SAFETY OF WATER-DEVELOPMENT WORKS

ASSIGNMENT OF CONDITION INDICES FOR IN-SERVICE HIGH CONCRETE DAMS

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According to the federal law "On the safety of water-development works," monitoring of the reliability and safety of water-development works is based on comparison of actual reliability indices with their standard values that have been properly corroborated. It is essential to assume that the limiting allowable values of the parameters being monitored are regulated by the "Rules for the commercial operation of power plants and grids" (RCO). As many years of experience with field observations on the performance of in-service structures have indicated, the establishment of limiting allowable values (LAV) for monitored parameters during the design of high concrete dams does not correspond to assessment of their actual reliability [1].

Noncorrespondence between regulatory documents relative to high concrete dams and their actual condition was exposed even at the very start of construction of such dams in Siberia (1950s). By regulating phenomena and processes observed at in-service dams (seasonal disturbance of the monolithic character of the profile of the dam, loosening beneath the thrust face) on the basis of results of field observations, the Construction Rules and Regulations have been altered several times. Despite these approximations of the Construction Rules and Regulations to the actual operating conditions of dams, the actual behavior of a dam cannot correspond completely to the design model due to the unpredictability of the construction procedure (especially the battering of the profile, which always differs from the initial design variant), the state of the geological medium in the new load regime, and the different properties of the concrete and foundation bed.

Different LAV of monitored parameters have been established for different dams. For high concrete dams, the filtration flow rate, settlement, the displacement of the crest of the dam, and the stresses at certain points have been designated as parameters that control the filtration regime and stress-strain state. Limiting allowable values for the total filtration flow, bed settlement, the displacement of the crest of the keyed section, and the stresses in the downstream face have been included as rating values at the Chirkey dam.

Based on their own numerical values, these LAV have represented maximum observed parameters, which have increased by 20-30%. In the 1980s, two LAV (settlement and displacements) were found to have been exceeded; this should have been formally taken as evidence of deterioration of the dam's performance. In truth, the dam and foundation bed reacted to a different load combination that had not previously been encountered [2].

Let us examine the potential of the assignment of LAV for basic parameters reflecting the dam's reaction to active loads as performance criteria of the structure.

**Filtration Flow in Foundation Bed.** In designing a dam, the overall flow rate is assigned to ensure the serviceability of the system used to evacuate the filtration flow. It is incorrect to link the rate of filtration flow to the possible development of suffosion processes, and to an increase in counter-pressure forces, i.e., to establish criteria for foundation-bed reliability on the value of the rate of the filtration flow. In the field, the flow rate may be appreciably lower than the design rate, but concentrated in a local section, giving rise there to negative phenomena. The rate of the filtration flow will be negligible due to poor filtration discharge; in addition, however, this will lead to an increase in counter pressure. A filtration flow rate exceeding the design value will in no way make itself felt on the stress-strain state of the dam, and so forth. We should therefore monitor not only the magnitude of the filtration flow rate, but primarily those parameters that determine its influence on the dam (plane displacements of the rock masses, counter pressure, suffosion, etc.).

**Displacement of Dam Crest.** Limiting allowable displacements of the body of the dam cannot be determined with sufficient accuracy during design due to the impossibility of making a valid prediction of the future flexibility of
the foundation bed, and the effectiveness of the dam's monolithic character. With respect to subsequent situations, this is difficult to do from both field data, and also retrospective calculations.

The rotation of the dam due to the hydrostatic load and nonuniformity of settlement beneath the lower surface, temperature displacements caused by a temperature gradient throughout the horizontal sections, and shearing along the lower surface are component parts of the measured displacement. The causes of the initial increase in crest displacement (approximation to the LAV) may differ: cracking on the thrust face, the opening of the contact joint beneath the thrust face, an increase in counter pressure, shear deformations of the rock masses, nonlinearity of the deformation of the geological medium, etc. Variation in the displacement of the dam crest is the only indication of changes that had initiated in the previous scheme of the dam's static functioning, and which should be observed from changes in other parameters. From the formal standpoint, it is necessary to assign several LAV for displacements: based on permissibility of the opening of construction joints and cracks on the thrust face, opening of the contact joint beneath the thrust face, and the permissible rotation of the dam due to nonlinearity of deformation of the geologic medium. Moreover, negative processes may develop in sections devoid of means of measuring displacements. This also renders the LAV assigned for displacements a rather conditional quantity.

**Settlement.** Limiting allowable settlements may not be the only indication of the dam's condition, since the structure may, by deforming jointly with the canyon, in no way react to plastic deformations of the geologic medium, and, conversely, negative phenomena may take place in the lower surface and body of the dam under a small, but nonuniform settlement, depending on the causes of its development [2].

**Stresses.** The assignment of LAV for stresses in a dam is very conditional. The stresses are not measured directly, but are calculated from deformations determined by strain-measuring methods. Averaged characteristics obtained for the given grade of concrete are used for the calculation. Plastic deformations are analyzed by different methods for each structure; this may result in a difference of 100%, depending on the period during which creep phenomena are accounted for in the concrete. A strain-gage rosette may be located in the zone of influence of a crack; this will also distort its readings. Moreover, each point should have its own reference stress level governed by the operating scheme of the dam; this will not enable us to compare stresses with the ultimate strength of the concrete as a material.

The establishment of numerical limiting values for stresses during design is also conditional due to the unpredictability of production stresses that develop during construction as the elasto-instantaneous compression modulus increases during the warming and cooling of the concrete blocks, their monolithizing, battering of the profile, etc. According to field observations, the production stresses may range from 10 to 90% of the stresses caused by operating loads.

In addition, strain-gage measurements are most informative for exposure of the specifics of the behavior of a dam, since the latter's reaction to the hydrostatic load, temperature effects, the role of seasonal and time-dependent disruption of the monolithic character of the effective profile of the dam, and correspondence between the stress-strain state and design prediction is determined from the pattern of the change and distribution of these measurements over the sections. In designing high concrete dams, unfortunately, it is not only difficult to predict numerical values of parameters defining its performance, but also the very scheme of the static functioning of the dam and foundation bed.

Long-term (from 2 to 10 years) impoundment of the reservoir is characteristic for domestic dams; here, the increasing hydrostatic load on the dam is taken up by the battered profile. It is precisely in this period that the stress-strain state of the dam, and its filtration regime are formed, and the specifics of the dam's future behavior is determined. The purpose of analyzing field data is to establish the role of production factors in that initial state of the dam in which it begins to take up the design loads.

A dam's actual scheme of static functioning, the basic indicators of which are the extent to which the body of the dam and the contact zone become seasonally and permanently nonmonolithic, and the relationship between the active loads and the parameters being monitored is defined within the first year's of service. The cause of an out-of-spec condition for the dam and foundation bed is determined from these data, and a new working model is compiled.

On-going monitoring of the condition of an in-service structure consists in the comparison of measured parameters with numerical values corresponding to the given operating scheme of the dam; here, the dependence itself should be determined for each combination of loads. Violation of the relationships suggests a change in the previous operating scheme. In that case, analysis of the data should reveal the causes of the change in the parameters controlling the stress-strain state of the dam. It is necessary to perform new mathematical modeling of processes recorded by field data, and determine the qualitative and quantitative changes in the previous scheme of the dam's static functioning. The development of negative processes is predicted, and measures required for their cessation...