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FOUNDATIONS

- CURS 13 -

Design of deep foundations

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CHAPTER VII – DEEP FOUNDATIONS

§ 7.1 Introduction

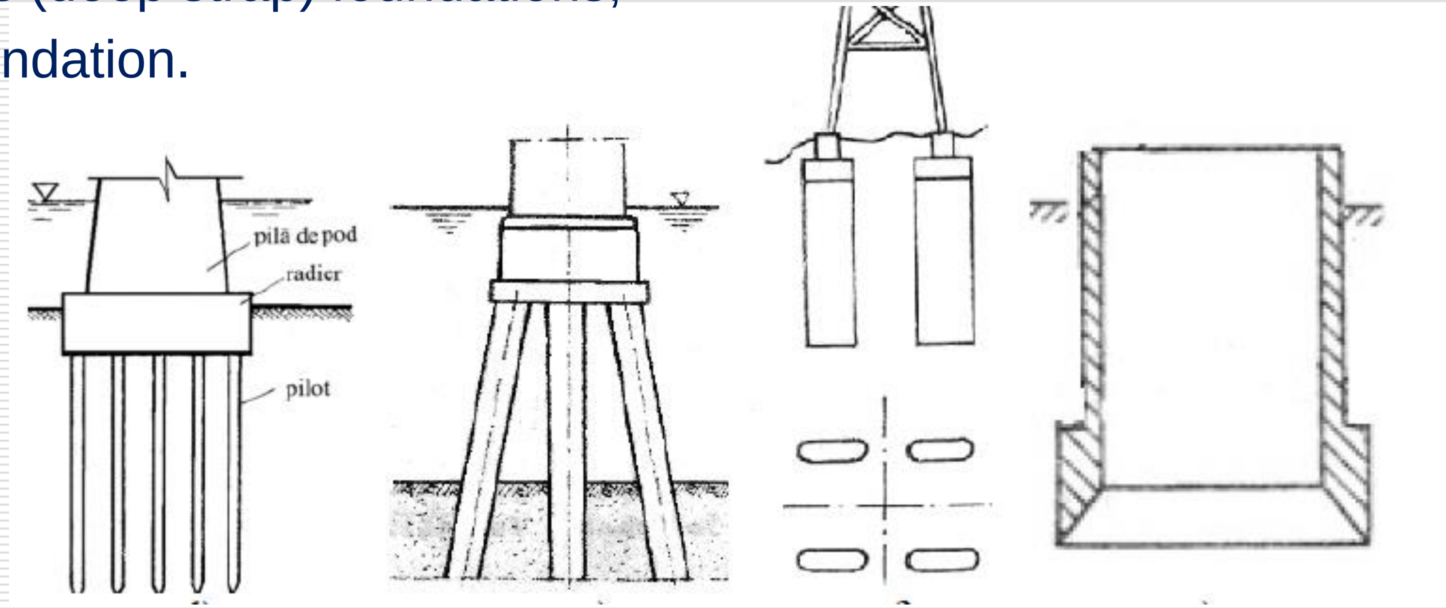
- Deep foundations are realized at medium and high depths;
- In general, deep foundations are long and slender structural members used to transmit foundation loads through soil strata of low bearing capacity to deeper soil or rook strata having a high bearing capacity;
- In most of the cases (exception: caisson foundations) the foundations are built on hidden grounds (not seen), based on experience.
- The connection with the structures is realized through a rigid mat, able of transmitting axial and bending loads by friction between the foundation elements and the soil as well as by direct contact on tip.
- Deep foundations are generally slender elements able of transmitting only axial loads.

Obs: The system adopted for foundation depends on the loads and choice of the design engineer. Sometimes several solutions are considered before final choice.

CHAPTER VII – DEEP FOUNDATIONS

§ 7.1 Introduction

- When the foundation soil is weak and the good soil is found at depths greater than 5-6m, correlated sometimes with the presence of ground waters, the shallow foundations are uneconomical.
- In these situations the use of **deep foundations** is recommended:
    - on pile foundations;
    - on pier foundations;
    - on barrettes (deep strap) foundations;
    - caisson foundation.

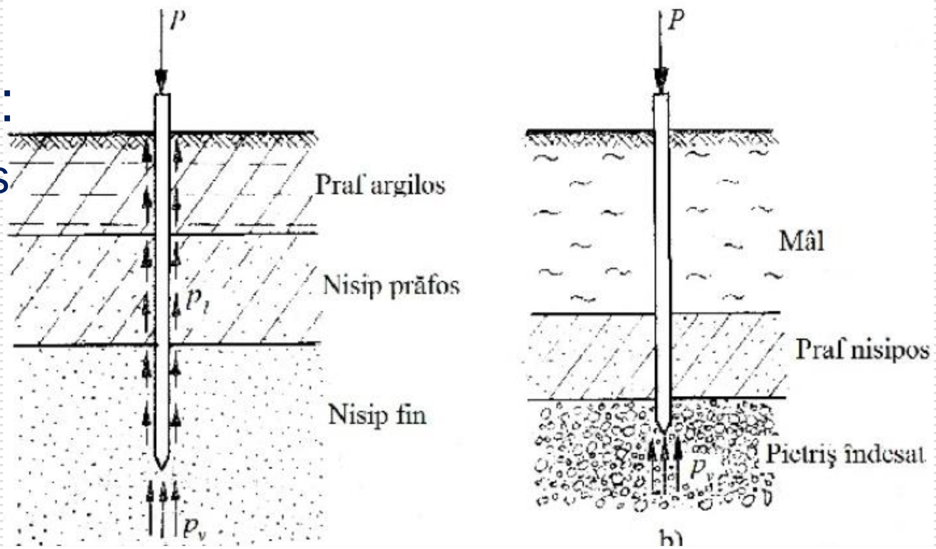


§ 7.2 Pile foundation

- **Piles** are long and slender structural members used to transmit foundation loads through soil strata of low bearing capacity to deeper soil or rook strata having a high bearing capacity.
- **Classification of piles.**
- Based on pile **material types**, piles can be divided into:
  - steel piles
  - concrete piles
  - timber piles
  - composite piles.
- According to the **method of installation**, the main types of piles in general use are as follows:
  - driven piles: piles, usually in steel, concrete or timber, driven into the soil by the blows of a hammer;
  - jacked piles: steel or concrete units jacked into the soil;
  - bored and cast-in-place piles: piles formed by boring a hole into the soil and filling it with concrete;
  - composite piles: combinations of two or more of the preceding types, or combinations of different materials in the same type of pile.

§ 7.2 Pile foundation

- Based on the **nature of their placement**, piles may be divided into:
  - displacement piles: soil is displaced as the pile is driven into the ground
  - non-displacement piles: the soil is first removed by boring a hole into which concrete is placed or various types of precast concrete (bored piles are non-displacement piles).

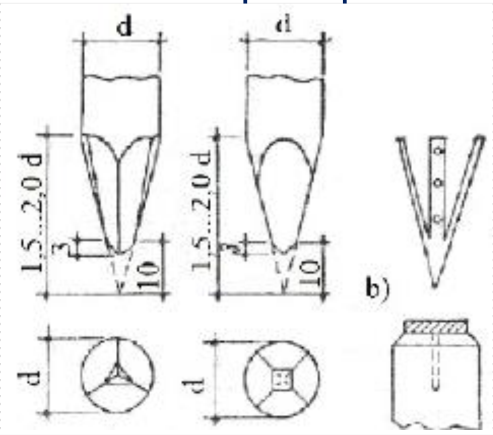


- Depending on the mechanisms of load transfer to the soil, piles can be divided into:
  - friction piles: if the piles do not reach an impenetrable stratum, the carrying capacity is derived partly from end bearing and partly form the skin friction (a);
  - point bearing piles: if the bearing stratum for piles is a hard and relatively impenetrable material (rock or a very dense sand and gravel), the piles derive its resistance of the stratum at the toe of the piles (b).

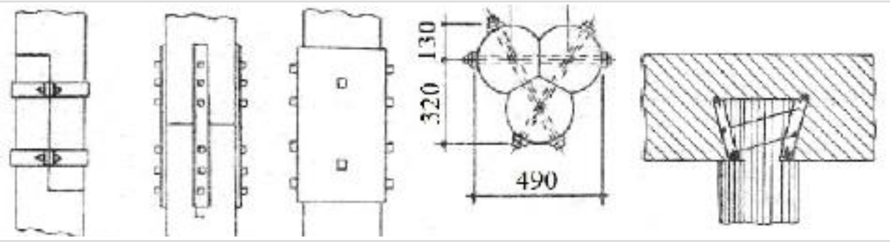
§ 7.2 Pile foundation

- **Wooden piles**:
  - Are used from ancient times;
  - Nowadays are used only for provisory foundations;
  - Cross-section: round worked logs (fir / oak);
  - Usual dimensions: Diameter 25-40 cm;
  - Tip: sharp grinded with steel shoe;
  - Top protection: steel cushion (ring);
  - Continuity connection: by steel plates, steel tubes or steel rings;
  - In water fluctuation zones the piles must be protected with bitumen materials
  - General use: piles of maximum 8m long;
  - The pile should be designed for transportation conditions, driven conditions and final structural loads.

Wooden pile tip



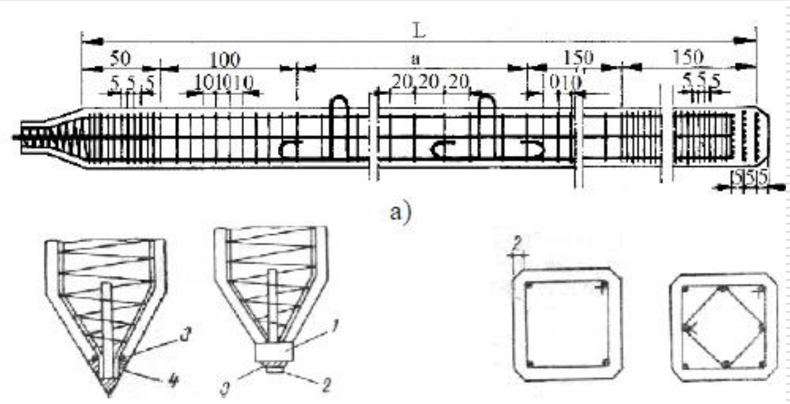
Wooden pile connection and cushion



§ 7.2 Pile foundation

- **Concrete piles**:
  - Used in modern times;
  - Cross-section: different compact CS (usual rectangular);
  - Usual dimensions: Diameter 25-40 cm;
  - Usual length: 6-25m (several sections);
  - Tip: special steel element anchored in concrete.
  - Reinforcement is necessary for:
    - overtaking the structural loads;
    - transportation;
    - results from design and minimum requirements;
    - driving: special reinforcement is necessary for tip and top;
    - usual longitudinal reinforcement: 4Φ14 (..22mm);
    - usual transversal reinforcement: stirrups or hoop reinforcement (Φ6/8);
- Concrete class: min C18/22.5 (min C25/30 for pre-stressed piles)

Concrete pile

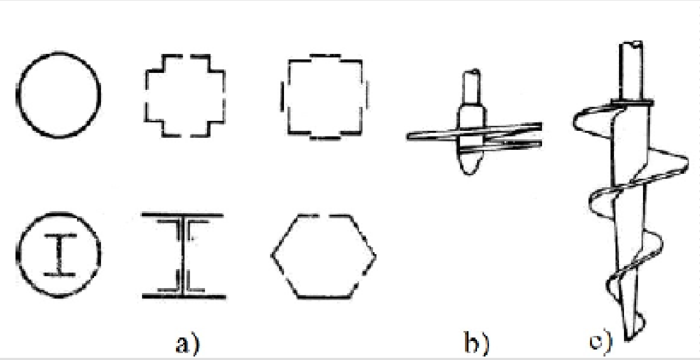


Special concrete pile cross-section

§ 7.2 Pile foundation

- **Steel piles**:
  - Used for building the water works: cofferdams, water-gates;
  - Cross-section: different hollow CS with a helical tip (screw), I/H profiles etc.;
  - Usual dimensions: can work on large CSs: limitation only by driving tool;

Steel pile cross-sections

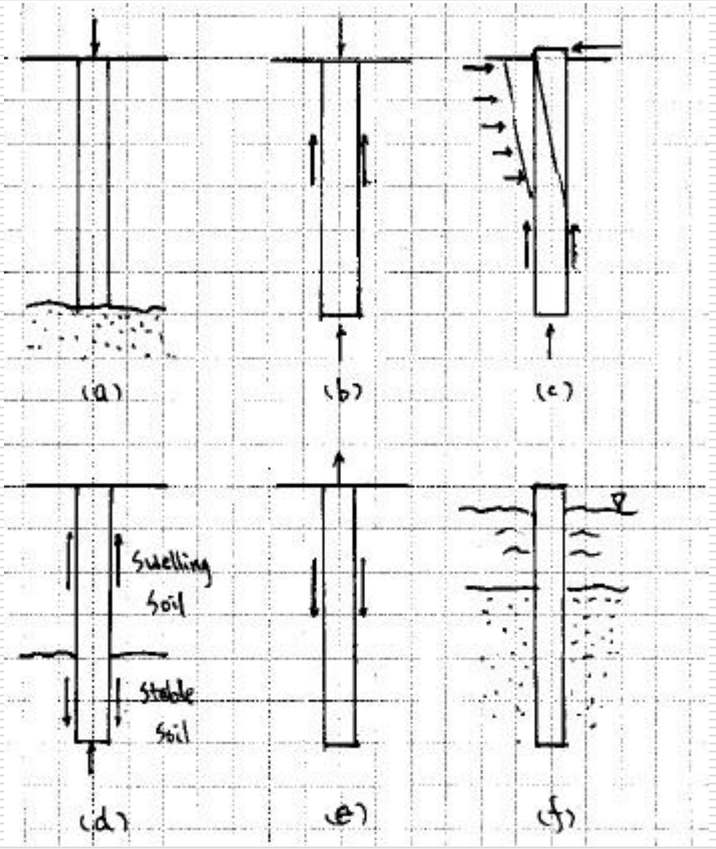


Special concrete pile cross-section

  - Usual lengths: steel piles can be connected for long depths;
  - Tip: special steel element (helical)
  - Advantages of steel piles: very light, high bearing capacity, high resistance in transportation and during driving, easy connection between vertical sections;
  - Disadvantages of steel piles: use of steel material; accelerated corrosion if working in water fluctuation zone;
  - Used in Romania as provisory construction, taken out after use.

§ 7.2 Pile foundation

- **Conditions of pile foundations:**
- (a) to support the load transmitted by the superstructure when the upper soil layer is highly compressible and too weak;
- (b) to transmit the load to the soil gradually, in the form of frictional resistance when bedrock or firm stratum is not encountered at a reasonable depth;
- (c) to resist horizontal forces (wind or earthquake forces);
- (d) to extend beyond the active zone of expansive and collapsible soils into stable soil layers;
- (e) to resist uplifting forces;
- (f) to conduct work over water;



§ 7.2 Pile foundation
- Design of piles -

- **Bearing capacity of piles to compression:**
- The general condition to be checked by piles in compression is: $F_{c;} \leq R_{c;d}$

Where:

F_c is the design value of the axial compression on a single pilot or group of pilots (derived from structural design);

$R_{c,d}$ is the design value of the compression resistance.

- The value $R_{c,d}$ could be derived in two ways:
  - By prescriptive method
  - By testing
- **Compression resistance $R_{c,d}$ computed by prescriptive method:**
  - The design resistance of general friction piles is computed by:

$$R_{c;d} = (R_{b;k}) / \gamma_b + (R_{s;k}) / \gamma_s$$

Where:

$R_{b;k}$ is the design resistance of the pile tip; γ_b – PFS for base (=1.40)

$R_{s;k}$ is the design resistance to friction of the pile; γ_s – PFS for friction.

§ 7.2 Pile foundation
- Design of piles -

- **Compression resistance $R_{c,d}$ computed by prescriptive method:**

$$R_{c;d} = (R_{b;k}) / \gamma_b + (R_{s;k}) / \gamma_s$$

  - The design resistance of the pile tip $R_{b,k}$ is given by: $$R_{b;k} = A_b \, q_{b;k}$$

Where:

A_b is the area of the pile tip: general case - $\pi d^2/4$ (*d* - pile diameter)

$q_{b;k}$ is the characteristic value of the base pressure: for rocky soils – 20000kPa, or according to following table:

Adâncimea de înfigere	Pământuri necoezive					Pământuri coezive						
	Pietriș	Nisipuri			Nisip prăfos	Ic						
		mari	medii	fine		≥ 1,0	0,9	0,8	0,7	0,6	0,5	0,4
(m)	$q_{b;k}$ (kPa)											
3	7500	6500	2900	1800	1200	7000	4000	3000	2000	1200	1000	600
4	8300	6600	3000	1900	1250	8300	5100	3800	2500	1600	1200	700
5	8800	6700	3100	2000	1300	8800	6200	4000	2800	2000	1300	800
7	9700	6900	3300	2200	1400	9700	6900	4300	3300	2200	1400	850
10	10500	7300	3500	2400	1500	10500	7300	5000	3500	2400	1500	900
15	11700	7500	4000	2800	1600	11700	7500	5600	4000	2800	1600	1000
20	12600	8200	4500	3100	1700	12600	8200	6200	4500	3100	1700	1100
25	13400	8800	5000	3400	1800	13400	8800	6800	5000	3400	1800	1200
30	14200	9400	5500	3700	1900	14200	9400	7400	5500	3700	1900	1300
≥ 35	15000	10000	6000	4000	2000	15000	10000	8000	6000	4000	2000	1400

§ 7.2 Pile foundation
- Design of piles -

- **Compression resistance $R_{c,d}$ computed by prescriptive method:**

$$R_{c;d} = (R_{b;k}) / \gamma_b + (R_{s;k}) / \gamma_s$$

- The design resistance to friction $R_{s,k}$ is computed for each soil layer on the foundation by: $R_{s;k} = \sum A_{s;i}\, q_{s;i;k} = U \sum q_{s;i;k}\, l_i$

Where:

$A_{s,i}$ is the lateral area of the pilot on the i^{th} layer;

U – is the lateral perimeter of the pile;

l_i – the length of the pile on the i^{th} layer;

$q_{s;i;k}$ - the characteristic value of lateral friction on the i^{th} layer (see table);

Adâncimea medie a stratului	Pământuri necoezive			Pământuri coezive Ic					
	mari si medii	fine	prăfoase	≥ 0,8	0,7	0,6	0,5	0,4	0,3
(m)	$q_{s;k}$ (kPa)								
1	35	23	15	35	23	15	12	5	2
2	42	30	20	42	30	20	17	7	3
3	48	35	25	48	35	25	20	8	4
4	53	38	27	53	38	27	22	9	5
5	56	40	29	56	40	29	24	10	6
7	60	43	32	60	43	32	25	11	7
10	65	46	34	65	46	34	26	12	8
15	72	51	38	72	51	38	28	14	10
20	79	56	41	79	56	41	30	16	12
25	86	61	44	86	61	44	32	18	-
30	93	66	47	93	66	47	34	20	-
≥ 35	100	70	50	100	71	50	36	22	-

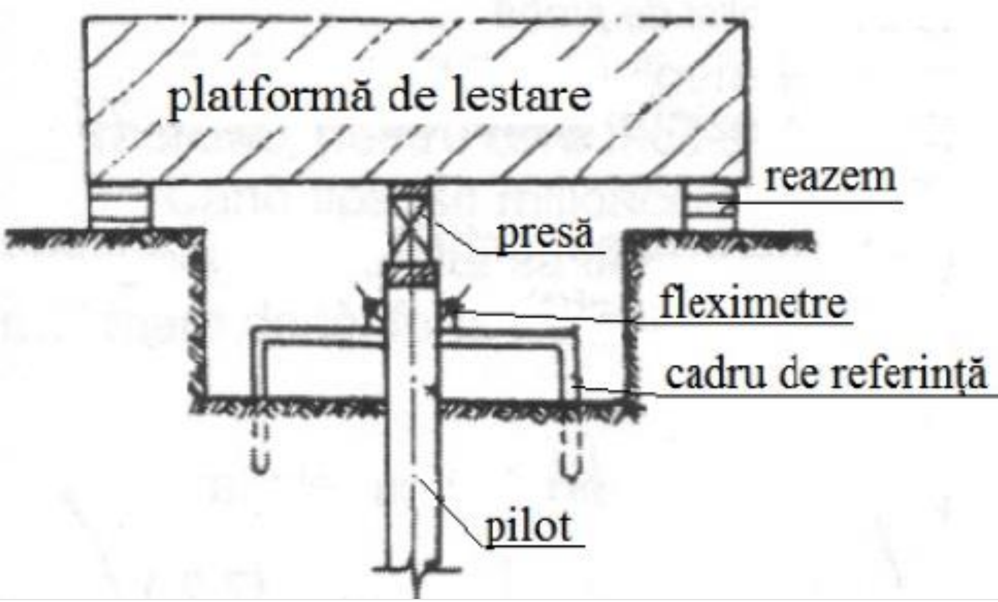
Obs: In case of friction piles only the resistance compression is considered in design.

§ 7.2 Pile foundation
- Design of piles -

- **Compression resistance $R_{c,k}$ computed by testing method:**
- In may cases the foundation soil is non-homogeneous and the best way of evaluating the compression resistance is through testing method.
- The number of piles tested depends on the total number of piles (d<600mm):

Numărul piloților conform proiectului	≤ 100	101…500	501…1000	1001…2000
Numărul piloților de probă încercați	2	3	5	6

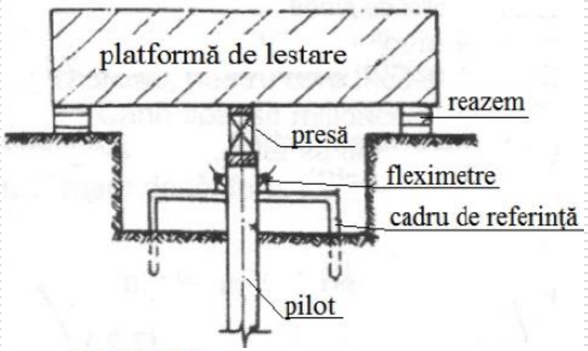
- the tests consists in pushing the piles in the foundation by force steps;
- the testing is realized on site (considering the real soil conditions) by installing a ballasted rigid frame in order to resist the compression forces applied to the pile;
- the load is introduced in steps of 50-500 kN (limited to $P_{max}/8$)



§ 7.2 Pile foundation
- Design of piles -

- **Compression resistance $R_{c,k}$ computed by testing method:**

- The critical load (P_{cr}) is defined as the loading step for which the mean settlement is greater than *d/10* (*d* – cross section dimension);

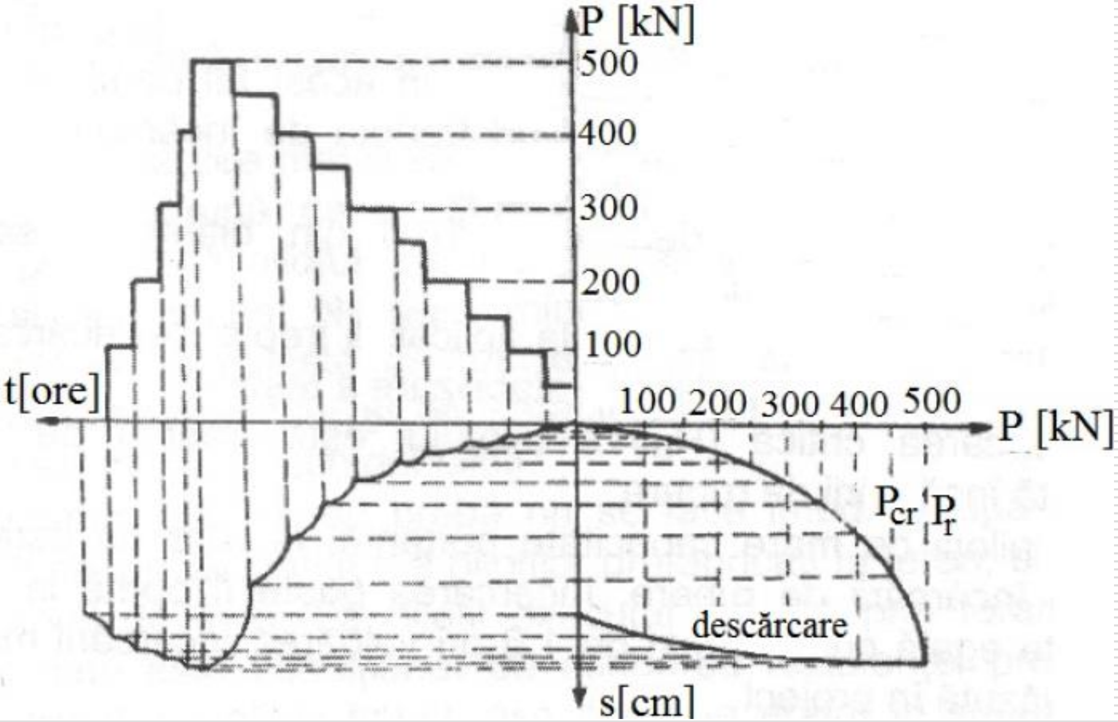


- After attainment of the maximum load, the pilot is discharged in steps

- The interpretation of testing results is made by graphical representation.

- The characteristic bearing capacity of the pile results as:

$$R_{c,k} = k \cdot m \cdot P_{cr}$$



Where:

k homogenity index (=0.70)

m is the coefficient of working conditions (=1.00).

§ 7.2 Pile foundation
- Design of piles -

- **Bearing capacity of piles to tension:**
- The general condition to be checked by piles in tension is: $F_{t;d} \le R_{t;d}$

Where:

$F_{t;d}$ is the design value of the axial tension on a single pilot or group of pilots (derived from structural design);

$R_{t,d}$ is the design value of the tensile resistance.

Obs: In case of tensioned piles, the resistance is assured only by friction.

- The value $R_{t,d}$ could be derived in two ways:
  - By prescriptive method
  - By testing
- **Tension resistance $R_{t,k}$ computed by prescriptive method:**
  - The design resistance of general friction piles is computed by:

$$R_{t;d} = R_{t;k} / \gamma_{s;t}$$

Where:

$R_{t;k}$ is the design tensile resistance of the pile;

$\gamma_{s,t}$ – PFS for tensile action

§ 7.2 Pile foundation
- Design of piles -

- **Tension resistance $R_{t,k}$ computed by prescriptive method:**
  - The design resistance of general friction piles is computed by:

$$R_{t;k} = \Sigma A_{s;i} \cdot q_{s;i;k}$$

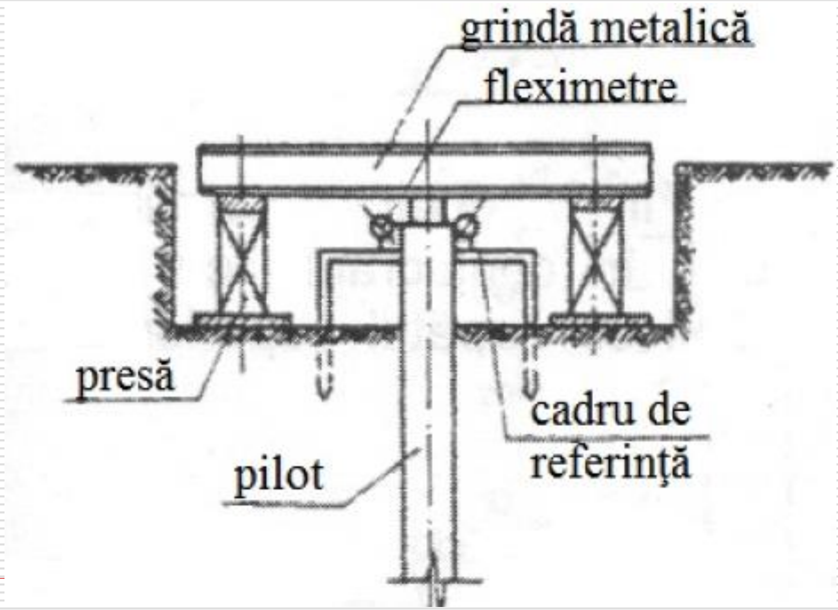
Where:

$A_{s.i}$ is the lateral area of the pilot on the i^{th} layer;

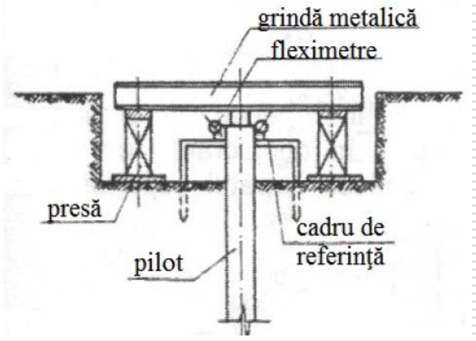
$q_{s;i;k}$ - the characteristic value of lateral friction on the i^{th} layer (see similar table for compression);

- **Tension resistance $R_{t,k}$ computed by testing method:**

- In this case the testing frame is reversed in order to introduce traction on the pile. This is assured by two lateral actuators resting on ground, acting on a rigid beam;
- Special devices are installed to monitor the pulling of the pile from the ground;
- The loading steps are of 10…15 kN (about 1/10 of Pcr).



§ 7.2 Pile foundation
- Design of piles -

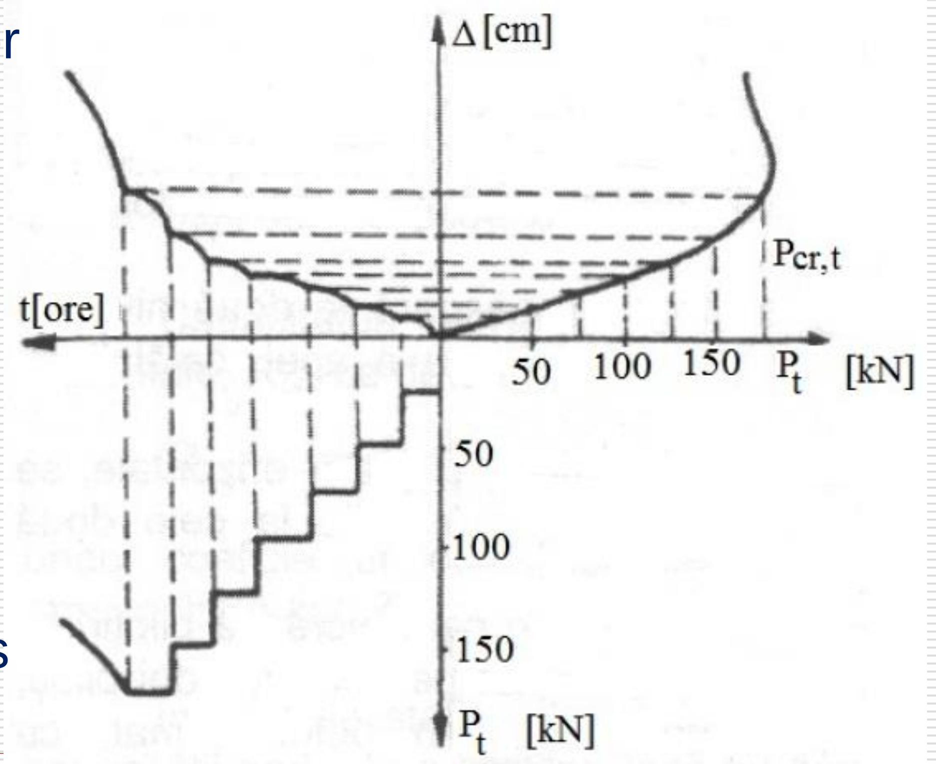


- **Tension resistance $R_{t,k}$ computed by testing method:**
  - The loading continues up to producing non-stabilizing deformations on the ground (diminishing of the traction resistance of the pilot);
  - The critical resistance in tension P_{cr} is defined as the maximum traction force for which the displacement is de-stabilized:
    - The interpretation of testing results is made by graphical representation.
    - The characteristic bearing capacity of the pile results as:

Where: $$R_{t,k} = k \cdot m \cdot P_{cr,t}$$

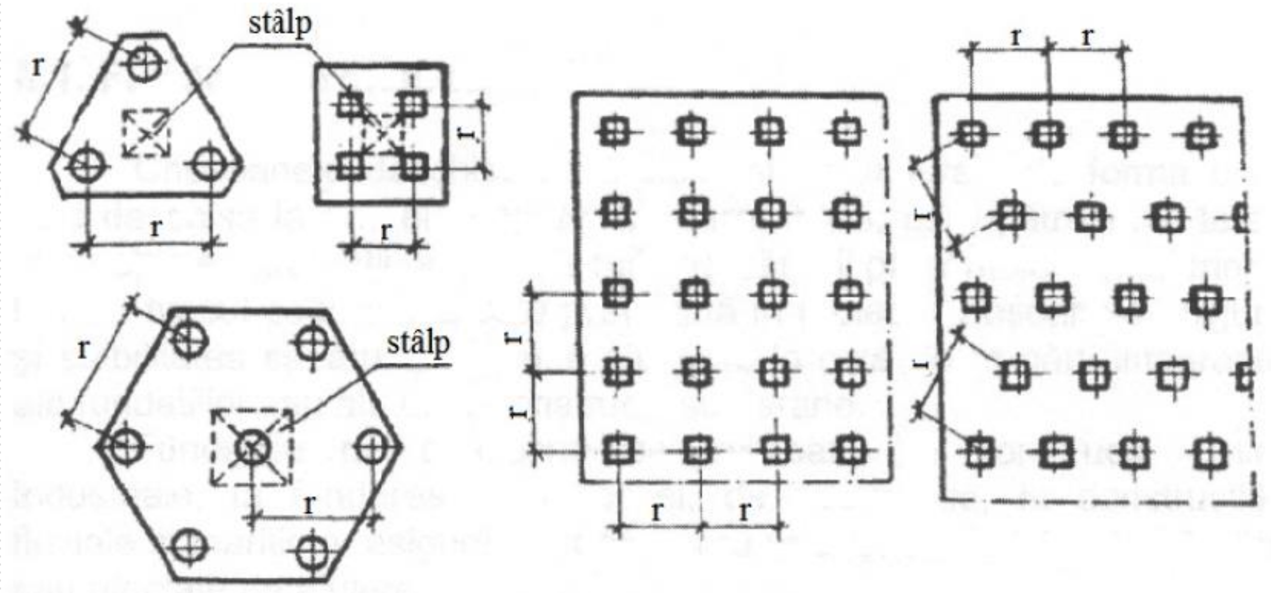
k homogenity index (=0.40)

m is the coefficient of working conditions (=1.00).



§ 7.2 Pile foundation
- Geometrical disposition of piles -

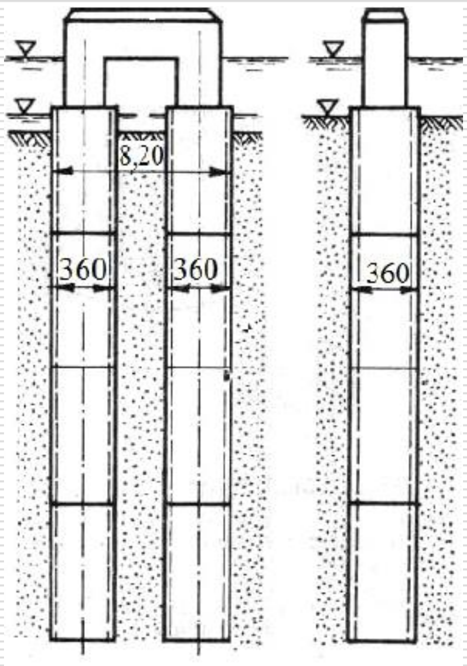
- The mat is considered as a rigid body and the disposition of piles results from the static design;
- However, the pile disposition should respect some requirements:
  - The minimum distances between piles is *3d* in case of non-displacement piles and *2d+3D/100* in case of displacement piles (d-outer diameter of the pile)
- The usual repartition of pile under the mat is on parallel rows, radial or in chess by respecting the minimum distances;
- The dimensions of the mat results from the static design;

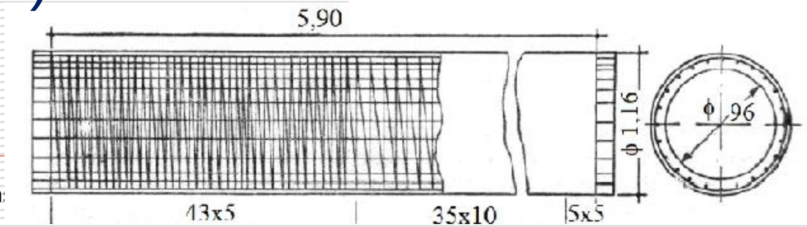


- The anchoring of the piles in the mat is done in accordance to the loads (tension / compression) and results from concrete design;

§ 7.3 Pier foundations

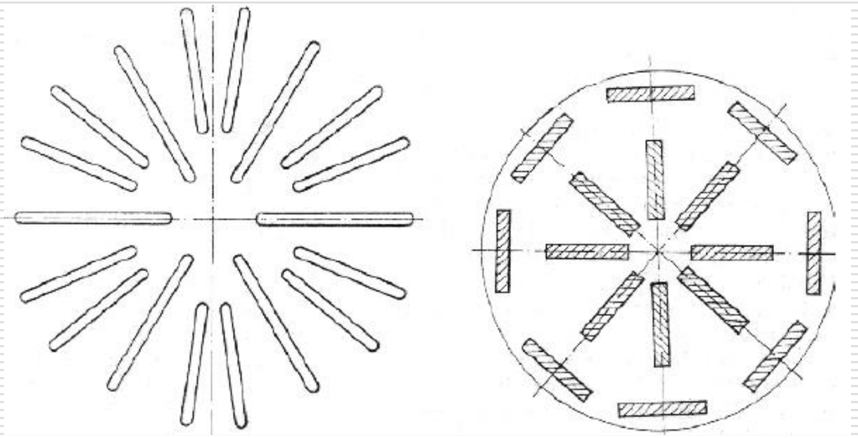
- **Pier foundations** are used in case of high loads, in order to assure a better stability on the foundation ground.
- Piers have tubular form having an *l/D* ratio higher than in case of usual piles: *D= 0.8….6m, l=10…80m* (in-ground length).
- The piers are made on sections on different lengths (depending on diameter) of 6…10 m length;
- Cross-section: tubular (reinforced concrete)
- First section has a sharp tip
- Concrete class: min C12/15
- Reinforced: closed stirrups
- Technology: introduced by vibration or boring
- The piles could be filled with (reinforced) cast concrete

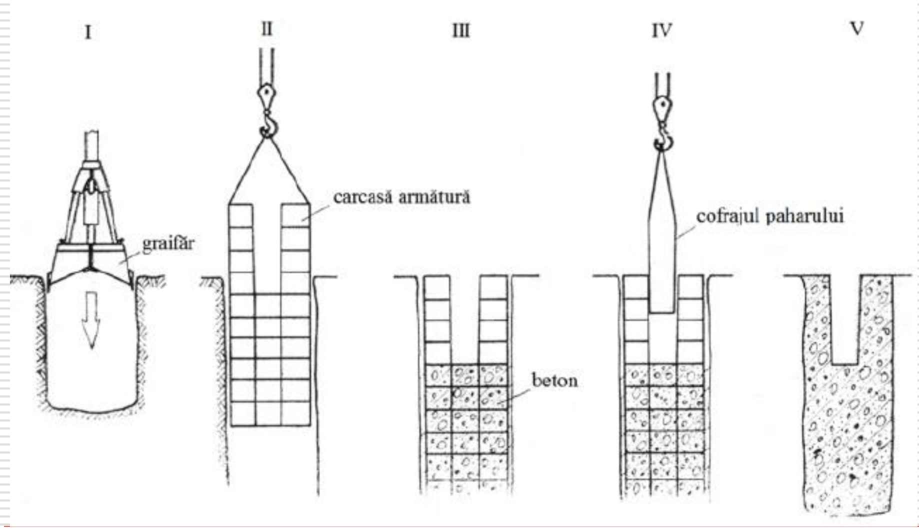


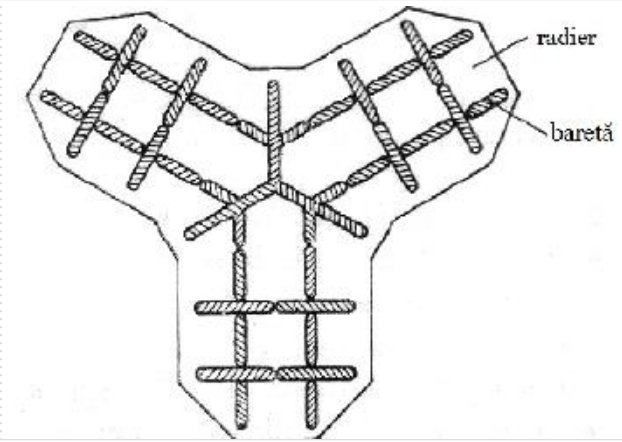


§ 7.4 Barrettes deep foundations

- **Barrettes foundations** are planar deep foundation systems.
- Similarly to pile foundations, the barrettes are linked to the structure by a mat.
- Geometrical condition: *B/t>8* (*t*-thickness, *B* – depth of the barrette);
- The barrette foundation system rest on tip and are executed as cast-in place concrete units

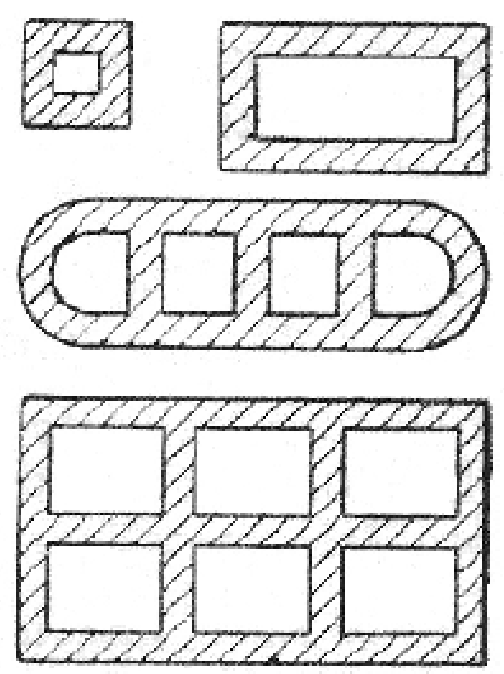




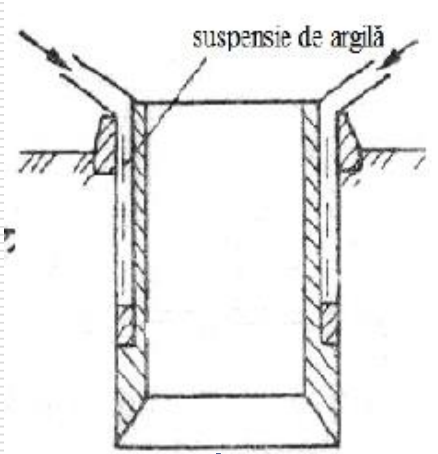


§ 7.5 Caisson foundations

- **Caisson foundations** are used in case grounds with high water levels, including rivers, harbors etc.
- The caissons are made in form of open boxes made of rigid walls;
- Caissons are made on reinforced concrete entering by gravity in the excavated ground.



- The caisson foundations allows working on dry even in case of lateral presence of water (exhausted by pumping);
- The caissons are usually disposed at intersection of building walls;



- In final stage, the caisson could be concreted or not;
- Caissons could be executed on sections;
- The design is made for all the construction stages;
- The design in final state is done similarly to a rigid foundation;