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THE INFLUENCE OF THE CONSISTENCY INDEX OF SOME CLAY ROCKS FROM MOESIAN PLATFORM

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Abstract *In this paper approximatively 400 values of liquidity index, performed on Pliocen and Quaternare clays, were examined statistically. The paper shows that the liquidity index doesn't lay stress on the quality difference which exists between the abovementationed clays, from the geotechnichal point of view. The liquidity index of Quaternare clays, regarding the examined dats, has a normal distribution low.*
Key words: *rock, drill, geotechnical conditions, consistency index, humidity, plasticity.*

1. INTRODUCTION

Any engineering construction requires (in one form or another), a detailed analysis of the foundation ground. This takes the form of a thorough study of geotechnical and hydrogeological conditions to considerable depths through drillings, folloed by laboratory tests and situ experiments. The geological laboratory research of the foundation lands for constructions, is in continuous improvement being closely related to the quantitative data acquisition and the age of the formations [5].

The interpretation of land and laboratory research results of physical – mechanical parameters based on geological time factor, will gradually open the perspective of a new orientation geological engineering research, based on conclusions that emerge from the statistical examination of collected evidence.

The present research proposes a statistical examination of over 400 values of the consistency indices obtained by laboratory analyzes of same clay rocks from the Moesian Platform (Figure 1) [3], regarding the area about 12 km from Craiova, an area located on a lower terrace level of the Jiu River. Both the consistency and plasticity indices characterize the clay rocks, calculated with the help of the plasticity limits (Atterberg limits) respectively of the humidity, in the natural state.

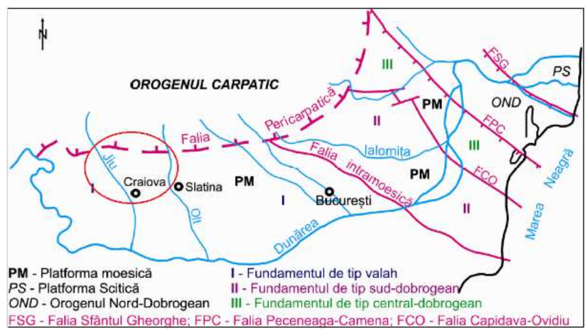

Figure 1 – Map of the area surveyed from Moesian Platform

By definition the *consistency index* (I_c) represents a function that depends on the natural humidity and the two determined humidity (w_L, w_P) [6]. The consistency indice can be calculated using the relation:

$$I_c = \frac{w_L - w_P}{I_P} \quad (1)$$

where:

I_c – consistency index;
I_P – plasticity index;
w_L – upper limit of plasticity;
w_P – lower plasticity limit.

The upper limit of plasticity called and the *limit of flow*, is defined as the maximum humidity for which the mechanical behavior of the clay is plastic.

The lower limit of plasticity called the *limit of kneading*, is defined as the minimum humidity for which the mechanical behavior of the clay is plastic.

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The three states of consistency (loud, plastic, flowing) are determined according to this index, as follows:

$I_c < 0$ – flowing state;
$0 < I_c < 0,25$– flowing plastic state;
$0,25 < I_c < 0,50$ – flowing state soft;
$0,50 < I_c < 0,75$ – consistency flowing state.
$0,75 < I_c < 1$ – edgy flowing state;
$I_c > 1$ – loud state.

The Plasticity index (I_P) is given by the humidity interval between the flow limit and the kneading limit. It can be calculated with the relationship:

$$I_P = w_L - w_P \quad (2)$$

However, the plasticity of the rocks is evaluated according to the values of the parameter expressed as a percentage, according to the following classification:

$0 < I_P < 10$ – reduced plasticity;
$10 < I_P < 20$ – medium plasticity;
$20 < I_P < 35$ – high plasticity;
$I_P > 35$ – very high plasticity.

2. DESCRIBE THE METHODS

From the lithological point of view, the rock is composed of pliocene marno-clays with the intercalations of fine clay sands (Figure 2).

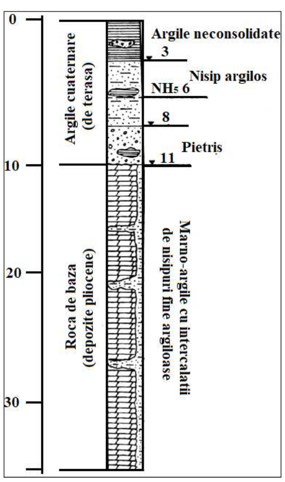

Figure 2 – Lithological column

Above the base rock is the terrance deposit, which contains gravel at the base and clays at the top. At the depth of 6 m, is identified a groundwater aquifer layer consisting of an impermeable layer constituting the bedrock.

It should be mentioned that, the aquifer layer doesn’t influence the humidity of the clays with which the terrace deposit ends. Also the marno-clays of the rock of the base have their natural humidity, without being influenced by the presence of the aquifer layer, because the rock of the base is impermeable.

This characteristic of the stratification and the structural position of the groundwater layer, represents an ideal condition that allows to realize a parallelism regardin the results of the statistical parameters determined for the two types of clay deposits analuzed, the clays of the terrace deposits respectively pliocene marno-clays.

The graphical simulation regarding consistency indices for both marno-clays (forming the base rock) and for the clay of the terrace deposit, is found in Figure 3.

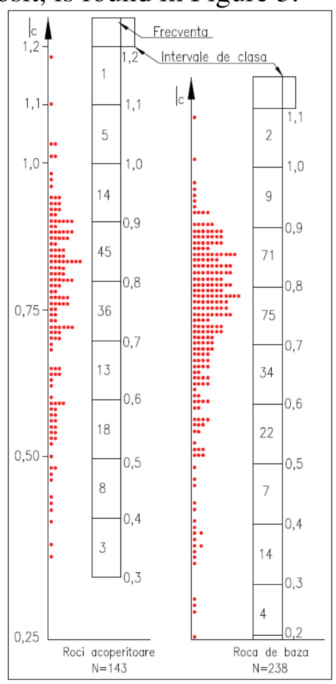

Figure 3 – Graphical simulation of consistency indices

Assimilating a class interval of 0,1 for both types of clays analyzed, was identified 9 distribution.

Based on these data, they were determined by calculation the main statistical parameters of the consistency indices, the arithmetic averages, the medium squared deviations respectively the coefficients of variability identified in Table 1 for the clays of terrace formation, respectively Table 2 for the marno-clays of the basic formations.

2.1 The calculation of arithmetic average ($\bar{x}$), medium square deviation (σ) and coefficient of variability (v) fot the quaternary clays of the terrace

Are considered the values (Table 1 and Figure 3):

$\bar{X}_0$=0,85 – the probable arithmetic average to the consistency index;

N=143 – number of values of the consistency index;

a=0,1 – the size of the class interval.

Tabel 1

(X_i)	Absolute frequency (n_i)	X'	$X'n_i$	$X'^2 n_i$
0,35	3	-5	-15	75
0,455	8	-4	-32	128
0,555	18	-3	-54	162
0,655	13	-2	-26	52
0,755	36	-1	-36	36
0,855	45	0	0	0
0,955	14	1	14	14
1,055	5	2	10	20
1,155	1	3	3	9

It can be written the mathematical relations:

$$\bar{X} = \frac{\sum X'n_i}{N} a + \bar{X}_0 = 0{,}755 \quad (3)$$

$$\sigma = a\sqrt{\frac{\sum X'^2 n_i}{N} - \left(\frac{X'n_i}{N}\right)^2} = 0{,}1\sqrt{\frac{496}{143} - \left(\frac{-136}{142}\right)^2}\ 0{,}16 \quad (4)$$

The square medium error:

$$\varepsilon_x = \pm\frac{\sigma}{\sqrt{N}} = \pm\frac{0{,}16}{\sqrt{143}} = \pm{,}0133 \quad (5)$$

$$v = \frac{\sigma}{\bar{x}} 100 = 20{,}6\ \% \quad (6)$$

The real arithmetic average of the consistency index for a significance level q = 0,05 with a probability coefficient (t=2) varies between the limits [4]: $\bar{X} - t\varepsilon_x < I_c < \bar{X} + t\varepsilon_x$ (7)

*0,755 – 2*0,0133< I_c<0,715+2*0,0133* (8)

0,755< I_c<0,78 (9)

It is calculated the arithmetic average error (errors that are identified in the tables) nothing that the consistency index of the terrace formations is equals to the marno-clays of the base formations. Thus, the errors of the arithmetic average are clase in values: ε_x=0,0133 for the quaternary clays and ε_x=0,0104 for the pliocene morno-clays. The concistency indices corresponding to the same genetic types are:

I_c = 0,73 – 0,78; 0,70 – 0,74.

Due to the fact that the ranges variation of the consistency indices and their indice are limited, a common consistency index can be established for the two types of clay rocks: I_c = 0,75.

2.2 The calculation of arithmetic average ($\bar{x}$), medium square deviation (σ) and coefficient of variability (v) for the pliocene marno-clays

Are considered the values (Table 2 and Figure 3):

$\bar{X}_0$=0,65 – the probable arithmetic average to the consistency index;

N=238 – number of values of the consistency index;

a=0,1 – the size of the class interval.

Tabel 2

(X_i)	Absolute frequency (n_i)	X'	$X'n_i$	$X'^2 n_i$
0,25	4	-4	-16	64
0,355	14	-3	-42	126
0,455	7	-2	-14	28
0,555	22	-1	-22	22
0,655	34	0	0	0
0,755	75	1	75	75
0,855	71	2	142	284
0,955	9	3	27	81
1,055	2	4	8	32

It can be written the mathematical relations:

$$\bar{X} = \frac{\sum X'n_i}{N} a + \bar{X}_0 = \frac{158}{238} 0{,}1 + 0{,}65 = 0{,}716 \quad (10)$$

$$\sigma = a\sqrt{\frac{\sum X'^2 n_i}{N} - \left(\frac{X'n_i}{N}\right)^2} = 0{,}1\sqrt{\frac{712}{238} - \left(\frac{-158}{238}\right)^2}\ 0{,}16 \quad (11)$$

The square medium error:

$$\varepsilon_x = \pm\frac{\sigma}{\sqrt{N}} = \pm\frac{0{,}16}{\sqrt{238}} = 0{,}0104 \varepsilon_x = 0{,}0104 \quad (12)$$

$$v = \frac{\sigma}{\bar{x}} 100 = \frac{0{,}16}{0{,}716} 100 = 22{,}4\ \% \quad (13)$$

The real arithmetic average of the consistency index for a significance level q = 0,05 with a probability coefficient (t=2) varies between the limits: $\bar{X} - t\varepsilon_x < I_c < \bar{X} + t\varepsilon_x$ (14)

*0,716 – 2*0,0104< I_c<0,716+2*0,0104* (15)

0,7< I_c<0,74 (16)

The coefficients of variability have values:

$v = 20{,}6$ % - covering rocks;

$v = 22{,}4$ % - basic rokcs.

Given that these coefficients have very small values in absolute value, a very good combination of values around the average results.

It should be noted that the results obtained for the coefficient of variability are approximately equal ($v = 20$ %).

In conclusion, the two types of clay rocks have the same consistency indices.

Recognizing the differences between the formations highlighted in the researched area of the Moesian Platform, through the statistical analysis of the compressibility coefficients determined during the constructions (regarding the homogeneous or non-homogeneous character of the compressibility of the basic rocks), it is observed that in the case analyzed based on the data available, the consistency indices do not have the capacity to reflect the differences between the quaternary and pliocene clays under geological engineering report.

Analyzing the laboratory data of the investigated probes, it turns out that the two clay formations have the same degree of consolidation. However, only pliocene clays are consolidated, while the quaternary clays show a pseudoconsolidation determined by the surface drying process in which the groundwater is about 5 m below the quaternary clay layer.

Regarding the industrial objectives, besides the mail constructions there are many light constructions that transmit small loads on the foundation ground. In the case of the investigated area, the permissible resistances were thus established [1]:

- p_a = 1,5 – 2 kg/cm^2 for quaternary clays in the case of light constructions;
- p_a = 5 kg/cm^2 for pliocene marno-clays in the case of heavy constructions.

The pressures transmitted in the constructions from the investigated area have reached the allowable pressures mentioned above.

The presentation of the practical data was done first to emphasize the engineering geological differences that exist between two clay formations separated as geological age, and secondly to highlight the values of the consistency indices as parameters depending on the permissible strength of the clay rocks.

From the stratification point of view, it can be said that this is a particular case that helps to determine the inability of the consistency indices to identify the differences that exist between the covering formations respectively the basic formation. This characteristic results as a consequence of position of the groundwater layer, which doesn't influence (even through capillarity) the humidity of the quaternary clays from the surface.

3. THE PROPOSE ALGORITHM RESULTS

Having the range classes as well as the absolute frequency on distribution classes (Figure 3 and Table 1), was realized the histogram of the selection values and frequency curve of the consistency indices from the quaternary clays (Figure 4).

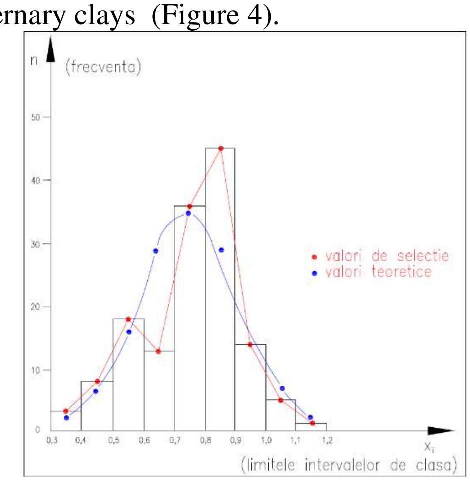

Figure 4 – Histogram of selection values

Based on the data available, it is calculated the theoretical frequencies of the consistency indices for the quaternary clays (Table 3).

Was determined the curve theoretical frequencies, which by its form determines a law of normal distribution of consistency indices. Checking this hypothesis (Table 4), it is observed that the consistency indices analyzed are based on the low of normal distribution.

From the geological engineering and geotechnical poin of view, the analyzed parameter doesn't have the capacity to reflect the different particularities that characterize the two formations.

3.1. Theoretical frequencies regarding the consistency indices for the quaternary clays

It was taken into consideration a number of determination (N = 143) [2].

Table 3

X_i	Normal values Z_i	Normal distribution $F(x_i)$	*Relative frequencies at Normal intervals* $F(x_i+1)- F(x_i)$	*Theoretical frequencies* N'_i
0,35	-2,20	0,014	0,014	2
0,45	-1,575	0,058	0,044	6,3
0,55	-0,950	0,171	0,113	16,1
0,65	-0,325	0,373	0,202	28,9
0,75	0,300	0,618	0,245	35
0,85	0,925	0,822	0,204	29,2
0,95	1,550	0,939	0,117	16,7
1,05	2,175	0,985	0,046	6,6
1,15	2,800	0,997	0,012	1,71

It can be calculated:

$$Z_i = \frac{X_i - \bar{X}}{\sigma} \quad (17)$$

where: $\bar{X} = 0{,}755$; $\sigma = 0{,}16$

3.2. Verification the hypothesis of the normal distribution of the consistency indices for the quaternary clays

The verification of the hypothesis of normal distribution consistency indices for the quaternary clays, is done using data from Table4.

Table 4

X_i	Absolute frequence n_i	Relative frequency $f=n_i/N$	*The cumulative relative frecuency* $F_n(X_i)$	*Normal distribution function* $F(x_i)$	$F_n(x_i)$- $F(x_i)$
0,35	3	0,021	0,021	0,014	0,007
0,45	8	0,056	0,077	0,058	0,019
0,55	18	0,126	0,203	0,171	0,032
0,65	13	0,091	0,294	0,373	-0,079
0,75	26	0,252	0,546	0,618	0,072
0,85	45	0,314	0,860	0,822	0,038
0,95	14	0,098	0,958	0,939	0,019
1,05	5	0,035	0,993	0,985	0,008
1,15	1	0,007	1	0,997	0,003

A total of 143 determinations were used.

Based on these values can be calculated:

$$d_n = max|F_n(X_i) - F(X_i)| = 0{,}079 \quad (18)$$

It is considered a level of significace $q = 0{,}05$, and $\lambda_{0,95}=1{,}36$.

$$d = \frac{\lambda_{0,95}}{\sqrt{N}} = \frac{1{,}36}{\sqrt{143}} = 0{,}113 \quad (19)$$

Due to the fact that $d_n < d$, it follows that the consistency indices follow the law of normal distribution.The determination of the admissible resistances clay rocks on the consistency basis of the indices for geological situations similar to the one investigated, must be considered purely informative.

Thus, the empirical statistical examination necessary to be used by referring to the ages of the geological formations based on the experience of the examination teams, will open the new perspectives in modern geology and geotechnics.

4. CONCLUSIONS AND PROPOSALS

The consistency and plasticity of the clay rocks represent two parameters influenced by humidity and the effective construction of the rocks (clays), more precisely by the fine fraction with the particle size at small of 2μ.

It is also possible to consider the representation of the activity index (I_A) that characterizes the general behavior of the analyzed rock and also defines the type of clay rock. This index can be calculated with he relation:

$$I_A = \frac{I_P}{\%<2\mu} \quad (19)$$

However, this index has it's characteristic limits, as well:

$0 < I_A < 0{,}75$ – kaolinitic rock (inactive);

$0{,}75 < I_A < 1{,}25$ – ordinary rock;

$I_A < 125$ –montmorillonitic rock (active).

Regarding the depth of the minimum foundation ground, this is established according to the hydrostatic level, thus:

- when the hydrostatic level is greater than 10 m depth, it will be considered the foundation depth of 2 m;
- when the hydrostatic level is less than 2 m depth, it will be considered the foundation depth of 1,5 m;
- if the hydrostatic level is kept constant at a depth of less than 2 m, the humidity is kept constant so that no volume changes can occur;
- in the situation where under the depth of foundation there are contractile clay rocks (organic nature), will be analyzed the possibility of partial or total overcoming of these layers.

In case the minimum depth of foundation is not respected, can be taken a series of important measures:

- the importance, size and resistance structure of a construction;
- the hydrostatic level in emplacement;
- the thickness and contraction potential of the clays that compose the foundation land;
- the variation of the humidity of the foundation land during the execution and operation of the construction;

- the admitted degree of construction insurance.

If the minimum depth of foundation is respected, in order to prevent degradation, are adopted a series of measures, as follows:
- the sectioning of buildings and foundations in sections of maximum through tapping joints;
- the water pipes should be constructed in such a way as to eliminate the water losses, even at the occurence of bumps, being accesible for inspection and repair;
- around the buildings shall be made watertight sidewalks with a minimum width of 1 m, placed on a stabilized laper of earth with a thickness of about 20 cm and an drainage slope of about 5 %;
- evacuation of surface water that has fallen directly or from the roof and the surrounding lad with drainage slope leading to distance greater than 10 m outside the building;
- avoid the existence of trees at distances less than 3 – 5 m from the construction, the distance taking into account the importance of the construction, the nature of the trees and the potential of construction-swelling of the land;
- the annexes of the buildings (stairs, terraces) will be founded at the same depth as the respective constructions, they either being rigidly linked to the construction or separating complet;
- will be folloed the movements in time of the constructions as well as their behavior;

In the case of founding at a depth within the zone of seasonal variation of humidity lower than the one idicated above (with high contractility), the following special construction measures will be provided:

The main causes of the degradation are:
- water leaks through the joints ang cracks of the insulation;
- breakage of the slopes as a result of water seepage through the cracks of the construction;

The following measures will be considered:
- provision of asphalt insulation or impremeable sheets of synthetic material;
- saturation of the land before the execution of the works;
- potection of the marginal areas.

In the active clay rocks, the structures will have to be reinforced and separated from the surrounding land by lapers of granular material, proving for drainage or waterproofing conditions.

5. REFERENCES

[1]. Bjerrum L., Casagrande A., Peck R. B., Skempton A. W. *From theory to practice in soil mechanics. Selections from the writings of Karl Terzaghi. John Willey and Sons* – New York.

[2]. Institutul de Studii și Proiectări Energetice – *Fișe geotehnice de laborator, amplasament Craiova (Platforma Moesică).*

[3]. Mutihac V. *Geologia României în contextul geostructural central – est european*, Editura Didactică și Pedagogică, 2010.

[4]. Sarapov I. *Utilizarea statisticii matematice în geologie*, Editura Tehnică, București.

[5]. Tomlinson M.J. *Proiectarea și executarea fundațiilor – Second Edition*, Pitman Publishing, 1969.

[6]. Vasiliu E. V. *Geotehnică. Caiet de lucrări practice*, Editura Universității Petrol – Gaze, Ploiești, 2000.

Influența indicelui de consistență al unor roci argiloase din Platforma Moesică

Rezumat *În această cercetare au fost examinate peste 400 de valori ale indicilor de consistență, determinat pe argile pliocene și cuaternare. Lucrarea arată că indicii de consitență nu pun accept pe diferența de calitate care existe între argilele anterior menționate din punct de vedere geotehnic. Din punct de vedere al datelor examinate, indicii de consistență al argilelor cuaternare prezintă o distribuție normal.*

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