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Properties of fine soils of Klaipėda Port area

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In the article, taking Klaipėda quays 7, 8 and 9 as examples, peculiarities of fine soil (silty clay, silty sandy clay and clayey silt) grain size distribution, physical state and mechanical properties are discussed. It was established that in these soils of a very similar physical state, the grain composition determines their mechanical properties.

Key words: Klaipėda Port, fine soils, geotechnical properties

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INTRODUCTION

While reconstructing quays, embankments before deepening the water area of the Klaipėda Port, due to the peculiarities of the engineering geological situation, some problems were faced when piles were installed for the supporting walls. After the reconstruction of the 7, 8 and 9 quays, their stability was questioned when the water area was deepened. Therefore, the subsoil of these quays was analysed in greater detail using field analysis, boring and later by performing the analysis of the samples. Besides the traditional laboratory analysis, we established also the full granulometric composition and samples with a full, undisturbed structure were analysed using a triaxial pressure equipment. A more detailed geotechnical research allowed characterizing the engineering geological situation at the quays 7–8–9 more specifically, together with the real construction of the reconstructed quays and the possibility of deepening the water area.

GENERAL GEOLOGICAL SITUATION

The geological organization of Klaipėda Sea Port is characterized by a huge variety. The topmost part of the port quay territory is covered by fill soil, usually underlain by sandy soil. Under these soils there is till soil of the upper Pleistocene. In some places, under this till there are soils of middle Pleistocene silt and silty clay of Pamarys formation. Deeper there lie stiff soils of the middle Pleistocene Medininkai till. The latter in some places is intersected by deep erosive trenches filled with silty and fine sand. The depth of trenches reaches 30 m in some places (Dundulis, Gadeikis, 1998; Gadeikis, 1998).

In the place of the 7, 8 and 9 quays of Klaipėda Port, the geological section up to 18.0 m NN in the mass is more ordinary but is distinguished by a variety of fine soils. Up to the depth of 6.5–7.5 m NN, there is fill soil underlain mostly by fine sand. The lower layers, up to 13.5 m NN and up to the depth reached by boring, consist of fine soils.

The biggest part of fine soils is made from silty clay till (Fig. 1), but in the bores No.1 and No. 2, in this soil from 8.1–9.8 m NN up to 9.9–13.2 m NN, there is an interlayer of clayey silt with silt. The thickness of this clayey silt is up to 1.8 m (bore No. 2) and up to 3.4 m (bore No. 1). In the bottom part of the fine soil thickening (bores No. 2 and No. 3) there is a layer of 1.2–1.5 m silty sandy clay. In the third bore, under the fine soils, there lies a layer of fine sand 3.4 m thick.

THE GRANULOMETRIC COMPOSITION AND PHYSICAL STATE OF THE FINE SOILS

In the territories of Klaipėda Port quays 7, 8, 9, according to the granulometric composition, the three main types of clayey soils were distinguished: silty clay, silty sandy clay and clayey silt. The granulometric composition of these soil types is presented in Table 1.

The graphs of the granulometric composition are presented in Fig. 2. They show the composition peculiarities of these soil types. The composition of clayey silt fraction has clear differences, silt fraction making a biggest part in it (up to 74.1%). The quantity of this fraction in the silty clay and in the silty sandy clay varies from 41.4 to 48.4%, the quantity of sand fraction parts being slightly less (39.4–28.8%). The soils of moraine silty and silty sandy clay are distinguished by a larger content of silty fraction and by a smaller content of sand fraction as compared with till soils of the Middle Lithuanian phase (Gadeikis, 1998). In the triangular scheme of grain composition distribution (Fig. 3), the two statistical fields can be clearly distinguished. The first is made from silty clays and silty sandy clay of moraine nature. Among the latter soil kinds,

the differences in grain size distribution are slight. The second field consists of clayey silts and silts, which in the geological section make a separate interlayer.

The values of the parameters reflecting the physical state of the soils varies marginally (Table 2). The density of solid particles, the density and void ratio are very similar. The above-mentioned kinds of soils vary marginally in the values of moisture content and plasticity parameters. According to the index of liquidity values, all soils are very stiff. Thus all the distinguished sorts of fine soils are very similar in their physical state.

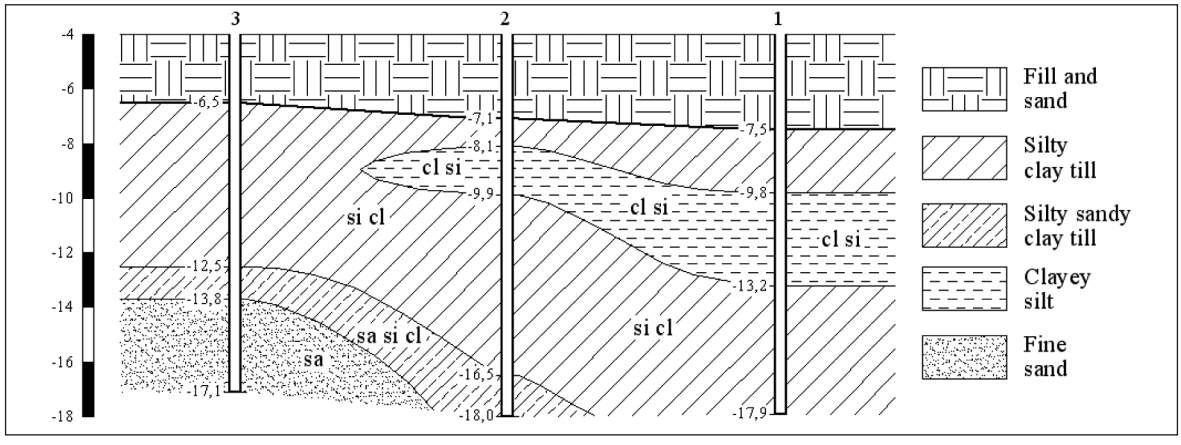

Fig 1. Engineering geological section

1 pav. Inžinerinis geologinis pjūvis

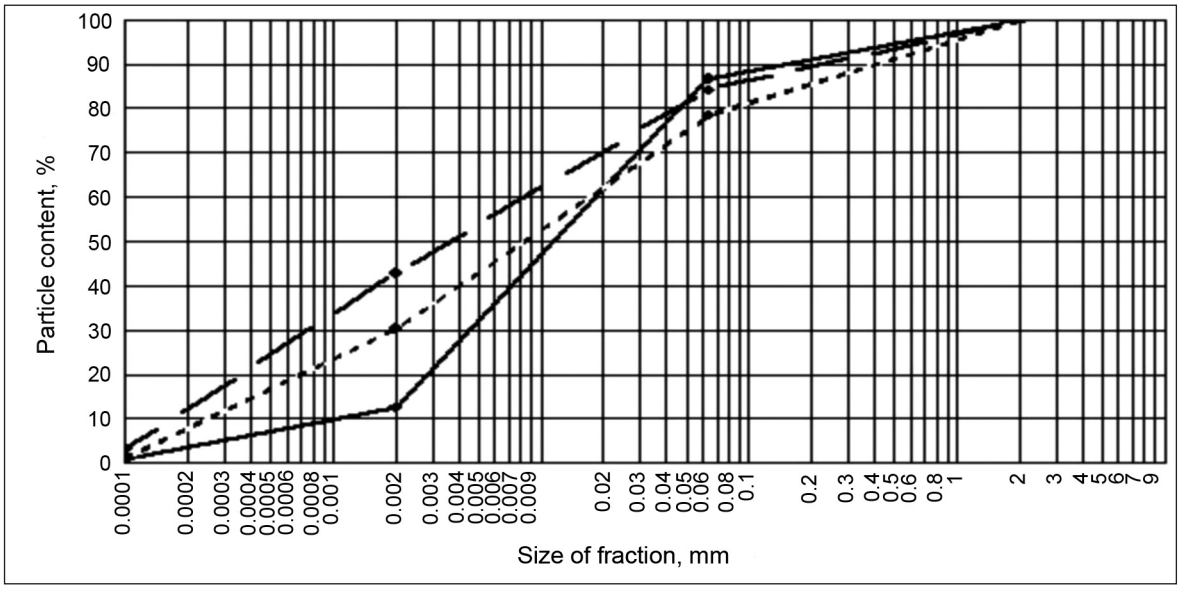

Fig. 2. Grain size distribution curves of fine soils (——clayey silt, — — —silty sandy clay, - - - silty clay)

2 pav. Smulkiųjų gruntų granuliometrinės sudėties kreivės (——molingas dulkis, — — —dulkingas smėlingas molis, - - - dulkingas molis)

Table 1. **Grain size distribution and statistical values of fine soils of Klaipėda Port territory quaywells**

Lentelė 1. **Klaipėdos uosto teritorijos krantinės smulkiųjų gruntų granuliometrinės sudėties statistinės vertės**

Soil type	Fraction, mm, and its content, %			
	>2	2.0–0.063	0.063–0.002	<0.002
Silty clay	0.44–3.37	22.93–32.42	41.95–57.26	16.00–26.50
	1.45 (12)	28.80 (12)	48.37 (12)	21.38 (12)
Silty sandy clay	0.83–6.98	34.78–46.42	37.80–44.90	13.34–19.50
	3.44 (5)	39.43 (5)	41.39 (5)	15.75 (5)
Clayey silt	0.00–3.56	2.15–24.88	58.06–85.10	10.20–18.50
	0.92 (10)	11.75 (10)	74.05 (10)	13.28 (10)

In numerator – min and max values, in denominator – average values, in brackets – number of samples.

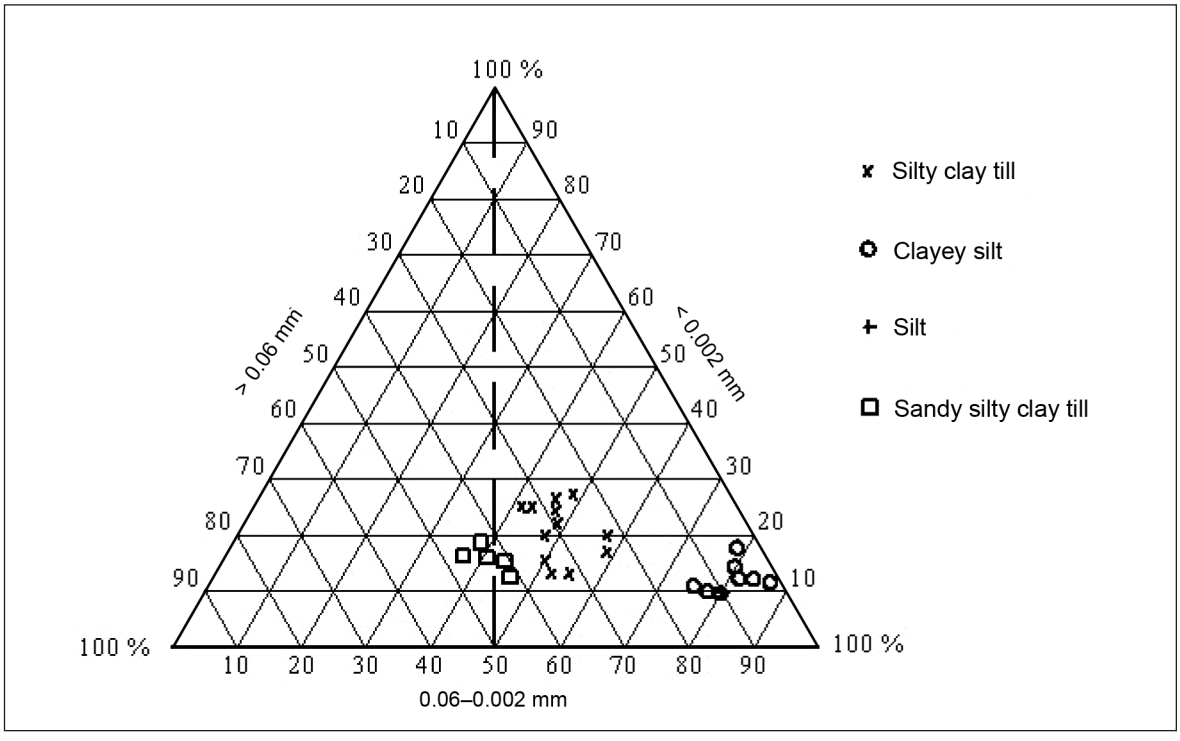

Fig. 3. Threeangular scheme of grain size distribution

3 pav. Trikampė granuliometrinės sudėties schema

Table 2. **Physical state parameters and statistical values of fine soils of Klaipėda Port territory quaywells**

2 lentelė. **Klaipėdos uosto teritorijos krantinių smulkiųjų gruntų fizinės būklės rodiklių statistinės vertės**

Soil type	Statistical values	Density of particles ρ_s, Mg/cm³	Density ρ, Mg/cm³	Void ratio e	Moisture content W, %	Liqiud limit, W_L, %	Plastic limit Wp, %	Plasticity index Ip, %	Liquidity index I_L, %
Silty clay	Average	2.71	2.20	0.38	12.07	25.54	14.68	10.86	–0.27
	Max	2.74	2.27	0.41	13.58	30.80	15.48	15.87	–0.13
	Min	2.67	2.15	0.31	10.00	18.80	13.54	4.68	–0.88
	Var. coefficient	0.067	0.013	0.06	0.09	0.11	0.04	0.25	–0.74
	Stdv	0.0182	0.0291	0.0258	1.1874	2.9682	0.6462	2.7585	0.2006
	Amount	12	12	12	12	12	12	12	12
Silty sandy clay	Average	2.69	2.22	0.33	9.57	24.84	13.69	11.15	–0.40
	Max	2.72	2.26	0.44	11.48	28.30	14.24	14.14	–0.10
	Min	2.66	2.10	0.30	8.97	21.80	12.77	7.67	–0.67
	Var. coefficient	0.01	0.03	0.18	0.11	0.09	0.05	0.22	–0.52
	Stdv	0.02	0.06	0.06	1.07	2.32	0.68	2.41	0.21
	Amount	5	5	5	5	5	5	5	5
Clayey silt	Average	2.71	2.21	0.40	14.59	25.60	17.79	7.82	–0.44
	Max	2.74	2.27	0.49	17.60	31.56	20.13	12.17	–0.01
	Min	2.68	2.13	0.33	9.72	23.20	14.94	5.13	–0.85
	Var. coefficient	0.01	0.02	0.11	0.18	0.10	0.11	0.25	–0.58
	Stdv	0.019	0.045	0.043	2.573	2.465	2.004	1.975	0.250
	Amount	10	10	10	10	10	10	10	10

SHEAR STRENGTH PARAMETERS

The clayey silt and silty clay layer resistance to the shear was analysed using the triaxial pressure equipment of Bishop & Wesley type. Ten undisturbed samples were prepared from the clayey silt layer and tested, and 18 undisturbed samples were prepared from silty clay and also tested. In the natural conditions of stratification, the very dense clayey silt, when the natural was changed, reconsolidated, became fragile and easily crannied in horizontal fractures. According to BS1377: Part 8 : 1990 provisions, samples 50 mm in diameter and 100 mm high of undisturbed structure, saturated with water and consolidated isotropically were tested. Using a triaxial pressure equipment, the consolidated undrained (CU) test was made by measuring

the porous pressure in a sample. The water saturation degree of a sample was checked by calculating the porous pressure ratio $B = \Delta u / \Delta\sigma^3$. According to the BS1377: Part 8 : 1990, the criterion B should be no less than 0.95 and to match the satisfactory degree of water saturation. For hard till soils, B can be less, but no less than 0.90. The radial pressure during the test was equal to a half, one and double effective pressure which was during the natural conditions of soil stratification. The vertical pressure was increased by following the consistent speed of axial deformation, whose magnitude was established according to the time of sample consolidation. During the testing, the speed of axial deformations was from 2 to 5 mm/h. Curves presented in Fig. 4 show the variations of clayey silt tension deviator and the porous pressure when the axial deformations increase with increasing the vertical pressure. The curves presented in Fig. 5 are typical of silty clay. The manner of the soils matches the manner of the overconsolidated soils.

In the curve of clayey silt tension deviator, we can determine the peak resistance to shear, when the maximum value of strain, tension deviator, is reached and the resistance to shear is settled. During the settled resistance to shear, negative values of porous pressure are recorded. According to the peak resistance, the average value of the internal friction angle in the clayey silt is φ_f = 34.2° and the cohesion c' = 68 kPa. During the settled resistance to the shear, the angle of internal friction is φ_{cr} = 32.9° and the cohesion c' = 29 kPa. The peak values were obtained with 3–6% axial deformations and their settling next to a steady value with 7–10% axial deformations. Porous pressure begins to decrease when the axial deformations exceed a 1% limit.

The dilatation effect is expressed by a difference between the peak and the settled resistance to the shear state, the angle of the internal friction value: $\Psi = \varphi_f - \varphi_{cr}$. Due to dilatation, the porous pressure in the silty clay decreases up to negative values. According to Ortigao (1995), the change in the angle of internal friction reaches 4–8° due to a dilatation in the silts. The circumstance that during the peak values a higher cohesion was received can be explained by a very high density of the clayey silt, when the particles are packed together very strongly. In the case of settled resistance, the cohesion and the angle of internal friction decrease in the shear plane due to dilatation.

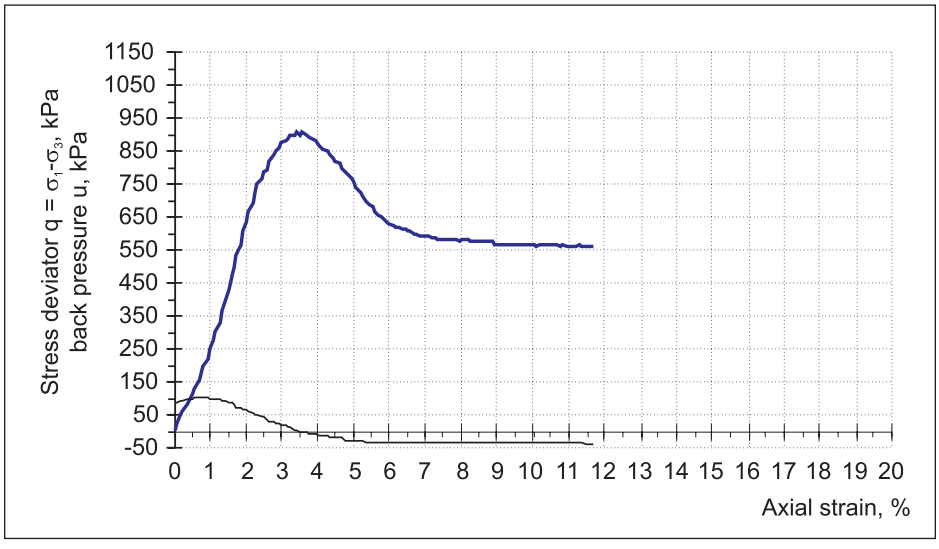

Fig. 4. Behaviour of clayey silt in consolidated undrained (CU) test

4 pav. Molingo dulkio būklė konsoliduoto drenuoto (CU) bandymo metu

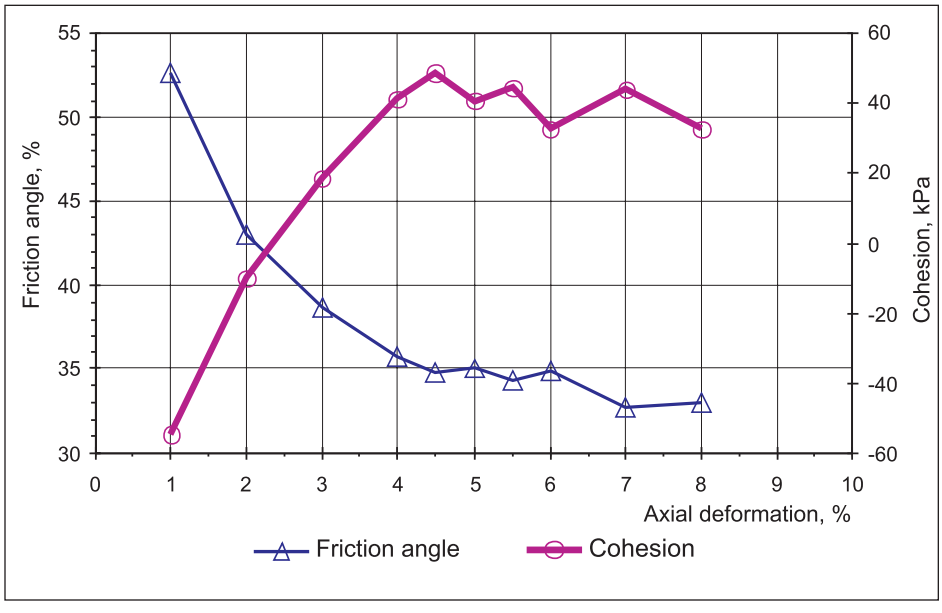

Fig. 5. Changes of initial friction angle and cohesion of clayey silt with increasing the axial strain

5 pav. Molingo dulkio vidinės trinties kampo ir sankibos pokyčiai didėjant ašinėms deformacijoms

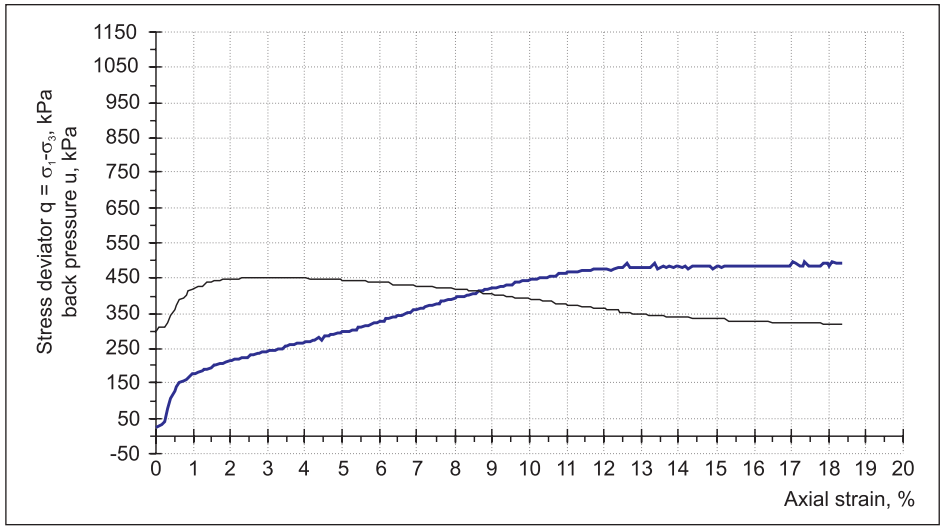

Fig. 6. Behaviour of silty clay in consolidated undrained (CU) test

6 pav. Dulkingo molio būklė konsoliduoto drenuoto (CU) bandymo metu

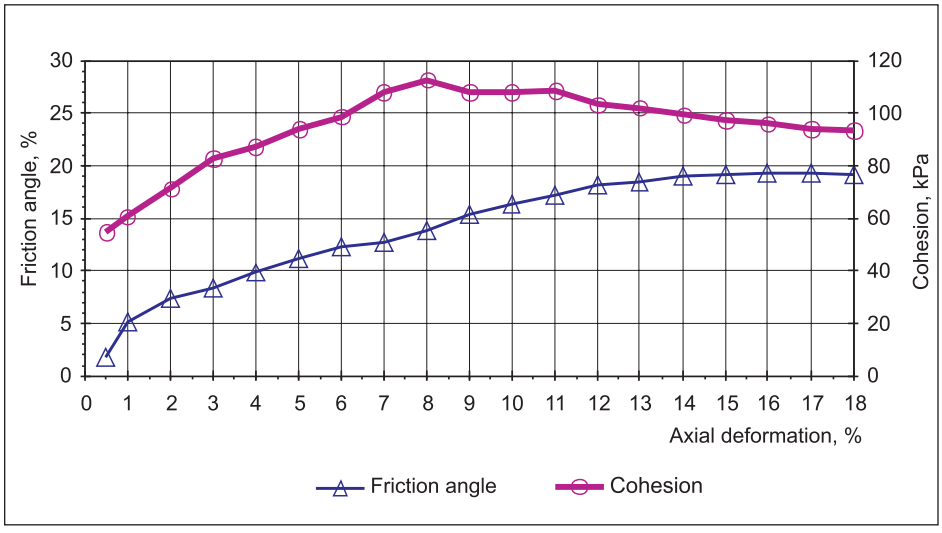

Fig. 7. Changes of initial friction angle and cohesion of silty clay with increasing the axial strain

7 pav. Dulkingo molio vidinės trinties kampo ir sankibos pokyčiai didėjant ašinėms deformacijoms

In Fig. 5, the variation of the angle of internal friction and of the middle cohesion values was calculated when the axial deformations increased. According to the curves, the peak value was reached when there were 4.5% of deformations, when the value of the internal friction angle in the clayey silt was $\varphi_f = 34.8°$ and cohesion $c' = 49$ kPa. When 7% of deformations is exceeded, $\varphi_f = 33.0°$, and cohesion $c' = 44$ kPa in the case of settled resistance to the shear.

The maximum resistance of a silty clay sample to the shear was reached when the axial deformations were much larger – 15–17% (Fig. 6). Such attribution of the curve, as stated in various publications and in one of the most important works in the field (Bishop, 1962), matches the manner of the overconsolidated clayey soil.

Effective strength parameters of the silty clay: average internal friction angle $\varphi_f = \varphi_{cr} = 20.4°$, cohesion $c = 94.2$ kPa. The decrease of the porous pressure during the test shows that the dilatation effect also exists in these soils. Ortigao (1995) states that in the consolidated drained test (CD) the dilatation effect would be bigger.

In Fig. 7, the variation of the silty clay internal friction angle and of cohesion is presented, calculated when the axial deformations increase. When the value of axial deformations is 14%, the angle of internal friction $\varphi = 19°$ and later it did not change much ($c = 99.4$ kPa). The maximum cohesion was $c = 112.4$ kPa, with the axial deformation value of 8% ($\varphi = 13.8°$).

CONCLUSIONS

1. In the geological section of fine soils of Klaipėda Port quays, next to widely spread moraine soils, there is an interlayer of clayey silt, and the geotechnical properties of it can change greatly when dug out.

2. According to the parameters characterizing physical state – the density of particles, density, the void ratio and plasticity, – the values of all fine soils are similar.

3. According to the granulometric composition, three sorts of soil have been distinguished: moraine silty clays, moraine silty sandy clays and non-moraine clayey silts.

4. When the triaxial test was performed, the results have shown that the mechanical behaviour of silty clays and clayey silts differs greatly both in peak strength features and in their changes when the axial deformations increase.

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KLAIPĖDOS UOSTO SMULKIŲJŲ GRUNTŲ SAVYBIŲ YPATUMAI

Santrauka

Klaipėdos uosto krantinių rekonstrukcijos vietose yra sudėtingas geologinis pjūvis. Nors didesniąją pjūvio dalį sudaro glacigeninės kilmės smulkieji rišlūs gruntai, tačiau juose randama dulkingo molio tarpsluoksnių ir intarpų. Statybos metu jie gali išmirkti ir būti išplauti. Atlikti tyrimai rodo, kad smulkiųjų gruntų rūšys – tai moreninis dulkingas molis, moreninis dulkingas smėlingas molis ir nemoreniniai molingi dulkiai. Visi minėti gruntai pasižymi panašia fizine būkle, tačiau skirtinga granuliometrinė sudėtis lemia įvairias stiprumo rodiklių vertes ir jų pokyčius esant skirtingomis ašinėmis deformacijomis.

Юргис Медзвецкас, Саулюс Гадейкис, Каститис Дундулис

ОСОБЕННОСТИ СВОЙСТВ МЕЛКИХ ГРУНТОВ В КЛАЙПЕДСКОМ ПОРТУ

Резюме

В местах реконструкции набережных Клайпедского порта встречается довольно сложный геологический разрез. Хотя бóльшую часть разреза составляют мелкие связные грунты гляцигенного происхождения, в них встречаются прослои и включения глинистых алевролитов, которые в ходе строительства могут размокать или размываться. Установлено, что в разрезе мелких связанных грунтов преобладают три вида: моренные пылеватые и моренные пылеватые песчаные глины, а также неморенные глинистые алевриты. Все эти грунты схожи по физическому состоянию, однако разный гранулометрический состав определяет разные значения прочностных показателей и их изменения при различных осевых деформациях.