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GEOLOGICAL NONHOMOGENEITY OF SOILS

The nonhomogeneity of typical soils in Poland (Tertiary, Miocene and Pliocene clays, Quaternary glacial tills and loesses, Holocene fluvial sands) was analyzed in the paper. The analysis was limited to the presentation of the results of investigation of variability coefficient V and Kagan nonhomogeneity coefficient K_1 determined for the basic parameters of lithological, microstructural, physical and mechanical properties used for designing the foundations of engineering objects. Nonhomogeneity of soils is determined by the geological conditions of their origin as well as by later changes.

1. Introduction. Soils are the subgrade for the majority of engineering structures. The subgrade is a part of the geological environment between the depth of foundation of the engineering object and the assumed range of practical structure influence ($0.3\sigma'_{zy} = \sigma_{zd\,\max}$). By its nature the subgrade built of various soils is a statistically unhomogeneous medium which is due primarily to original nonhomogeneity – geological origin, mainly sedimentation and consolidation. The nonhomogeneity of soils can be intensified by later processes (factors) including those human-inducted.

In solving concrete geotechnical and engineering geological problems theoretical physical or mathematical models are applied. Parameters used in these models describing the physical and mechanical properties of soils and their behaviour under load are random values.

Parameters used in engineering calculations e.g. when checking the limit state (load-bearing capacity and serviceability) are defined by the statistical analysis of field and laboratory results. The calculation parameter can be defined only for a separate homogeneous soil layer. Therefore the crucial issue is to establish reliable homogeneity/nonhomogeneity criteria for soils.

In building practice the standard coefficient of materials γ_m is used to assess soil nonhomogeneity. In this case also the Kagan nonhomogeneity coefficient K_1 can be taken into account (Table 1).

Table 1. Nonhomogeneity of microstructural parameters of Pliocene clays from Warsaw

Microstructural parameters	R	$\bar{x}$	σ	V	Δ_1	γ_m	K_1
Porosity n, %	37–52	43.94	3.86	0.09	8.1	0.91	0.48
Number of pores $n \cdot 10^3$	0.8–347	87.66	106.42	1.21	259.3	–	0.41
Average pore diameter D_{av}, μm	0.79–5.29	1.69	0.99	0.59	3.6	0.41	0.28
Total pore area $S_t \cdot 10^3$, μm^2	27–1181	473.46	464.07	0.98	707.5	0.02	0.66
Average pore area S_{av}, μm^2	2.55–47.33	11.45	11.42	1.01	35.85	–	0.32
Total pore perimeter $P_t \cdot 10^3$, μm	27–2393	737.93	790.68	1.07	1655.1	–	0.48
Average pore perimeter $P_{av} \cdot 10^3$, μm	6.27–45.82	13.16	8.64	0.66	32.66	0.34	0.26
Average pore form index K_{fav}	0.432–0.599	0.51	0.05	0.09	0.089	0.91	0.56
Dominant orientation direction α, °	1.8–178.5	75.92	59.51	0.78	102.58	0.22	0.58
Microstructure anisotropy index K_a, %	3.8–41.9	21.26	9.93	0.47	20.64	0.53	0.48

R – range of variability ($R = x_{\max} - x_{\min}$), $\bar{x}$ – arithmetical mean, σ – standard deviation, V – variability coefficient, $\Delta_1 = x_{\max} - \bar{x}$, $\gamma_m = 1 \pm V$ –

standard coefficient of materials, $K_1 = \sigma/\Delta_1$ – Kagan nonhomogeneity coefficient, $N = 30$ – number of tests.

The changeability (nonhomogeneity) of subgrade properties (parameters) is not always the same depends on microstructural and lithological (granulometric) features. Also soil parameters show a variable nonhomogeneity.

In this paper analyzed are measures of nonhomogeneity γ_m and K_1 for various typical Polish soils including Tertiary clay, boulder clay and fluvial sands. Nonhomogeneities of various essential physical and mechanical soil parameters are considered.

2. Characteristics of analyzed soils. Nonhomogeneity of the soils properties is considered on the example of the following soils occurring in Poland:

- Tertiary, Miocene and Pliocene clays;
- Quaternary glacial tills, loesses and fluvial sands.

The physical and mechanical properties of the clays were established during their long and complicated geological history when they were subjected to several cycles of loading and unloading processes causing their overconsolidated state.

The Tertiary (Miocene) clays from the Carpathian Foredeep (southern Poland) consist of marine, illitic and montmorillonitic, marly, laminated soils. These clays are very sensitive to exogenic factors. Due to cyclic drying/wetting processes they were passed from soils with very favourable properties to weathering waste with low strength parameters.

The Tertiary (Pliocene) clays from the Warsaw area are generally quite monotonous. Their main components are clay minerals and quartz. Mineralogical researches [2, 3, 5, 6, 7, 9] indicate that clay minerals are represented by mixed-packed minerals of beidellite-illite series.

The Quaternary glacial tills are a typical result of glacial sedimentation. They include lodgement, melt-out and flow tills. They are composed of heterogeneous material and their composition depends on the rocks transported by the glacier from distant and nearby areas as well as the rocks taken from the glacier base. The tills contain quartz grains of various size as well as the grains of other rocks: gneiss, granite, quartzite, limestone. The sediment matrix is comprised of composition of fine grains calcite and particles of clay minerals (illite or montmorillonite).

Loesses represent a part of the sediments of Pleistocene origin. They are characterised by disordered texture and a carbonate content up to 10% $CaCO_3$. Typical loesses have a silt structure. They exemplify eolic facies, unweathered and mostly homogeneous, as it has been proved in various investigations.

The Holocene fluvial sands deposited in rivers valleys are a product of mechanical crumbling of rocks by flowing water. The sedimentation of the material is very complex and depends mostly on the velocity and quantity of water in the river. Fluvial sediments almost always consist a composition of various fractions. The analyzed results concern the fluvial sands from the area of Warsaw. Mineral composition of these sands is monotonous – they mainly consist of feldspar and quartz grains. The sands are also characterized by variable compaction degree.

3. Nonhomogeneity of soils. Tables 1–3 present the results of soils investigations. Nonhomogeneity of the tested soils are characterised by variability coefficient – V, standard coefficient of materials – γ_m, Kagan's nonhomogeneity coefficient – K_1.

Parameters describing the pore space of the Tertiary (Pliocene) clays reveal a large nonhomogeneity. The coefficient V ranges between 9–121%, and $K_1 = 0.26 - 0.66$ (Table 1). High values of V (sometimes above 100%) occur for: number of pores, average pore area, total pore perimeter.

Variability coefficient V for granulometric (lithological) composition of the tested soils presents following (Table 2):

- Tertiary (Pliocene) clays $V = 19 - 75\%$; $K_1 = 0.29 - 0.64$;
- glacial tills $V = 37 - 101\%$; $K_1 = 0.32 - 0.60$;
- loesses $V = 9 - 54\%$; $K_1 = 0.23 - 0.50$;
- fluvial sands $V = 3 - 5\%$; $K_1 = 0.04 - 0.85$.

Table 2. Lithological nonhomogeneity of various soils

Type of soil		Fraction content, %	R	$\bar{x}$	σ	V	Δ_1	γ_m	K_1
Pliocene clay	$N = 636$ *Pias-kowski* (1963)	clayey < 0.002 mm	7.0–65.0	29.3	10.5	0.36	35.7	0.64	0.29
		silty 0.002–0.05 mm	20.7–63.6	50.3	9.3	0.19	13.3	0.81	0.70
		sandy 0.05–2.0 mm	3.6–65.9	20.5	15.1	0.74	45.4	0.26	0.33
	$N = 25$ *KBN* (2000)	Clayey	28–89	56	19	0.34	33.0	0.66	0.58
		Silty	11–64	37.5	17	0.46	26.5	0.54	0.64
		Sandy	0–29	6.5	8	0.75	22.5	0.25	0.36
Boulder clay	$N = 15 - 30$	Clayey	8–45	21.1	7.7	0.37	23.9	0.63	0.32
		Silty	10–70	31.5	14.8	0.47	38.5	0.53	0.38
		Sandy	2–78	45.0	19.6	0.44	33.0	0.56	0.60
		gravelly > 2.0 mm	0–10	2.4	2.4	1.01	7.6	–	0.32
Loess	$N = 80$	Clayey	2–11	6.3	2.1	0.34	8.9	0.74	0.24
		Silty	49–93	79.3	6.8	0.09	13.7	0.81	0.50
		Sandy	2–47	14.2	7.6	0.54	32.8	0.46	0.23
Sand	$N = 50$	clayey + silty	0–3	1.9	0.095	0.05	1.1	0.95	0.09
		Sandy	92–100	95.5	3.82	0.04	4.5	0.96	0.85
		Gravelly	0–4	2.21	0.066	0.03	1.79	0.97	0.04

Explanations according to Table 1.

The nonhomogeneity of physical and mechanical properties is variable – the variability coefficient of physical parameters, generally, does not exceed 30–40%, whereas the same coefficient for strength and deformability parameters exceed 50%, and in the case of clays and tills even 100%. Very nonhomogeneous parameter of analysed soils is the liquidity index (Table 3).

Table 3*a*. Nonhomogeneity of the physical-mechanical parameters of various soils (explanations according to Table 1)

Parameter	Tertiary clay						
	R	$\bar{x}$	σ	V	Δ_1	γ_m	K_1
Specific density, Mg/m^3	2.57–2.76	2.70	0.04	0.02	0.06	0.98	0.57
Volume density, Mg/m^3	1.58–2.30	1.93	0.18	0.09	0.49	0.91	0.37
Volume density of soil skeleton, Mg/m^3	1.18–2.04	1.51	0.23	0.15	0.53	0.85	0.43
Porosity, %	25.2–54.2	43.9	8.04	0.19	10.3	0.81	0.78
Natural water content, %	17.2–46.2	24.5	9.30	0.38	21.7	0.62	0.43
Liquidity limit, %	34.3–94.2	60.3	13.52	0.22	33.9	0.78	0.40
Plastic limit, %	14.0–41.0	33.5	8.67	0.26	7.5	0.74	>1
Plasticity index, %	18.9–53.2	33.5	7.0	0.21	19.7	0.79	0.36
Liquidity index	−0.51–0.96	0.015	0.23	> 1	0.45	< 0	0.51
Angle of internal friction, °	3.0–27.5	14.5	21.5	> 1	13	< 0	> 1
Cohesion, kPa	10–425	86	390	> 1	339	< 0	> 1
Modulus of compressibility, MPa	0.9–148	23	30	> 1	125	< 0	0.24

Table 3*b*

Parameter	Boulder clay						
	R	$\bar{x}$	σ	V	Δ_1	γ_m	K_1
Specific density, Mg/m^3	2.63−2.75	2.69	0.031	0.015	0.06	0.985	0.52
Volume density, Mg/m^3	1.78−2.08	1.90	0.079	0.042	0.18	0.958	0.44
Volume density of soil skeleton, Mg/m^3	1.48−1.85	1.62	0.035	0.022	0.23	0.98	0.15
Porosity, %	28.1−45.5	36.5	3.65	0.101	9.0	0.90	0.40
Natural water content, %	11.6−25.9	17.2	4.16	0.24	10.3	0.76	0.35
Liquidity limit, %	14.2−47.1	28.9	8.73	0.30	21	0.70	0.36
Plastic limit, %	11.9−20.7	15.4	3.15	0.20	6.7	0.80	0.43
Plasticity index, %	2.3−19.2	13.4	6.20	0.46	7.1	0.54	0.74
Liquidity index	−0.31−0.65	0.13	0.20	> 1	0.52	< 0	0.38
Angle of internal friction, °	6.0−25.5	11.8	5.0	0.42	14.5	0.58	0.28
Cohesion, kPa	0.5−43.5	24.0	9.1	0.38	18.5	0.62	0.48
Modulus of compressibility, MPa	5.1−35.6	12.5	21.35	> 1	23.1	< 0	0.92

Table 3*c*

Parameter	Loess						
	R	$\bar{x}$	σ	V	Δ_1	γ_m	K_1
Specific density, Mg/m^3	2.64−2.71	2.68	0.02	0.01	0.03	0.99	0.33
Volume density, Mg/m^3	1.35−2.05	1.77	0.12	0.07	0.28	0.93	0.43
Volume density of soil skeleton, Mg/m^3	1.20−1.71	1.50	0.08	0.05	0.21	0.95	0.38
Porosity, %	32.9−57.6	41.0	3.8	0.09	17.6	0.91	0.22
Natural water content, %	7.2−21.9	12.5	3.0	0.24	9.8	0.76	0.31
Liquidity limit, %	23.8−27.3	25.5	0.8	0.04	1.8	0.96	0.44
Plastic limit, %	18.6−24.7	20.6	1.3	0.07	4.1	0.93	0.32
Plasticity index, %	1.0−6.5	4.9	1.3	0.27	1.6	0.73	0.81
Liquidity index, -	–	< 0	–	–	–	–	–
Angle of internal friction, °	15−31	25	4.5	0.18	6	0.82	0.75
Cohesion, kPa	10−90	35	15	0.43	55	0.57	0.27
Modulus of compressibility, MPa	0.39−5.0	2.01	0.94	0.46	2.99	0.54	0.31

Table 4. Criteria for determining of soil nonhomogeneity in terms of the variability coefficient V [%] for various parameters

Parameter / Author	Clay fraction content	Specific density	Volume density of natural soil	Volume density of the soil skeleton	Porosity	Natural water content	Liquidity limit	Plastic limit	Plasticity index	Liquidity index	Angle of internal friction	Cohesion	Modulus of compressibility
Ingles O. [4]	–	–	3	–	25	–	10	10	30	–	10	30	30
Biernatowski K. [1]	–	–	2.5	–	30	–	15	10	20(30)	–	5(15)	12.5−30	5−20
Kagan A. [8]	–	–	–	3	–	–	20	20	–	–	–	–	–
Proposal	25	2	3	5	25	20	20	20	25	50	20	20−40	50

4. Assessment of soil nonhomogeneity. The assessment of nonhomogeneity may be made using various criteria, often basing on the limit values of the variability coefficient − V. The limit values which can be found in the literature are given in Table 4. Different authors assume different values of V for particular parameters. The new criteria of nonhomogeneity of the properties of soils have been proposed taking into account the literature data, author's experience, accuracy of the testing methods and natural variability of soils.

5. Conclusions. It should be emphasised that, generally, the soils are nonhomogeneous media. Nonhomogeneity of soils is affected by the origin and later changes, including the anthropogenic ones.

1. Nonhomogeneity of soils is mainly determined by granulometric and mineral composition and by their microstructures.
2. Soil nonhomogeneity depends on the various impurities, inclusions, and concretions. Variable consolidation and occurrence of weakened surfaces are also of great importance.
3. The highest nonhomogeneity has been noted in cohesive soils (clays and boulder clays). More homogeneous are loose soils.
4. Particular values are characterised with uniform values of variability coefficient V. High values of coefficient V and Kagan nonhomogeneity coefficient K_1 are revealed mainly in mechanical and deformability parameters: moduli, cohesion, angle of internal friction and liquidity index.
5. Considering engineering geological properties, for the purposes of engineering calculations, the analysed soils may be classified as the homogeneous ones, characterised by a value of the variability coefficient the limit value. The proposed limit values of V are presented in the Table 4.

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ГЕОЛОГІЧНА НЕОДНОРІДНІСТЬ ҐРУНТІВ

Проаналізовано неоднорідність типових ґрунтів на території Польщі. Аналіз обмежено до подання результатів дослідження зміни V, а також параметра змінності K_1*, визначених для основних літологічних мікроструктурних параметрів, і фізичних та механічних параметрів, які використовуються при проектуванні об'єктів. Неоднорідність ґрунтів зумовлена геологічними умовами, а також наступними змінами.*

ГЕОЛОГИЧЕСКАЯ НЕОДНОРОДНОСТЬ ПОЧВ

Проанализирована неоднородность типовых почв на территории Польши. Анализ ограничен представлением результатов исследования изменения V, а также параметра K_1*, определяемых для основных литологических микроструктурных параметров, физических и механических свойств, используемых при проектировании объектов. Неоднородность почв обусловлена геологическими условиями, а также последующими изменениями.*

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