The expansive properties of Poland’s clay subsoil

Propriétés de l'argile expansive de substrat de la Pologne

Kumor M. K.
Geotechnical Department, University of Technology and Life Sciences, Bydgoszcz, Poland

ABSTRACT: The paper presents the expansive properties of Neogen clays of the Poznań series that form the foundation stratum of Northern Poland. The phases of swelling and shrinkage of expansive clays were analysed as a function of humidity changes. Functional relationships were determined. Expansive clays of Northern Poland are classified as soils of a very high degree of expansiveness due to the contractibility range *(LL –SL)* = 82.1% > 50 %. In the natural condition, they are half-compact or, at most, rigid-flexible. The examination results of volumetric changes in clays in shrinkage and swelling phases make it possible to determine the range of dislocations of the foundation-expansive substratum contact zone at a free swelling or shrinkage.

RÉSUMÉ : L’article présente les propriétés d’expansion des argiles du Néogène de la série Poznań qui constituent la couche de fondation du nord de la Pologne. Les phases d’expansion et de contraction de ces argiles ont été analysées comme une fonction des changements d’humidité. Des relations fonctionnelles ont été définies. Ces argiles expansives du nord de la Pologne sont classées comme des sols possédant un grand degré d’expansivité en raison de l`étendue de leur contractilité (LL - SL) = 82,1 % > 50 %. A l’état naturel ils sont semi-compacts ou tout au plus rigide-flexibles. L`examen des résultats des variations volumétriques des argiles pendant les phases d`expansion et de contraction permet de déterminer l’éventail des dislocations de la zone de contact foundation/sous-couche expansive lorsqu`expansion ou contraction sont libres de toute contrainte.

KEYWORDS: expansive clays of Poland, expansive parameters, swelling, shrinkage.

1. INTRODUCTION

The notion of soil expansiveness in geotechnics is usually related to a definition of swelling, Chen (1988). As is well known, soil expansiveness encompasses the more general phenomena of swelling and shrinkage, Przystański (1991).

***Shrinkage** – is a process of reducing soil volume as a consequence of pore water loss; it is a characteristic property of cohesive soils with significant content of clay-like fraction.*

*The **swelling** of cohesive soils is a process which is opposite to shrinkage.*

From a practical point of view, expansive soils are soils that show an increase in the initial volume in contact with water and shrink as a result of drying. A characteristic feature here is differentiated phases of shrinkage and swelling that always accompany changes in humidity.

In the literature relating to classification of expansive soils, e.g. Chen (1988), Seed et al. (1962), Sorochan (1974), van der Merwe (1964) and others, attention is chiefly paid to the swelling process. In the classifications, the following indicative features are used in the first place: liquid limit – LL, contractility limit – SL, plasticity index – I_p = *(LL –PL)* , soil humidity index – w_o, specific surface – S.

In practice, there are few clay expansiveness classifications that introduce shrinkage parameters as classification criteria, e.g. Holtz (1959), Rangantham and Satanarayana (1965), Niedzielski (1993). In Polish soils the expansiveness classification developed by Niedzielski, the so called contractility range *(LL –SL)* (%) was introduced to characterise shrinkage. Four expansiveness stages were distinguished on the basis of the range:

- very high *(LL –SL)* > 50 %,
- high 35 < *(LL –SL)* < 50,
- medium 20 < *(LL –SL)* < 35,
- low *(LL –SL)* < 20.

From an engineering point of view, the occurrence of the substratum shrinkage phase after the swelling phase is the most dangerous for constructions. Shrinkage brings about a post-consolidation settlement of expansive clays which in Poland’s geotechnical conditions are the principal cause of nearly all construction failures, see Figure 1.

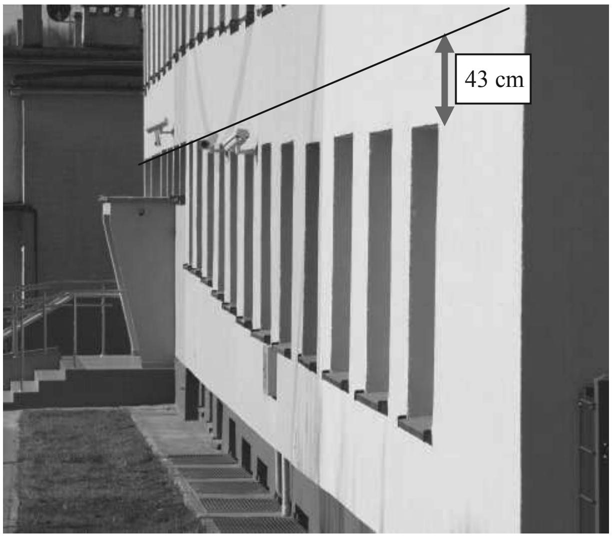

Figure 1. An example of a construction failure resulting from the swelling-shrinkage cycles.

2. EXPANSIVE CLAY CHARACTERISTICS

The building substratum surface zone in Central European conditions is exposed to specific factors, e.g. those related to climate, atmosphere, anthropopressure, etc. Highly dispergated clays with expansive properties are particularly sensitive to the impact of these factors. Expansive clays, typical to nearly half of Poland’s territory, are represented by tertiary deposits of the Poznań series.

They form the substratum in the area of the Polish Lowland, see Figure 2.

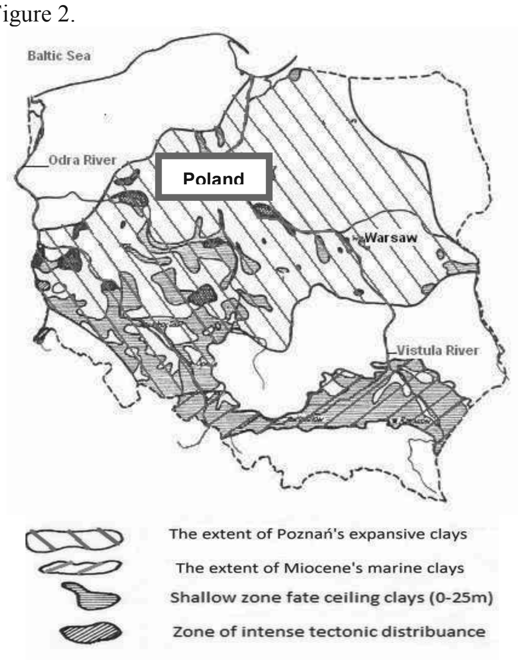

Figure 2. Occurrence of expa**n**sive soils in Poland.

Clays are characterised by a high variability of graining and mineralogical composition. The mineral with strong expansive properties, i.e. *beidelite, montmorillonite* prevails in the mineralogical composition. The contents of clayey minerals are as follows:

- smectite: 11 % to 23 %, with the exchangeable ion Ca, Na,
- illite: 5 % to 9 %,
- kaolinite: 6% to 11 %,
- other minerals, chlorite, silica.

The thickness of the Poznań series usually does not exceed 20 m in Poland.

In Poland, the areas of occurrence of tertiary clays of the Poznań series are characterised by a slight overlayer of quaternary formations over the Cenozoic, Kumor (1993). From above, usually a thin (0 to 1.4 m) layer of new deposits occurs that covers the basic complex of Neogene formations. The Neogene has been exposed mainly along erosive river valleys of the Vistula, the Odra, the Brda, the Drwęca and the Warty. It is developed in the form of Mio-Pliocene mottled clay (Poznań series clays), locally washed away and broken.

1.1 *Expansive clay properties*

The clays of the Poznań series are characterised by expansive properties that are atypical in comparison with other genetic clays of Poland's region, Kumor (2006), Niedzielski (1993). Below, expansive indices values as typical for the Poznań series in Poland are presented (see Table 1).

Table 1. Same parameters of Polish expansive clays.

Parameter	Max.	Medium
Swelling time t_p *(h)*	>340	24 - 36
Swelling pressure p_c *(kPa)*	1200	200-400
Shrinkage v_o *[%]*	44.1	32-34
Swelling humidity w_c*[%]*	137.0	80-99
Liquid limit LL *[%]*	148.5	82.1
Swelling index v_p *[%]*	*62.0*	~21.7

The expansive indices of clays are not constant, they depend on temperature and increase as temperature rises, e.g. a swelling index 18 % higher was obtained as the temperature rose from +20 to +55^o C.

Expansive clays of Northern Poland can be classified as very highly expansive due to the contractibility range *(LL –SL)* = 82.1% > 50%. Characteristic features of an expansive substratum in the natural condition are high cohesion (strength) and low compressibility.

In the general opinion, these are soils with favourable geotechnical properties, basically half-compact or, at most, rigid-flexible. In real geological conditions, there are always differentiated, genetic zones of irrigated or dried soils. These problems naturally impede the execution of foundation works. The photograph shows a spatial open excavation where clays simultaneously dried in local zones and irrigated in others have been found, see Figure 3.

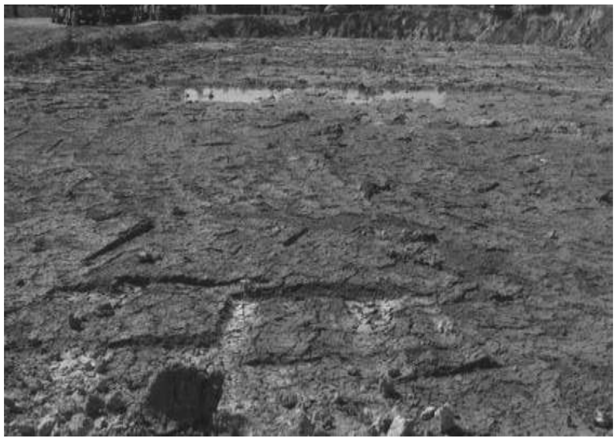

Figure 3. The view of the typical system of clays in the gout of the large building excavation with extremely diverse proprieties, simultaneous drying - the nearer zone, and irrigating - the background.

An example of destruction of expansive clay in the excavation bottom is the situation when under the influence of natural drying, a macro-disintegration of the clay massif is initially noticed, then a volumetric shrinkage and a further granular disintegration of the massif leading to the occurrence of breccia, see Figure 3, 4 and 5.

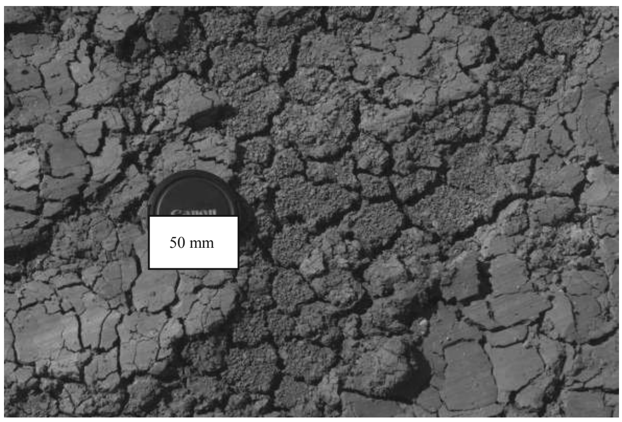

Figure 4. The granular disintegration of dry clay in natural conditions, after 24 hours.

It follows from the presented photograph that the process of clay drying (shrinkage) is characterised by a volumetric shrinkage and the occurrence of a breccia structure with numerous separated grains and deep shrinkage fissures. One of geotechnically undesirable effects is a locally differentiated rigidness and deformability of such substratum. By monitoring the foundation settlement (upon uniform loading), differences ranging from Δs = 0.0 mm (a dried zone) to Δs = 30.0 mm in humidified clay zones, see Figure 3.

Figure 5. The natural process of clay drying after exposure of the excavation's bottom, (after 2 hours) the superficial macrodisintegration fully developed.

Detailed examination of the shrinkage and swelling phases of expansive clays, as presented in this paper, were conducted from the constructional substratum of the city of Bydgoszcz situated in the northern region of Poland, (Niedzielski, Kumor 2009).

Expansive clays are characterised by extremely high numerical values of expansive parameters against a background of other tertiary clays in Poland. They should be classified in respect to the contractibility range *(LL –SL)* = 82.1% > 50 %, as very highly expansive soils.

1.2 *Shrinkage phase examination*

The soil contractibility examination is a determination infrequently performed for practical purposes. The volumetric shrinkage (V_s) of expansive clay was examined according to the following see Eq.:

$$V_s = (V' - V'') / V' \quad (\%) \qquad (1)$$

where:
V' – soil sample initial volume [cm^3],
V'' - final volume of the sample after drying [cm^3].

Typical results of the shrinkage progress are presented in Figure 6 and see Table 2.

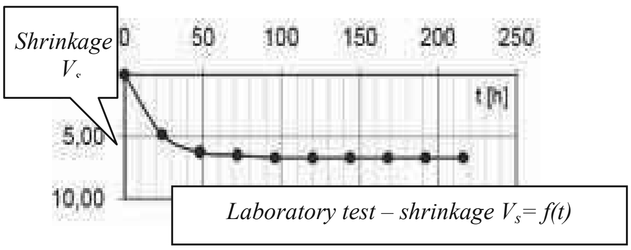

Figure 6. A typical progress of expansive clay shrinkage over time.

Table 2. Same shrinkage parameters of Polish expansive clays.

Parameter	Max.
Shrinkage time t_s *(h)*	50 -96
Volumetric shrinkage V_s *[%]*	23-24
Shrinkage limit SL *[%]*	18.2-18.9

The shrinkage examination results reveal losses in the massif volume and a high sensitivity of expansive clays to changes in humidity in a short time after the start of drying, see: Figure 5 and Figure 6.

The volume loss ΔV_s for the shrinkage phase of the expansive clay in the Northern Poland can be determined by means of see Eq. 2:

$$\Delta V_s = 0{,}783 * (w_o - w_k) \quad \text{at} \quad w_k > SL \qquad (2)$$

where:
w_0 – initial humidity, *[%]*
w_k – final humidity *[%]*.

From a practical point of view, it is important to learn the volumetric shrinkage values. The form of the function between relative volumetric shrinkage (V_s) and humidity is linear for expansive clay, with statistical significance $R^2 = 0.9545$:

$$V_s = -3{,}5731 + 0{,}783 * w \qquad (3)$$

where:
V_s – relative volumetric shrinkage [%],
w – humidity, > w_s [%].

In the process of drying and with humidity lowered by the value of $\Delta w = (w_o - w_k)$, the volume of the relative volumetric shrinkage is important for forecasting post-consolidation settlements of newly erected buildings, as well as for preventing failures in buildings used for many years. It follows from observations Kumor (2006), that differences in actual shrinkage settlements under a damaged building amount to tens of millimetres, Figure 1.

The parameters describing the shrinkage process, as well as swelling, are individual *material features* of each expansive soils.

1.3 *Swelling phase*

The swelling parameters of expansive clays were examined using methods applied in soil mechanics laboratories.

Table 3. Swelling parameters of expansive clays.

Parameter	Max.	Medium
Swelling pressure p_c *(kPa)*	1200	200-400
Swelling humidity w_c*[%]*	137.0	80-99
Contractility range *($w_L - w_s$) [%]*	130.5	99.1
Swelling index v_p *[%]*	*62.0*	~21.7

The following values were measured: swelling humidity - w_c, swelling index – V_p, according to Vasiliev, swelling pressure – p_c, in a consolidometer, swelling time - t_p. Exemplary testing results are presented in Table 3, Figure 7, 8.

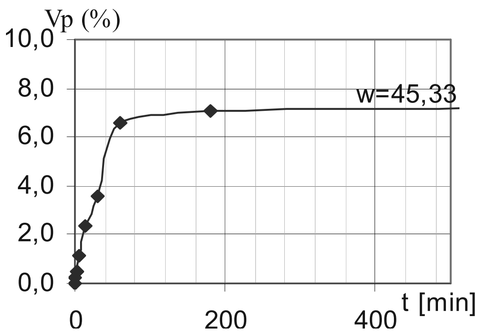

Figure 7. Dependence of the swelling index - *Vp,* on the expansive clay swelling time - *t*.

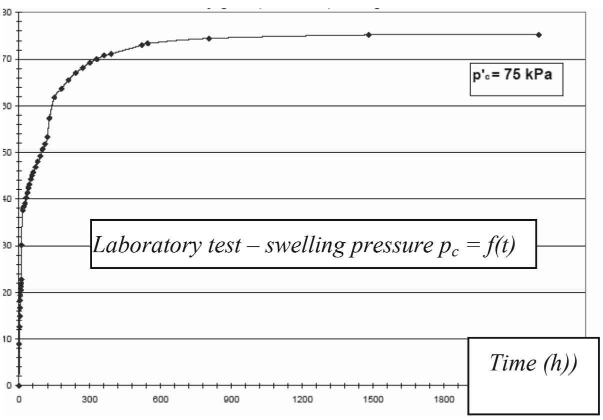

Figure 8. Progress of the expansive clay swelling pressure in time.

Characteristics obtained of the progress of potential volumetric change in the examined clays in relation to the humidity condition are presented see Figure 9. The dependence between the swelling index and humidity can be written down in a general form:

$$Vp = f(w) \quad (4)$$

where: Vp – swelling index,
w – humidity.

$$Vp=(h_k – h_o) : h_o \quad (5)$$

The function form of the potential expansiveness change characteristics for the examined clay with statistical significance $Rxy = 0.912$ is as follows:

$$Vp = 3E\text{-}05w^3 + 0{,}011w^2 + 0{,}102w - 5{,}867 \quad (6)$$

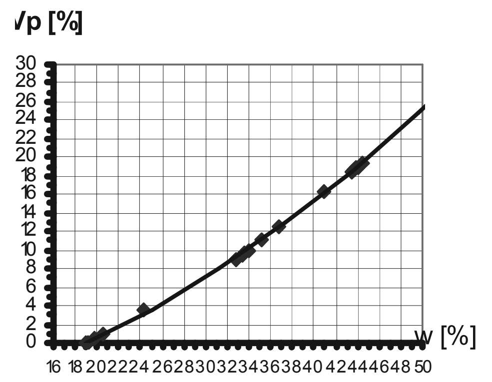

Fig. 9. Dependence of the swelling index – Vp, on the swelling expansive clay humidity - w.

The characteristics of dependence of the swelling index in relation to humidity, as presented in Fig. 9, allows one to determine the progress and expansiveness phase characteristics as well as changes in clay deformation values during swelling. Knowing the final swelling humidity of a particular clay w_k, and anticipating the direction of the humidity change on the basis of initial humidity w_o, we know that one expansiveness phase will occur, i.e. $(+\Delta w)$ – humidity increase – swelling phase, when $(-\Delta w)$ - drying – shrinkage phase.

Having the characteristics of potential volumetric changes in relation to humidity as determined experimentally for a particular type of clay, one can relatively easily forecast in practice the range of substratum displacements.

A potential increase in the swelling clay volume can be calculated from the obtained relationship (6) in the following form:

$$\Delta Vp = Vp\ (w_o) – Vp\ (w_k) \quad (7)$$

For the case of humidity increase by value $\Delta w = (w_o – w_k)$, we will determine a positive swelling index – $(+\Delta V_p)$ in relation to the positive condition on the basis of the swelling phase characteristics.

In the clay shrinkage phase, during the swelled massif drying, we obtain from the characteristics and calculations made according to formula (7), a negative value $(-\Delta V_p)$ – shrinkage, in relation to the initial state after the completed swelling, with humidity w_o.

2 ENDING AND CONCLUSIONS

The results obtained enable forecasting building behaviours in relation to determined natural fluctuations in the expansive substratum humidity. On the basis of already conducted expansiveness studies (25 cases) one can predict that for other clays, material differences are related only to the range of limit values, i.e. the limit of swelling contractibility and humidity (R – space), swelling index and swelling pressure, Kumor (2006). When analysing the results obtained for numerical values of expansiveness parameters for the Poznań series Neogen clays from the northern Poland, one can describe them as very cohesive, with a very high and extremely high plasticity as well as a very high and extremely high swelling. They point to the necessity for very careful forecasting of dislocations of buildings when they are founded in expansive clays.

The presented results point to the need for determining characteristics of potential expansiveness for various types of clays, depending on humidity, swelling pressure as well as the time and chemistry of the environment.

3 REFERENCES

Chen F.H. (1988): Foundations on Expansive Soils. Dev. In Geot. Eng. *Elsevier,* Amsterdam.

Danilov A.A. (1964): Grafik dla rozdelenia gruntov na obuhnye, prosadochnye i nabukhajushhie. *Osn. Fund. i Mekh. Gruntov,* 5: pp. 26-26.

Kumor M.K., (2006): Investigation of shrinkage-swelling of clays as the potential tool to predict deformation of expansive subsoil. *XIV Krajowa Konferencja Mechaniki Gruntów i Inżynierii Geotechnicznej,* (in Polish) Białystok, Vol. 1, pp. 234-242.

Niedzielski A., (1993): Factors Determinig swelling Pressure and Free Swelling of Posnanian and Varved Clays. *Rozprawy Akademia Rolnicza zeszyt nr 238,* Poznań.

Niedzielski A., Kumor M.K., (2009): Geotechnical Problems of a Foudation on Expansive Soils in Poland. *Inzynieria Morska i Geotechnika 3/2009,* (in Polish), pp. 180-190.

Przystański J., and all, (1991): Foundation on Expansive Soils, (In Polish) *Zeszyt Politechniki Poznańskiej Rozprawy 224,* Poznań.

Sorochan E.A. (1974): Stroitelstvo Sooruzenijj na Nabukhajushhikh Gruntach. Stroizdat, Moskva.