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Evaluation of expansivity of Neogene clays and glacial tills from central Poland (Warszawa area) on the basis of suction tests

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This paper presents the characteristics of the expansivity and quantitative prediction of heave of clay soils from Poland based on suction testing. Eleven Neogene clays and six glacial tills, differing in genesis and plasticity, were analysed to identify the expansive potential using eight empirical methods. The laboratory studies included measurements of soil-water characteristic curves and soil index properties. Data from water content, volume and suction measurements served to determine the suction compression index C_h and the suction-water content index $\Delta h/\Delta w$ of the soils examined. The values of these indices are clearly dependent on the clay fraction content in tested soils. Compared with glacial tills, Neogene clays are expected to exhibit greater changes in volume due to changes in soil suction. Comparative results of the evaluation of expansivity suggest that the chosen classification methodologies provided consistent expansion ratings for glacial tills, while the values for Neogene clays vary from low to very high. The lowest expansivity classes have been obtained from evaluation based on soil suction. The McKeen (1992) method has been adopted for calculations of the potential field heave of Neogene clays and glacial tills. In order to provide a rational estimation of expansive soil behaviour, specialists should take into consideration the specific site and design features.

Key words: expansive soil, Neogene clays, glacial tills, suction, suction compression index, heave.

INTRODUCTION

Foundation engineering on expansive soils is regarded as one of the difficult geotechnical tasks. According to the standing rules and Polish legal regulations, the engineering conditions of expansive soil are defined as complex and building objects erected under complex soil conditions, are classified into the third geotechnical category (Rozporządzenie, 2012). Compared with other mineral soils, swelling clays are one of the most expensive geologic hazards. Practical recommendations and guidelines as to designing foundations, executing foundation works, as well as conservation and protection of existing objects were given by Przystański (1990). In the light of available investigations, one of the main causes of damages of buildings erected on expansive soils is improper founding systems and inadequate structural bracing (Jeż, 1989; Kumor, 1990, 1994, 2008). In geotechnical engineering practice, the range of soil investigations is usually limited to the main physical and mechanical (e.g., shear strength) parameters. As reported by professional literature, Neogene clays in Poland are most often stiff and firm, have a high shear strength and low compressibility, thus providing favourable conditions for land development (Kumor, 2008). However, their sensitivity to moisture changes that determine a proper soil/building interaction during construction work, and predicted exploitation time are, as a rule, underestimated.

Numerous attempts have been made to systematise factors controlling the changes in the volume of clay soils. Noteworthy is that the deformation ability is distinctive of potential soil due to activation of the factor which initiates shrinkage or swelling of soils susceptible to such processes. Expansivity is controlled not only by the composition of soil described on the basis of conventional indices (grain-size distribution, clay fraction content, mineral composition of the clay fraction, type of the exchange cation, chemical composition of pore water), but is induced also by various factors in a soil environment sensitive to expansion. These environmental factors include: climatic changes (long-lasting draughts, torrential rains), human impact (spatial development – densely built-up areas, root effect, use effects – extensive watering of lawns, poor insulation of heating systems, failure of water supply systems). Due to these factors, a near-surface zone, called the active zone, is formed. It covers the depth of the soil that interacts with the surface environmental conditions and is characterized by variable moisture content and suction (Fig. 1). Other crucial factors are: the state of stress, the structure/texture as well as initial moisture and saturation degree of the soil. Therefore, a rational approach to planning the investigations of such soils is recommended, with special emphasis on mineralogy, direct determinations of swelling and shrinkage parameters, and changes of strength due to volume changes.

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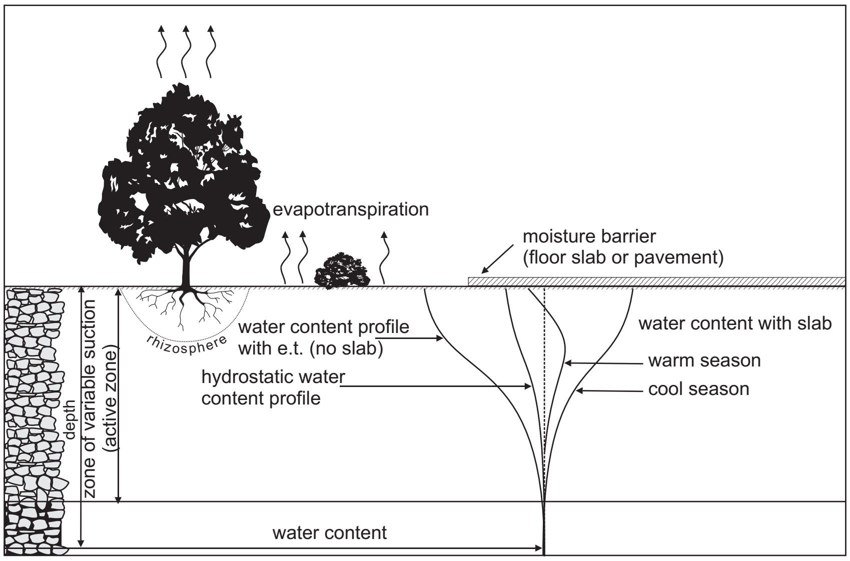


Fig. 1. Water content profiles in the active zone (Nelson and Miller, 1992; modified)

Expansive soils present significant geotechnical and engineering challenges all over the world. Therefore, the identification of soils sensitive to volumetric changes has been the subject of active research for the past 40 years. At the turn of the last decades, several tens of various classifications have been created (for comprehensive review see Izdebska-Mucha and Wójcik, 2014). Three types of approaches for estimating soil expansivity have been adopted. The first group includes methods based on empirical correlation of engineering index properties of soils – e.g., liquid limit – LL, plasticity index – PI, clay content. The second approach defines expansivity in terms of swelling parameters determined in oedometer measurements. The third one employs total suction testing for the assessment of the degree of volume change. Johnson and Snethen (1978) have been the first to use the suction parameter in expansive soils classification. Initially, a definition and descriptions of practical use of soil suction appeared rarely in professional literature due to the lack of simple and reliable methods of suction determination. On the other hand, the role of moisture changes in soil was commonly underestimated. Conventional soil mechanics were focused on problems related to the full saturation state or completely dry formations. Numerous reports of expansive soil problems and resulting damages had been made available in various countries, which convinced the geotechnical engineering community to devote particular attention to soils existing between these two extreme stages. The parameter which most accurately describes the state of unsaturated/partly saturated soils is suction. Soil suction is a macroscopic property that indicates the intensity or energy level with which a soil sample attracts water. The soil-water characteristic curve (SWCC) is an important soil function relating the water content of a soil to soil suction, and it has become of great value in estimating functions of unsaturated soil properties (Fredlund, 1995). On the log scale, soil suction varies with water content in a wide range. This is an extremely sensitive parameter defining various soil properties (e.g., physical, chemical and mineralogical) essential in engineering practice. The shape and run of the soil-water characteristic curve is indicative of the suction-water content index *h*/ *w*, suggested by McKeen (1992) for estimation of soil expansivity. Another method, based on soil suction *in situ* is the United States Army Engineer Waterways Experiment Station (USAEWES) classification system (Snethen et al., 1977), where consistence parameters are additionally taken into account.

Whilst much research has been carried out to characterize the mineralogy, index properties, swelling and expansivity of Polish clay soils (e.g., Niedzielski et al., 1988; Kaczyński and Grabowska-Olszewska, 1997; Gawriuczenkow, 2003, 2008), few data on soil suction have been published and are available in Polish databases (e.g., Garbulewski and Żakowicz, 1993a, b, 1995; Wojtasik, 1994, 1997; Barański and Wójcik, 2007, 2008). In the light of the above, this paper is also intended to fill this gap and to present the characteristics of suction of Polish Neogene clays and glacial tills. The authors relate the results discussed herein to the previous findings, which permits a comprehensive evaluation of soil expansivity based on various methodological procedures.

Foundation design on expansive clay sites requires a reliable classification of soil expansivity and a quantitative assessment of probable volume changes. Thus, prior to foundation design, the soil heave should be known. The classification system by McKeen (1992) permits to predict the heave and soil expansivity. However, it is widely acknowledged that no universal classification system for all soils exists, but the correlations may vary within climatic and geological zones. More reliable results can be obtained locally for given subsoil and site conditions. Another purpose of this paper is to adopt McKeen's (1992) methodology to estimate the behaviour of potentially expansive soils from Poland, based on assumptions applicable to local conditions and actual measurements of the considered soils.

Soils described in this paper are partly the same ones that have been examined in the previous study (Neogene clays from the Dobre polygon) and the collected experimental data come from a number of research projects conducted in the Department of Engineering Geology, Faculty of Geology, University of Warsaw, over the past several years. The selection of material was determined by the fact that for these samples additional measurements of the soil-water characteristic curve were carried out by the present authors.

MATERIALS AND METHODS

The cohesive soils selected for this research are common subsoils for numerous objects in more than a half of the area of Poland. The distribution of sampling sites is given in Figure 2. Polygons 1–3 are represented by Neogene clays. The former two are located in the Stegny and Buraków districts of Warszawa, respectively (samples: C-W1–C-W4 and C-WB5, C-WB6), and polygon 3 in the locality of Dobre (samples: C-D1–C-D5) about 50 km north-east of Warszawa. Polygons 4–6, located in Warszawa (districts of Ochota and Służew), are represented by glacial tills of the Odra and Warta glaciations (samples: T1–T6).

In total, 17 samples have been classified in accordance with the Unified Soil Classification System (USCS, according to ASTM D 2487-06) mainly as CH fat clays and SC clayey sand, for which the basic physical parameters such as clay content (CI) and Atterberg limits (LL, PL) have been defined. The results are given in Table 1.

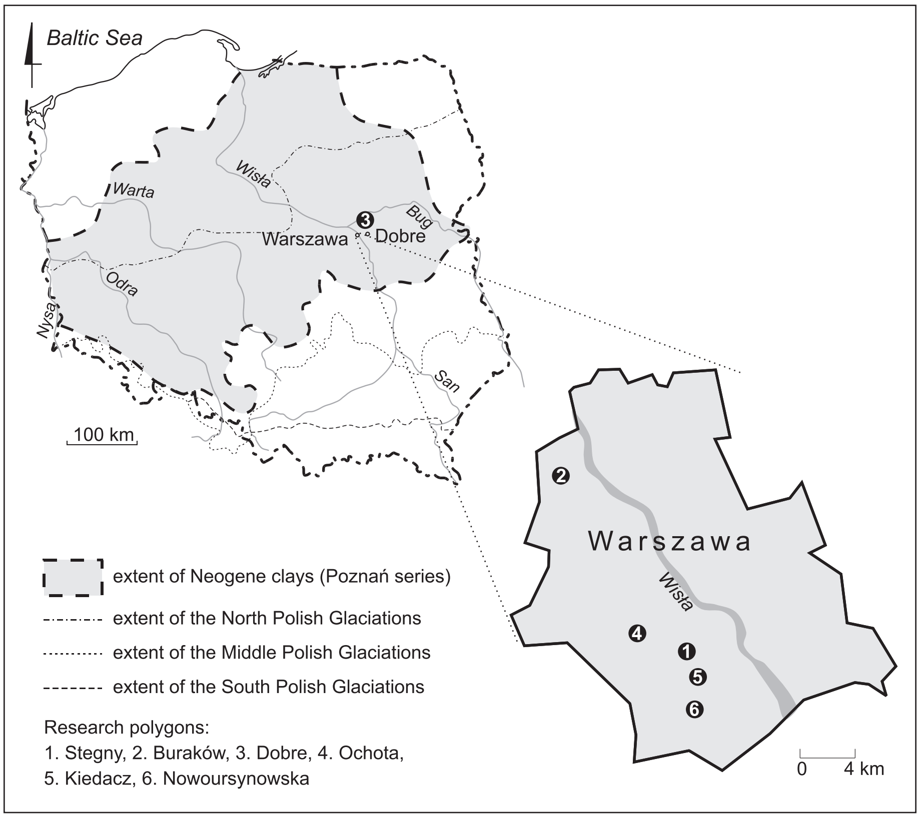


Fig. 2. Location map of the study area showing distribution of various soil types and sampling sites

Table 1

Summary of properties of tested soil samples

Soil type		Sample ID	Soil classification USCS	Clay content Cl [%]	Liquid limit LL [%]	Plastic limit PL [%]
Neogene clays		C-W1	CH fat clay	80	96.0	41.0
		C-W2	CH fat clay	72	83.0	35.0
		C-W3	CH fat clay	63	69.5	22.5
		C-W4	CH fat clay	70	70.1	31.1
		C-WB5	CH fat clay	65	99.0	32.3
		C-WB6	CH fat clay	61	64.4	25.4
		C-D1	CH fat clay	88	71.1	30.9
		C-D2	CH fat clay	60	69.6	23.7
		C-D3	CH fat clay	72	82.5	31.7
		C-D4	CH fat clay	58	76.9	27.4
		C-D5	CH fat clay	85	111.9	38.5
Glacial tills	Warta Glaciation	T-1	CL sandy lean clay	21	20.6	12.0
		T-2	SC-SM silty clayey sand	18	19.3	13.7
		T-3	SC clayey sand	12	23.0	12.5
		T-4	SC-SM silty clayey sand	10	19.1	12.4
	Odra Glaciation	T-5	SC clayey sand	20	22.3	11.1
		T-6	SC clayey sand	15	24.4	11.4

The relationship between soil moisture and suction has been examined using the pressure plate apparatus (Soilmoisture Equipment Corp. model 1500). The main elements of this apparatus are a pressure chamber, a porous ceramic plate and a compressor producing pressure. This method permits to complete a number of determinations of soil moisture content at different pressures. In the laboratory, the samples were placed in small cylinders (about 54 mm in diameter and 20 mm in height), saturated and subsequently balanced with respect to the increasing values of the suction. The moisture tensions were obtained by creating a series of under- and over-pressures. Weighing of the sample after each balance adjustment yields the moisture content for each suction tension. Each determination has been completed on at least three identical samples and the results used in further investigations are their arithmetic mean. Thus, the obtained curve, illustrating the dependence between the pressure and the moisture, is a typical desorption (drying) curve. Samples from the Stegny and Ochota polygons show pressure values exceeding pF 4.2 (measurements completed using a psychrometer), which enabled a thorough description of soil behaviour within a wider suction pressure range. A single determination procedure lasted from 7 to 15 days. It has been assumed that the balance between pressure inside the chamber, soil and pressure plate is attained when water ceases to flow out of the chamber. When each of the applied suction was equalized, the height, diameter and mass of each specimen were measured. The relationship between soil suction and water content (SWCC) was determined for 17 different soil samples – 6 glacial clays, and 11 Neogene clays. Figure 3A shows data illustrative for each type of soil. This relationship allows determining the suction-water content index $\Delta h/\Delta w$, defined as the slope between the suction levels of 6 and 3 pF. Using pairs of volume measurements – at the imposed suction level and after drying the samples at 105°C – a change of volume can be computed according to the equation:

$$\Delta V = \frac{V_i - V_d}{V_i} \qquad [1]$$

where: ΔV – volume change, V_i – volume of the sample at the given suction level [cm^3], V_d – final volume of the sample after drying at 105°C (378°K) [cm^3]

In Figure 3B, volume change (ΔV) measurements are plotted versus the corresponding suction (h) level. This relationship permits to calculate the suction compression index C_h, which is the slope of the volume change-suction relation in the suction range of 2.0–2.5 pF to 5.5 pF, and represents soil response to the suction change. The values of C_h identified for selected examples of Neogene clays and tills are –0.1209 and –0.0192, respectively, which is reflected in the differences in the slopes – tills have clearly flattened slopes and less negative values of C_h than clays.

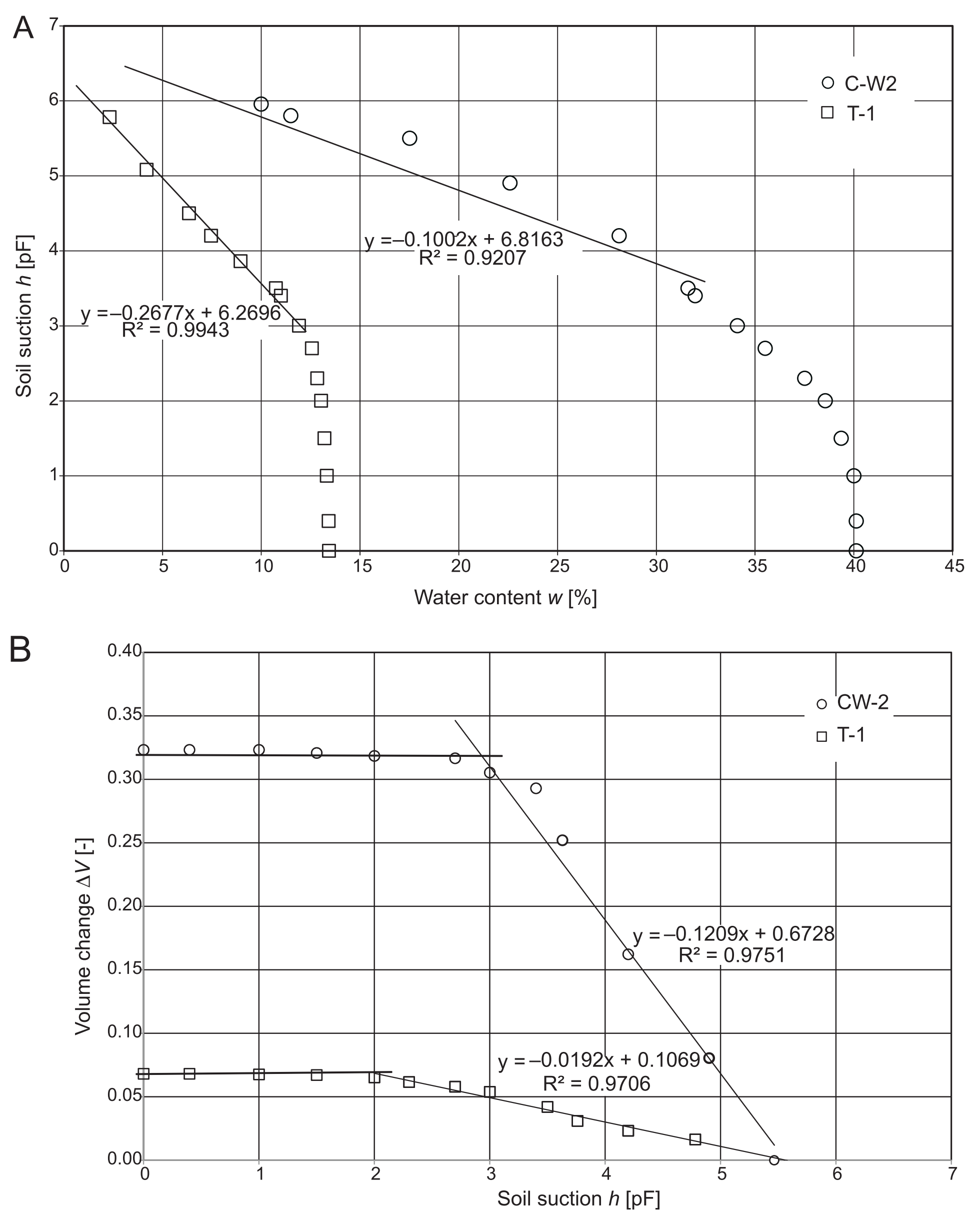


Fig. 3. Examples of A – soil-water characteristics curves, B – volume change-suction relation of Neogene clays (CW-2) and glacial tills (T-1)

McKeen (1992) has proposed an expansive soil classification methodology based on soil suction testing, which yields:

- a qualitative assessment of soil expansivity categorising the soils into five classes: nonexpansive, low, moderate, high and special case (very high);
- a quantitative prediction of heave corresponding to these categories, computed for given site and design conditions (Table 2).

The classification system is based on two relationships: 1) soil suction *versus* water content and 2) volume change *versus* soil suction (Fig. 3). On the basis of these two indices the expansive soils were classified and the heave of the considered soil layer may be calculated from equation:

$$\Delta H = C_h \cdot \Delta h \cdot \Delta t \cdot f \cdot s \qquad [2]$$

where: ΔH – heave (the vertical movement of the soil layer), C_h – suction compression index, Δh – suction change in the soil layer, Δt – thickness of the soil layer, f – lateral restraint factor $f = (1+2K_0)/3$; K_0 – coefficient of earth pressure at rest, s – coefficient of load effect on heave, $s = 1–[0.01 \cdot (\%SP)]$, for $\%SP \leq 50$, %SP being the percentage of swell pressure (SP) applied

The proposed methodology was adopted to predict the potential heave of Neogene clays and glacial tills from Poland with respect to the local soil and climatic characteristics. Therefore, the heave was computed using the following data and assumptions:

- C_h – average values were assumed from the measurements of the tested soil samples, Neogene clays: C_h = –0.101 ± 0.028; glacial tills: C_h = –0.018 ± 0.005.
- Δh – to take account of the most unfavourable conditions in the ground, the average of the maximum range of the suction change that can occur in the field (from 6 to 2 pF) was assumed: Δh = (6–2)/2 = 2 pF.
- Δt – thickness of the soil layer, corresponding to the depth to which moisture changes occur in the ground (active zone). In professional literature, various data are reported for clays, depending on climatic and environmental factors, as for example: Fityus et al. (2004) – about 2 m, Jones and Jefferson (2012) – about 3 m, Biddle (2001) – 1.5–2.0 m and McKeen (1992) – 1.5 m. For the purpose of this research, the depth of Δt = 1.5 m was assumed for the active zone in Neogene clays. In Poland this depth covers the zone of significant moisture-volume changes. However, according to Jeż (1995), in clay soils it might be extended up to 3.5 m due to water transpiration by tree roots. For glacial tills the accepted thickness of the active zone is Δt = 0.6 m (after Pisarczyk, 2001).
- K_0, f – four values of the coefficient of earth pressure at rest have been assumed to reflect various conditions in the ground; K_0 = 0.5; 1; 2; 2.5, which gives f = 0.67; 1.00; 1.67; 2.00 respectively.
- s – three values of the coefficient for load effect on heave have been assumed: s = 0.5; 0.7; 0.9, which illustrate the heave under loads corresponding to 50% SP, 30% SP and 10% SP, respectively.

By selecting adequate climate-induced variables and using data directly obtained in laboratory measurements, the estimation of potential heave is most likely to adequately reflect the local conditions.

Table 2

Expansive soil classification system (McKeen, 1992)

Category	C_h	$\Delta h/\Delta w$	ΔH* [m]	ΔH [%]	Remarks
I	–0.227	> –6	15.3	10.0	special case
II	–0.227 –0.120	–6 to –10	8.1	5.3	high
III	–0.120 –0.040	–10 to –13	2.7	1.8	moderate
IV	–0.040 nonexp.	–13 to –20	–	–	low
V	nonexp.	< –20	–	–	nonexp.

* – ΔH calculated for f = 0.5, Z_a = 1.5 m (5ft), Δh = 1.0 pF, s = 0.9

RESULTS AND DISCUSSION

Figures 4 and 5 illustrate the effect of clay content on the suction-water content index and suction compression index. In Figure 4, suction-water content index $\Delta h/\Delta w$ values are plotted against clay percentage. It is thus evident that soils with a lower clay content tend to have a lower suction-water content index. Samples T1-6 with the clay content as low as about 20% have the most negative values of this index (from –30.68 to –24.72). For Neogene clays – with the clay content exceeding 60% – the suction-water content index ranges from –15.43 to –8.65. The relationship between the suction compression index C_h and clay percentage (Fig. 5) shows a similar distribution of values – samples T1-6 are clearly separated from the samples of Neogene clays. With the increase of clay content, the suction compression index C_h values decrease, which indicates that soils become more sensitive to the change in water content and volume with respect to suction.

Figure 6 shows plots of the suction-water content index *versus* suction compression index C_h. The relationship obtained by the present authors has the form of C_h = [–0.0053*($\Delta h/\Delta w$)]–0.1628 at R^2 = 0.8456 and generally agrees with the relationship reported by McKeen (1992). Tills have more negative $\Delta h/\Delta w$ values while the suction compression index C_h approaching zero. Such soils show insignificant changes of volume related to suction changes. Clays, in turn, exhibit lower (more negative) values of C_h as $\Delta h/\Delta w$ approaches 0. Such soils are expected to exhibit considerable changes in volume due to changes in soil suction.

Table 3 shows the comparative results of expansivity obtained for glacial tills and Neogene clays using different methods. Results according to classification systems by Seed et al. (1962), van der Merwe (1964), IS 1498 (1970), Chen (1975), Yilmaz (2006), Yukselen and Kaya (2008) are presented along with the systems based on suction parameters: USAEWES (Snethen et al., 1977) and McKeen (1992). Such an approach adds considerably to the characteristics of the soils examined and provides a more comprehensive evaluation of soil expansivity. Results from Table 3 have revealed that the considered classification methodologies provide consistent expansion ratings for glacial tills and conflicting ones for samples of Neogene clays. Classifications by van der Merwe (1964), IS 1498 (1970) and Chen (1975) based on Atterberg limits and related parameters, assign a very high degree of expansivity, whereas the Seed et al. (1962), Yilmaz (2006) and Yukselen and Kaya (2008), systems, which consider soil mineralogy indicators, predict a high and a very high degree of expansivity. This confirms the findings of the present authors from their previous studies

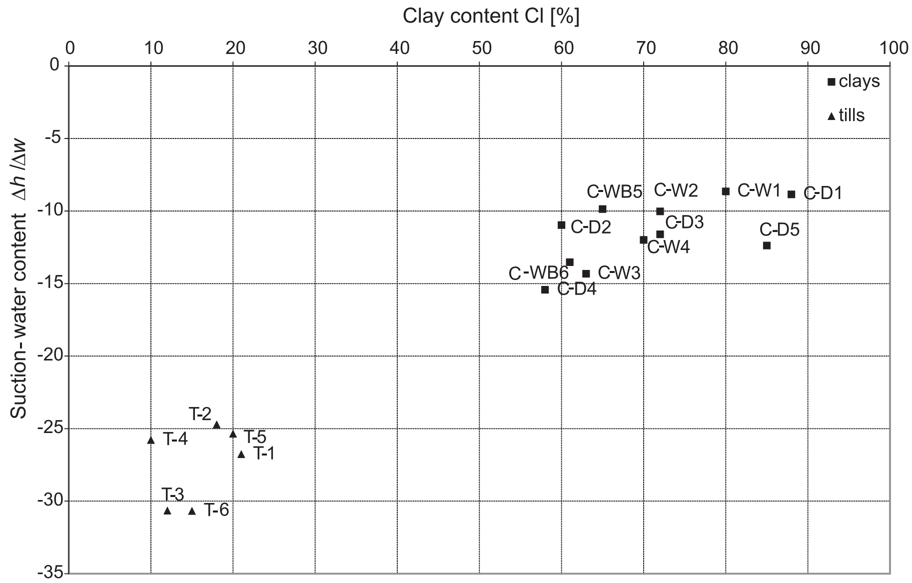


Fig. 4. Suction-water content index *versus* clay content

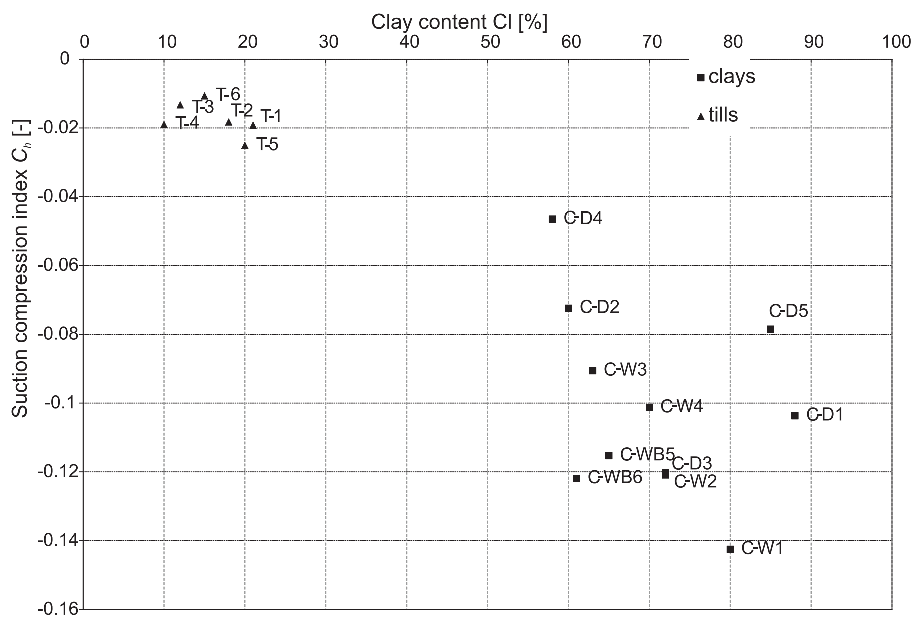


Fig. 5. Suction compression index *versus* clay content

(Izdebska-Mucha and Wójcik, 2014). According to the USAEWES (Snethen et al., 1977) classification, Neogene clays were identified as showing a high degree of expansion while high to low values have been revealed by the McKeen (1992) system. Similar results are reported by Sawangsuriya et al. (2011), who, applying different classification systems, confirmed that the lowest expansivity classes were obtained from the McKeen system (1992).

Figure 7 illustrates the evaluation of the potential expansivity of soils based on *in situ* moisture content and soil suction measurements (filter paper technique according to ASTM D 5298-94, filter paper Whatman no. 42) plotted on the classification system proposed by McKeen (1992). The results corroborate the conclusions from Table 3 and show that tills should be classified into category V – nonexpansive soils, while the expansivity of Neogene clays varies from high to low. Depending on their expansivity class, the considered clays should be given due attention. For example, in case of highly expansive soils, the effects of volume change can be mitigated by very careful assessment of environmental factors. For the low degree of expansivity, a behaviour typical of expansive soils is not expected, therefore special consideration of shrink/swell behaviour is not required.

Figure 8 presents the calculations of the potential field heave of Neogene clays and glacial tills. For each soil, 12 variants have been computed with regard to different values of the load effect on heave (s) and the coefficient of earth pressure at rest (K_0). It has been found that the amount of potential heave increases with the increase of the coefficient of earth pressure at rest ($K_0 = 0.5 \rightarrow K_0 = 2.5$) and the decrease of the applied load ($s = 0.5 \rightarrow s = 0.9$). For the assumed variables, the heave of Neogene clays may vary within a wide range from 10 to

Table 3

Prediction of potential expansivity of Neogene clays and glacial tills by various classification systems

Soil No.	Soil type	Location	Sample ID	Soil parameters			Classifications							
				Clay content CI [%]	Liquid limit LL [%]	Plasticity index PI [%]	Chen (1975)	IS 1498 (1970)	van der Merwe (1964)	Seed at al. (1962)	Yukselen and Kaya (2008)	Yilmaz (2006)	USAEWES (1977)	McKeen (1992)
1	Neogene clays	Warszawa	C-W1	80.0	96.0	55.0	VH	VH	VH	VH	VH	VH	H	H
2			C-W2	72.0	83.0	48.0	VH	VH	VH	VH	VH	VH	H	H
3			C-W3	63.0	69.5	47.0	VH	VH	VH	VH	H	H	H	L
4			C-W4	70.0	70.1	39.0	VH	VH	VH	VH	H	H	H	M
5			C-WB5	65.0	99.0	66.7	VH	VH	VH	VH	VH	VH	H	M
6			C-WB6	61.0	64.4	39.0	VH	VH	VH	H	H	H	H	L
7		Dobre	C-D1	88.0	71.1	40.2	VH	VH	L	H	H	H	H	M
8			C-D2	60.0	69.6	45.9	VH	VH	VH	VH	H	H	H	M
9			C-D3	72.0	82.5	50.8	VH	VH	VH	VH	H	VH	H	M
10			C-D4	58.0	76.9	49.5	VH	VH	VH	VH	H	H	H	L
11			C-D5	85.0	111.9	73.4	VH	VH	VH	VH	H	VH	H	M
12	Glacial tills	Warta Glaciation	T1	21.0	20.6	8.6	L	L	L	L	L	L	L	N
13			T2	18.0	19.3	5.6	L	L	L	L	L	L	L	N
14			T3	12.0	23.0	10.5	L	L	L	L	L	L	L	N
15			T4	10.0	19.1	6.7	L	L	L	L	L	L	L	N
16		Odra Glaciation	T5	20.0	22.3	11.2	L	L	L	L	L	L	L	N
17			T6	15.0	24.4	13.0	L	L	L	L	L	L	L	N

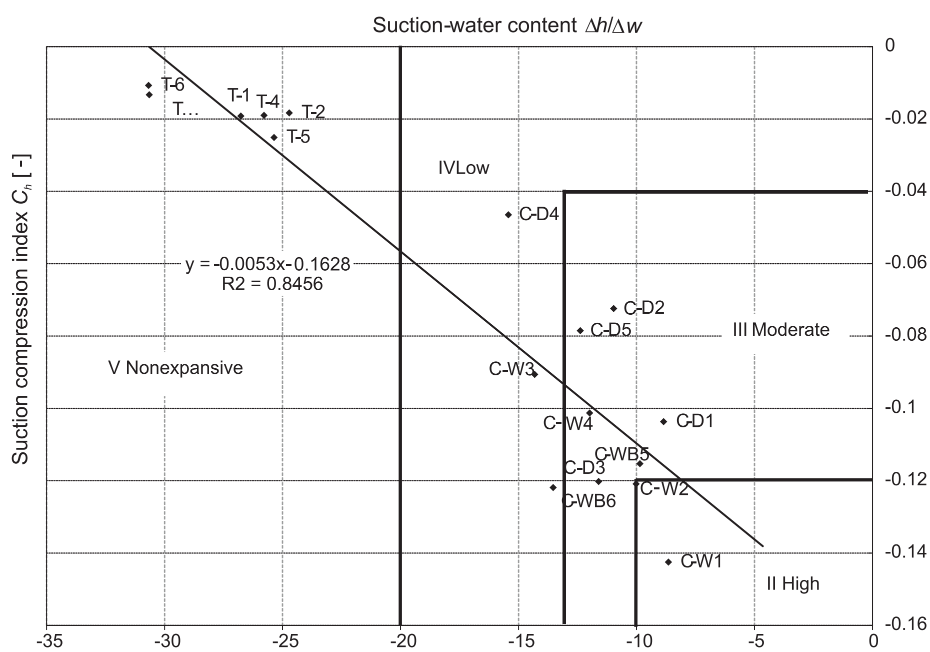


Fig. 6. Suction compression index (C_h) *versus* suction-water content index ($\Delta h/\Delta w$) with McKeen (1992) classification of expansive soils

55 cm, whereas for glacial tills the values change between 0.7 to 3.8 cm. These estimates indicate that a serious vertical movement may occur at the top 1.5 m of clays in response to an average suction change of 2 pF. For glacial tills, the results agree well with the aforementioned classifications and indicate their very low sensibility to suction changes in terms of their potential to volume change.

In order to provide a rational estimation of the studied soils behaviour based on the findings presented in Figure 8, specialists should take into consideration the specific site and design features. One of the important factors in estimation of heave is the coefficient of earth pressure at rest – a parameter strictly related to stress conditions in a soil. According to Szczepański (2007), soil preconsolidation is a total effect of mechanical preconsolidation (glacier pressure, overburden pressure, water

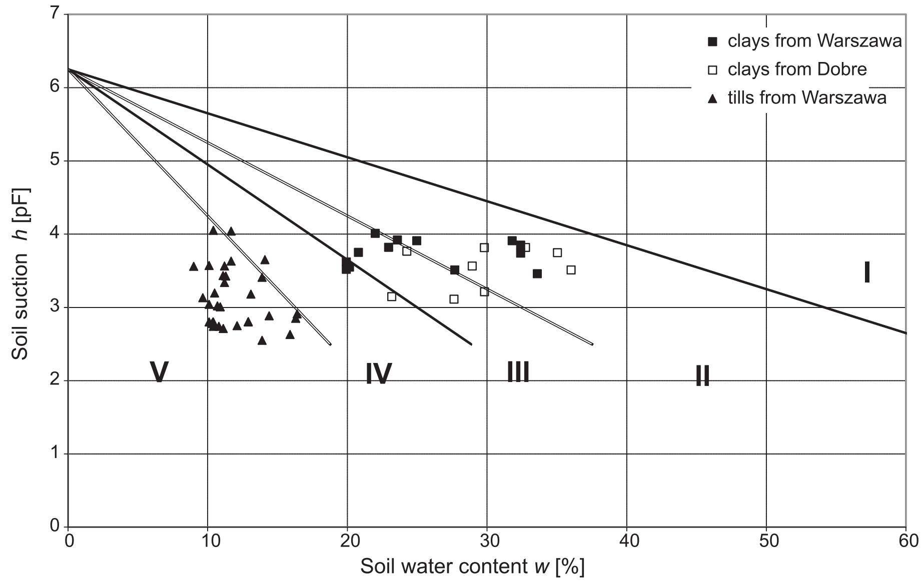


Fig. 7. Potential expansivity of Neogene clays and glacial tills on the McKeen (1992) classification chart

I – special case, II – high, III – moderate, IV – low, V – nonexpansive

table fluctuations) as well as apparent preconsolidation (ageing effect, structural strengthening) resulting from processes such as cementation, recrystallisation of minerals, changes of pore water chemistry and others. Both soils considered in this study are overconsolidated due to glaciations history, which points to K_0 > 1. Data reported by Barański et al. (2004) indicate that the average value of K_0 of Neogene clays from Warszawa is 1.1, as determined by several field methods. Recent field monitoring of K_0 in the polygon Warszawa Stegny yielded values of K_0 = 1.5 (Barański, pers. comm., 2014). In the case of the glacial tills occurring in the edge zone of the glacial till plain (polygons 5 and 6), the ageing processes might be of particular importance. According to Kaczyński et al. (2010), who studied the geological engineering properties of glacial tills of the Warta and Odra glaciations from the area of Warszawa, compared to typical glacial tills from other sites in Warszawa, the tills from the Służew area exhibit a higher consolidation manifested by low values of porosity, moisture content and degree of saturation and a high consistency index. *In situ* cone penetrometer testing (CPT) revealed the average value of K_0 for tills to be K_0 = 2.4 (Kaczyński et al., 2008). Another important factor in heave estimation is the applied load, which restrains the soil swelling. This effect is expressed in terms of a percentage of swell pressure removed, and represented by the coefficient s in heave computations. As reported by Barański and Wójcik (2007), the average swelling pressure of the tested clays was 200 kPa. Therefore, the assumed *s* values = 0.5; 0.7; 0.9 correspond to the applied loads of 100, 60 and 20 kPa, respectively. The swelling pressure of the tested tills is very low and does not exceed 15 kPa (Kaczyński et al., 2010), which points to the lowest values of s as the most rational in heave estimation of this type of soil.

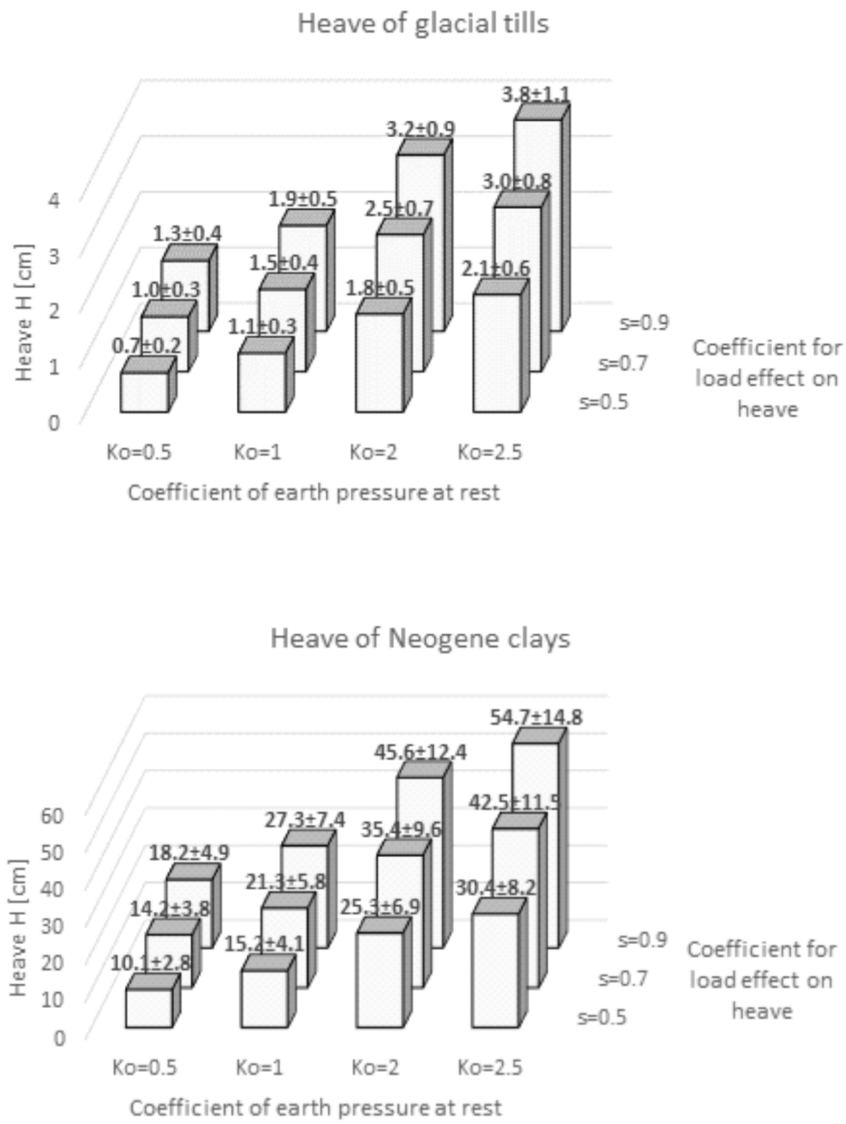
SUMMARY

Expansive soils are those which exhibit significant volume changes due to changes in water content. Various classification systems have been developed over the past decades to evaluate soil expansivity. With this respect, suction is considered to be a more definitive and reliable measure of potential expansion than the index soil properties. This paper discusses:

– the characteristics of suction of Neogene clays and glacial tills from six different locations in central Poland;
– the comparison of expansivity of the soils based on suction and index properties of soil;
– the estimate of heave calculated according to the method of McKeen (1992). This method was adopted to reflect Polish conditions by using the assumptions that correspond to local environmental, site and design conditions along with the actual suction-volume change measurements of the studied soils.

A thorough analysis of the effect of the clay content on the suction-water content index $\Delta h/\Delta w$ (Fig. 4) shows that the suction-water content index of soils with a low clay content has less negative values. However, the lower the clay content, the higher (less negative) the suction compression index C_h (Fig. 5). A strong linear relationship between the suction-water content index and the suction compression index has been found, expressed by the formula: C_h = [–0.0053*($\Delta h/\Delta w$)]–0.1628 (Fig. 6). This relationship reflects the correlation between changes in moisture content, suction and volume in soils. The results obtained and the distribution of data in charts 4 to 6 clearly point to a strong soil volume response to suction changes in the case of highly plastic soils with high clay content, such as Neogene clays, and a weak one in the case of glacial tills.

The comparison of soil expansivity obtained from different classification methods, based on index properties of soils and suction (Table 3), has revealed that they provide consistent expansivity ratings for glacial tills – referred to as low degree of expansivity or nonexpansive, and conflicting ratings for Neogene clays. However, the suction-based systems (USAEWES, Snethen et al., 1977; McKeen, 1992), yield the lowest ratings for clays – from high to low degree of expansion. The conclusion on the variability of the potential expansivity of Neogene clays has been additionally confirmed by numerous tests of the *in situ* soil suction (filter paper method) and moisture content, plotted on the McKeen (1992) classification chart (Fig. 7).



Assumptions for heave computations $\Delta H = C_h \, \Delta h \, \Delta t \, f \, s$		
	Value	Comments
C_h	Clays: -0.101±0.028	Measured values,
	Tills: -0.018±0.005	see Fig. 5
Δh	2 pF	Average of the maximum suction change in the field
Δt	Clays: 1.5 m	Typical value assumed
	Tills: 0.6 m	Pisarczyk (2001)
f	0.67; 1.00; 1.67; 2.00	Calculated for K_0: 0.5;1; 2; 2.5
s	0.5; 0.7; 0.9	Swell pressure removed: 50%; 30%; 10%

Fig. 8 Prediction of potential field heave of Neogene clays and glacial tills

The potential field heave of Neogene clays and glacial tills has been computed with regard to different values of load effect on heave (s = 0.5–0.9) and coefficient of earth pressure at rest (K_0 = 0.5–2.5). For the assumed variables, the heave of Neogene clays may vary within a wide range, whereas for glacial tills, the values range between 0.7 to 3.8 cm (Fig. 8). In order to provide a rational estimation of expansive soil behaviour based on these findings, geotechnical engineers should take into consideration the specific site and design features.

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