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FACTORS INFLUENCING THE DEGREE OF SOIL COMPACTION

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Abstract: *The degree of soil compaction by mechanical procedures depends on the soil properties and on the technical characteristics of the compaction equipment. A study regarding the influence of soil properties on the degree of compaction is presented in this paper. The study focuses on the influence on the degree of compaction of some physical and mechanical properties, such as humidity, the number of passes etc.*
Key words: *degree of soil compaction, humidity.*

1. INTRODUCTION

Any study conducted on the behavior of the machines used to increase the mechanical strength of the soil has to consider the interaction between the machine and the soil, and respectively, its properties and composition, as well as some conditions. In order to determine the soil behavior the influence of the physical and mechanical properties on the compaction process has to be known.

The soil is a dispersive medium consisting of three phases: solid, liquid and gas. The percent in which the three phases are found determine the properties of the soil.

Compaction *represents the physical–mechanical process, through which, under the influence of an exterior mechanical work the particle realignment of the solid phase is conducted by the particle interpenetration, but also by the reduction of the volume occupied by the liquid and gas phases in the mineral structure.*

Considering their nature, the volumetric mass and their behavior at mechanical digging, the soil can be classified in four categories: easy (I), medium (II), hard (III), very hard (IV).

In the study of the compaction process the following three categories of variables have to be considered:

- parameters regarding the compacted material: initial density, granularity, material humidity etc.;
- machine parameters: the mass of the machine, the frequency and the amplitude of the vibrations that are generated and transmitted to the compacted material;
- compaction method (machine type, number of passes, speed of the vibratory compactor etc.).

The purpose of the soil compaction process consists in: increasing the shear strength of soil, decreasing future settlements, reducing the compressibility of soil, decreasing permeability.

In practice there are four types of methods of compaction: vibration, impact, kneading, pressure.

2. PHYSISCAL AND MECHANICAL SOIL CHARACTERISTICS

From the point of view of compaction the mechanical and physical properties present interest.

Humidity (w): it characterizes the ratio between the liquid and the solid phase and is defined as the ratio between the weight of the liquid phase G_l and the solid one G_s, expressed as a percent:

$$w = \frac{G_l}{G_s} \cdot 100\,[\%] \quad (1)$$

Pore index (*e*): it is defined as the ratio between the volume of the cavities V_g and the volume of the solid phase V_s:

$$e = \frac{V_g}{V_s} \quad (2)$$

Between the porosity *n* and the pore index *e* there are the following connections:

$$e = \frac{n}{1-n}, \quad n = \frac{e}{1+e} \quad (3)$$

The **specific weight** of the structure γ_s: represents the ratio between the weight of the solid phase (the weight in dry state) G_s and its volume V_s:

$$\gamma_s = \frac{G_s}{V_s} \ [\text{daN/m}^3] \quad (4)$$

According to STAS 1913/2-88 and [PAUN_82] the specific weight of the soil depends on its nature (table 1):

Table 1.

Soil nature	γ_s [kN/m^3]
Gravels, sands and powdery or clayey sands	26,5 … 26,8
Powders and sandy or clayey powders	26,8 … 27,0
Clays or sandy or powdery clays	27,0 … 27,2
Rich clay	27,2 … 27,5

The **volumetric weight** or the apparent specific weight represents the ratio between the soil weight G and its apparent volume, including the cavities (pinholes), V_a:

$$\gamma_p = \frac{G}{V_a} \ [\text{daN/m}^3] \quad (5)$$

The **consistency** of the soil represents the level of soil cohesion as a function of its water content and it can be assessed using the consistency index I_c:

$$I_c = \frac{w_L - w}{w_L - w_p} = \frac{w_L - w}{I_p} \quad (6)$$

The **compaction degree** is computed using:

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \quad (7)$$

where *e* represents the pore index of the analyzed soil.

Resistance to shear stress of the soil is influenced by the water quantity from the pinholes, the resistance increasing with the decrease of the humidity.

A mechanical model of the soil is presented in figure 1 as a mechanical system consisting in a mass *m*, a coil spring with the spring constant *k* and a buffer with the damping coefficient *c*.

The spring constant *k*, respectively the damping coefficient *c* can be determined using:

$$k = \frac{4 \cdot G \cdot r}{1-\nu}; \quad c = \frac{3{,}4}{1-\nu} \cdot r^2 \cdot \sqrt{\frac{G \cdot \gamma_t}{g}} \quad (8)$$

where: G –transversal modulus of elasticity, r – the equivalent radius of the foot, ν –Poisson's coefficient, γ_t – total soil specific weight;

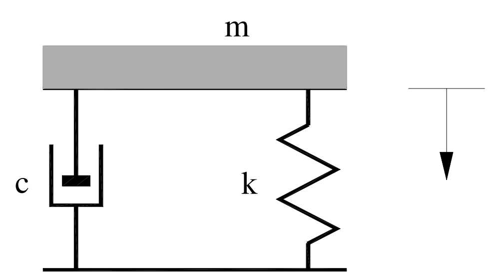

Fig. 1. Mechanical model of soil

Between the spring constant *k* and the damping coefficient *c*, the following relation exists:

$$c = 2 \cdot D \cdot \sqrt{m \cdot k} \quad (9)$$

where D is a damping coefficient.

Between **G** –the transversal modulus of elasticity and **E** – modulus of elasticity the following relation exists:

$$G = \frac{E}{2 \cdot (1+\nu)} \quad (10)$$

where **ν** represents Poisson's coefficient. For **ν** the following values can be used: clay (ν = 0,45 … 0,50); clayey soil (ν = 0,40 … 0,45); gravel (ν = 0,35 … 0,40); sand (ν = 0,30 … 0,35).

3. FACTORS INFLUENCING THE COMPACTION

Compaction process is influenced by three factors: soil type, compaction effort and water content (figure 2).

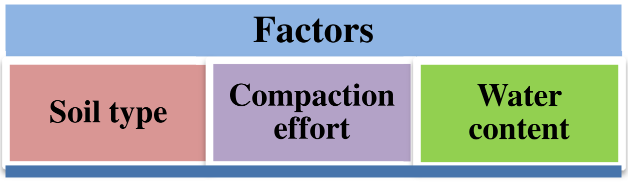

Figure 2. Factors affecting compaction

The compaction can be measured using the **degree of compaction** (*D*) which depends on more factors: machine type, module of applied force, its duration and periodicity, the thickness of layer to be compacted, physical and mechanical properties of the compacted material (humidity, thickness of the light layer etc.).

Degree of compaction depends on: characteristics of the compaction equipment (mass, size, area over which the applied compactive force is applied), characteristics of the soil (type – cohesive, granular, mixt, water content, initial density), construction process (number of passes, lift thickness, travel speed, vibration – frequency, amplitude, intensity).

The degree of compaction can be found using multiple methods: the method of relative volumetric weight, the method of air pockets, the method of penetrability coefficients.

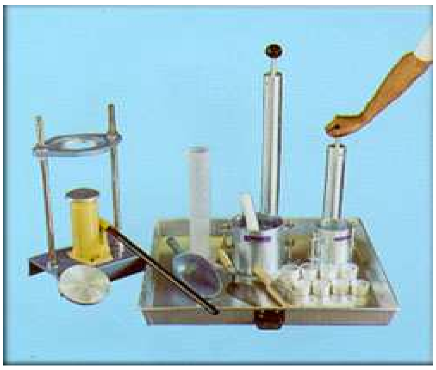

Fig. 3. Proctor instrument set

The degree of compaction is expressed using [BARD_85][DOMS_87][PAUN_82]:

$$D = \frac{\gamma_{de}}{\gamma_{d\,\max}} \cdot 100 \quad [\%] \qquad (11)$$

where: γ_{de} represents the actual volumetric weight of the soil in dry state [kN/m^3], respectively γ_{dmax} represents maximum soil volumetric weight in dry state determined in the laboratory [kN/m^3].

According to [STAS_1913] the degree of compaction is determined by the *standard Proctor* method or *modified Proctor* method, using special instruments (figure 3).

In figure 4 the Proctor curves are presented for five categories of soil: 1 - gravel with 50 - 75% sand, 2 – rough sand, fine gravel, 3 – uniform sand, 4 – sandy mud, 5 – rich clay [PAUN_90][RAYM_05].

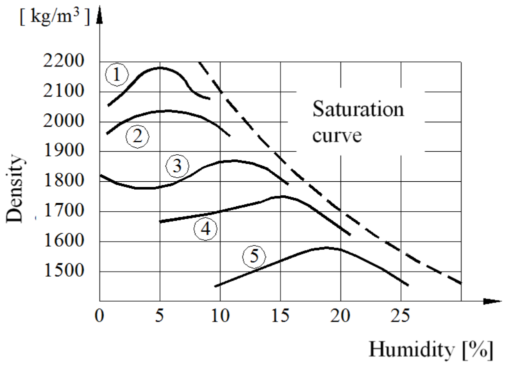

Fig. 4. Proctor curves for different soil types

The most important factor in the process of compaction is the soil *humidity*. Depending on the granulometric and the mineralogical nature of the soil, the optimal humidity is different from case to case.

The optimal humidity of compaction represents 0,8 ÷ 0,9 of the soil optimal humidity.

When the humidity is larger than the optimal one the soil behaves as a viscous fluid.

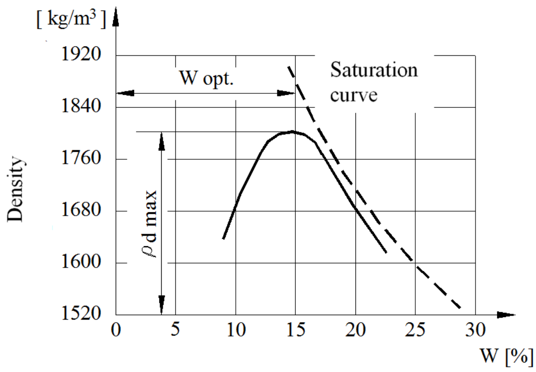

Fig. 5. Density variation in dry state as a function of humidity

The density variation in dry state as a function of humidity is presented in figure 5 in order to obtain a compaction degree similar to the one similar at an optimal humidity of the material the consumed mechanical work has to be increased.

If the effective humidity of the soil is larger than the optimal one, the obtained degree of compaction is lower because a part of the mechanical work is consumed in the liquid phase.

It can be observed that the density variation (and the degree of compaction implicitly) depends on the exterior mechanical work consumed.

In figure 6 the density variation in dry state is presented as a function of the consumed mechanical work.

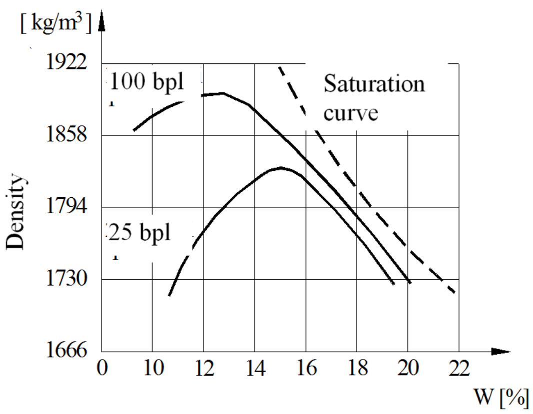

Fig. 6. Density variation in dry state as a function of the compaction mechanical work

Another parameter that influences directly the compaction process is the *number of passes*.

This is determined according to an optimal humidity, by successive compaction until the same density is obtained.

The number of passes can be also determined theoretically:

- for compacting by rolling:

$$n_t = \frac{L \cdot B \cdot h_a}{0{,}9 \cdot G} \qquad (12)$$

where: L represents the specific mechanical work of compaction [N/m^2], B represents the width of the machine passing mark [m], h_a is the thickness of the compacted soil [m], G is the weight of the compaction machine [N].

- compacting by hitting (the number of hits on the same mark):

$$n = \frac{L \cdot A \cdot h_a}{G \cdot h_l} \qquad (13)$$

where: A represents the surface of the plate (contact surface), h_l being the drop height of the rammer.

In figure 7 the dependence of the volumetric weight in dry state is shown as a function of the number of passes for a roller compactor [PAUN_82] (the results were obtained experimentally).

In figure 8.a the variation of the modulus of elasticity ***E*** is shown as a function of humidity, while in figure 8.b the variation of the modulus of elasticity ***E*** is presented as a function of the compaction degree for four categories of soil, the classification being according to the Directive ATV-A 127 (table 2).

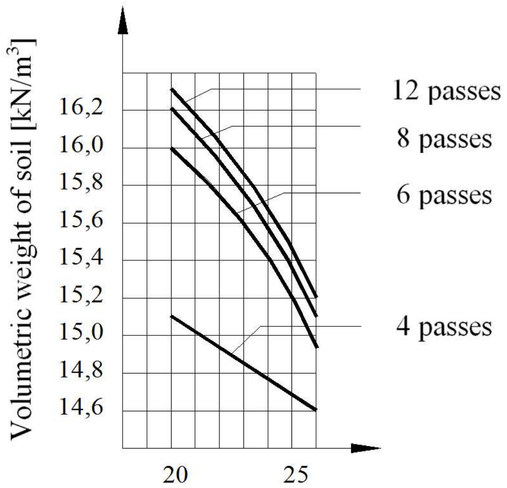

Fig. 7. Dependence of volumetric weight in dry state of the number of passes

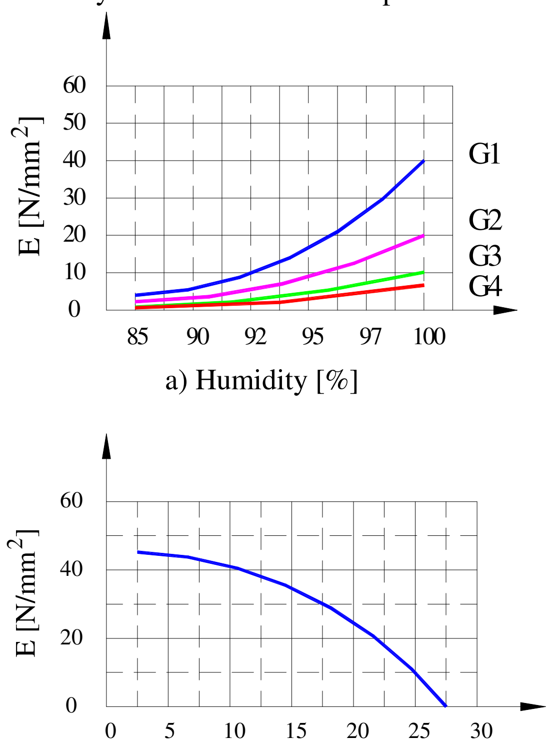

Fig. 8. Variation of modulus of elasticity E

For the mechanical characteristics the values of the modulus of elasticity E are given as a function of the degree of compaction [GLAV_95], such as (table 2).

For the elastic and damping constants used in the mechanical model of the soil the following values are recommended (table 3).

Table 2.

Group	Soil type	Compaction degree [%]					
		85	90	92	95	97	100
G1	Granulated sand, granulated gravel	2	6	9	16	23	40
G2	Clay with gravel, sand with mix of small granulated soil	1,2	3	4	8	11	20
G3	Mud with gravel, clay with sand, clayey gravel, muddy gravel	0,8	2	3	5	8	13
G4	Mud with sand	0,6	1,5	2	4	6	10

Table 3.

Group	Degree of deformation [%]			
	85	90	92	95
	Elastic constant k [N/m]			
G1	715000	2135000	3200000	5600000
G2	425000	1050000	1420000	2840000
G3	300000	730000	1100000	1800000
G4	240000	600000	800000	1600000
	Damping coefficient c [N*s/m]			
G1	3000	5250	6400	8540
G2	2350	3700	4250	6000
G3	1935	3050	3750	4850
G4	1750	2750	3200	4500

4. CONCLUSION

The compaction degree is influenced by several factors, some of these having a larger influence.

The physical and mechanical characteristics of the soil influence the compaction degree and determine the procedures and the machines required for the compaction.

Between the soil particles there are the following types of forces: friction forces (for non-cohesive soil), respectively attraction and friction forces (for cohesive soil).

Due to the fact that the compaction is the result of a mechanical action on the layer to be compacted, another parameter that influences the compaction is the type of forces developed by the machine.

In practice there are the following categories of forces: pressure force, remoulding force, impact force.

Besides the three categories of forces the vibrations are also used, vibrations which transmitted in the material layer determine a relative displacement of the particles and their realignment, contributing to the increase of the compacting effect with the decrease of the necessary mechanical work. All compaction machines use the pressure combined with one or more forces (or with vibrations).

The value of the mechanical work consumed for reaching a certain value of the compaction degree is influenced by three factors: optimal compaction humidity, granularity and compaction type.

In this paper are presented several diagrams that show the variations of several factors that influence the degree of compaction.

Choosing the compaction method is difficult due to the large number of parameters which influence the compaction process. A certain degree of compaction is obtained by choosing the method and the compaction machine while considering the soil properties.

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FACTORI CARE INFLUENŢEAZĂ GRADUL DE COMPACTARE A SOLULUI

Rezumat: *Gradul de compactare a solului prin procedee mecanice depinde de proprietăţile solului şi de caracteristicile tehnice ale utilajelor de compactat. În această lucrare este prezentat un studiu privind influenţa proprietăţilor solului asupra gradului de compactare. Sunt studiate influenţa asupra gradului de compactare a unor proprietăţi fizice şi mecanice, cum ar fi: umiditatea, numărul de treceri, etc.*

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