation

§ 6.2 Types of shallow foundations

Single foundation

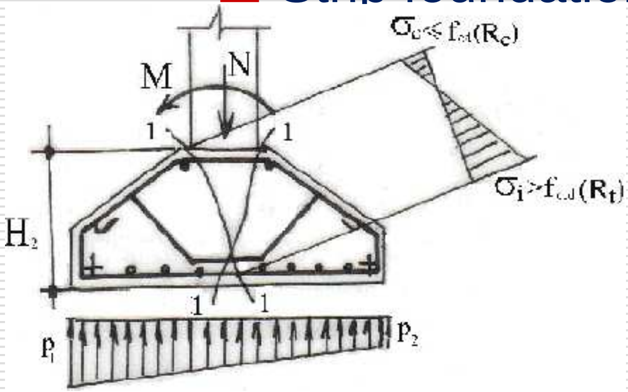


Strip foundation

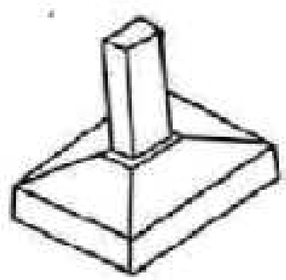


§ 6.2 Types of shallow foundations

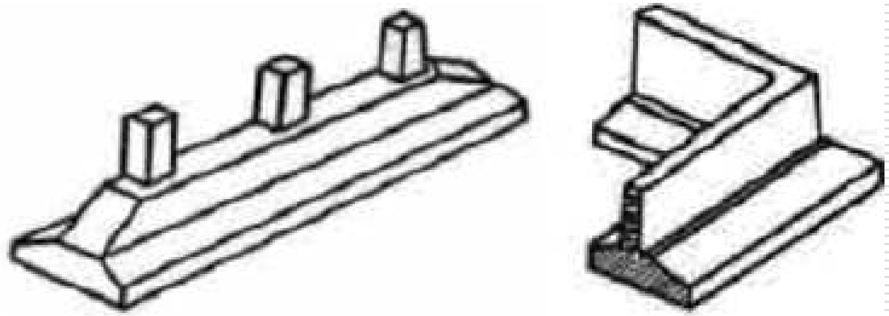
- The main types of shallow foundations are differentiated in function of the way in which they transmit the stresses and internal forces:
  - **Elastic foundations**: Subjected to bending and are made of reinforced cast or pre-cast concrete. Internal deformations are not neglected in design.
  - Elastic foundations could be realized for:
    - Single foundations under columns;
    - Strip foundations under a row of columns
    - Strip foundations under bearing walls



Stresses in elastic foundation



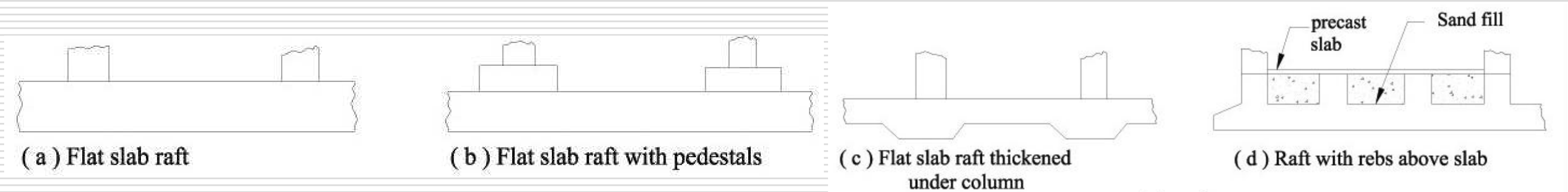
Single foundation



Strip foundations

§ 6.2 Types of shallow foundations

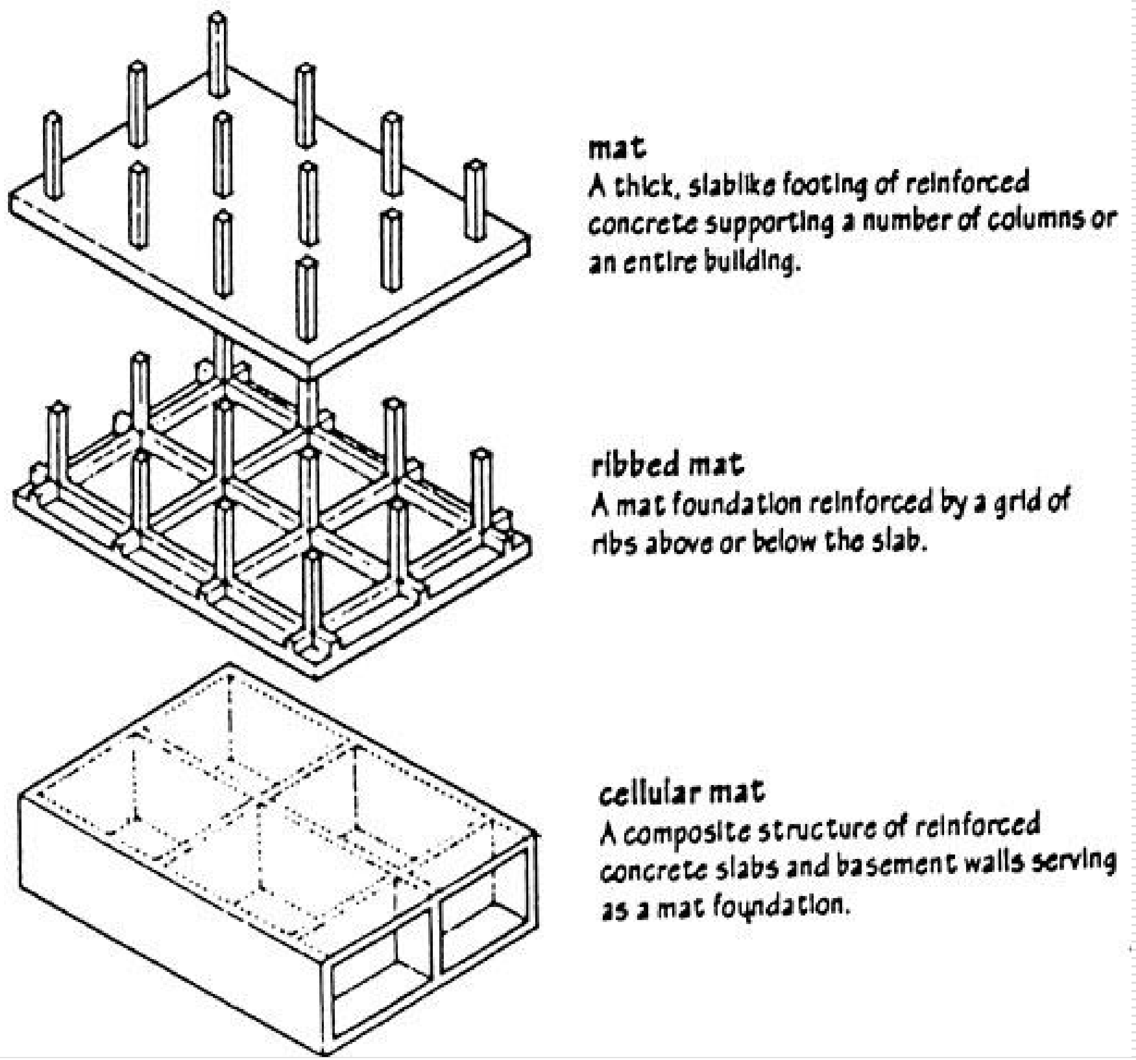
- The main types of shallow foundations are differentiated in function of the way in which they transmit the stresses and internal forces:
  - **Raft (mat) foundation**: The raft foundation is continuous footing that cover the entire area beneath a structure and supports all the walls and columns.
  - It is used generally on *soil of low bearing capacity* and where the area covered by spread footings is more than half the area covered by the structure.
  - Raft foundation is also used where the soil mass contains compressible lenses or the soil is sufficiently erratic so that *differential settlement would be difficult to control*.



Types of raft foundations

§ 6.2 Types of shallow foundations

- The main types of shallow foundations are differentiated in function of the way in which they transmit the stresses and internal forces:
  - **Raft (mat) foundation**:



§ 6.3 Criteria for choosing the foundation depth

- The **foundation depth** represents the vertical distance from the ground to the foundation footing.
- The criteria in choosing the foundation depth should include:
  - the freezing depth;
  - scour depth (for bridges);
  - foundation depth of neighbor buildings;
  - destination, constructive particularities of the building;
  - geological and hydrological conditions of the site.

- The following table offers the conditions of choosing the foundation depth in function of the soil type, freezing depth and the level of underground water:

§ 6.3 Criteria for choosing the foundation depth

Terenul de fundare	Hî adâncimea de îngheţ (cm)	H adâncimea apei subterane faţă de cota terenului natural (m)	Adâncimea minimă de fundare (cm)	
			Terenuri supuse acţiunii îngheţului	Terenuri ferite de îngheţ*)
Roci stâncoase	oricare	oricare	30÷40	20
Pietrişuri curate, nisipuri mari şi mijlocii curate	oricare	$H \geq 2{,}00$	Hî	40
		$H < 2{,}00$	Hî + 10	40
Pietriş sau nisip argilos, argilă grasă	Hî ≤ 70	$H \geq 2{,}00$	80	50
		$H < 2{,}00$	90	50
	Hî > 70	$H \geq 2{,}00$	Hî + 10	50
		$H < 2{,}00$	Hî + 20	50
Nisip fin prăfos, praf argilos, argilă prăfoasă şi nisipoasă	Hî ≤ 70	$H \geq 2{,}50$	80	50
		$H < 2{,}50$	90	50
	Hî > 70	$H \geq 2{,}50$	Hî + 10	50
		$H < 2{,}50$	Hî + 20	50

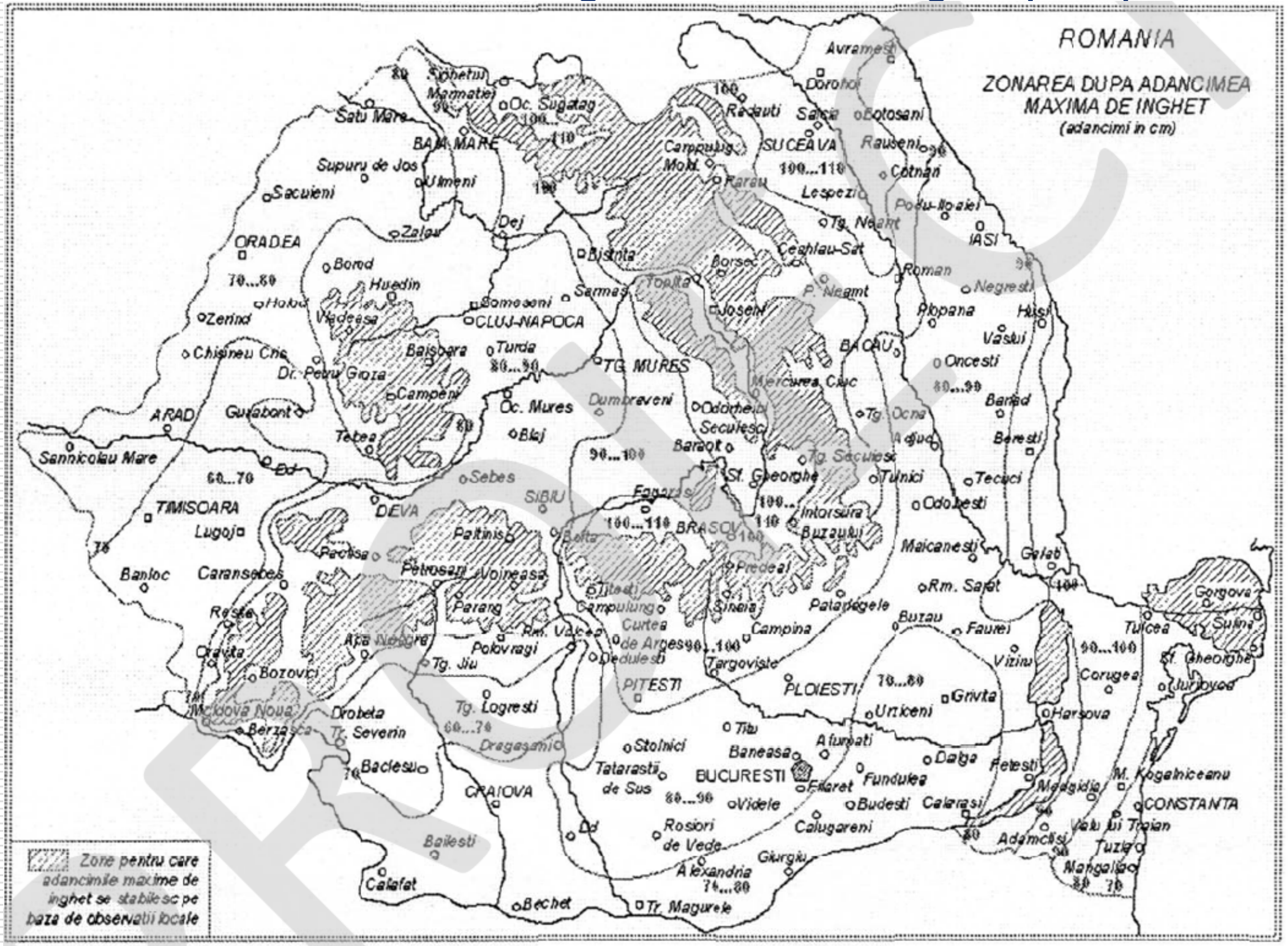
§ 6.3 Criteria for choosing the foundation depth

- The **freezing depth** is defined as the minimum level of the 0^0C isotherm.
- Maximum values are specified for different zones of each zone (country). The freezing depth in Romania is between 70 and 115 cm (see the zonation map).

- If the foundation depth is smaller than freezing depth, the soil under foundation can increase its volume during freezing (due to the formation of ice lenses) leading in thawing to loosing of the foundation soil. This further leads to a drop of soil compression and shear resistances.

§ 6.3 Criteria for choosing the foundation depth

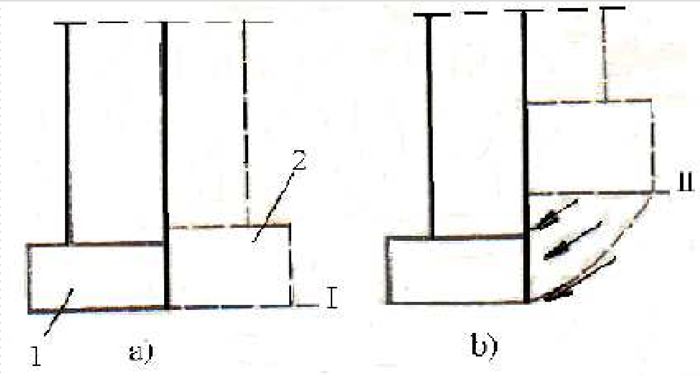
- Romanian zonation according to the freezing depth (NP112/2014)

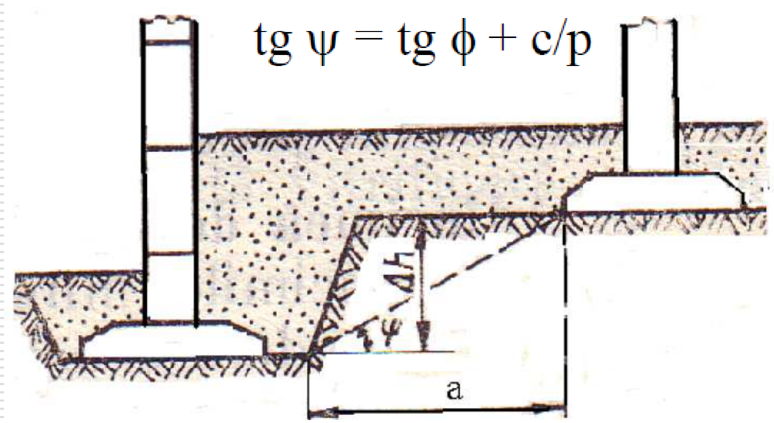


§ 6.3 Criteria for choosing the foundation depth

- The **foundation depth** of neighboring buildings can affect the foundation depth of the new building:
  - The new foundation should be realized at the same depth or lower: the pressures generated by the new foundation will subject the old foundation to new-born stresses for which the old foundation was not designed;
  - a settlement joint of minimum 4 cm should exist between the two foundations;
  - if the new foundation is located at a certain distance from the old one, the difference between the two foundations must fulfill: $\Delta h \leq a \, tg\psi$

$$tg\,\psi = tg\,\phi + c/p$$





§ 6.3 Criteria for choosing the foundation depth

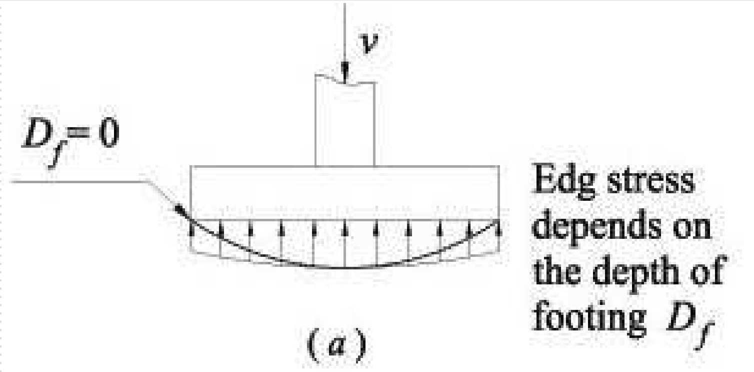
- The **destination and constructive particularities** of the building can also affect the foundation depth:
  - presence of one or more underground levels;
  - presence of sewage systems;
  - need for special foundations (machine foundations), etc.

- The **geological and hydrological conditions of the site** of the building can also affect the foundation depth:
  - if possible foundation under the water ground level should be avoided;
  - the foundation base should be located in the best foundation layer (30-50cm in the soil).

Obs: In many cases the foundation depth can be established after different design iterations.

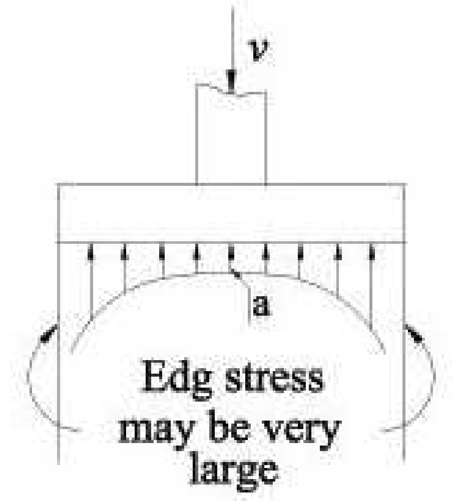
§ 6.4 Pressure distribution under foundation

- The distribution of stresses under footings is considered linear although it is not the case in reality.
- The error involved in this assumption is small and could be ignored.
- Theory of elasticity analysis indicates that the stress distribution beneath footings, symmetrically loaded, is not uniform.
- The actual stress distribution depends on the type of material beneath the footing and the rigidity of the footing.
- For footings on loose **cohesion-less solis**, the soil grains tend to displace laterally at the edges from under the load, whereas in the center the soil is relatively confined.

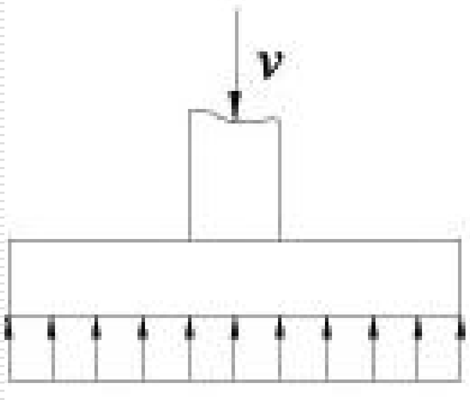


§ 6.4 Pressure distribution under foundation

- For the general case of footings on cohesive soils the theoretical pressure distribution is much greater near the edges of the foundation.
- The high edge pressure may be explained by considering that edge shear must take place before settlement can take place (due to cohesion).



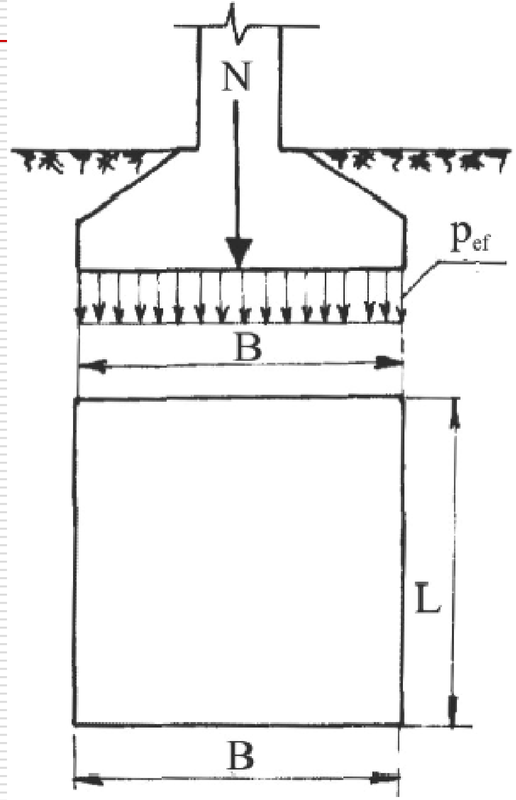
- The pressure intensities beneath the footing depend on the rigidity of the footing, the soil type and the condition of the soil.
- It is common practice to use a linear pressure distribution beneath the footings and this procedure will be used for design of foundations.



§ 6.4 Pressure distribution under foundation

- **Eccentric loading**
- In case of centric vertical loading - *N*, the pressure under foundation is uniform (p_{ef}):

$$p_{ef} = \frac{N}{S} = \frac{N}{B \cdot L}$$



- However, in usual design, at inferior sections of columns the vertical (axial) forces - *N* are accompanied by horizontal (shear) forces - *T* and bending moments – *M*.
- These forces will be transferred to the base center of the foundations into base axial forces – N_0 and base bending moments – M_0.
- These forces will lead to a linear distribution of pressure on the foundation base.

§ 6.4 Pressure distribution under foundation

□ Eccentric loading

$$N_0 = N + Gf$$
$$T_0 = T$$
$$M_0 = M + T\cdot(H+h_c)$$

□ The pressures on the foundation base could be found by:

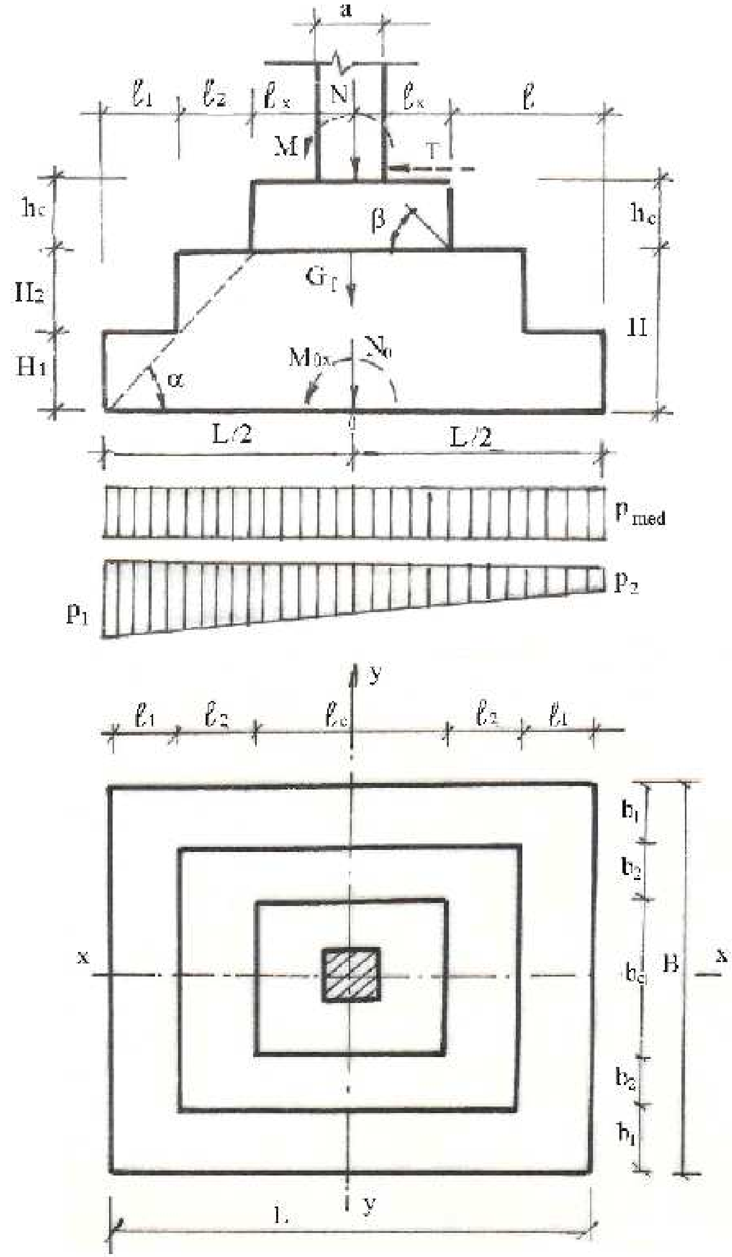
$$p_{1,2} = \frac{N_0}{B\cdot L} \pm \frac{M_0}{W_0}$$

with: W_0 – the section modulus of the foundation:

$$W_0 = \frac{B^2\cdot L}{6}$$

□ The effect of the combination of vertical force and the bending moment could be replaced by the effect realized by the vertical force moved aside from the center of the foundation with:

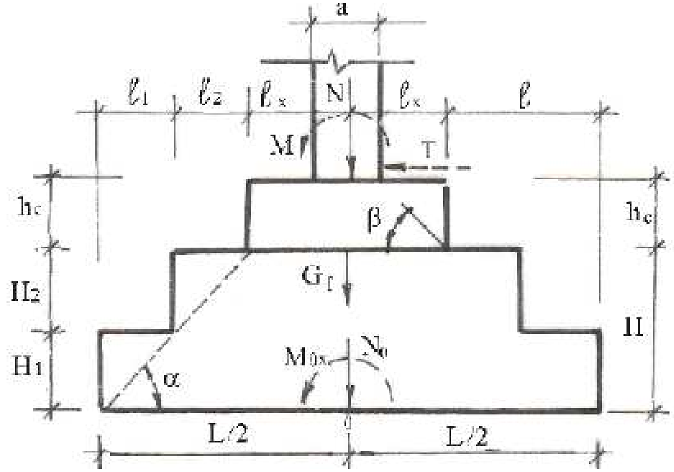
$$e_0 = \frac{M_0}{N_0}$$



§ 6.4 Pressure distribution under foundation

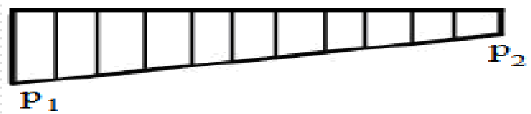
Eccentric loading

- e_0 represents the eccentricity of the vertical load (producing the additional moment M_0).

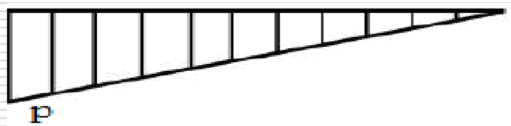


- In function of the value of the eccentricity e_0 we can observe three cases:

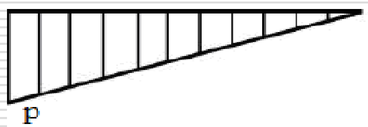
- Case 1: e_0<B/6: both p_1 and p_2 pressures are positive (transmitting compression);



- Case 2: e_0=B/6: pressure p_2 is equal to 0 (limit of contact);



- Case 3: e_0>B/6: pressure p_2 is negative. As the foundation cannot transmit tension, in this case the pressure p_1 will be greater as resulted from the primary design. In this case the foundation width is: $B'=B-2e$



§ 6.4 Pressure distribution under foundation

Eccentric loading

- If the foundation is loaded by bending moment on two directions, then the pressures on the corners of the foundation are found by:

$$p_{1,2,3,4} = \frac{N_0}{B \cdot L} \pm \frac{M_{0x}}{W_{0x}} \pm \frac{M_{0y}}{W_{0y}}$$

with: W_{0x} , W_{0y} – the resistance moduli of the foundation:

$$W_{0x} = \frac{B^2 \cdot L}{6} \qquad W_{0y} = \frac{B \cdot L^2}{6}$$

- For tension stresses in both principal axes, the contact pressure will be applied on:

$$B' = B - 2e_x$$

$$L' = L - 2e_y$$