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Estimation of ability to volume changes of Mio-Pliocene clay from Warsaw

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Deformation changes occur in cohesive soils as a result of interaction of their solid and liquid phases. The paper presents a comprehensive geological engineering evaluation of the ability to volume changes of overconsolidated Mio-Pliocene clay from the Warsaw area. To evaluate these changes, we used grading and mineral composition and the physical properties of soil as well as its specific surface, MBC, free swelling, swell pressure, suction pressure, and soil-water retention characteristic curves.

Key words: geological engineering properties, Mio-Pliocene clay, swelling, suction pressure

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INTRODUCTION

Deformation changes observed as swelling, shrinkage, collapse, expansivity, heaving, etc. may result in adverse effects of subsoil on constructions. An appropriate assessment of susceptibility of cohesive soils to deformation changes is thus needed for practical reasons since it enables a more economical planning and full exploitation of the actual properties of the soil.

Mio-Pliocene clay in the area of Warsaw is at present and will be in the future a subsoil of newly-built edifices because of an extensive development of underground constructions such as parking lots, tunnels, and the subway. The last decades brought numerous constructions several dozen storeys high, with a few levels of underground parking lots. Mio-Pliocene clays in Warsaw occur from 2 to 100 m bgl, and their thickness varies from 50 up to 100–150 m. Because of their expansion properties and a complex geological history they require both field and laboratory studies.

TESTED SOILS

Soils from the Geological Engineering Experimentation Site Stegny and from the bed of a deep excavation of the Warsaw subway station A19 Marymont were used for assessing the deformation changes of Warsaw clay. This clay is overconsolidated. The Stegny site is located in the valley of the Vistula River, and the subway station is in a moraine upland.

The soil deformability assessment was based on the analysis of its properties and parameters such as grading and mineral composition, specific area, MBC, free swelling, swell pressure, suction pressure, and soil-water retention characteristic curves.

Geological engineering experimentation sites exist in a great number in the United States (e. g., the National Geotechnical Experimentation Sites, VanMarcke and Fenton, 2003), but they are scarce in Poland. The Stegny site is located in a residential area in the Mokotów district in Warsaw (Fig. 1). Morphologically, it is located in the valley of the Vistula River, on a flood plain. The object of geological engineering studies is Mio-Pliocene clays of the Poznań formation. Samples of clay for analysis were collected from 4.5 to 36 m bgl to Shelby thin-walled tube samplers.

The geological engineering site facilitates continuation and development of field and laboratory studies of Neogene clay. The soil and groundwater conditions of the Stegny site was investigated by test drilling down to 36 m bgl and by CPTU sounding down to 46 m bgl (Barański, 2004). The soil complex of the Poznań formation is located below a layer of alluvial sands about 4 m bgl (Kaczyński et al., 2000).

The Warsaw subway is of shallow type. The station A 19 Marymont was constructed with the use of an open excavation method. The station is located about 200 m away from a steep bank separating a moraine upland from the Vistula valley (Fig. 1).

Monolith soil samples were collected from the station excavation pit from about 14 m bgl. The subsoil of the station is composed solely of Mio-Pliocene clay. The soil is mainly composed of clay, silty clay, sandy clay, silt and fine sand. The roof of Tertiary structures at the site of the station is glacio-tectonically disturbed and uplifted.

GEOLOGICAL-ENGINEERING PROPERTIES

The basic properties and parameters of the soils under discussion are presented in Tables 1 and 2. The tables list statistical parameters such as minimum and maximum values, mean, standard deviation, coefficients of variability and the number of samples.

The highest variability is observed in the liquidity degree and the liquidity index. In the case of the liquidity degree I_L, the

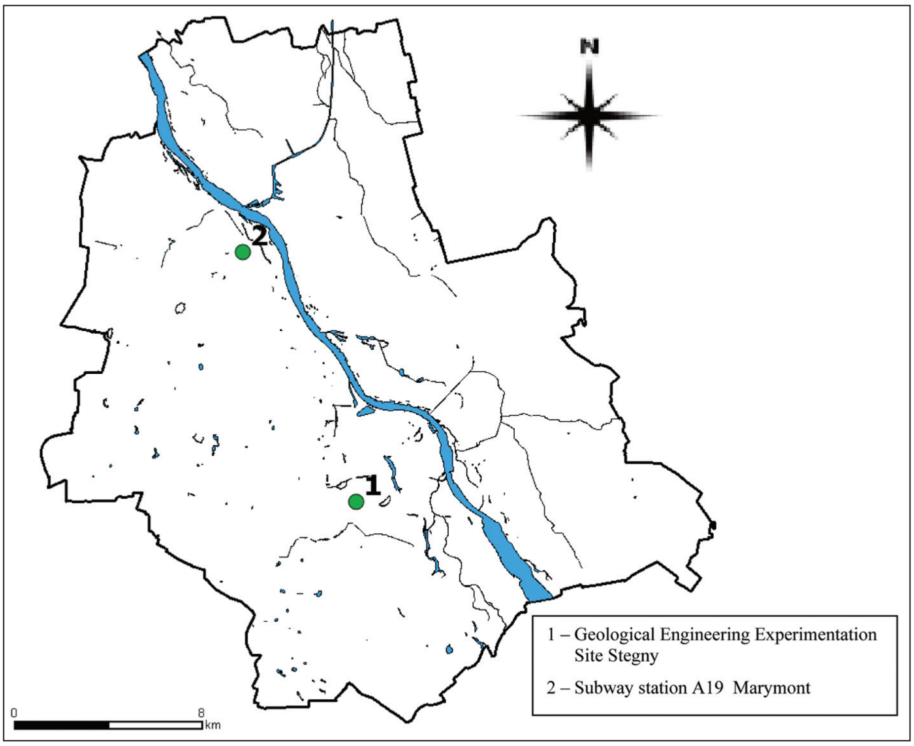

Fig. 1. Localization of test Mio-Pliocene clay from Stegny and Marymont

Table 1. **Basic properties of Mio-Pliocene clay from Stegny**

Parameter	Properties									
	ρ_s, Mg/m³	ρ, Mg/m³	ρ_d, Mg/m³	e	w, %	w_P, %	w_L, %	I_P, %	I_L	A
Min	2.67	1.85	1.36	0.45	16.67	16.8	35.5	16.9	–0.27	0.52
Max	2.73	2.17	1.86	0.99	36.52	41.0	96.0	58.0	0.24	1.04
X	**2.70**	**2.04**	**1.64**	**0.67**	**24.78**	**29.0**	**72.1**	**43.1**	**–0.10**	**0.80**
σ	0.02	0.07	0.12	0.13	4.68	6.1	16.2	12.1	0.10	0.13
ν %	1	4	7	19	19	21	22	28	103	16

Table 2. **Basic properties of Mio-Pliocene clay from Marymont**

Parameter	Properties									
	ρ_s, Mg/m³	ρ, Mg/m³	ρ_d, Mg/m³	e	w, %	w_P, %	w_L, %	I_P, %	I_L	A
Min	2.65	1.97	1.49	0.68	24.04	25.7	70.1	40.8	–0.26	0.49
Max	2.71	2.04	1.61	0.78	33.01	49.8	115.9	72.9	–0.01	1.16
X	**2.68**	**2.00**	**1.57**	**0.71**	**27.42**	**36.4**	**91.7**	**55.3**	**–0.16**	**0.87**
σ	0.02	0.02	0.04	0.03	2.82	6.6	13.5	7.9	0.08	0.21
ν %	1	1	3	4	10	18	15	14	48	24
N	11	7	7	7	15	15	15	15	15	11

coefficient of variability is equal to 103% for the Stegny clay and 48% for the subway clay. The coefficient of variability for the liquidity index I_P is equal to 28% for the Stegny clay and to 14% for the subway clay. The coefficients of variability of the other parameters do not exceed 24%.

The content of clay in the Stegny samples is 53%, of silty clay 32% and of sandy clay 13%. Concerning its mineral composition, beidelite is more abundant than illite and kaolinite: $B^{11-82\%} > I^{0-53\%} > K^{3-38\%}$ (Barański et al., 2004).

In samples from the Marymont subway station, clay makes up 91% of the samples collected, and the rest are silty clays. Analysis of the mineral composition of clay from the subway excavation suggests that the dominant mineral is beidelite ($B^{47-72\%} > K^{9-17\%}$). The analysis did not show illite (Wszędyrówny, 2006).

ASSESSMENT OF DEFORMATION CHANGES OF SOILS

The assessment of susceptibility of soil to deformation was begun with an analysis of the percentage of the clay fraction and of its mineral composition. Because of the content of clay minerals (on the average 60%), of the clay fraction (on the average 50%), and of the domination of beidelite (on the average 29%), the Mio-Pliocene clay from the Stegny site should be deformable, similarly to the clay from the subway station: the average content of clay minerals exceeds 70%. The dominant mineral being also beidelite, while the mean content of the clay fraction is about 59%.

Assessment of susceptibility to volume changes of cohesive soils was carried out with the use of indirect methods as well. Analysis of the Casagrande chart suggests that about 50% of the test samples of the Stegny clays and almost all samples from the subway station show a very high or extremely high liquidity (Fig. 2). Hence also a very high and extremely high swelling should be expected.

Analysis of the relation between the swelling index $Is = w/w_L$ and water content at liquid limit w_L, proposed by Vijayvergiya and Ghazzaly (1973), showed that for the samples of Mio-Pliocene clay from the Stegny site one can expect a variable swell pressure as shown in Fig. 3. For more than 50% of the samples, the estimated values of swell pressure should exceed 150 kPa. In the case of clay samples from the subway station, the expected swell pressure values also exceed 150 kPa.

Swell pressure was determined using the method of constant volume of a soil sample. The tests were performed using an automatic h-200A swell pressure analyzer from the GEONOR AS company, Norway.

Generally, the swell pressure values obtained for clay samples from the Stegny site agree with expectations. The results are within 36–323 kPa. Results for clay samples from the subway station do not agree with the expected values: the variability interval is 19–93 kPa. Table 3 shows the measured swell pressure values.

For a quick assessment of the ability of cohesive soils to swell, the method of free swell test FS_{HG} according to Holtz and Gibbs (1956) was used. Susceptibility to volume changes under the influence of water was found in cohesive soils with high values of specific area S_t, clay fraction f_i and with large values of MBC.

The results are listed in Table 3. The mean value of free swell for clay from Stegny is equal to 96% and for clay from the subway station to 65%. Clay from the Geological Engineering Experimentation Site Stegny is expansive down to 20 m bgl (Barański et al., 2004). In the case of clay from the subway station, the free swell pressure is about half as low as in the Stegny clay. This is related to differences in the mineral composition of these soils.

Another nomogram used to assess potential expansion was after van der Merwe (1965). It enables determining the expansivity based on a relation between the liquidity index I_p and the percentage of the clay fraction f_i. Figure 4 shows a nomogram with the values obtained for test samples of clay. Based on this nomogram, most of the clay samples tested should feature a very high expansion.

Figure 5 presents a classification of the soils studied with respect to their potential expansion according to a nomogram developed by McKeen (1992). This classification takes into account suction pressure. Samples of the Mio-Pliocene clay from Stegny were classified as highly and moderately expansive (class II and III), while clay from the subway station as highly expansive (class II).

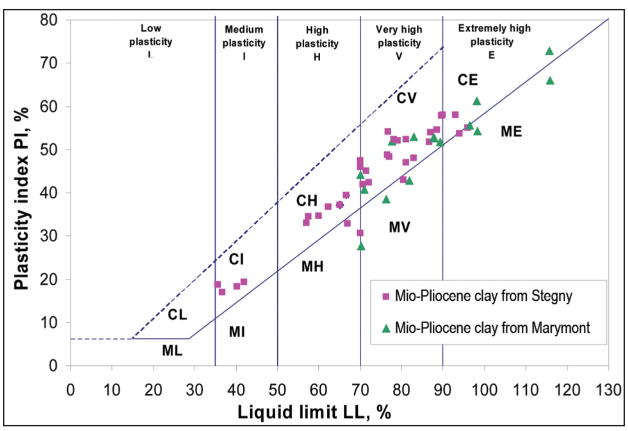

Fig. 2. Plasticity chart for evaluation of expansive ability with values for Mio-Pliocene clay from Stegny and Marymont

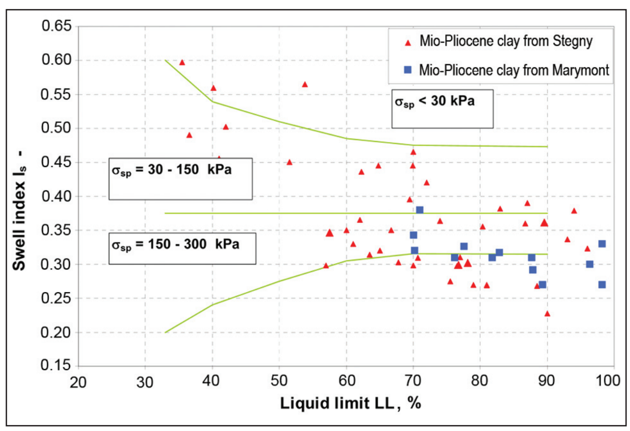

Fig. 3. Vijayvergiya and Ghazzaly chart for evaluating swell pressure values

Table 3. **Values of swell pressure of clay from Stegny and from Marymont**

Parameter	Specific surface S_t, m²/g	Sorption capacity MBC g/100g soil	Swell pressure σsp, kPa	Free swelling FS_{HG}, %	Swell pressure σsp, kPa	Free swelling FS_{HG}, %
	Geological Engineering Experimentation Site Stegny				Subway station A19 Marymont	
Min	85	4.03	36	50	19	35
Max	389	18.57	323	172	93	85
x	228	10.88	165	96	55	65
σ	82	3.91	104	30	25	19
ν %	36	36	63	31	46	29
n	34	34	17	43	12	7

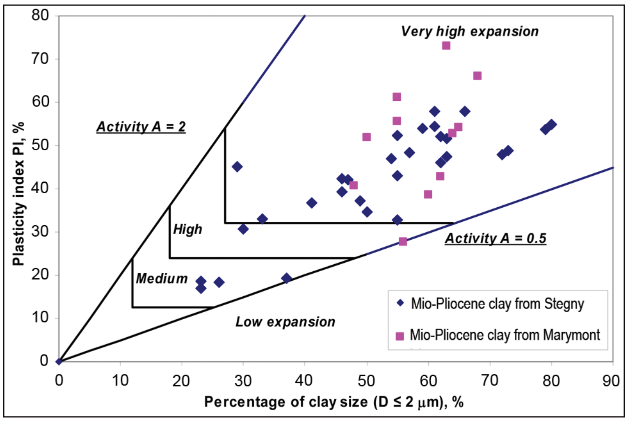

Fig. 4. Van der Merwe chart for evaluation of potential expantion

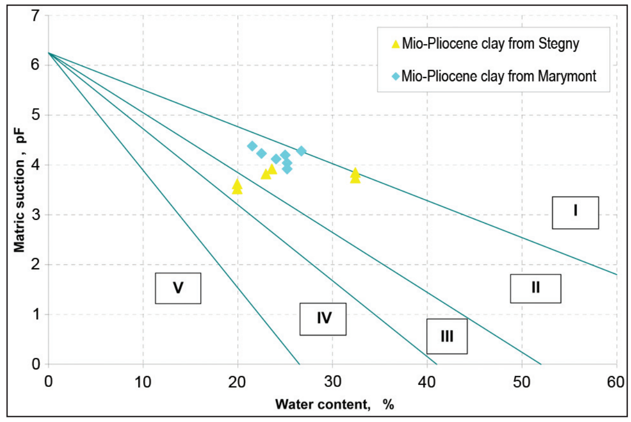

Fig. 5. McKeen (1992) classification

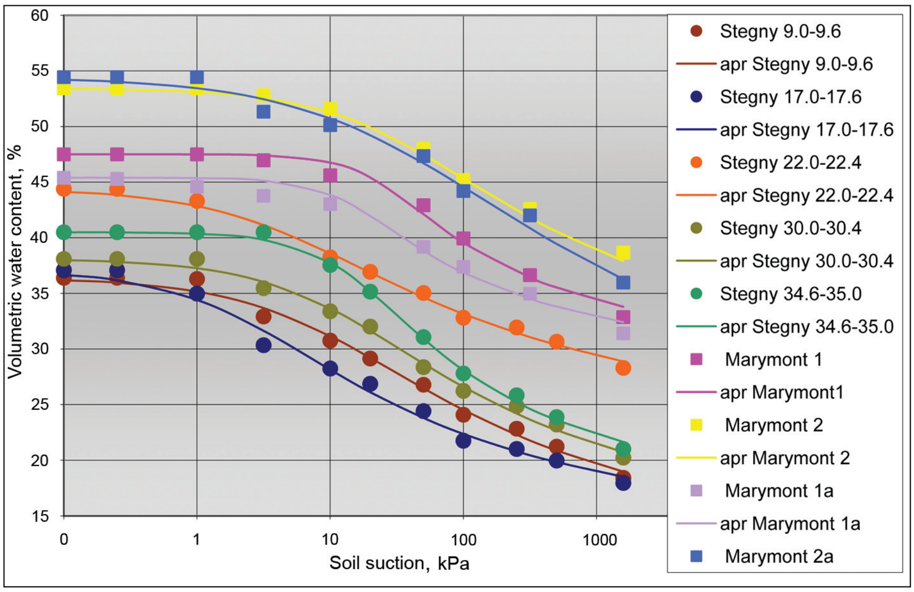

Fig. 6. Soil–water characteristic curve for Mio-Pliocene clay from Stegny and from Marymont
• experimental data line – best-fit curve.

Assessment of deformation changes was also based on the analysis of characteristic curves of soil retention. The SWCC curve is a basic characteristic of the behaviour of unsaturated soil. It represents a relation between the water content and suction pressure of the soil and is very important for analysis of strength, compressibility, permeability, thermal properties, diffusion, heat conductivity, etc. (Fredlund, 1996).

The relation between water content and suction pressure in Mio-Pliocene clay was determined at various depths at the Stegny Experimenation Site (9.0–9.6–34.5–36.0 m bgl), as well as in the clay from the subway station excavation (Marymont 1, 2, 1a, 2a).

The tests were carried out with the use of pressure plate extractors from the Soilmoisture Equipment Corporation. The characteristic curves were determined from 9 to 11 tests carried out from 0.1 to 1600 kPa. Each determination was performed on at least three identical soil samples, and the results were adopted as their arithmetical mean values. They are shown in Fig. 6.

A number of empirical formulas were proposed to interpret SWCC characteristics. In this paper, a three-parameter equation of Fredlund and Xing (1994) was used:

$$\theta_w = \frac{\theta_s}{\left\{\ln\left[e + \left(\frac{u_a - u_w}{a}\right)^n\right]\right\}^m},$$

where:
θ_w – volumetric water content,
θ_s – volumetric water content at saturation,
$u_a - u_w$ – matrix suction,
u_a – pore air pressure,
u_w – pore water pressure,
a, n, m – approximation parameters.

The characteristic formula describing the soil–water system was fitted to the data set of water content and suction pressure values with the use of the mean-squares method. The model curve calculated with the parameters found from the fitting showed a sufficient agreement with the data points (Wójcik, 2003). The parameters are listed in Table 4.

Table 4. **Parameters of Fredlund and Xing (1994) equation**

Location	Parameters of equation		
	a	n	m
Geological Engineering Experimentation Site Stegny	1.60–12.35	0.792–1.392	0.261–0.439
Subway station A19 Marymont	11.80–20.00	0.65–1.80	0.159–0.371

Table 5. **Estimation of ability to deformation changes of test clay**

Parameter / method	Geological Engineering Experimentation Site Stegny	Subway station A19 Marymont
Content of clay size D ≤ 2 μm	Average 50%	Average 59%
Content of clay minerals	Average 60%	Average 70%
Mineral composition	$B^{11-82\%} > I^{0-53\%} > K^{3-38\%}$	$B^{47-72\%} > K^{9-17\%}$
Swell pressure	36–323 kPa	19–93 kPa
Free swelling	50–172%	35–85%
Casagrande chart	High plasticity – 24% of samples very high plasticity – 47% of samples	High plasticity – 64% of samples very high plasticity – 36% of samples
Vijayvergiya, Ghazzaly chart	>150 kPa – over 50% of samples	>150 kPa – over 90% of samples
Van der Merwe chart	Very high expansion 80% of samples	Very high expansion 90% of samples
Mc Keen chart	Class II – 33% of samples Class III – 67% of samples	Class II
Soil water characteristic curves	Volumetric water content changes 18% Relative volumetric water content changes 35–49%	Volumetric water content changes 15% Relative volumetric water content changes 28–33%

Clay samples from the subway excavation show a higher volumetric water content than clay samples from the Stegny site. The air entry pressure is equal to 3–8 kPa for the clay from the Stegny site and 6–10 kPa for the clay from the subway station.

Analysis of the SWCC curves suggests that for the suction pressure interval 1–1580 kPa relative changes of the volumetric water content are equal to 35–49% for clay from the Stegny site and to 28–33% for clay from the subway station.

Results of all tests are collected in Table 5. The assessment of compressibility of the samples was based on 10 parameters and test methods.

CONCLUSIONS

The paper presents an analysis of susceptibility to volume changes of overconsolidated Mio-Pliocene clay from the Warsaw area (the Stegny Geological Engineering Experimentation Site and the excavation of the Warsaw subway station A19 Marymont).

Samples of clay from the Stegny Geological Engineering Experimentation Site were obtained from boreholes with the use of thin-wall Shelby tube samplers, and samples of clay from the subway station trench excavation were collected as soil monoliths. One has to realize that the process of collection of samples in the field and of their preparation for lab tests affect the measured values of suction and swell pressures (Chandler et al., 1992). Sample collection and preparation for tests induces unavoidable changes in the stress-strain state and in the structure of the soil samples. Therefore, the values obtained from lab tests are somewhat overestimated. An attempt to quantitatively assess the influence of the sampling procedure on changes in sample structure is the subject of this research.

The assessment of compressibility of soils discussed in this paper was based on the analysis of a number of properties and parameters. Only such complex studies enable a correct and credible assessment of the potential expansion of cohesive soils. Based on the analysis of the data obtained, we concluded that a higher compressibility is expected in the soil from the Stegny Geological Engineering Experimentation Site.

The clay fraction in clay from the subway station did not include illite. The mean content of beidelite was lower than in clay from the Stegny site.

The test samples were collected from trench excavation in the form of soil monolith. This method of sampling is less harmful the soil structure than in the case of collection to thin-walled Shelby samplers.

One should also note that clay from the subway station had a higher natural water content than clay from the Stegny site. Both these factors explain the differences between the expected swell pressure and the measurement values obtained from tests performed by the method of constant volume of a soil sample.

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VARŠUVOS RAJONO MIOCENO–PLIOCENO MOLIO DEFORMACINIŲ SAVYBIŲ ĮVERTINIMAS

Santrauka

Straipsnyje pateikiamas perkonsoliduoto mioceno–plioceno molio tūrio pokyčių įvertinimas. Tyrimai atlikti Stegny eksperimentinėje aikštelėje ir metro stotyje (A19 Marymont). Ištirta molio mineralinė ir granuliometrinė sudėtis, pagrindinės fizikinės savybės, nustatyta savitasis paviršius, sorbcinė talpa, brinkimo įtempiai, retencijos rodikliai. Laboratoriniais tyrimais užfiksuotas didelis ir labai didelis molio bandinių brinkimas. Pagal nomogramas įvertintos brinkimo slėgio vertės atitinka laboratorinius duomenis. Mažesnio tūrio deformacijos stebėtos metro stotyje paimtuose ėminiuose. Šių ėminių mažesnės plėtimosi deformacijos sietinos su drėgnesniu gruntu ir illito nebuvimu. Pastebėta, kad įtakos turi ėminių paėmimo būdas ir jų paruošimas laboratoriniams tyrimams. Ėminiai metro stotyje paimti tiesiogiai iš masyvo, o eksperimentinėje aikštelėje – iš gręžinio. Taigi galima daryti prielaidą, jog didesnės deformacijos atsiranda dėl iš dalies pažeistos grunto struktūros.

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OCENA ZDOLNOŚCI DO ZMIAN DEFORMACYJNYCH IŁÓW MIO-PLIOCEŃSKICH Z OBSZARU WARSZAWY

Streszczenie

Zmiany deformacyjne zachodzą w gruntach spoistych w efekcie współdziałania fazy stałej gruntu z fazą ciekłą. W artykule przedstawiona została kompleksowa, geologiczno-inżynierska ocena zdolności do zmian objętościowych przekonsolidowanych iłów mio-plioceńskich z obszaru Warszawy, tj. z poligonu badawczego Stegny oraz z podłoża stacji metra A19 Marymont.

Do oceny wykorzystano: skład granulometryczny i mineralny, podstawowe właściwości fizyczne oraz parametry gruntowe, takie jak powierzchnia właściwa, pojemność sorpcyjna, pęcznienie swobodne, ciśnienie pęcznienia, ciśnienie ssania oraz charakterystyki w postaci krzywych retencji iłów.

Na podstawie szeregu badań laboratoryjnych stwierdzono, że potencjalna ekspansywność jest wysoka lub bardzo wysoka dla większości badanych próbek iłów. Oszacowane wartości ciśnienia pęcznienia były zgodne z wartościami otrzymanymi z badań laboratoryjnych w przypadku iłów z poligonu badawczego Stegny.

Mniejsza zdolność do zmian deformacyjnych w iłach ze stacji metra Marymont wynika między innymi z braku illitu oraz wyższej wilgotności gruntu. Istotnym czynnikiem jest także naruszenie struktury próbek iłów podczas pobierania i przygotowywania do badań laboratoryjnych. Próbki ze stacji metra były pobrane w postaci monolitów, zaś próbki z terenu poligonu pobrano z otworów do cienkościennych próbników typu Shelby. Naruszenie struktury iłów było większe w przypadku iłów z poligonu badawczego. Z tego powodu należy sądzić, że ocena zdolności do zmian objętościowych dla iłów z poligonu badawczego jest w pewnym stopniu zawyżona.

Марек Бараньски, Эмилия Войцик

ОЦЕНКА ДЕФОРМАЦИОННЫХ СВОЙСТВ МИО-ПЛИОЦЕНОВЫХ ГЛИН ВАРШАВСКОГО РАЙОНА

Резюме

В статье оцениваются объемные деформации переуплотненных миоплиоценовых глин. Исследования проведены на экспериментальной площадке Стегны и на станции метро (А19 Марымонт) в Варшаве. Изучались минеральный и гранулометрический состав, основные физические свойства миоплиоценовых глин. Кроме того, определялись: удельная поверхность, сорбционная емкость, напряжение набухания, показатели ретенции. Установлены высокие и очень высокие значения набухания глин. Рассчитанные по номограммам значения давления набухания соответствуют данным лабораторных исследований. Условно меньшие значения объемных деформаций получены на образцах, взятых со станции метро. Это связано с низкой естественной влажностью и отсутствием иллита. Отмечено, что на результаты влияют способ отбора образцов и их подготовка для испытаний. Предполагается, что нарушение естественной структуры глин вызывает повышенные объемные деформации.