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DETERMINATION OF THE FINE-GRAINED COMPONENT PARAMETERS OF THE SOIL MIXTURE FOR THE ESTABLISHING OF THE ELEMENTS OF BULKS EARTH DAMS

Abstract. Perform theoretical research, aimed at solving problems of determining the physical parameters of the components (fine and coarse earth) of soil mixtures intended for the construction of elements (thrust prisms, cores, depressions, screens, impervious devices) of bulk earth dams. In a new formulation the tasks have been solved in relation to two variants of the state of the soil mixture. As the first option, the case is considered when free water, air and gaseous substances take place in the pores of the fine earth, and the second option, when only water is in the pores of the fine earth.

The received formulas, allowing to establish the volume and mass of fine powder and large amount of soil mixture. There are also formulas for determining the density of fine-grained and coarse-grained for the indication of two variants of soil mixtures. The formulas are recommended to be used at the stage of realization of the process of conditioning of soil mixtures, that is, to change the moisture, density and granulometric composition of their components. In this case, the formulas relating to the first variant state of soil mixtures, preferably used for their conditioning in quarries, reserves (warehouses) and transportation. The results of checking the formula for determining the density of a fine-grained component in a dry state are given.

The novelty of the obtained solutions lies in the fact that, unlike existing methods, they take into account the presence of free water, air and gaseous substances in the composition of soil mixtures, which have a significant effect on the compaction of the mixtures.

Keywords: Soil mixture, fine earth, coarse earth, volume, mass, density.

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Introduction. The research on solving a number of topical problems in the field of hydraulic engineering structures is carried out at M.Kh. Dulaty Taraz Regional University. According to them, the research is carried out to establish the optimal compositions of soil mixtures for the construction of earthworks [1], as well as work on the study of new pile structures for the supports of linear structures [2,3].

The work discusses issues related to the selection of soil mixtures for bulk earth dams.

Soil mixtures are used for the construction of thrust prisms, cores, depressions, screens and impervious devices of bulk earth dams must have a certain composition and properties, and their volumetric and weight parameters must comply with the requirements. Therefore, at the stage of dam design and experimental work on their construction, as a rule, the selection of the type, composition and parameters of the components of the soil mixture is made. It is necessary to have reliable methods for determining the parameters of the soil mixture and its constituent components, which include coarse-grained (coarse earth) and fine-grained (fine earth) components to ensure the reliability of the important process.

Conditions and methods of research. Currently, in the field of hydraulic engineering there are methods that allow determining the parameters of the soil mixture and its components, taking into account various influencing factors.

Thus, [4] proposes to determine the coefficient of soil compaction of embankments and dams on the basis of correlation. The dependencies between the values of the compaction coefficient and soil resistance, penetration of the tapered tip of the probe unit is established based on the results of laboratory and field tests. Tests of compacted soil with a sounding unit (static, dynamic or vibration) are carried out to a depth of 1 m in a construction site. The soil compaction coefficient is determined based on the results of laboratory experiments using samples taken from wells drilled at a distance of no more than 1.0 m from the sounding sites. The considered method is laborious and requires the involvement of additional equipment in the form of a sounding installation. In addition, the accuracy of the method significantly depends on the reliability of the used correlation dependence.

[5] as new technological parameters of clay soils for their effective compaction during the construction of hydraulic structures, it is recommended to use the values of the consistency index and the coefficient of water saturation of soils. The coefficient of water saturation of the soil, taken equal to 0.85-0.95, is used to establish the required density of the soil in a dry state. The required density of the soil in a dry state is determined by the formula, which, in addition to the water saturation coefficient, includes the density of particles and the natural moisture content of the soil. It is assumed that when the soil reaches the required density, its flocculation structure transforms into a dispersing structure. The compaction of clay soil to the required density is ensured by the selection of an appropriate soil compacting mechanism, the type and energy parameters of which are assigned depending on the indicator of soil consistency. The method can be used when compacting clay soils.

In the work, the authors propose to use the Talbot equation [6,7] to determine the density of the "skeleton" of the soil (clay soil containing coarse inclusions). The equation is a power-law function that allows you to determine the content of the soil fraction depending on the ratio of the particle diameter of the fraction to their maximum size in the soil. The method includes:

- construction of curves of granulometry composition based on the Talbot equation;
- establishment of the envelope curves of the granulometry composition of the soil;
- determination of the density of soil in a dry state.

The density of the soil in a dry state is determined using a calculation formula that takes into account the type, heterogeneity and density of soil particles, as well as the content of various fractions in it. The method allows obtaining approximate results, since the actual curves of the granulometry composition of real soils and their mixtures of 100% do not correspond to the curves that are described by the Talbot equation.

The specialists of JSC "Moscow Institute of Hydraulic Engineering" recommend controlling the density of coarse-grained soil [8,9], used for the construction of stone-earth dams, according to the density of the fraction with a particle size of less than 200 mm. The density of coarse soil in a dry state, including boulders and lumps, is recommended to be set according to the formula, depending on the following parameters:

- the percentage of boulders and blocks;
- the average value of the density of particles of boulders and boulders;
- density of the fraction with particle sizes less than 200 mm.

The developed method is acceptable for the case when the density of the soil is established using samples taken from the pits (reduced size) after laying the soil.

The work provides for the permissible values of the density and moisture content of the fine-grained component of the soils of proluvial deposits to be determined according to the graphs built on the basis of the test results of the samples [10,11]. The graphs show the lines of the minimum and maximum values of the density and moisture content of the fine-grained component, depending on its percentage in the composition of crushed-clay soil. The method is proposed for use in the construction of dams from soils of proluvial deposits and takes into account the specifics of the variability of the type and properties of the clay component of these soils.

From the analysis of the research results presented in [4-11], it follows that the existing methods and methods for determining the parameters of soils are acceptable only for special cases of earthen structures, because some of them are characterized by limitations in the type and properties of soils, and for others - high labor intensity or insufficient reliability.

The methods included in the regulatory documents are devoid of such disadvantages. These include the methods included in the [12] and the guidance document [13]. The relevance of the application and the prevalence of these methods is dictated by the fact that they, to one degree or another, take into account the peculiarities of the structural composition of soils.

The method presented in the [12] makes it possible to determine the mass of fine earth, the mass of coarse earth, the density of fine earth in a dry state and the density of a soil mixture in a dry state. In this case, particles less than 1-5 mm are taken as a fine-grained component of the mixture. The method sets requirements:

- to the minimum amount of a fine-grained component when constructing anti-seepage elements of dams;
- to the density of the coarse-grained component at which the suffusion stability of soils is ensured in case of their possible segregation.

Analysis of the initial equation underlying this method shows that in it the soil mixture is considered as a dry mixture and its pores are completely filled with fine earth. But, this does not take into account that the fine earth itself may have pores, and they may contain water, air and gaseous substances. Therefore, the parameters of the fine-grained component and the mixture are set without taking into account the moisture content of the fine-grained soil.

The guidance document [13] includes a method for determining the following parameters:

- the density of the sand (fine-grained component) in the dry state;

- the density of solid particles of the soil mixture;
- the density of the stone (coarse-grained component) in a dry state;
- the porosity of the stone;
- the percentage of sand in the soil mixture.

When developing the method, the soil material was adopted as a two-component mixture in the form of stone and sand with the presence of pores in the mixture. When developing the method, the authors of the method did not take into account that the pores of the mixture are pores of both stone and sand. And they usually contain water, air and gaseous substances. In addition, given that the size of the coarse earth particles exceeds the size of the fine earth, it can be assumed that part of the pores of the coarse earth is filled with fine particles.

As can be seen, the considered methods do not take into account the state of the pores of the soil mixture, i.e. the presence in them of such elements as pore water, air and gaseous substances, which have a significant effect on the density-moisture state of the mixture and its components.

Consequently, the reliability of the existing methods is not high enough, which in turn indicates the relevance of developing a method that is devoid of these disadvantages. Proceeding from this, the purpose of the research is to solve the problems of determining the parameters of the components of the soil mixture, taking into account the presence of water, air and gaseous substances in their pores. The research provided for the theoretical solution of the following two problems:

- determination of the parameters of fine soil mixture;
- determination of parameters of coarse soil mixture.

Research results. Included the compilation of the initial equations and their solution using well-known mathematical techniques and rules. The tasks were solved in relation to the following variants of the states of the soil mixture:

- the first option - the space between the particles of coarse earth is completely filled with fine earth, the pores of which are partially filled with water, and the rest
- with air and (or) gaseous substances;
- the second option is the same, only the pores of the fine earth are completely filled with water.

The following provisions were adopted as prerequisites for solving research problems:

- the volume of soil mixture in the structure (fill dam) completely occupies the volume of a specific element (core, anti-seepage device, etc.) of the dam;
- in the soil mixture, fine earth in terms of weight content exceeds the amount of coarse earth and the properties of the mixture are determined by the properties of fine earth;
- in the process of laying the soil mixture is subjected to layer-by-layer compaction at the optimum or close to the optimum moisture content of the fine soil.

The results of solving research problems are presented below.

Determination of the parameters of fine soil mixture.

*First option***.** The first variant state of the soil mixture is characterized by the following initial equality

$$V_{mix} = V_c^{so} + V_c^{por} = V_c^{so} + V_f = V_c^{so} + \left(V_f^{so} + V_f^{por}\right) = V_c^{so} + \left(V_f^{so} + V_f^{w} + V_f^{g}\right), \quad (1)$$

where V_{mix} - volume of soil mixture; V_c^{so} - volume of solid particles of coarse soil; V_c^{por}- pore volume of coarse soil; V_f - fine earth volume; V_f^{so}- volume of fine particulate matter; V_f^{por}- pore volume of fine earth; V_f^{w} - the volume of water in the pores of the fine earth; V_f^{g} - the volume of air and gaseous substances in the pores of the fine earth.

The parameters included in the right-hand side of equality (1), based on the known regularities of soil mechanics, can be set by the following formulas

$$V_c^{so} = m_c^{so}/\rho_s^c, \tag{2}$$

$$V_f^{so} = m_f^{so}/\rho_s^f, \tag{3}$$

$$V_f^{w} = m_f^{w}/\rho_w = w_f m_f^{so}/\rho_w, \tag{4}$$

$$V_f^{g} = \left(V_f^{por} - V_f^{w}\right) = \left[e_f V_f^{so} - \left(w_f m_f^{so}/\rho_w\right)\right] = \left[\left(e_f m_f^{so}/\rho_s^f\right) - \left(w_f m_f^{so}/\rho_w\right)\right] = m_f^{so}\left(e_f/\rho_s^f - w_f/\rho_w\right), \tag{5}$$

where m_c^{so} - mass of solid particles of coarse earth; ρ_s^c- density of solid particles of coarse earth; m_f^{so} - fine particulate matter mass; ρ_s^f- solid particle density of fine earth; m_f^{w} - mass of water in the pores of fine soil; ρ_w - density of water in the pores of fine earth; w_f - fine soil moisture; e_f - porosity coefficient of fine earth.

Substituting expressions (2) - (5) into equality (1), we can obtain the following formula

$$V_{mix} = (m_c^{so}/\rho_s^c) + \left\{\left(m_f^{so}/\rho_s^f\right) + \left[\left(w_f m_f^{so}/\rho_w\right) + m_f^{so}\left(e_f/\rho_s^f - w_f/\rho_w\right)\right]\right\} = \left\{(m_c^{so}/\rho_s^c) + \left[\left(m_f^{so}/\rho_s^f\right) \times \left(1 + e_f\right)\right]\right\} \tag{6}$$

We accept the following relations

$$\left(V_f/V_{mix}\right) = a_v, \tag{7}$$

$$(V_c^{so}/V_{mix}) = b_v, \tag{8}$$

$$a_v + b_v = 1, \tag{9}$$

where a_v - coefficient that determines the proportion of the volume of fine earth in the volume of soil mixture (in fractions of a unit); b_v - coefficient that determines the proportion of the volume of solid particles of coarse earth in the volume of soil mixture (in fractions of a unit)

Based on relation (7), the formula for determining the volume of fine soil with a known volume of soil mixture can be represented as the following expression

$$V_f = V_{mix} a_v, \tag{10}$$

Based on formula (10), we can obtain a formula for determining the mass of fine earth in the form of the following expression

$$m_f = V_{mix} a_v \rho_f, \tag{11}$$

where ρ_f - density of fine earth.

Taking into account formula (6), formulas (10) and (11) can be written as

$$V_f = \{(m_c^{so}/\rho_s^c) + [(m_f^{so}/\rho_s^f) \times (1 + e_f)]\} a_v, \tag{12}$$

$$m_f = \{(m_c^{so}/\rho_s^c) + [(m_f^{so}/\rho_s^f) \times (1 + e_f)]\} a_v \rho_f, \tag{13}$$

We take the following relation

$$m_f^{so}/m_c^{so} = c_m^{so}, \tag{14}$$

where c_m^{so} - coefficient that determines the fraction of the mass of fine earth from the mass of coarse earth.

Taking into account relation (14), formula (12) can be transformed into the following expression

$$V_f = a_v m_f^{so} [(1/c_m^{so} \rho_s^c) + (1 + e_f)/\rho_s^f], \tag{15}$$

Dividing both sides of equality (15) by the volume of fine earth V_f and taking into account that the ratio m_f^{so}/V_f is the density of fine earth in the dry state ρ_d^f, we can obtain the following formula

$$\rho_d^f = 1/a_v\, [(1/c_f^{so} \rho_s^c) + (1 + e_f)/\rho_s^f], \tag{16}$$

Taking into account relation (14), formula (13) can be represented as

$$m_f = \rho_f a_v m_f^{so} [(1/c_f^{so} \rho_s^c) + (1 + e_f)/\rho_s^f], \tag{17}$$

To simplify further calculations in formulas (15) - (17), we take the following notation

$$[(1/c_f^{so} \rho_s^c) + (1 + e_f)/\rho_s^f] = \eta, \tag{18}$$

Taking into account the accepted notation, formulas (15) - (17) can be rewritten as

$$V_f = a_v m_f^{so} \eta, \tag{19}$$

$$\rho_d^f = 1/a_v \eta, \tag{20}$$

$$m_f = \rho_f a_v m_f^{so} \eta, \tag{21}$$

To determine the parameters of fine earth V_f and m_f using formulas (19) and (21), it is necessary to know the mass of solid particles of fine earth m_f^{so}. It is known that the soil mixture selected according to the required parameters is intended for the construction of a specific element of an earth dam. Therefore, the volume of the mixture V_{mix} can be taken equal to the volume of the structure element V_{st}. Then, taking into account relation (7), we can obtain a formula for determining the parameter m_f^{so} in the form

$$m_f^{so} = V_f \rho_d^f = a_v V_{mix} \rho_d^f = a_v V_{st} \rho_d^f, \qquad (22)$$

Substituting formula (22) into formulas (19) and (21), we can obtain the following expression

$$V_f = a_v^2 V_{st} \rho_d^f \eta, \qquad (23)$$

$$m_f = \rho_f a_v^2 V_{st} \rho_d^f \eta, \qquad (24)$$

As already mentioned above, the parameter a_v determines the proportion of the volume of fine earth in the volume of the soil mixture In some cases, it is more practical to use the fraction of fine earth mass in the total mass of the soil mixture (parameter a_m). For this, dependence (25) can be used, which reflects the relationship between these parameters.

$$a_v = (V_f / V_{mix}) = (m_f \rho_f / m_{mix} \rho_{mix}) = a_m (\rho_f / \rho_{mix}), \qquad (25)$$

where ρ_{mix}- soil density.

The parameter a_v plays an important role in the selection of the composition of cohesive soil mixtures, since its value is used to assess the suffusion stability of the mixture [12]. So, to ensure the suffusion stability of these soil mixtures, it is recommended to take the parameter a_v value at least 0.5. Therefore, the parameter for cohesive soil mixtures must satisfy the condition. Therefore, the parameter a_m for cohesive soil mixtures must satisfy the condition

$$a_m \geq [0.5/(\rho_f / \rho_{mix})], \qquad (26)$$

It is known that the properties of coarse-grained soil with a sandy aggregate content of more than 40% or a clay aggregate of more than 30% are determined by the properties of the aggregate. Then, as applied to such soils in formulas (26) - (28), the density of the soil mixture ρ_{mix} can be taken equal to the density of fine earth ρ_{mix}.

As a rule, the soil mixture, when laid in the body of a structure element, is subjected to layer-by-layer compaction. In this case, the moisture content of the fine soil should be equal to the optimum or close to the optimum moisture content w_o. Then, taking into account this condition, the volume and mass of fine earth according to formulas (23) and (24) can be set taking into account the following indicators:

- maximum density of fine earth in a dry state $\rho_{d,o}^f$,
- optimal (or close to it) moisture content of fine soil w_o.

In this case, the parameter η is set by formula (18), in which the porosity coefficient of fine earth $e_{f,o}$ is determined by formula (27). In turn, the density of fine earth $\rho_{f,o}$ in formula (27) and in formula (24) is determined by formula (28).

$$e_{f,o} = \left[\rho_s^f\left(1 + w_{f,o}\right)/\rho_{f,o}\right] - 1, \qquad (27)$$

$$\rho_{f,o} = \left(1 + w_{f,o}\right)\rho_{d,o}^f, \qquad (28)$$

where w_o and $\rho_{d,o}^f$- respectively, the optimal (close to it) moisture and maximum density of the fine-grained component in the dry state, determined from the test results in accordance with the requirements of the standard [14].

*The second option***.** For the second variant state of the soil mixture, the original equation can be written in the form

$$V_{mix} = V_c^{so} + V_c^{por} = V_c^{so} + V_f = V_c^{so} + \left(V_f^{so} + V_f^{por}\right) = V_c^{so} + \left(V_f^{so} + V_f^{w}\right), \qquad (29)$$

Taking into account dependencies (2) - (4), expression (29) can be represented as

$$V_{mix} = (m_c^{so}/\rho_s^c) + \left[\left(m_f^{so}/\rho_s^f\right) + \left(w_f m_f^{so}/\rho_w\right)\right] = \left\{(m_c^{so}/\rho_s^c) + \left[m_f^{so}\left(1/\rho_s^f + w_f/\rho_w\right)\right]\right\}, \qquad (30)$$

Applying the mathematical calculations adopted in the derivation of formulas (19) - (21) on the basis of expression (30), it can obtain the following dependence for determining the parameters of the fine-grained component

$$V_f = a_v m_f^{so}\lambda, \qquad (31)$$

$$\rho_d^f = 1/a_v\lambda, \qquad (32)$$

$$m_f = \rho_f a_v m_f^{so}\lambda, \qquad (33)$$

$$\lambda = \left[(1/c_m^{so}\rho_s^c) + \left(1/\rho_s^f\right) + \left(w_f/\rho_w\right)\right], \qquad (34)$$

As can be seen, formulas (31) - (33) and formulas (19) - (21) differ only in the parameters η and λ. Further, performing the actions taken in the derivation of dependencies (23) and (24), we can write down similar expressions

$$V_f = a_v^2 V_{st}\rho_{d,o}^o\lambda, \qquad (35)$$

$$m_f = \rho_{f,o}a_v^2 V_{st}\rho_{d,o}^f\lambda, \qquad (36)$$

In formulas (35) and (36), the parameter λ is determined by formula (34) at optimal or close to it humidity $w_{f,o}$, and the rest of the parameters are set in the same way as for dependencies (23) and (24).

Determination of parameters of coarse soil mixture.

The first option. The volume of solid particles of coarse earth, taking into account relation (8), can be represented as

$$V_c^{so} = b_v V_{mix} = (1 - a_v)V_{mix}, \quad (37)$$

Substituting expression (6) into formula (37), we can obtain the following equation

$$V_c^{so} = (1 - a_v)\{(m_c^{so}/\rho_s^c) + [(m_f^{so}/\rho_s^f) \times (1 + e_f)]\}, \quad (38)$$

Taking into account relation (14), dividing both sides of equation (38) by the volume of solid particles of coarse earth $V_c^{so}$and solving the resulting equation for the density of solid particles of coarse earth ρ_s^c, we can derive the following formula

$$\rho_s^c = \rho_s^f a_v/b_v c_m^{so}(1 + e_f), \quad (39)$$

Based on formula (38), we can also obtain a formula for determining the density of coarse soil in a dry state ρ_d^c. For the equation (38), taking into account relation (14), is reduced to the following form

$$V_c^{so} = (1 - a_v)m_c^{so}[(1/\rho_s^c) + (1 + e_f)c_m^{so}/\rho_s^f], \quad (40)$$

We introduce the following notation

$$\mu = (1/\rho_s^c) + [(1 + e_f)c_m^{so}/\rho_s^f], \quad (41)$$

In equation (40), the mass of solid particles of coarse earth m_c^{so} is taken as the product of $\rho_d^c V_{mix}$. Then equation (40), taking into account dependence (41), can be written in the form

$$V_c^{so} = (1 - a_v)\rho_d^c V_{mix}\mu, \quad (42)$$

Dividing both parts of expression (45) by a parameter V_{mix} and taking into account relations (8) and (9), we can obtain a formula for determining the density of coarse soil in a dry state ρ_d^c in the following form

$$\rho_d^c = 1/\mu, \quad (43)$$

Taking the volume of soil mixture V_{mix} equal to the volume of a structure element V_{st} formula (42) can be used to determine the volume of solid particles of coarse earth in the following form

$$V_c^{so} = (1 - a_v)\rho_d^c V_{st}\mu, \quad (44)$$

The second option. Substituting formula (30) into expression (37), we can obtain the following dependence for determining the volume of solid particles of the coarse-grained component

$$V_c^{so} = (1 - a_v)\{(m_c^{so}/\rho_s^c) + [m_f^{so}(1/\rho_s^f + w_f/\rho_w)]\}, \quad (45)$$

Taking into account relation (14), dividing both parts of expression (45) by the volume of solid particles of the coarse-grained component V_c^{so} and solving the resulting equation for the density of solid particles of coarse earth ρ_s^c, we can obtain the following formula

$$\rho_s^c = a_v / b_v c_m^{so} \left(1/\rho_s^f + w/\rho_w\right), \tag{46}$$

Formula (45) can be used to determine the density of the coarse-grained component in the dry state ρ_d^c. For this dependence, taking into account relation (14) is reduced to the following form

$$V_c^{so} = (1 - a_v) m_c^{so} \left[(1/\rho_s^c) + c_m^{so}\left(1/\rho_s^f + w_f/\rho_w\right)\right], \tag{47}$$

We accept the following notation

$$\varsigma = (1/\rho_s^c) + \left[c_m^{so}\left(1/\rho_s^f + w_f/\rho_w\right)\right], \tag{48}$$

Further, following the steps taken when deriving formula (44), we can obtain a formula for determining the density of coarse soil in a dry state in the following form

$$\rho_d^c = 1/\varsigma, \tag{49}$$

Similarly, performing the actions taken when deriving formula (45), we can obtain a formula for determining the volume of solid particles of coarse earth in the following form

$$V_c^{so} = (1 - a_v) \rho_d^c V_{st} \varsigma, \tag{50}$$

Discussion of results. The research results can be used to implement the process of conditioning soil mixtures, i.e. to change the moisture content, density and particle size distribution of their components. In this case, the formulas concerning the first variant state of soil mixtures are preferably used for their conditioning in quarries, reserves (warehouses) and transportation. This is due to the fact that at these technological stages, the mixtures are in a loose state and both pore water and air (gaseous substances) take place in the pores of their components. When the mixture is poured into the body of a structure with compaction, a denser arrangement of solid particles within the mixture occurs. Particles of fine earth fall into the pores of the coarse earth, the pore volume is significantly reduced, and the volume of air (gaseous substances) in them reaches a minimum. At this stage of preparing soil mixtures, it is advisable to use formulas related to the second variant state, when there is practically no air in the pores (gaseous substances). To assess the reliability of the formulas proposed to determine the parameters of coarse-grained and fine-grained components, the authors conduct appropriate studies. Below the results of studies are to verify the validity of formula (32).

The studies were carried out using artificial compositions of mixtures obtained on the basis of heterogeneous coarse gravel soil (the mass of particles larger than 2 mm - 53.65%) with sandy loam filler (clay filler content - 30.65%).

Six groups of prototypes of a fine-grained component with a particle size of 5 mm and less were compiled by means of dosed selection and addition:

- 1 group: samples with an increasing content of the fraction m_{5-2} (particles with a particle size of less than 5 mm and more than 2 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%;

- 2 group: samples with an increasing content of the fraction m_{2-1} (particles with sizes less than 2 mm and more than 1 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%;

- 3 group: samples with an increasing content of fraction $m_{1-0,5}$ (particles with sizes less than 1 mm and more than 0.5 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%;

- 4 group: samples with an increasing content of the fraction $m_{0,5-0,25}$ (particles with sizes less than 0.5 mm and more than 0.25 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%;

- 5 group: samples with an increasing content of fraction $m_{0,5-0,1}$ (particles with sizes less than 0.25 mm and more than 0.1 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%;

- 6 group: samples with an increasing content of fraction $m_{<0,1}$ (particles with sizes less than 0.1 mm) at which the weight content of the fine-grained component by weight increases from 50 to 75%.

The increase in the percentage of each experimental fine-grained fraction was carried out by reducing the percentage of the coarse-grained component fractions. The percentage of the remaining fractions in the fine-grained component did not change.

The granulometry composition of coarse-grained soil (with a particle size of more than 0.1 mm), as well as the micro-aggregate composition of a sandy loam aggregate (with a particle size of 0.1 mm or less) were established in accordance with the requirements of the standard [15].

Samples were tested in accordance with the requirements of the standard. [14]. The samples were compacted by shock loading using the PSU-A device (manufactured by OOO RNPO RosPribor).

Based on the test results, it was found that the calculated values of the density of the fine-grained component in the dry state (ρ_d^f), obtained by formula (32), are 6.6-22.2% higher than their experimental values (ρ_d^f). For clarity, Table 1 shows the research results obtained using samples with an increasing content of the fraction m_{5-2}, at which the amount of the fine-grained component in the soil (by weight) increases from 50 to 75%.

Table 1

Research results of samples with increasing fraction content m_{5-2}

Humidity W,%	Dry density, t/m^3		Humidity W, %	Dry density, t/m^3	
	$\rho_d'^f$	ρ_d^f		$\rho_d'^f$	ρ_d^f
50%			55%		
1	2	3	4	5	6
2.61	1.698	2.075	2.75	1.737	2.063
4.30	1.716	2.087	4.28	1.751	2.072
6.07	1.725	2.096	6.17	1.762	2.080
7.23	1.763	2.122	7.49	1.836	2.125
9.15	1.844	2.181	9.24	1.929	2.205
10.87	1.960	2.259	10.97	1.98	2.237
12.17	1.975	2.270	11.5	1.99	2.246
12.56	1.971	2.268	12.82	1.976	2.238
13.74	1.922	2.235	13.99	1.934	2.207
16.15	1.878	2.204	16.07	1.906	2.188

Table 1 continuation

1	2	3	4	5	6
60%			65%		
2,89	1,778	2,052	2,81	1,804	2.034
4,26	1,784	2,057	4,43	1,82	2.047
6,26	1,796	2,066	6,51	1,847	2.069
7,75	1,909	2,153	8,15	1,959	2.159
9,33	2,009	2,228	9,88	2,049	2.229
10,78	2,025	2,238	10,51	2,055	2.233
11,18	2,023	2,039	10,85	2,05	2.230
13,21	1,986	2,211	11,86	2,025	2.213
14,24	1,951	2,185	13,62	1,986	2.180
16,09	1,923	2,164	16,08	1,974	2.172
70%			75%		
2.69	1.81	2.010	2.920	1.842	1.991
4.15	1.835	2.022	4.567	1.903	2.054
6.43	1.937	2.115	6.366	2.002	2.145
7.11	1.961	2.134	8.092	2.068	2.192
8.84	2.055	2.213	9.132	2.085	2.203
9.99	2.075	2.225	10.14	2.089	2.214
10.45	2.078	2.232	10.65	2.086	2.203
11.04	2.072	2.213	11.65	2.079	2.192
12.99	2.039	2.191	13.23	2.044	2.174
15.99	2.009	2.172	15.52	2.019	2.153

In addition, it was revealed that the values of the coefficient K, taken in the form of the ratio $\rho_d^{\prime f} / \rho_d^f$, vary in the range from 0.814 to 0.948. The main factors influencing the values of this coefficient are the moisture content of the fine-grained component and its amount in the soil composition. Figures 1 and 2 show the graphs of the change in the coefficient of the specified factors in relation to samples with an increasing content in the fine-grained component of the fraction m_{2-1}.

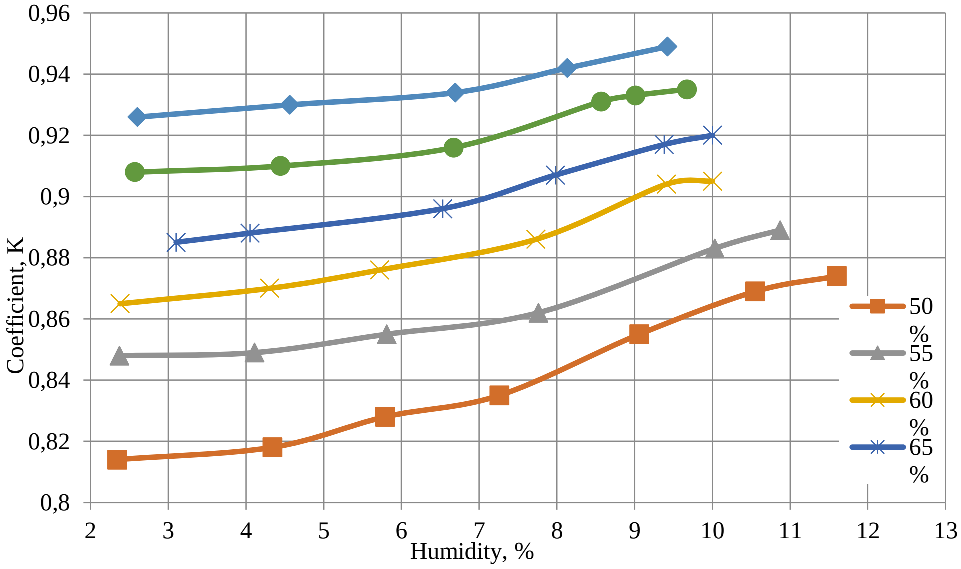

Figure 1. Change in coefficient K as the moisture content of the fine-grained component increases from 2.34 to 11.82% and its amount in the soil from 50 to 75%.

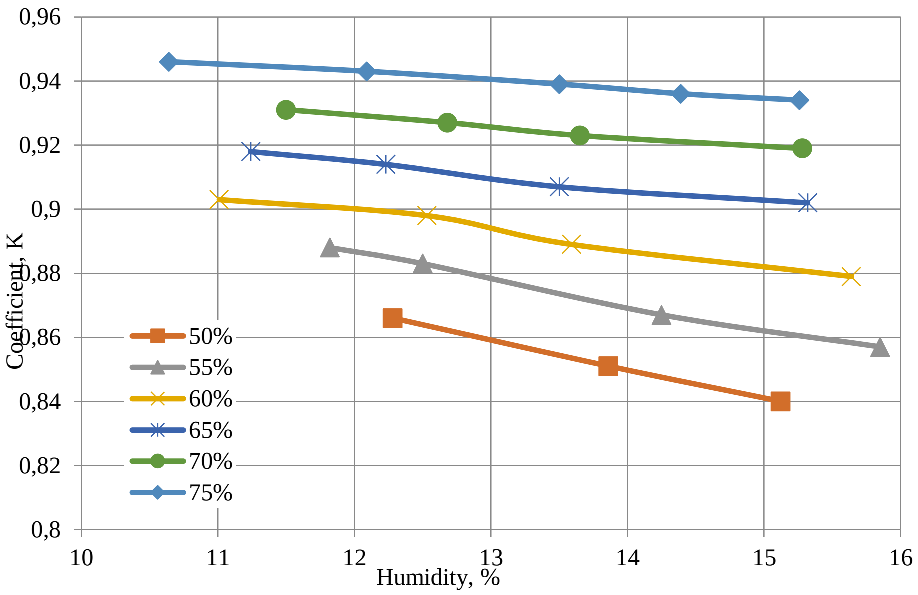

Figure2. Change in coefficient K as the moisture content of the fine-grained component increases from 10.64 to 15.85% and its amount in the soil from 50 to 75%.

Computer processing found that the dependence of the coefficient K on influencing factors can be described by the following linear function

$$K = \alpha W + \beta, \tag{51}$$

where W - moisture content of the fine-grained soil component in percent; α and β - coefficients taken according to Table 2.

The value of the reliability of the data approximation $R \cap 2$ according to the formula (51) is 0.908-0.986.

Table 2

Coefficient values α and β

The content of the fine-grained component in the soil, %	Coefficient values	
	α	β
until optimum humidity is reached		
50	0.0067	0.799
55	0.0058	0.825
60	0.0057	0.845
65	0.0047	0.867
70	0.0040	0.888
75	0.0032	0.907
after reaching optimum humidity		
50	-0.0077	0.963
55	-0.0062	0.964
60	-0.0053	0.965
65	-0.0043	0.969
70	-0.0035	0.972
75	-0.003	0.978

Taking into account dependence (51), formula (32) for practical application can be represented in the form

$$\rho_d^f = K(1/a_v\lambda) = (\mu W + \beta) \times (1/a_v\lambda), \quad (52)$$

Conclusion. Based on the results of the studies performed, the following conclusions can be formulated:

1. Formulas were obtained to determine the density, weight and volumetric parameters (indicators) of fine-grained and coarse-grained components of soil mixtures, taking into account the presence of water, air and gaseous substances in their pores;

2. The formulas are acceptable for two variants of the state of soil mixtures and can be used differentially, both before laying (at the design stage and during experimental work) and when laying soil mixtures into the body of the structure (during the main types of work).

3. Formula (52) can be used to determine the density of a fine-grained component in a dry state with sufficient reliability of the results.

In conclusion, it should be noted that the presented solutions were obtained for the first time and differ from the existing solutions in composition and structure. For the practical testing of the obtained formulas, it is relevant to carry out further experimental studies using samples of various soil mixtures.

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ТОПЫРАҚ БӨГЕТТЕРІ ЭЛЕМЕНТТЕРІНІҢ ҚҰРЫЛЫМЫНА АРНАЛҒАН ТОПЫРАҚ ҚОСПАЛАРЫНЫҢ ҰСАҚ ТҮЙІРШІКТІ ТОПЫРАҚ ПАРАМЕТРЛЕРІН АНЫҚТАУ

Аңдатпа. Топырақ бөгеттерінің элементтерін (тіреу призмалары, өзектер, понурлар, экрандар, сүзілуге қарсы құрылғылар) салуға арналған топырақ қоспаларының (ұсақ және ірі топырақ) құрамдас бөліктерінің көлемін, массасын және тығыздығын анықтау мәселелерін шешуге бағытталған теориялық зерттеулер орындалған. Міндеттер топырақ жағдайының екі нұсқасына қатысты жаңа тұжырымда шешілген. Бірінші нұсқа ретінде ұсақ түйіршікті топырақ құрамдас бөлігінің кеуектерінде бос су, ауа және газ тәрізді заттар орын алған жағдайда, ал екінші нұсқа – ұсақ түйіршікті компоненттің кеуектерінде тек су болған кездегі жағдайда.

Топырақ қоспасының ұсақ түйіршікті және ірі түйіршікті топырақтың көлемі мен массасын анықтауға мүмкіндік беретін формулалар алынды. Сондай-ақ, топырақ қоспаларының көрсетілген екі нұсқалық күйі үшін ұсақ түйіршікті және ірі түйіршікті топырақтың тығыздығын анықтауға арналған формулалар ұсынылған. Формулаларды топырақ қоспаларын кондициялау процесін жүзеге асыру сатысында,

яғни олардың құрамдас бөліктерінің ылғалдылығын, тығыздығын және бөлшектерінің мөлшерін өзгерту үшін пайдалану ұсынылады. Бұл ретте, топырақ қоспаларының бірінші нұсқа күйіне жататын формулалар оларды карьерлерде, қорларда (қоймаларда) және тасымалдауда кондициялау үшін қолданылуы ыңғайлы болып табылады. Құрғақ күйдегі ұсақ түйіршікті компоненттің тығыздығын анықтау формуласын тексеру нәтижелері келтірілген. Ұсынылған формула топырақ қоспасындағы ұсақ түйіршікті топырақтың және ірі түйіршікті топырақтың массасын және көлемін анықтауға мүмкіндік береді.

Тірек сөздер: топырақ қоспасы, ұсақ түйіршікті топырақ, ірі түйіршікті топрырақ, көлем, масса, тығыздық.

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ОБ ОПРЕДЕЛЕНИИ ПАРАМЕТРОВ МЕЛКОЗЕРНИСТОГО КОМПОНЕНТА ГРУНТОВОЙ СМЕСИ ДЛЯ УСТРОЙСТВА ЭЛЕМЕНТОВ НАСЫПНЫХ ЗЕМЛЯНЫХ ПЛОТИН

Аннотация. Выполнены теоретические исследования, направленные на решение задач по определению физических параметров компонентов (мелкозёма и крупнозёма) грунтовых смесей, предназначенных для устройства элементов (упорных призм, ядер, понуров, экранов, противофильтрационных устройств) насыпных земляных плотин. Задачи решены в новой постановке применительно к двум вариантам состояния грунтовой смеси. В качестве первого варианта, рассмотрен случай, когда в порах мелкозёма имеет место свободная вода, воздух и газообразные вещества, и второй вариант, когда в порах мелкозёма находится только вода.

Получены формулы, позволяющие устанавливать объем и массу мелкозёма и крупнозёма грунтовой смеси. Представлены также формулы по определению плотности мелкозёма и крупнозёма для указанных двух вариантных состояний грунтовых смесей. Формулы рекомендуются использовать на стадии реализации процесса кондицирования грунтовых смесей, то есть для изменения влажности, плотности и гранулометрического состава их компонентов. При этом формулы, относящие к первому вариантному состоянию грунтовых смесей, предпочтительно использовать при их кондицировании в карьерах, резервах (складах) и транспортировке. Приведены результаты проверки формулы по определению плотности мелкозернистого компонента в сухом состоянии.

Новизна полученных формул заключается в том, что в отличие от существующих, они учитывают наличие в составе грунтовых смесей свободной воды, воздуха и газообразных веществ, которые оказывают существенное влияние на уплотняемость смесей.

Ключевые слова: грунтовая смесь, мелкозём, крупнозём, объем, масса, плотность.