Determination of the stress-strain state of earth dams with account of elastic-plastic and moist properties of soil and large strains

D.Sc., professor, chief of department M.M. Mirsaidov*;
Ph.D., associate professor, vice-rector T.Z. Sultanov,
Tashkent Institute of Irrigation and Melioration;
lecturer Sh.A. Sadullaev,
Tashkent State Technical University

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Introduction

A necessity to take into consideration real properties of soil and finite strains is now increasing in connection with world-wide construction of high earth dams. Not all the aspects of the work of soil under the load are clarified through. There is a great number of different theories more or less easily realized in solution of concrete problems. One of the most important problems in assessment of the structure strength is an account of elastic-plastic, moist properties of soil and large strains, occurring in earth dams under different effects [1–6].

Scientific papers [7–20] are devoted to the solution of certain aspects of this problem:

- in [8] the method for simulation of the structure response subjected to seismic excitation of high level is offered; it allows to account geometric non-linearity and inelastic character of material. Performed studies in non-linear dynamics show a good agreement with experimental results;
- in [10] finite element is used for numeric calculation of earth dams; it takes into consideration moist, non-moist and plastic properties of soil. Calculations of three dams were carried out with the use of the offered model;
- the work [11] considers the model which takes into account geometric factors, depending on stress-strain state of earth dams at the process of filling it with water. The use of such model allows determining factual mechanism of strains and explaining the reasons of strain in case of unexpected behavior of the structure under the study;
- the work [12] with the use of different software evaluates a possibility of occurrence of large displacements; it is noted that input acceleration increases with the rise of the height of a dam and in the crest of a dam the large displacements appear; so the evaluation of the dam strength should be carried out with consideration of both static and seismic loads;
- the work [13] offers the methods which allow predicting the behavior of a dam and the degree of its reliability under given expected strains from external effects and calculating the parameters of required protective constructive-technological measures;
- [14] considers the determination of stress-strain state of heterogeneous structure, which rests on elastic half-space; its mathematical model and algorithm of design were realized for investigation of stress-strain state of earth dam.

Numerical simulation of stress-strain state of earth dams furnished with aseismic belts with account of both elastic and moist properties of soil is considered in [15]; these studies allow to reveal that an installation of aseismic belts strengthens the area of slope directly adjoining it.

The problem of influence of these factors on the stress-strain state and strength of earth dams is not thoroughly studied and needs detailed research.

The paper presented below is devoted to the development of mathematical model, methods and algorithms for determination of the stress-strain state of earth structures with account of elastic-plastic properties, moisture content of soil and large strains; it presents the study of stress-strain state of concrete earth dams of different heights with account of mentioned factors under different static effects.

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1. Models, methods and algorithms for determination of the stress-strain state of the structures

1.1. Statement of a problem

Earth dam [18] with volume $V = V_1 + V_2 + V_3$, under the effect of mass forces $\vec{f}$ on the surface S_p with hydrostatic water pressure $\vec{p}_c$ is considered. The crest and lower slope of a dam are stress-free. The structure is essentially heterogeneous: physical properties of its parts (V_1, V_2, V_3) greatly differ from each other. Moreover, displacements, normal and tangential stresses are continuous on the boundary of division.

The task is to assess stress-strain state of earth dams with account of elastic-plastic, moist properties of soil and large strains.

The problem is considered within the limits of plane deformation of a structure.

Initial variation equation is written in the form:

$$- \int\limits_{V_1+V_2+V_3} \sigma_{ij} \delta\varepsilon_{ij}\, dV + \int\limits_{V_1+V_2+V_3} \vec{f}\,\delta\vec{u}\, dV + \int\limits_{S_p} \vec{p}_c\,\delta\vec{u}\, dS = 0 \ . \tag{1}$$

In the base $\sum_u$ homogeneous boundary conditions are taken into consideration:

$$\vec{x} \in \sum\nolimits_u : \vec{u} = 0 \ . \tag{2}$$

Displacement vector has two components $\vec{u} = \{u_1, u_2\}$ in the system of coordinates $\vec{x} = \{x_1, x_2\}$, $i, j = 1,2$; ε_{ij}, σ_{ij} – are tensors of strains and stresses, respectively; $\delta\vec{u}$, $\delta\varepsilon_{ij}$ – isochronic variations of displacements and strains; V_1, V_2, V_3 – volumes of upper, lower retaining prisms and central kernel of a dam, respectively.

1.1.1. The connection between the components of tensors of stresses σ_{ij} and strains ε_{ij} is expressed by Hooke's generalized law for linear elastic body, and components of tensor of large strains ε_{ij} are taken in a general form with account of both linear and quadratic summands:

$$\varepsilon_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i} + u_{\ell,i} * u_{\ell,j}\right),\ i, j, \ell = 1,2 \ . \tag{3}$$

1.1.2. When solving the problem with account of elastic-plastic strain of soil the hypothesis of energy forming is used to describe the equation of state of media. According to it, the transfer from elastic state into plastic one in discussed point of medium is realized after satisfying the condition $\sigma_i = \sigma_y$ (σ_i – stress intensity; σ_y – yield limit). In different parts of the body the state of media may be different, depending on the fact whether yield limit is passed in that or this part.

Here in Hooke's generalized law instead of elastic parameters E_n, ν_n, μ_n variable parameters E_n^*, ν_n^*, μ_n^* are used, determined by the following way [21]:

$$E_n^* = \frac{\dfrac{\sigma_i^*}{\varepsilon_i}}{1 + \dfrac{1-2\nu_n}{3E_n}\dfrac{\sigma_i^*}{\varepsilon_i}} \ ; \ \mu_n^* = \frac{\sigma_i^*}{3\varepsilon_i} \ ; \ \nu_n^* = \frac{\dfrac{1}{2} - \dfrac{1-2\nu_n}{3E_n}\dfrac{\sigma_i^*}{\varepsilon_i}}{1 + \dfrac{1-2\nu_n}{3E_n}\dfrac{\sigma_i^*}{\varepsilon_i}} \ , \tag{4}$$

where E_n, v_n, μ_n are modulus of elasticity, shear modulus and Poison's coefficient of soil, respectively; n refers to the part of the dam, which these mechanical characteristics are selected for.

Variable parameters (4) in each point of a body are determined from reached strain state ε_i (strain intensity) and corresponding to it stress intensity σ_i^*, selected from experimental diagram of strains $\sigma_i^* = \sigma_i^*(\varepsilon_i)$ for concrete soils [2,22].

Dependence between components of strain tensors and displacement vector is determined by Cauchy linear correlation.

1.1.3. As a result of water filtration through the body of a dam, the soil, located under depression curve, becomes a water-saturated one; characteristics of soil, which determine stress-strain state of a dam, are changed. In this case the model is used, which accounts non-linear law of volume deformation with account of structural damage and moisture content of soil, defined by dependencies [23–26]

$$P = K_n(I_S, I_W) \cdot \theta,$$
$$S_{ij} = \frac{2\sigma_i}{3\varepsilon_i} e_{ij}. \tag{5}$$

Compression modulus, being the function of parameters of structural change of soil under compression I_s and moisture content I_w, is determined according to formula

$$K_n(I_S, I_W) = K_{ns} \exp(\alpha_1(1 - I)). \tag{6}$$

The parameter of structural change of soil $I \in [0,1]$ under compression and moisture content is determined by

$$I = I_S + I_W. \tag{7}$$

The parameter, characterizing structural change of soil under compression load, is determined form formula:

$$I_S = \theta / \theta_*. \tag{8}$$

Structural change of soil under saturation is determined by:

$$I_W = W / W_*, \tag{9}$$

here: $e_{ij} = \varepsilon_{ij} - \theta \delta_{ij} / 3$; $\theta = \varepsilon_{ij}$; S_{ij}, e_{ij} – are components of deviators of stresses and strains; σ_i, ε_i – intensity of stresses and strains; δ_{ij} – Kronecker's symbol; P – total pressure; θ – volume strain; θ_* – the value of volume strain, when soil structure is subjected to complete destruction; W_* – the value of moisture content, determined from experiment [27], when soil skeleton completely loses its strength; K_{ns} – modulus of soil compression, its state is corresponding to the case $\theta = \theta_*$ and $W = W_*$; α_1 – dimensionless coefficient, which characterizes the degree of change of compression modulus under wetting, determined form tests.

In solution of concrete problems within the law of deformation of saturated soil a modified method of variable parameters of elasticity is used; it uses not a traditional dependence $\sigma_i = f(\varepsilon_i)$ [22], but the law of deformation (5), offered in [23], which connects volume strain θ and total pressure P in soil. Expressions, determined by the value of variable parameters of elasticity, include variable modulus of compression $K_n(I_S, I_W)$, which depends not only on the degree of soil destruction I_S, but its moisture content I_W as well:

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$$E_n^* = \frac{\sigma_i / \varepsilon_i}{1 + \dfrac{\sigma_i}{\varepsilon_i} \dfrac{1}{9K_n(I_S, I_W)}} \; ; \; \mu_n^* = \frac{\sigma_i}{3\varepsilon_i} \; ; \; \nu_n^* = \frac{\dfrac{1}{2} - \dfrac{\sigma_i}{\varepsilon_i} \dfrac{1}{9K_n(I_S, I_W)}}{1 + \dfrac{1}{9K_n(I_S, I_W)}} \; . \tag{10}$$

So, the developed method may be also called the method of variable elastic parameters, which differs from known method [21, 22] by design formulae.

In solving the problem with account of soil wetting, Cauchy linear relation is also used.

1.2. The method and algorithm of solution of the problem

All problems are solved using finite element method.

1.2.1. In determination of the stress-strain state of heterogeneous structure with account of large strains the problem with the procedure of finite element method [5, 28] is reduced to resolving system of non-linear algebraic equations of N order

$$[K(u)]\{u\} = \{F\}, \tag{11}$$

where the elements of rigidity matrix $[K(u)]$ depend not only on geometrical and physical parameters of a structure, but on its strain state as well; $\{u\}$ is a vector of nodal displacements; $\{F\}$ – vector of external load from mass forces, hydrostatic water pressure and other aspects.

Further the system of non-linear algebraic equations (11) is substituted by equivalent system of the following type [5, 29]:

$$[K]\{u\} = \{F\} - [K_n(u)]\{u\}, \tag{12}$$

where $[K]$ is rigidity matrix of linear-elastic problem; $[K_n\{u\}]$ – non-linear part of rigidity matrix, depending on displacement of nodes of a system, obtained as a result of extraction from matrix $[K\{u\}]$ its linear component – $[K]$.

To solve an equation (12) the method of consecutive approximation is used [29], its convergence defined by selection of initial approximation $\{u_0\}$. As an initial approximation a solution of linear-elastic problem is used:

$$[K](u_0) = \{F\}. \tag{13}$$

Further approximations are found by formula:

$$[K]\{u_{s+1}\} = \{F\} - [K_n\{u_s\}\{u_s\}], \; s = 0,...,n \; . \tag{14}$$

A criterion of the end of iteration is a realization of condition:

$$|u_{s+1} - u_s| \le \varepsilon \; , \tag{15}$$

where ε is a given accuracy.

1.2.2. In determination of the stress-strain state of a structure with account of elastic-plastic deformation of material the problem is reduced to non-linear algebraic system of equations

$$[K(\sigma_i, \varepsilon_i)]\{u\} = \{F\}. \tag{16}$$

Here the elements of rigidity matrix $[K(\sigma_i, \varepsilon_i)]$ depend not only on elastic parameters, but on reached stress-strain state of the structure as well. Solution of equation (16) is carried out with iteration method; on each step Gauss' method is used.

The first step is elastic design of earth structure, being in a state of balance under the effect of applied forces. Then the stress-strain state is analyzed in all finite elements. If in certain elements the

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intensity of stresses σ_i exceeds the yield limit σ_y for given material, then with (10) for these elements new parameters of elasticity are determined, rigidity matrixes are built and then general matrix $\left[K\left(\sigma_i, \varepsilon_i\right)\right]$ is formed for the whole structure. Such procedure goes on till the convergence σ_i is reached along the whole structure with a given accuracy. The described method presents a modified method of variable elastic parameters [5, 21, 22].

1.2.3. In determination of the stress-strain state of a structure with account of non-linear volume strain and water-saturation of soil the problem is reduced to the system of non-linear algebraic equations of *N* order:

$$\left[K\left(P_i, \theta_i\right)\right]\{u\} = \{F\},\tag{17}$$

where $\left[K\left(P_i, \theta_i\right)\right]$ is a rigidity matrix, determined with modified method of variable elastic parameters; $\{F\}$ – vector of external load.

So, the method offered here consists in performing the following iteration procedure: in each step an equation (17) is solved by Gauss' method; in each finite element an intensity of stresses and strains $\left(\sigma_i \text{ and } \varepsilon_i\right)$, total deformation (θ) are determined and then with non-linear dependency (5) – new values of variable elastic parameters (10) are obtained; further they are used to obtain the following approximation for the components of stress-strain state of the structure – σ_{ij} and ε_{ij}. Initial value of compression modulus at zero strain and moisture content [23, 25] is used as a zero approximation:

$$K_n = K_{ns} \exp(\alpha).\tag{18}$$

The process is reiterated till the given accuracy between two subsequent values of stress intensity σ_i in each finite element of the structure is reached.

2. Results of the stress-strain state determination

In this chapter stress-strain state of three earth dams under different static loads with account of elastic-plastic properties, moisture content of soil and large deformations are studied using the developed methods, algorithms and PC design program: 1) Nurek dam: height *H*=296m, crest width b_g=20.0m, slopes laying m_1=2.25 (upper) and m_2=2.2 (lower); 2) Ghissarak dam: height *H*=138.5m, crest width b_g=16.0m, slopes laying – m_1=2.2 and m_2=1.9; 3) Sokh dam: height *H*=87.3m, crest width b_g=10.0 m, slopes laying m_1=2.5 and m_2=2.2. In specific calculations the heterogeneity, structural specific features, real geometry and elastic characteristics of material were taken into consideration for each part of the structure [5, 18–20].

2.1. Determination of the stress-strain state
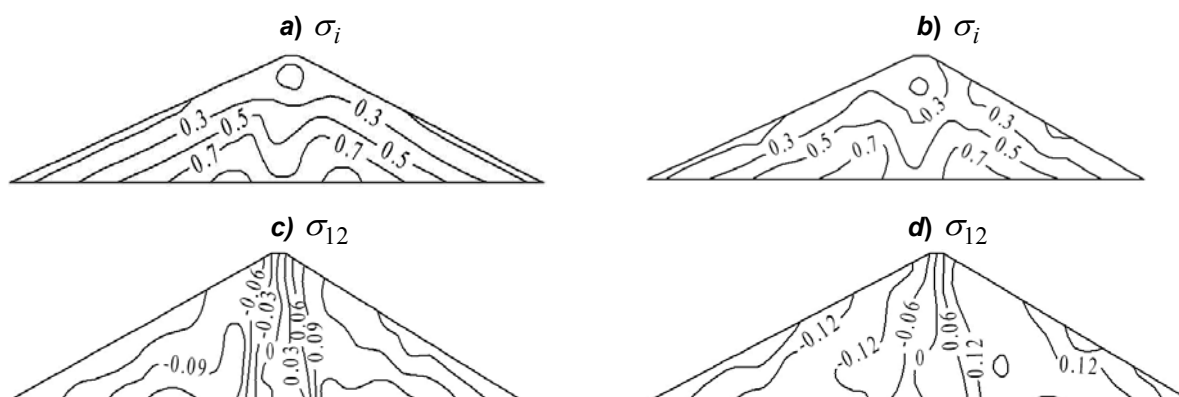### with account of elastic-plastic properties of soil

In this chapter the stress-strain state of earth dams is studied with account of elastic-plastic properties of soil and heterogeneity of the structure under the effect of mass forces.

In design, elastic-plastic properties of soil are considered according to bilinear strain diagram $\sigma_i = f\left(\varepsilon_i\right)$ with degree of strengthening $\overline{\lambda} = \left(1 - E_p / E\right) = 0.75,$ that is an angle of incline of plastic part E_p is four times less than an incline of elastic part $E : E_p = E/4$ [30]. Yielding limit is taken according to [31], for kernel material (loamy soil) $\sigma_y = 0.3$ MPa, and for material of retaining prisms within the limits 0.45MPa - 0.50 MPa.

Figure 1 shows isolines of intensity distribution (σ_i) and tangential (σ_{12}) stresses in Sokh dam, obtained with account of heterogeneity of the structure, elastic (Fig. 1*a* , 1*c*) and elastic-plastic (Fig. 1*b,* 1*d*) properties of soil under own weight. Comparison of results shows that an account of elastic-plastic properties of soil of retaining prisms leads to the change in values and character of stress state of a dam, namely to 20% decrease in intensity (σ_i) and vertical stresses (σ_{22}) and to the strengthening of arch effect in the kernel of a dam. The reason is a difference of straining properties and limits of yielding of soils in a kernel and retaining prisms. An increase up to 0.05 MPa of horizontal stresses σ_{11} in upper

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part of a dam may be the cause of a change of its profile. Vertical stresses σ_{22} in lower level of a kernel are decreasing down to 20%. In slope zones tangential stresses σ_{12} are increasing up to 0.05-0.06 MPa, this also may lead to the change of profile form and to the drop of safety factor of dam slopes.

Figure 1. Isolines of distribution of intensity σ_i and tangential σ_{12} stresses (MPa) in Sokh dam with account of heterogeneity of the structure, elastic (*a, c*) and elastic-plastic (*b, d*) properties of soil

Analysis of data obtained states that an account of elastic-plastic properties of soil leads to the occurrence of residual strains in the most stressed sections inside the body of a dam and in slopes zones.

In Figure 2 isolines of distribution of intensity σ_i and tangential stresses σ_{12} in heterogeneous Ghissarak dam are shown with account of elastic-plastic properties of soils.
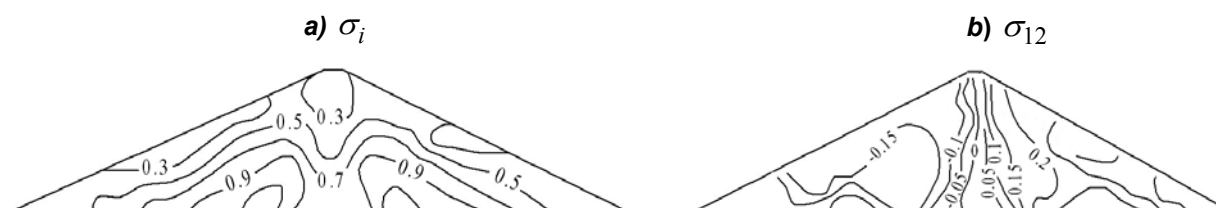
Figure 2. Isolines of distribution of intensity σ_i (*a*) and tangential σ_{12} (*b*) stresses (MPa) in heterogeneous Ghissarak dam with account of elastic-plastic properties of soil

Isolines of distribution in Figure 2 show that an account of elastic-plastic properties of soil leads to re-distribution of stress state of high dams by the following way: intensity - σ_i and vertical stresses – σ_{22} in a kernel become 15% less (arch effect is stronger), and tangential stresses in upper and lower slope zones are increasing considerably up to 50%, that leads to decrease of safety factor near the slopes. It is stated that the effect of elastic-plastic properties of soil on stress-strain state of a dam is increasing with the height of a dam. The greatest difference in stresses is observed near the slopes; this may lead to the occurrence of shear strains and landslides. In the zone of a kernel the values of tangential stresses remain insignificant.

Theoretical investigations, given above, show that in assessment of the strength of high and average dams it is necessary to account heterogeneity of structures and real elastic-plastic properties of soil.

2.2. Determination of the stress-strain state of earth dams with account of elastic-plastic properties and optimal moisture content of soil

In this chapter stress-strain state of earth dams is studied with account of heterogeneity of the structure, elastic-plastic properties and optimal moisture content of soil under the effect of own weight.

In correspondence with data, given in [32], the values of optimal moisture content of soil under strengthening are taken within the limits: for sandstone ≈7–10%, for sandy loam ≈9–15%, for loamy

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soil ≈12–20%. Under compaction of gravel-pebbles alluvial soils and rock mass the value of optimal moisture content may be taken as equal to moisture content of soil in natural state, that is ≈5–12%.

The values of soil parameters, used in design, were selected according to [23, 25]: for loamy soil $K_{ns} = 28\text{-}30$ MPa, $\alpha = 2.5$, $\theta_* = 0.0015$; for material of prisms $K_{ns} = 38\text{-}42$ MPa, $\alpha = 2.0$, $\theta_* = 0.002$.

To analyze the effect of elastic-plastic properties and moisture content of soil on stress-strain state of dam some static calculations were carried out with account of elastic-plastic law of straining and optimal moisture content of soil under prisms and kernel.

Figure 3 shows isolines of distribution of stresses in Sokh dam with account of elastic-plastic properties and optimal moisture content of soil. In calculations, the values of optimal moisture content for soil under prisms – W=10% and under kernel – W=16% were used.

Comparison of obtained results with results of elastic statement (Fig. 1a, 1c) shows that an account of elastic-plastic properties and optimal moisture content of soil leads to the change of the character of stress-strain state of a dam. Considered factors lead to an increase of arch effect in a kernel, typical for σ_i and σ_{22}. In the kernel the intensity of stresses σ_i becomes ≈25% less, and vertical stresses ≈20% less. The value of tangential stresses σ_{12} reaches 0.06 MPa. The greatest straining is observed in the most stressed section of a dam – in its lower part. In kernel zone the intensity and vertical straining have smooth character, which is not so for stress isolines. This happens due to the difference of deformation and physical-mechanical properties of a kernel and retaining prisms. Though stress value in a kernel is less, but due to more intensive straining of kernel soil, strain isolines have smooth character. Shear strains are distributed similar to tangential stresses along the section of a dam.

a) σ_i　　　　　　　　　　　　　　b) σ_{12}
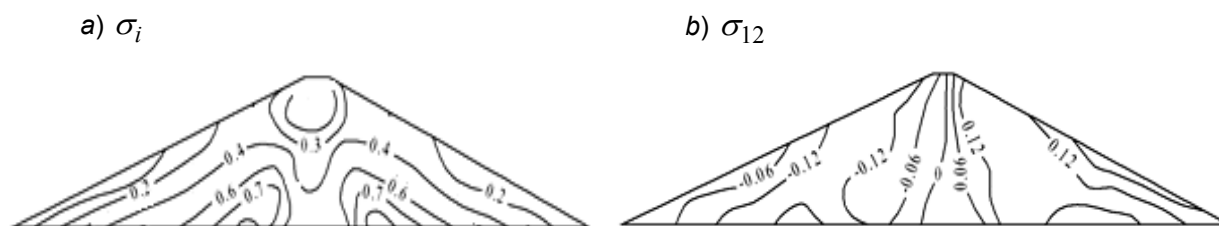
Figure 3. Isolines of intensity distribution σ_i and tangential σ_{12} stresses (MPa) in heterogeneous Sokh dam with account of elastic-plastic properties and water saturation of soil (moisture content of prism soil – W=10%, kernel soil – W=16%)

According to bilinear model, elastic-plastic straining of soil begins after the moment of time when stress intensity σ_i reaches the limit of yielding, but in model, offered in [23, 25], non-linear elastic-plastic properties of soil occur at the very beginning of loading. So the model from [23, 25] may be used to account residual strains on those sections of a dam, where the values of stress intensity do not exceed yielding limit σ_{22}. The main advantage of this model is the possibility to take into consideration moisture content and to use real parameters $\left(K_{ns}, \alpha, \theta_*\right)$ of soil in concrete design.

Results obtained on each of these two models give similar character of stress-strain state of earth dams, with ≈7% difference for some components of stresses.

Based on obtained results we may draw a conclusion on a necessity to account moisture content and elastic-plastic properties of soil, as moisture content considerably effects stress-strain state of a dam, making stronger arch effect in a kernel typical for σ_i and σ_{22}. Stress intensity near the base and prisms of a dam become approximately 10% less, horizontal stresses in lower part of a dam are 8% greater and tangential stresses σ_{12} in a kernel are two times greater. The difference in mentioned stresses becomes greater with the height of a dam: the higher is the dam the greater is the difference.

The decrease of σ_i and increase of σ_{11} in lower part near the base lead to the drop in resistance of the structure to shear horizontal forces; an increase of tangential stresses σ_{12} in a kernel and near upper slope may lead to the occurrence of cracks and landslides.

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2.3. Determination of the stress-strain state of earth dams with account of large strains

In this chapter stress-strain state of earth dams with account of large strains and heterogeneity of structures is studied under the effect of mass forces and hydro-static pressure on a dam.

1. Model problem of stress-strain state of homogeneous earth dams of different height (H=25 m; H=50 m; H=70 m) and similar physical-mechanical parameters of material with account of finite strains under the effect of mass forces was solved.

Analysis of results shows that an account of large strains leads to 2% increase of stresses comparing with linear case at each 20 meter increase of the structure height.

2. The problem of the stress-strain state determination of the homogeneous Ghissarak dam model with account of large strains was considered.
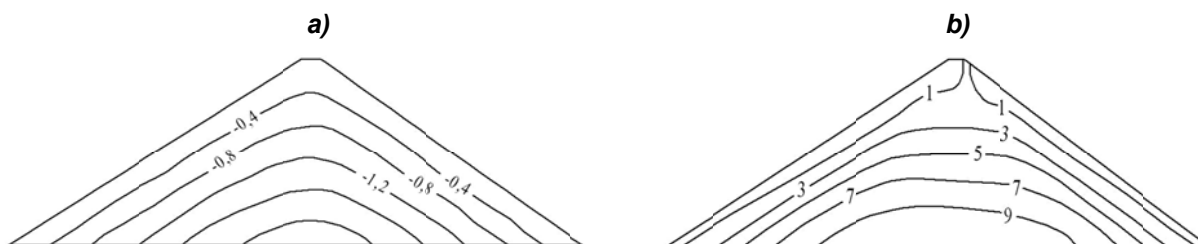
Figure 4 shows isolines of distribution of horizontal stresses – σ_{11} for homogeneous Ghissarak dam under the effect of mass forces: in Figure 4a – σ_{11}^{gn}, obtained with account of large strains, in Figure 4b – relative difference of linear – σ_{11}^{lin} and non-linear – σ_{11}^{gn} design, obtained by formula $\left(\left(\mid \sigma_{11}^{gn}\mid - \mid \sigma_{11}^{lin}\mid\right)*100\%\right)/\mid\sigma_{11}^{lin}\mid$.

a)   *b)*
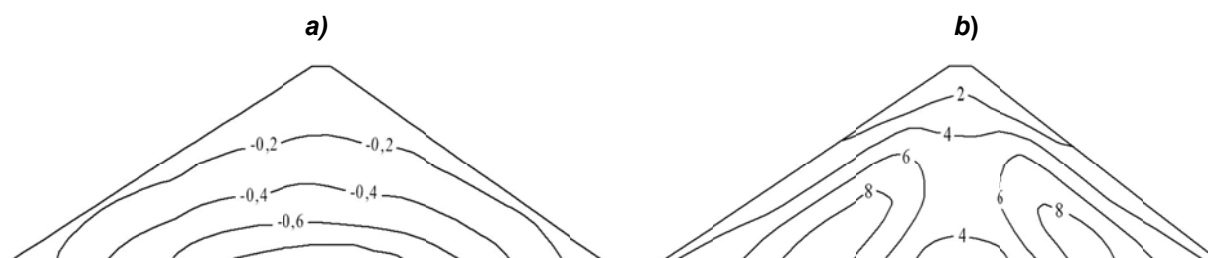
Figure 4. Isolines of distribution of horizontal stresses σ_{11} (MPa) in section of homogeneous dam under the effect of mass forces with account of large strains of the structure (*a*) and relative difference (in %) of linear and non-linear design (*b*)

Figure 5 shows results of design (isolines of distribution) vertical stresses – σ_{22} for Ghissarak dam under the effect of mass forces: in Figure 5a – with account of large strains – σ_{22}^{gn}, Figure 5b – relative difference of linear and non-linear design.

Analysis of results in Figures 4 and 5 shows that in high structures there occur large strains approximately 10% higher than results of linear design; this proves the conclusions, obtained in model problem about 2% increase in stresses with every 20 m of the height of a dam.

a)   *b)*

Figure 5. Isolines of distribution of vertical stresses σ_{22} (MPa) , in a section of homogeneous dam under the effect of mass forces with account of large strains (*a*) and relative difference, (in %) of linear and non-linear design (*b*)

3. The problem of the stress-strain state determination with account of large strains and heterogeneous specific feature of Ghissarak dam under the effect of mass forces was considered.

Figure 6 shows isolines of distribution of intensity of stresses – σ_i in section of heterogeneous Ghissarak dam under own weight; Figure 6a – design with account of large strains – σ_i; Figure 6b – relative difference of linear and non-linear design (in %).

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a)   *b)*
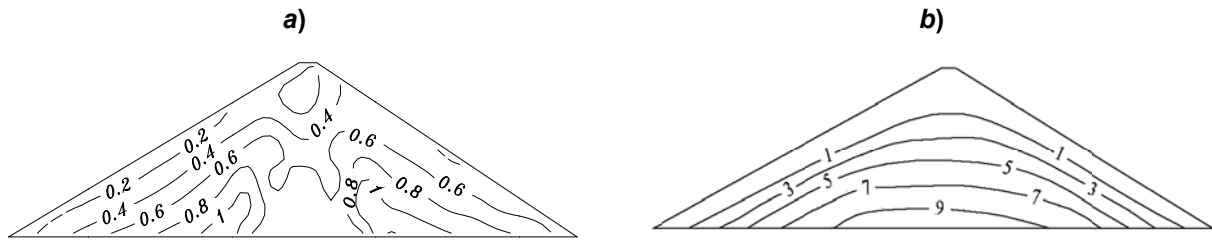
Figure 6. Isolines of distribution of stress intensity σ_i (MPa) in a section of heterogeneous dam under own weight with account of large strains of the structure (*a*) and difference (in %) between linear and non-linear design (*b*)

Analysis of stresses $\sigma_{11}, \sigma_{22}, \sigma_{12}$, obtained with account of large strains, shows that heterogeneity of a dam considerably changes the stresses in the middle part of slope zones, in the center of upper slope and in a kernel. An abrupt stress drop is observed in the lower part of a kernel in the joint point of a filter and upper retaining prisms; this may lead to crack-forming.

Maximal tangential stresses τ_{max} and intensity of stresses σ_i in heterogeneous dams, obtained with account of large strains, differ essentially from intensity of stresses σ_i, obtained in linear statement for homogeneous model. Here the greatest stresses are observed in the upper part of a dam and on kernel-slope contact. Maximal tangential stresses τ_{max} are reached on the upper part of upper slope; this may damage stability of this zone.

Abrupt change of stress intensity in joint point of a kernel with transient zones of a dam may lead to formation of cracks in these sections. Mentioned effects occur in sufficiently high heterogeneous dams. Thus, in assessment of high structures strength it is necessary to take into account large strains of the structure and real structural specific features.

Conclusion

Methods, algorithms and PC programs to assess stress-strain state of heterogeneous earth dams with account of moisture content, elastic-plastic properties of soil and large strains under static effects were worked out. Performed studies show, that:

- an account of elastic-plastic properties of material leads to qualitative and quantitative changes of stress-strain state of high earth dams. The difference of strain properties and yield limits of a kernel and prisms leads to an increase of arch effect, typical for vertical stresses and to occurrence of plastic shear strains in slope zones; this may facilitate the change of dam profile;
- an account of moisture content of soils alters stress state of a dam and leads to an increase of horizontal stresses in the lower part of a dam and almost two times increase of tangential stresses in a kernel and near upper slope;
- an account of large strains and heterogeneity of the high dam leads to considerable change of stress-strain state of the whole structure and to stress drop in a contact of different parts of it.

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* Mirziyod Mirsaidov, Tashkent, Uzbekistan

Phone number: +7(987)2370981; e-mail: theormir@mail.ru

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An assessment of stress-strain state of earth dams with account of elastic-plastic, moist properties of soil and large strains

M.M. Mirsaidov;
T.Z. Sultanov,
Tashkent Institute of Irrigation and Melioration, Tashkent, Uzbekistan
Sh.A. Sadullaev,
Tashkent State Technical University, Tashkent, Uzbekistan
+7(987)237-09-81; e-mail: theormir@mail.ru

Key words

Abstract

Mathematical statement, methods and algorithms of assessment of stress-strain state of earth dams with account of elastic-plastic, moist properties of soil and finite strain, structural heterogeneity of structures under static effects, are presented in the paper. Stress-strain state of three erected structurally heterogeneous earth dams of different heights was studied with account of elastic-plastic, moist properties of soil and large strains in a structure.

In the process of investigation it was revealed, that an account of elastic-plastic properties and moisture content of soil, as well as large strains and heterogeneity of a structure, qualitatively and quantitatively vary the state of high earth dams, increasing arch effect for vertical stresses and horizontal stresses in the base of a dam, changing stress state of a structure on the whole and bringing the drop in pressure on the contacts of different parts of a structure.

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