EXPERIENCE IN OPERATING STRUCTURES AND EQUIPMENT AT HYDROELECTRIC STATIONS

DISTURBANCES OF THE DOWNSTREAM REVETMENT OF THE VOTKINSK HYDROELECTRIC STATION THAT OCCURRED DURING OPERATION

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The Votkinsk hydroelectric station was constructed in 1956-1963 on the Kama River 350 km below Perm city and 35 km southeast of Votkinsk city. The structures include (Fig. 1) a 273-m-long powerhouse (channel type), earth dams with a total length of 4770 m, and a single-lift twin lock with protecting and approach structures (these structures are maintained by enterprises of the Department of Waterways and Hydraulic Structures (Glavvodputi) of the Russian Federation). According to the original variant of the project a capacity of 540 MW (six turbine-generator units) was to be installed. However, during construction the project was revised toward an increase of the installed capacity up to 1000 MW. The Votkinsk reservoir has a total storage of 9.4 km$^3$ and useful storage of 3.7 km$^3$. The maximum head of the hydrostation is 23.5 m, the design head is 16.75 m. The average annual production of the Votkinsk hydrostation is 2320 million kWh. As is seen from the given characteristics (comparatively small reservoir, small production), the Votkinsk hydrostation operates as a peak-load station. As a consequence of a frequent change in the active power of the hydrostation, considerable fluctuations of the lower pool level occur.

Two stages of operation of the Votkinsk hydrostation were considered in the project. The first stage was operation of the Votkinsk hydrostation before completing construction of the Lower Kama hydrostation under conditions of a free lower pool of the Votkinsk hydrostation. It was assumed that the duration of the first stage would be three or four years. The second stage was operation of the Votkinsk hydrostation with a backwater in the lower pool from the Lower Kama hydrostation after putting the latter into operation. In the first stage daily fluctuations of the lower pool of 3.5 m in the summer and 5 m in the winter were allowed. In the second stage fluctuations of the lower pool in the presence of a backwater from the Lower Kama hydrostation were about 50% of the fluctuations of the level under conditions of a free lower pool of the Votkinsk hydrostation (according to the designers' hydraulic calculations).

Engineering-Geologic Conditions. The concrete structures of the hydro development are located on rocks of the Tatarian and Kazanian Stages of Permian deposits represented by a facies-variable mass of interbedded silty clays, siltstones, and sandstones with infrequent marl lenses.

The earth structures of the Votkinsk hydro development consisting of dams Nos. 1, 2, 3, and 4 are located in the channel, floodplain, and partially (at places of abutment) on floodplain terraces.

A special feature of the Quaternary deposits occurring in the foundation of the earth dams is the clearly expressed two-layer structure: on top are loam—clay rocks with a thickness of 2-5 m and lower are sands and gravel—pebble material.

The design revetment in the lower pool of the Votkinsk hydrostation should have "withstood" several years of operation under the harsh conditions of the first stage of operation and subsequently should have operated under conditions of the backwater of the Lower Kama hydrostation. However, life dealt with it differently. For more than 30 years now the Votkinsk hydrostation has been operating under conditions of the first stage of operation. Filling of the reservoir of the Lower Kama hydrostation to the design elevation of the normal pool level is not foreseen in the near future. During these years disturbances of the downstream revetment of the Votkinsk hydrostation occurred in various places.

A drop of the lower pool levels caused by transformation of the Kama River channel due to changes in the natural regime of sediment runoff and quarrying in the channel had an additional effect on the process of disturbance of the revetments. This drop by 1990 amounted to about 1 m compared with the design water levels [2].

On the Right-Bank Earth Dam No. 2 the design provided for draining waters from the drainage outlet as well as rain- and meltwaters into a special drainage ditch with subsequent discharge into the lower pool. According to the design, the banks of the ditch should have been revetted with reinforced-concrete slabs. However, this was not done. As a result, during marked changes in the load of the hydrostation and, accordingly, marked fluctuations of the lower pool level, the ditch banks were eroded. By 1980 progressive erosion of the banks of the drainage ditch reached a threatening size. The downstream slope of the earth dam and 500-kV transmission-line support were threatened. In 1981, in accordance with the recommendations of the Leningrad branch of the State Planning, Survey, and Research Institute (Lengidroproekt), the operating personnel of the hydrostation jointly with the Votkinsk Hydrostation Construction Administration (Votinskkgėsstroy) began to take measures to eliminate the aforementioned erosion. A 1-m-diameter reinforced-concrete collecting drain was laid along the channel of the drainage ditch discharging the drainage waters from the outlet of dam No. 2 to the lower pool (Fig. 2). A cofferdam that cut off the ditch from the Kama channel (lower pool of the hydrostation) was constructed to an elevation of 73.5 m. The downstream slope of the cofferdam was subsequently revetted with reinforced-concrete slabs.

State of the Downstream Slope of Channel Earth Dam No. 1. In the downstream shoulder of the channel dam there is a berm dumped from stone and a sand—gravel mixture; its role amounted to the creation of still water for hydraulic filling of the dam at the time of closing the channel. The given berm does not participate as drainage in the work of the structure. Drainage of earth dam No. 1, representing a combined construction of the batter part of the drainage and toe drainage with a reinforced-concrete drain pipe, is of the open type. The drainage waters are discharged through two outlets directly into the lower pool. The downstream slope, with the exception of the section of the batter drainage, is revetted with a layer of gravel 0.2 m thick. The outer slope of the surcharge of the batter drainage within elevations 80-71 m is revetted with reinforced-concrete slabs (Fig. 3).

During operation flattening of the downstream slope of dam No. 1 — the removal of soil from the dam body into the river channel — occurred as a result of pronounced changes in the lower pool level as well as ice phenomena in the winter. This occurrence was noted during an inspection of the hydraulic structures of the Votkinsk hydrostation by a commission of the Russian power corporation “EES Rossi” in 1994. Reworking of the slope in the indicated stretch has been observed since 1982, but most intense reworking occurred during 1993-1995.

In the summer of 1995 tongues of undercutting in certain stretches reached under the reinforced-concrete revetment slabs of the outer slope of the surcharge of the batter drainage. The washout tongues were backfilled by the hydrostation’s personnel in 1995. In accordance with the order of the Votkinsk hydrostation, Lengidroproekt designed the revetment of the downstream slope of dam No. 1, for the safe service of which during operation of the hydrostation in the sharp peak-load regime it is necessary to make a protective revetment of the slope.

Revetment of the Left-Bank Slope of the Discharge Channel of the Hydrostation. The discharge channel of the hydrostation was realized together with the discharge channel of the dam and has an elevation of the original clearing of the bottom of 64 m, which coincides with the natural elevations of the river bottom along the axis of the overflow dam. The left bank of the discharge channel is configured to provide smooth draining of the flow to the main river channel without whirlpool zones. The channel slope revetments are designated with consideration of joining with the retaining walls as well