TECHNICAL UNIVERSITY OF CIVIL ENGINEERING OF BUCHAREST

DOCTORAL SCHOOL

RESEARCH REPORT NO. 1

METHODS OF IMPROVING MOISTURE-SENSITIVE SOILS

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CUPRINS

I. MOISTURE SENSITIVE SOILS

Moisture-sensitive soils are those which, under the loads transmitted by foundations or just under their own weight, have additionally settlement when the moisture content rises above certain limits.

In case if these soils are flooded, there is an additional settlement that usually has a sudden collapse.

In Romania, the most widespread moisture-sensitive soils are loess and loesses-like soils.

Loesses are silty, light yellow (sometimes gray to brown) and high porosity. They are made up of silt as predominant fraction (more than 60%), clay (about 30%), the rest is calcium carbonate sand.

Loess and loesses-like soils, in terms of how they make additionally settlement when moistened, are divided into two groups.

Group A includes the soils that, when moistened, does not significantly subside from the geological load, but has additional settlement under the external load. Conventionally, additional settlement when moistened under the action of their own weight (geological load) not exceeding 5 cm are considered to be significant.

Group B comprises the soil that is additionally settlement from the geological load and under external loads.

About 20% of Romania's surface is covered with moisture-sensitive soils. The most important areas are found in the Campia Romana, Dobrogea, Podisul Moldovei, along the Siret rivers, Prut and their tributaries. In the counties of Braila, Constanta, Galati, Tulcea, Calarasi and Ialomita these soils have a significant appearance. In Braila and Galati the sensitive soils layers thickness is about 10-35 m, in Fetesti 25-35 m, in Constanta between 6-10 m, as similar in Giurgiu.

Before building on these soils it is absolutely imperative that require a geotechnical study, and often need to improve the soils to meet the technical requirements of construction.

II. METHODS OF IMPROVING MOISTURE-SENSITIVE SOILS

1. Introduction

The surfaces of land with good geotechnical characteristics are being reduced both on the territory of Romania and around the world. This aspect, coupled with the requirement to set specific objectives in well-defined areas, often raises the question of the use of land with difficult foundation conditions after a number of improvement methods have been applied. The varied geological nature, but also the diversity of relief forms, make it a relatively small space to encounter a wide range of lands with very different physical and mechanical properties.

The need for foundation on difficult soil emerged on the one hand due to regional development, technological conditions, increasing the living standards of the population and, on the other, due to the attempt to rationally use the entire territory. The development of large urban agglomerations imposed in a progressive manner the implementation of foundations, deep excavations, etc. on virgin plots, which are often land of the category considered difficult to found. In order to place the constructions on such soil, have to find solutions that are technically satisfactory but also cost-less.

Methods to improve difficult soil foundations are in continuous progress, both quantitatively and qualitatively, as a result of the development of new technologies, but also of the awareness of economic and environmental benefits through the use of modern methods.

Thus, a significant number of techniques have been developed to improve the mechanical characteristics of the difficult soil foundations. Two major categories of methods can be distinguished (Schlosser, F. 1997):

- soil improvement technologies where the soil's structure is improved especially at the level of particle contact by means of an additive or by reduction of porosity in order to achieve a higher level of deposition - methods of improving the physical properties;
- soil reinforcement technologies where structural elements are introduced into the ground for the purpose of increasing mechanical strengths - methods of improving mechanical properties.

The results, which are aimed at improving the difficult soil foundation, can be classified as such (Kirsch, K., 2003):

- Increasing density and shear resistance
- reduction of compressibility
- influence on permeability to reduce infiltrated water flow or accelerate the consolidation process
- improving homogeneity.

In order to choose the optimal improvement method, a technical and economic analysis is required for each given situation.

The process and the intensity of the improvement of the difficult soil foundation depend on the destination and the constructive solution adopted for the construction located on the respective ground.

In addition to the mechanical methods for improving moisture-sensitive soil, a number of other physical methods can be successfully applied:

- control moistening;
- silicification;
- thermal treatment.

Table 1 presents a list of mechanical methods for improving difficult soil foundation according to the "Norms on improvement of soft soils by mechanical procedures. Indicative C 29-85. ".

Table 1 - Indicative list of mechanical methods for the improvement of soft soils foundation.

Method name			Applicability to diffirent types of soils: Moisture sensitive loess A	Moisture sensitive loess B	Loose sands	Soft rocks and clays	Ffilling soil	Loess and loose soil, very moist, below the water level
Distribution platform	Made of soil		Y	Y	-	-	Y	Y
	of granular materials		Y	Y	-	Y	Y	Y
Surface Compaction	With heavy mallet		Y	Y	Y	-	Y	-
	With ultra-heavy mallet		Y	Y	Y	Y	Y	Y
	with vibro-roller		Y	Y	-	-	-	Y
Depth compacting	With vertical columns - according to the execution technology	by impact	Y	Y	Y	-	Y	-
		by vibrare, vibro-pressing or vibrating punching	-	-	Y	Y	Y	Y
		by vibro-flotation	-	-	Y	-	-	-
	With vertical columns - according to filling material	By soil	Y	Y	-	-	-	-
		by granular material	-	-	Y	Y	Y	Y
		with cemented material	Y	-	-	Y	-	Y
	By deep bursts		Y	Y	Y	-	-	-
	By leaching	Pretesting	-	-	-	Y	-	Y
		Through the guided execution of the construction	-	-	-	Y	-	Y

		By lowering the groundwater level	-	-	-	Y	-	Y
	by wetting	Flooding the ground	Y	Y	-	-	-	-
		Directed humidification	Y	-	-	-	-	-
Accelerating soil improvement	With vertical drains of granular material		-	-	-	Y	-	Y
	With vertical drains of geotextiles		-	-	-	Y	-	-

On the basis of the structural strength σ_0 which value is known, the deformable areas can be defined as the areas in the field in which deformations occur as a result of the soil structure damping by moistening.

The upper deformable area extends to the depth at which the vertical stress σ (sum of the geological load with the load from the loads transmitted by the foundation) becomes equal to σ_0 (Figure 1).

In the case of a certain thickness of the moisture-sensitive layer, additional compressions may occur on the basis of an underlying layer. This area is called the lower deformable area.

Within the deformable lower geological load (σ_{gz}) area is large enough for the total vertical unitary stress (σ_z) to be also higher than σ_0.

In the case illustrated in Figure 1 (NP 125: 2010), an inert zone is interposed between the two deformable zones, so called, since in this area the total vertical effort (σ) is less than a0, and therefore is not produce settlement cause of moistening (NP 125: 2010).

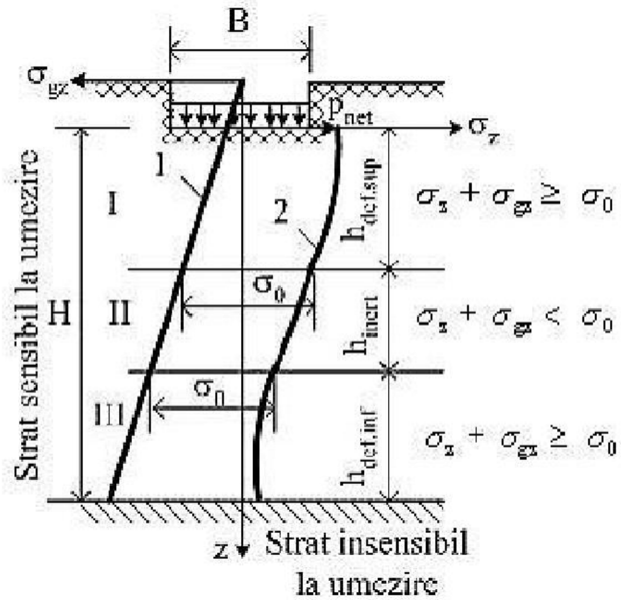


Figure 1 - Characteristic areas in the soil foundation made up of moisture sensitive soil: I - upper deformable area; II - inert area; III - lower deformable area; 1 - diagram of variation with the depth of effort σ_{gz}; 2 - the stress-strain variation diagram σ_z.

In the choice of measures to limit the size of the additional settlement cause by moisture, there are generally 2 situations (NP 125: 2010):

- The foundation soil falls into moisture-sensitive soil group A (Figure 2 - a). With punctuated line was marked isobar of structural resistance that delimits the upper deformable area. In this case it is analyzed by applying various improvement measures to remove the moisture insensitivity of the layer of the deformable zone (Figure 2 - b) or the entire thickness of the deformable zone (Figure 2 - c).

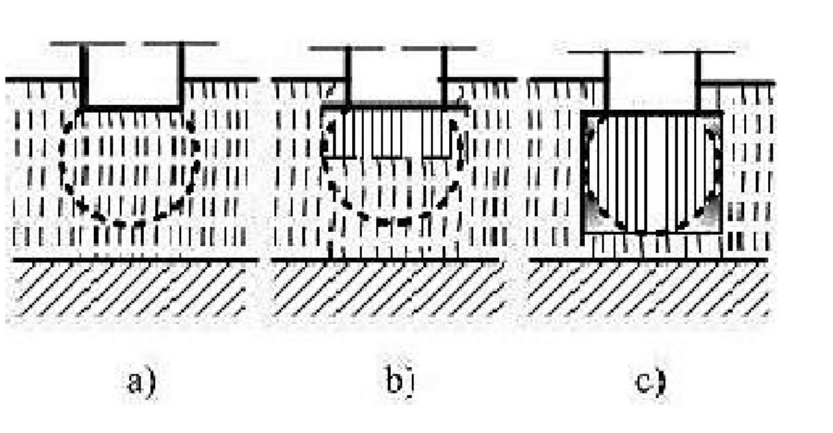


Figure 2 - Foundation variants on soil of group A.

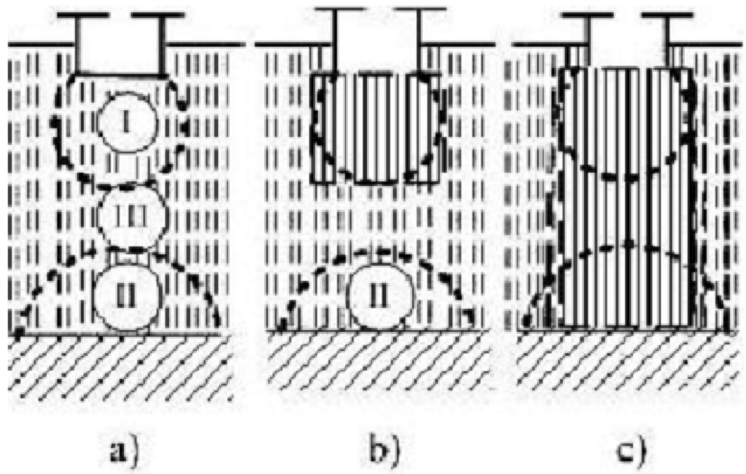


Figure 3 - Foundation variants on soil of group B.

- The soil foundation is belong to group B of moisture-sensitive soil (Figure 3-a)). In this case, the upper deformable zone I coexists with the lower deformable zone III and the inert zone II. Solutions are being analyzed to eliminate moisture sensitivity for moisture-sensitive soil group A, up to the upper deformable zone (Figure 3 - b)). If the action measures do not provide guarantees that the stresses that may occur at the lower deformable area can be maintained within acceptable limits for the structure of resistance and for the normal exploitation conditions, piercing the moisture-sensitive layer through a deep foundation (Figure 3 - c)).

2. Improvement of moisture-sensitive soil by compaction methods

2.1. Compaction

Compaction is the construction work process that improves the ground's ability to withstand the weight of buildings, communication paths, and facilities on it. During compaction, the solid particle component of the soil approach each other under the effect of external forces, decreasing the pores and eliminating the excess water. Compaction is differentiated according to the properties of the soils and construction materials used.

**** Compaction can be accomplished by the following processes:***

- by static pressure, by passing over the land to be compacted of rollers whose surface may be smooth or with projections called compaction by roller;

- through dynamic action, by hitting by plates or jumping machines;

- by vibrations with a frequency close to that of the resonance oscillations of the compaction material produced by vibrators and vibrating machines,

- by combined actions (static pressure and vibration, static pressure and impact).

The choice of compaction methods is based on the soil's type, the thickness of the compaction layer, the rate of compaction required and the working surface.

**** Mechanical compaction of the soil aims to reduce and uniformize the settlement in the future constructions.***

In order to establish optimal compaction parameters, machinery, and how technology is applied depending on the nature of the land in a particular location, it is necessary to perform specific laboratory tests and / or experimental polygons in situ.

For the laboratory study of the optimal compaction parameters, the Proctor test, which is regulated by STAS 1913/13 - 83, is performed. The purpose of this test is to determine, for a certain mechanical compaction (L), the optimum compaction moisture content (w_{opt}) to which the ground to be compacted must be brought so as to obtain a maximum dry weight ($\gamma_{d\ max}$). The specific mechanical work is 0.6 dJ / cm^3 for the Proctor normal test and 2.7 dJ/cm^3 for the modified Proctor test.

The specific mechanical compaction work is determined with the relation:

$$L = \frac{m * g * h * n}{A * a} \quad \left[J / cm^3 \right]$$

Where:

m - mass of the rammers [kg];

g - gravitational acceleration = 9.807 m/s^2;

h - height of fall of the rammer [m];

n - the number of strokes on each layer;

A - the section of the cylinder section [cm^2];

a - the thickness of the compacted soil layer [cm].

The test consists in compaction with the same mechanically specific samples of the same soil brought to different moisture content and determine dry density for each sample. Then graphically plot the variation in volume weight versus moisture content, thus obtaining the optimum compaction moisture content value as the value corresponding to the maximum dry density (Figure 4).

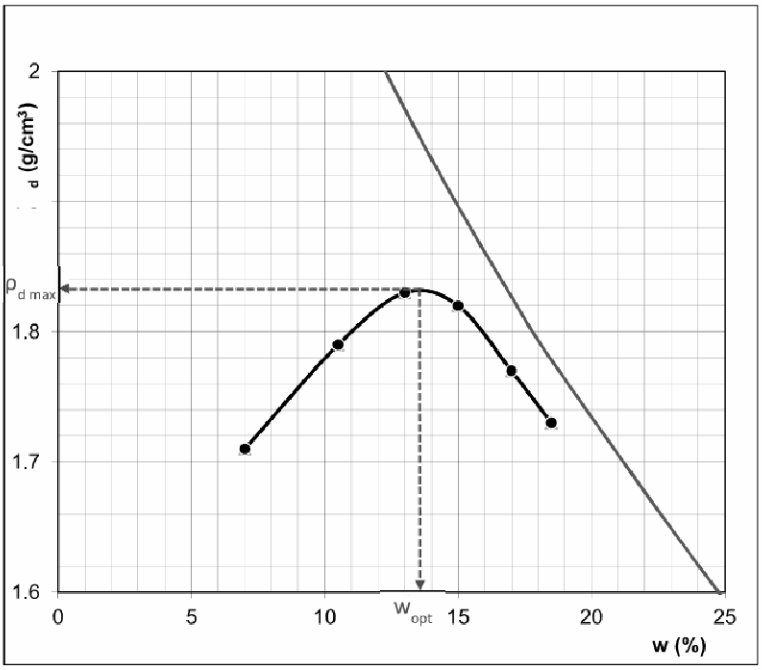


Figure 4- Proctor diagram.

STAS 193-13 - 83 recommends that the normal Proctor test be carried out in the case of improvement of the foundation ground and also provides indicative values of optimal compaction moisture content for soil types (Table 2) together with a relationship of verification of the value obtained in the case of maximum dry density:

$$\rho_{d\,\max} = \frac{\rho_s}{1 + \rho_s \dfrac{w_p + 0.2 * I_p}{100}}$$

in which:

ρ_s – particale density; w_p - the lower limit of plasticity; I_p - the plasticity index.

Table 2- Indicative values of optimal moisture content for compaction.

Type of soil	Optimal moisture content for compaction, W_{opt} (%)	
	Standard Proctor	Modified Proctor
Fat clay	20...25	15 ...20
Clay	16...23	12 ... 18
Silty clay	16...22	12 ... 17
Sandy clay	14...20	10 ... 16
Sandy silty clay	16... 18	12 ... 14
Clayey silt	14... 18	10 ... 14
Sandy clayey silt	12... 16	9. .. 12
Silt	12... 16	10 ... 12
Sandy silt	11 ... 16	8. .. 12
Clayey sand	13... 16	10 ... 13
Silty sand	11 ... 14	8. .. 11
Sand	8... 11	8 ...8
Gravel	4...8	3 ...6

When designing works where this improvement method is used, the build-up condition to be obtained on site is expressed by the rate of compaction:

$$D = \frac{\rho_d}{\rho_{d\max}} * 100$$

In which:

ρ_d - dry density to be achieved in the designed work;

$\rho_{d\,max}$ - dry density obtained on the same soil in the laboratory.

depending on the purpose and importance of the future construction, the rate compaction D values may vary between 90% and 98%.

2.2. Compaction of the surface

**** Distribution platform made of compacted soil (cushion)***

The surface compacting of loess soils is frequently used to reduce or even eliminate their sensitivity to moistening.

Surface compacting is accomplished by applying static pressures and / or vibrations or shocks to the ground, which lead to the deposition of relatively small thickness layers of soil. Depending on the way of execution, the surface compaction can be manual or mechanized.

Manual compaction is used for low volume works and in narrow spaces where access to mechanized machinery is not possible. The effect of the equipment used for manual compaction is felt at reduced depths of the order of 20 - 30 cm.

The compacted soil cushions aim at reducing or even eliminating the moisture sensitivity of the soil that forms the foundation ground.

If the cushions layer is placed on loess soil belonging to the group A of moisture-sensitivity and comprise the entire active area of the future foundation, the moistening sensitivity of the soil foundation is completely eliminated.

If the cushions layer is place on soil belonging to the group B of moisture-sensitivity, the moisture sensitivity is partially or totally eliminated only in the active zone of the foundation, but there is the possibility of extra depths forming under the action of geological load (Dianu, V., Dianu, F., 1992).

In the case of moisture-sensitivity soils, the cushions are made of pre-excavated material. These involve the laying and compacting of successive layers of material until a compacted soil layer is obtained, the thickness of which can be 1-4 m.

Mechanized compaction varies with the machine used (Figure 5 - www.cat.com) and the working mode.

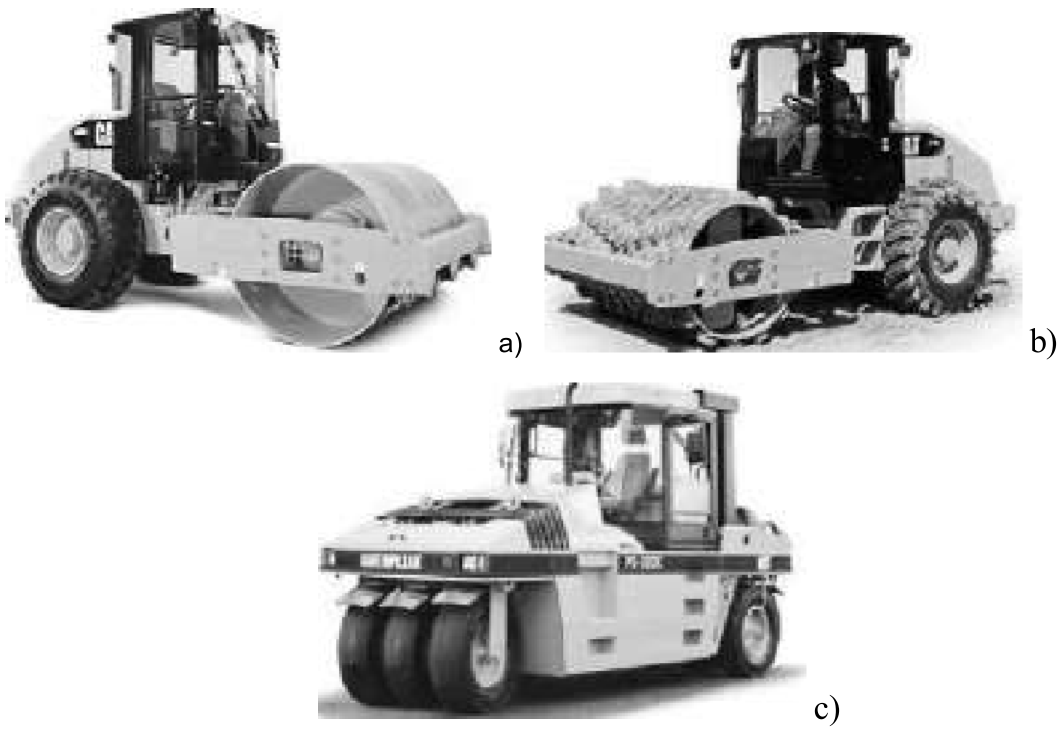


Figure 5- Rolling Compaction Equipment

a) Cylinder smooth roller; b) Camshaft Cylinder (Sheep Foot); c) Tire equipment compactor.

Roller compaction is done with smooth compactor rollers, cams (sheep feet) or tires.

The use of smooth cylinders is indicated for compacting the soil in layers of 15 - 30 cm thick. Compaction is accomplished through several passes of the machine over the layer to be compacted. At first passes, the loading effect is higher, then gradually decreasing until the efficiency becomes almost null. The optimum number of passages is determined taking into account the thickness of the compacted layer based on the dry density γ_d.

Large roller "sheepsfoot" compactors are especially indicated for clay and silty soil. The compaction principle for these machines differs from compaction with smooth cylinders to the extent that the ground can pick up the large pressures under each foot. Otherwise, the feet plunge completely into the ground, the machine resting on the cylindrical side. These cylinders rest on the ground only through the cams that penetrate into the ground and thus increase the values of local pressures.

The tire roller is equipped with a large number of large diameter tires, the inflation pressure being equal to the one exerted on the ground. At the beginning of the compacting, lower pressures are made (the bearing surface being larger), and as the compaction increases, the tire pressure increases. The number of machine passes is determined by experimental polygons in situ.

In most cases, compacted soil cushions are made by roller.

In the first stage a digging under the level of foundation of the future construction is carried out. The filling material (local) is arranged in layers of 25-30 cm and brought to the optimum compaction moisture content. If the moisture in the field is less than the optimum, the material is wetted and if the natural moisture content is higher than the optimum compaction it is let to dry.

Once the material is brought to optimum compaction muisture, it is compacted by roller. Operations are repeated until reaching the projected requirement (Figure 6).

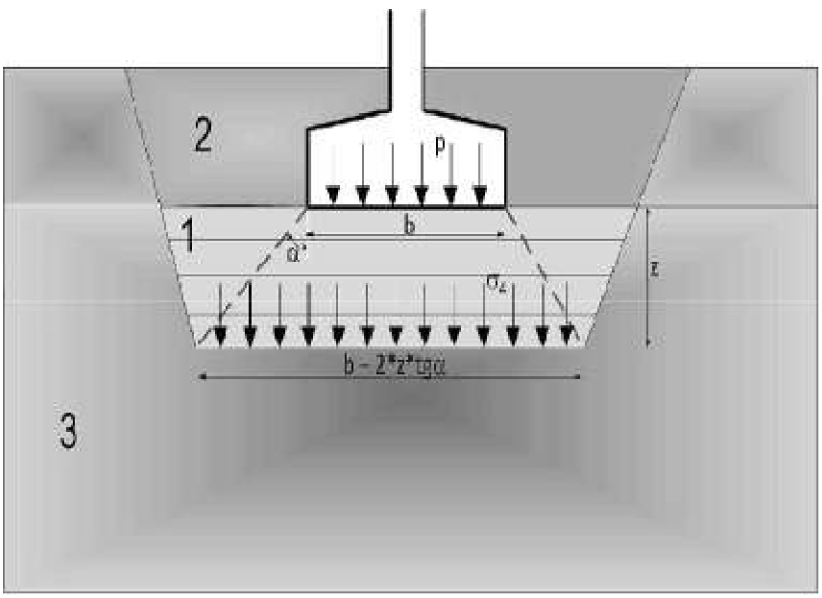


Figure 6- Compacted soil cushion. 1 – cushion; 2 - compacted filler; 3 - the moisture-sensitive soil layer.

The total thickness of the cushion results from the condition that unconsolidated soil deformations remain under the cushion not to exceed the admissible values for that foundation.

Quality control is carried out by sampling for which moisture and dry unit weight are determined. As shown, the rate of compaction is calculated as the ratio between the dry unit weight obtained on the site after compaction and the maximum dry unit weight obtained in the laboratory by the Proctor test.

2.3. Compaction with the heavy mallet (dynamic compaction)

Dynamic compaction of the soil is carried out with the heavy mallet, this being applied in order to increase the bearing capacity of the difficult soil of foundation made up of loose sands, sandy soils or moisture-sensitive soils (C 29-85).

Dynamic compaction is used for moisture-sensitive soils in the following situations:

- when the relatively low compaction depth which can be achieved with the heavy mallet is sufficient to eliminate the additional settlement cause of moisture, within the entire deformation zone of the foundations;
- when it is necessary to achieve by compaction a superficial crust which is hardly permeable, to protect against infiltration.

The moisture content of the compacted soil must be as close as possible to the optimum compaction moisture content, with the maximum permissible deviation of ± 3%. Optimal compaction moisture content can be approximated by:

$w_{opt}=w_p + (1...3)\%$

where w_p is the lower limit of plasticity.

If $(w_{opt}-w) > 3\%$ then add water to the soil mass to get optimum moisture content. The required amount of water can be calculated by:

$$\Delta w = \eta * \frac{\rho_d (w_{opt} - w)}{100 * \rho_w} * V$$

where:

η - coefficient for water loss compensation, with values between 1.1 - 1.25 depending on the season;

ρ_d – dry density;

ρ_w – density of water;

w_{opt} - optimal compaction moisture content;

w - the moisture content of the soil to be compacted;

V - the volume of soil involved in compacting.

The wetting of the soil (which will be compacted) by additional water Δw is achieved only by spraying in successive turns as the water penetrates into the soil, over the entire thickness of the soil layer to be compacted. If the soil moisture content of the soil to be compacted is higher than the optimum compaction moisture content due to atmospheric precipitation, the compaction process is delayed until the moisture content decreases to the expected value.

The heavy mallet is a block of concrete with a mass of 2 - 4 tons which is lifted by a crane at a height of 4 - 8 m and allowed to fall freely (figure 7).

Compaction with the heavy mallet is done in two cycles. in the first cycle, the traces of the mallet are tangent, and in the second cycle the traces of mallet will be offset by half the diameter of the first cycle. Within each compaction cycle, several strokes are applied at the same place until the denial is reached (reaching a constant 1-2 cm of settlement under each stroke).

To determine the number of strokes N1 required in the first cycle, a sample stroke is run. After each fall of heavy mallet, the compaction is measured, and the attempt is made until the refusal is reached. This is considered to be achieved if for 3 consecutive strokes the trough values are obtained that do not differ by more than 5mm. The number of strokes N1 is the lowest for which this difference was obtained. With determined N1, the first beat cycle is performed, then it is passed to cycle 2. The number of N2 strokes is determined similar to N1 (C 29-85).

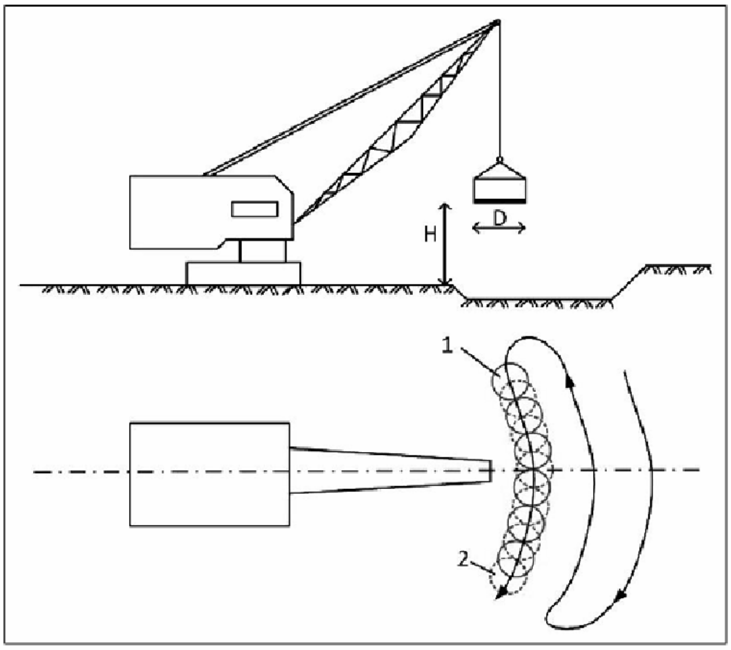


Figure 7- Compaction with the heavy mallet

1 - the first compaction cycle; 2 – the second compaction cycle.

The depth “hc” which compaction by heavy mallet is felt can be determined by the empirical relationship (Manoliu, I., 1977):

$$h_c = k * d$$

where:

d - base diameter of the mallet;;

k - coefficient that depends on the nature of the soil and it’s equal to: 1.55 for sands, 1.45 for silty soil, 1.20 for clay fillings, 1.0 for clay.

The weight of the heavy mallet and its base dimensions are chosen so that a minimum pressure of 15 kPa for non-cohesive soil and at least 20 kPa for cohesive soil is developed on the ground. According to C29-85, for the development of such pressures on the ground, the mass of the heavy mallet is written in the values in Table 3.

Table 3- Values of the beating masses of heavy mallet.

Diameter (m)	Area of the heavy mallet (m^2)	Heavy mallet weight (tons) to develop pressure on the ground:	
		15kPa	20kPa
1.2	1.13	1.70	2.26
1.4	1.54	2.31	3.08
1.6	2.03	3.00	4.06

According to C29-85, the rates of compaction to be achieved in the case of moisture-sensitive soil are shown in the following table:

Table 4- Compaction rates in the case of moisture-sensitive soil.

Works executed by compacting moisture-sensitive soil	Compaction rates, D (%)	
	Medium	Minimum
Compaction works for the foundation of residential and social - cultural buildings	95	92
Compaction works required to build industrial wet manufacturing sites	98	95

2.4. Depth compaction

**** Soil columns made by beating***

Deep soil compaction is applied to moisture-sensitive soil to eliminate its sensitivity to moisture, but also to increase the bearing capacity of the foundation soil.

This method is used when the moisture-sensitive area exceeds 5-6 m thick, and can not be sufficiently compacted by surface methods. In the case of adopting this deepening solution due to the fact that usually the length of the columns is considered to be equal to the thickness of the landfill of moisture-sensitive soil, the risk of the occurrence of additional settling in the deepening is eliminated.

In order to make the columns of the soil, the place of the future columns is forced to be executed, thus filling the surrounding material. Subsequently, in the hole thus created, soil gaps are added to the optimum compaction moisture content and are compacted by applying a series of ram strikes.

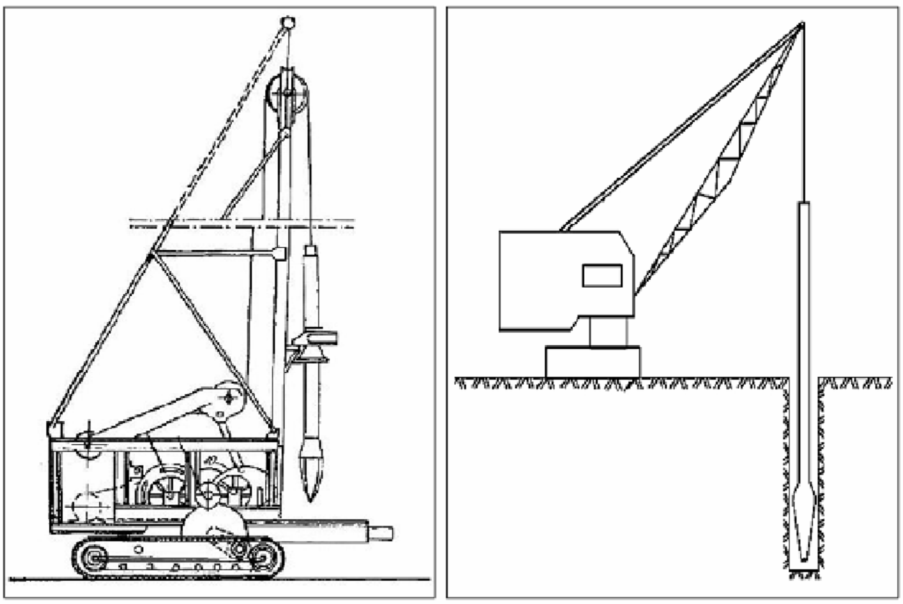
Thus, the compaction effect is a double one, on the one hand, due to the ground in the lateral when the hole of the future column is created, and on the other by the compaction of the material making up the column body.

The most used equipment in Romania up to the 1990s for making such columns is sonnet "Galați" (figure 8 - a - C29 - 85), but other equipments (eg excavators - figure 8 - b) have been used which have been equipped with a 2-3 ton rammer guidance system provided with a ram tip similar to the sonnet (Figure 8 - c).

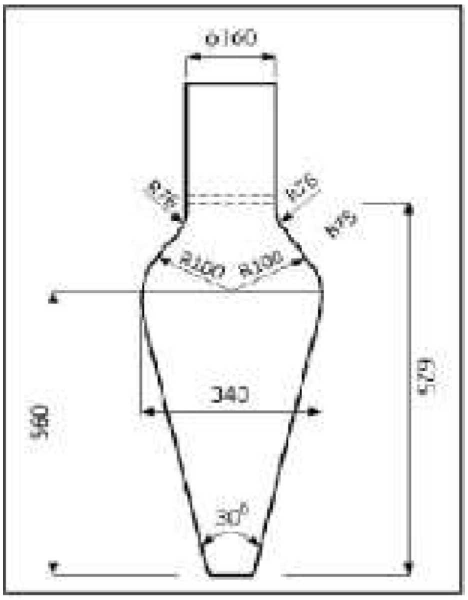
The sonnet is mounted on a metal chassis with a mass of 13.5 tons, which works by percussion and can reach a number of about 55 strokes per minute.

Aries consists of a heavy rod with a mass of 1500-1600 kg. In order to ensure verticality, its length is 8 - 10 m, and may consist of 1 or more pieces joined by tapping. The ram's tip has a length of 620mm, an outside diameter of 340-350mm and a 30 ° tip angle.

The drilling is carried out by the free fall of the ram, the operation starting with slow blows (7-8 strokes per minute) from the height of about 1m, until depths of 1-1.5 m, then their number being increased to 44 - 55 strokes per minute. As the depth increases, the height of the ram can also increase.



a) b)



c)

Figure 8 - Machinery used to make soil columns:

a) Sonnet "Galați"; b) Excavator adapted for making columns; c) The tip of the ram.

When drilling the hole, it is forbidden to add water, local wetting of the soil causing uneven nesting around the columns.

The body of the columns is made by adding into the hole the created portions of the soil, which is compacted by the application of some ram strikes. The added material must be preloaded at optimum compaction moisture content.

Operations are repeated until the column body reaches the pitch of the tapping platform.

The pitch of the beating platform is set above the foundation ground by approximately 1.20 m due to the fact that there is no good compaction on the surface because of The pitch of the beating platform is set above the foundation by about 1.20 m due to the fact that there is no good compaction on the surface due tosoil replenishment when making columns..

In order to achieve the number of blows required for compaction of the soil columns experimental polygons are made. There is a column for which, when compaction of each portion of soil, a series of blows are applied until the refusal is reached.

The refusal is considered to be achieved if, in the case of three consecutive strokes, the values obtained for the ram's advance do not differ by more than 1 cm, the number of optimum blows being the lowest number at which this condition is met.

The design of earth column improvement consists in determining the diameter of the columns, the distance between them and their distribution in plan.

The diameter of the columns can vary between 20 cm and 60 cm, but the most used is the diameter of 40 cm. According to C29-85, the interax distance can be established by making the average solid mass density of 1.65 g/cm^3 achieved on the whole solid mass, which can be determined with the relation:

$$l = 0.95 d_c \sqrt{\frac{\rho_{dm}}{\rho_{dm} - \rho_d}}$$

where:

$\rho_{d\,m}$ - average dry density of compacted soil; ρ_d - average dry density of compacted natural soil; d_c - column diameter.

Table 5 shows the approximate distance between the columns according to the characteristics of the natural soil (C29-85):

Table 5- approximate values of the distances between the columns.

Average dry density of compacted soil	Distances between column centers depending on n, e or ρ_d					
$\rho_{d\,max}$=1.65g/cm^3	n (%)	52	50	48	46	44
	e(-)	1.083	1.0	0.92	0.85	0.785
	ρ_d (g/cm^3)	1.3	1.35	1.4	1.48	1.52
	l	2.1 d_c	2.2 d_c	2.4 d_c	3.0 d_c	3.4 d_c

With regard to the positioning of the columns, they are generally planted after an equilateral triangle (Figure 9).

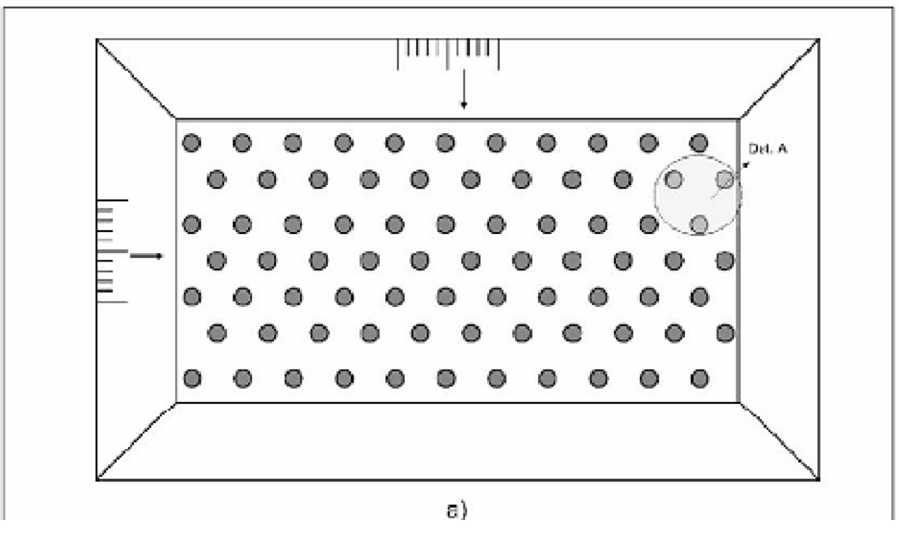
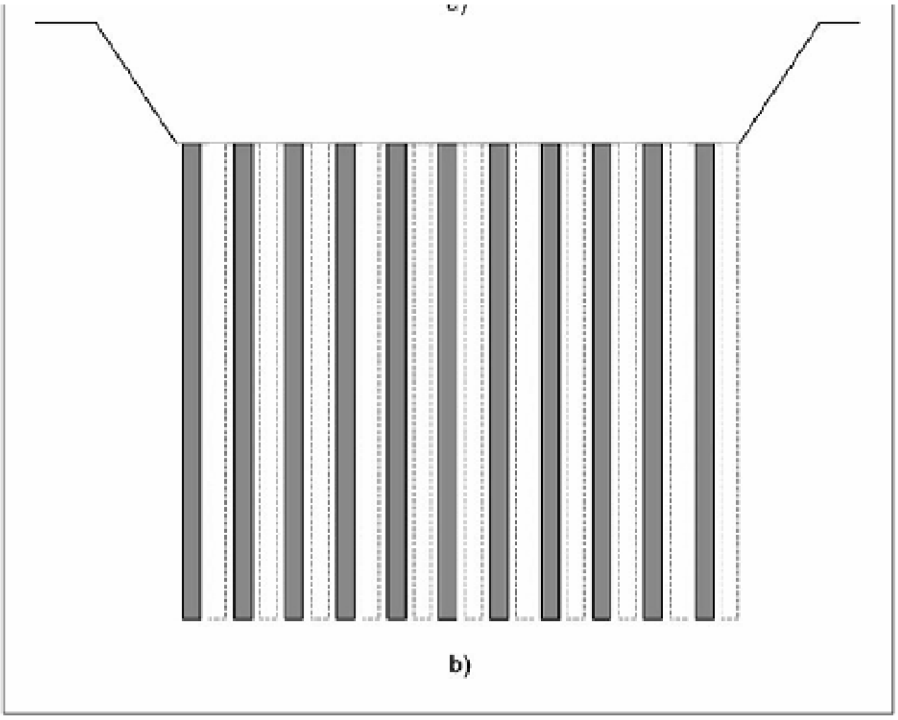


Figure 9.a)



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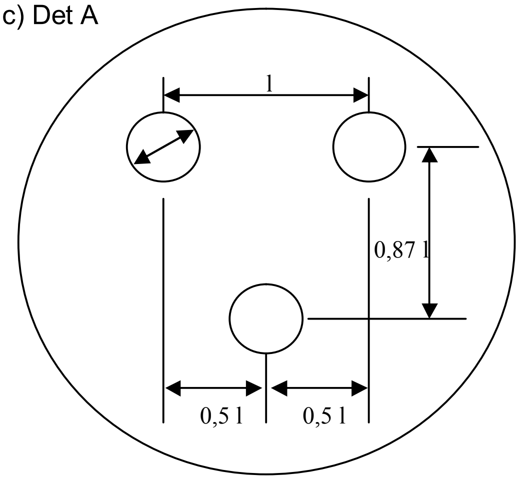

Figure 9 - Laying compacted soil columns: a) Plan view; b) Section; c) Detail.

Compacting is checked after the compacted surface has been cleaned and flattened.

Depth column verification over their entire length can be performed by static penetration or radiometric surveys. Also, the dry density soil at the foundation's level should be checked.

REFERENCES

[1] Aurelian Cătălin BURLACU, TEZA DE DOCTORAT “Contribuții la soluții de îmbunătățire a terenurilor slabe de fundare », 2012

[2] C29 - 85 (1985) - *„Normativ privind îmbunătățirea terenurilor de fundare slabe prin procedee mecanice. Indicativ C 29-85"*

[3] Diana DROSU & Mihnea CHEAR, Pământurile colapsibile. proprietăți mecanice în stare saturată

[4] Dianu, V.D., Dianu, F.N. (1992) - *„Fundare eficientă în condiții de teren dificile".* Bucureşti: Editura Tehnică.

[5] Ghid privind interpretarea şi controlul lucrărilor de compactare a pământurilor necoezive cu granulație mare, Indicativ GT 067-2013

[6] http://www.casamea.ro/casa/constructii/etape-de-constructie/pamanturi-sensibile-la-umezire-5104

[7] https://ro.wikipedia.org/wiki/

[8] https://www.sciencedirect.com/topics/engineering/dynamic-compaction

[9] Institutul central de cercetare, proiectare si directivare in constructii, “Buletin Constructilor”, 1985

[10] Kirsch, K., Sondermann, W. - *"Geotechnical engineering handbook", Volume 2 -Procedurees, Chapter 2.1: "Ground improvemenfA* - 50. Germany: Ernst & Sohn, A valley company

[11] Manoliu, I. (1977) - *„Fundații şi procedee de fundare".* BucureştkEditura didactică şi pedagogică.

[12] NP 125 (2010) - *„Normativ privind fundarea construcpilor pe pământuri sensibile la umezire colapsibile*

[13] Schlosser, F. (1997) - *«Expose surla theme: Ameliorqtion et renforce,ent des sols».* Proceedings of the Fourteenth International Confrence on Soil Mechanics and Fountation Engineering, Volume 4, Hamburg:2445 – 2466