SEEPAGE REGIME IN THE FOUNDATION OF THE SAYANO-SHUSHENSKOE DAM DURING CONSTRUCTION AND OPERATION

E. N. Reshetnikova and T. G. Balashkina

Monitoring seepage in the foundation and body of the high gravity-arch dam of the Sayano-Shushenskoe hydrostation has been being carried out since the start of the construction and operating period (since 1978) and as the dam was constructed the range of monitoring tasks broadened. At the first stages the main tasks were to determine the parameters of the seepage flow and to assess the effectiveness of engineering antiseepage elements. During stage-by-stage construction of the dam and filling the reservoir, seepage inhomogeneity of the foundation and the changes in the seeping medium occurring were evaluated. On the basis of the accumulated information the maximum allowable values of the seepage parameters for normal operating conditions were determined and recommendations were worked out for improving the seepage regime and extending monitoring. These tasks were accomplished on the basis of the results of observations of seepage, deformations, stress-strain state of the foundation and banks with consideration of geology, hydrogeology, hydrochemistry, grouting works, and special model and prototype investigations.

The main objects of monitoring are the dam foundation and bank abutments composed of strong crystalline schists: paraschists under the right-bank part and spillway sections (36-66) and orthoschists under the powerhouse part of the dam and left bank (1-35). The paraschists have greater strength and toughness; the orthoschists are more brittle, fractured, more subjected to tectonic deformations. The rock foundation is cut by steeply and gently dipping joint systems filled with quartz-carbonate rocks and dense clay and grus filling.

The waters of the rocks form an artesian aquifer with a decrease of water permeability deep into the mass. In the upper zone of the foundation, at a depth to 30 m (elevation 280 m), are the most decompressed and permeable rocks with a permeability coefficient $K_p = 0.1-0.3$ m/day. The middle zone with a thickness of 40 m (to elevation 240 m) has $K_p = 0.05-0.1$ m/day, below which the values of the permeability coefficient are less than 0.05 m/day.

To strengthen the foundation and increase its impermeability, the design called for blanket grouting from 15 m under column II to 30 m under the upstream shoulder of columns III-IV; three-row contact grouting from the upper pool to the deep curtain (rows A, B, and C) with a depth of 35 m; deep two-row 100-m curtain, the downstream row of which is brought practically to the aquiclude; one-row grouting with a depth of 16 m is carried out along the upstream face beneath the upstream apron. During the grouting works, maximum absorption of grout was noted in the foundation of sections 26-31, 34, 35, and 39, and in the powerhouse section the weakened zone was confined to elevation 240 m and in the spillway sections to the upper 30 m (elevation 280 m). Contact, deep, and blanket grouting was carried out also in the canyon-wall abutments. In accordance with the design, drainage of the foundation was arranged from a gallery at elevation 307-316 m by holes with a depth of 51-56 m and spacing of 3 m, inclined 25° toward the lower pool. Descending and ascending 50-m drains with a spacing of 3-5 m and groups of fanlike drains at the ends of all adits of the left and right banks are provided for in the bank adits and galleries.

A special feature of the engineering protection of the foundation of this structure is that it was put into operation during construction and step-by-step filling of the reservoir with consideration of the results of on-site observations. On one hand, this made it possible to promptly increase protection and, on the other, it introduced quantitative and qualitative changes into a determination of the seepage parameters and hindered an analysis of the results.

The regular observations of seepage included visual and instrumental observations. Visual inspections of the drainage-grouting galleries, surfaces of rock and concrete, and local seepage zones are made at times of minimum and maximum upper pool levels (UPLs). Instrumental monitoring is realized by means of an observation network consisting, according to the design, of 250 piezometric and more than 500 drain wells, which are located in the foundation and wall abutments.

When drawing up the plan of arrangement of the monitoring and measuring instruments (MMIs), control sections with telemetry apparatus embedded uniformly over the length of the dam without consideration of the

geologic characteristics of the foundation were taken as the base, which already in the construction period necessitated designating additional piezometric sites in stretches with complex tectonics. As a result, the piezometric network is represented by six transverse sites in the left-bank and three sites in the right-bank masses. Furthermore, sites in the foundation of the powerhouse and piezometers for monitoring bypass seepage were provided for in the foundation of the powerhouse. A longitudinal site of contact piezometers was organized on the downstream side of the grout curtain for checking the effectiveness of draining the foundation. The bank abutments are also equipped with contact piezometers with water intakes at various levels of the rock mass (eight measuring points on each bank). A typical piezometer site (Fig. 1) includes 10-19 lowered point piezometers with water intakes at several elevations throughout the foundation: on the line of contact and at the boundaries of the contact, blanket, and deep grouting.

The number of drain wells by means of which the seepage flow is discharged and the flow rates are monitored was 40-50 in 1978 and increased to 500 by the end of 1989. Today the drainage system includes 270 wells in the channel part of the foundation and 430 wells in the bank embankments. In accordance with the character of the discharge of the seepage flow, from 5 to 10 drain wells were drilled in the foundation of each section. The scheme of discharging the seepage flows provides for free outflow from the drain wells. The seepage water from the drainage-grouting gallery is continuously pumped into the lower pool, and from the bank adits is discharged by gravity flow along collectors made at lower elevations (344 m) of both banks.

Certain difficulties in the construction and operating period from 1978 through 1988 hindered monitoring seepage and interpretation of the results:

- the equipment of the new drains precluded the possibility of comparing the quantities being measured;
- the poor state of the drainage galleries (severe invasion of water and glogging with mud) and conduction of