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Engineering geological properties of Vilnius and Warsaw region tills as building subsoils

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Based on the funds and literature on the engineering geological research, statistical analysis was made of the composition, physical state and mechanical properties of tills occurring in active building impact zones in Vilnius and Warsaw city territories. The advantages of till granulometric composition were established. The soil density differences were evaluated. The analysis has shown that with the increasing age of tills, the index values of their mechanical properties improve.

Key words: Vilnius, Warsaw, tills, properties

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INTRODUCTION

International cooperation in scientific and practical engineering geology is gaining more importance in determining similarities and differences of conditions in different regions.

The article analyses the engineering geological properties of soils prevailing in Lithuania's capital Vilnius and Poland's capital Warsaw. Both cities are situated in the Pleistocene glaciation zones. Frequently tills form the subsoil for buildings. Statistical evaluation of the composition, physical state and mechanical properties of different glaciations and stages of till soils occurring in the territories of these cities provides the possibility to establish the similarities and differences of these indexes, which is important for both engineering geological research and geotechnical decision-making.

STRATIGRAPHICAL POSITION OF TILLS

Geologically, the Vilnius city is situated in the zone of three Pleistocene glaciations. The city territory is divided by the deep valley of the River Neris placing up to seven benches. In most of the city territory, tills form the direct subsoil for engineering buildings or occur in the bench bases under a thin cover of sand-gravel soil. In the geological section of active impact zones of the Vilnius city buildings three till layers are found, which are most frequently separated by till sand soil layers. The Grūda (Wurm I = Vistulian = Valdaisk) till occurs in the top part of the section. The till is composed of brown, greyish brown sandy silty clay, sometimes of sandy clay. The thickness of the sediment varies in a wide interval of 3–5 m up to 40–50 m. The prevailing thickness is 20–25 m (Petrulis, 1957).

The middle part of the section contains the Medininkai (Warta = Riss II = Moskovskij) till occurring beyond the valley of the River Neris and in the top bench bases. These are brown or grey sandy clay or sandy silty clay. The average thickness is 16–18 m. The till is completely washed out in some places.

The underlying Žemaitija (Odra = Riss I = Dnieper) till is widespread in the whole territory, except for certain intervals in the valley of the River Neris within the third bench level. These are mostly brown, dark brown, sometimes grey sandy silty clay. The average thickness is 20–35 m.

The city of Warsaw is situated within the area of two geomorphological units: the Vistula river valley (right bank part) and the postglacial upland (left bank part). For the left bank part of Warsaw, tills are the main layer of the engineering subsoil for most construction activities. Within the vertical range of the influence of engineering objects on the subsoil, predominant are tills related to two Mid-Polish glaciations – Odra and Warta.

On the basis of stratigraphic data collected for the compilation of the Detailed Geological Map of Poland 1 : 50 000 (sheets Warsaw East and Warsaw West), the two upper till horizons in the environs of Warsaw were classified into the maximum stage (now the Odra glacial = RissI = Dnieper = Žemaitija) and the Mazowsze–Podlasie stage (now the Warta glacial = RissII= Moscowian = Medininkai) of the Mid-Polish glaciations (Sarnacka, 1979, Morawski, 1978). Often in borehole profiles there is no distinct boundary between the younger (Warta) and the older (Odra) till. In general, the Warta till proves to be more sandy with numerous intercalations of slightly clayey sand, decalcified at the top, brown and grey-brown in colour. Its thickness is 3–5 m, but often it has been removed by human activity or directly overlies the Odra till. The latter forms a continuous layer, more than 10 m thick more cohesive, brown to grey-brown at the top and dark grey in the lower parts of the sequence.

ENGINEERING GEOLOGICAL PROPERTIES

The evaluation and analysis of the main indexes of till composition, physical state and mechanical properties in the Vilnius city was carried out by using rich funds and literature (Dundulis, Mikšys, 1970; Mikšys, 1971; Dundulis, Šustikas, 1973; Dundulis et al., 1995, etc.). The summarised data on the composition and properties provided herein (Table 1) indicate certain distribution qualities of these index values. A similar granulometric composition, which is close to optimal mixes, is characteristic of all tills. The Žemaitija (Odra) till has higher sandy qualities up to 68%. Natural moisture content values are similar in all tills, however, they are characterised by a great fluctuation. The lowest density is typical of the youngest Grūda (Vistalian) till. The average liquidity index value is regularly decreasing while changing from the Grūda (Vistalian) till towards the older Medininkai (Warta) and Žemaitija (Odra) tills. The same regularity can be seen in the values of the initial friction angle, cohesion and the modulus of deformation.

The data of cone penetration and dynamic probing tests (Table 2) based on cone resistance (q_c) and dynamic point resistance (q_d) values shows that the variation regularities comply with the variation regularities of mechanical properties determined by the laboratory research. The lowest q_c and q_d values are typical of Grūda (Vistalian) till, while Žemaitija (Odra) till shows the highest values.

The Warsaw tills were subjected to numerous laboratory tests and field examinations, the results being presented in engineering-geological reports. Studies by W. C. Kowalski and N. Lipińska (1963) revealed the tills to have a greatly diversified lithology. Of the 1068 determinations, 23% proved to be slightly clayey sands,

Table 1. **Parameters of grain-size distribution, physical and mechanical properties of Vilnius tills**

Value	f_{g+sa}	f_{si}	f_{cl}	ρ, Mg/m³	W_n, %	W_L, %	W_P, %	I_P, %	I_L	c, kPa	φ, °	M_O, MPa	E^*, MPa
Grūda (Vistalian) till													
Max.	72	41	19	2.30	16,2	29	18	16	0.46	52	32	24	62
Min.	50	17	4	1.95	6	14	6	3	–0.12	24	21	11	21
$\overline{x}$	63	26	11	2.12	12,2	15.7	10.2	8.5	0.23	44	28	18	30
n	3.48	34	34	168	209	192	192	192	192	43	43	15	
σ	5.88	6.77	3.71	0.045	3.14	1.64	2.48	1.77	0.10	34.1	2.91		
v	0.09	0.26	0.33	0.02	0.26	0.11	0.24	0.21	0.43	0.77	0.09		
Medininkai (Warta) till													
Max.	78	36	17	2.40	20.1	26.2	22.0	16.2	0.48	72	33	29	79
Min.	55	12	7	2.03	6.5	12.9	4.7	4.5	–0.03	28	29	19	32
$\overline{x}$	64	24	11	2.23	10.9	18.3	10.2	7.7	0.22	64	32	24	55
n	40	40	40	261	301	301	301	301	301	34	34	12	
σ	5.34	5.8	3.32	0.07	2.66	3.92	3.31	1.47	0.08	26.9	1.71		
v	0.08	0.24	0.29	0.03	0.24	0.21	0.32	0.19	0.36	0.42	0.05		
Žemaitija (Odra) till													
Max.	80	30	20	2.40	19	37	20	15	0.29	75	35	31	80
Min.	56	7	6	2.05	7	14	6	4	–0.20	58	27	24	42
$\overline{x}$	68	21	11	2.24	10.7	18.8	11.1	8.0	–0.05	68	32	25	63
n	32	32	32	119	1.36	136	13.6	136	136	21	2.64	11	
σ	5.86	5.26	3.82	0.08	2.75	4.67	4.15	1.72	0.09	0.77	0.08		
v	0.09	0.24	0.35	0.03	0.26	0.25	0.37	0.21	0.49	0.10			

f_{g+sa} – particles of gravel and sand; f_{si} – particles of silt; f_{cl} – particles of clay; ρ – density; W_n – moisture content; W_L – liquid limit; W_P – plasticity limit; I_P – plasticity index; I_L – liquidity index; M_0 – odometric modulus; E^* – modulus of deformation; *n* – number of tests; σ – standard deviation; $\overline{x}$ – average value.
Note: E^* – PTL tests.

Table 2. **Data on cone penetration and dynamic probing tests of Vilnius tills**

Stratigraphical division	Cone resistance q_c, MPa	Dynamic point resistance q_d, MPa	Modulus of deformation *E*, MPa
Grūda (Vistalian)	0.7 – >15.0 (3.0)	–	12.0 – >67.0 (29.0)
Medininkai (Warta)	1.0 – >20.0 (6.0)	4.5 – >70.0 (15.0)	7.0 – >80.0 (42.0)
Žemaitija (Odra)	6.0 – >20.0 (10.0)	8.0 – >100.0 (28.0)	40.0 – >80.0 (52.0)

Note: min. – max. (average).

57% clayey sand, 10.1% sandy clay, 6.8% clayey and sandy silt, 1.7% sandy and silty clay, 0.2% clayey silt and 0.1% sand according to British Standard Classification.

For comparison, the following data were selected: laboratory tests completed for the Engineering Geological Atlas of Warsaw (2000), those carried out by the "Geoprojekt" enterprise and compiled by W. C. Kowalski and N. Lipińska (1963), tests completed at the Department of Engineering Geology for the Ursynów Escarpment, and the authors' field investigations from the Escarpment and housing estate in Ryżowa Street.

The pronounced vertical lithological variability of tills is responsible for a great scatter of laboratory results (Tables 3, 4). Therefore, more reliable proved to be the strength-deformation parameters obtained from *in situ* CPT and DMT tests (Table 5). An example in Figure gives the results of CPT tests and illustrates the variability of tills (from four testing points in Ryżowa Street in Warsaw, Table 5). Generally, the strength-deformation parameters of tills obtained from laboratory tests show values lower than the parameters from *in situ* examinations.

Generally, tills as building subsoil are characterized by a very high bearing capacity and a relatively low deformability for average building conditions. But the Odra tills are more consolidated, and their deformation modulus and shear strength are higher than those for the Warta tills. Laboratory tests yield elevated strength-deformation parameter values. A serious difficulty in designing foundation work is the presence of sandy intercalations, particularly in the Warta tills. Often these intercalations bear groundwater which necessitates dewatering of the excavations, the original state of the tills being preserved. As a result of the high lithological variability, the boundaries of the engineering geological layers between the boreholes are not always being interpreted with sufficient accuracy. Therefore, data from each excavation must be always approved by a geologist prior to starting foundation works.

COMPARATIVE ANALYSIS OF VILNIUS AND WARSAW TILLS

The comparative analysis of Medininkai (Warta) and Žemaitija (Odra) tills in Vilnius and Warsaw territories provided the possibility to highlight the similarities and differences of till composition, physical state and mechanical properties.

By granulometric composition, the middle Pleistocene tills occurring in the territories of both Vilnius and Warsaw are to be ascribed to optimal mixes, and no distinctive differences are observed. A slight increase of clay fraction up to 2–3% was found in tills of the Warsaw territory.

Table 3. **Parameters of grain-size distribution, physical and mechanical properties of Warta (Medininkai) till**

Value	f_{g+sa}	f_{si}	f_{cl}	ρ, Mg/m³	W_n, %	W_L, %	W_P, %	I_P, %	I_L	c, kPa	φ, °	M_O, MPa	E^*, MPa
1													
Max.	74.5	24.0	18.0	2.25	19.0	26.5	13.1	15.4	0.6	50.0	30.0	250.0	68.0
Min.	61.9	16.0	6.5	1.80	9.0	16.7	9.21	7.1	–0.15	7.0	9.0	24.0	9.0
$\bar{x}$	66.4	20.4	13.1	2.14	12.8	22.3	10.9	11.4	0.17	32.6	19.1	49.68	32.49
n	8	8	8	50	52	38	38	30	57	55	55	43	37
σ	21.56	6.59	14.4	0.01	6.19	4.80	0.52	3.31	0.02	55.68	11.89		
v	0.33	0.32	1.1	0.01	0.48	0.22	0.05	0.23	0.12	1.71	0.62	>1	>1
2													
Max.	98.0	67.0	30.0	2.24	26.2	53.1	23.6	29.5	0.79	90.0	42.0		
Min.	7.0	2.0	2.0	1.43	7.2	10.1	9.2	2.7	0.00	9.0	2.0		
$\bar{x}$	64.4	23.2	10.1	2.09	14.1	24.1	11.7	12.3	0.26	37.7	13.0		
n	97	98	95	206	367	246	249	125	466	220	259		
σ	11.8	9.5	5.0	0.1	2.8	4.7	1.6	5.3	0.10	19.0	7.7		
v	0.18	0.41	0.50	0.05	0.2	0.2	0.14	0.43	0.38	0.5	0.59		
3													
Max.	56.0	38.0	29.0	2.21	14.2	36.8	14.3	22.5	0.17	125.9	36.7	24.5	
Min.	33.0	25.0	18.0	2.11	9.05	19.1	12.2	6.6	–0.32	36.9	23.3	12.7	
$\bar{x}$	44.8	32.9	22.3	2.18	11.31	25.5	12.8	12.7	–0.01	77.0	30.6	17.3	
n	7	7	7	7	12	5	5	5	5	9	9	3	
σ	5.35	4.74	4.03	0.04	1.76	6.89	0.89	6.13	0.18	111.6	5.14	6.3	
v	0.12	0.14	0.18	0.02	0.16	0.27	0.07	0.48	–18.0	1.45	0.17	0.36	

According to:

1) A. Koc, Department of Engineering Geology, UW;

2) Engineering-Geological Atlas of Warsaw;

3) Research of Department of Engineering Geology, UW;

4) Research of "Geoprojekt", collected by W. C. Kowalski, N. Lipińska.

*) Modulus by Rowe consolidometer (50–400 kPa).

Table 4. **Parameters of grain-size distribution, physical and mechanical properties of Odra (Žemaitija) till**

Value	f_{g+sa}	f_{si}	f_{cl}	ρ, Mg/m³	W_n, %	W_L, %	W_P, %	I_P, %	I_L	c, kPa	φ, °	M_O*), MPa	E*, MPa
2													
Max.	99.0	49.0	51.0	2.26	98.0	46.3	16.5	31.4	0.45	170.0	32.0		
Min.	42.0	1.0	4.0	1.78	7.0	17.0	9.4	3.3	–0.71	5.0	2.2		
$\overline{x}$	65.5	21.2	13.9	2.11	13.7	23.2	10.9	12.5	0.15	54.0	17.4		
n	38	38	36	53	190	73	73	58	275	116	120		
σ	11.4	9.4	7.7	0.1	7.0	4.8	1.3	4.5	0.2	32.0	6.6		
v	0.17	0.44	0.55	0.05	0.51	0.21	0.12	0.36	1.33	0.59	0.38		
3													
Max.	50.0	49.0	29.0	2.29	16.6	48.1	17.3	30.8	0.21	200.9	34.7	28.0	
Min.	30.0	24.0	18.0	2.09	9.0	18.9	10.7	6.7	–0.27	36.2	20.4	11.7	
$\overline{x}$	41.4	34.5	24.1	2.21	11.7	25.0	12.8	13.0	–0.02	104.1	30.2	19.3	
n	15	15	15	33	42	20	20	20	20	16	16	13	
σ	5.87	6.93	3.93	0.04	2.20	7.05	1.41	5.85	0.12	47.36	4.64	5.1	
v	0.14	0.20	0.16	0.02	0.19	0.28	0.11	0.45	–6.0	0.45	0.15	0.26	
4 – Nondisconnected till (Warta + Odra stage)													
Max.	84.0	73.0	30.0	2.28	33.3	47.6	29.6	17.8	0.87	150.0	30.0		30.0
Min.	18.0	13.0	10.0	1.82	6.1	16.7	10.0	9.4	<0.0	2.0	2.0		4.8

Table 5. **The average and extreme values of engineering-geological properties according to CPT sounding (Warsaw, Ryżowa Str.)**

Stratigraphical division		Cone resistance q_c, MPa	Liquidity index, I_L	Modulus of deformation E, MPa	Odometric Modulus M, MPa	Ungrained shear strength τ_u, MPa
Part	Stage					
Middle Pleistocene	Warta	1.4–9.9 (2.8)	0.12–0.39 (0.29)	14.5–39.8 (27.6)	15.4–56.8 (34.8)	0.05–0.39 (0.11)
	Odra	3.8–28.9 (10.6)	–0.27–0.17 (–0.04)	29.1–124.9 (76.0)	41.6–151.9 (108.5)	0.14–1.15 (0.42)

Note: min.–max. (average).

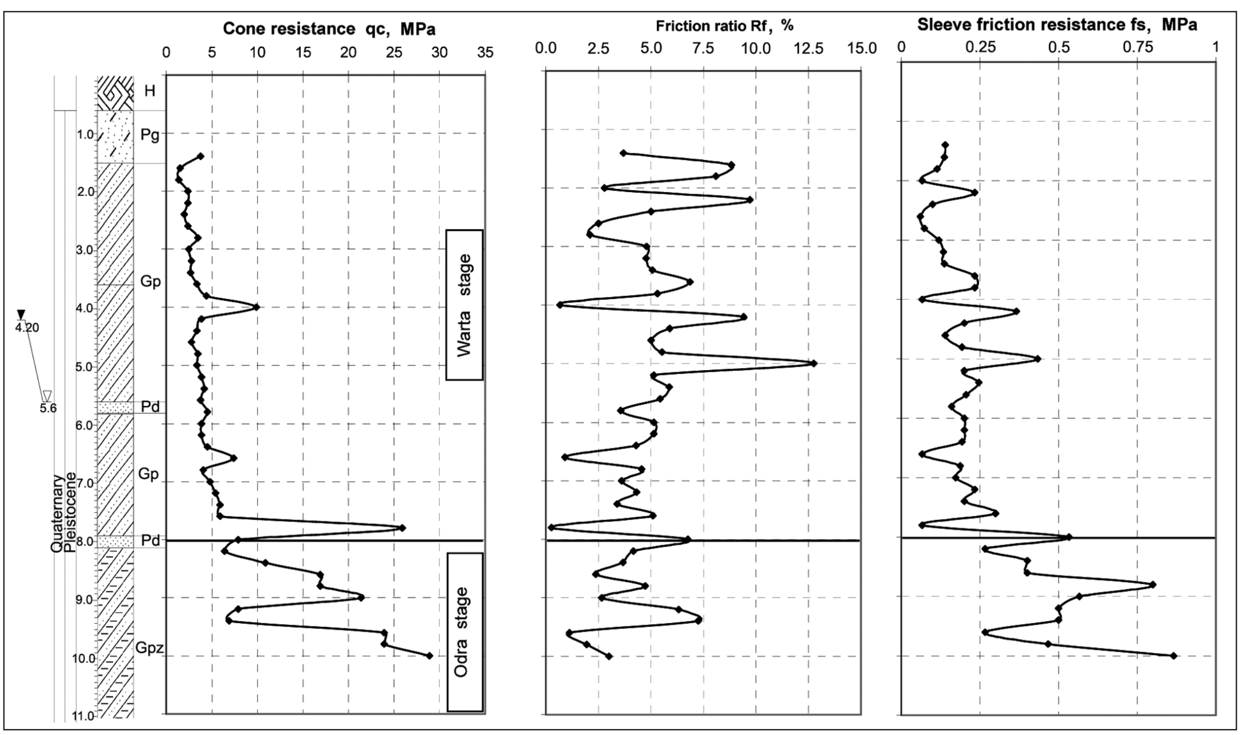

Figure. Example of cone penetration test results from Ryżowa Street in Warsaw

More distinctive differences were observed when analysing the physical state indexes. A higher density is characteristic of both lower tills in the Vilnius territory. Their average density values stand at 2.23–2.24 Mg/m^3. The Warsaw territory tills have lower values (ρ = 2.11–2.14 Mg/m^3). Natural moisture content in Vilnius territory tills (W_O = 10.7–10.9%) is lower than in Warsaw tills (W_O = 12.8–13.7%). The plasticity index I_p in Warsaw tills is higher (I_p = 11.4–12.5%) than in the same tills of Vilnius (I_p = 7.7–8.0%). By the average I_L values, both territories of Warsaw show a very stiff physical state. In the Vilnius territory, Medininkai (Warta) by average values is in a stiff state, while Žemaitija (Odra) is in a very stiff state.

Distinct differences are observed when analysing the average values of the initial friction angle and cohesion. The initial friction angle of tills in the Vilnius territory make about 32°, while in the Warsaw territory tills it makes only 17–19°. Respectively, the average cohesion values are also higher in Vilnius territory tills (c = 64–68 kPa), while c values standing at 32–54 kPa are typical of Warsaw territory tills.

CONCLUSIONS

Tills occurring in Vilnius and Warsaw city territories are characterised by a similar composition, differences in their physical state and a rather high variation of mechanical properties. By granulometric composition, the tills are ascribed to optimal mixes. Higher density and lower moisture content are typical of Vilnius city territory tills. Analysis of mechanical properties has revealed the general regularities that older tills indicate a higher strength and lower compressibility qualities.

References

1. Atlas Geologiczno-Inżynerski Warszawy. 2000. PIG Warszawa. Praca niepublikowana.
2. Дундулис К., Микшис Р. Б. 1970. Отчёт Инженерно-геологические условия г. Вильнюса. Вильнюс, Геологический фонд Геологической службы Литвы. 243 с.
3. Дундулис К., Шустикас К. 1972. Отчёт инженерно-геологических изысканий для технико-экономических основ г. Вильнюс на 2000 год. Вильнюс, Архив АО „Инженерные изыскания“. 165 с.
4. Dundulis K., Mikšys R. B., Brilingas A. 1995. Geological analysis of geotechnical properties of Vilnius soils. *Proc. of XI Europ. Conf. on Soils Mech. DGS*. Copenhagen. ***8***(*8*). 49–8.53.
5. Kowalski W. C., Lipińska N. 1963. Rodzaje gruntów serii glin zwałowych Warszawy. *Przegląd Geologiczny*. ***9***. 426–428.
6. Микшис Р. Б. 1971. Инженерно-геологические условия г. Вильнюса. Кандидатская диссертация. Ленинград, Ленинградский горный институт им. Г. В. Плеханова. 180 с.
7. Morawski W. 1978. Szczególowa Mapa Geologiczna Polski 1 : 50000 ark. Warszawa–Zachód. Instytut Geologiczny. Wyd. Geologiczne, Warszawa.
8. Петрулис Л. В. 1957. Квартерные отложения в г. Вильнюсе. *Труды Института геологии и географии*. ***4***. 17–19.
9. Sarnacka Zd. 1979. Szczególowa Mapa Geologiczna Polski 1 : 50000 ark. Warszawa–Wschód. Instytut Geologiczny. Wyd. Geologiczne, Warszawa.

Kastytis Dundulis, Ryszard R. Kaczyński, Kazimierz S. Krauźlis, Gintaras Žaržojus

VILNIAUS IR VARŠUVOS REGIONŲ MORENŲ, KAIP PAGRINDO STATINIAMS, INŽINERINĖS GEOLOGINĖS SAVYBĖS

S a n t r a u k a

Vilniaus ir Varšuvos miestų teritorijose paplitusių morenų, kurios naudojamos kaip pagrindas inžineriniams statiniams, sudėties, fizinės būklės ir mechaninių savybių apibendrinimas bei analizė leido įvertinti šių morenų savybių kaitos dėsningumus. Morenų granuliometrinė sudėtis abiejuose miestuose yra panaši ir priskiriama optimaliems mišiniams. Vilniaus miesto morenos yra kur kas tankesnės ir ne tokios drėgnos. Nors pagal morenų mechanines savybes tiek Vilniaus, tiek Varšuvos miestų morenos priskirtinos stipriems ir mažai spūdiems gruntams, tačiau Vilniaus moreniniams gruntams būdingos daug didesnės sankibos ir vidinės trinties kampo vertės. Stebimas dėsningas fizinės būklės ir mechaninių savybių verčių didėjimas didėjant morenų geologiniam amžiui.

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GEOLOGICZNO-INŻYNIERSKIE WŁAŚCIWOŚCI GLIN LODOWCOWYCH, Z REJONU WILNA I WARSZAWY, JAKO PODŁOŻA BUDOWLANEGO

S t r e s z c z e n i e

Gliny lodowcowe, jako podłoże budowlane, powszechnie występują w rejonie Wilna i Warszawy. Analiza ich właściwości fizyko-mechanicznych pozwoliła ocenić zmienność oraz uogólnione prawidłowości. Skład granulometryczny glin jest zbliżony dla obu omawianych rejonów i można je zaliczyć do gruntów mieszanych o optymalnym składzie granulometrycznym. Gliny lodowcowe z rejonu Wilna odznaczają się znacznie większą spójnością i mniejszą wilgotnością. Ze względu na właściwości mechaniczne, zarówno gliny lodowcowe z rejonu Wilna jak i Warszawy należy zaliczyć do gruntów bardzo mocnych i mało ściśliwych. Obserwuje się w obu rejonach prawidłowość taka, że wartości stanu fizycznego i właściwości mechanicznych zwiększają się ze wzrostem wieku geologicznego omawianych glin lodowcowych.

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ИНЖЕНЕРНО-ГЕОЛОГИЧЕСКИЕ СВОЙСТВА МОРЕН В ВИЛЬНЮССКОМ И ВАРШАВСКОМ РЕГИОНАХ, ИСПОЛЬЗУЕМЫХ КАК ОСНОВАНИЯ ДЛЯ ИНЖЕНЕРНЫХ СООРУЖЕНИЙ

Р е з ю м е

Анализ состава, физического состояния и механических свойств используемых в качестве оснований для инженерных сооружений морен Вильнюсского и Варшавского регионов позволил установить закономерности изменения свойств этих морен. Гранулометрический состав морен в обоих городах похож и относится к оптимальным смесям. Морены города Вильнюса отличаются более высокой плотностью и низкой влажностью. По механическим свойствам морены в Вильнюсе и в Варшаве следует отнести к прочным и малосжимаемым грунтам, однако моренные грунты в Вильнюсе характеризуются более высокими значениями сцепления и угла внутреннего трения. Наблюдается закономерное повышение значений некоторых показателей физического состояния и механических свойств в зависимости от геологического возраста морен.