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# FOUNDATIONS

- CURS 2 -

Basis of Design
Bearing Capacity of Foundations

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# CHAPTER II – BASIS OF DESIGN
## § 2.3 Design Approaches

- The Partial Safety Factors defined in §2.2 can be applied either:
  - to the uncertainty source of geotechnical design, or
  - to design (action effects and bearing capacity)

- EN 1997-1 proposes three design approaches in geotechnical design, expressed symbolically by combination of partial safety factors for:
  - Actions and Action Effects (A)
  - Material Properties (M)
  - Resistances (R)

Obs: Interpretation for combinations in subsequent approaches: in the Combination A1 "+" M1 "+" R1 the partial safety factors for actions (A) are combined with the partial safety factors for materials (M) and with the partial safety factors for resistances (R).

# § 2.3 Design Approaches

## Design Approach 1

- In **Design Approach 1**, the partial safety factors are applied at source, e.g. on the representative values of actions and on the characteristic values of Shear resistance of the soil.
- In **DA 1**, there are two combinations of partial safety factors:
  - Combination 1: A1 “+” M1 “+” R1

    This combination targets the safety in regard to the unfavorable deviations for the characteristic values of actions or action effects. The design properties of soils are close to characteristics values.
  - Combination 2: A2 “+” M2 “+” R1

    This combination targets the safety in regard to the unfavorable deviations for the characteristic values of actions, resistance parameters of soils and design model uncertainities.

Obs: The DA1 is recommended for ULS STR and ULS GEO checks.

Exception for Design Approach 1: axially loaded piles and anchors.

# § 2.3 Design Approaches

## Design Approach 1

- Values of partial safety factors used in Design Approach 1.

| Design Approach 1 | | | Combination 1 | | | Combination 2 | | |
|---|---|---|---|---|---|---|---|---|
| | | | A1 | M1 | R1 | A2 | M2 | R2 |
| **permanent Actions (G)** | Unfavorable | $\gamma_G$ | 1.35 | | | 1.0 | | |
| | Favorable | $\gamma_{G, fav}$ | 1.0 | | | 1.0 | | |
| **variable Actions (Q)** | Unfavorable | $\gamma_Q$ | 1.5 | | | 1.3 | | |
| | Favorable | $\gamma_{Q, fav}$ | 0 | | | 0 | | |
| **angle of shearing resistance** | (tg φ) | $\gamma_\varphi$ | | 1.0 | | | 1.25 | |
| **Effective cohesion** | (c′) | $\gamma_{c'}$ | | 1.0 | | | 1.25 | |
| **undrained shear strength** | ($c_u$) | $\gamma_{cu}$ | | 1.0 | | | 1.4 | |
| **unconfined strength** | ($q_u$) | $\gamma_{qu}$ | | 1.0 | | | 1.4 | |
| **Weight Density** | (γ) | $\gamma_\gamma$ | | 1.0 | | | 1.0 | |
| **Resistance** | (R) | $\gamma_R$ | | | 1.0 | | | 1.0 |

Obs: Usually the geotechnical design is made using Combination 1 while the Structural design uses the Combination 2.

# § 2.3 Design Approaches

## Design Approach 2

- In **Design Approach 2**, the safety of foundations is checked by applying partial safety factors to actions or action effects and resistances while the geotechnical parameters are taken with characteristic values.
- In **DA 2**, the following combination is considered:
  - Combination 1: A1 “+” M1 “+” R2

  The values of the partial safety factors for DA2 are given in previous table.

Obs: The DA2 is recommended for ULS of rupture or excessive deformation.

However, the Romanian National Annex does not recommend the use of DA2.

## Design Approach 3

- In **Design Approach 3**, the characteristic structural actions are multiplied with A1 set of factors to offer the design values. The design values of soil actions (geotechnical actions) are established using partial safety factors M2 and the set A2 of factors for actions.

- In **DA 3**, the following combination is considered:
  - Combination: (A1*orA2†) "+" M2 "+" R3
  - * on structural actions
  - † on geotechnical actions

Obs: The DA3 is recommended for ULS STR and ULS GEO checks.

# § 2.3 Design Approaches

## Design Approach 3

- Values of partial safety factors used in Design Approach 3.

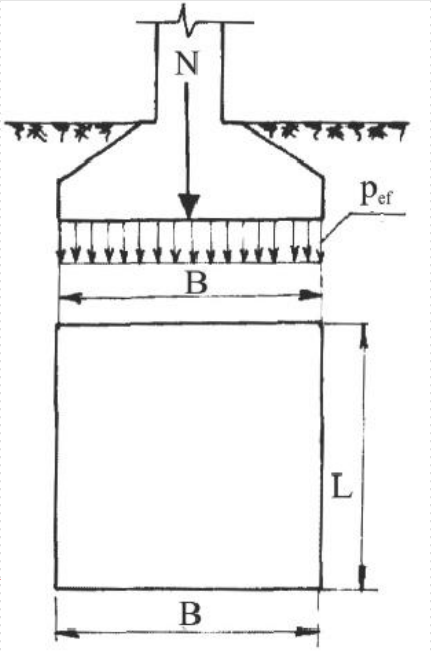
| Design Approach 3 | | | A1 | A2 | M2 | R3 |
|---|---|---|---|---|---|---|
| permanent Actions (G) | Unfavorable | $\gamma_G$ | 1.35 | 1.0 | | |
| | Favorable | $\gamma_{G, fav}$ | 1.0 | 1.0 | | |
| variable Actions (Q) | Unfavorable | $\gamma_Q$ | 1.5 | 1.3 | | |
| | Favorable | $\gamma_{Q, fav}$ | 0 | 0 | | |
| angle of shearing resistance | (tg φ) | $\gamma_\varphi$ | | | 1.25 | |
| Effective cohesion | (c′) | $\gamma_{c'}$ | | | 1.25 | |
| undrained shear strength | ($c_u$) | $\gamma_{cu}$ | | | 1.4 | |
| unconfined strength | ($q_u$) | $\gamma_{qu}$ | | | 1.4 | |
| Weight Density | (γ) | $\gamma_\gamma$ | | | 1.0 | |
| Resistance (exception pile surface in traction) | (R) | $\gamma_R$ | | | | 1.0 |
| Resistance for pile surface in traction | | | | | | 1.1 |

# CHAPTER III – BEARING CAPACITY OF FOUNDATIONS

## § 3.1 Behaviour of the foundation soil

- The **bearing capacity of the foundation** and the foundation soil represents the allowable load that can be transmitted to the foundation base in order to avoid:
  - excessive settlement of the foundation soil
  - loss of stability of the foundation – foundation soil.

- The loads transmitted to the foundation soils born a stress state which overlaps the original proper weight of the soils, leading to its deformation.

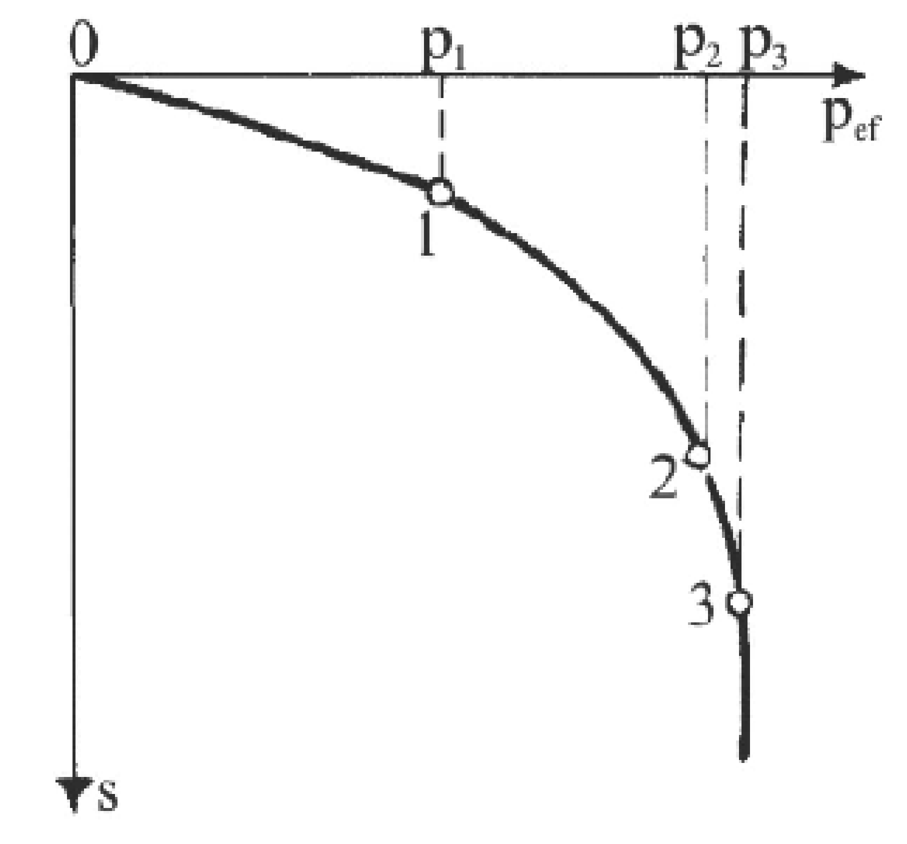


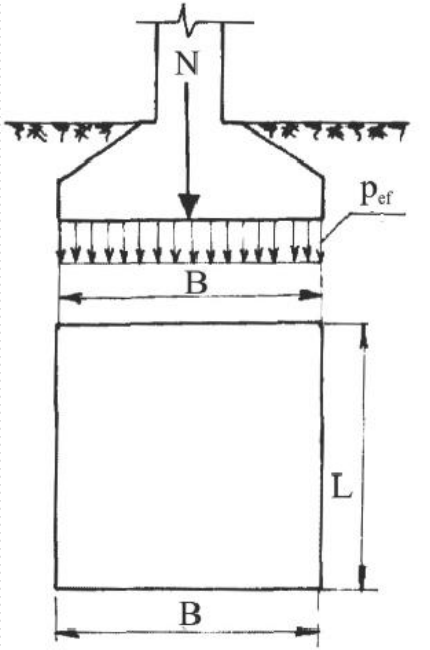

- Considering the generic foundation (figure right) loaded by the axial load N, then the soil pressure, denoted as **contact pressure** or **effective pressure** is given by:

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

# § 3.1 Behaviour of the foundation soil

- Under the force N, the foundation soil will settle (*s*).
- If the force N will continue to increase the following graph can be drawn by measuring $p_{ef}$ and *s*:

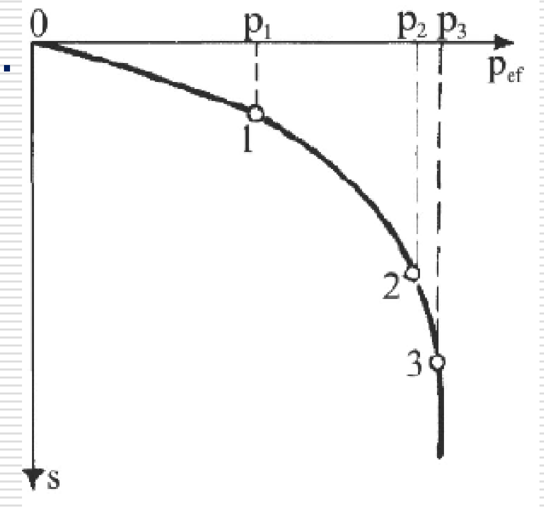


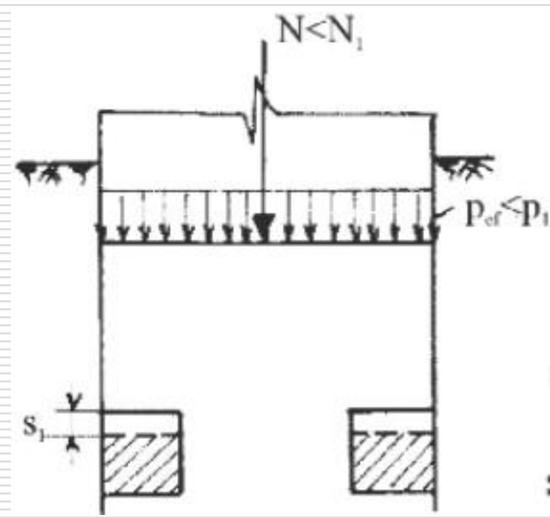




On this graph there can be distinguished three segments corresponding to three characteristic deformation phases under foundation load.

# § 3.1 Behaviour of the foundation soil

- **linear behavior:** corresponds to the segment 0-1. The relationship between the deformation (settlement) and pressure is quasi-linear.
- The diagram on this segment can be assimilated with a straight line.
- Considering two differential soil volumes located on vertical lines delimiting the foundation basis will compress by **contraction of soil pores** under foundation pressure.

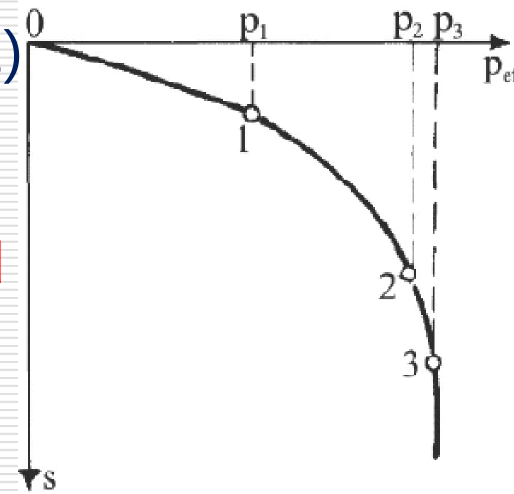


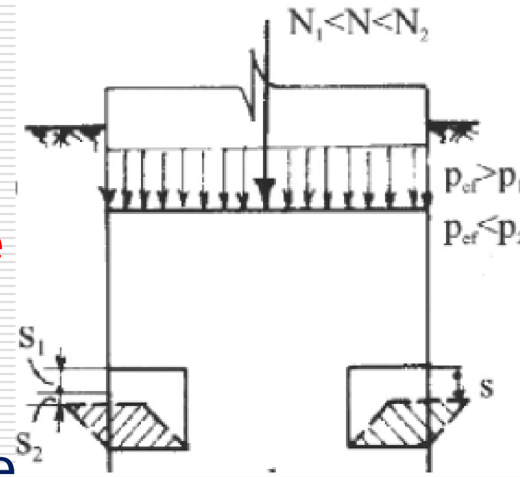

- The settlements measured for $p_{ef}<p_1$ are due mainly to compaction → **compaction pahse.**
- The behavior of the soil in this deformation phase depends mainly on its deformability characteristics.

# § 3.1 Behaviour of the foundation soil

- By increasing the effective pressure (segment 1-2) the relationship between pressure and deformation becomes non-linear. In this stage the deformation of the foundation soil is due in part to **compaction and in part to sliding phenomena**: besides volume variations appear form variations.




- By increasing the effective pressure to $p_2$ value, tangential stresses increase. Thus the shear capacity of the soil is exceeded:
  - initially in isolated points
  - finally on plastic zones




- This phases is denoted as sliding phase or **phase of development of plastic zones**
- The pressure corresponding to this phase is named **plasticity pressure *$p_{pl}$*** or allowable pressure for the foundation soil.

# § 3.1 Behaviour of the foundation soil

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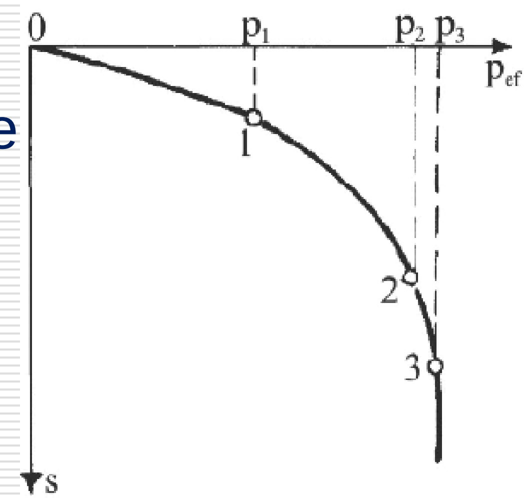
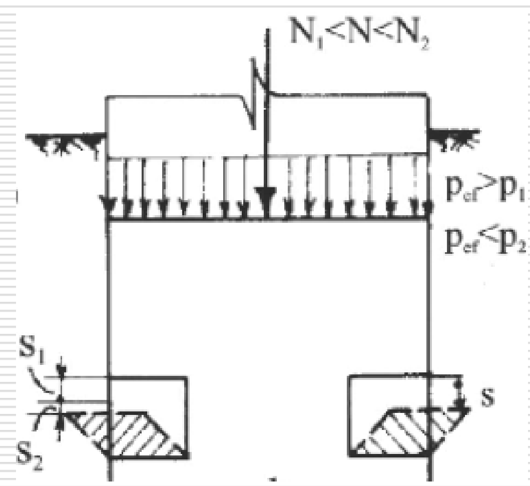
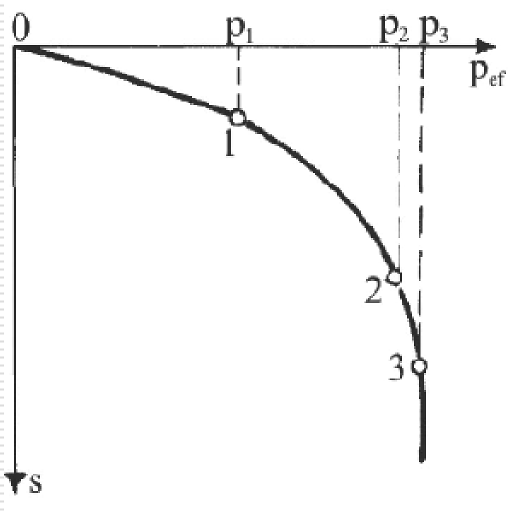


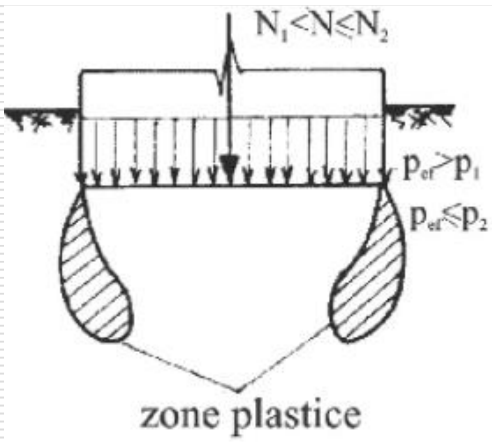

- The plasticity pressure $p_{pl}$ represents the admissible pressure for the foundation soil for which the extension of the plastic zones is limited.
- This values depends on the conditions set for each soil type (conditions for limiting the extension of the plastic zones into the foundation soil).



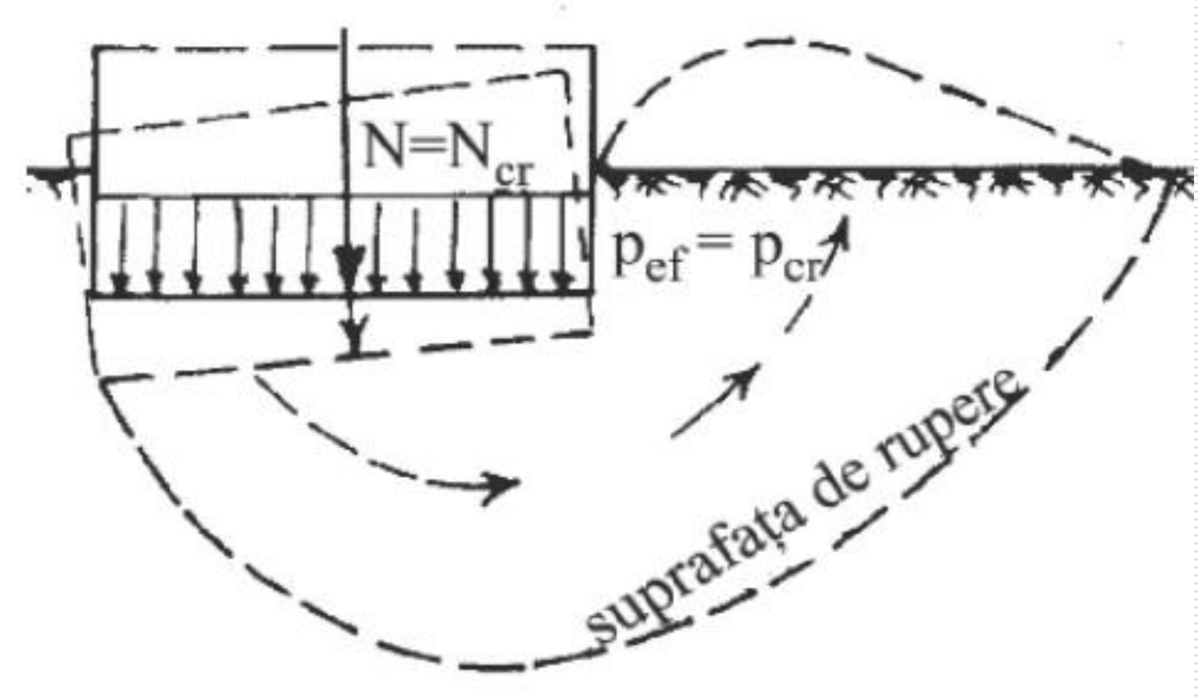
# § 3.1 Behaviour of the foundation soil

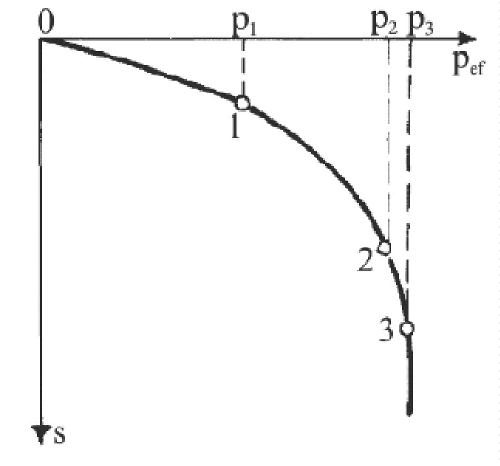
- If the effective pressure $p_{ef}$ is greater that $p_2$, the soil deformations are accumulated for small increments of soil pressure due to the extension of plastic zones and the formation of failure mechanisms by shear (sliding surfaces).
- At a certain value of the effective pressure $p_{ef}=p_3=p_{cr}$ , the foundation soil reaches its bearing capacity.
- In this stage the soil slides on a shear failure surface.
- This phase is denoted as **failure phase**.
- For shallow foundations $p_3$ represents the **critical pressure** on the foundation soil $p_{cr}$.



# § 3.2 Failure of the foundation soil



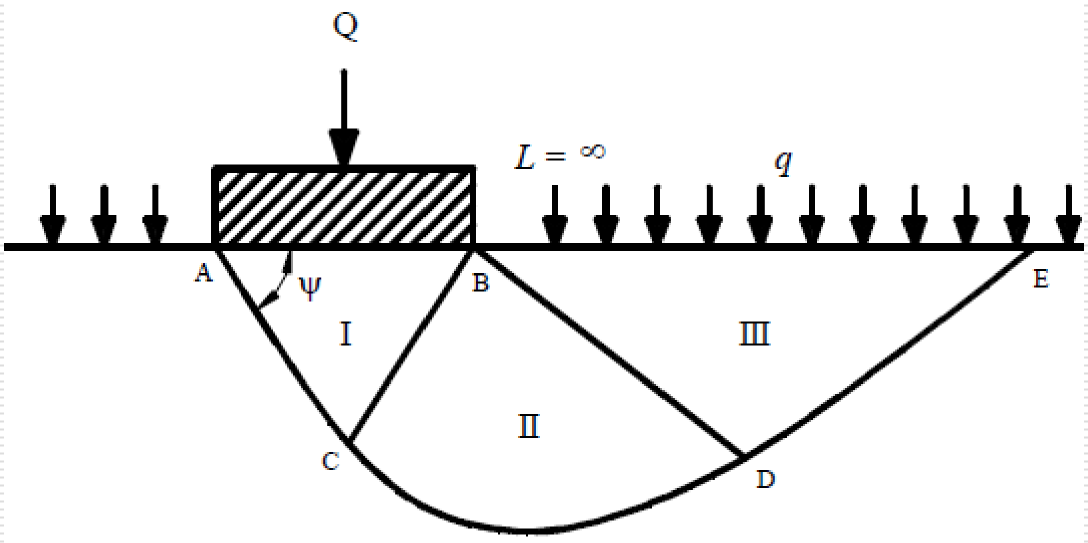




The way of variation of the effective pressure with the soil deformation and the formation of the soil failure mechanism depends on:

- The nature of the foundation soil
- Nature of action
- Action speed

# CHAPTER III – BEARING CAPACITY OF FOUNDATIONS

## § 3.1 Behaviour of the foundation soil



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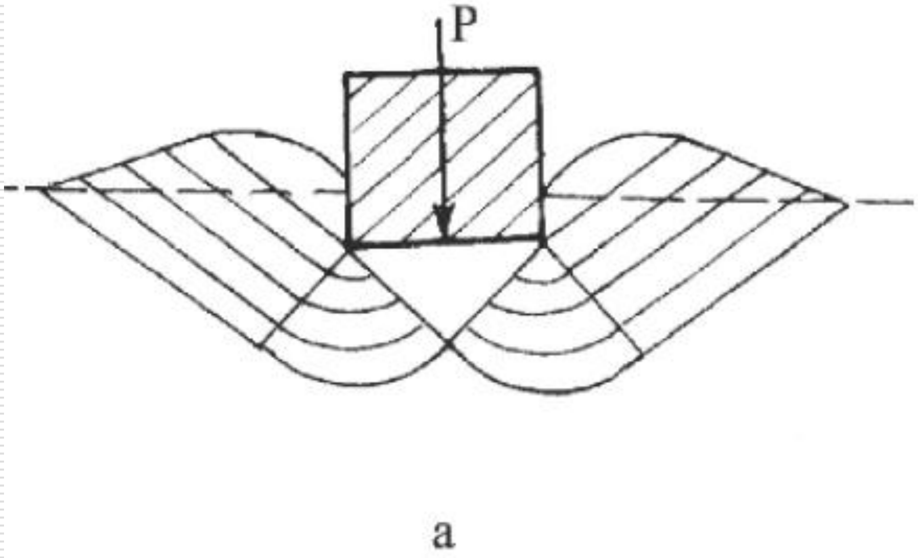
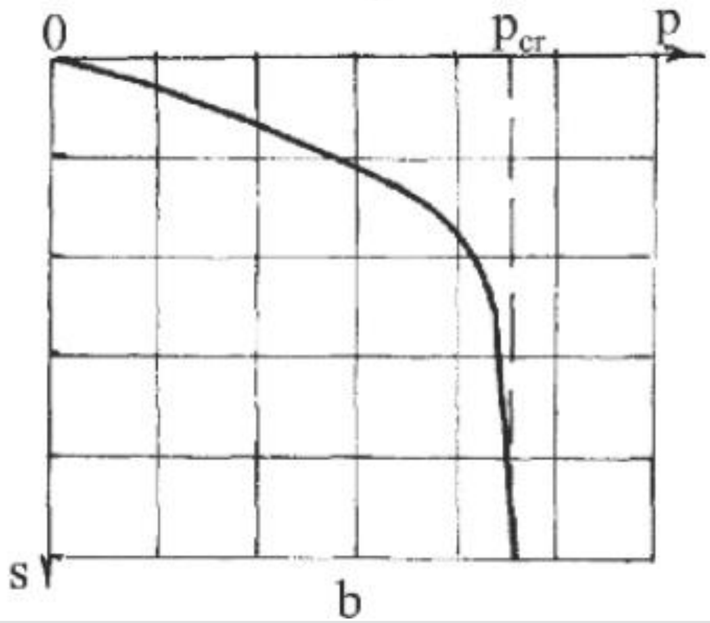
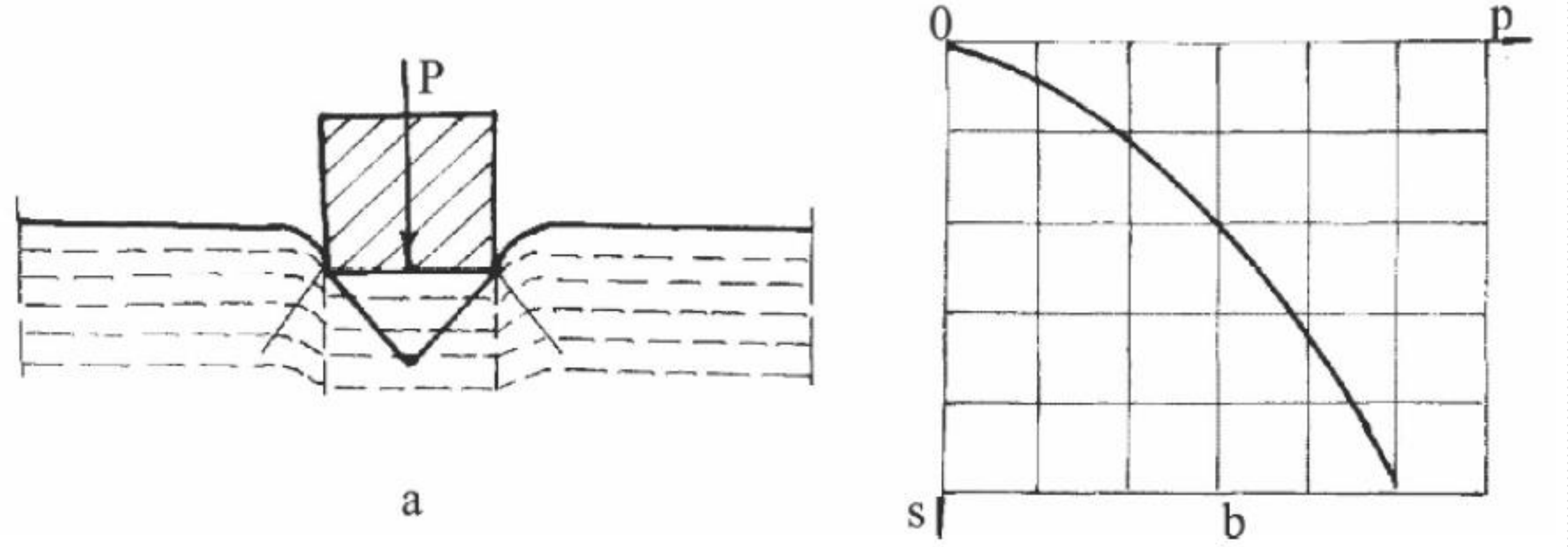



Possible failure modes - **general shear**:

- Characteristic for foundation soils with low compressibility: sands and compressed gravels, compact clays, stony soils etc.
- Under foundation is formed a continuous fracture surface
- The soil in the fault behaves elastically

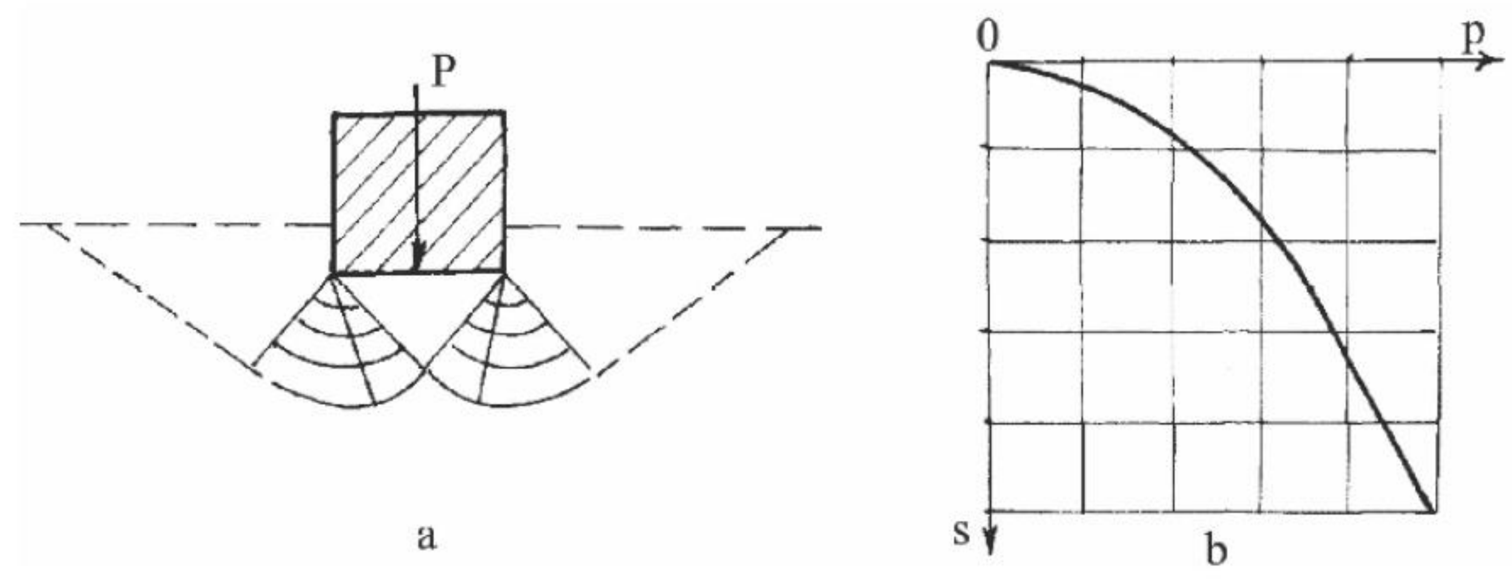
# § 3.2 Failure of the foundation soil




Possible failure modes – **punching shear**:

- Characteristic for foundation soils with high compressibility: loose sands and gravels, silty clays with low consistency etc.
- The foundation penetrates the ground as a piston without affecting the surrounding soil.
- The characteristic behavior has a constant speed of penetration (no linear behavior)

# § 3.2 Failure of the foundation soil



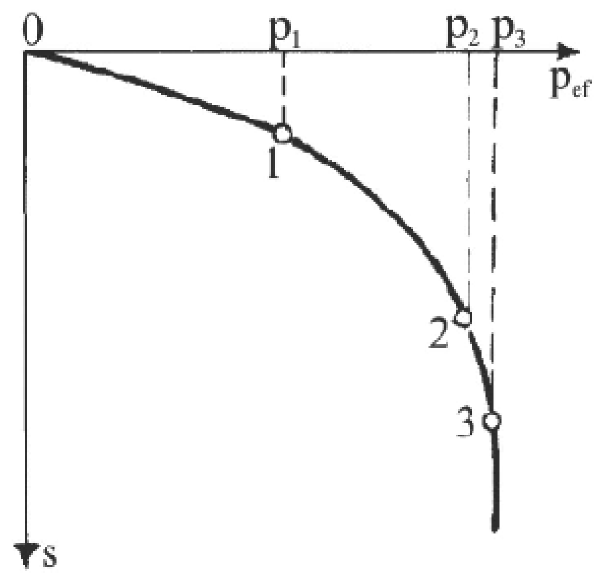

Possible failure modes – **local shear**:

- Characteristic for foundation soils with medium compressibility.
- It represents an intermediate failure: although there are tendencies of lateral shear of the soils, the sliding shears close in the soil mass without sliding to the ground surface.
- In this case the $p_{cr}$ value can be defined through defining a deformation criterion.

# § 3.3 Bearing capacities according to Romanian norm NP 112-2014

In different design situations we may use as bearing capacity:

- Conventional pressure $p_{conv}$
- Plastic pressure $p_{pl}$
- Critical pressure $p_{cr}$




□ The conventional pressure $p_{conv}$ is used for usual “prescriptive method” used in NP112-2014

□ The plastic pressure $p_{pl}$ is used in serviceability limit state design, according to NP112-2014 and EN 1997-1.

□ The critical pressure $p_{cr}$ is used for usual “hybrid model method” used in NP112-2014