UDC [622.271.33:624.131.537].001.57

O.V. Solodiankin, Dr. Sci. (Tech.), Prof.,
O.S. Kovrov, Cand. Sci. (Tech.), Assoc. Prof.,
N.N. Ruban

State Higher Educational Institution "National Mining University", Dnipropetrovsk, Ukraine, e-mail: solodyankinO@znmu.org.ua, kovrova@nmu.org.ua, nina_ruban@mail.ru

INVESTIGATION OF PHYSICAL AND MECHANICAL PROPERTIES OF SUBSIDING SOILS AT THE YEVPATORIYSKAYA RAVINE LOCATED IN THE CITY OF DNEPROPETROVSK

О.В. Солодянкін, д-р техн. наук, проф.,
О.С. Ковров, канд. техн. наук, доц.,
Н.М. Рубан

Державний вищий навчальний заклад „Національний гірничий університет", м.Дніпропетровськ, Україна, e-mail: solodyankinO@nmu.org.ua; kovrova@nmu.org.ua; nina_ruban @mail.ru

ДОСЛІДЖЕННЯ ФІЗИКО-МЕХАНІЧНИХ ВЛАСТИВОСТЕЙ ПРОСАДОЧНИХ ГРУНТІВ БАЛКИ ЄВПАТОРІЙСЬКА М. ДНІПРОПЕТРОВСЬК

The determination of the physical and mechanical properties of soils and soft overburden rocks is an important part of the engineering and geological studies both in development of mineral deposits and in the civil engineering. The reliable values of such parameters as cohesion and internal friction angle available from experiments determine the stability and reliability of various facilities and technical installations during their construction and operation.

Purpose. To perform the laboratory tests of physical and mechanical properties of soils and soft overburden rocks and their shear strength parameters.

Methodology. The paper describes the method of the shear test of soil and soft overburden rock by means of direct shear device PS–10 with a fixed cut plane. The monolithic undisturbed soil samples were selected from the slopes of Yevpatoriyskaya ravine in the city of Dnipropetrovsk. When the samples are loaded by critical values of vertical and tangential loads in the operating space of the shear device, the cartridge shifting occurs and shear deformations in the soil sample are observed in the form of horizontal cut. The measurement of soil strength properties and shear strength parameters were determined at different values of moisture. The values of moisture content in samples were measured by the KERN MLB hydrometer.

Findings. Laboratory tests of the subsiding soil samples with undisturbed structure and different values of moisture content allowed us to determine the following physical and mechanical properties: shear strength τ, internal friction angle φ and specific cohesion C.

Originality. As a result of numerous experiments the dependencies of shear strength parameters of soils and soft overburden rocks from the slopes of Yevpatoriyskaya ravine on the moisture content have been obtained. It allowed establishing patterns of relationship between the physical and mechanical properties of the soft rocks and the degree of their moisture saturation.

Practical value. The application of the reliable experimental data obtained from the shear tests for soils and soft rocks is useful for the assessment of stability of natural slopes, man-made and bulk rock massifs, as well as civil engineering objects.

Keywords: *shear strength of soils, internal friction angle, specific cohesion, shear device PS–10, Mohr-Coulomb failure criterion, stability of natural slopes*

Introduction. Loessial soils are found on all continents, but they are the most widely spread in Europe, Asia and America. There is 34% of the area covered by the loessial soils on the continental part of the CIS countries. The continuous layer of loess lies over the most of the territory of Ukraine (80%) and the South of the European part of Russia. Large areas are covered with loess in Central Asia, Kazakhstan, East, South and West Siberia. Quite often they are found in Belarus, the Volga region, Yakutia and other regions. Dnepropetrovsk is one of the most dangerous cities by the manifestation of landslides in Ukraine, because one third of its territory is represented by subsidence of loess loam.

The properties of the soil subsidence were studied by: Abelev Yu.M., Abelev M.Yu., Sokolov V.N., Shvetsov G.I., Larionov A.K., Sergeev Ye.M., Sadovenko I.A. The strength, stability and durability of buildings and structures founded on loess soils largely depend on the complete exception the possibility of soaking foundation during exploitation. An accident of water engineering communications and under flooding territory may cause an abrupt reduction of strength and deformation characteristics of foundation. Under these circumstances, the loess soil goes into the category of weak soils even without an increase the external load on the base. This causes landslide processes in soils, also differential settlement of ground, leading to the destruction of the surface facilities and communications. The paper [1] presents the results of the research of the strength and deformation properties subsidence of soils selected in the ravines and gully network of the city of Dnepropetrovsk. However, despite a lot of researches devoted to the strength properties of loess soils, the problem remains opened yet, because in most cases depends on their physical and mechanical properties, which vary depending on the conditions of occurrence.

The experimental investigations of physical and mechanical characteristics of soft overlaying rocks are an important part of the engineering-geological surveys in the assessment of slope stability and foundation of structures. These rocks usually are light yellow loess loams, yellow-brown dense loams, sandy and other engineering geological elements.

Formulating objectives and setting tasks. The objective of the current research is the performance of laboratory tests to determine the strength properties of the upper loam layers at Yevpatoriyskaya ravine in the city of Dnepropetrovsk. Within the researching the following tasks are performed: 1) determination of the values of cohesion, internal friction angle and the shear resistance for the overlying rocks represented by light yellow loess loams, yellow-brown dense loams using direct shear device PS–10 with a fixed cut plane; 2) investigation of the dependence between the strength properties of loams and the moisture saturation.

Methods of the strength characteristics of the dispersed soil definition. The laboratory methods for studying the soil properties do not address specific macrostructure, the specificity of its natural structure and occurrence, as well as the nature of the distribution in it inhomogeneities and inclusions. The laboratory methods for studying the soil properties do not address specific macrostructure, the specificity of its natural structure and occurrence, as well as the nature of the distribution in its inhomogeneities and inclusions. However, the laboratory tests of rocks results can be used to assess the stability of the natural slopes and man-made slopes, predicting the bearing capacity of rainfall or soil bases with a certain approximation. The most important parameters of the soil are: the internal friction angle, and both the cohesion and deformation modulus, which allow getting a full engineering assessment for base of construction, and take into account its physical properties. One of the most widely used in the practice of the weak soil engineering geology is the direct shear method, implemented in the shear device PS-10.

The shear strength is the most important property of soil strength; knowing it is necessary to solve various geotechnical problems. Under the influence of some external load in certain soil zones, the connections between the particles are destroyed, and there is a displacement (shear) in some particles relative to the others so the soil acquires the ability to deform indefinitely under this load. The destruction of the massif occurs as a displacement of one its part relative to the other (slope slip, foundation uplift from the building and so on). The soil shear strength in a certain range of pressures (from tenths of MPa to full units MPa) that can be expressed with a linear dependence established by Coulomb in 1773

$$\tau_{lim} = \sigma \, tg\varphi + C, \qquad (1)$$

where τ_{lim} is the shear stress limit, σ is normal stress, Pa; $tg\varphi$ is the internal friction rate, φ is the internal friction angle, C is the cohesion, Pa.

The values of φ and C affect the soil shear strength and require the engineering calculations for the strength and stability of the massif of soft soils and overburden, as well as their pressure on the building and structure.

The character of soil samples deformation depends on the design of instruments and conditions of loading. The strength characteristics of the light yellow loess loams and yellow-brown loams are determined by the shear device PS-10. It is aimed for the field and laboratory testing of clays and organic-mineral soils by shear strength (determination of the internal friction angle and cohesion of the soil); on the "load–direct shear" principle (fig. 1, *a*).The instrument has been designed for the following limit values of the unit pressure: horizontal to a maximum of 6 kg/cm^2; vertical to a maximum of 6.5 kg/cm^2. The volume of the soil sampling device does not exceed 50 cm^3. The technique of carrying out the laboratory tests is regulated by State standard DSTU 2.1-4-96 [Sergeyev, Ye.M.].

Soil shear strength is determined as the limit mean shear stress at which a soil sample is cut on a fixed direct under certain normal pressure.

To determine C and φ at least three tests at different values of the normal stress were applied.

To perform the series of experimental shear tests the monolithic undisturbed soil samples have been selected at Yevpatoriyskaya ravine located in the city of Dnepropetrovsk. According to the State standard DSTU 2.1-8-2001, the nature physical and mechanic characteristics, along with the granulometry composition were saved [2].

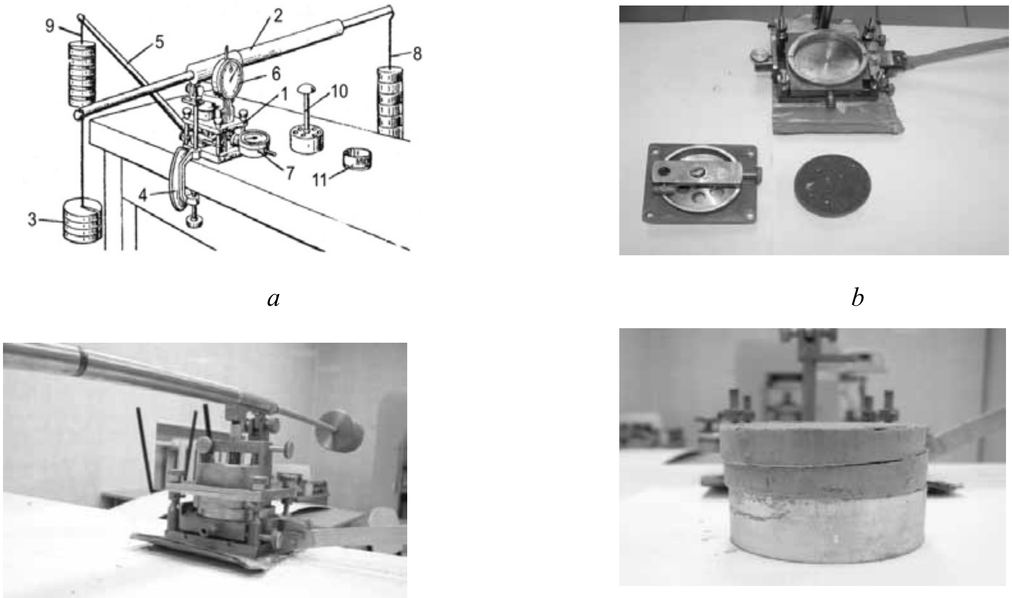
The dimensions of the monolithic samples were 100x100x100 mm. The number of samples was 3 monoliths for each lithological layer to be selected in different parts of the ravine.

The upper layer soil samples presented as a light yellow and yellow-brown loam were selected in the areas affected by landslide processes. The wedge-shaped shovel was applied for excavating soil samples. In order to preserve the natural humidity, the soil was packed into polyethylene packages and hermetical plastic containers, and then the connection of the cap and container was covered with adhesive tape.

For determining the loam strength properties the laboratory test by direct shear device PS-10 under normal stress 0,1;0,2;0,3 MPa was carried out The essence of unconsolidated and drain tests with appliance PS-10 is in destruction soil samples by shifting one part of a sample relative to the other (fig. 1). Next properties were defined: shear resistance τ friction angle φ and cohesion c. To determine the shear strength cylindrical soil samples were used. The samples were cut with a compression sleeve. The fastening device being applied, the lower part of the appliance was reliably fixed.

On the upper and lower layers of the soil sample a filter paper was laid. A free sleeve without soil is removed, the upper part of appliance is emplaced, and a tight press piston is placed onto the surface of the sample and fixed with screws.

The first thing to be applied is a compressive load and then horizontal shearing load should be. If the test is carried out only for deriving the shear strength, the predetermined value of the vertical load should be applied to the test sample immediately, regardless of its value.



a *b*

c *d*

Fig. 1. PS-10 for shear soil samples in ise: a – general view of PS-10 shear device; b – preparation of the sample for testing; c – sample loading; d – rock sample after the test; 1 – main part of the device; 2 – lever system for vertical load with pendants for cargoes; 3 – counterbalance weight of lever system 2; 4 – appliance and lever system attaching clamp; 5 – lever for horizontal loads with pendants for cargoes; 6 – vertical piston displacement indicator; 7 – horizontal bottom carriage displacement indicator; 8 – pendant with cargoes for vertical load; 9 – pendant with cargoes for horizontal load; 10 – device for moving the soil sample from the sleeve into the appliance; 11 – coring device

Immediately within a minute, the normal pressure P is transmitted onto the soil sample and at this pressure the sample will be cut into. Next, the normal load transmission is set in motion mechanism for producing a tangential load. Shearing requires operating within 2 minutes after the normal stress transmission has been performed.

The tangential load is transmitted with the 10% interval of the normal stress at which the sample will be cut into. The interval application should take every 10–15 seconds. The values of the normal and tangential loads, measured during the test, are used for determining the normal and tangential stresses accordingly to the formulas

$$\tau = \frac{T}{A}; \quad (2)$$

$$\sigma = \frac{P}{A}, \quad (3)$$

where *T* and *P* are tangent and normal force against the shear plane, kg respectively, and *A* is the cut area in cm^2.

On the basis of the tests the main parameters of the shear are calculated: the internal friction angle and cohesion. The test results are given as a diagram between the normal stress and shear resistance (fig. 2). The horizontal axis represents the vertical load σ and the vertical axis represents corresponding values of shear forces *τ*. The straight line ABC is drawn through the points received with the result of testing soil samples. These points represent a line of shear stresses. The angle of this line against the abscissa axis makes the internal friction angle *φ*, and the cut segment of the line ABC against the ordinate axis represents the cohesion volume.

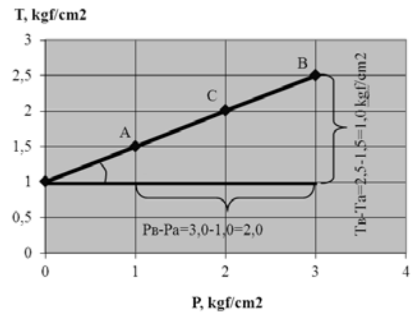


Fig. 2. Typical diagram of the correlation between the normal stress and shear resistance

These characteristics are calculated by the following formulas:

- the internal friction coefficient

$$tg\phi = \frac{T_B - T_A}{P_B - P_A}; \quad (4)$$

- cohesion

$$C = T_A - P_A \cdot tg\varphi \cdot \quad (5)$$

The specific values of the internal friction angle *φ* and cohesion *C* are calculated by the formulas under the analysis at least of three soil samples of each lithological variety

$$tg\phi = \frac{n\Sigma\tau_i\sigma_i - \Sigma\tau_i\Sigma\sigma_i}{n\Sigma(\sigma_i)^2 - (\Sigma\sigma_i)^2}; \quad (6)$$

$$c = \frac{\Sigma\tau_i\Sigma\sigma^2{}_i - \Sigma\sigma_i\Sigma\tau_i\sigma_i}{n\Sigma(\sigma_i)^2 - (\Sigma\sigma_i)^2}, \quad (7)$$

where τ_i is the experimental shear resistance, determined at different values, σ_i belongs to the same engineering and geological element or soil monolith ($n \geq 3$), n is the test number.

Influence of humidity on the physical and mechanical characteristics of loam. Next, the physical properties of the loam samples with undisturbed condition in its natural state were studied. The properties of the studied soils, determined by DSTU B V.2.1-3-96 [3], are summarized in table 1.

Table 1

Physical characteristics of natural soil samples

Physical characteristics		Light yellow loess loams	Yellow-brown loams
soil density ρ, g/cm³		1.48–1.65	1.56–1.7
The average values of soil humidity	nature W, %	9.8	11.01
	plasticity limit W_p, %	19.2	21.5
	liquid limit W_L,%	28.35	30.79
porosity, n, %		41	39.6
voids ratio, e, fractions		0.69	0.65

To prepare the soil samples the certain humidity in terms of soaking the soil to full water saturation was performed (fig. 3, *a*), and then carried out a gradual drying in a muffle furnace at t=100 ... 105ºC. After drying the samples were kept in insulated environment (fig. 3, *b*) with alternate inversion on different sides for the even distribution of humidity within a 3-day period. The degree of humidity in the samples was tested with the KERN MLB moisture meter (fig. 3, *c*).

Results. To obtain the soft subsidence soil samples in the undisturbed condition with the fixed step of humidity is a difficult task. This takes place because each sample has a set of physical and mechanical properties that vary in a certain range, according to the laws of probability, even within the investigated area. However, the aforesaid methodology of the soaking samples, partial drying and aging in sealed containers enables to obtain samples with the total moisture distribution over the entire volume and a fixed value. To determine the moisture content in the soil some material in the upper, lower and middle portions along the shear line were taken from the prepared samples. The measurement results are summarized in table. 2.

Table 2

Determination of the moisture content in the yellow-brown loam samples while drying

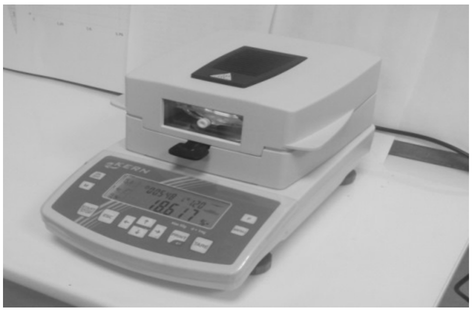
Sample drying time	Humidity value of the samples W,%			
	in the upper part of sample	in the middle part of sample	at the bottom part of sample	average value
0.5 hr. later	26.29	25.95	26.74	26.33
	24.96	24.70	24.84	24.83
	23.91	23.76	24.65	24.11
1.0 hr. later	20.75	21.76	20.90	21.14
	21.76	22.24	20.47	21.49
	20.20	20.87	20.36	20.48
1.5 hrs.	15.16	15.46	15.06	15.23
	14.95	15.99	15.38	15.44
	14.39	14.69	13.34	14.14
2.0 hrs. later	10.30	11.13	10.70	10.71
	9.06	8.78	10.06	9.30
	10.65	11.50	10.57	10.91

It is established that during half an hour drying the sample loses up to 4...5% of the initial moisture content. It allows preparing the required number of loam samples with certain moisture content for testing in PS-10 device.

The prepared samples with different moisture content were tested for shear to the above procedure, whereby the relationship between the normal load and shear resistance were obtained (fig. 4, 5).

a

b



c

Fig. 3. Preparation of loam samples with the required humidity: a – soaking the samples in sampling sleeves; b – curing samples in the insulated enclosure after drying; c – determining humidity of the soil sample with the moisture meter KERN MLB

Thereby, the strength characteristics of the yellow-brown and light yellow loess loam humidity were determined. Figure 6 and 7 show the correlation between the cohesion, the internal friction angle and the moisture content. Thus, for the yellow-brown loams at a predetermined range of moisture content W=11 ... 29% the value of the cohesion and the angle of internal friction varies within C=0.017…0.073 MPa and φ=14…35°. For the light yellow loess loams at a predetermined range of moisture content W=9.7…35%, the value of the cohesion and the internal friction angle varies between the range C=0.013…0.033 MPa and φ=8.5…15.4°.

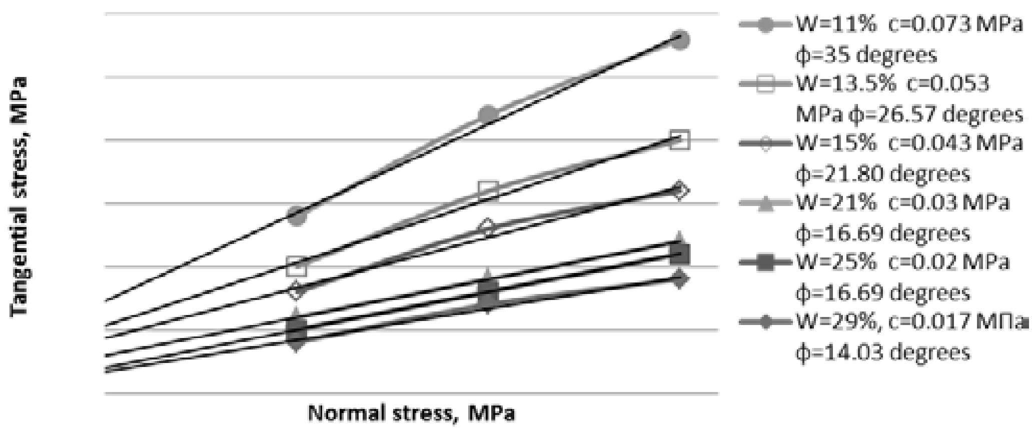


Fig. 4. Change of strength properties of the light yellow loams due to the moisture content

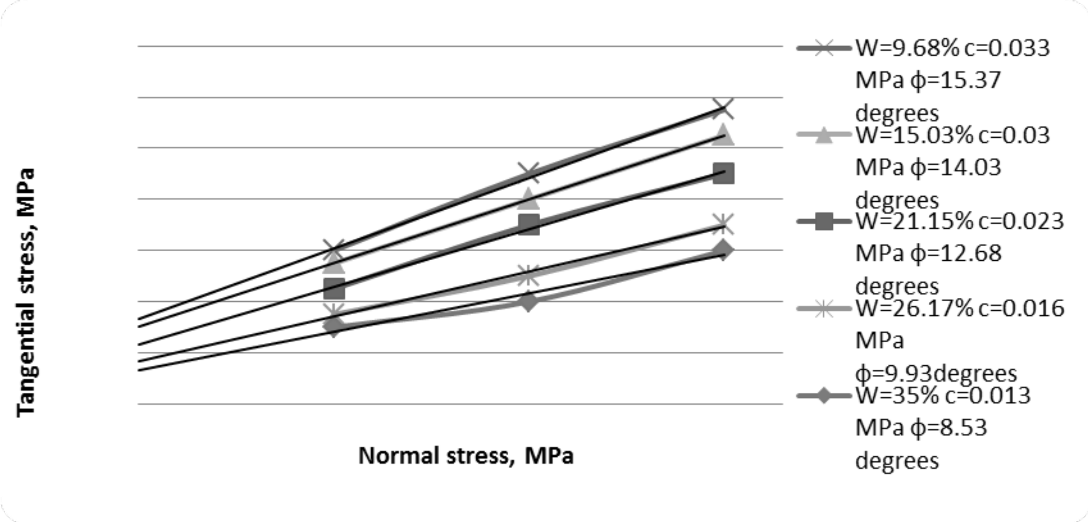


Fig. 5. Change of strength properties of the yellow-brown loam due to the moisture content

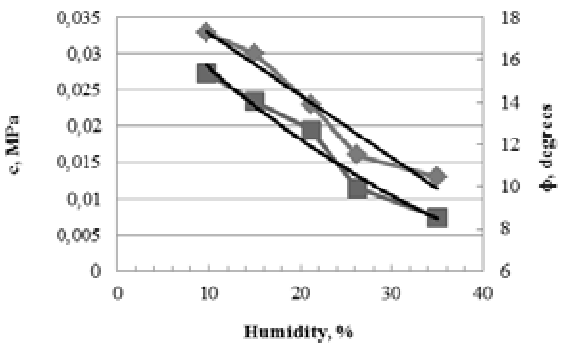


Fig. 6. Reducing cohesion and internal friction angle of light yellow loams during humidity increase

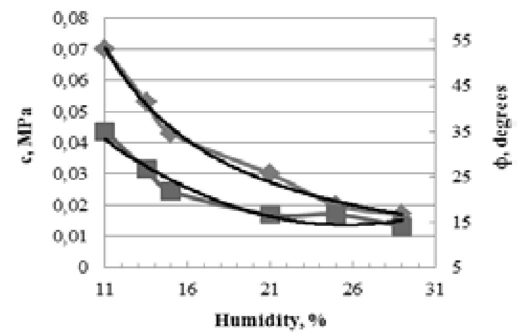


Fig. 7. Reducing cohesion and internal friction angle of yellow-brown loams during humidity increase

Conclusions. The physical and mechanical properties of soils are the most important subject of the geotechnical research. They are necessary for the assessment of the stability and deformability of the soil massif, assessing the strength of the bases of engineering structures and constructions.

In order to perform the series of experimental shear tests for the soils from the Yevpatoriyskaya ravine located in the city of Dnepropetrovsk the monolithic rock samples in undisturbed condition with dimensions 100x100x100 mm were selected. In the laboratory the sample of subsiding soil, along with the presented light yellow loess loam and yellow-brown loam, were tested. By means of the direct shear device PS-10 the physical and mechanical characteristics: shear resistance τ, cohesion *C* and angle of internal friction *φ* were determined.

The values of *C* and *φ* obtained experimentally are the important input data for the digital simulation of slope stability and ground structures involving the modern engineering programs based on the finite element analysis.

References / Список літератури

1. Sokolov, V.N. (1996), "Loess Problem", *Sorosovskiy Obrazovatelnyi Zhurnal*, no. 9, pp. 87–93.

Соколов В.Н. Проблема лессов / В.Н. Соколов // Соросовский образовательный журнал – 1996. – № 9. – С. 87–93.

2. State standard DSTU Б В.2.1-4-96, "Soils. Laboratory methods for determination of the strength and deformability."

ДСТУ Б В.2.1-4-96 „Грунты. Методы лабораторного определения характеристик прочности и деформируемости".

3. State standard DSTU Б В.2.1-8-2001, "Soils. Sampling, packaging, transportation and storage of samples."

ДСТУ Б В.2.1-8-2001 „Грунты. Отбор, упаковка, транспортирование и хранение образцов".

4. State standard DSTU Б В.2.1-1-95, "Methods of laboratory testing of physical properties."

ДСТУ Б В.2.1-1-95 „Методы лабораторного определения физических характеристик".

Визначення фізико-механічних характеристик просідаючих ґрунтів є важливим елементом інженерно-геологічних досліджень у процесі цивільного будівництва. Вірогідні значення таких величин як зчеплення, кут внутрішнього тертя, що отримані експериментальним шляхом, є запорукою стійкості та надійності різноманітних споруд і технічних об'єктів у процесі їх будівництва та експлуатації.

Мета. Лабораторні дослідження фізико-механічних властивостей ґрунтів і їх опір зсуву.

Методика. Описана методика експериментальних випробувань ґрунтів і м'яких розкривних порід на зсув з використанням одноплощинного зрізувального приладу ПС–10 з фіксованою площиною зрізу. Монолітні зразки ґрунту непорушеного складу були відібрані з укосів балки Євпаторійська м. Дніпропетровськ. При критичному навантаженні зразків вертикальним та дотичним навантаженням у робочому просторі приладу відбувається зрушення гільзи, а в ґрунті спостерігаються зсувні деформації у вигляді горизонтального зрізу. Вимірювання міцнісних характеристик ґрунту й опір зсуву визначалося при різних значеннях вологості зразків. Вологонасичення зразків вимірювалося за допомогою вологоміра KERNMLB.

Результати. Лабораторні дослідження зразків м'яких просідаючих ґрунтів непорушеного складу та з різними значеннями вологості дозволили визначити фізико-механічні характеристики: опір порід зрізу τ, кут внутрішнього тертя φ і питоме зчеплення C.

Наукова новизна. У результаті численних експериментів отримані залежності опору м'яких порід балки Євпаторійська зрушенню в залежності від їх вологості, що дозволило встановити закономірності зміни фізико-механічних характеристик ґрунтів від ступеня їх вологонасичення.

Практична значимість. Використання вірогідних експериментальних даних опору м'яких порід зрушенню дозволяє використовувати їх для оцінки стійкості природних схилів, техногенних і насипних масивів порід, а також об'єктів цивільного будівництва.

Ключові слова: *опір ґрунтів на зріз, кут внутрішнього тертя, питоме зчеплення, зрізний прилад ПС-10, критерій міцності Кулона-Мора, стійкість природних укосів*

Определение физико-механических характеристик просадочных грунтов является важным элементом инженерно-геологических изысканий в процессе гражданского строительства. Достоверные значения таких величин как сцепление, угол внутреннего трения, полученных экспериментальным путем, предопределяют устойчивость и надежность разнообразных сооружений и технических объектов в процессе их строительства и эксплуатации.

Цель. Лабораторное определение физико-механических характеристик грунтов и их сопротивление сдвигу.

Методика. Описана методика экспериментальных испытаний грунтов на сдвиг с использованием одноплоскостного срезного прибора ПС–10 с фиксированной плоскостью среза. Монолитные образцы грунта ненарушенного сложения были отобраны с участков естественных обнажений грунта балки Евпаторийской г. Днепропетровск. При критическом нагружении образцов вертикальной и касательной нагрузкой в рабочем пространстве прибора происходит сдвижение гильзы, а в грунте наблюдаются сдвиговые деформации в виде горизонтального среза. Измерение прочностных характеристик грунта и сопротивление сдвигу определялось при различных значениях влажности образцов. Влагонасыщение образцов измерялось с помощью влагомера KERNMLB.

Результаты. Лабораторные испытания образцов просадочных грунтов ненарушенного сложения и с различными значениями влажности позволили определить физико-механические характеристики: сопротивление пород срезу τ, угол внутреннего трения φ и удельное сцепление C.

Научная новизна. В результате многочисленных экспериментов получены зависимости сопротивления мягких пород балки Евпаторийская сдвигу в зависимости от их влажности, что позволило установить закономерности изменения физико-механических характеристик почв от степени их влагонасыщения.

Практическая значимость. Применение достоверных экспериментальных данных сопротивления грунтов сдвигу позволяет использовать их для оценки устойчивости природных склонов, техногенных и насыпных массивов пород, а также объектов гражданского строительства.

Ключевые слова: *сопротивление грунтов срезу, угол внутреннего трения, удельное сцепление, срезной прибор ПС-10, критерий прочности Кулона-Мора, устойчивость естественных откосов*

Рекомендовано до публікації докт. техн. наук О.О. Сдвижковою. Дата надходження рукопису 23.02.14.