The consequences of seismic loads are checked through stresses in the antiseismic reinforcement and accelerations at the points of installing seismographs in the dam body, differentiated for three possible earthquake-generating zones. The constancy of the fundamental frequency of the natural vibrations of the dam will be checked after installing the service seismic apparatus in the dam.

Table 1 reflects Stage I of checking the safety of the dam.

As an example, Fig. 2 gives the allowable and limit values of stresses at the measurement points of the dam. Further investigations should substantiate and establish a system of indices of the state for monitoring the structure in Stage II during long operation with a limited number of these indices.

OPTIMIZATION OF THE DESIGNS OF EARTH DAMS

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Problems of optimization of designs will occupy a leading place in the design of hydraulic structures. In many areas they have become dominant. A method of optimizing the design of earth dams with the use of the principle of coordinated optimum (Pareto principle) was published in [1, 2]. Factors affecting the cost and performance of a dam are selected. Such factors are the steepness of the upstream and downstream slopes, density of placing the soil, base width, and slope angle of the watertight element. With the use of the mathematical apparatus of experimental design theory, a function expressing the cost of a structure and functions expressing different dam performance criteria \( (K_s^{us}, K_s^{dus}, K_s^{cre}, K_s^{crh}, \text{ etc.}) \) were obtained.

The solution of the optimization problem by means of the Pareto principle requires only two response functions.

The first function is the cost function \( E(x) \). The performance of the dam is evaluated as a result of reducing all performance criteria to a single generalized optimization criterion \( D(x) \). For this purpose, all performance criteria \([K_s])\) are converted by means of the Harrington function \( d_i = \exp[-\exp(-y')] \) to dimensionless coefficients \( d_i \), and the singularities of the Harrington function in its central part, where \( 0.37 \leq d_i \leq 0.69 \) is the region of allowable values of \( d_i \), are used. On leaving this region the value of \( d_i \) very rapidly decreases or increases, exit from the allowable region should affect the value of \( D(x) \). The region of allowable values is the same as for \( d_i \).

The \( D(x) \) is determined by means of the following expression:

\[
D = \sqrt[4]{d_1 \times d_2 \times \ldots \times d_n}.
\]  

Optimization of the design of earth dams with the use of the Pareto principle is accompanied by certain inconveniences and assumptions.

An important assumption is the fact that the condition of limitation of factor space is not taken into account when solving the optimization problem. As a result of solution, the values of the factors satisfying the minimum of the structure cost function \( E(x) \) can prove to be beyond the limits of factor space. The coordinate descent method was used for solving this problem, i.e., if at least one of the factors falls outside the limits of factor space, then to this factor (the most distant from its closest boundary) is attached the value of the closest boundary as constant for this factor and so forth with all factors until during solution they all are within or at the boundary of factor space. The Pareto solution of the optimization problem in such a case is approximate owing to the use of the Harrington function.

In connection with this arose the need to solve the optimization problem with the direct participation of all performance criteria (each separately) and all constraint conditions of factor space. The formulation of the problem reduces to minimization

\[
E(x)_i = 1, 2, \ldots, n
\]
The method of penalty functions was used for solving this problem. This method is based on the method of Lagrangian multipliers, i.e., transformation of the constrained optimization problem to unconstrained.

For solution by the method of penalty functions, all constraint functions multiplied by an indeterminate multiplier \( t \) (penalty function) are added to the function \( E(x) \) \( [4] \). Difficulties related primarily with unsuccessful scaling of the function occur when using penalty function methods. The problem will be poorly scaled if the absolute values of the variables and functions figuring in this problem strongly differ among themselves.

As calculation practice has shown, when the values of the coefficients of the objective function and constraints differ by several orders of magnitude, sequential solution of subproblems and minimization lead to incorrect results, i.e., only a certain part of the variables fulfilled the constraint conditions and the other did not.

Among all types of penalties \( \Omega \), the exterior point method \([3]\) (quadratic truncation, Fig. 1) was used for solving the dam design optimization problems. It was most acceptable for such problems.

The expanded penalty minimizing function has the form

\[
E(x, t) = E(x) + t \left\{ \sum_{i=1}^{n} \frac{|g'_i(x)|}{2} + \sum_{i=1}^{n} \frac{|g''_i(x)|}{2} \right\},
\]

where \( g_j(x) = K_{sj} - [K_{sj}] \); \( g'_j(x) = x_i^{\text{max}} - x_i \); \( g''_j(x) = x_i - x_i^{\text{min}} \).

Actually, in (6) the penalty functions are equal to zero, if \( g_j(x) \), \( g'_j(x) \), and \( g''_j(x) \) are greater than zero, and acquire a large value when \( g_j(x) \), \( g'_j(x) \), and \( g''_j(x) \) are less than zero. Thus the constraint function should be constructed according to this principle.