Hydraulic research results for cantilever spillway at Hydroelectric power station 2 of Chirchik – Bossuv waterway

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Abstract. To date, in the water sector, such urgent problems of our time as the observed decrease in the reliability and safety of hydraulic structures and their individual elements are highlighted. The level of effectiveness of water distribution management and the timely supply of electricity to consumers depends on the stable operation of the entire hydraulic complex. Water management construction is very material-intensive and requires constant expenditures of material and energy resources to maintain the level of stable operation. However, in the event of an emergency at hydroelectric power station facilities, it is extremely difficult to provide the necessary resources for carrying out restoration work on time. In the practice of hydraulic engineering, various designs of cantilevered spillways have been widely used. Reliability and trouble-free operation of such spillway structures with the conjugation of downstream divers by a jet largely depend on perfection. This article discusses the problems of local erosion in the downstream of hydraulic structures, sets out the results of experimental studies to determine the depth of local erosion behind a cantilever spillway in the outlet channel with recommendations on its end structure.

1. Introduction

To date, a number of design solutions for consoles are known for discarding the flow from the structure and damping its excess kinetic energy to and in the washout funnel. Along with energy from the horizontal console, devices such as an inclined threshold (springboard), a splitter (spreader) of the stream in the form of dividing walls, a sock splitter, a comb springboard, and other structural elements placed on the console part of the spillway are used.

The need to develop an improvement in the design of the lower tail of the spillway structure is caused by the fact that several known and used devices and elements with a high degree of flow splitting require additional work and materials to expand the lower tail within the size of the trail of the falling stream, which entails an increase in the volume of fastenings downstream and rising construction costs.

At the same time, the available constructive solutions of the consoles, providing a slight expansion of the jet being discharged, have the low energy-absorbing ability. Also, most of the designed and used console designs have a complex configuration, are laborious to manufacture or require monolithic concreting using special formwork. Other well-known design solutions provide reliable operation of the structure in a relatively narrow range of variation in the missed costs. Due to the
insufficient quenching of the excess flow energy, local erosions occur in the lower downpipes of the cantilever spillways.

Therefore, there is an urgent need for research aimed at the development and implementation of modern technological elements of hydraulic structures, ensuring their trouble-free operation. The operating experience of cantilevered spillway structures on the canals of Uzbekistan shows that the phenomenon of local erosion in the downstream is more or less observed in the vast majority of existing structures, which requires significant additional costs. In some cases, local erosion can cause destruction of the structure [1, 2, 3].

The analysis of the current state of knowledge of the issue under consideration showed that at this stage, theoretical and experimental studies on the study and formation of local erosion behind cantilevered spillways for the conditions of fastening the downstream have not been fully completed.

Also, the influence of various constructive solutions of the end part of the cantilever spillway structures on local erosion for a wide range of water discharge discharged by the structure has not been sufficiently studied, which, in combination, predetermined the choice of the topic of scientific research.

2. Materials and methods

The main goal of the research was to study the local erosion behind cantilever spillway with recommendations on its end structure from the condition of preventing erosion of the bottom and slopes of the outlet channel.

The solution to this problem was performed on a spatial fragmenary hydraulic model carried out according to the rules of gravitational similarity (according to Froude) on a scale of 1:50 [4, 5, 6]. In the study, methods of the theory of similarity and dimension were also used.

3. Results and discussion

On the model, the section of the outlet channel of the hydroelectric power station #2 of the Chirchik-Bossuv water tract at the place of its interface with the cantilever spillway was washed out. This was done because we conventionally replaced the concrete cladding with incoherent material.

The application of this modeling method is based on the fact that when the concrete cladding is destroyed under the influence of hydrodynamic loads caused by the flow of water, the connection between the concrete parts is broken, and it turns into a disconnected material.

Considering that the thickness of the concrete lining of the outlet channel is 20 cm (in terms of model dimensions 4 mm), on the model the bottom and slopes of the channel were made of disconnected material with a grain size of 3-5 mm with a specific gravity of 2.6 g cm$^3$. This made it possible to select the fastener from the condition of preventing erosion of the facing of the outlet channel.
Experimental hydraulic studies have shown that the dimensions of the cantilever spillway provide maximum flow throughput $Q_{\text{max}} = 70 \text{ m}^3/\text{s}$.

The curves of the free surface of the flow constructed from experimental data indicate that no overflow of water through the walls occurs (Figure. 1). However, in the downstream (at the interface between the cantilever spillway and the outlet channel) when passing through the spillway model, the water discharge $Q = 70, 50, 30 \text{ m}^3/\text{s}$ and a water level of the downstream of -608.5, erosion of the bottom and slopes of the channel were observed (Figure. 2).

So, with a water flow rate of $Q_{\text{max}} = 70 \text{ m}^3/\text{s}$ and a downstream water level (DWL) is 608.5m, the maximum depth of the erosion pit was $h_p = 2.32 \text{ m}$. With a water pass of $Q = 30 \text{ m}^3/\text{s}$ and a DWL is 608.5m, the depth of the erosion pit was $h_1 = 1.2 \text{ m}$. but at the same time, the erosion pit funnel spread to part of the channel slope.

To prevent erosion of the bottom and slope of the outlet channel at the interface between it and the cantilever spillway, two options for its protection were proposed:

a) Fix the bottom and the slope of the discharge channel in the area of its interface with the spillway of concrete (recommended option);

b) Reconstruct the outlet of the cantilever spillway.

These two options were investigated in detail on the model.
A variant with fixing the bottom and the slope of the outlet channel in the area of its conjugation with the spillway of concrete (Figure 3). Studies of this option were carried out on a spillway model using concrete with various side sizes 0.5x0.5x0.5 m as a fastener; 0.8x0.8x0.8 m; 1.2x1.2x1.2 m (in terms of nature). Further, the experiments were carried out with finally selected concrete dimensions (side dimensions 0.8x0.8x0.8m).

Studies have shown that when passing water through a cantilever spillway $Q = 70,50,30 \text{ m}^3/\text{s}$ of a water level mark in the downstream 608.5 m, the destruction of slopes and the bottom of the channel was not observed. Concrete laid to the bottom and slopes were not shifted by the flow of a freely falling stream. Similar experiments were carried out at lower water levels in the downstream: DWL - 608.0 m; 607.0 m; 606.5 m.

As the results of the series of these experiments showed, when passing the maximum water flow through the cantilever spillway $Q_{\text{max}} = 70 \text{ m}^3/\text{s}$ and at the DWL – 607.0 m mark, the concrete was scattered by a stream of water freely falling from the cantilever spillway (Figure 3).

Considering that in nature, the levels of the downstream level cannot be lower than 608.5 m, then the sizes of the adopted concrete (0.8x0.8x0.8m) are, in our opinion, quite acceptable.
Figure 3. The bottom and slopes of the canal are fastened with concrete with side dimensions 0.8x0.8x0.8m at the interface between the spillway and the discharge channel.

Option with the reconstruction of the outlet part of the cantilever spillway. This option was proposed, based on the principle of creating a surface flow pairing mode in the downstream. For this purpose, the console is removed in the tray part of the spillway, starting at 611.35 m. Further, the tray continues (is being completed) downstream with the same slope \( i = 0.26 \) and the same rectangular cross-section to the level of 608.5. The results of studies on the eroded model showed that for all possible water flows flowing through the spillway \( Q = 70, 50, 30 \, m^3/s \) and water level marks in the downstream \( \text{DWL} = 608.5 \, m \), there was always a free flooded hydraulic jump with a surface drum. Moreover, erosion of the bottom and slopes throughout the channel section did not occur. However, this option was not accepted, since in this case additional costs will be required for the reconstruction of the console dump, etc.

4. Conclusion

Thus, the performed experimental hydraulic studies of the cantilever spillway allow us to draw the following conclusions:

1. The dimensions of the cantilever spillway are currently sufficient to pass the maximum flow rate \( Q_{\text{max}} = 70 \, m^3/s \). However, its normal operation is impossible without additional measures to protect the bottom and slopes of the outlet channel from destruction.

2. Of the two options investigated on the model, the most acceptable was the option with fastening the bottom and slopes of the channel with concrete (Figure. 3).

3. Studies have shown that for all possible water flows flowing through the cantilever spillway \( Q = 70, 50, 30 \, m^3/s \) and lower water level marks in the downstream of the \( \text{DWL} = 608.5 \, m \), slope destruction and the bottom of the mount were not observed.

4. The research results were used in the reconstruction of the existing structure, in the section of the outlet channel of the hydroelectric power station # 2 of the Chirchik-Bossuv waterway at the place of its interfacing with the cantilevered spillway.

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