GEOLOGIJA. 2006. T. 53. P. 52–56

Influence of morphometric characteristics of sand particles on the strength parameters of sand soils in Lithuania

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Dundulis K., Gadeikis S., Influence of morphometric characteristics of sand particles on the strength parameters of sand soils in Lithuania. *Geologija*. Vilnius. 2006. No 53. P. 52–56. ISSN 1392-110X

The values of sphericity, roundness and specific surface of sand particles for sand soils of various genesis in Lithuania were studied. For the estimation of the morphometry of sand particles the integral index of morphometry Q was suggested. Parallelly, sand soil strength properties using the direct shear and penetration methods were investigated. One of the factors determining the parametric values of sand soil strength is the morphometric characteristic of sand particles. Morphometric analyses of sand particles of different genesis showed their significant influence on the strength parameters of soils. The morphometric parameters of sand particles of different genesis in different fractions differed significantly. By correlation and regressive analysis the dependence of sand strength parameters on the roundness, sphericity and specific surface of sand particles has been evaluated.

Key words: sand, roundness, sphericity, specific surface, angle of internal friction, Lithuania

Received 4 November 2005, accepted 19 December 2005

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INTRODUCTION

In terms of modern dispersive system deformation, the strength of sand soils is a function dependent on two values – the number of contacts among particles and the deformation resistance of the unit contact (Бабак, 1974; Field, 1963; Gray, 1968; Oda, 1977, 1999). However, these parameters are hard to evaluate during experiments. Therefore, the prediction of strength parameters of sand is based on indirect methods correlating the said parameters with the grain size distribution, grain shape, their density, etc.

One of the mentioned factors is the shape of sand particles, which has been analyzed in a number of tests (Левков, 1968; Nowak, 1984). Specialists in soil mechanics and geotechnique also mention the influence of particle shape on the mechanical behavior of soils (Ortigao, 1995; ISO 14688-1:2004; Dundulis, 2004).

In the general sequence of factors determining the strength parameters of sand soils, with the first level of factors corresponding to the number of contacts among particles and the strength of their unit contact taken as the basis, the characteristics of particle surface and morphology should be considered as the second level. These factors are dependent on the next level of factors, which comprises grain size distribution and the genetic peculiarities of soil (Осипов, 1984).

METHODS

Admitting the mentioned propositions, the scheme of analysis was drawn up in the following manner: sands of different genesis and age (f III bl, m IV) and aeolian sand originating from the first two genetic types (v IV^{m} and v IV^{f}) were chosen for analysis Fig. 1).

For evaluation of sand particle morphometry, two-dimensional (planar) methods of analysis were applied, in which the particle sphericity was calculated according to the formula of N. A. Riley:

$$P = \sqrt{\frac{d}{D}},$$

where d is the diameter of the circle inscribed in the plane of a particle and D is diameter of the encircling circle in the plane of a particle.

Fig. 1. Location of sampling sites.
♦ – glaciofluvial sands, ■ – aeolian sands, ● – marine sands
1 pav. Bandinių paėmimo vietos.
♦ – fliuvoglacialinis smėlis, ■ – eolinis smėlis, ● – jūrinis smėlis

The roundness coefficient was calculated from E. O. Cox's formula:

$$K = \frac{4 \cdot \pi \cdot S}{P^2},$$

where S is the area of the particle plane, and P is the perimeter of the particle plane.

For evaluating the summary shape of a particle, the integral morphology index was used:

$$Q = P \cdot K = \frac{4 \cdot \pi \cdot S}{P^2} \cdot \sqrt{\frac{d}{D}}.$$

To evaluate the morphometric characteristics of the particles, analyses of 1–0.5 mm, 0.5–0.25 mm and 0.25–0.1 mm fractions was performed.

For measuring the specific surface, B. V. Deriagin's (1970) rarefied gas stationary filtration method was applied. This method is based on the resistance of a porous body occurring while filtering the rarefied gas or air through this body under molecular flow. In this case, an average distance of gas molecule movement between the two strokes is significantly bigger than the maximum diameter of pores.

When testing the influence of the parameters of sand grain morphometry and the specific surface on the strength values of sand, fractions of 2–1 mm, 1–0.5 mm, 0.5–0.25 mm, 0.25–0.1 mm and 0.1–0.05 mm and mixes of these fractions in different ratios were tested. For testing, samples of equal porosity (e = 0.7) and moisture (W = 0.05) were prepared. The values of strength parameters were established by using a VSV-2T direct shear device, with the tests being performed by controlled deformations (v = 0.1mm/min) under three vertical pressures of 100, 200, 300 kPa. Simultaneously, sand analyses with a laboratory penetrometer for calculation of the penetration index R were performed. With the invariance of R established by the reverse calculation method under V. Berezancev's marginal equilibrium theory derivation of asymmetric proposition, the sand strength parameters $\tan\varphi_p$ and c_p were calculated.

A correlation of both methods (shear and penetration tests) allowed to establish the regressive equation $\tan\varphi = 0.717*\tan\varphi + 0.036$, with the correlation coefficient R = 0.724.

RESULTS

The morphometric analyses of different genetic sand types (glaciofluvial (f III bl), marine (m IV), aeolian from marine (v IV^m) and aeolian from glaciofluvial (v IV^f)) fractions 1–0.5 mm, 0.5–0.25 mm, 0.25–0.1 mm with the sphericity evaluated according to N. A. Riley, roundness to E. P. Cox and the integral index Q allowed us to evaluate the morphology of particles in two aspects:

– with reference to the genetic peculiarities;
– with reference to the dispercity of sands.

The average results of the performed analyses are given in Table.

The lowest polished sands are glaciofluvial sands. Material of this sand type mainly consists of the initial moraine (till) material in which, as a rule, original sand grains are slightly polished (Gaigalas, 1986). Aeolian sands formed from glaciofluvial sands are characterized by only a slightly increased sphericity, but by a significantly higher roundness. The highest sphericity values are characteristic of marine sands. The values of morphometric indices for the aeolian sands formed from the marine sands are lower.

While analyzing the morphometric indices of grain particles by fractions, each genetic type showed certain

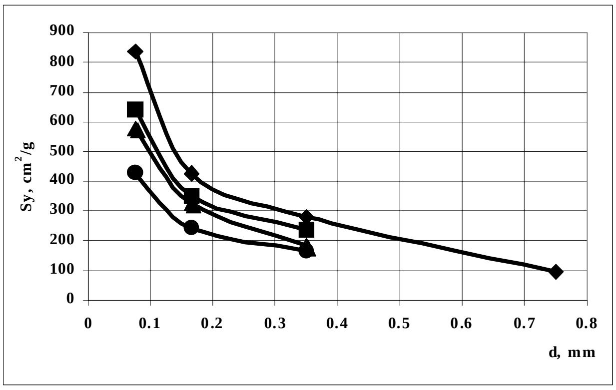

Fig. 2. Relationship between specific surfaces of sand particles Sy and particle diameter d.
♦ – glaciofluvial sand (f III bl), ● – marine sand (m IV), ■ – aeolian sand formated from glaciofluvial sand (v IV^f), ▲ – aeolian sand formated from marine sand (v IV^m)
2 pav. Smėlio dalelių savitojo paviršiaus Sy ir diametro d tarpusavio priklausomybė.
♦ – fliuvoglacialinis smėlis (f III bl), ● – jūrinis smėlis (m IV), ■ – eolinis smėlis, suformuotas iš fliuvoglacialinio smėlio (v IV^f), ▲ – eolinis smėlis, suformuotas iš jūrinio smėlio (v IV^m)

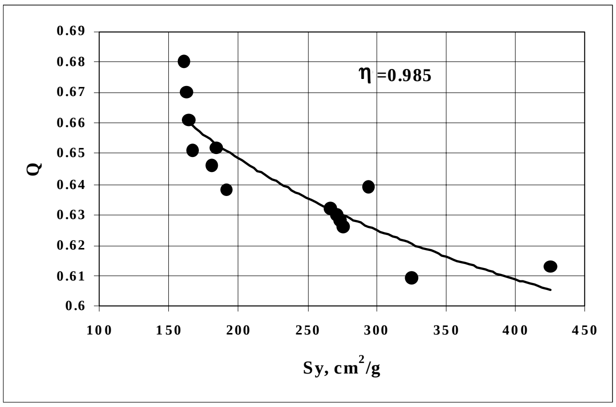

Fig. 3. Relationship between integral morphometric coefficient Q and specific surface of sand particles Sy;
η – correlation ratio

3 pav. Smėlio dalelių integralinio morfometrijos koeficiento Q ir savitojo paviršiaus Sy tarpusavio priklausomybė;
η – koreliacijos santykis

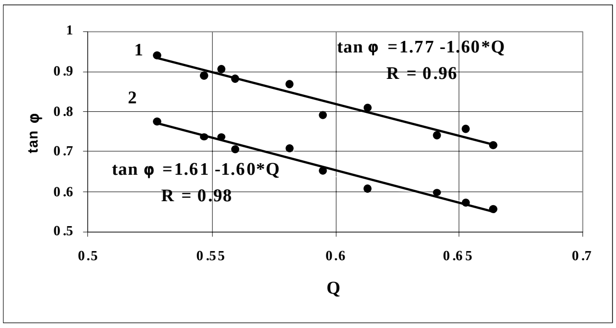

Fig. 4. Relationship between coefficient of internal friction tanφ and morphometric coefficient Q
1 – by data of peak shear stresses, *2* – by data of residual shear stresses

4 pav. Vidaus trinties koeficiento tanφ ir morfometrijos koeficiento Q tarpusavio priklausomybė: *1* – pagal maksimalų kerpamąjį stiprį, *2* – pagal minimalų kerpamąjį stiprį

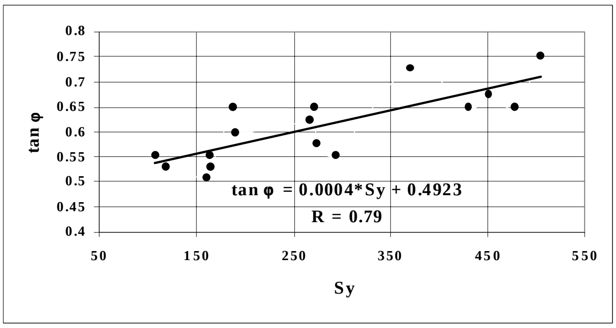

Fig. 5. Relationship between coefficient of internal friction tan φ and specific surface of sand particles Sy

5 pav. Smėlio dalelių vidaus trinties koeficiento tanφ ir savitojo paviršiaus koeficiento Sy tarpusavio priklausomybė

regularities. According to the morphometric index Q, glaciofluvial sands are distinguished for their clearly expressed decrease in polishability level resulting from the increase in sand dispersity. In marine sands, a decrease of the Q value is traceable only in fractions from

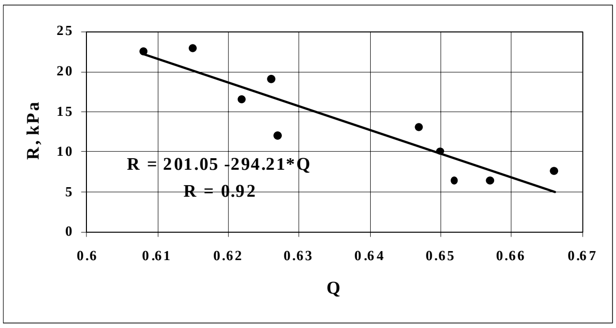

Fig. 6. Relationship between penetration index R and morfology coefficient Q of sand

6 pav. Smėlio gruntų penetracijos rodiklio R ir morfometrijos koeficiento Q tarpusavio priklausomybė

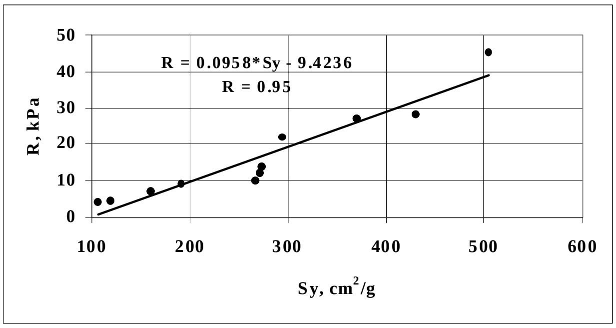

Fig. 7. Relationship between penetration index R and specific surface Sy of sand

7 pav. Smėlio dalelių penetracijos rodiklio R ir savitojo paviršiaus Sy tarpusavio priklausomybė

1–0.5 mm to 0.5–0.25 mm. In the fraction of 0.25–0.1 mm the Q value slightly increases. In aeolian sands formed from marine sands the highest polishability is observed in the fraction 0.5–0.25.

Analyses of the sand specific surface with sands of different genetic types and fractions showed that the specific surface depends both on the size of particles and their genetic type (Fig. 2). The highest values of the specific surface Sy are characteristic of the fraction 0.1–0.05 mm. In this case, their variation interval in sands of different genetic type ranges from 836 cm^2/g to 427 cm^2/g. The increase in the average fraction diameter results in decreased Sy values and their variation interval. In the fraction 0.25–0.1 mm, the variation interval varies from 425 to 242 cm^2/g, whereas in the fraction 0.5–0.25 mm it reaches 276–167 cm^2/g.

When analyzing the Sy values in different genetic types of sands it has been stated that the highest values of specific surface are characteristic of glaciofluvial sands. The lowest values of specific surfaces are typical of marine sands. The Sy values of aeolian sands take the intermediate position. It should be noted, however, that the specific surface values of aeolian sand fractions, irrespective of their primary origin, are rather close.

The dependence of the index Q of the integrally analyzed sands on their specific surface, shown in Fig. 3, reveals a close exponential interdependence and a high correlative relation η = 0.985. The obtained

Table. **Average values of sphericity coefficient R, roundness coefficient K and integral morphometric coefficient Q of sand particles**
Lentelė. **Smėlio dalelių sferiškumo koeficiento R, apvalumo koeficiento K ir integralinio morfometrijos koeficiento Q vidurkinės vertės**

Genesis and age	Morphometric indices	Size of sand particles, mm		
		1–0.5	0.5–0.25	0.25–0.1
f III bl	P	0.770	0.769	0.731
	K	0.831	0.783	0.753
	Q	0.639	0.602	0.550
v IV^f	P	0.709	0.801	0.815
	K	0.902	0.794	0.830
	Q	0.713	0.611	0.607
m IV	P	0.842	0.827	0.841
	K	0.868	0.788	0.795
	Q	0.731	0.651	0.668
v IV^m	P	0.778	0.842	0.816
	K	0.825	0.774	0.746
	Q	0.642	0.652	0.609

data allow stating that both the morphometric coefficient of particles Q and the coefficient of specific surface are closely interdependent and directly reflect the genetic peculiarities of sands.

The simultaneously performed tests of strength parameters of sand soils by the method of direct shear allowed evaluating the influence of the morphometric index Q and the specific surface Sy on the strength parameters of sand soils. The dependence of the internal friction coefficient on the morphometric index of sand particles Q (Fig. 4) and the specific surface Sy (Fig. 5) shows a linear dependence between these indices and can be expressed by linear regression equations, and the value of their correlation coefficient amounts from 0.96 to 0.98. Analogous results were received by correlating Q and Sy with the penetration index R (Figs. 6 and 7).

The obtained results allow stating that both Q and Sy are the major factors that determine the strength parameters of sand. As regards the deformation process of soils, it can be stated that the index Q determines the resistance of sand particles to both push and torsion, and the contact resistance of soil in this process is determined by smaller morphometric shapes of particles (small convexities and concaves). In order to evaluate the totality of push, torsion and smaller contact tensions, the integral morphometric index Q is required. In addition, it the curvilinear dependence between Q and Sy shows that the specific surface, besides reflecting the morphologic surfaces of sand particles, provides information on the other surface peculiarities of a sand particle as well, i.e. on the coverage of a sand particle by various types of pellicles, etc. (Dundulis, 1998).

CONCLUSIONS

While analyzing the deformations of sand soils, one of the major factors determining the strength of these soils is the morphological indices of particles.

Employment of the integral morphometric index Q gives the possibility to quantitatively evaluate the influence of the sand particle shape on the strength parameters. It has been proven that the values of the integral index Q and the special surface of sand Sy depend on the genetic type of sand and its geological history, and at the same time allow predicting the strength parameters of different genetic types of sands.

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SMĖLIO DALELIŲ MORFOMETRINIŲ YPATUMŲ POVEIKIS GRUNTO STIPRUMUI

S a n t r a u k a

Vienas veiksnių, nulemiančių smėlio grunto stiprumo rodiklių vertes, yra smėlio dalelių morfologiniai ypatumai. Įvairios kilmės smėlio grūdelių sferiškumo, apvalumo ir integralinio morfometrinio rodiklio Q tyrimai rodo šių rodiklių verčių ir jų pasiskirstymo dėsningumus fliuvioglacialiniame, jūriniame ir eoliniame smėlyje Lietuvoje. Nustatyta glaudi koreliacija tarp rodiklio Q ir smėlio savitojo paviršiaus Sy. Atlikus koreliacinę ir regresinę analizę įvertinta smėlio stiprumo rodiklių priklausomybė nuo dalelių apvalumą bei sferiškumą įvertinančio integralinio morfometrijos rodiklio Q ir savitojo paviršiaus Sy. Nustatyta, kad koreliaciją tarp vidinės trinties koeficiento tanφ ir integralinio morfometrinio rodiklio Q įvertinančio koreliacijos koeficiento vertė yra 0,96, o tarp tanφ ir lyginamojo grūdelių paviršiaus Sy – 0,79. Lygiagrečiai atlikti smėlio bandinių laboratoriniai penetracijos bandymai ir nustatytas penetracijos rodiklis R. Penetracijos rodiklio R koreliacinė priklausomybė nuo Q ir Sy yra dar glaudesnė. Šiuo atveju koreliacijos koeficiento vertės atitinkamai yra 0,92 ir 0,95.

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ÂËÈßÍÈÅ ÌÎÐÔÎËÎÃÈ×ÅÑÊÈÕ ÎÑÎÁÅÍHÎÑÒÅÉ ÏÅÑ×ÀÍÛÕ ×ÀÑÒÈÖ ÍÀ ÏÐÎ×ÍÎÑÒÍÛÅ ÑÂÎÉÑÒÂÀ ÃÐÓÍÒÎÂ

Р е з ю м е

Одним из факторов, определяющих прочностные свойства песчаных грунтов, являются морфологические особенности песчаных частиц. Проведенные исследования сферичности и округлости песчаных частиц разного генезиса с помощью интегрального показателя морфологии частиц Q позволили установить значения данного показателя и закономерности его распределения в водноледниковых, морских и эоловых песках Литвы. Параллельные исследования удельной поверхности Sy песков дали возможность установить явную корреляционную зависимость Sy от морфометрического показателя Q. С помощью корреляционного и регрессивного анализа установлена тесная зависимость прочностных свойств песков от морфологического показателя Q и удельной поверхности песков Sy. Установлено, что значение корреляционной взаимосвязи между коэффициентом внутреннего трения tanφ и интеграционным морфометрическим коэффициентом Q составляет 0,96, а между tanφ и удельной поверхностью зерен Sy – 0,79. Параллельно проведены лабораторные пенетрационные испытания и установлен показатель пенетрации R. Корреляционная зависимость показателя пенетрации R от Q и Sy еще более тесная. В данном случае значения коэффициента корреляции составляют 0,92 и 0,95 соответственно.