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A. Aitkazina

D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan
E-mail: a.aytkazina@mail.ru

Study of the deformation characteristics of soils with a change in humidity

Abstract. *This paper discusses the anisotropic properties of soils and the issue of the influence of soil wetness on the stress-strain state of an anisotropic foundation. The study of material properties and the nature of these properties is directly related to the origin and structure of the object under study. The most important of them from the point of view of calculations of foundations, design of buildings, and structures are deformation, strength, and filtration anisotropy, which introduce changes to a greater or lesser extent in the stress-strain state of soil massifs. The entire set of physical and mathematical properties of soils is determined by their structure and texture, which, in turn, are formed depending on the composition and genesis of soil deposits, as well as under the influence of external factors leading to the transformation of the stress state of the soil mass. Practically in all experiments in which the deformation, filtration, strength, and other properties of soils were studied in various directions, a difference in their indicators was noted. Such results testify to the anisotropic manifestation of these properties. An elastic (linearly deformable) soil model is considered a design model of soils that make up an anisotropic base.*
Keywords: *soil, deformation, anisotropic, properties, model.*

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1. Introduction

The anisotropic properties of ground sediments and rocks have been studied by many researchers. The peculiarity of the object predetermined the study of anisotropy of a number of properties of rocks and soils, in particular, such properties as deformability, strength, swelling, permeability, and thermal conductivity [1]. The most important of them in terms of calculations of foundations, design of buildings, and structures are deformation, strength, and filtration anisotropy, which make more or fewer changes in the stress-strain state of soil masses: foundations, embankments, etc [2-3]. Soils as products of rock and rock destruction are dispersed media. The entire set of physical and mathematical properties of soils is determined by their structure and texture, which, in turn, are formed depending on the composition and genesis of soil deposits, as well as under the influence of external factors that lead to the transformation of the stress state of the soil massif.

In many studies [4-5] in which deformation, filtration, strength, and other properties of soils in different directions were investigated, differences in their indicators were noted. Such results indicate an anisotropic manifestation of these properties. It is impossible to develop precise methods of calculating soil based on the action of the external load because of the influence of various factors [6-8]. Therefore, in practice, they replace real foundations with simplified ones, i.e., models. The existing models of foundations are shown in Fig. 1.

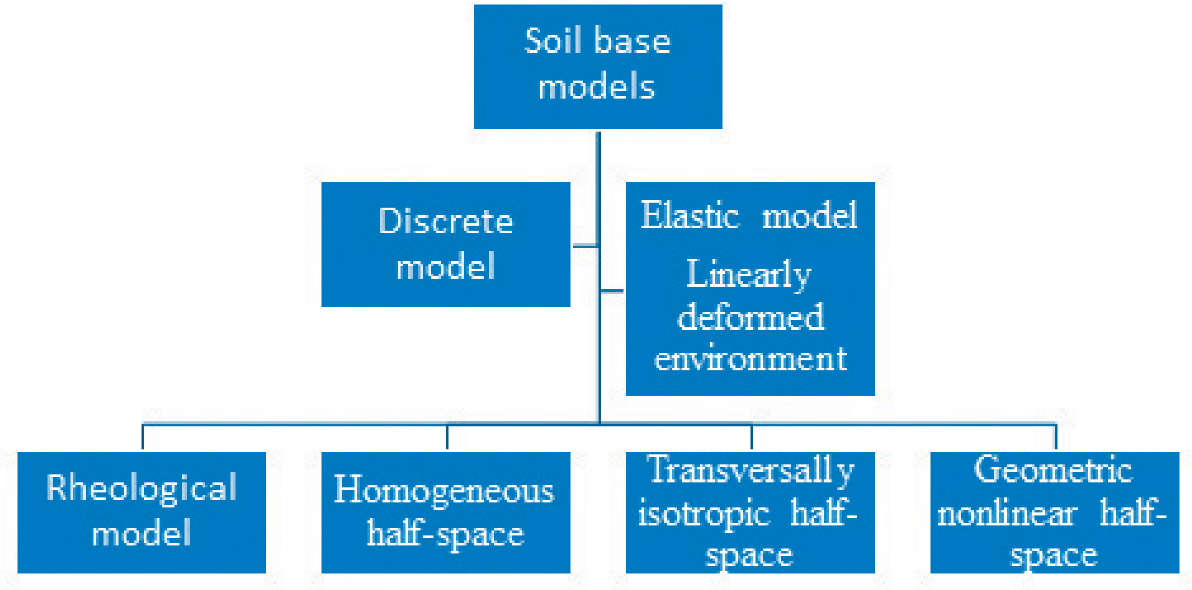


Figure 1. Models of soil bases

The main computational models of soils are the theory of linear deformation for calculations of finite stresses and stabilized settlements; the theory of filtration consolidation for calculations of settlement development in time; the theory of limiting stress state of soil - for calculations of bearing capacity, strength, stability and soil pressure on enclosures [6].

In addition to theoretical methods, experimental studies are of great importance for improving the calculated strain anisotropy of soils.

The choice of the optimal type of foundation depends on the data on soils and their properties.

Clay soils are the most unfavorable for laying foundations: they can shrink when drying, be eroded by floods, and swell when freezing [7]. These properties are due to the fact that clay soils consist of tiny particles, having mainly flake shape, and a large number of thin capillaries. Through them, water fills all the pores of the clay and envelopes the soil particles. The created mutual attraction provides viscosity to the clay soil. The strength of the ground itself has a strong dependence on the state it is in (moisture saturation, temperature).

It is not only the study of the degree of transferable stress from the mass of the building or structure that is significant in testing. Significant conditions for calculation are the forces acting on the building itself. Additional forces such: as atmospheric pressure; additional mass from precipitation; wind.

At the level of laboratory tests the maximum and safe level of horizontal and vertical loads is established. This determines the bearing capacity of the soils and the level of hazard that should be provided for in case of emergency consequences. During the conclusion of such tests, the main indicator is the resistance to shear deformation, which leads to changes in the integrity and fracture. Thus, when designing foundations for structures, an important step is the selection of a design model for soils [9-10].

The strain modulus is determined by testing soils using compression tests, three-axial tests, and field tests with stamps. In most cases of geotechnical surveys, strain modulus is determined using compression tests of sandy and silty clay soils under laboratory conditions [3].

In most cases, when conducting engineering and geological surveys, the deformation modulus is determined using compression tests of sandy and dusty-clayey soils in the laboratory [8].

A brief analysis of the issue under investigation shows that several aspects need to be deepened. The nature of anisotropy is poorly investigated experimentally.

Thus, clayey soils of normal layering without apparent layering (most experimentalists tend to argue that the soil in the direction of the gravitational forces will be less than in the horizontal compressibility of such there is the opposite though direction, the statements); completely unexplored anisotropy of sandy soils.

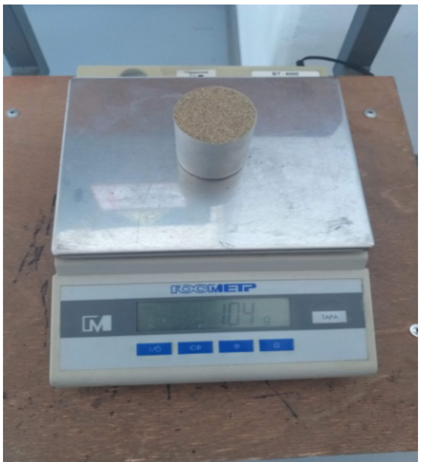
2. **Methods and materials**

The laboratory study was carried out on the odometer device. In the following sequence:

1. Soil preparation (Fig. 2);
2. Determine the mass of the soil (Fig. 3);

Fine sand has a particle size of (0.25÷0.1) mm. In the studied sample of soil particles size ≥ 0.01 mm, was 76%, such soil is called “fine sand”.

Figure 2. Tested soil samples



a) sand b) sandy loam

Figure 3. Weighing samples

Place the examined soil samples in the odometer (sample area A = 24.6 cm^2; sample height h_o = 20 mm). Leverage ratio h = 1:5 (Fig.4).

Figure 4. Test of soil

Compression tests were performed for sand and sandy loam.
We determine the characteristics of soils.
Soil density of natural moisture:

$$\rho = \frac{m_1}{V} \qquad (2)$$

where, *m* – soil mass, g;
V – cutting ring volume equal to 50 cm^3.

Natural humidity:

$$w = \frac{m - m_d}{m_d} \qquad (3)$$

where, m_d – the mass of dry soil, g.

Dry ground density:

$$\rho_d = \frac{\rho}{1 + w} \qquad (4)$$

Initial soil porosity coefficient:

$$l_0 = \frac{\rho_s (1 + w)}{\rho} - 1 \qquad (5)$$

where, ρ_s - density of solid particles.

Using the dependence *E=f(p)*, determined the deformation modulus of natural moisture sand in the pressure interval 0÷1.3 kg. We determine the change in the porosity coefficient of the sample. The calculation of the coefficient of porosity e of the soil of natural moisture is performed in tabular form.

Vertical stress in soil:

$$\sigma = \frac{P \cdot g}{A \cdot n} \qquad (6)$$

where, *P* – a mass of the load, kg;
g = 9.81 m/c^2;

A – cross-sectional area (24.6 cm^2);
n – leverage ratio (lever arm ratio n = 1/5).

Soil deformation modulus:

$$E = \frac{\Delta\sigma}{\Delta e}(1 + l_0)^{\beta} \quad (7)$$

where,

$$\beta = \frac{2v^2}{1 - v} \quad (8)$$

Compression tests for sand

Wetness not included

The cutting ring method, the volume of which is V = 50 cm^3, takes a sample of sand of natural moisture. The diameter of the ring is 5.6 cm; the cross-sectional area A = 24.6 cm^2. The mass of sand m_1 = 85 g. The density of sand of natural moisture: ρ = 1.7 g/cm^3;

The mass of dry soil was determined after drying the soil sample at t = 105°C. The value of the mass of dry soil is obtained m_d = 78.7 g.

The indicators were determined using the following formulas:

Natural humidity: w = 0.08

Density of dry soil: ρ_d =1.57 g/cm^3 ρ_d

Initial coefficient of sand porosity: l_0 = 0.69

Using the dependence E=$f(p)$, determined the deformation modulus of natural moisture sand in the pressure interval 0÷1.3 kg.

Water-saturated sand test.

The sand has been moistened with water until saturation. Saturation is characterized by the appearance of water on the surface.

The mass of the sand sample in the cutting ring is calculated m_2 = 95.23 g, density ϱ_2 = 1.9 g/cm^3

Natural humidity: w_2 = 0.21

Density of dry soil: ρ_{d2} = 1.57 g/cm^3

The degree of water saturation of the sample is:

$$S_r = \frac{\rho_s \cdot W_2}{e \cdot \rho_w} = 0.804 \geq 0.8$$

where, V = 50 cm^3 – cutting ring volume;

m_{s1} = 93 g – mass of loam in the cutting ring;

After drying the sample at 105ºC, the mass of dry soil $m_{d(s1})$ = 84 g was obtained.

Natural humidity: w_{s1} = 0.107

Dry ground density: ρ_{ds1} = 1.68 g/cm^3

Density of sandy loam solids: ϱ_{ss1} = 2.75 g/cm^3

Initial porosity factor: l_0 = 0.64

Deformation modulus of sandy loam saturated with water.

To test the loam with regard to its wettability we moisten the loam sample. The mass of the sandy loam sample was m_{s2} = 99.96 g.

Density of a sandy loam sample: ρ_{s2} = 1.99 g/cm^3

After drying the sample at 105ºC, a mass of dry soil was obtained m_{ds2} = 84 g.

The moisture content of sandy loam: w = 0.19

Density of dry soil: ρ_{ds2} = 1.99 g/cm^3
The degree of water saturation of the sample is: S_r = 0.808 ≥ 0.8 (saturated with water).
Density of sandy loam solids ρ_{ss2} = 2.75 g/cm^3
Initial porosity coefficient l_0 = 0.646.

3. **Results and Discussion**

3.1 Results of compression tests for sand

Determination of the deformation modulus of sand without taking into account wettability
Table 1 shows the calculation of the coefficient of porosity of sand with natural moisture.

Table 1. Calculation of the coefficient of porosity of sand with natural moisture

Load P(kg)	Vertical tension σ, (kg/cm^2); (MPa)	Conditionally stabilized sediment, mm S_i	Relative compressive strain: ε_i	Porosity coefficient e_i
0.1	0.02 (0.00199)	0.01	0.0005	0.6898
0.3	0.06 (0.00598)	0.015	0.00075	0.6896
0.8	0.159 (0.0159)	0.03	0.0015	0.6895
1.3	0.26 (0.026)	0.06	0.003	0.689

Deformation modulus of sand: E = 30.14 MPa.

Determination of the modulus of deformation of sand saturated with water
Table 2 shows the change in the porosity coefficient when loading the test soil sample with a load varying from 0 to 1.3 kg.

Table 2. Changing of the porosity coefficient

Load P (kg)	Vertical tension σ, (kg/cm^2); (MPa)	Conditionally stabilized settlement, mm S_i	Relative compressive strain: ε_i	Porosity coefficient e_i
0.1	0.02 (0.00199)	0.03	0.0015	0.6874
0.3	0.06 (0.00598)	0.045	0.00225	0.6862
0.8	0.159 (0.0159)	0.06	0.003	0.6849
1.3	0.26 (0.026)	0.066	0.0033	0.6844

Initial coefficient of sand porosity: l_o = 0.69
Deformation modulus:
E = 10.8 MPa.

3.2 Sandy loam compression test results

Determination of the modulus of deformation of sandy loam without taking into account wetness

Determine the modulus of deformation of naturally occurring sandy loam in the pressure range 0-3 kg. Table 3 shows calculation of porosity coefficient of sandy loam.

Table 3. Calculation of the porosity coefficient for naturally moist sandy loam

Load *P* (kg)	Vertical tension *б*, (kg/cm^2); (MPa)	Conditionally stabilised sludge, mm S_i	Relative compressive strain: ε_i	Porosity coefficient e_i
0.1	0.02 (0.00199)	0.014	0.0015	0.6388
0.3	0.06 (0.00598)	0.021	0.00105	0.68827
0.8	0.159 (0.0159)	0.034	0.0017	0.6372
1.3	0.26 (0.026)	0.038	0.0019	0.6368

Determination of the deformation modulus of sandy loam saturated with water

Table 4 shows the calculation of the moisture porosity coefficient W=0.15.

Table 4. Calculation of the porosity coefficient

Load *P* (kg)	Vertical tension *б*, (kg/cm^2); (MPa)	Conditionally stabilised sludge, mm S_i	Relative compressive strain: ε_i	Porosity coefficient e_i
0.1	0.02 (0.00199)	0.016	0.0008	0.64468
0.3	0.06 (0.00598)	0.024	0.0012	0.64402
0.8	0.159 (0.0159)	0.042	0.0021	0.6425
1.3	0.26 (0.026)	0.068	0.0034	0.6404

Considering the character of σ distribution in a transversally isotropic half-space under the action of a vertical point force on its surface, it is seen that when ground layers get wet, stresses along the line of action of the point force decrease in comparison to those obtained by taking into account the anisotropy of the ground.

Deformation modulus: E = 6.2 MPa.

The theory of calculation of structures on an anisotropic soil foundation is based on the solutions of the theory of elasticity of anisotropic bodies [5]. Simple anisotropy schemes are used to describe and determine the physical characteristics of a homogeneous transversal-isotropic foundation. A homogeneous elastic-isotropic medium can be composed with a medium consisting of a number of parallel layers, of different thicknesses, of isotropic materials having different elastic properties.

If we denote the value of the deformation modulus of an anisotropic medium as a whole as Ex, for the direction parallel to the length of the layers, and through Ey for the direction perpendicular to the length of the layers, then these moduli will be related to the properties of individual layers.

Deformation moduli of the base formed by the two layers:

E_y = 22 MPa;
E_x = 20 MPa.
Strain moduli in the water saturation state:
E_y = 8.1 MPa;
E_x = 8.5 MPa.

$$\frac{E_x}{E_y} = 0.95$$ — state close to isotropic

These relations are derived from the condition of constant strain for tension along the layers and constant stress for tension perpendicular to the layers.

4. Conclusion

These relations are obtained from the condition of constant strains for the case of tension along the layers and the constancy of stresses for the case of tension in the direction perpendicular to the layers.

Based on the results, the following conclusion can be drawn:

1. Soil deformation modulus changes (decreases) when it is saturated with water.

2. The moduli of deformation of the base in case of layered occurrence of soils have different values in the direction perpendicular to the layers and along the layers, in the event that the water saturation of the layers is $S_\tau < 0.8$, i.e. soils in their natural state.

When the soil is saturated with water, at $S_\tau < 0.8$, the deformation moduli in the direction perpendicular to the layers and along the layers become the same, i.e. soils are isotropic throughout the volume.

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А.К. Айтказина
Д. Серікбаев атындағы Шығыс Қазақстан техникалық университеті, Өскемен, Қазақстан

Ылғалдылық өзгерген кезде топырақтың деформациялық сипаттамаларын зерттеу

Андатпа. Бұл мақалада топырақтың анизотропты қасиеттері және анизотропты негіздің кернеулі деформацияланған күйінің топырақ суlануының әсері қарастырылады. Материалдың қасиеттерін және осы қасиеттердің табиғатын зерттеу зерттелетін объектінің шығу тегі мен құрылымы мәселелерімен тікелей байланысты. Олардың негіздерін есептеу, ғимараттар мен құрылыстарды жобалау тұрғысынан ең маңыздысы-деформациялық, беріктік және сүзгіш анизотропия, бұл жер массаларының кернеулі-деформацияланған күйіне азды-көпті өзгерістер әкеледі. Топырақтың физика-математикалық қасиеттерінің барлық жиынтығы олардың құрылымы мен құрылымымен анықталады, олар өз кезегінде жер асты шөгінділерінің құрамы мен генезисіне байланысты, сондай-ақ топырақ массивінің кернеулі күйінің өзгеруіне әкелетін үшінші тарап факторларының әсерінен қалыптасады. Әр түрлі бағыттар бойынша топырақтың деформациялық, сүзу, беріктік және басқа қасиеттерін зерттеген барлық дерлік тәжірибелерде олардың көрсеткіштерінің айырмашылығы байқалды. Мұндай нәтижелер осы қасиеттердің анизотропты көрінісін көрсетеді. Анизотропты негізді құрайтын топырақтың есептік моделі ретінде топырақтың серпімді (сызықтық-leформацияланатын) моделі қарастырылады.

Түйін сөздер: топырақ, деформация, анизотропты, қасиеттері.

А.К. Айтказина
Восточно-Казахстанский технический университет им. Д. Серикбаева, Усть-Каменогорск, Казахстан

Исследование деформационных характеристик грунтов при изменении влажности

Аннотация. В данной статье рассматриваются анизотропные свойства грунтов и вопрос влияния намокаемости грунта напряженно-деформированного состояния анизотропного основания. Изучение свойств материала и природы этих свойств непосредственно связано с вопросами происхождения и строения исследуемого объекта. Наиболее важным из них с точки зрения расчетов оснований, проектирования зданий и сооружений являются деформационная, прочностная и фильтрационная анизотропия, вносящие в большей или меньшей степени изменения в напряженно-деформированное состояние грунтовых массивов. Весь набор физико-математических свойств грунтов определяется их структурой и текстурой, которые, в свою очередь, формируются в зависимости от состава и генезиса грунтовых отложений, а также под влиянием сторонних факторов, приводящих к трансформации напряженного состояния массива грунта. Практически во всех опытах, в которых исследовались деформационные, фильтрационные, прочностные и другие свойства грунтов по различным направлениям, отмечалось различие их показателей. Такие результаты свидетельствуют об анизотропном проявлении этих свойств. В качестве расчетной модели грунтов, слагающих анизотропное основание, рассмотрена упругая (линейно-деформируемая) модель грунта.

Ключевые слова: грунт, деформация, анизотропные, свойства.

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Information about authors:

A. Aitkazina – Senior Lecturer, Serikbayev East Kazakhstan Technical University, 69 Protozanov str., Ust-Kamenogorsk, Kazakhstan.

А.К. Айтказина – аға оқытушы, Д. Серікбаев атындағы Шығыс Қазақстан техникалық университеті, Протозанов көш., 69, Өскемен, Қазақстан.