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Swelling, expansion and shrinkage properties of selected clays in the Mazowsze province, central Poland

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Tertiary clays and tills, the most widespread soils in Poland, were used for the examination of swelling, expansion and shrinkage properties. Results of laboratory tests and the values of selected parameters obtained by indirect methods show that the Tertiary clays examined, when compared with Quaternary tills, show greater volumetric changes under the influence of water, which is primarily connected with their higher silt content.

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Key words: Tertiary clay, till, swelling, expansion, shrinkage.

INTRODUCTION

Samples of Tertiary clays and Quaternary tills were collected in the Mazowsze province, where they are widely applied as raw material for the pottery industry.

Tertiary clay samples from Kosewo were analysed (Fig. 1). Stratigraphically, these clays are not *in situ*: glacitectonic processes have deformed them into, probably, a raft within younger Quaternary deposits (Baraniecka, 1995). The Tertiary clays for examination were taken from an open pit in the grey clay level (represented by grey-brown clays: samples 1–2 and grey clays: samples 3–5) and in the green clay level (represented by green clays: samples 6–8).

Analysis of tills from the Odra Glaciation, taken from a slope in Dębe on Narew, was made (Fig. 1). These are represented by samples 9–12.

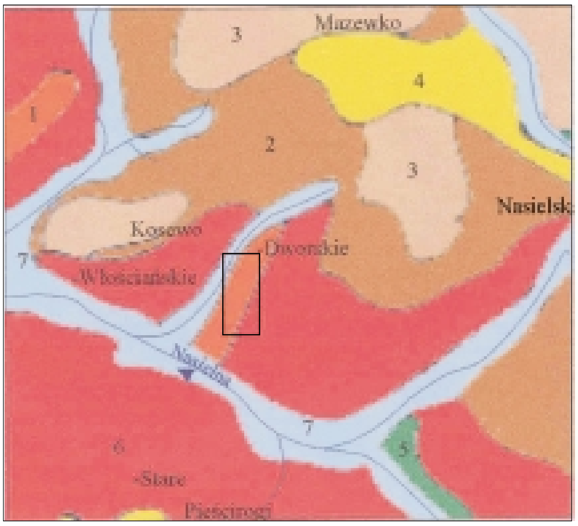
These results in total made it possible to evaluate and to compare the swelling, expansion and shrinkage properties of Tertiary and Quaternary soils.

MINERALOGICAL COMPOSITION

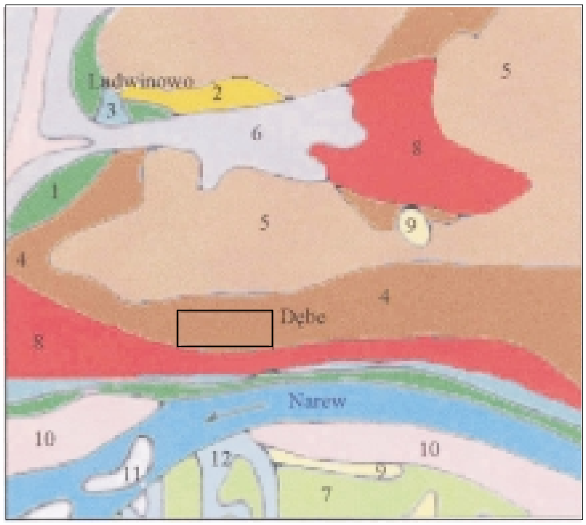
Thermal differential analysis of the samples examined was used to determine the mineralogical composition of the silt fraction. The results are presented in Table 1 (quantitative determination of mineralogical composition according to Kosciówko and Wyrwicki, 1996; Wyrwicki, 1998).

The data obtained show that the mineralogical composition and the percentage share of the component clay minerals in the clay fraction of the Tertiary clays are varied. Clay minerals overall comprise make over 65% of the whole deposit. However, in grey Tertiary clays it is beidellite that is the dominant clay mineral, while the percentage content of illite and kaolinite is more than two times smaller. In green clays, the clay fraction is dominated by illite. The share of kaolinite, as in the case of grey clay, is much smaller, and does not exceed 10%. There are trace amounts of beidellite. The analysis of both soil types did not show any presence of organic matter or carbonates, which indicates that these factors will not have any significant influence on the swelling, expansion and shrinkage properties of the Tertiary clays examined. The content of geothite ranges from 2% in grey clays to 8% in green clays.

KOSEWO



DĘBE



sampled localities

Fig. 1. Geological map at the 1:50 000 scale (according to Nowak, 1967, 1978)

KOSEWO — **Tertiary**: Pliocene: 1 — Tertiary clay; **Quaternary**: Pleistocene: Middle-Polish Glaciation: 2 — till, 3 — sand, gravel and pebbles of terminal moraine, 4 — glaciofluvial sand; Baltic Glaciation: 5 — fluviatile sand; Late Pleistocene: 6 — eluvial sand of till; Holocene: 7 — peat; DĘBE — **Quaternary**: Pleistocene: Middle-Polish Glaciation: 1 — fluviatile and glaciofluvial sand with gravel, 2 — glaciofluvial sand with gravel, 3 — ice dammed lake clay and mud, 4 — till, 5 — sand, gravel and pebbles of terminal moraine; Baltic Glaciation: 6 — periglacial silt (hill-side and dry valley), 7 — sand overflood terrace; Late Pleistocene: 8 — eluvial sand of till, 9 — aeolian sand and dunes; Holocene: 10 — sand and mud flood-plain terrace, 11 — sand, 12 — sandy aggradations with humus

Tills differ from these Tertiary deposits in their lower total content of clay minerals, which is approximately 16%. The component clay minerals comprise illite with small amount of beidellite; the analysis revealed also small content of geothite and a much greater proportion of carbonates. Significantly organic matter traces were also detectable.

PHYSICAL PARAMETERS

Examination of the physical properties of the samples was preceded by macroscopic evaluation. The Tertiary clays taken from the grey and green clay levels show similar properties, not reacting with hydrochloric acid, indicating a lack (or a minimal

Table 1

Results of thermal differential analysis of Tertiary clay and Quaternary till samples

Clay minerals [%]	Tertiary clay grey		Tertiary clay green		Till Odra Glaciation	
	Percentage share of minerals					
	$B^{60}>>I^{25}>K^{15}$		$I^{90}>>>(K+B)^{10}$		$I^{88}>>>B^{12}$	
	Percentage content in relation to the whole sample					
	67.0		79.3		16.0	
Beidellite (B)	40.2	67.0	accessory	79.3	1.9	16.0
Illite (I)	16.8		71.4		14.1	
Kaolinite (K)	10.0		7.9		0.0	
Geothite	2.0		7.9		1.0	
Carbonates	0.0		0.0		8.0	
Organic matter	0.0		0.0		0.3	
Quartz + thermally inactive components	31.0		12.8		74.7	
Total	100.0		100.0		100.0	

Table 2

The physical parameter values of the soils examined

Parameter	Symbol and unit	Samples											
		1	2	3	4	5	6	7	8	9	10	11	12
		Tertiary clay								Till			
		grey-brown		grey			green						
Initial water content	w_0 [%]	35.83	33.01	33.26	30.81	31.67	38.05	43.87	41.11	12.00	11.71	10.45	11.01
Density	ρ_s [Mg/m^3]	2.74	2.74	2.73	2.74	2.73	2.74	2.74	2.74	2.71	2.70	2.70	2.69
Cations exchange capacity	CEC [cmol/kg]	36.2	35.6	42.6	42.0	42.5	42.0	42.6	42.6	19.9	9.6	9.6	19.9
Specific surface	S_t [10^{3}m^2/kg]	283.5	278.9	333.6	328.7	332.9	328.9	333.4	333.4	155.9	75.6	75.5	155.9
Activity	A	0.68	0.67	0.57	0.53	0.53	0.52	0.56	0.51	0.49	0.61	0.64	0.53
Bulk density	ρ [Mg/m^3]	1.81	1.81	1.88	1.91	1.90	1.86	1.88	1.87	2.11	2.10	2.09	2.10
Dry density	ρ_d [Mg/m^3]	1.33	1.36	1.41	1.49	1.44	1.35	1.31	1.33	1.88	1.88	1.89	1.89
Porosity	n [%]	51	50	48	45	47	51	53	52	30	30	30	30
Void ratio	e	1.06	1.01	0.94	0.83	0.89	1.03	1.12	1.07	0.44	0.44	0.43	0.42
Degree of saturation	S_r [%]	96	94	100	91	100	100	100	100	71	69	63	68

content) of calcium carbonate. In natural conditions these samples occur in a plastic or soft plastic state.

The tills, though, reacted with hydrochloric acid, which indicates the presence of calcium carbonate (on the basis of macroscopic examination it was found that the quantities do not exceed 5%). In natural conditions these soils occur in a semi-compact or compact state.

Examination of physical parameters was made on samples 1–12, and the results are shown in Table 2. Figures 2 and 3. These results show that both Tertiary clays and Quaternary tills may be regarded as non-homogenous soils, as is evident from the variations in the percentage content of the individual soil fractions and the variable mineralogical composition of these soils. The obtained values show that Tertiary silts will be much more sensitive to the influence of the liquid phase on the solid phase compared to tills.

SWELLING, EXPANSION AND SHRINKAGE

Swelling of cohesive soils results from the combined action of the solid and liquid phases of the soil. It comprises an increase in soil volume as a result of the influence of solutions of various chemistries, and depends, among other things, on grain size composition, the percentage content of clay fraction, the miner-

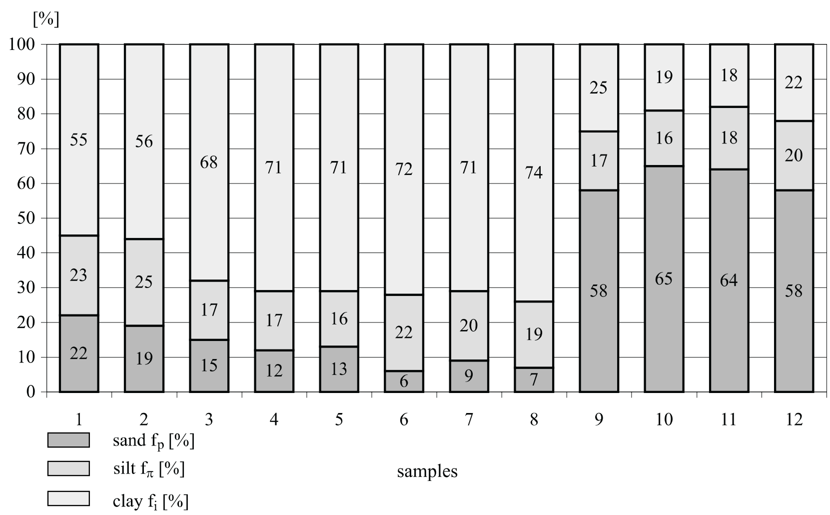


Fig. 2. Granulometry chart

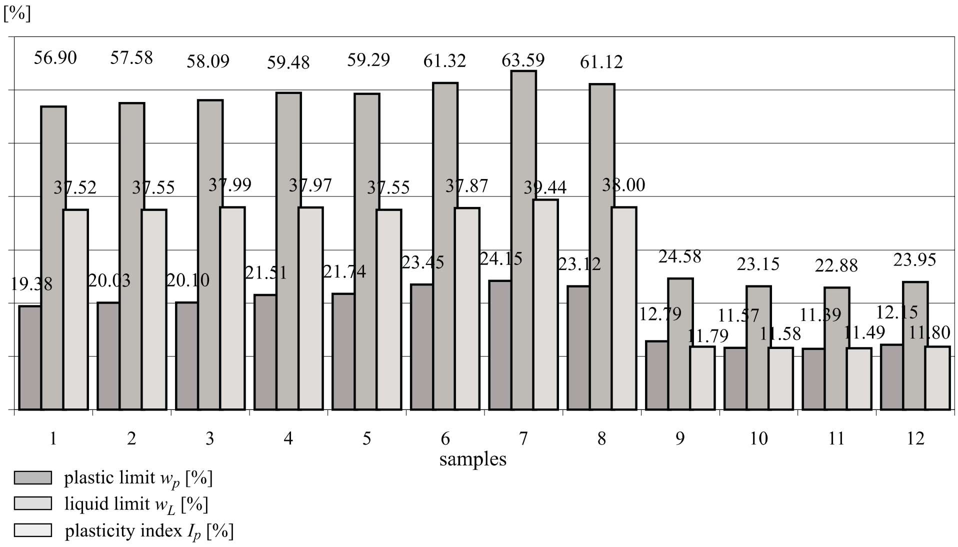


Fig. 3. Plastic limit w_p, liquid limit w_L and plasticity index I_p chart

alogical composition of the soil (mainly the clay fraction), the chemistry of the pore fluid saturating the soil, the composition of exchangeable cations, the percentage content of organic matter and carbonates, the degree of saturation, and soon. The mineralogical composition of the clay fraction is a factor of special significance. The more stable, "rigid" the lattice of a mineral is, the smaller its participation in swelling, in accordance with the following series:

minerals with labile, "mobile" structure	smectite>smectite/illite >illite>kaolinite	minerals with stable, "rigid" structure
	← increase of swelling	

Kaolinite, having a stable, "rigid" structure (due to the strong book bonds), reacts with water to a minimum extent, by contrast with minerals of the smectite group, which are regarded as very hydrophile due to their labile, "mobile" structure. Illite, in turn, is a mineral that reacts with water to a limited extent.

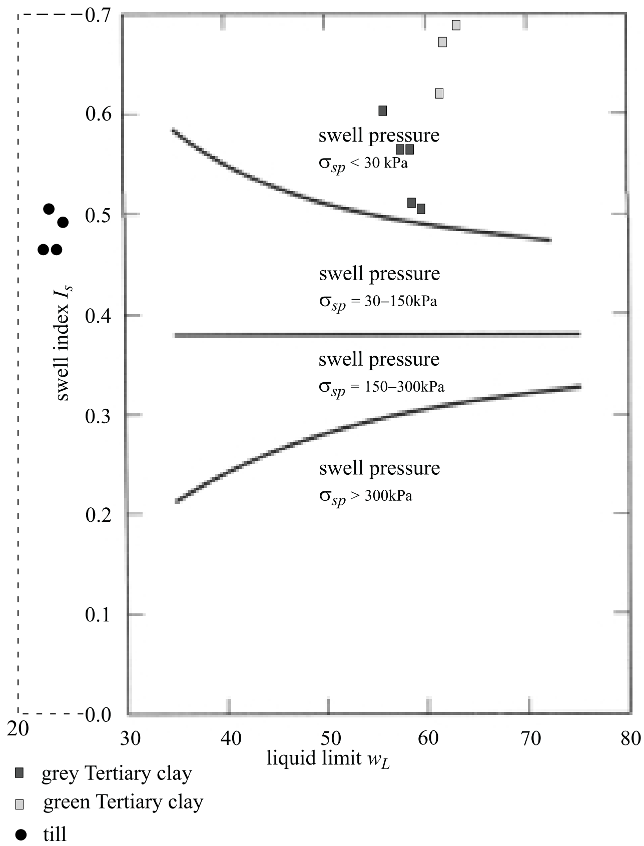


Fig. 4. Relationship between swelling index I_S and liquid limit w_L, (according to Chen, 1988)

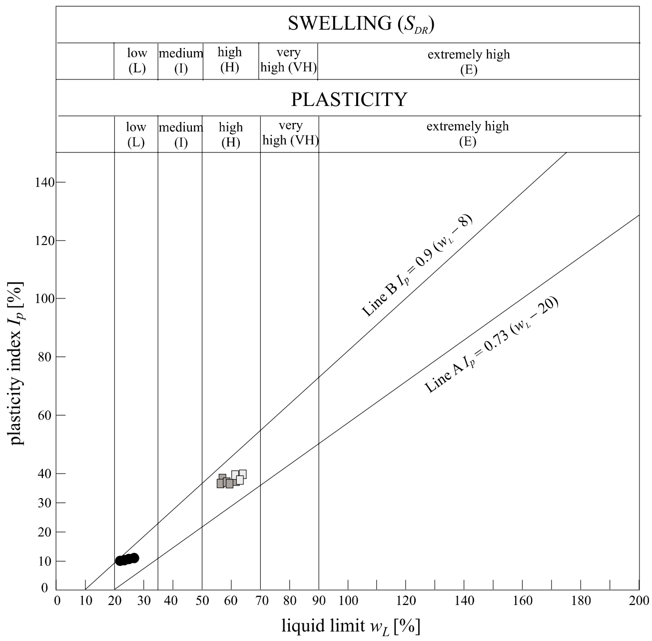


Fig. 5. Casagrande's chart modified by Grabowska-Olszewska (1998) for the evaluation of plasticity and swelling S_{DR}

Explanations see Fig. 4

Table 3

Swelling, expansion and shrinkage values of the soils examined

Parameter	Symbol and unit	Samples											
		1	2	3	4	5	6	7	8	9	10	11	12
		Tertiary clay								Till			
		grey-brown		grey			green						
Free swell	FS [%]	47.69	45.26	52.05	50.43	49.32	49.21	47.76	49.30	15.21	14.20	14.23	15.37
Free swell (according to Holtz-Gibbs, 1956)	FS_{HG} [%]	75	75	84	84	80	82	85	80	32	28	25	30
Final water content	w_f [%]	53.92	53.83	49.44	49.39	50.16	50.36	51.56	51.48	34.98	30.59	30.42	34.82
Swelling potential	S [%]	25.0	25.0	25.7	25.7	25.0	25.5	28.2	25.8	1.5	1.4	1.4	1.5
Swell index	I_S	0.63	0.57	0.57	0.47	0.53	0.62	0.69	0.67	0.49	0.51	0.46	0.46
Swell pressure	σ_{sp} [kPa]	< 30	< 30	< 30	< 30	< 30	< 30	< 30	< 30	30–150	30–150	30–150	30–150
Plasticity / swelling	S_{DR}	H/H	H/H	H/H	H/H	H/H	H/H	H/H	H/H	L/L	L/L	L/L	L/L
Potential expansivness	PE	VH	VH	VH	VH	VH	VH	VH	VH	L	L	L	L
Degree of expansion	DE	VH	VH	VH	VH	VH	VH	VH	VH	L	L	L	L
Total heave	TH [m]$\cdot 10^{-2}$	1.02	0.76	0.76	1.77	1.27	2.54	1.52	8.12	0.00	0.00	0.00	0.00
Linear shrinkage	Ls [%]	15.73	15.50	16.29	15.73	15.91	15.57	16.13	16.21	3.19	3.06	2.99	3.16

L — low, H — high, VH — very high

From the swelling parameter values obtained for the soils examined, as shown in Table 3, it is evident that:

— the values of free swelling factor (FS) according to ASTM D 4546-90 and Holtz-Gibbs (1956) free swelling factor (FS_{HG}) are the highest for grey clays ($FS \approx 50.60\%$; $FS_{HG} \approx 82.67\%$) and green clays ($FS \approx 48.76\%$; $FS_{HG} \approx 82.33\%$), medium for grey-brown clays ($FS \approx 46.48\%$; $FS_{HG} \approx 75.00\%$), and the lowest for tills ($FS \approx 14.75\%$; $FS_{HG} \approx 28.75\%$);

— the final water content (w_f), obtained from the examination of the free swelling factor (FS), is the highest for green clays ($w_f \approx 51.13\%$) and grey clays ($w_f \approx 49.66\%$), medium for grey-brown clays ($w_f \approx 43.87\%$), and the lowest for till ($w_f \approx 32.70\%$);

— the values of the swelling potential (S):

$$S = (3.6 \text{ x } 10^{-5}) \times (100) \times (I_p^{2.44}),$$

where: I_p — plasticity index

and swelling index (I_S):

$$I_S = w_0/w_L,$$

where: w_0 — initial water content, w_L — liquid limit

are the highest for green clays ($S \approx 26.5\%$; $I_S \approx 0.66$), medium for grey clays ($S \approx 25.5\%$; $I_S \approx 0.52$) and grey-brown clays ($S \approx 25.0\%$; $I_S \approx 0.6$), and lowest for tills ($S \approx 1.5\%$; $I_S \approx 0.48$);

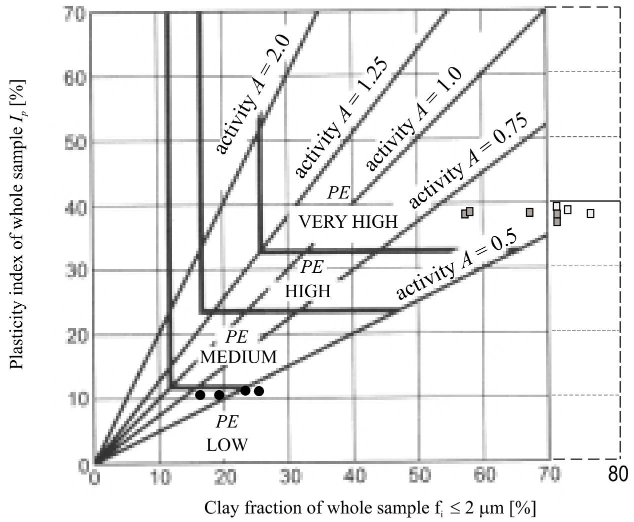


Fig. 6. Van der Merwe (1964) chart modified by Grabowska-Olszewska (1998) for the evaluation of potential expansiveness

PE — potential expansiveness: low, medium, high, very high; other explanations see Fig. 4

— swelling pressure (Fig. 4) is higher for till (30–150 kPa) than for Tertiary clays (below 30 kPa);

— on the basis of the nomogram (Fig. 5) the plasticity and swelling were determined as high (H) for Tertiary clays and low (L) for tills.

The **expansion** of soils entails a substantial increase of volume, occurring throughout the soil and rock mass, under the influence of changes in natural conditions: long-lasting and abundant rainfall, sewage system failures, or changes in the groundwater regime. It expresses volumetric changes resulting from the influence of water, and depends on the same factors as swelling.

From the expansion parameter values obtained for the soils examined, as given in Table 3, it is evident that:

— Tertiary clays are characterised by very high (VH) potential expansiveness, and till has low (L) potential expansiveness (Fig. 6);

— the degree of expansion is very high (VH) for Tertiary clays and low (L) for till (Fig. 7);

— the values of total heave according to formula:

$$TH = \sum_{D=1}^{D=n} F_D \left(PE\right)_D$$

where: F — is the factor by which the heave decreases with depth, D — depth, PE — potential expansiveness (Van der Merwe, 1964)

are the highest for green clays (TH: 1.52×10^{-2}– 8.12×10^{-2} m), lower for grey clays (TH: 0.76×10^{-2}–1.77×10^{-2} m) and grey-brown clays (TH: 0.76×10^{-2}–1.02×10^{-2} m), and equal to zero for till.

Shrinkage is a phenomenon shown in the decrease of soil volume caused by loss of water. The process occurs until the sample reaches a moisture content close to shrinkage limit. Then the particles are at a very small distance from each other, and continued drying of the soil does not result in a further decrease of the sample volume.

The values of linear shrinkage shown in Table 3, as in the case of free swelling factor, are the highest for grey and green Tertiary clays. The mean value of L_S ranges from 15.5–16.3%. For grey-brown clays medium values were obtained, approximately L_S = 15.5%. The linear shrinkage of till is several times lower and ranges from 2.9–3.2%.

CONCLUSIONS

Summing up the results obtained, one may state the following:

— Tertiary clays: grey and green, the most clayey and plastic among the examined soils, have the highest values of parameters expressing expansion, swelling and shrinkage. Grey-brown clays, containing admixtures or interlayers of till and sand deposits, are not so sensitive to the influence of water.

Analysis of the results in comparison with the mineralogical composition shows that grey clay, in the clay fraction of which beidellite is the dominating clay mineral, is characterised by deformation properties comparable to those of green clay, which contains mainly illite. The mineralogical composition, in turn, indicates that grey clays should be more sensitive to the influence of water. This situation results, among other things, from the fact that green clay is characterised by a higher percentage content of clay fraction (up to 20% more compared to grey clay), so the participation of the clay minerals (mainly illite), contained in this soil, is much more intensive in deformation processes.

— Till. Results of till sample analyses showed that this is a non-homogenous deposit. Samples taken from the top and the bottom of the till deposit are characterised by an increased per-

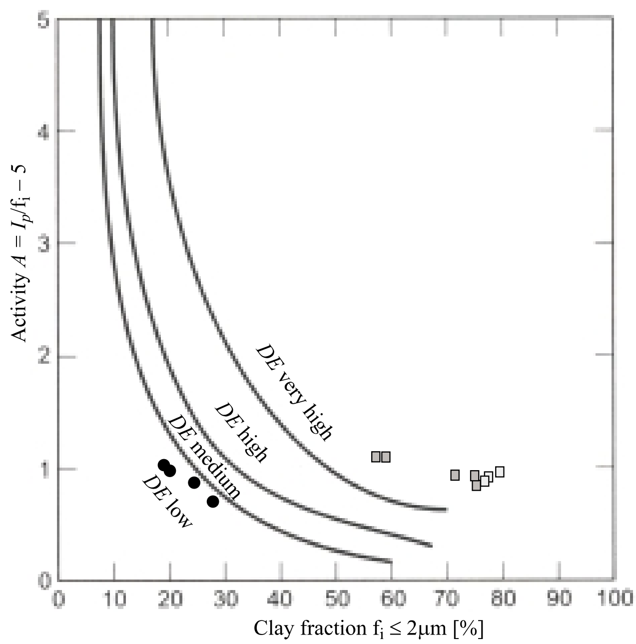


Fig. 7. Degree of expansion (*DE*) classification chart according to Seed *et al*. (1962)

centage content of clay fraction, but also by higher moisture content, plasticity and swelling, and therefore they will undergo greater volumetric changes in relation to the middle part of the till deposit. However, in comparison with Tertiary clays the till examined shows much smaller deformation values.

On the basis of these conclusions, the soils examined may be arranged with regard to their swelling, expansion and shrinkage properties in the following order (towards decreasing values):

— Tertiary clays from Kosewo: green clays, grey clays (grey and grey-brown);

— till from Dębe.

In many countries statistics are maintained which show that if swelling, expansion and shrinkage properties of soils are not taken into account, there is a hazard for not only for built objects, but also to human life, with obvious economic consequences. The importance of the problem is confirmed by the National Science Foundation, which among factors, most dangerous to buildings, apart from hurricanes, earthquakes and floods, lists expansive soils (Chen, 1988).

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