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Sand soils of Lithuanian coastal area and their geotechnical properties

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Sand soils form the upper part of the geological cross-section of the Lithuanian coast. Theses soils are the basis for building construction. The major part of the Lithuanian Baltic Sea coastal area of consists of sands of different genesis and age; besides, they include a wide interval of grain size distribution from gravelly to silty sands. A large part of the geological cross-section is formed from sand soils with organic matter. During the research, the index values of the physical mechanical properties of the soils were evaluated and summarized; the main factors predetermining the mechanical behavior of sands were determined.

Key words: sand, geotechnical properties, coastal area, Lithuania

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INTRODUCTION

The Baltic Sea coastal area takes about 3% of the total area of Lithuania (Gudelis, 1998). Sand soils of different genesis and age make up the top part of the geological section. Besides, sand soils are often used as the foundation of various buildings. Therefore, generalization of the indices of soil properties is one of the relevant geotechnical problems. The recent engineering geological mapping work conducted in the coastal area by Geological Survey of Lithuania (Bucevičiūtė et al, 1997, 2000) and evaluation of engineering geological conditions of the Klaipėda City conducted by the Department of Hydrogeology and Engineering Geology of Vilnius University (Gadeikis, 1999) permitted summarization of the research data (Fig. 1). On the basis of the material collected, by the statistical correlation methods certain important factors predetermining the mechanical behavior of soils were explained.

Short review of the geological section

The coastal part of Lithuania was mainly formed in the Pleistocene and Holocene. During the Baltija stadial of Nemunas glaciation of the late Pleistocene, the glaciolimnic (lg III bl) and glaciofluvial (f III bl) sandy sediments were formed. The formation of the sediments was specifically influenced by the Baltic Ice Lake during the Late Glacial, which left a rather varied sediment section in the study territory with fine and silty sand sediments prevailing (lg III B). Also, sands with adulterant organic matter of the Holocene can be found in different sites (Bitinas, et al, 1997, 2000).

At the beginning of the Holocene, the limnic sediments of Lake Ancylus were stratified (l IV_A). They basically consist of fine, silty sands, randomly with adulterant organic matter (Fig. 2). The later marine sediments of the Litorina Sea (m IV_L) and post-Litorina sand sediments (m IV_{PL}) are mainly made of fine and

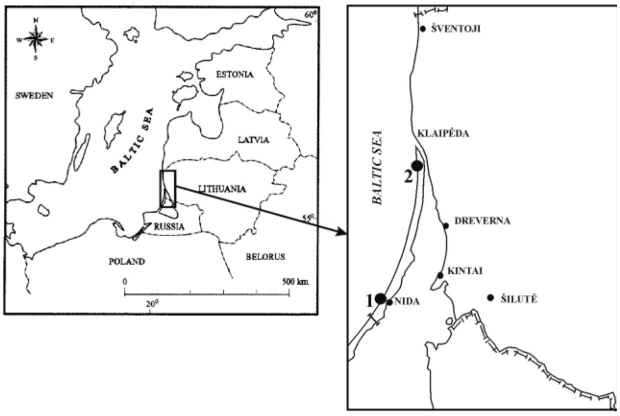

Fig. 1. Location of geological cross-section: *1* – geological cross-section of sand soils in Nida (N 55°19'02" E 20°59'18"), *2* – geological cross-section of sand soils in Smiltynė (N 55°'41'39" E 21°06'11")

1 pav. Geologinių pjūvių vietos: *1* – smėlio grunto geologinis pjūvis Nidoje (N 55°19'02" E 20°59'18"), *2* – smėlio grunto geologinis pjūvis Smiltynėje (N 55°'41'39" E 21°06'11")

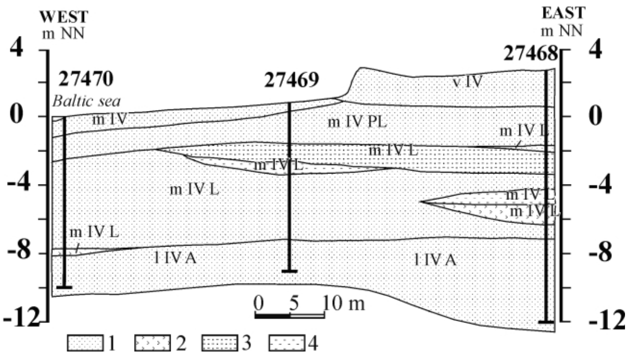

Fig. 2. Geological cross-section of sand soils in Nida. *1* – sand, *2* – sand with organic matter, *3* – silty sand, *4* – silt

2 pav. Smėlio grunto geologinis pjūvis Nidoje: *1* – smėlis, *2* – smėlis su organine medžiaga, *3* – dulkingas smėlis, *4* – dulkis

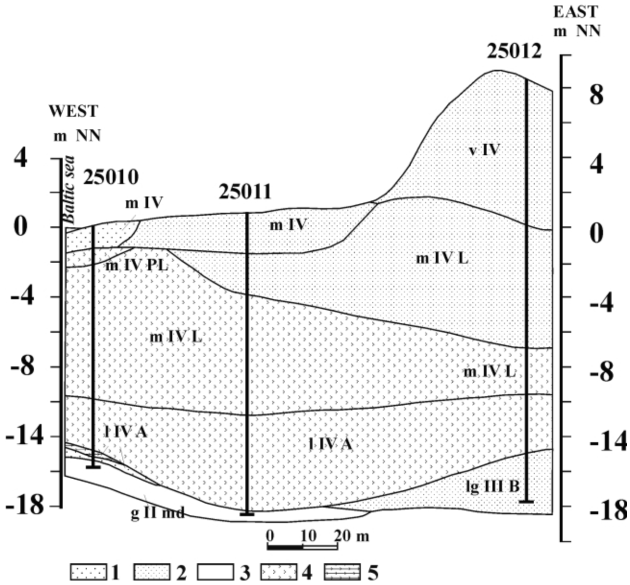

Fig. 3. Geological cross-section of sand soils in Smiltynė: *1* – gravelly sand, *2* – sand, *3* – till (clayey sand, silty clay, clay), *4* – sand with organic matter, *5* – silty clay with organic matter admixture

3 pav. Smėlio grunto geologinis pjūvis Smiltynėje: *1* – žvyringas smėlis, *2* – smėlis, *3* – morena (molingas smėlis, dulkingas molis, molis), *4* – smėlis su organine medžiaga, *5* – dulkingas molis su organine medžiaga

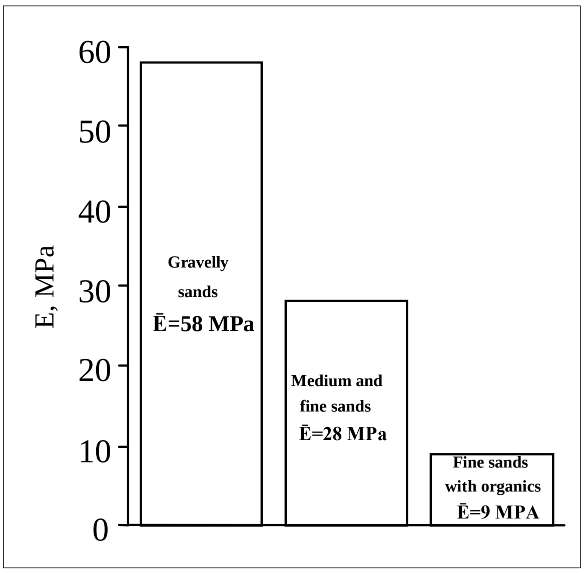

Fig. 4. Relationship between the modulus of deformation E and grain size distribution of sands

4 pav. Smėlio grunto deformacijos modulio E ir granuliometrinės sudėties tarpusavio priklausomybė

silty sands, randomly with adulterant organic matter. Also, coarser sediments (gravelly sand) can be found (Fig. 3). The recent marine sediments (m IV) consist mainly of gravelly, medium and fine sands. Aeolian sands (v IV) are spread all over the Baltic Sea coast; they are really thick in the Curionian Spit. These are medium and fine sands. Alluvial (a IV) sands can be found in the vales of the rivers Danė, Minija, Šventoji, where they make an accumulative cover of the first and second terraces above the floodplanes. The sands layered here vary from gravelly to clayey.

Physical and mechanical properties

The density of particles (ρ_s) given in Table shows that the density of all genetic types of sediments as well as subtypes of grain size distribution is similar and corresponds to the prevailing composition of quartz and feldspar. The average density of particle value is 2.66 Mg/m^3 and ranges from 2.65 to 2.67 Mg/m^3. The density (ρ_s) values depend on the saturation degree and organic matter content. The rise of the average values can be observed in individual genetic types, depending on the grain size distribution. The natural moisture content depends on the water saturation degree. Moisture content (W) of saturated soils ranges from 13.7 to 22.5%. The natural moisture content of sands occurring

Table. **Average index values of physical mechanical properties of sands**
Lentelė. **Smėlio grunto fizinių mechaninių savybių vidurkinės vertės**

Geological index	Name of soil	Particles of density ρ_s, Mg/m^3	Density ρ, Mg/m^3	Moisture content W, % MPa	Void ratio e	Cone resistance q_c, MPa	Modulus of deformation E,
l IV	Fine sand with organics	2.64	1.45	48.0	1.704	0.7	6
a IV	Gravelly sand	2.68	2.16*	12.1	0.390	1.97	65
	Fine sand	2.66	1.78	8.5	0.625	3.2	10
	Fine sand with organics	2.65	1.77*	22.8	0.851	1.1	3
	Clayey sand	2.67	1.90	13.2	0.592	1.8	6
m IV	Gravelly sand	2.67	2.17*	13.7	0.400	17.6	60
	Medium sand	2.66	2.02*	24.8	0.642	7.8	33
	Fine sand	2.67	2.02*	23.1	0.643	7.2	32
m IV_L + P_L	Gravelly sand	2.68	1.68	4.1	0.660	21.8	69
	Fine sand	2.66	1.67	10.4	0.766	10.8	42
	Fine sand with organics	2.65	1.96	16.3	0.575	4.1	12
	Silty sand with organics	2.65	1.87*	17.5	0.665	1.5	5
l IVA	Fine sand	2.65	2.07*	15.2	0.474	9.6	38
	Fine sand with organics	2.66	2.04*	15.9	0.506	2.0	6
v IV	Medium sand	2.65	1.68	5.9	0.671	6.5	24
	Fine sand	2.66	1.54	3.7	0.778	7.6	33
lg III B	Fine sand	2.67	1.76	7.5	0.631	5.2	25
	Fine sand with organics	2.66	2.06*	18.4	0.528	2.6	15
	Silty sand with organics	2.65	2.00*	21.2	0.606	0.8	2
lg III bl	Fine sand	2.66	1.57	2.5	0.737	3.5	12
f III bl	Gravelly sand	2.66	2.06*	13.7	0.466	11.6	44
	Fine sand	2.67	1.81	11.1	0.637	6.8	30
	Silty sand	2.66	2.08*	18.2	0.811	11.2	43

* – saturated soils.

in the aeration area makes just a few percent (3.7–8.5%). A really high value of moisture content is characteristic of limnic fine sands with organic matter. It is 48.0%.

The void ratio values given in Table show that the average values grow regularly from fine-dispersed sand varieties to course-dispersed ones. The void ratio in fine sands changes from 0.474 to 0.778, and in gravelly sands it ranges from 0.390 to 0.660. Higher void ratios are often characteristic of soils with organic matter.

Sand strength is evaluated by the CPT of the obtained cone resistance (q_c). By grain size distribution, the highest cone resistance is characteristic of gravelly sands. In different genetic types of sand its alteration interval is not big and makes from 11.6 to 21.8 Mpa, the average value being 17.6 MPa. The average value of medium sands q_c is 7.1 MPa. Cone resistance of fine sands ranges from 3.2 to 10.8 MPa, and the average value is 6.7 MPa. The lowest cone resistance values are characteristic of sands with organic matter. Here the q_c variation interval ranges from 0.7 to 4.7 MPA, the average value reaching 1.8 MPa. The same regularities of change are reflected in the modulus of deformation, too (E) (Table).

Factors predetermining the mechanical behavior

The mechanical properties of sands, which predetermine their rational use as the foundation, depend on many factors, including their composition and physical form (Osipov, 1983). These factors, as well as links among the mechanical properties, as a rule, have a complex character. Mechanical properties are predetermined by grain size distribution of sands, the shape of grains, density and adulterant organic matter.

Depending on grain size distribution, their strength and compressibility indices differ greatly (Fig. 4). The values of the modulus of deformation on average are twice higher in gravelly than in fine sands.

The strength and compressibility of sands are significantly influenced by the content of organic matter in

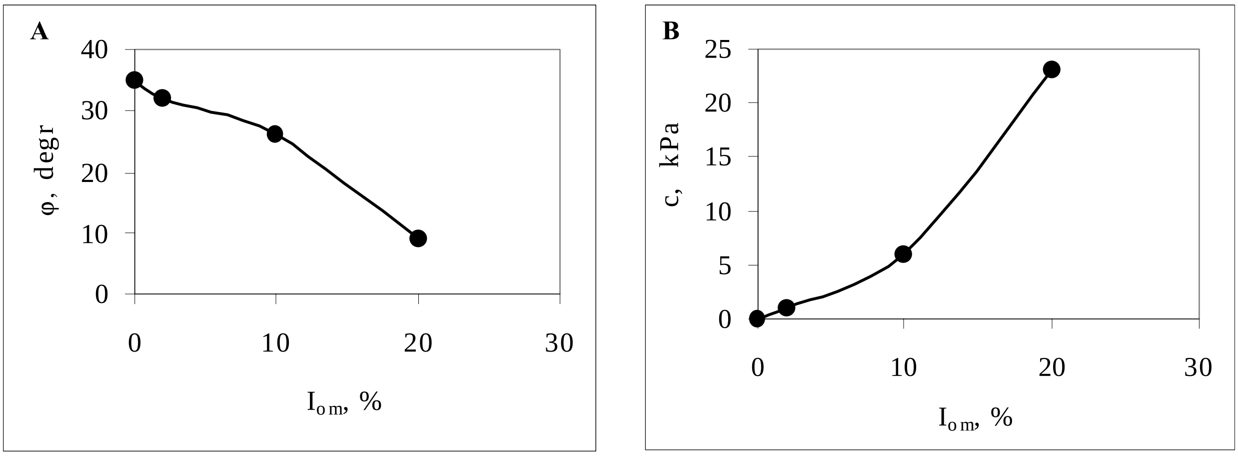

Fig. 5. Relationship between organic content (I_{om}) and the angle of internal friction φ (*A*) and cohesion c (*B*)
5 pav. Organinės medžiagos kiekio (I_{om}) tarpusavio priklausomybė su vidinės trinties kampu φ (*A*) ir sankiba c (*B*)

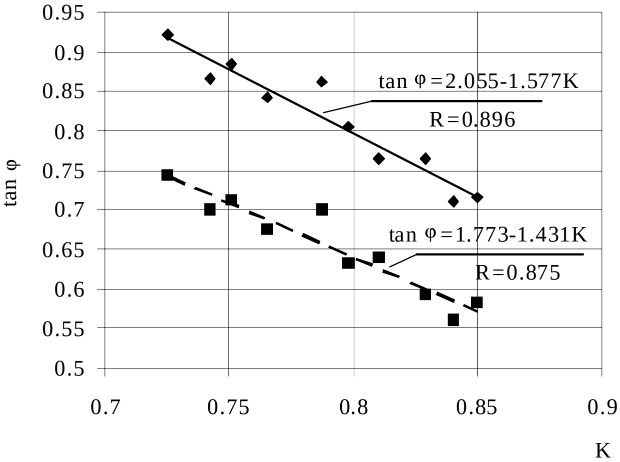

Fig. 6. Relationship between the roundness ratio K and the angle of internal friction φ:
♦ by maximal shear strength, ■ by residual shear strength
6 pav. Apvalumo koeficiento K ir vidinės trinties kampo φ tarpusavio priklausomybė:
♦ pagal maksimalų kerpamąjį stiprumą, ■ pagal minimalų kerpamąjį stiprumą

soil (Fig. 4). Due to adulterant organic matter in fine sands, the average value of the modulus of their deformation decreases more than 3 times.

Our evaluation of the influence of organic matter content on the angle of internal friction (φ) and cohesion (c) (Fig. 5) allows us maintain that the aforementioned influence is particularly important at the increase of organic matter content (I_{om}). When the I_{om} content is less than 2%, the influence of organic matter is insignificant. When organic matter content increases to 10%, the angle of internal friction is reduced to 9–10°, whereas cohesion increases to 6 kPa. When organic matter content increases to 20%, shear strength indices (t) change absolutely. In this case, φ = 9°, c = 23 kPa.

Moreover, the strength of sands is greatly influenced by the shape of grains (Dundulis et al., 2004). The morphological research of grains conducted for determining their roundness ratio (K) according to E. P. Cox as well as a study of strength properties of the sands (tan φ) show that the grain shape and strength properties are closely correlated (Fig. 6). When the roundness ratio is low (K = 0.7), the coefficient of internal friction (tan φ) at the maximum peak shear strength is 0.88. With the growth of the ratio K, the value of tan φ is reduced to 0.72. A similar trend is observed in the correlation of data under residual tangent tension.

CONCLUSIONS

1. The top part of the geological section of the Lithuanian Baltic Sea coastal area consists of sand soils of different genesis and age.
2. The composition of sand soils, their physical condition and mechanical properties are characterized by a big interval of variation.
3. The biggest problems in the construction of engineering buildings arise when sand soils contain adulterant organic materials.
4. The main factors that predetermine the strength and compressibility of sands are grain size distribution, the shape of sand grains, the density and content of organic admixture.

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LIETUVOS PAJŪRIO SMĖLIO GRUNTAS IR JO GEOTECHNINĖS SAVYBĖS

S a n t r a u k a

Lietuvos pajūrio smėlio gruntas sudaro viršutinę geologinio pjūvio dalį, kuri panaudojama kaip pagrindas arba aplinka inžineriniams statiniams. Šis gruntas, susiformavęs vėlyvojo pleistoceno ir holoceno metu, skiriasi savo kilme bei amžiumi ir apima platų granuliometrinės sudėties spektrą nuo žvyringo iki dulkingo smėlio. Nemažą pjūvio dalį sudaro smėlio gruntas su organinės medžiagos priemaiša. Fondinės medžiagos bei atliktų tyrimų rezultatai leido pateikti apibendrintas pajūrio smėlio fizinių mechaninių savybių rodiklių vertes. Įvertinta grunto mechaninių savybių priklausomybė nuo jų granuliometrinės sudėties, organinės medžiagos priemaišos bei grūdelių formos. Tyrimų rezultatai rodo, kad pereinant nuo žvyringo į smulkų smėlį deformacijos modulio vertės sumažėja perpus. Organinės medžiagos kiekiui smėlyje pasiekus 20%, vidinės trinties kampo vertė sumažėja nuo 35˚ švariame smėlyje iki 9˚. Mažėjant grūdelių apvalumo koeficientui K nuo 0,725 iki 0,550, vidinės trinties koeficientas sumažėja nuo 0,925 iki 0,705.

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Р е з ю м е

Песчаные грунты Литовского побережья Балтийского моря составляют верхнюю часть геологического разреза, которая используется как основание или среда для инженерных сооружений. Данные грунты сортировались в позднем плейстоцене и голоцене и явно различаются своим генезисом и занимают широкий спектр по гранулометрическому составу – от гравелистых до пылеватых. Значительную часть разреза составляют пески с примесью органического материала. В результате обобщения фондового материала и проведенных исследований выявлены показатели физико-механических свойств песков. Установлена зависимость механических свойств песков от их гранулометрического состава, количества примесей органического материала и формы зерен. Результаты исследований показали, что при переходе от гравелистых песков к мелким значение модуля деформации снижается в 2 раза. При достижении примеси органического материала в песке 20% угол внутреннего трения понижается от 35° в чистом песке до 9°. При понижении коэффициента округлости К от 0,725 до 0,550 коэффициент внутреннего трения уменьшается от 0,925 до 0,705.