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STATISTICAL CORRELATIONS OF SOME ENGINEERING PROPERTIES RELATED TO ACTIVE SOILS

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Abstract: *The present paper presents a detailed study of geotechnical characteristics of several plastic clay samples with susceptibility to swelling, in order to set a prognosis of volume changes or magnitude of swell potential. Various clay samples collected from different sites of Romania have been used in the study and specific laboratory tests, as grain size analysis, plasticity limits, free swell and swelling pressure have been performed for assessing the most significant and weighted parameters for active potential. As a result of data processing, linear regression analysis and correlation equations based on quantitative variables were developed, as well as comparative analysis of experimental and predictable parameters. The end-result will serve to soil behavior assessment based on typical determinant properties for swell character, but also as an essential tool to better awareness and understanding of damages and risk management strategies in treating damages caused by active soils.*

Key words: *active soils, clay volume changes, soils behavior, statistic correlations*

1. Introduction and Objective

In technical literature, clayey soils capable to manifest large swelling and shrinkage character are well known as expansive, contractive or active soils. From engineering point of view, soil types subjected to volume changes as a response of excessive wetting and local conditions are distinguished by special behavior and its effects on strength and stability of built environment. These soils are linked to geological, hydrological, mineralogical and climatic conditions, being widely considered as soil type which may lead to geo-hazard events.

The behavior of expansive soil is controlled by a variety of factors. Any environmental factor, which can influence water quantity or quality of expansive soil, has implicitly expansive effect on its behavior.

Natural clayey soils with swelling-shrinkage behavior are extensively

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widespread in many regions of the world. The distribution of main areas where building damages [1] had been reported is correlated to rainfalls amount. Clayey soils located in areas with excessive rainfalls will manifest a large shrinkage behavior during drought period, in comparison to those from areas with a reduced amount of rainfalls, which can lead to a large swelling during rainy period.

From geological point of view, expansive clay formations from Romania are included in temperate climate category consisting of glacial, lacustrine and marine deposits dated from late Tertiary and early Quaternary with limestone-marl nature, decalcified by flushing and enriched with colloids.

Buildings founded on active soil types can cause substantial damages, economical losses and adverse effect on people due to several factors as poor quality of construction material, inappropriate design and insufficient site investigation [2].

2. Parameters and Assessment Method for Active Soil Behavior Using Laboratory Testing

In order to identify and predict the behavior of active clays, several authors proposed different classification systems. These are based on some indexes and criteria for establishing characteristic correlations and estimating specific behavior [3, 4]. According to prescriptions of Romanian norm [5], identification and characterization of soil swelling-shrinkage can be assess by using indexes which expressed soil behavior in quantitative terms [6].

The article outlines an analytical and experimental prognosis of engineering properties obtained for swelling-shrinkage samples collected from various Romanian sites as Cluj, Aleşd, Hunedoara, Deva, Piteşti, Motru, Iassy and Botoşani.

The implemented procedures for data processing and analysis have allowed defining swelling or shrinkage character on the basis of statistical tools, in order to emphasize correlations between specific parameters of investigated soil samples. For this purpose, determinant indexes were quantified by laboratory testing: colloidal clay fraction $A_{2\mu}$, plasticity index PI, activity index I_A, plasticity criterion C_p, free swell FS, volumetric shrinkage C_v, adsorption capacity C_A and swelling pressure p_u.

Taking into account the significant influence of clay content on swelling-shrinkage phenomenon, soil activity index I_A related to water has been determined using the following equation:

$$I_A = \frac{PI}{A_{2\mu}} \quad (1)$$

where: PI - plasticity index and $A_{2\mu}$ - clay content with particles smaller than 2 μm.

Depending on liquid limit w_L, plasticity criterion has been obtained applying the equation:

$$C_p = 0{,}73 \cdot (w_L - 20\%) \quad (2)$$

Free swell testing has been performed by measuring the sediment volume resulted by adding dried and milled samples in water. The final results are calculated by using percentage ratio between difference of initial V_i and final volumes V_f and initial volume V_i, as follows:

$$FS = \frac{(V_f - V_i) \cdot 100}{V_i} \quad (3)$$

It is considered that soils with less than 70% free swell does not present expansive characteristics, as compared to soils with more than 70% free swell, corresponding to a moderate expansion potential. Free swell values greater than 100% are associated with clay soils which can produce a substantial swelling, especially on reduced loads.

Swelling pressure determination has been performed using odometer equipment. Inundated samples have been subjected to 10 kPa initial pressures, while recording swelling evolution under different loads. Volumetric shrinkage is defined as percentage ratio between volume changes of a soil saturated due to dry conditions and final volume:

$$C_v = \frac{(V_i - V_f) \cdot 100}{V_f} \tag{4}$$

where: V_i – initial volume in saturated state, V_f - final volume.

For calculation of adsorption capacity, it is used the following equation:

$$C_A = \frac{w_L}{M_d}(\%) \tag{5}$$

where: w_L – mass of adsorbed water at suction $p \cdot F = 0$, M_d – mass of dried and milled soil.

3. Results Analysis and Statistic Correlations

Processing and interpretation of values corresponding to determined geotechnical indices by laboratory tests have allowed to establish statistical correlations between several soil characteristics: liquid limit – plasticity index, free swell – plasticity index, liquid limit – swelling pressure; plasticity criterion – plasticity index and activity ratio – colloidal clay content.

Following results systematization, basic methods have been applied in order to reflect an outline of statistical links and its direction for further applications of adequate methods used in correlation measuring. The method is based on correlation chart setting as a function of factorial and result data, being obtained a correlation field by plotting each pair of values. Graphical representations have been achieved as a correlation result of two sets of values, with the purpose to provide data concerning link meaning.

For studied samples, a very good correlation of parameters, in positive direction, has been remarked with correlation coefficient around 1,00 for linear regression type (Figure 1).

By analyzing the distribution of values corresponding to plasticity index and free swell, an intermediate to good correlation in a positive direction can be noticed, with correlation coefficients around or greater than 0,5 for linear regression type (Figure 2).

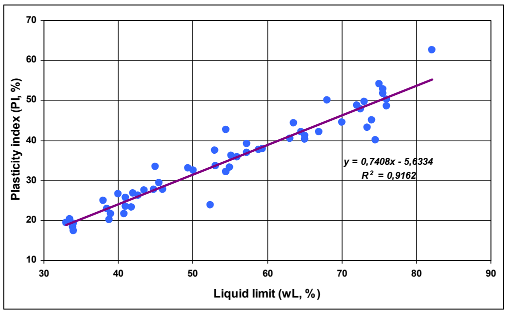

Fig. 1. *Plasticity characteristics variation*

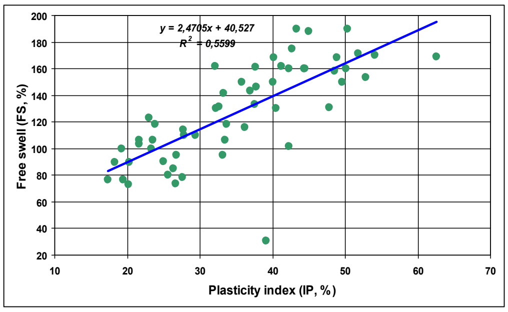

Fig. 2. *Free swell-plasticity index variation*

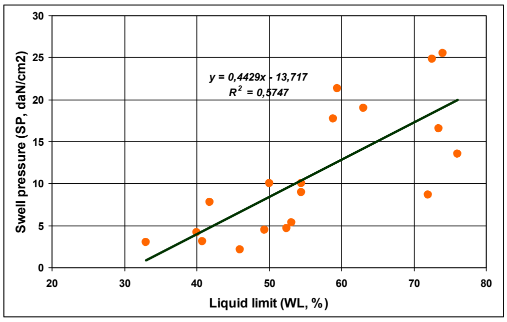

Fig. 3. *Swell pressure-liquid limit variation*

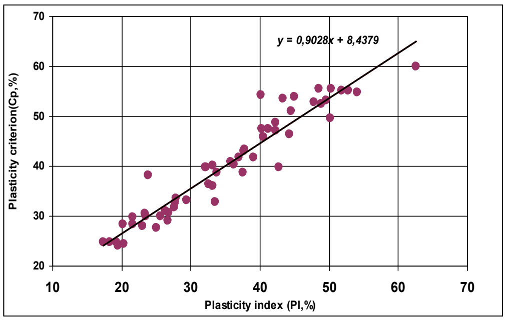

Fig. 4. *Plasticity criterion-plasticity index variation*

An intermediate correlation in a positive direction (Figure 3), with correlation coefficient around 0,5 between liquid limits values and swelling pressure has revealed. Following the same procedure, correlation between plasticity criterion and plasticity index is graphically illustrated in Figure 4. It can be observed a very good correlation, with correlation coefficient around 1,00 for linear regression type.

Based on processed values corresponding to colloidal clay content and activity ratio calculated with equation (1), a very weak correlation in a negative direction were obtained for investigated soil samples.

The results achieved from experimental laboratory tests have been used for developing linear regression models by simple regression analysis (Table 1).

Correlations of soil samples characteristics using simple linear regression analysis

Table 1

Pattern	Correlation equation	Correlation coefficient
PI vs. w_L	$PI = 0.7408 \cdot w_L - 5.6334$	$R^2 = 0.9162$
FS vs. PI	$FS = 2.4705 \cdot PI + 40.527$	$R^2 = 0.5599$
SP vs. w_L	$SP = 0.4429 \cdot w_L - 13.713$	$R^2 = 0.5747$
C_p vs. PI	$C_p = 0.9028 \cdot PI + 8.4379$	$R^2 = 0.9227$

The research conducted in present paper started from the fact that shrinkage-swelling character is related to colloidal processes, by reflecting the connection with amount of clayey fine particles. In this regard, it was selected λ index, considered as a suitable parameter for establishing several correlations with shrinkage-swelling indexes, given by following equation:

$$\lambda = \frac{Cl}{Si + Sa} \qquad (6)$$

where: Cl, Si and Sa are the corresponding percentages for clay, silt and sand fractions, obtained from grain size curves.

Taking into account tested soil samples and annexed charts approximated as linear, the connections between λ index and shrinkage-swelling parameters have been highlighted, as follows:

- adsorption capacity: relation $Ca = f(\lambda)$ is presented as an ascending conical fascicle, with a line inclination of about 450. The chart emphasizes that most active samples are corresponding to Cluj and Aleşd sites up to 7.00 m depth and less active to the ground surface (1-4 m), as presented in Figure 5.

- swelling pressure: correlation *SP = f(λ)* is represented by an irregular fascicle due to a reduced number of samples, as illustrated in Figure 6. It can be noticed that maximum values (>25 daN/cm2) are related to samples collected from Deva site.

- free swell: correlation *FS=f(λ)* is presented as a fascicle of parallel lines (Figure 7), by indicating most active soils in Deva and less active in Hunedoara.

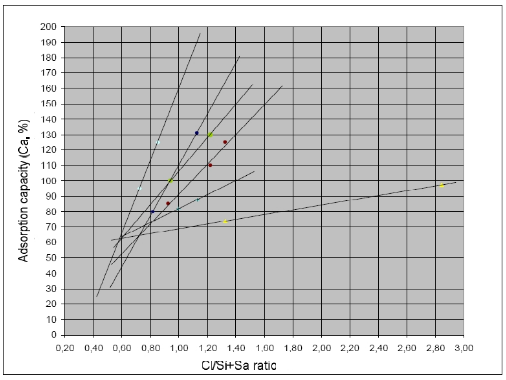

Fig. 5. *Variation of adsorption capacity with λ index*

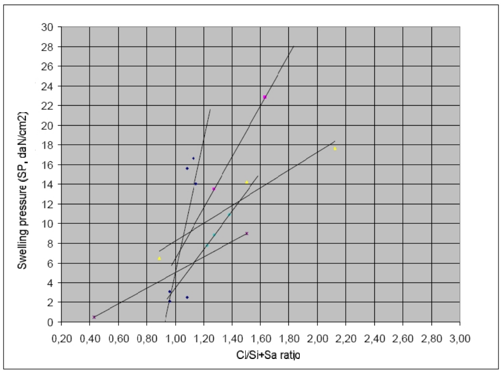

Fig. 6. *Variation of swell pressure with λ index*

- volumetric shrinkage: correlation C_v*=f(λ)* is graphically represented by an ascending parallel fascicle, with a pronounced inclination, as showed in Figure 8. The maximum values are corresponding to Hunedoara site (at ground surface) and minimum ones to Deva and Hunedoara up to a depth of 14.00 m.

4. Conclusions and Discussions

According to values resulted for activity ratio, swelling pressure, plasticity index and free swell, analyzed samples are included in a large variety from less active to very active, in terms of classification and characterization of soils which manifest a shrinkage-swelling activity [5].

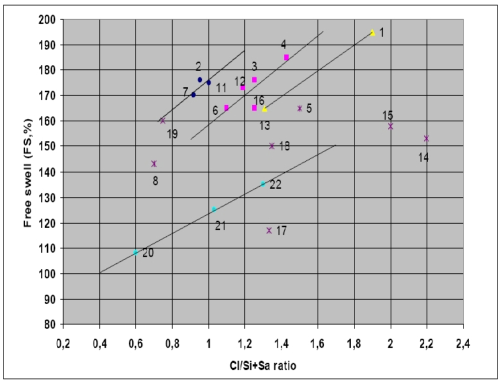

Fig. 7. *Variation of free swell with λ index*

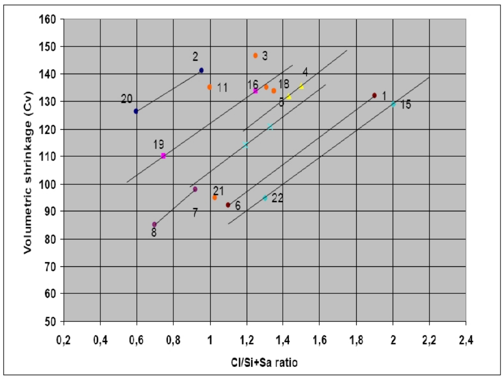

Fig. 8. *Variation of volumetric shrinkage with λ index*

By applying simple linear regression analysis of quantitative variables, a very good correlation between (PI vs. w_L), (C_p vs. PI) and an intermediate correlation between (FS vs. PI), (SP vs. w_L) have been emphasized.

The correlations derived from linear regression analyzes of geotechnical parameters were carried out on the basis of a substantial number of values. These can provide the opportunity of comprehensive studies of shrinkage-swelling soils [7, 8] and comparison between soils with similar behavior located in other areas.

For a detailed characterization of soils with shrinkage-swelling character, the identification of errors caused by laboratory testing results is considered to be useful for implementation of peculiar index correlations.

Quantification of geotechnical parameters and their correlations will serve to behavior assessment of soils with activity in relation to water, but also as essential tools for setting sustainable strategies in risk management in order to prevent and treat damages caused by active soils.

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