ORGANIZATION OF MONITORING IN STRUCTURES OF THE ZAGORSK PUMPED-STORAGE POWER PLANT

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The Zagorsk pumped-storage power plant (PSPP) is the main plant in a series of unified PSPP with a head of 100-200 m for lowland regions. The structures of the Zagorsk PSPP, which is built on the Kun'ya River, include the following: earthen dikes, which form the upper basin, a water intake with adjoining retaining walls, steel-reinforced-concrete penstocks, powerhouse, and a lower basin formed by upstream and downstream dams with spillways. The normal surface levels in the lower and upper basins are 162.5 and 266.5 m, respectively. The structures of the PSPP are placed on a bed that is complex in geological respects. Thus, the bed of the water intake and retaining walls of the first tier is composed of morainic clayey loams underlain by interlayers of highly plastic "green" clays, and even lower by sands of the "senomansk" horizon; the latter are underlain by "Paramonovsk" clays. These strata also serve as the bed for the pipelines over a large part of their length. Concertal clayey sands with infrequent inclusions of gravel and clayey interlayers serve as the bed for the powerhouse. A whole series of new solutions was adopted in developing the design of the structures for the PSPP [1, 2]. The following can be classified as such solutions:

- foundation slabs with planform dimensions of 69 x 103 and 67.1 x 145.6 m for the water intake and powerhouse, respectively, without forming temperature-settlement joints;
- filterless designs of slabs for securing the slopes of the upper basin to an anchor slab in the slopes;
- rejection of the waterproof coating of the channel for the upper basin;
- construction of drainage beneath the foundation slabs of the retaining walls and curtain drains; and,
- steel-reinforced-concrete sectional-monolithic penstocks with an inside diameter of 7.5 m.

The class of structures, the complex hydrogeologic conditions of the beds beneath the structures of the PSPP, and the innovation of design solutions required the development of a system for operational monitoring of their condition during construction and operation. Monitoring of the stress-strain state of the structures and seepage regime in the bed of the structures and slopes was called for by a program of field observations. For this purpose, the structures, their beds, and slopes were fitted with remote and geodesic monitoring-measuring apparatus, as well as apparatus for seepage observations (Fig. 1).

The program called for the measurement of the following physical values:

- settlement of the structures using surficial and lateral marks, and effective and fundamental benchmarks;
- horizontal displacements of the water intake and powerhouse, the incline of the penstocks using sighting targets, and displacement measurements of inverse plumb lines (DMIL);
- the relative vertical displacements (settlements) of the foundation slabs of the water intake, powerhouse, and pipeline courses using hydrostatic systems (PUZhS);
- contact stresses along the lower surfaces of the foundation slabs of the powerhouse, water intake, and retaining walls using contact stress meters (CSM);
- the stresses in the reinforcement of the foundation slabs of the powerhouse, water intakes, and retaining walls of the upper pool, the steel-reinforced-concrete jackets of the pipelines, and compensator sections using force transducers (PSAS);

Fig. 1. Schematic diagram showing arrangement of sites of monitoring-measuring apparatus in structures of Zagorsk pumped-storage power plant: 1) upper basin; 2) dikes of lower basin; 3) water intake; 4) pipelines; 5) powerhouse; 6) lower basin; 7) downstream dam of lower basin; 8) upstream dam of lower basin. Measurement stations with monitoring-measuring apparatus: I) surface marks, and pressure and temperature transducers, piezometers, flowmeters; II) force, linear-displacement, and temperature transducers, surface and lateral marks; III) fluid-level, force, temperature, and linear-displacement transducers, three-mark slits; IV) pressure transducers, piezometers; V) piezometers, pressure transducers, flowmeters.

the openings of construction joints in the foundation slabs of the water intake, powerhouse, and retaining walls using linear-displacement transducers (PLPS);

the temperature of the concrete of the structural components of the powerhouse, water intake, retaining walls, and pipelines using temperature transducers (PTS); and,

the parameters of the seepage regime (piezometric levels, counterpressure, seepage flows, etc.) using pressure transducers (PDS), piezometers, and flowmeters.

As of June 1993, 1153 remote string-type transducers, 11 inverted plunges, 195 surface and lateral marks, 357 piezometers of different types, and 8 flowmeters had been installed to monitor the stress-strain state of the structures and their beds and the parameters of the seepage regime.

Four slide manifestations initiated by faulty design and production rules for earthwork developed during the building of the structures. Three of them — two on the right bank and one on the "northern" left bank — could have been eliminated by removing the slide-prone soils, placing overhanging embankments with surcharging of the retaining parts of the slope, and creating drainage and waterway systems. The problem involving the stabilization and provision for stability of the left-bank "Southern" slide was found to be considerably more difficult. We developed anti-slide measures, which included a change in the layout and construction of the right-bank abutment of the dike for the upstream basin toward the water intake,