The Relationship of Physical Property Indicators and Clay Soil Structural Strength of Tomsk Oblast Territory

V V Kramarenko[1], A N Nikitenkov[2], V Y Molokov[3], I A Matveenko[4] and A V Shramok[5]

[1] Associate professor, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
[2] Senior Teacher, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
[3] Post-graduate, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
[4] Associate Professor, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
[5] Student, National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia

E-mail: [1] kramarenko-v-v@mail.ru; [2] nik@tpu.ru; [3] vik3011347@yandex.ru; [4] mia2046@yandex.ru

Abstract. The article deals with the characteristic of initial condition in fine-grained soils – its structural strength – p_{str}. Estimation and measurement of this factor at soil testing are of primary importance for defining its physical and mechanical properties as well as for subsequent calculation of foundation settlements that is insufficiently covered in Code of practice, national standard and inefficiently applicable in practice of engineering geological investigations. The article reveals the relationship between soil physical property, its occurrence depth, which will make possible to forecast p_{str} over the given territory.

1. Introduction

By structural strength p_{str} we mean the strength conditioned by the presence of structural bonds and characterized by pressure up to what soil sample is not or lightly deformed at its vertical loading [10]. It is one of the characteristics defining the soil initial conditions in natural environment that is of great significance for determination of its physical-mechanical properties, state of consolidation of sediments, calculation of foundation settlements and estimation quality of selection sample with undisturbed structure. It is obvious that clay soil with mixed microstructure has a pronounced discontinuity point related to their structural strength. Consequently, at low loads, coefficient of volume compressibility equals the hundredth parts of MPa $^{-1}$, whereas at higher loads its values increase to the tenth parts of MPa $^{-1}$. Structural strength influences the soil shear parameters as well. At loads increasing its angle of internal friction and cohesion sufficiently decrease in case of undrained shear strength, particularly. The value of residual strength amounts not less than 30-40 %. There often occur week or overconsolidation soils among them. The former are developed due to early cementation, but the latter are formed at lithified rock tipping with partial content of cement phase

[23]. According to [3] "… *all misunderstandings of soil mechanical properties and calculations based on them are connected with complete neglecting the initial condition of soil and reluctance of recognition that soil bearing capacity is defined by its initial state*". «The *initial conditions* can be established in terms of two sets of parameters: (a) indices; and (b) state parameters. *The index parameters provide a measure on the types, shapes, ranges, and descriptive values on the particles that make up the composition. Indices can be performed on remoulded or disaggregated samples from the field. The state parameters represent quantification on how the particles are arranged or packed with respect to each other, thus leanding to concepts such as "loose" vs. "dense" and "soft" vs. "hard", as well as special facets concerning bonding, cementation, fracturing, sensitivity and structural fabric. The initial state reflects the long-term geostatic conditions, often over many thousands to millions of years, and the value of these state parameters is given a subscript "nought" to indicate its beginning, such as initial void ratio (e_0), initial effective overburden stress (σ_{v0}'), initial hydrostatic porewater pressure (u_0), and initial lateral stress state (K_0)*» [16].

The value of soil structural strength depends on age, lithification, genesis, structural bonds and disturbances, such as loading or sampling. It is believed that the least structural strength is typical for relatively young clay soils with weak coagulative contacts, whereas the highest one is inherent to relatively old lithified ones with strong mixed and phase cement contacts that to some extent reflect the basic characteristics of soil physical properties such as density, dry soil density, and moisture. As a result, relationship of p_{str} with soil composition and dependence of physical properties from soil stress history and formation conditions is of great interest for researchers. Therefore, the purpose of the given article is to estimate state of consolidation and reveal the relations of structural strength and characteristics of physical property of cohesive soils over the territory of Tomsk Oblast to forecast p_{str} preliminarily.

The research tasks include sampling, laboratory investigation of main soil physical and mechanical properties, and statistic processing of the results obtained to verify the relationships between soil composition and its properties.

2. Methods

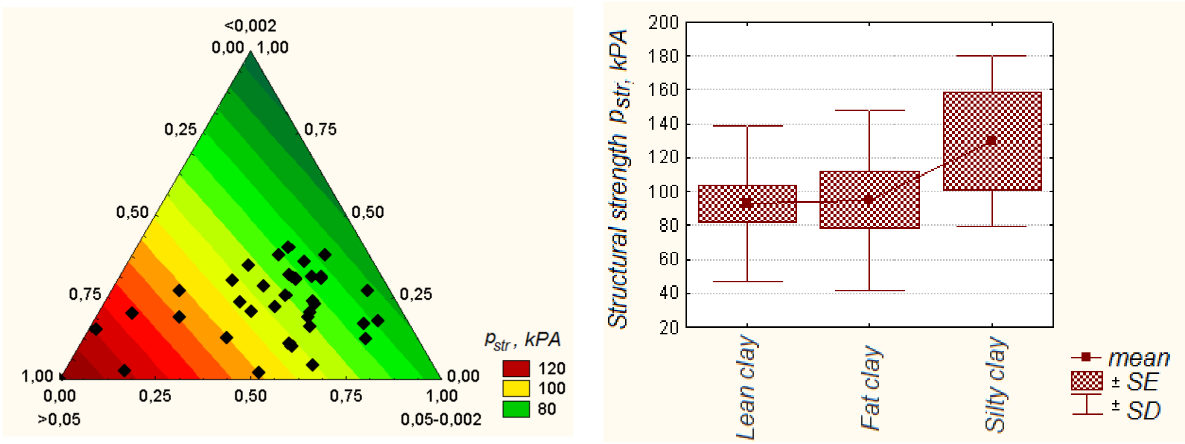
Soil testing was made in accordance with the methods given in the Russian national standard [8, 10, 11]. Sampling was performed in 60 points; they were mostly located in the central, most developed part of Tomsk Oblast as well as its under-developed Northern and Northern-West regions. Sampling was carried out up to the depth of 230 m from sediments of Quaternary system, Paleogene and Cretaceous periods. In total about 220 samples of clay soils were treated. The following parameters were defined: grain size composition, density (ρ), solids density (ρ_s), dry soil density (ρ_d), water content (w), plastic and liquid limits (w_L and w_p), deformation and strength characteristics; the following characteristics were calculated: porosity, void ratio, degree of saturation, plasticity and liquidity indexes, over consolidation ratio (*OCR)* and others.

Structural strength obtained in compression tests is defined in the same way as pressure of preconsolidation stress σ_p' by the methods of Casagrande, Burmister, Schemertmann, Akai, Janbu, Christensen, Sellfors, Pacheco Silva, Butterfield**,** Tavenas, Oikawa, Jose, Sridharan, Burland, Jacobsen, Van Zelst, Becker, Lebert and Horn, Senol, Saglamer, Nagaraj, Thøgersen, Einav, Carter , Gregory, Grozic, Imhoff, Dias Junior and others [1, 2, 4, 5-7, 9, 10, 12-14, 17-33, 24]. The most common ones are graphical techniques of Casagrande, Butterfield, Becker, Strain Energy-Log Stress, Sellfors and Pacheco Silva; in Russia, the Casagrande method is widely applied. There are a lot of interesting papers dealing with existing methods of estimation of the preconsolidation stress, history of mechanical stress, factors and characteristics defining state of consolidation of sediments [23-25].

Factor p_{str} determined in this work by the standard technique described in GOST 12248 [10]. In compression test for determination of p_{str} the first and subsequent stages of loading were taken as equal to 0,0025 MPa up to the compression point of soil sample, for which relative vertical soil deformation is taken ε >0,005. *Structural strength* of soil was defined in terms of the initial portion of compression curve $e_i = f(lg\ \sigma')$, where e_i – the void ratio at load σ_i. The break point after initial linear portion of curve corresponds to soil structural compression strength. Graphical processing of the results was performed by the traditional methods of Casagrande and Becker, as well.

3. Results and discussion

The research was made for clay soil of mostly solid and semisolid consistency. The results showed that in general dry density changes from 1,16 to 1,77 g/cm^3 for lean soil; from 1,18 to 1,65 g/cm^3 for fat and silty clay increasing with depth. On average, solid particle density for all types amounted 2,68-2,69 g/cm^3, at minimum 2,50-2,58 g/cm^3 and maximum 2,83-3,00 g/cm^3 and more – for rock and clay soil cemented with iron oxides and hydroxides. The statistic results showed that the values of structural strength change depending on the magnitudes close to 0 kPa to 300 kPa and higher – for rock and solid clay. Distribution of p_{str} depends on grain size composition (hydrometer analysis was performed for 60 samples) and the differences of clay soil are presented in figure 1. It is seen that the maximum values are obtained for silty clay: 130 kPa on average (at maximum - 177 kPa); on the whole the values 93-95 kPa prevail for fat and lean clays at maximum 170-188 kPa.



a) b)

Figure 1. Distribution values of structural strength depending on a) grain size composition; b) different clay soils/

OCR change analysis with depth revealed that soils lower 20 m are normally consolidated; it should be noted that in the upper part of cross-section the *OCR* values range is wider – there occur overconsolidation soils. Such a picture is typical, since aerated zone soils occur in solid and semisolid state, whereas with increase water content, maximum water capacity and degree of saturation, the structural strength decreases, which was supported by correlation analysis.

The closest relationship was noted between structural strength and density parameters (figure 2): p_{str} and dry soil density ρ_d (the ratio coefficient r = 0,53); p_{str} and solids density ρ_s (r = 0,50); p_{str} and density ρ (r = 0,41); as well as between the following characteristics: p_{str} and water content w (r=-0,48); p_{str} and maximum water capacity w_n (r = -0,43); p_{str} and liquidity index I_L (r=-0,42). The insignificant relationships were obtained for plasticity index I_p, liquid limit w_L and plastic limit w_p. In correlation analysis the rock data were not used. But, as the graph shows, some samples had high density and structural strength values a well. Based on the stated relationships, the following equations of regression were obtained allowing prediction of structural strength (in kPa) depending on soil density and moisture:

$$p_{str} = 211{,}6 \cdot \rho - 301{,}4;$$
$$p_{str} = 210{,}8 \cdot \rho_s - 465{,}5;$$
$$p_{str} = 195{,}5 \cdot \rho_d - 187{,}7;$$

p_{str} = 222,7 - 4,1 · *w*;
p_{str} = 221,6 - 387,8·w_n.

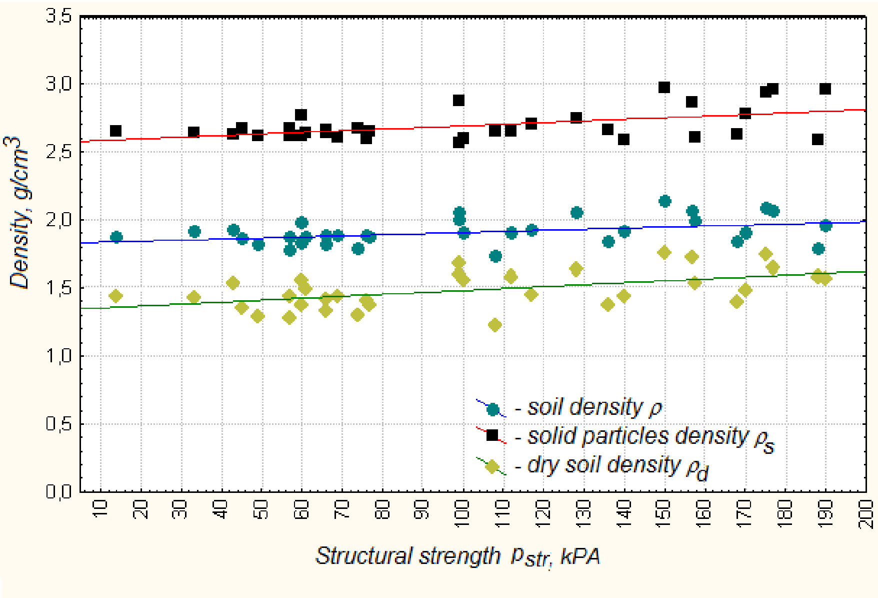


Figure 2. Dependence of soil density from its structural strength.

Besides, the relationship of indicator change with depth *h* (*r* = 0,79) was revealed.

p_{str} = 19,6 + 0,62·*h*.

According to [15], it is enough for one value of σ_p' to determine *OCR*, but to obtain characteristics of deformation necessary for settlement calculation at spotting the curve straight line section before and after p_{str}. It is desirable to obtain the two key points describing minimal $p_{str/min}$ and maximal $p_{str/max}$ structural strength. These can be points of tangent separation to the initial and final curve sections, or additional points obtained at processing of compression curves by Casagrande, Sellfors and Pacheco Silva methods [7, 19, 20]. As a guideline for research of deformation parameters we can recommend to determine soil physical properties as: void ratio, density, and water content, which correspond to minimum and maximum structural strength.

3. Summary

The results of laboratory research in composition, structural strength, and physical soil properties of Tomsk Oblast have permitted us to characterize their changes numerically and evaluate the state of soil consolidation up to 230 m depth. The *OCR* change analysis showed that soils lower 20 m are normally consolidated, i.e. structural strength does not exceed effective pressure, in the upper part of the cross-section there occur both week and overconsolidation soils. The stated closest relationships between p_{str} and soil density and moisture parameters allowed the regression equations to forecast the structural strength values. Such a forecast is useful for its express evaluation before soil shear and consolidation test for the given area, as well as estimation quality of undisturbed samples for laboratory testing.

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