Geological Quarterly, 2014, **58** (2): 281–290
DOI: http://dx.doi.org/10.7306/gq.1151

Expansivity of Neogene clays and glacial tills from central Poland

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Izdebska-Mucha, D., Wójcik, E., 2014. Expansivity of Neogene clays and glacial tills from central Poland. Geological Quarterly, **58** (2): 281–290, doi: 10.7306/gq.1151

The revision of classification methodologies for determination of soil expansivity revealed that parameters most frequently used for this purpose are: the liquid limit, plasticity index and swelling parameters which also predominate in older systems of expansive soil assessment, regarded as classical. Seventy-nine soil samples, including Neogene clays and glaciall tills from central Poland, with a wide range of plasticity were examined for a comparative analysis of soil expansivity with a use of eight empirical methods. The study revealed that Neogene clays are mostly highly and very highly expansive, while glacial tills exhibit low to medium expansivity. Compared to classifications considering soil mineralogy indicators, those correlated solely to Atterberg limits and related parameters were found to overestimate soil expansivity. It is evident that the classifications are in better agreement for glacial tills than for clays. The comparison of mineral composition measured and predicted from swelling tests yielded consistent results.

Key words: expansive soil, Neogene clays, glacial tills, index parameters.

INTRODUCTION

The recognition of soil properties is a key step to be taken in site investigations, foundation design and spatial planning. The characteristics of soil expressed as values of the specific parameters, and the assessment of geologic conditions are never unquestionable, but charged with uncertainty resulting from three crucial factors: the random nature of the environment, inadequate recognition of its properties and incompleteness of data (Staveren, 2006) As indicated by Hauryłkiewicz (2005), feasible errors (likely to be made) are important, too.

Nowadays, numerous procedures of soil identification are available, including those for expansive soils. This is a vital issue, as much as it applies to practically all geographical sites worldwide. Over the years, numerous direct and indirect methodologies for the assessment of expansive soil properties have been offered. Described in professional literature, they are based on different parameters and show a substantial diversity. Is, therefore, expansivity assessment always reliable? Will classifications based on different indexes convincingly assess the expansivity of the soils examined? The present paper is an attempt at answering this question based on a case study of some expansive soils of Poland.

The highly swelling soils of Poland are represented by Neogene clays, commonly known as clays of the Poznań Formation, Miocene clays of the Carpathian Foredeep and Oligocene clays known from central and NW Poland (Kaczyński and Grabowska-Olszewska, 1997). The Quaternary glacial tills and varved clays of central Poland are generally believed not to pose hazards to building objects (ITB 296, 1990). Nevertheless, in order to check the consistency of expansivity classifications for soils of a wide plasticity range, the present studies included both Neogene clays and glacial tills (Fig. 1).

METHODOLOGY

According to O'Neill and Poormonyed (1980), the methodology for foundation design on an expansive clay site requires four steps:

1. Preliminary identification of the soil.
2. Classification of soil expansivity.
3. Quantification – measurements of probable volume changes if sufficiently expansive soils were stated in step 2:
   a. evaluation of design alternatives.

Categorizing expansive soils – step 2 – is an attempt to assess their probable engineering behaviour and to define the range of further investigations.

Over many decades, several parameters were introduced into the classifications of expansive soils, permitting to classify them into three to five expansivity classes. These parameters are listed in Table 1, which also gives a fair review of professional literature on a wide spectrum of expansivity problems. These classifications are based on one (the so called single index method, e.g., Chen, 1975) to eight different parameters at the maximum (e.g., Niedzielski et al., 1988). Some classifica-

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Received: October 15, 2013; accepted: January 28, 2014; first published online: February 20, 2014

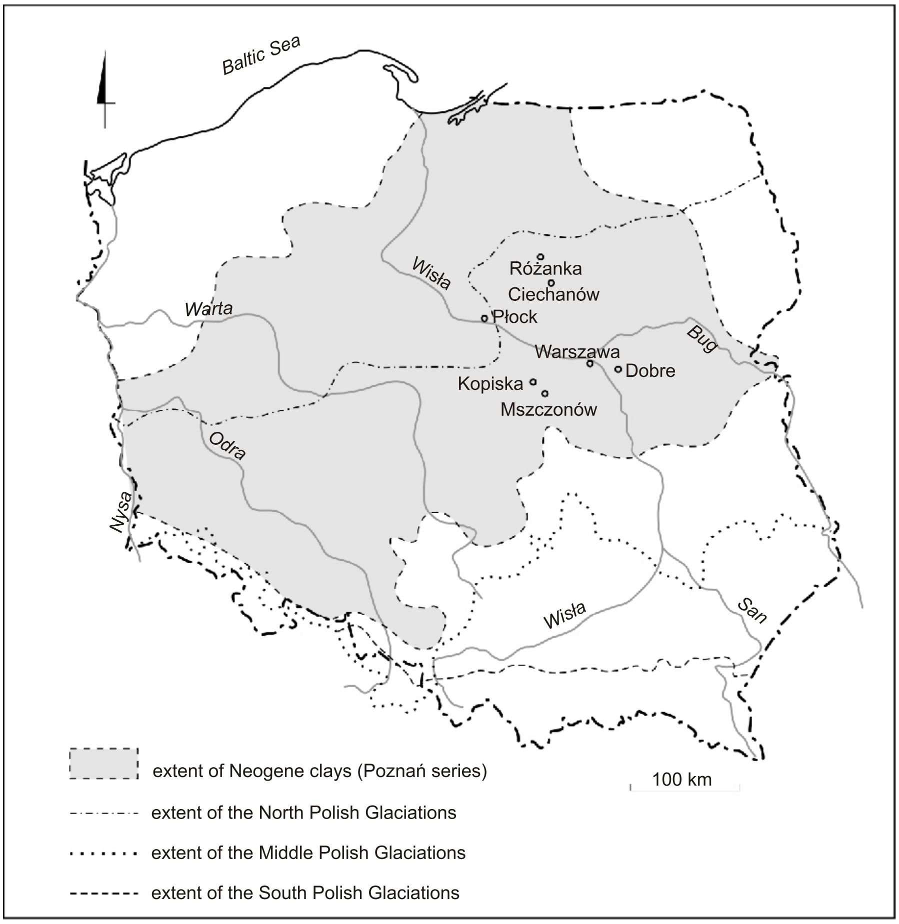

Fig. 1. Location of sampling sites

tions duplicate the criteria known previously, others introduce new factors. Out of the 35 parameters listed in Table 1, 18 appear only once. The frequency of occurrence of other parameters is given in Figure 2. Unquestionably, the most common parameters used for expansivity assessment are as follows: the liquid limit, plasticity index and swelling parameters.

Among a number of classifications developed in different locations (Table 1), eight systems were chosen to evaluate expansivity of the studied Neogene clays and glacial tills. These systems (Seed et al., 1962; Merwe, 1964; IS 1498, 1970; Chen, 1975; Sridharan and Prakash, 2000; Yilmaz, 2006; Yukselen and Kaya, 2008; International Residential Code, 2012) are based on basic soil properties, including Atterberg limits and particle size distribution, along with quick, simple and economic sorption and swelling tests, which in turn are indicative of soil mineralogy.

MATERIAL

The selected soils, widespread in Poland, are the building foundation for many engineering objects. The location of sampling sites is shown in Figure 1. The total number of the samples examined included 54 clays and 25 glacial tills. The following soil parameters were defined: clay content (Cl), liquid limit (LL), plastic limit (PL), plasticity index (PI), activity (A), methylene blue value (MBV), specific surface area (SSA) and cation exchange capacity (CEC). In addition, the mineral composition of soils was determined and free swelling tests in water and kerosene were completed. Further, these parameters served to define the expansivity of the soils. The data presented herein are derived from the experiments carried out as part of several research projects, carried out in the Department of Engineering Geology, Faculty of Geology, University of Warsaw, over the past few years.

Figure 3 and Table 2 summarize the results of expansive soil classification according to empirical methodologies. It should be added that due to a limited database on free swelling tests in water and kerosene, which are used in Sridharan and Prakash (2000) system, only 7 out of 25 till samples and 20 out of 54 clay samples were rated by this method (Table 2).

INTERPRETATION AND DISCUSSION

The comparison of Neogene clays expansivity according to various evaluation systems (Fig. 3A) revealed substantially divergent results. Nevertheless, two groups of values can be clearly distinguished. Classifications by Chen (1975), IS 1498 (1970) and Merwe (1964), which are based on LL, PI and Cl, assigned a very high degree of expansivity in 74–80% of cases, whereas the Seed et al. (1962), Yilmaz (2006) and Yukselen and Kaya (2008) systems, correlated to A, Cl, LL, MBV and CEC, predicted a high and a very high degree of expansivity in 52–78% and 11–35% of cases, respectively. Evidently, the first group of classification systems, correlated solely to Atterberg

Table 1

Summary of criteria for identifying expansive

Reference		Criteria
1	Altmeyer (1955)	1. Shrinkage limit SL [%] 2. Linear shrinkage L_s [%]
2	Bruyn et al. (1957)	1. Specific surface area SSA [m^2g^{-1}] 2. w_H – percent moisture (at 85% relative humidity)
3	Holtz (1959)	1. Percent of clay <0.001 mm [%] 2. Plasticity index PI [%] 3. Shrinkage limit SL [%] 4. Swell index $_p$ [%] based on loading of 6.9 kPa
4	Ladd and Lambe (1961)	1. Free swell index $_p$ [%] 2. Plasticity index PI [%] 3. Hygroscopic moisture w_{100} 4. Percent volume change resulting from drying a structured sample from Field Moisture Equivalent to the shrinkage limit V_{SL} 5. Potential of swell PVC [-]
5	Seed et al. (1962)	1. Activity A 2. Percent of clay <0.002 mm [%] 3. Swelling potential PVC [%]
6	Van der Merwe (1964)	1. Plasticity index PI [%] 2. Percent of clay <0.002 mm [%]
7	Rangantham and Satanarayana (1965)	1. Shrinkage index LL-SL [%]
8	Raman (1967)	1. Shrinkage index LL-SL [%] 2. Plasticity index PI [%]
9	Uniform Building Code (1968)	1. Percent swell 2. Fraction passing no. 4 sieve (4.75 mm)
10	Sowers and Sowers (1970)	1. Plasticity index PI [%] 2. Shrinkage limit SL [%]
11	IS 1498 (1970)	1. Liquid limit LL [%] 2. Plasticity index PI [%]
12	Dakshanamurthy and Raman (1973)	Based on plasticity chart: 1. Liquid limit LL [%] 2. Plasticity index PI [%]
13	Olson (1973)	1. Swell index $_p$ [-]
14	Sorochan (1974)	1. Swell index $_p$ [-]
15	Chen (1975)	1. Plasticity index PI [%]
16	Chen (1975)	1. Percent of particles <0.074 mm [%] 2. Liquid limit LL [%] 3. Results of SPT (standard penetration resistance, blows 30 cm) 4. Swell index $_p$ [%] 5. Swelling pressure P_c [kPa]
17	Johnson and Snethen (1978)	1. Liquid limit LL [%] 2. Plasticity index PI [%] 3. Swell index $_p$ [%] 4. Natural soil suction $_s$ [kPa]
18	Schuler and Goedecke (1982)	1. Plasticity index PI [%] 2. Liquid limit LL [%] 3. Percent of clay <0.002 mm[%] 4. Free swell index FS [%] from United States Bureau of Reclamation (USBR) 5. Swell index $_p$ [%] 6. Swelling pressure P_c [kPa]
19	Snethen (1984)	1. Liquid limit LL [%] 2. Plasticity index PI [%] 3. Swell potential 4. Natural soil suction $_{nat}$ [kPa]
20	Stomatopoulus and Kotzias (1987)	1. Swell index $_{FS}$
21	Tountoungi (1988)	1. Plasticity index PI [%] 2. Shrinkage limit SL [%] 3. Free swell index $_p$ [%]

Tabl. 1 cont.

Reference		Criteria
22	Niedzielski et al. (1988)	1. Percent of clay <0.002 mm [%] 2. Liquid limit LL [%] 3. Plasticity index PI [%] 4. Shrinkage index LL-SL [%] 5. Maximum hygroscopicity MH [%] 6. Specific surface area SSA [m^2g^{-1}] 7. Free swell index $_p$ [%] 8. Swelling pressure p_c [MPa]
23	McKeen (1992)	1. Water content w [%] 2. Suction (pF)
24	Parker et al. (1997)	1. Percent of clay <0.002 mm [%] 2. COLE (coefficient of linear extensibility) [%]
25	Sridharan and Prakash (2000)	1. Free swell ratio FSR
26	Yilmaz (2006)	1. Liquid limit LL [%] 2. Cation exchange capacity CEC (meq/100g)
27	Yukselen and Kaya (2008)	1. Methylene blue value MBV [g/100g]
28	IRC (2012)	Based on Unified Soil Classification System (USCS): 1. Liquid limit LL [%] 2. Plasticity index PI [%] 3. Grain size distribution (Sa, Gr, <0.075 mm) 4. Uniformity coefficient C_u 5. Coefficient of curvature C_c

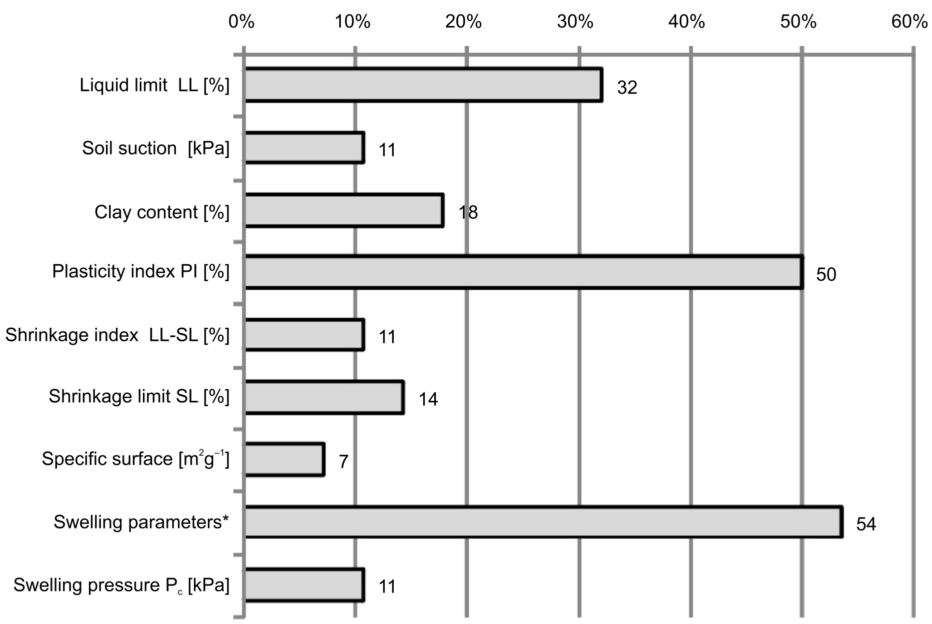

Fig. 2. The proportion (in %) of parameters most frequently used in 28 expansive soil classifications

* Swelling parameters: swell index, free swell index, free swell ratio, swelling potential

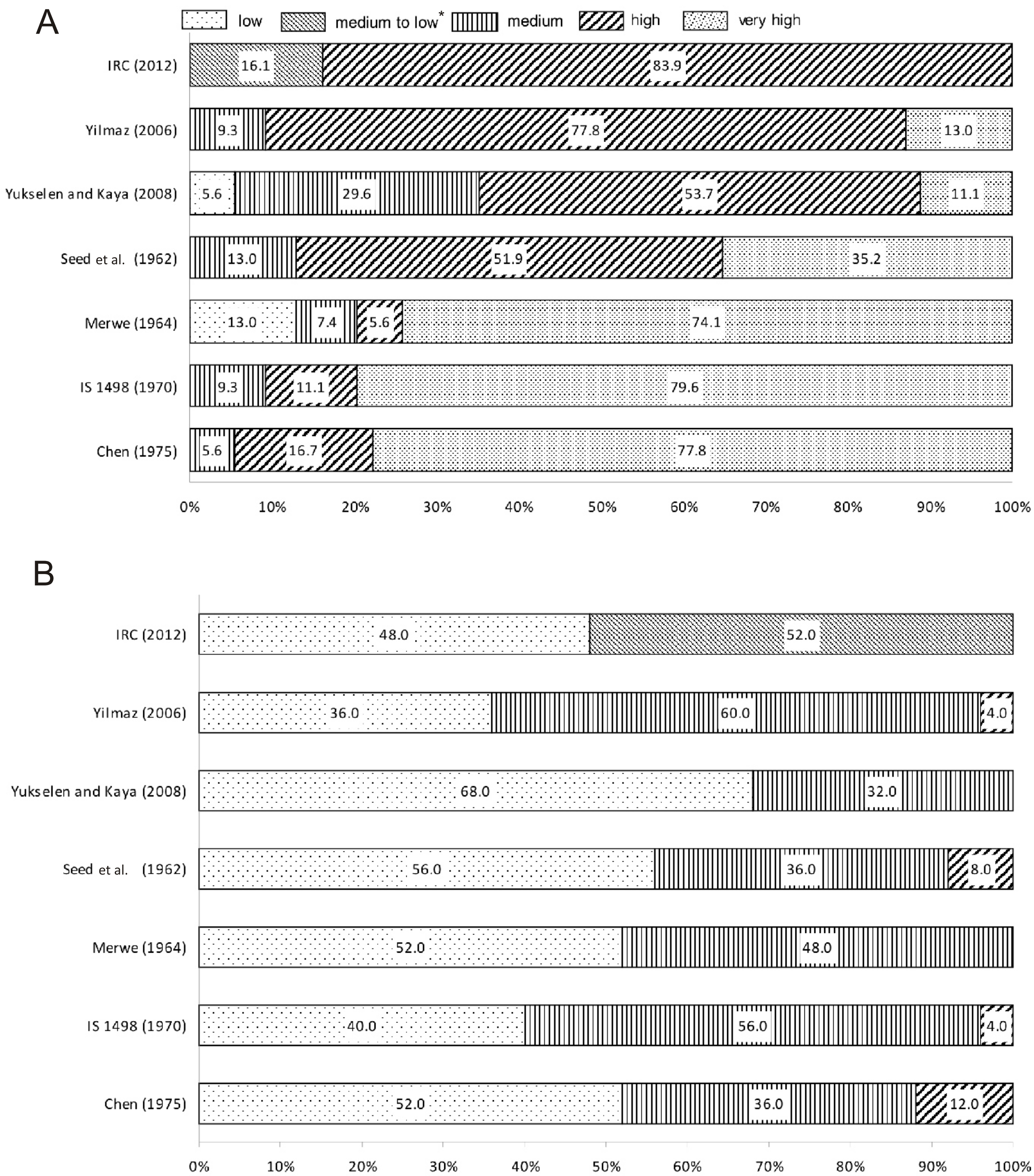

Fig. 3. Prediction of expansivity in various classifications

A – Neogene clays, B – glacial tills; * in IRC (2012) system only

Table 2

Comparison of the expansivity of the studied soils by various classifications

Soil no.	Soil type	Location	Soil parameters			Classifications							
			Clay content Cl [%]	Liquid limit LL [%]	Plasticity index PI [%]	Chen (1975)	IS 1498 (1970)	Merwe (1964)	Seed et al. (1962)	Yukselen and Kaya (2008)	Yilmaz (2006)	Sridharan and Prakash (2000)	IRC (2012)
1	Neo-gene clays	Dobre	88.0	71.1	40.2	VH	VH	L	H	H	H	M	H
2			60.0	69.6	45.9	VH	VH	VH	VH	H	H	M	H
3			72.0	82.5	50.8	VH	VH	VH	VH	H	VH	H	H
4			58.0	76.9	49.5	VH	VH	VH	VH	H	H	M	H
5			57.0	70.9	47.8	VH	VH	VH	VH	VH	H	H	H
6			85.0	111.9	73.4	VH	VH	VH	VH	H	VH	M	H
7		Warszawa	68.0	81.0	39.9	VH	VH	VH	H	H	H	H	H
8			63.0	77.2	40.3	VH	VH	VH	H	H	H	M	H
9			31.0	48.0	23.4	H	H	M	M	M	H	L	M to L
10			33.0	45.2	21.1	H	M	M	M	M	H	L	M to L
11			47.0	54.8	34.9	H	VH	VH	H	M	H	M	H
12			33.0	42.7	23.4	H	H	M	M	M	M	L	M to L
13			82.0	85.2	43.7	VH	VH	VH	VH	VH	VH	H	H
14			38.0	47.9	27.1	H	H	H	H	M	H	M	M to L
15			29.0	39.8	20.3	M	M	M	M	M	M	M	M to L
16			66.0	68.4	41.0	VH	VH	VH	VH	H	H	H	H
17			81.0	72.5	43.5	VH	VH	VH	VH	H	H	H	H
18			64.0	68.9	38.8	VH	VH	VH	H	H	H	M	H
19			40.0	75.8	44.6	VH	VH	VH	H	L	H	L	H
20			88.0	64.2	30.0	VH	H	L	H	VH	H	H	H
21	Gla-cial tills	Różanka	22.4	21.4	11.0	L	L	L	L	L	L	L	L
22			20.1	19.5	9.1	L	L	L	L	L	L	L	L
23			20.5	20.7	10.4	L	L	L	L	L	L	L	L
24			22.4	20.8	10.2	L	L	L	L	L	L	L	L
25		Kopiska	16.4	25.4	14.1	L	M	M	L	L	M	L	L
26			17.9	27.0	12.0	L	M	L	L	L	M	L	L
27			14.1	24.4	10.5	L	L	L	L	L	L	L	L

Soil expansivity: L – low, M to L – medium to low (only in IRC, 2012), M – medium, H – high, VH – very high

limits and related parameters, yields overestimated soil expansivity in comparison with those considering also soil mineralogy indicators. Sridharan and Prakash (2000) suggested that without considering soil mineralogy, the liquid limit and related parameters do not properly define the soil expansivity due to different mechanisms controlling the liquid limit of kaolinite and montmorillonite.

In the case of glacial tills (Fig. 3B), all classifications are in better agreement than in the case of clays, which might be attributed to a more uniform composition of the till samples in terms of clay content and mineralogy. It is worth noticing that the best matching systems are by Chen (1975), Seed et al. (1962) and IS 1498 (1970). They indicated a low, medium and high degree of expansion in 40–56, 36–56 and 4–12% of cases, respectively. These ratings are again higher than those yielded by the Yukselen and Kaya (2008) system.

Results from the IRC (2012) classification tend to agree with the lower ratings, however, due to a slightly different class system (i.e., low, medium to low, medium, high), an exact comparison with the rest of the systems is not possible.

Table 2 presents the comparison of the expansivity of the selected clay and till samples, obtained from the method given by Sridharan and Prakash (2000) in addition to the classifications shown in Figure 3. The above-mentioned method is based on the value of free swell ratio (FSR), which stands for the ratio of equilibrium sediment volume of 10 g oven-dried soil passing a 425 μm sieve in distilled water (V_d) to that in kerosene (V_k). Data presented in Table 2 indicate that in the case of Neogene clays the Sridharan and Prakash (2000) classification tends to be in line with the Seed et al. (1962), Yukselen and Kaya (2008), Yilmaz (2006) and IRC (2012) systems. Furthermore, in about 50% of the clay cases, it yielded yet one degree lower expansion rating than the other ones. For glacial tills, all classification systems provided fairly consistent expansion ratings.

The analysis of the aforementioned results with respect to soil index properties (Table 2) leads to the conclusion that while evaluation of the soils containing <30% of clay fraction by various criteria was in a relatively good agreement, classification of the other soils provided conflict expansion ratings for particular samples. Therefore, with respect to the genetic type of soils, an inconsistency of expansivity assessment is to be expected for Neogene clays, while a good agreement of results can be obtained for glacial tills.

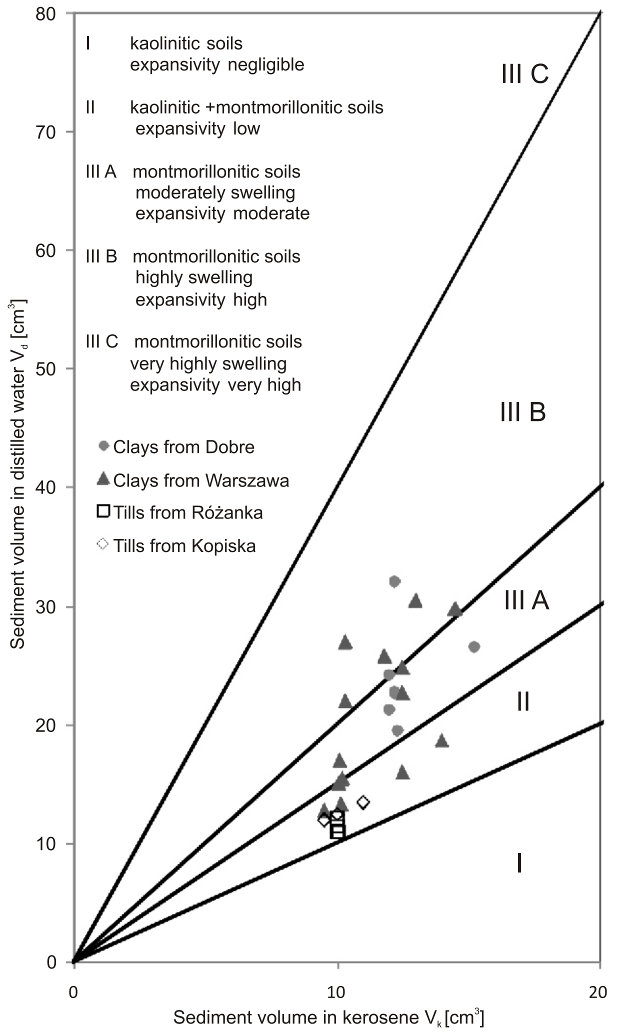

Fig. 4. Identification of swelling degree and dominant clay mineral of the soils examined on the Prakash and Sridharan's (2004) chart

The free swell ratio was later proposed by Prakash and Sridharan (2004) also as a criterion for predicting the soil mineralogy. The results of FSR measurements plotted on a classification chart (Fig. 4) provided information not only on swelling and expansion degree but also on the approximate soil mineralogy, indicating the dominant clay mineral. The predicted FSR-based mineralogy is presented in Table 3 along with the actual composition obtained from differential thermal analysis (DTA) or X-ray diffractometer (XRD).

For glacial tills, which are typically polimineral soils containing smectites, illite and kaolinite, the classification reasonably indicated a mixture of swelling and non-swelling minerals. For Neogene clays, the results that based on empirical approach and laboratory tests also matched very closely. In a few cases though, the assessment of swelling degree is questionable and the values seem to be underrated (Table 3, positions 1, 2, 6 and 18). Altogether, the tested method proved to accurately estimate clay mineralogy of soils and can be applied in engineering practice to predict it by means of quick, simple and low-cost swelling tests. In addition, whenever full laboratory facilities are not available and results of lower accuracy are acceptable, the test can be useful as the on-site procedure.

SUMMARY

Expansive soils, widespread all over the world including Poland, are a common building foundation. Classification of expansive soils is a very important step in foundation design. Empirical methods should be regarded as simple indicator methods, nevertheless they are the first step to decide whether expansive soils exist and if further laboratory tests need to be taken to quantify potential vertical movements.

Revision of classification methodologies for determination of expansivity revealed the liquid limit, plasticity index and swelling parameters to be the most frequently used criteria for a qualitative definition of expansivity.

Eight classifications compared in the course of the present studies provided fairly satisfactory results for glacial tills, while values for Neogene clays proved rather divergent. Majority of Neogene clays exhibited either high or very high expansivity, while glacial tills low to medium degree. The analysis revealed that the classifications based on liquid limit, plasticity index and clay content tend to overestimate soil expansivity, as compared with those considering soil mineralogy indicators. As regards the classification systems considered herein, the lowest values were provided by the Sridharan and Prakash (2000) system.

The free swell ratio method gives information about soil expansivity and nature of clay mineralogy. For the soils examined, the empirical approach and laboratory tests (DTA or XRD analysis) matched very closely. Thus, this method can be successfully used in engineering geological practice to predict mineralogy of expansive soils when a result of lower accuracy is acceptable.

With respect to the genetic type of soils, an inconsistency of expansivity assessment might be expected for Neogene clays, while a good agreement of results can be obtained for glacial tills.

The empirical classification methods reviewed in this study do not take into account *in situ* conditions (e.g., moisture content, soil suction, soil structure, soil heterogeneity, climate) which are the very important factors influencing soil expansion and crucial for its proper evaluation. Bell and Maud (1995) suggested carrying out suction or oedometer tests in addition to empirical assessment of potential expansivity of the soil. Additional tests based on suction measurements of the soils discussed in this study are underway in order to provide an alternative technique to classify the expansive soils in Poland.

Acknowledgements. The authors are grateful to two anonymous reviewers and Prof. T.M. Peryt for the revision and valuable comments that significantly improved the manuscript.

Table 3

Comparison of dominant clay minerals obtained from laboratory analysis and free swell ratio classification

Soil no.	Soil type	Location	Free swell ratio FSR [-]	Dominant clay mineral(s)	
				Predicted from FSR (Fig. 4)	Determined from DTA[1] or XRD[2] analysis
1	Neogene clays	Dobre	1.86	montmorillonitic soils moderately swelling	[1]S:82%; K:8%
2			1.74	montmorillonitic soils moderately swelling	[1]S:51%; K:9%
3			2.02	montmorillonitic soils highly swelling	[1]S:71%; K:4%
4			1.59	montmorillonitic soils moderately swelling	[1]S:43%; K:14%
5			2.62	montmorillonitic soils highly swelling	[1]S:47%; K:10%
6			1.77	montmorillonitic soils moderately swelling	[1]S:69%; K:17%
7	Neogene clays	Warszawa	2.06	montmorillonitic soils highly swelling	[1]S:60%; K:15%
8			1.98	montmorillonitic soils moderately swelling	[1]S:51%; K:14%
9			1.28	kaolinitic+montmorillonitic soils	[1]S:27%; K:8%
10			1.34	kaolinitic+montmorillonitic soils	[1]S:42%; K:7%
11			1.68	montmorillonitic soils moderately swelling	[2]S>I.K
12			1.31	kaolinitic+montmorillonitic soils	[2]S>I, K
13			2.62	montmorillonitic soils highly swelling	[2]S>I,K
14			1.52	montmorillonitic soils moderately swelling	[2]S>I,K
15			1.50	montmorillonitic soils moderately swelling	[2]S>I,K
16			2.13	montmorillonitic soils highly swelling	[2]S>K>I
17			2.19	montmorillonitic soils highly swelling	[2]S>I+K
18			1.82	montmorillonitic soils moderately swelling	[2]S>I+K
19			1.35	kaolinitic+montmorillonitic soils	[2]S>K+I
20			2.35	montmorillonitic soils highly swelling	[2]S>I+K
21	Glacial tills	Różanka	1.10	kaolinitic+montmorillonitic soils	[1]I:6.2%; K:1.6%
22			1.15	kaolinitic+montmorillonitic soils	[1]I:8.4%; K:1.1%
23			1.09	kaolinitic+montmorillonitic soils	[1]I:11.4%; K:0.6%
24			1.22	kaolinitic+montmorillonitic soils	[1]I:6.7%; K:1.4%
25		Kopiska	1.23	kaolinitic+montmorillonitic soils	[2]S>I>K
26			1.26	kaolinitic+montmorillonitic soils	[2]S>I>K
27			1.25	kaolinitic+montmorillonitic soils	[2]S>I>K

I – illite, K – kaolinite, S – smectite

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