Soil chart, new evaluation method of the swelling-shrinkage potential, applied to the Bahlui's clay stabilized with cement.

L'empreinte du sol, une nouvelle méthode d'évaluation du potentiel de gonflement, appliquée à l'argile de Bahlui stabilisée avec du ciment.

Stanciu A., Aniculaesi M., Lungu I.
The "Gheorghe Asachi" Technical University from Iaşi, România

ABSTRACT: Clays, in both their remoulded and natural state, can present a certain swelling-shrinkage potential. A specific behaviour characterized by extreme swelling and shrinkage values is exhibited by the colloidal clays such as London's, Swellhaven's, Cambridge's clay. Bahlui's clay from Romania fits the same domain, based on the authors' proper tests. The indirect evaluation of the Bahlui's clay swelling potential, besides using the classical methods has been performed also based its own "chart". By consequence, the variation of the swelling potential was analyzed in this paper, based on the indirect methods (Seed 1962, Van der Merwe 1964) and as novelty, also based on the activity coefficient (C_A) (Stanciu et al. 2011) for the Bahlui's clay both in its natural state and mixed with Portland cement and respectively with ecologic cement. The laboratory test results indicated the decrease of the swell-shrinkage potential presenting reduced values of $C_A = 0.58 \div 0.18$.

RÉSUMÉ: Les argiles, à la fois naturelles et restructurés, disposent d'un certain potentiel de retrait-gonflement. Un comportement spécifique des argiles colloïdales telles que celles de Londres, de Swellhaven, de Cambridge, etc. est caractérisé par des valeurs extrêmes du gonflement et du retrait. Dans la même catégorie, basée sur des mesures propres, on peut aussi encadrer l'argile de Bahlui, de Roumanie. L'évaluation indirecte du potentiel de gonflement de l'argile de Bahlui, avec des méthodes traditionnelles, a été effectuée sur la base de son "empreinte". Dans cet article, basé sur des méthodes indirectes (Seed 1962, Van der Merwe 1964) et comme nouveauté, basé sur l'empreinte des sols (Stanciu et al. 2011), nous avonsanalysé la variation du potentiel de gonflement de l'argile de Bahlui, à la fois naturelle et mélangée avec de ciment de Portland et avec du ciment écologique. Les résultats ont indiqué une diminution du potentiel de retrait-gonflement mis en évidence par une diminution des valeurs $C_A = 0.58 \div 0.18$.

KEYWORDS: expansive clay, swell potential, soil chart, activity coefficient, stabilization with ecologic cement

1 INTRODUCTION

The swell potential evaluation for a certain soil has a very significant importance in the mitigation and limitation of potential structural damages of future constructions founded on active soils.

Among soils with special behaviour, the expansive ones take an important place due to their volume variations determined by moisture variations. These volume variations are reflected in soil differential swells/shrinkages due to soil uneven drying or wetting processes developed both beneath foundations and near them. Various solutions such as chemical stabilization techniques have been developed with more or less satisfactory results to limit the potential degradations of constructions on these soils (Gueddouda et al. 2011). The objective of the expansive soils stabilization is to reduce the swell potential within acceptable limits. The expansive soils stabilization with Portland cement reduces the swell potential as well as increases their mechanical strength. The substitution of the Portland cement in soil stabilization with 50% eco-cement has lead to promising results. The substitution solution of the Portland cement with eco-cement has the purpose of reducing the negative environmental impact, especially due to the manufacturing process of the Portland cement. The direct determination of the physical parameters that characterize the expansive soil behaviour such as the swell pressure, free swelling, volumetric shrinkage and of other properties takes a long time and is costly, due to the rather complex laboratory works. By consequence, it is necessary to develop and use simple and fast estimation methods for the swell potential. There is an important number of empirical methods to estimate the swell potential available in publications. It is generally considered that the swell potential is directly correlated with: the Atterberg limits (w_P, w_L), he colloidal clay fraction ($A_{2\mu}$), the shrinkage limit (w_s), the dry density (ρ_d), etc. These correlations are currently semi-empirical and based on statistics (Yilmaz 2006).

2 EVALUATION METHODS OF THE SWELL POTENTIAL

There are many methods to determine the parameters that characterize the swell-shrinkage of clays. The most utilized parameter to estimate the swell-shrinkage potential is the plasticity index (I_P). It is well known that the swell-shrinkage potential is dependent on the granulometric composition of the investigated clay ($A_{2\mu}$) as well as on the specific available surface for the interface phenomena display (Stanciu 2006).

Numerous attempts have been made to find an acceptable system to evaluate the swell potential. The most utilized systems for the indirect evaluation and classification of the swell potential are based on the graphical correlation between two or more geotechnical indices (Van Der Merwe – Figure 1and respectively Casagrande – Figure 2).

The principal physical properties of the representative clays investigated in this research are presented in Table 1.

The swell potential has been estimated based on these properties reflected by the indices ($A_{2\mu}/w_L/I_P$) and their representation on the diagrams in Figures 1 and 2. The swell potential of the investigated clays, established using the Van Der Merwe's and respectively Casagrande's diagrams is presented in Table 2. The domains of the swell potential, from very high to low, within these two diagrams, have generally a conventional representation on a (0-1) or (0-100) scale. This reflects the attempt to correlate the degradation magnitude of constructions founded on such soils, with the intensity of the swell potential (Figure 1 and Figure 2) (Das 1995).

Table 1. The physical properties of the representative investigated clays.

Soil	*Liquid limit (%)*	*Plasticity index (%)*	*Colloidal fraction (%)*	*Reference*
Bahlui clay-Romania	83÷98	57÷67	51÷87	Boti, 1974
London clay-U.K.	60÷71	36÷43	42÷60	Gasparre , 2005
Hubballi clay- India	51÷71	32÷53	51÷56	Hakari, 2010
Ankara clay -Turkey	64÷75	29÷34	39÷55	Hakari, 2010

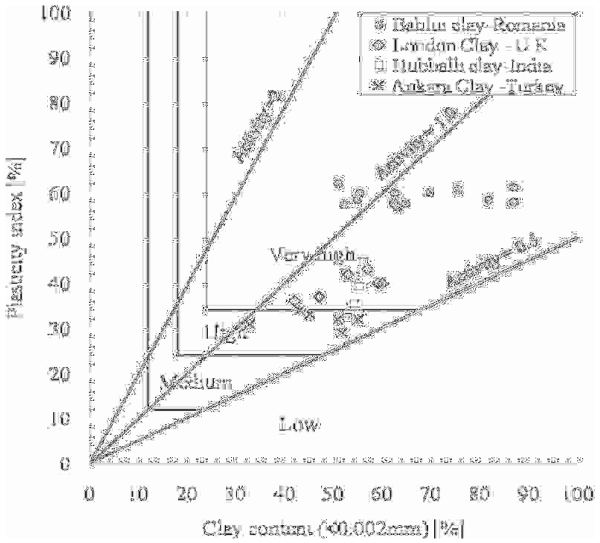

Figure 1. The classification of the swell potential, after Van Der Merwe, 1964.

It was noticed though, both from the published data and from the results in Table 2 that these two approaches (Van Der Merwe and Casagrande) using only two indices (I_P, w_L), indicate different magnitudes of the swell potential for the same soil.

By consequence, the Romanian Norms (STAS 1913/12-88 and Code N.E. 0001-96) propose the use of the "soil chart" to identify and characterize the expansive soils. This representation, considered unique (Andrei 1980) and specific for each soil, is obtained by joining the points I; II; III; IV and V on a composite diagram by assembling on the same graph, the Casagrande-Chleborad diagram, the Skempton-Van Der Merwe diagram and the granulometric curve (Figure 3). The size of the figure area (I, II, III, IV and V), (A) constitutes a first criterion to characterize the soil swell potential (Andrei 1997). The reference circle that intersects the 50% w_L, I_P, X_d points and the 1mm diameter as the point of interest on the diameter axis is introduced to scale the graph on the four axes. The normalized surface is calculated (A_0^n) using the reference circle area (A_{circle}) with the formula:

$$A_0^n = A / A_{circle} \tag{1}$$

It is defined an activity coefficient (C_A), constructed similarly as the consistency index (I_C), to evaluate the magnitude of the swell potential (Stanciu et al. 2011), fixing as the variation limits, the chart minimum and maximum areas for two soils with extreme behaviour: with maximum content of kaolinit, as with the lowest potential, and of sodium montmorillonite as for soils with maximum volume variations.

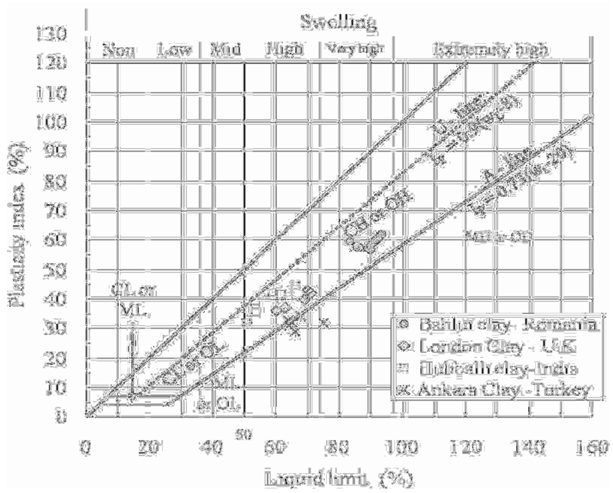

Figure 2. The classification of the swell potential based on the Casagrande's plasticity chart.

Table 2. The swell potential of the investigated clays.

Soil	The classification of the swell potential after	
	Van Der Merwe	Casagrande
Bahlui clay-Romania	Very high	Very high
London clay-U.K.	Very high	High
Hubballi clay- India	Very high	High
Ankara clay -Turkey	High	High

By consequence, the activity coefficient C_A for the normalized area of the soil chart A_O^n is given by the relation:

$$C_A = (A_O^n - A_C^n) / (A_M^n - A_C^n) \tag{2}$$

where: C_A – the activity coefficient; A_O^n - the normalized area of the chart referring to the investigated soil; A_C^n - the normalized area of the kaolin chart; A_M^n - the normalized area of the sodium montmorillonite chart.

The clay swell potential can be classified based on the value of the activity coefficient as presented in Table 3.

Table 3. The classification of the soil swell potential based on the activity coefficient, after Stanciu 2011

Activity coefficient C_A	Swell potential
0 ÷ 0.24	low
0.25 ÷ 0.49	medium
0.50 ÷ 0.74	high
0.75 ÷ 1.00	very high

The example of this new evaluation procedure for the clay swell potential is presented in Figure 3, where the average charts have been plot for four representative clays: from London, Hubbali, Ankara and Bahlui-Romania, together with the corresponding Romanian kaolinitic and montmorillonitic clays. The values of the normalized area A^n and respectively the values of the activity coefficient C_A have been calculated for each soil, based on the plotted charts from Figure 3 (Table 4).

The resulted swell potential from the classification based on the activity coefficient C_A, referring to the diagrams of

Skempton-Van Der Merwe, Casagrande-Chleborad and the granulometric curve has been reduced from high to medium for the London, Hubbali and Ankara clays, and from very high to high for the Bahlui clay (Tables 2 and 4).

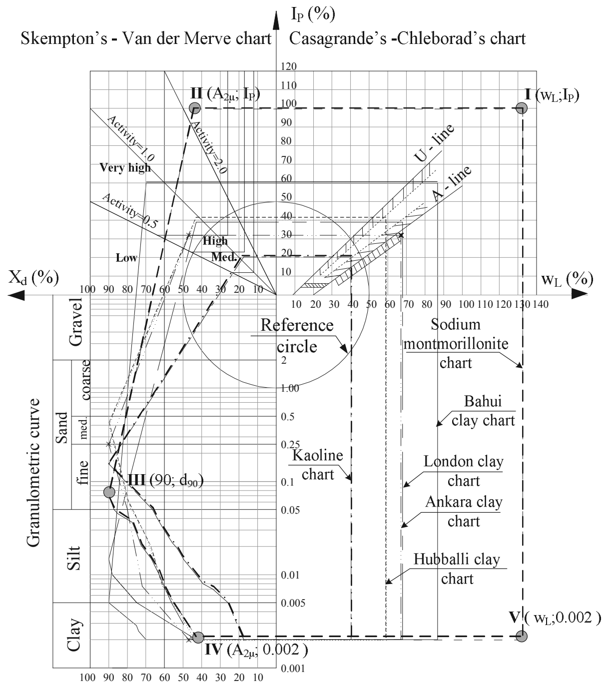

Figure 3. The average soil charts of the investigated clay.

Table 4. The classification of the swell potential based on the activity coefficient (C_A).

Soil	Normalized area A^n	Activity coefficient C_A	Swell potential
Sodium Montmorillonite	7.212	1	very high
Kaolinit	2.433	0	low
Bahlui clay-Romania	5.198	0.578	high
London clay-U.K.	3.868	0.30	medium
Hubballi clay-India	3.665	0.26	medium
Ankara clay - Turkey	3.823	0.29	medium

3 THE INFLUENCE OF THE PORTLAND/ECO-CEMENT STABILIZATION ON THE SWELL POTENTIAL OF THE BAHLUI CLAY

Many methods exist to reduce the swell-shrinkage potential of expansive soils to overcome the difficulties in foundation engineering practice on such sites. One of the most used methods to reduce the soil swell potential is the chemical stabilization using Portland cement.

Ecological issues resulting from the end-product pollutants related to the manufacturing of Portland cement lead to the development of new chemical binders named eco-cements.

This paper intends, apart from the introduction of the index (C_A) characterizing the swell potential, to reduce this potential by introducing new chemical binders that would provide less environmental pollution during manufacturing. Thus, a comparative analysis has been performed regarding the Bahlui clay stabilization with Portland cement and respectively with Portland and eco-cement mixture.

During the first testing series, the Portland cement participation was 2.5 ÷10% from the soil dry mass. For the second testing series, the previous Portland cement amount was 50% substituted with eco-cement.

The results quantified by the main parameters (w_L, w_P, I_P, $A_{2\mu}$) are presented in Tables 5a and 5b.

Table 5a. The physical properties of the Bahlui clay stabilized with Portland cement.

Properties	Bahlui clay stabilized with Portland cement			
	2.5%	5%	7.5%	10%
w_L (%)	88.3	79.7	69.6	63.2
w_P (%)	35.5	37.6	44.5	40.3
I_P (%)	52.8	42.1	25.1	22.9
$A_{2\mu}$ (%)	78	51	47	26

Table 5b. The physical properties of the Bahlui clay stabilized with Portland and eco-cement mix.

Properties	Bahlui clay stabilized with Portland and eco-cement			
	2.5%	5%	7.5%	10%
w_L (%)	86.2	75.1	75	65.6
w_P (%)	44.32	44.72	43.16	43
I_P (%)	41.88	30.38	31.84	22.6
$A_{2\mu}$ (%)	63	55	48	26

The charts of the stabilized Bahlui clay with Portland cement (Figure 4) and with the mix (50% Portland cement and 50% eco-cement) (Figure 5) were plotted based on the obtained results.

The new material structure will display a reduced swell potential determined based on the activity coefficient for a 10% Portland cement mix (Table 6a).

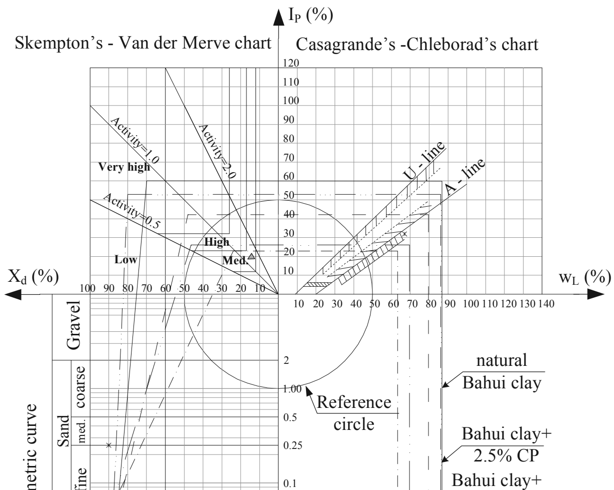

Figure 4. The chart of the Bahlui clay stabilized in various percentages with Portland cement.

The activity coefficients have been calculated using the plotted charts for the stabilization with Portland cement (Table

6a) and respectively with a combination of Portland/eco-cement (Table 6b).

Table 6a. The swell potential of the Bahlui clay stabilized with Portland cement.

Bahlui clay with	Normalized area A^n	Activity coefficient C_A	Swell potential
0% CP*	5.198	0.578	high
2.5% CP*	5.162	0.571	medium
5% CP*	4.321	0.395	medium
7.5% CP*	3.756	0.277	Medium
10% CP*	3.185	0.157	low
(*) Portland cement			

Table 6b. The swell potential of the Bahlui clay stabilized with Portland and eco-cement

Bahlui clay with	Normalized area A^n	Activity coefficient C_A	Swell potential
0% cement*	5.198	0.578	high
2.5% cement*	4.729	0.48	medium
5% cement*	4.109	0.35	medium
7.5% cement*	3.983	0.324	medium
10% cement*	3.272	0.175	low
(*) Portland and eco-cement with 50% participation each			

The chart of the stabilized Bahlui clay has been plotted for each cement percentage used in the mix (Portland and eco-cement) using the results obtained from the granulometric analyses and plasticity limits determination (Figure 5).

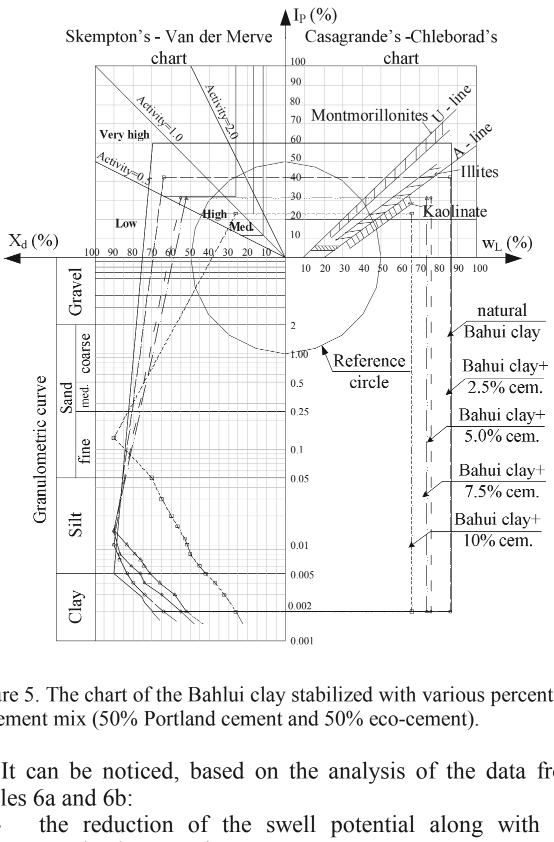

Figure 5. The chart of the Bahlui clay stabilized with various percentage of cement mix (50% Portland cement and 50% eco-cement).

It can be noticed, based on the analysis of the data from Tables 6a and 6b:

- the reduction of the swell potential along with the Portland cement increase;
- the ecologic cement presents a smaller influence than the Portland cement.

4 CONCLUSIONS.

The comparative analysis on the evaluation of the swell potential of the London, Hubbali, Ankara and Bahlui-Romania clays confirmed, as presented in previous publications, that the use of only two indices I_P, w_L or $A_{2\mu}$, may lead to different classifications of the swell potential of active clays.

The assemblage in one representation of the Skempton-Van Der Mewe diagram, the Casagrande-Chleborad diagram and the granulometric curve has made possible the plotting of a specific soil "print" for each soil. On its basis, a "unifying" coefficient has been defined C_A, namely the soil's activity coefficient. Thus, active soils can display a low, medium, high and very high swell potential.

This coefficient was also utilized to study the influence of the Portland and ecologic cement stabilization on the swell potential of the Bahlui clay from Romania. Stabilization with the Portland or the ecologic cement presents a decrease of this potential from high to low, along with the increase of the cement participation from 2.5% to 10%.

The eco-cement is not providing a significant decrease of the swell potential by comparison with the Portland cement, but it reduces the environment pollution during the manufacturing process.

5 REFERENCES.

Gueddouda M.K., Goual I., Lamara M., A. Smaida , Mekarta B. 2011. Chemical Stabilization of Expansive Clays from Algeria. *Global Journal of Research in Engineering*, vol. XI, 1-8

Yilmaz I. 2006. Indirect estimation of the swelling percent and a new classification of soils depending on liquid limit and cation exchange capacity. *Engineering Geology* 85, 295-301

Stanciu A. and Lungu I. 2006. Foundations, *Technical Publishing House*, Bucuresti, in Romanian

Das B.M., 1995. Principles of Foundation Engineering. *PWS Publishing Co*. 828p

Boti N. 1974. Contributions on studying the shrinkage soils from the foundation ground in the Iasi city area, *Doctoral Thesis*, Polytechnic Institute „Gh. Asachi" Iasi, (in Romanian)

Gasparre A., 2005. Advanced laboratory characterization of London clay- *Thesis submitted to University of London in partial fulfillment for the degree of Doctor of Philosophy and for the Diploma of Imperial College London*

Hakari U.D. and PuranikS.C., 2010. Evaluation of swelling potential and identification of expansive and problematic soils in civil engineering works by newly developed matrices based on index and grain size properties. *EJGE* 15, 1712-1726

STAS 1913/12. 1988. Determination of the physical and mechanical characteristics for soils with swellings and shrinkages*, Romanian Standardization Institute*. (in Romanian)

NP 001. 1996. Design and construction code for civil engineering works founded on clays with high swells and shrinkages. *Construction Bulletin no.7*. (in Romanian)

Andrei S. and Antonescu I. 1980. Geotehnică şi fundaţii, Vol. I,II. *Institute of Constructions Bucharest*. (in Romanian)

Andrei S. and Manea S. 1997. La systematisation, le stokage,et la reutilisation de information geotechniques, *Revue francaise de Geotechnique* 78, 51-61

Stanciu A., Lungu I., Ciobanita L., Aniculaesi M. 2011. A new concept to identify and characterize active clays, *Proc. of the XVth European Conference on Soil Mechanics and Geotechnical Engineering, Athens, Greece*