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FEATURES OF LABORATORY TESTING METHODS OF CLAYEY SOILS

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Abstract: The article compares the results of laboratory tests of dispersed soils to determine their strength characteristics. For this purpose, soils were tested on devices with three-axis compression and single-plane cut. In calculations for clay and sandy soils, indicators of their strength properties are used, which include such characteristics as the angle of internal friction φ and specific adhesion c. Based on the results of this work, recommendations on the practical application of the obtained soil characteristics for the geo-information geotechnical database of Astana were compiled.

Key words: clayey soil, shear strength, cohesion, friction angle, stiffness.

ОСОБЕННОСТИ ЛАБОРАТОРНЫХ МЕТОДОВ ИСПЫТАНИЯ ГЛИНИСТЫХ ГРУНТОВ

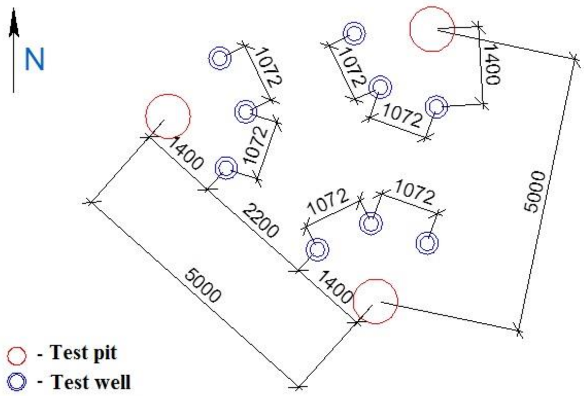
Аннотация: В статье сравниваются результаты лабораторных испытаний дисперсных грунтов для определения их прочностных характеристик. Для этого грунты испытывались на устройствах с трехосным сжатием и одноплоскостным срезом. В расчетах для глинистых и песчаных грунтов используются показатели их прочностных свойств, которые включают такие характеристики, как угол внутреннего трения φ и удельная сцепления с. По результатам этой работы были составлены рекомендации по практическому применению полученных характеристик грунта для геоинформационной геотехнической базы данных Астаны.

Ключевые слова: глинистый грунт, прочность на сдвиг, удельная сцепления, угол трения, жесткость.

Introduction. Among the many mechanical characteristics of the soil, deformation and strength properties remain as the main and widely used ones, the determination of which is an important experimental task. In recent years, new test schemes, more advanced designs of instruments and equipment for the study of various soils have been proposed [1]. Like any material, the soil has limited strength, and under certain external influences the soil massifs collapse, as a result of which their individual parts get unlimitedly large displacements. Field observations and experiments show that the destruction in most cases occurs by shearing - cutting arrays along certain fracture surfaces. To assess the moment of occurrence of this state, the conditions of the limiting stress state (limiting equilibrium, strength, and yield) of various types, corresponding to one or another concepts of soil destruction, are applied.

Selection of samples of soil for tests. Samples of soil for laboratory research were taken in the process of engineering and geological surveys of the construction site. Packaging and transportation of soil samples are made in accordance with GOST 12071-2000.

The distances between the wells were 1-1.2 m. The number of wells was taken with regard to 6 samples for conducting compression tests, 6 samples for triaxial tests and 6 as a reserve, in case of unsuitability of samples for testing. After sampling for laboratory tests of the deformation module, soil samples were taken for engineering geological surveys at a depth of up to 30 m. The layout of the sampling is shown in Figure 1.



Figures 1. Soil sampling for laboratory studies

Determination of the strength characteristics of unsaturated soils. The results of experimental studies of the strength characteristics of soils are presented by varying the degree of water saturation G and the density of the soil by the single-plane cut method and the method of triaxial compression. For testing, artificially prepared soil samples of disturbed structure were used .

According to K. Terzagi, the resistance of clay soils to shear is described by expression (1), proposed at the time by Coulomb (XVIII century) for sandy soils:

$$\tau_p = p \cdot tg\varphi + c \qquad (1)$$

τ_p – soil shear resistance at load-pressure p; φ – internal friction angle; c – specific grip. where τ_p is the resistance of the soil to shear under load-pressure *p*; *φ* is the angle of internal friction; *c* - specific grip.

This expression is valid when testing the clay soil with a preliminary compression of soil samples under load (p). Under this condition, each of the points of the linear equation (1), corresponding to the loads of experience (p), will be characterized in the general case by different densities (ρi) and humidity (Wi).At the suggestion of N.N. Maslova, for the resistance to shift of clay soils, the theory of "density-humidity" was developed [2-3]. According to the theory of "density-humidity", the magnitude of the internal friction angle φ and the initial adhesion to the large group of soils do not remain some constant values, as provided for by the Terzagi-Coulomb theory in its pure form. Moreover, in the theory of "density-humidity", these parameters were set in direct dependence on the initial state, and primarily on the moisture (W) of the soil, as well as on the load (p) applied to it.

The final expression of this theory was the dependency:

$$\tau_{pW} = p \cdot tg\varphi_W + \Sigma_W + c_c = p \cdot tg\varphi_W + c_W \qquad (2)$$

where τ_{pW} is the soil's resistance to shear at some of its density-humidity and the load acting on it; φ_W - the true angle of internal friction, independent of the increasing connectivity of the soil with the load; c_W - total adhesion, depending on the density - soil moisture.

In Figure 2 shows the dependence of the form $\tau_{pW} = f(p)$ for one of the varieties of coarse-plastic clay with different density-humidity (W_i). On each of the rays given here $\tau_{pW} = f(p)$ for different values of loads (p_i) the density-humidity of the soil (W_i) remains constant. Consequently, each of these rays corresponds to the test soil in its state of a certain density-humidity. From here, according to the theory of N.N. Maslov, and the connection Σ_W of clayey soil, depending on its density-humidity state, for each of these rays under different loads also remains unchanged. The initial total adhesion, determined by the natural properties of the soil and the initial state of its density-humidity, for example, the natural humidity W_{np}, also remains unchanged[4].

At the same time, the intrinsic friction angle (φ_{Wi}) inherent in the soil and the initial connectivity Σ_{Wi} are functionally related to its density and humidity (W_i) for a given soil.

According to this graph, we have the opportunity to find the values of φ_W and c_W for a given soil and then from the expression (2), the value of the soil's resistance to shear (τ_{pW}) for any of its density-humidity conditions.

The graph (Fig. 3) is plotted for each of the loads p_i using the found dependence τ_{pW} = f(W). Based on the graph of the form τpW= f(p, W), shown in Fig. 3, it is possible to find the values of τ_{pW} for some selected values of W, for those or other accepted loads p_i.

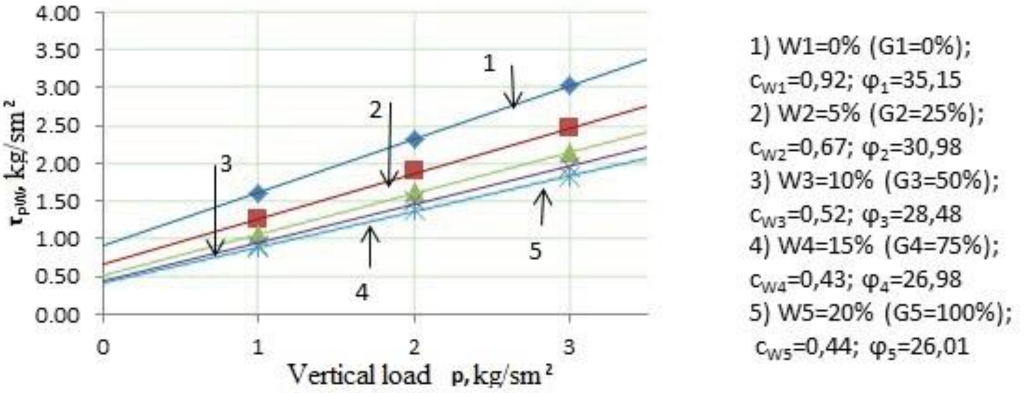


Figure 2. The value of the true angle of internal friction and the overall adhesion depending on the density and humidity of the soil

In case of incomplete water saturation (G <100%), the characteristics of the strength of the soil increase and reach a maximum value when G = 0%, however, this value of water saturation has only a theoretical value, since in nature, the soil has a certain humidity greater than zero [5]. Finding the dependence of the characteristics of the strength of the soil on the state of density-humidity has practical importance, since an essential issue in assessing the stability of slopes is the correct determination of the parameters of internal friction and adhesion of soils. For example, soil layers above the groundwater level, which are not under the influence of capillary rims and surface waters, should have strength characteristics higher than those that were at full saturation.

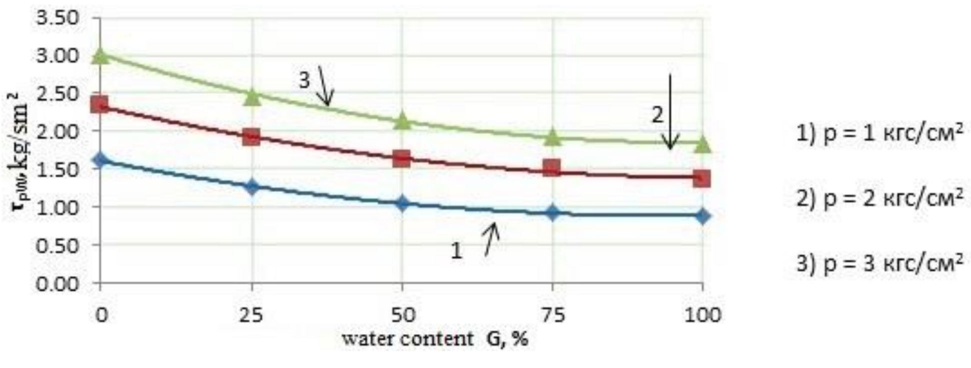


Figure 3. The graph of the primary data processing experiments on the shift by the method of "density-humidity"

Study of soils on the device of three-axis compression. Vertical load tests were performed at a given comprehensive pressure on the soil sample or at a given average normal stress.

The loading trajectories of a soil sample when tested on three-axis compression devices are shown in Figure 2. Tests for determination of the strength characteristics were carried out for at least three samples of the testing soil at various values of comprehensive pressure on the sample, and to determine the deformability at a given comprehensive pressure on the sample. Soil samples had a cylinder shape with a diameter of 75 mm, a height of 158 mm and a ratio of height to diameter of more than 2: 1.

The method of static three-axis compression of water-saturated soils is divided into 3 stages:

1. Stage of soil reconsolidation. An indicator of water saturation is the parameter $B = \Delta U / \Delta\sigma$, where ΔU and $\Delta\sigma$ are the increments of the pore pressure and hydrostatic load, respectively, by the time of measurement. When $B \geq 0.95$, the soil is considered as fully water-saturated.

2. The consolidation process. In this study, consolidated undrained tests (CN) were performed.

3. The stage of destruction of samples.

The soil sample in the triaxial is adjusted to the moment of destruction, which occurs either in the form of the formation of a “barrel” or in the form of a “chip”. The explanation of the type of destruction of the sample can be carried out using the warning value of prepacking P'_c [4]. The determination of the P'_c value according to the Kazangrande method [4] is carried out in compression devices that transmit the vertical stresses to the sample. If the effective pressure is less than the warning pressure (over-compaction coefficient OCR > 1), then the sample is characterized by elastic deformations [4-6], the form of destruction takes the form of "cleavage"; otherwise, the sample experiences both elastic and residual deformations (over-compaction coefficient OCR ≤ 1), the form of destruction takes the form of a “barrel”. Experimental studies of the deformation of clay soils under conditions of static triaxial compression under deviator loading $\sigma_1>\sigma_2=\sigma_3$ have been carried out. After testing, typical fracture patterns of prototypes of the following type were obtained:

– at the initial effective stress $\sigma'_{1,3}$ = 50 kPa, the destruction of the sample has the form of a "cleavage" (Fig. 4a);

– at $\sigma'_{1,3}$ = 100, 200 kPa, the destruction of the sample has the form of a “barrel” (Fig. 4b).

a) b)

Figure 4: a - the destruction of samples in the form of "cleavage"; b - in the form of a “barrel”

According to the results of testing soil samples under conditions of three-axis compression, the following were determined :

- for different values of $\sigma'_{1,3}$ = 50; 100; 200 kPa absolute vertical deformation of the soil sample: Δh = 10.32 mm; 12.28 mm; 15.24 mm;
- relative vertical deformation during destruction ε_1 = 12.57%; 15.31%; 19.74%.

According to the test results for the first sample (initial effective stress $\sigma'_{1,3}$ = 50 kPa), a graphic of relative vertical strain versus voltage difference ($\sigma1 - \sigma3$) was plotted (Fig. 5). At the time of destruction, the effective stresses reach: σ'_3 = 28.1 kPa and σ'_1 = 178.7 kPa.

The strength characteristics φ and c are determined by the circles of ultimate stresses: tgφ = 0.39 (φ = 21 ° 30 ') and c = 0.29 kgs / cm^2.

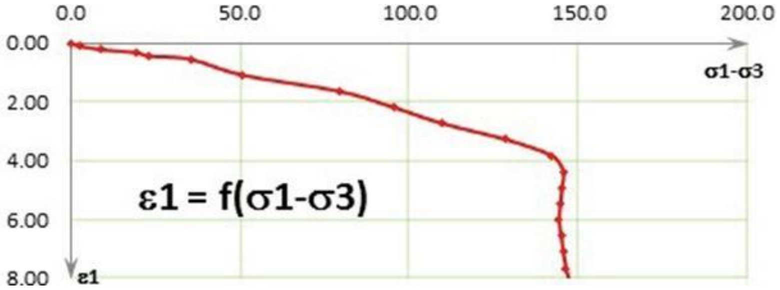


Figure 5. Dependence of relative vertical deformation on deviator loading

It should be noted that the strength characteristics are determined by tests of saturated soil samples, and tests of unsaturated soils are described in studies.

The obtained values of φ and c are given in table. 1. Note that between the results of tests on different devices there are no large differences in the values of φ and c. The value of φ decreased by 14.8%, and the value of c decreased by 25.6% compared to the tests with a one-plane cut.

It is necessary to note the differences in the test results of other authors, which can be explained by the following factors:

– when using the one-plane cut method, the lateral expansion coefficient μ is not taken into account;
– the plane of destruction on the device of a one-plane cut is determined in advance;
– when testing soil using the method of static triaxial compression, lateral expansion occurs, in addition, the sample was reconsolidated before testing, thus, the calculated fracture plane is in good agreement with the theoretical one.

Table 1.

Comparison of strength characteristics according to the scheme of one-plane cut and three-axis compression.

Strength Characteristics	Test method	
	one plane cut	triaxial compression
φ (°)	25°35'	21° 30'
c (kgs / cm^2)	0,39	0,29

Conclusion. The test results on a one-plane cut device and on a static triaxial device give a slight difference. The values of φ and c, obtained with a one-plane cut, are larger than those obtained during triaxial tests. The higher the density of the skeleton of the soil, the greater its strength characteristics. The research showed that a distinctive feature of the soils of Astana is that the soils of the same addition within one geological element represent an anisotropic structure and have uneven strength, density, humidity, etc. in depth. For example, the moisture content of loam is about 10.2 - 27.7%, density 1.84 - 2.09, porosity coefficient 0.51 - 0.68 in Astana.

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