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Influence of Soil Humidity on the Stress-Strain State of Earth Dam

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ABSTRACT

The most important stage of laying the soil in the body of the dam is its compaction. The design degree of compaction (soil density), usually expressed in terms of dry soil density, should provide sufficiently high strength, deformation and filtration characteristics of the material laid in the body of the dam. The compaction process is highly dependent on soil moisture. Compaction of the soil with the least expenditure of energy can be achieved at a certain moisture content, which is called optimal. To achieve the optimal moisture content of the laid soil in the body of the dam, the soil is moistened with water (and the waterlogged ones are dried during layer-by-layer laying) according to a special technology [2].

The task of studying the stress-strain state of soil dams, taking into account soil moisture, is a complex problem in the theory of continuum mechanics, in solving which it is necessary to take into account the properties of materials, the design features of structures, the variety of acting loads, etc. The solution of such a problem is currently difficult due to the lack of sufficiently substantiated data on the rheological properties of soils, the difficulty of simultaneously taking into account the influence of all possible factors in the numerical implementation of the solution, etc.

At the same time, the solution of particular problems with the adoption of certain assumptions and prerequisites can be most fully and accurately obtained using numerical methods, for example, the finite element method (FEM) or the finite difference method (FDM) [3-6, 9-10].

Based on the above, this work is devoted to the study of the stress-strain state (SSS) of earth dams, taking into account the design features and soil moisture.

The considered earth dam has a trapezoidal cross section, the crest and slopes of which are free from stress, and the base ($\bar{x} \in \sum_u$) is rigidly fixed (Fig. 1). A building in equilibrium occupies a volume V \u003d V $_1$ + V $_2$ + V $_3$ (V $_{1,}$ V $_3$ - the volume of the upper and lower supporting prisms, V $_2$ - the volume of the core), limited by the surface $\sum_p + \sum_u$ ($\sum_p$ - stress-free surface of the trapezoid, $\sum_u$ - its base). It is assumed that the dam is under its own weight and the problem is solved in a flat setting using the finite element method.

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The mathematical formulation of the problem includes the variational equation for the minimum total energy

$$\delta\Pi - \delta' W = 0 \tag{1}$$

kinematic boundary conditions based on

$$\bar{x} \in \sum_u \; : \delta\bar{u} = 0 \tag{2}$$

and conditions on free borders:

$$\bar{x} \in \sum_p \; : \sigma_N = 0 \tag{3}$$

In (1)-(3) δP - variation of potential energy, δ'W - sum of work of external forces, $\delta\bar{u}$ - possible displacements of dam points, - σ_N normal stresses on free faces.

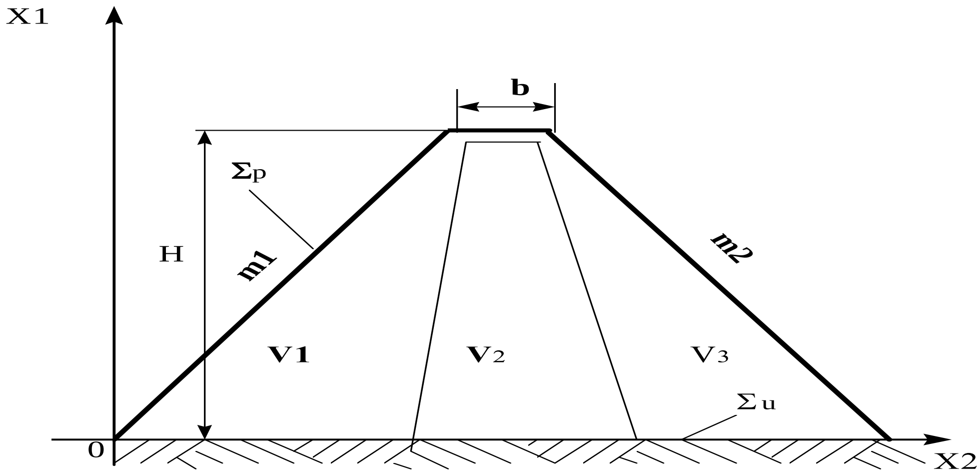

Fig.1 Calculation scheme of earth dam

When describing the equation of state of the soil medium, the soil deformation model proposed in [7] was used, which takes into account the structural destruction of the soil during deformation. Following this work, the model of soil deformation taking into account moisture content is proposed in the following form:

$$\frac{dP}{K_D(I)dt} + \mu\frac{P}{K_S(I)} = \frac{d\theta}{dt} + \mu\theta \text{ at } \frac{d\theta}{dt} \geq 0 \tag{4}$$

$$\frac{dP}{K_R(I)dt} = \frac{d\theta}{dt} \qquad \text{at} \frac{d\theta}{dt} < 0 \tag{5}$$

where P is pressure, K_D and K_S - functional dependence of dynamic and static compression modules; K_R - function of the unloading module; I - parameter characterizing the structural change of the soil.

Equations (4) and (5) relate the volumetric deformation of the soil to the compressive pressure. The law of volumetric deformation, taking into account the structural destruction of the soil, is determined by the dependences given in [7, 8].

The parameter used in (4) and (5)I $\in$[0, 1] is defined by the sum:

$$I = I_S + I_W \tag{6}$$

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where I_S is a parameter characterizing the structural change of the soil under the action of a compressive load:

$I_S = \theta/\theta_*$ (7)

Whereθ_* - the value of volumetric deformation, at which the structure of the soil undergoes a complete change;

I_W - characterizes the structural change of the soil under the action of moisture

$I_W = W/W_*$ (8)

where W_* - the value of moisture at which the soil skeleton completely loses its strength.

Taking into account (5) and (7), expressions are accepted to determine the functions of the compression and unloading modules

$K_D(I) = K_{D*} \exp(\beta(1-I))$ (9)

$K_S(I) = K_{S*} \exp(\alpha(1-I))$ (10)

$K_R = K_{RN} \exp(\beta_R(I-1))$. (11)

Where, K_{D*} and K_{S*} are soil compression moduli, the state of which corresponds to the case $\theta = \theta_*$ and $W = W_*$; K_{RN} - the value of the unloading modulus of structurally undisturbed soil; α, β, β_R - dimensionless coefficients characterizing the degree of change in the compression and unloading moduli during compression and soaking, determined from the results of experiments; in (10) $I_S = \theta/\theta_R$ θ_R is the volumetric strain value at which unloading begins.

The stated variational problem (1), taking into account (2)–(11), is solved by the finite element method [3, 6]. When taking into account the inelastic law of soil deformation, the elements of the stiffness matrix $K^*(P_i, \theta_i)$ are determined using a modified method of variable elasticity parameters, which uses not the traditional dependence $\sigma_i = f(\varepsilon_i)$ [1], but the deformation law proposed in [7], which relates the volumetric deformation θ and the total pressure in the soil P. Thus, at each iteration step, linear system of algebraic equations with matrix $K^*(P_i, \theta_i)$ depending on the VAT achieved. The resulting system is solved by the Gauss method.

To assess the effect of soil moisture on the SSS of soil dams, taking into account the design features and the inelastic law of deformation of the material of the prism and the core of structures, several dams were considered, the height of which is more than 70 m [2] : Nurek dam with a height of 296 m in Tajikistan on the Vakhsh River with slope coefficients $m_B = 2.25$ and $m_n = 2.2$ and thrust prisms with physical and mechanical parameters $E = 3.068 \cdot 10^5$ t / m^2, $\gamma = 2.15$ t / m^3, $\nu = 0.28$; Hissarak dam, 138.5 m high on the Aksu River in Kashkadarya region, with slope coefficients $m_B = 1.9$ and $m_n = 1.7$ and thrust prisms $E = 3.6 \cdot 10^5$ t/m^2, $\gamma = 1.9$ t/m^3 and Sokh dam 86.5 high m on the Sokh River in the Fergana region with slope coefficients $m_B = 2.4$ and $m_n = 2.1$ and parameters of thrust prisms $E = 3.55 \cdot 10^5$ t/m^2, $\gamma = 2.15$ t/m^3, $\nu = 0{,}28$. All considered dams have a thin core of loam with parameters $E = 2.399 \cdot 10^5$ t/m^2, $\gamma = 2.0$ t/m^3, $\nu = 0.35$. The optimal soil moisture in the body of the dam was taken in the range of 8-12% [2].

To analyze the effect of structural features and soil moisture on the SSS, the calculations for each of the considered dams were carried out in two stages: at the first stage, the SSS was calculated in an elastic setting, taking into account the design features of the core and the actual geometric dimensions of the dam. At the second stage, the soil moisture content of the dam body was taken into account.

On the basis of the results obtained, contour lines of normal and shear stresses and their change were constructed on the profiles of all dams, taking into account the above factors: linear or nonlinear laws of soil deformation.

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An analysis of the results obtained showed that an increase in the geometric dimensions, namely the height of the dam, as well as taking into account the design features of the core, leads to a significant change in the SSS of the dam. With an increase in the height of the dam in its lower part, stresses also increase in the core zones. In all dams in the core, the arch effect is manifested both for vertical stresses σ_{22} and for stress intensity values σ_i. In the core zones σ_i and σ_{22} in the Gissarak dam, the values decrease to 22%. The value of shear stresses σ_{12} in both dams in the core zones increases to 60%. Horizontal stresses σ_{11} are practically unchanged. These results indicate that taking into account design features - the presence of a core that differs in its characteristics from thrust prisms - can lead to the appearance of vertical cracks in the transition zones.

Comparison of the results obtained taking into account the optimal soil moisture with the results without taking into account soil moisture shows that soil moisture significantly affects the SSS of the dam. Namely: the intensity of stresses near the base and in the sloping zones of the dam decreases up to 10%, the horizontal stresses at the bottom of the dam increase up to 8%, and the tangential stresses in the core almost double.

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