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PROBLEMS OF SOILS NONHOMOGENEITY

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ABSTRACT

Soils constitute the subgrade of many building objects. There is thus a justified need to identify the nonhomogeneity of soil parameters. Parameters used in engineering calculations e.g. when checking the limit state (load-bearing capacity and serviceability). The present work gives an assessment of soil nonhomogeneity, Tetiary (Pliocene) clays being taken as an example. Their microstructures, granulometric composition and major engineering-geological features have been analyzed. In the assessment of nonhomogeneity both the coefficient of nonhomogeneity/changeability and the Kagan coefficient have been considered. In the Tables listed are concrete values of the above coefficients. Particular attention has been given to the Kagan coefficient of general nonhomogeneity. Finally, critical values of the nonhomogeneity coefficient γ_m have been suggested (in Table 4) which can be used for the assessment of soil nonhomogeneity depending on the parameter (feature) analyzed.

Key words: nonhomogeneity, soils, properties, subsoil, capacity.

INTRODUCTION

In practice [9] in the course of construction of an engineering object two limit states are tested – the load-bearing capacity (1) and the serviceability (2):

$$S_{cal} = \Sigma S_i = \frac{\sigma_{zdi} \cdot h_i}{M_{oi}^{(r)}} + \lambda \frac{\sigma_{zsi} \cdot h_i}{M_i^{(r)}} < S_{per} \tag{1}$$

$$q \le m \cdot q_f = m\left[\left(1 + 0{,}3\frac{B}{L}\right) N_c \cdot C_u^{(r)} + \left(1 + 1{,}5\frac{B}{L}\right) N_D \cdot D_{\min} \cdot \gamma_D^{(r)} + \left(1 - 0{,}25\frac{B}{L}\right) N_B \cdot B \cdot \gamma_B^{(r)}\right] \tag{2}$$

where:

S – settlement, q – applied stress, q_f – unitary computational resistance of soil, m – correction coefficient;

$M_{oi}, M_i, \gamma, C_u, \Phi_u = f$ (lithological-granulometric and mineral composition, water content, liquidity index, density index);

$\Phi_u = f(N_C, N_B, N_D)$;

$C_u, \Phi_u = f$ (shear strength);

C_u (or C) – cohesion; Φ_u (or Φ) – angle of internal friction;

M_{oi}, M_i – oedometric modulus of compressibility;

N_C, N_B, N_D – bearing capacity factors;

L, B, D – length, breadth and depth of foundation;

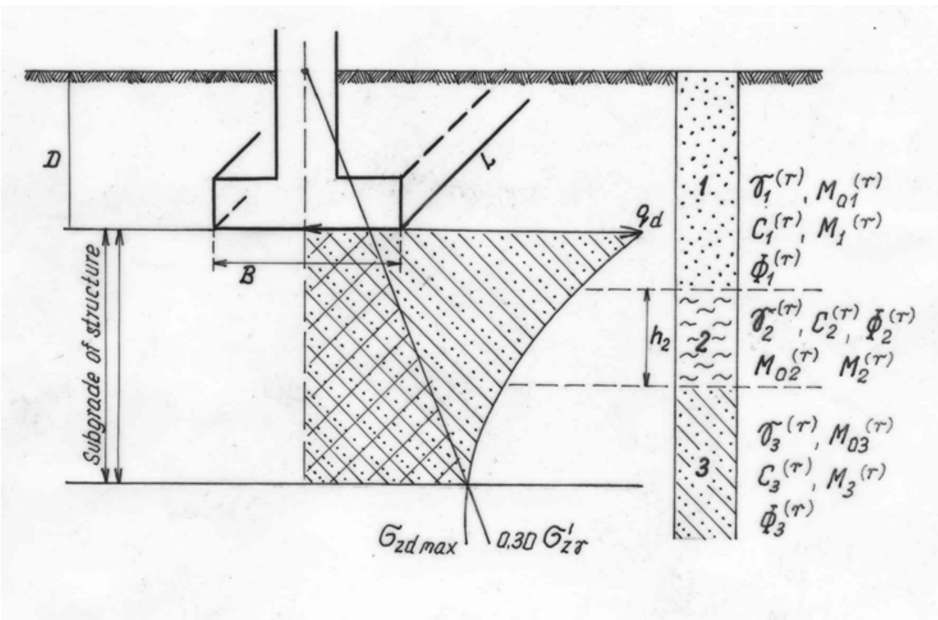
h – thickness, σ – stress (σ_{zdi} - additional stress, σ_{zsi} - secondary stress), γ – unit weight, m – correction coefficient.

Soil parameters x_i (M_{oi}, M_i, C_u, γ) used in formulas (1) and (2) defined as $X^{(r)}$ are calculation parameters where the magnitude of nonhomogeneity/changeability is considered. In this paper the nonhomogeneity of selected soils from the area of Warsaw is assessed. Besides nonhomogeneity coefficients known previously [1,2,3,4,9] also the Kagan nonhomogeneity coefficient [8] has been presented evaluating the general nonhomogeneity of soils.

PARAMETERS OF SOIL NONHOMOGENEITY

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 $\sigma'_{z\gamma} = \sigma_{zd\,max}$ (Fig. 1).

Fig. 1. Subgrade of structure



By its nature the subgrade – built of various type of soils – is statistically an unhomogeneous medium which is due primarily to original nonhomogeneity – geological origin, mainly sedimentation and consolidation.

In engineering practice the nonhomogeneity of soils is expressed by the standard coefficient of materials (γ_m) as defined by the previous version of Polish Building Standard [9] and the one now adapted to Eurocord 7 [2]. The calculation parameter $X^{(r)}$ used in the above calculations is assumed as follows:

$$x^{(r)} = x^{(n_1)} \cdot \gamma_{m_1} \tag{3}$$

$$x^{(r)} = \frac{x^{(n_2)}}{\gamma_{m_2}} \tag{4}$$

where:

$\gamma_{m_1} = 1 \pm V$, $V = \dfrac{\sigma}{x^{(n_1)}}$

V – variability coefficient, σ – standard deviation, $x^{(n_1)}$ – characteristic parameter = arithmetical mean $\bar{x}$.

The above evaluation of nonhomogeneity of soils applies to the separate coefficients. Kagan [8] has suggested the following parameter:

$$K = \frac{\sigma}{\Delta}, \qquad \Delta = x_{\max} - \bar{x}\,, \qquad or \quad \bar{x} - x_{\min} \tag{5}$$

where:
$R = x_{\max} - x_{\min}$ – range of variability,

where K can be used both for a single parameter and to define the general coefficient of nonhomogeneity K^o which includes several parameters

$$K^o = K_a + K_b + K_c + K_d \qquad \text{or} \tag{6}$$

$$K^o{}_\gamma = K_{\gamma a} + K_{\gamma b} + K_{\gamma c} + K_{\gamma d} \tag{7}$$

where:
a,b,c,d – selected parameters essential for the given task**.**

ENGINEERING GEOLOGICAL CHARACTERISTICS OF THE SOIL EXAMINED

The analysed soils (Fig. 2a,b) occur over a considerable area of Poland and are overlain by Quaternary drift deposits of various thickness. They represent the youngest Neogene (Tertiary – Pliocene) deposits.

Fig. 2a,b. Pliocene clays in the Warsaw underground's tunnel (b – sharply outlined glaciotectonic dislocation)

a)

b)

These deposits (soils) different in lithological meaning also show certain differences in their clay fraction composition, physical properties and thickness. In the Warsaw area (north-eastern, peripheral part of the basin) the sediments have a lower content of clay fraction proper. On the basis of ca. 1000 analyses of granulometric composition of Warsaw Pliocene clays Stamatello and Rossman [10] differentiated first of all: clays 35%, silty clays 38%, sandy and silty clays 27%. Table 1 shows the granulometric composition of each fraction (clayey, silty, sandy) of the Warsaw Pliocene clays.

Table 1. Lithological nonhomogeneity of the analysed clays

Type of soil		Fraction content, %	R	$\overline{x}$	σ	V	Δ_1	γ_{m_1}	K
Pliocene clay	N = 636 *Piaskowski (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 <0.002 mm	28-89	56	19	0.34	33.0	0.66	0.58
		silty 0.002-0.05 mm	11-64	37.5	17	0.46	26.5	0.54	0.64
		sandy 0.05-2.0 mm	0-29	6.5	8	0.75	22.5	0.25	0.36

Explanations: R – range of variability ($R = x_{max} - x_{min}$), $\overline{x}$ – arithmetical mean, σ – standard deviation, V – variability coefficient, $\Delta_1 = x_{max} - \overline{x}$, γ_{m_1} – standard coefficient of materials, K – Kagan nonhomogeneity coefficient, N – number of tests = 30

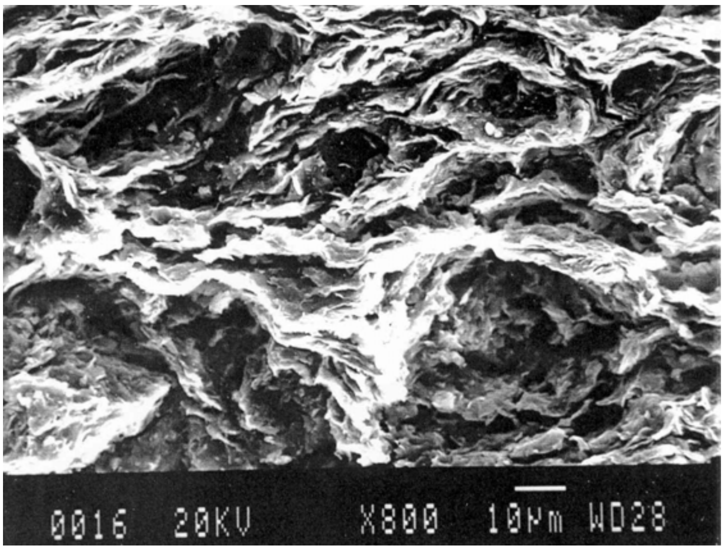
Qualitative SEM investigation of the analysed soils enabled to determine of the microstructural parameters of the porous space: porosity, number of pores, total pore area, total pore perimeter, average perimeter of pores (Tab. 2). The morphology of pores is characterised by form index.

Table 2. Nonhomogeneity of microstructural parameters of Pliocene clays from Warsaw

Microstructural parameters	R	$\overline{x}$	σ	V	Δ_1	γ_{m_1}	K
Porosity n, %	37-52	43.94	3.86	0.09	8.1	0.91	0.48
Number of pores $n x10^3$	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 $S_t x10^3$, $μm^2$	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 $P_t x10^3$, μm	27-2393	737.93	790.68	1.07	1655.1	-	0.48
Average pore perimeter $P_{av} x10^3$, 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

Warsaw Pliocene clays are characterised by transitory types [5,6,7,11]: matrix-turbulent and turbulent-laminar (Fig. 3).

Fig. 3. Typical SEM micrograph of Pliocene clay from Warsaw area



The mineral composition of the analysed soils is quite monotonous. The main components are clay minerals and quartz. Mineralogical studies indicate that clay minerals in the Pliocene deposits are represented by mixed-packet minerals of the beidellite-illite series. Basic engineering geological properties of these clays are very close to parameters characterising other clays from Poland. It was observed that (Tab. 3):

Table 3. Nonhomogeneity of the physical-mechanical parameters of the analysed clays

Parameter	R	$\bar{x}$	σ	V	Δ1	γ_{m_1}	K
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	27.5	>1	13	<0	>1
Cohesion, kPa	10-425	86	590	>1	339	<0	>1
Modulus of compressibility, MPa	0.9-148	23	30	>1	125	<0	0.24

- natural water contents are close to total water contents at full saturation, the degree of saturation is most often above 0,97,
- natural water contents w_n are usually lower than plastic limit w_P, whereas $w_S<w_n<w_P<w_L$ indicate that clays are characterised by semi compact consistency (w_L, w_S – liquidity and shrinkage limits,
- average parameters denoting natural compactibility of soils indicate that there were external loads during their geological history (overconsolidation ratio >1, often 5-10, and even 10-15).

ASSESMENT OF SOIL NONHOMOGENEITY

Tables 1-3 present the results of soil investigations. Nonhomogeneity of the analysed soils is characterised by variability coefficient *V*, standard coefficient of materials $\gamma_m(\gamma_{m_1}, \gamma_{m_2})$, Kagan's nonhomogeneity coefficient *K* (*K*, K^o).

Depending on the existing experience and conditions it is advisable to assume γ_{m_1} = 0,80-1,25 [9] and γ_{m_2} = 1,0-1,4 [2]. Within the given range the nonhomogeneity assessment applies to the separate parameters, whereas Kagan's [8] assumptions for various soils are as follows:

- homogeneous and highly homogeneous $K \geq 0,5$ and $K^o \geq 2$
- relatively homogeneous $0,33 < K \leq 0,5$ and $1,3 < K^o \leq 2$
- nonhomogeneous $K \leq 0,33$ and $K^o \leq 1,3$.

Parameters describing the pore space of Pliocene clays reveal a large nonhomogeneity. The coefficient *V* ranges between 0,09-1,21 and *K* = 0,26-0,66. High values of *V* (sometimes above 1,0) occur for: number of pores, average pore area and total pore perimeter.

Variability coefficient for granulometric composition of analysed soils *V* = 0,19-0,75 however Kagan's nonhomogeneity coefficient *K* = 0,29-0,64.

Nonhomogeneity of engineering geological properties is variable – the variability coefficient of physical parameters does not generally exceed 0,3-0,4, whereas the same coefficient of strength and deformability parameters exceed 0,5 and even 1,0.

Following a thorough analysis of data obtained the following values of the γ_{m_1} coefficient are suggested for the evaluation of soil nonhomogeneity (Tab. 4).

Tab. 4. Criteria for determining of soils nonhomogeneity in terms of the standard coefficient of materials γ_{m_1} for various parameters

Parameter / Author	Clay fraction content f_i	Specific density γ_s	Unit weight γ	Natural water content w_n	Liquidity limit w_L	Plastic limit w_P	Liquidity index	Angle of internal friction Φ_u	Cohesion C_u	Modulus of compressibility M_o
PN-81/B-03020	1.25	0.80	0.80	1.25	1.25	1.25	1.25	0.80	0.80	0.80
Ingles 1979	-	-	0.97	-	1.10	1.10	-	0.90	0.70	0.70
Biernatowski 1984	-	-	0.98	-	1.15	1.10	-	0.85 0.95	0.70 0.88	0.80 0.95
Kagan 1985	-	-	0.97	-	1.20	1.20	-	-	-	-
Frankowski et al. 1998	1.20	0.98	0.98	1.20	1.20	1.20	1.50	0.85	0.80	0.70
Proposal	1.25	0.98	0.97	1.20	1.25	1.20	1.50	0.80	0.60-0.80	0.50

An example of γ_{m_1} coefficient used in the suggested Kagan nonhomogeneity coefficient is given below:

$$K^o{}_\gamma = K_{fi} + K_{wn} + K_{\Phi_u} + K_{C_u} = 1{,}25 + 1{,}20 + 0{,}80 + 0{,}60 = 3{,}85$$

CONCLUSIONS

1. Nonhomogeneity of soils is mainly determined by granulometric and mineral composition and also by their microstructures (otherwise by the geological conditions of their sedimentation as well as by later changes).
2. The analysed soils are characterised by variability coefficient V and Kagan's nonhomogeneity coefficient range for:
   - granulometric composition $V = 0{,}19\text{-}0{,}75$ and $K = 0{,}29\text{-}0{,}64$
   - parameters describing the pore space $V = 0{,}09\text{-}1{,}21$ and $K = 0{,}26\text{-}0{,}66$
   - engineering geological properties (physical: $V = 0{,}3\text{-}0{,}4$; mechanical: $V = 0{,}5\text{-}1{,}0$ and often $V > 1{,}0$), K = from 0,24 to >1,0.
3. Considering the engineering geological properties for the purpose of engineering calculations, the analysed soils can be classified as the homogeneous ones, characterised by a value of the standard coefficient of materials. The proposed limit values of γ_1 are presented in the Table 4. Kagan's proposal of K^o can also be used for estimation of soils nonhomogeneity.

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