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GEOTECHNICAL CHARACTERIZATION OF LOESSOID SOILS AND IMPROVMENT METHODS

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Abstract

Collapsible behaviour of loessoid soils in response to water content change is a worldwide problem. These soils are named problematic soils; they can generally be characterised as poor-quality materials. They usually have the potential to show undesirable engineering behaviour. Stabilisation is commonly used to improve the mechanical properties of these problematic soils.The main improvements aimed in the stabilization of collapsible soils are: reduction of supplementary settlement to wetting, increase of shear strength, reduction of permeability. The paper aimed to analyse the geotechnical characteristics of loessoid soils and to present the main improvement methods of these soils.

Key words*:loess, collapsible soils, soil stabilization.*

INTRODUCTION

Loessoid soils are also known in the scientific literature as collapsible soils. The expression ‘‘soil collapse’’ is used to describe a wetting-induced deformation in collapsible soils. These soils have an open structure as the particles are held together by a temporary bonding. If the loess becomes saturated, the material structure collapses and records large supplementary settlements. Normally, collapsible soils have a high porosity and low moisture content.

Such soils are very common in Romania, they are found over some 17% of the area, mainly in Dobrogea, Galati, Braila, etc. In these regions the collapsible soils are responsible for much of the damage in public and private buildings, which has resulted in considerable financial loss. In such situations, the ability to identify the presence of these difficult soils is very important for urban planning.

Design of footings on loessoid soils has been the concern of engineers since the beginning of soil engineering.

It is necessary for designers to take into consideration local economic factor as well as environmental conditions and project location in order to make prudent decisions for considered in many projects.

Stabilisation is commonly used to improve the mechanical properties of these problematic soils. The main improvements aimed in the stabilization of collapsible soils are: reduction of supplementary settlement to wetting, increase of shear strength, reduction of permeability.

MATERIALS AND METHODS

In order to characterize the geotechnical parameters of loessoid soils and its improvement methods we used a series of classifications from the professional literature. The activity in the first stage of the study focused on accumulating published information about the loess classification according to Romanian standards in force and loess improvement methods.

During the second stage of the study, we determined: grain-size distribution, natural density, dry densityand the optimal parameters of compaction of a loess sample from Mangalia.

The grain-size distribution was determined according to STAS 1913/5-85 by sedimentation method.
The natural and dry density of the loess sample was determined according to STAS 1913/3-76.
The compaction test was performed according to STAS 1913/13-83. The optimal parameter of compaction was determined by Standard Proctor method; they are defined by the optimum of compaction moisture content (w_{opt}) and maximum dry density of the soil (ρ_d^{max}).

RESULTS AND DISCUSSIONS

Geotechnical characteristics

In order to characterize a loessoid soil it is necessary to determine the following characteristics:

- Soil composition:
  - Grain-size distribution
  - Chemical-mineralogical composition
- Physical properties
  - Humidity
  - Density of natural, dry and saturated soil
  - Density of solid particles
  - Porosity
  - Plasticity
- Hydric properties
  - Permeability
- Mechanical properties
  - Compressibility and deformability
  - Structural strength
  - Shear strength parameters

These geotechnical properties are determined according to Romanian standards in force.
In order to characterize loessoid soils after the grain size distribution and plasticity index we use the following characterization.

Table 1. Loess classification (after Nicolescu 1981 and NP 125-2009)

Soil type	Plasticity index, I_p	Clay particles, %
Sand silty	$I_p < 1$	< 3
Silt sandy	$1 < I_p < 7$	3 – 10
Silt clay	$7 < I_p < 17$	10 – 30
Clayey silt	$I_p > 17$	> 30

In order to identify a soil as a loessoid soil, by geotechnicaly point of view, has been determined the follow values of parameters.

Table 2. Geotechnical characteristics of loessoid soils (after NP 125-2009)

Soil property	Symbol	M.U.	Characteristics values
Bulk density of soil	ρ_s	g/cm^3	2,52 - 2,67
Unit weight of soil	γ	kN/m^3	12,0 - 18,0
Unit weight of dry soil	γ_d	kN/m^3	11,0 - 16,0
Natural humidity	w	%	6 - 15
Porosity	n	%	40 - 55
Liquid limit	w_L	%	12 – 30
Shrinkage limit	w_P	%	9 – 18
Plasticity index	I_P	%	5 – 22
Swelling pressure	p_u	kPa	0 – 10
Permeability coefficient	k	m/sec.	10^{-4} - 10^{-6}
Supplementary settlement to wetting below 100 kPa	i_{m100}	%	0 - 0,6
Supplementary settlement to wetting below 200 kPa	i_{m200}	%	1 – 4
Supplementary settlement to wetting below 300 kPa	i_{m300}	%	2 – 14
Oedometric modulus	$E_{oed\ 200-300}$	kPa	5000 - 15000
Angle of internal friction	ϕ	grade	5 – 25
Cohesion	c	kPa	10 - 30

One very important property of these soils is the supplementary settlement to wetting below 300 kPa load. This property can be determined in two methods:

- **The simple method:** it consist in running one oedometer compression test a sample at constantinitial water content up to 300 kPa stress; the unsaturated sample is wetted and loaded up to 500kPa
- **Double method:** it consist in running two oedometer compressions test: a) a test at a constant initial water content,

corresponding to the initial natural state of the soil and a test in which the unsaturated sample is wetted under a small load, cause, and subsequently loaded in a zero section condition, close to saturation.

The supplementary settlement to wetting is taken from the difference void ration taken into the two curves under the 300kPa load.

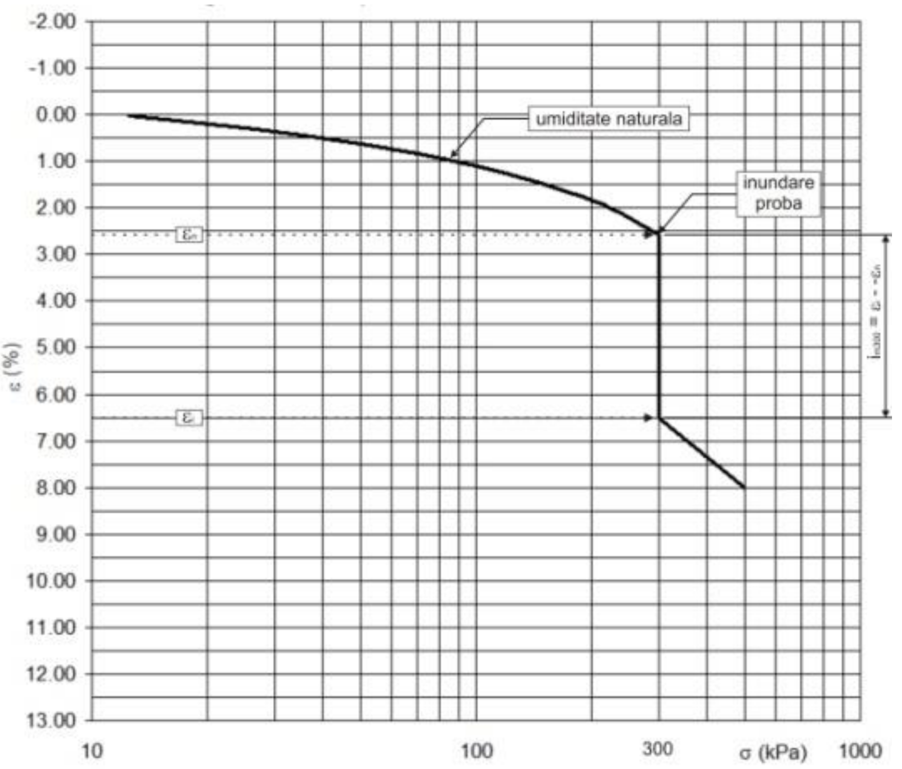

Figure 1. The simple oedometer test (NP 125/2009)

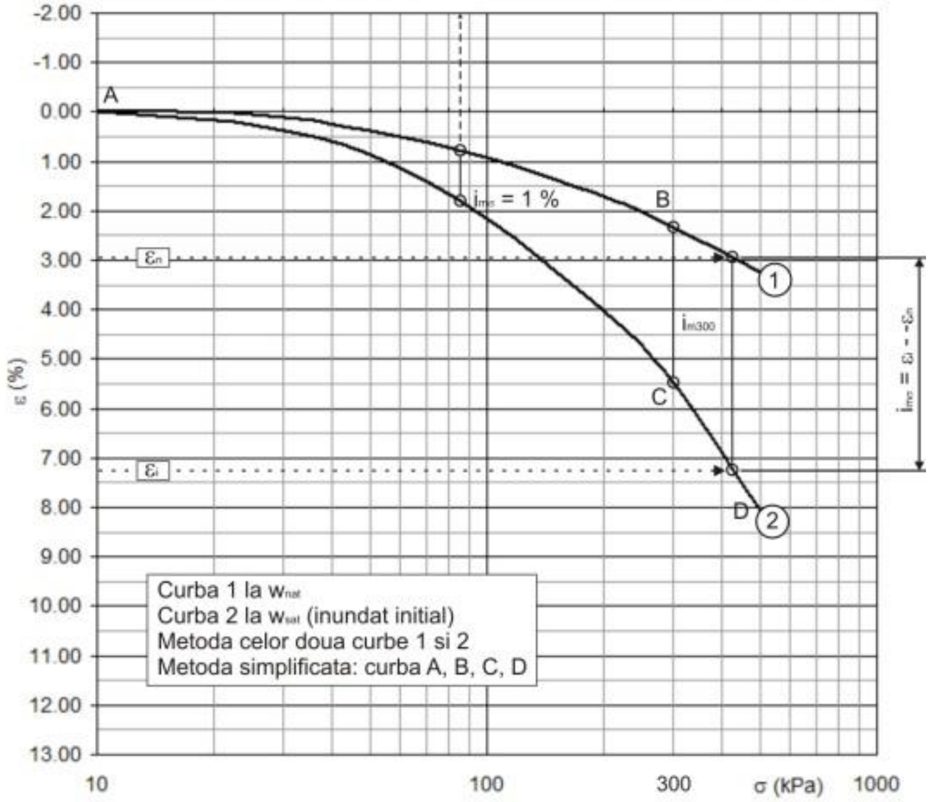

Figure 2. The double oedometer test (NP 125/2009)

Loess – difficult soil

In Romania, for a soil to be considered sensible to wetting (difficult soil for foundation) it must perform one of two criteria from each category of properties: physics and mechanics.

Physic properties:

-Silt fraction 50-80% for S_r<0,8;

- Porosity > 40 %

-The index I in the interval [0.1 ; 0,3]; e- the index for pores; e_L – the index for pores at W_L

$$I = \frac{e_L - e}{1+e} \quad (1)$$

Mechanic properties:

- i_{M300}> 2% is determined in laboratory with the doubles curve:

1. Natural curve saturated at 300 kPa
2. Natural curve saturatedinitially.

In the scientific literature, Rukovodstvo, 1977 (according to Soviet norms), depending on the extent of collapsibility under geological load, δ_n, related that loess based are divided into: Type I (δ_n<5 cm) and Type II (δ_n>5 cm). This classification has been accepted in Bulgaria (Pravilnik, 1983) and in some other countries. Loess base Type I is usually <8 m thick, but there is also loess of a thicker collapsible zone, which does not collapse under overburden. The loess base of Type II is δ_n> 8 – 10 m thick, sometimes reaching a thickness in dozen of meters. The value of δ_n is most frequently obtained by laboratory methods, but experience has shown that sometimes there are considerable disparities between laboratory calculated and actual collapses. It has been recommended, therefore, that the type of loess base be determined by experimental wetting in situ (Evstatiev, 1988).

Soil stabilization

The main methods used for the improvement of loessoid soils of foundation depend on the used mechanical work and on the type of the materials that are used to obtain the soils mixtures. They are classified as follows (Ivasuc, 2013):

1. Methods regarding the stabilization of the soils by:
   - physical stabilization
   - chemical stabilization
   - mechanical stabilization
   -thermal stabilization
2. Methods regarding the blocking of the humidity variations: pre-wetting the soil and preventing access of water to the soil.
3. Removal of loessoid soil and replacement with a better soil.

Physical stabilizationis done by the modification of the granulometric composition of a soil by mixing it with another soil. The best or optimal granulometric mixture consists of gravel, sand, silt and clay, which under the concrete natural conditions and way of applying, has the best strength and resistivity in the compacted state. Such a mixture is mostly used in road. Laboratory studies have shown that the strength parameters of the mixture are substantially improved after the addition of small quantities of binders (Evstatiev, 1988).

Chemical stabilization is done by altering the soil structure by mixing it with some chemicals: cement, lime, fly ash, bentonite. Stabilization using cement, lime and some waste materials. This method is most widely applied in road construction. Studies have established the optimal percentages of the binding materials, the mechanism of formation of strength and the strength and technological performance of loess-cement mixtures. Investigations have also been carried out to replace cement by residual ash from cement plants and by activated fly ash from thermo-electric plants (Evstatiev, 1988).

Mechanical stabilization is done by application of surcharge pressure. This group comprises the methods whereby an increase of the density of loess is achieved with the ensuring elimination of collapsibility, reduction of permeability and greater bearing capacity. This is realized under the influence of static or dynamic forces.

Huge masses of compacted loess are used for road embankments, earth dams, various water irrigation facilities, levels and back embankments in civil engineering. Compaction proceeds in optimal moisture content w_{opt}until the attainment of the standard density.

Thermal stabilizationis a treatment realized by burning the soil at temperatures higher than 300-1000°C.The fuel mixtures are burnt in closed boreholes under pressure. The expenditure of air per hour in the case of liquid fuel is 25 m^3 per 1 kg of fuel on the average and in the case of gas fuel it is 10m^3 per 1 m^3 of gas. In a borehole with a diameter of 0.15-0.20 m a stabilized soil column with a diameter of 1.5-2.0 m and depth of 8-10m can be built in the course of 8-10 days. Usually the stabilization is done in groups of 12-15 boreholes. Loess is burnt at a temperature of 300-1000°C whereby its collapsibility is entirely eliminated and its bearing capacity greatly increases (Evstatiev, 1988).

Methods regardingthe blocking of humidity variations. In loessoid soils geomembranes are chiefly used in water irrigation construction, in building water reservoirs and enhancing the impermeability of the concrete revetments of the canals. Observations have been made for many years on the durability of the screen depending on the kind of polymer, the thickness of the membrane and the soil and climatic conditions. Geomembranes are expected to be still more widely used in the future in combating collapsibility and filtration leakage of loess soils (Evstatiev, 1988).

Removal of loessoid soils and replacement with a better soilthis group includes several methods in which part of the collapsible surface layer directly under the foundation or in depth is excavated and replaced by some other suitable soils or materials. The ground becomes a non-homogeneous medium and the interaction between the foundation, the improved and unmodified loess is of particular importance for its bearing capacity. In this way the way the danger of collapse of the loess layer situateddirectly under the foundation where the stresses are thegreatest is eliminated.
Replacement in depth is accomplished by excavating the entire collapsible layer with a scraper or in some other method and introducing with suitable material (Evstatiev, 1988).

Geotechnical characteristics of Mangalia loess

According to STAS 1913/5-85, the grain size distribution (Figure 3) is composed of 20% clay, 60% silt and 20% sand.
In order to determine the optimal parameters of compaction the Standard Proctor test was performed on Mangalia loess; optimal humidity of compaction =13.89%, maximum density of dry soil = 1.93. These characteristics have been determined from Proctor curve (Figure 4).

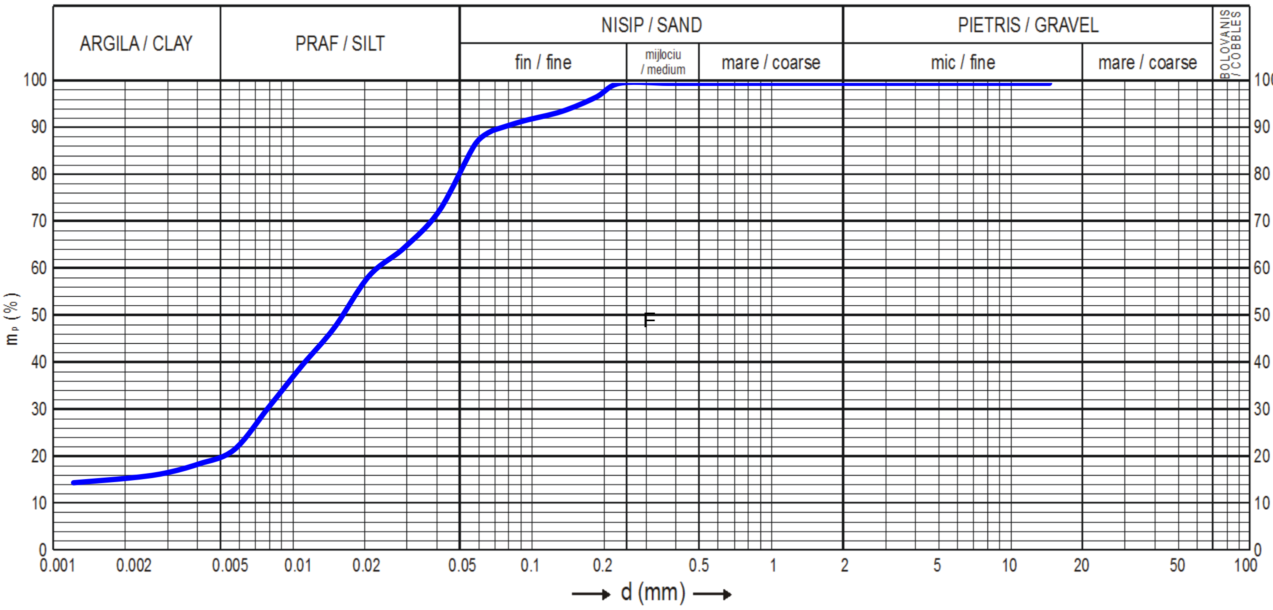

Figure 3. Grain size distribution of a Mangalian loess sample

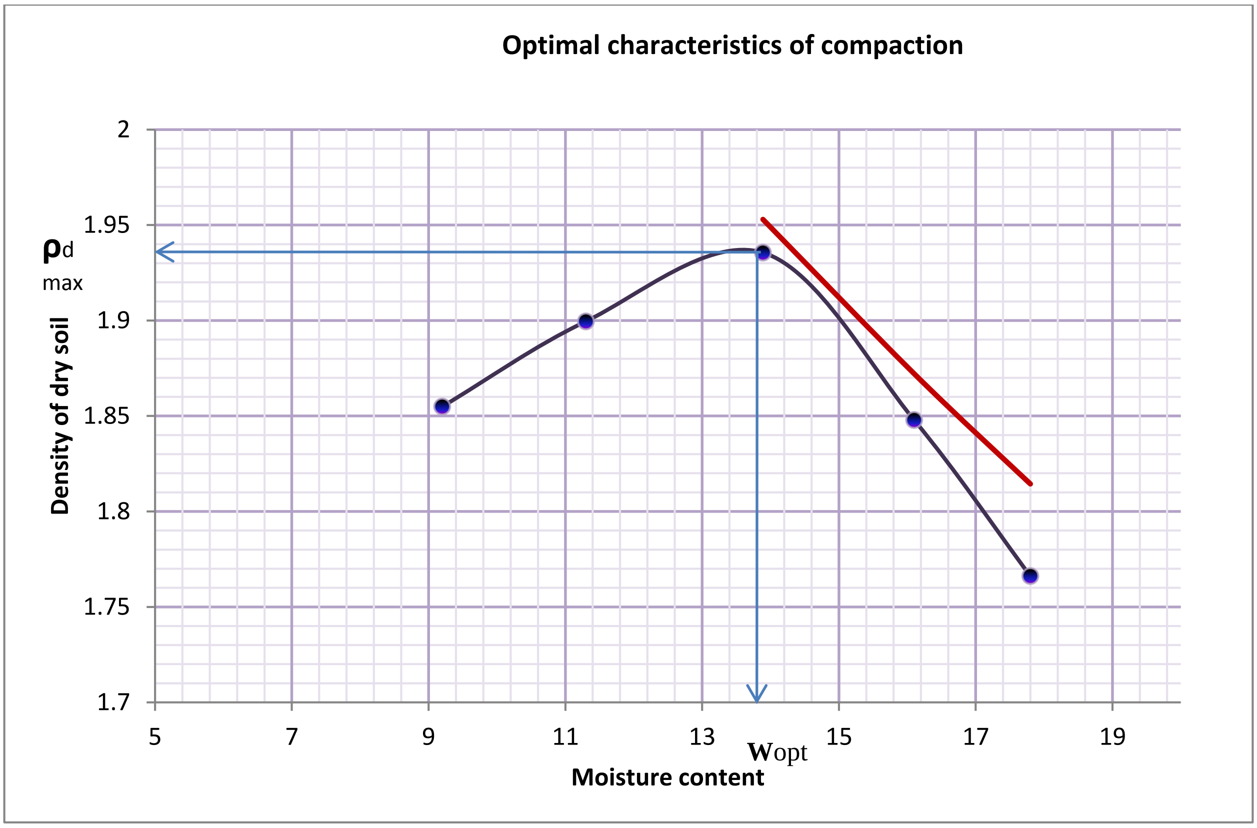

Figure 4. Optimal characteristics of compaction

In our case an approximation of supplementary settlement to wetting below 300 kPa load can be made using only the parameters of humidity according to the follow relation:

$$i_{m3oo} = -0{,}48\omega + 10{,}85 \qquad (2)$$

For Mangalia loess, we used the relation 2, using the optimal humidity with the following value: 13.89% and was resulted$i_{m300} = 4.17$ %which is making the analysed soil to be part of soils sensible to wetting (collapsible soils).

CONCLUSIONS

This paper serves the purpose of reviewing some current practices and points out successes in modifying loessoid soils.

The supplementary settlement to wetting corresponds to a particular behaviour of loessoid soils.

Loessoid soils are one of the most significant ground related hazards found globally.

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