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Hydrodynamic characteristics of water flow in area of lower pool junction of spillway structures

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Abstract. One of the important issues is the assessment of the strength of the elements of hydraulic structures, spillway structures, reservoirs, and hydraulic complexes, the determination of the connection mode of the basins, and the reduction of kinetic energy in the reinforced fields of the downstream pool. In this regard, it is especially important to determine the hydrodynamic characteristics of the flow of water moving in the apron and risberme area, which provides the stability of the downstream pool - the areas that indicate the distribution and direction of velocity and pressure.

1 Introduction

To begin with, as far as we know, the lower pools of the spillway structures will be divided into two parts:

1. An apron is a structure that protects against washing and ensures the quenching of the kinetic energy of the water flow.
2. The reinforced area that protects the structure from washing from the bottom is the risberme.

Energy extinguishers will be designed and built in the apron. Of course, the construction of power extinguishers also has some disadvantages:

- increase in absorption voltages due to the reaction of energy extinguishers;
- damage to the fish as a result of the high-speed impact of the water stream on the extinguisher;
- reduction of surface difference due to additional stagnation.

The shape of power extinguishers is selected depending on the facility's intended use. Many energy extinguishers are used for several purposes.

I.A. Sherenkov [1] theoretically substantiated the need to construct energy extinguishers in the lower reaches of the hydraulic complex to increase flow stability.

In general, in hydraulic complex spillway structure calculation of the impact plates' length and thickness, the energy extinguishers' location and the hydrodynamic stresses on them, the mode of flow movement in the apron and risberme, and the magnitude of the local flushing behind the structure.

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N.P.Rozanov [2,3], a scientist who conducted experimental studies to determine the hydrodynamic characteristics of the lower pool of hydraulic structures, argued that it is advisable to build devices such as water tanks, wall rows, and platforms in the area of the first hydraulic jump behind the compressed section after the power switches.

NN Pashkov proposed the construction of a triangular checkerboard extinguisher for the distribution of water flow energy for the construction of pipeline spillways in the lower pools of medium and low-pressure hydraulic complexes [4].

Spherical power extinguishers were recommended by N.N.Belyashevsky, N.G.Pivovar, N.I.Kalantyrenko [5]. Depending on the requirements, in the experimental studies, the two-row checker power switch view and the lower pool connection option were selected for the flat issue, and convenient forms of power breakers were recommended.

T. Rebok proposed the development of carved platform structures called Rebok, which justified itself, serving to extinguish the energy in the lower part of the hydraulic complexes. At present, some structures are built on his recommendation and work effectively [6].

In hydraulic engineering, medium and low-pressure hydraulic complexes are widely used in water reservoirs located in the lower pools of the spillway structures due to the high efficiency of the above energy extinguishers, which expand mainly from the head (expansion angle 60^0) [7] and triangular expansion (acute angle 70^0). In three-pipe constructions, a convenient view of the speed distribution can be achieved only in certain moving water flow barriers cases. However, it should be noted that due to its geographical location, the practice of using hydropower plants and reservoirs, which mainly serve irrigation purposes, has shown that energy extinguishers selected experimentally do not always give the expected results in practice.

Additional hydraulic extinguishers must be used in outages at the lower pools of all designed or constructed spillway facilities or to adapt them to a specific facility. Therefore, spillway facilities continue to use aprons as the main form of energy extinguisher in the lower reaches.

2 Methods

In the physical modeling of hydraulic phenomena, ensuring the similarity of the initial and boundary conditions for the model and the similarity of the dynamic and kinematic laws corresponding to the forces involved in forming the flow is necessary.

In experimental studies, the implementation of modeling of connection pools in the lower pools of spillway structures in low- and medium-pressure water pools is mainly represented by the Freud and Reynolds criteria. The conditions are met that the values of these criteria in nature and in the model do not change.

By making the experimental studies, 2 schemes, two rows in Scheme 1 - straight rectangular checker-type power reducing, in Scheme 2 three rows - 2 rows of rhombus-shaped current-distributing checkers and energy-extinguishing wall-type power reducing were selected.

Graphs were obtained that allowed determining the hydrodynamic characteristics of the water flow, i.e., the areas showing the distribution and direction of velocity and pressure.

3 Results and Discussion

The implementation of physical modeling of lower pool connections in the lower basins of low and medium-pressure reservoirs is mainly characterized by the Froude number. Achieving Froude numerical similarity has been recognized as a key factor in many scientific studies [7]:

$$Fr_n = Fr_m = idem; \qquad Fr = \frac{v^2}{gh_{ўр}}$$

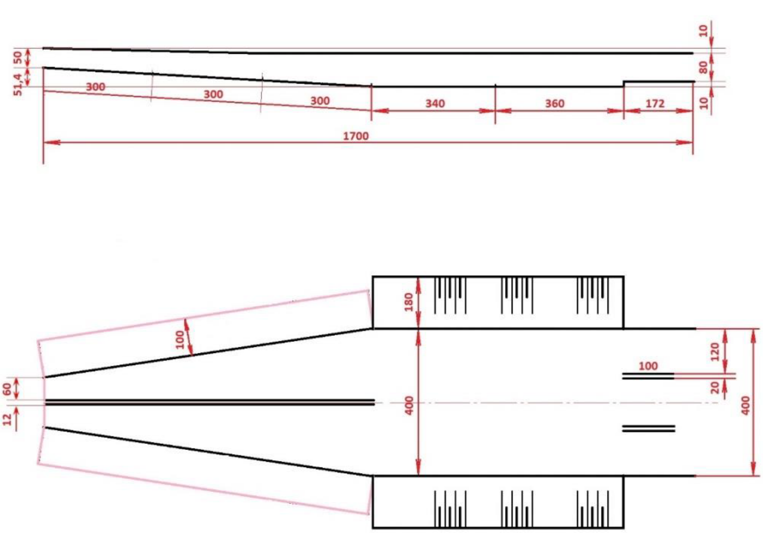
Fr_n and Fr_m are Froude number for the moving current in nature and model, respectively; y is the average velocity of the flow, g = 9.81 m/s^2 is the acceleration of free fall; h_{av} is the average depth of water flow in the area under consideration.

In addition, the following conditions are sufficient for the Reynolds number in experimental studies aimed at studying the flow dynamics in the field of lower pools of spillway structures [7, 73, 81, 115]:

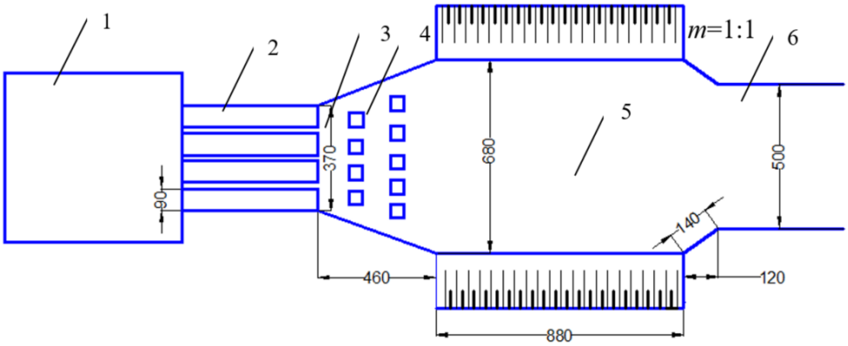
$$Re_n = Re_m = idem; \qquad Re_n > Re_m; \qquad Re = \frac{vl}{\nu}; Re_{чег} = \frac{14R}{\sqrt{\lambda}\Delta},$$

where, Re_n and Re_m are the Reynolds number for the moving current in nature and model, respectively [8-10]. l is the characteristic linear dimension of the flow in the open well, $l = 4R = 4\omega/\chi$ determined by the formula; R is the hydraulic radius for the flow section in motion, $l = h_{cs}$ equal to the flow depth at the bottom of the structure; ω is the cutting surface for moving flow; χ is the wetted perimeter; υ is the average flow rate at the point where the Froude number value is determined; ν is the kinematic viscosity coefficient, m^2/s; Re_b is the limit value of the Reynolds number corresponding to the lowest boundary field of the square resistance area, Δ is the value of the absolute roughness determined by the hydraulic radius measurement, λ is the hydraulic friction or course coefficient.

To increase the energy efficiency of the lower basins of the low and medium-pressure reservoirs, a 1:50 scale experimental model of the Akdarya reservoir pumping station was built (figure 1).



a) Longitudinal and plan view of a 2-pipe spillway structure, dimensions are given in mm



b) Plan view of a 2-pipe spillway structure, dimensions given in mm

Fig.1. An experimental device built to study the processes in the lower pools of spillway structures of low- and medium-pressure reservoirs.

In the study's second phase, 2 and 4 pipe structures were selected to monitor the hydrodynamic stress of the lower basin elements of the low and medium-pressure reservoirs.

Parameters of the device for experimental studies: pipe diameter d=0,09 m, pressure H=(1÷1.5)d, depth at the outlet h_2=(0.5÷2,3)d is the total specific energy of the water flow at the outlet of the pipe $E_1 = h_1 + v_1^2/2g$, where h_1 and v_1 are the depth and velocity at the outlet of the outlet pipe, (1,5÷4,5)h_1 tube difference p=(0÷1,4)d. The propagation angle at the exit portal is $24^0 \dots 46^0$.

The Reynolds number in the automodel model area (l=10h_1; Re=20 000÷75 000) while maintaining the gravitational similarity criterion in the modeling processes of all different target studies.

Determination of the voltage in the water and risberme elements was carried out for a specific energy parameter - constant consumption, which corresponds to the following three corresponding modes of connection in the lower pool: (tubular, external, and mixed modes). In this case, the burial coefficient was determined by the formula and varied in the range of $n = (h_2 - p)/h_1$. The water capacity of the spillway structure was changed in the range of 10÷30 l/sec.

Two schemes were used to conduct the experimental studies [11]: in Scheme 1, two rows of rectangular-shaped checkers were selected; in Scheme 2, three rows of rhombus-type current-dissipating checkers and in Scheme 2, two types of power switches were selected (Figure 3).

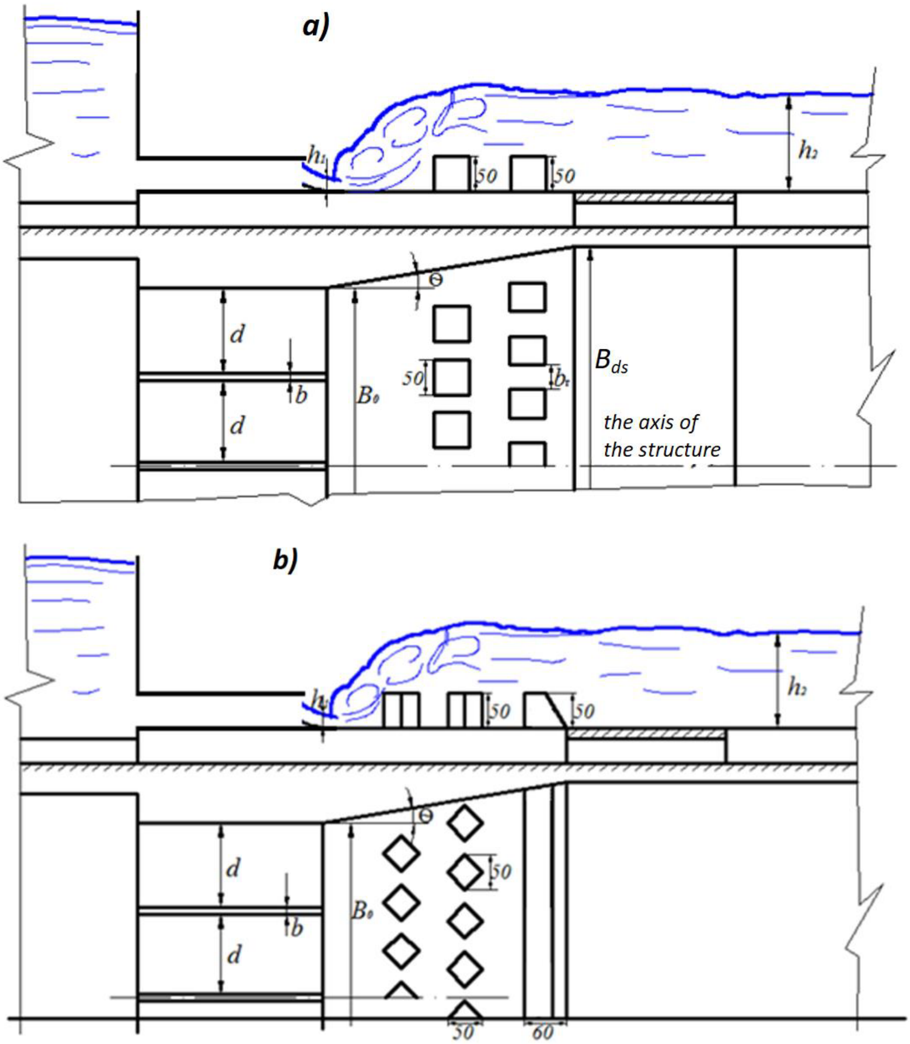


Fig. 2. Location of power extinguishers according to 2 schemes selected in the reservoir at the bottom of low and medium pressure reservoirs: a) Scheme 1, b) Scheme 2

The values of the ranges performed in the experiments are as follows:

$$\frac{E_1 + p}{h_1} = 1.5 \div 4.5; n = 0.5 \div 2.5;\ \theta = 24^0 \div 46^0$$

where, $E_1 = h_1 + v_1^2/2g$ is the total specific energy of the water flow at the outlet of the pipe; v_1 is average velocity of water flow at the outlet of the pipe; $n = (h_2 - p)/h_1$ is buried coefficient of the pipe at the outlet; h_1, h_2 are flow depth at the outlet of the structure and in the outlet channel; p is the difference between the outlet of the structure and the bottoms of the outlet channel; θ is the angle of expansion of the water tank.

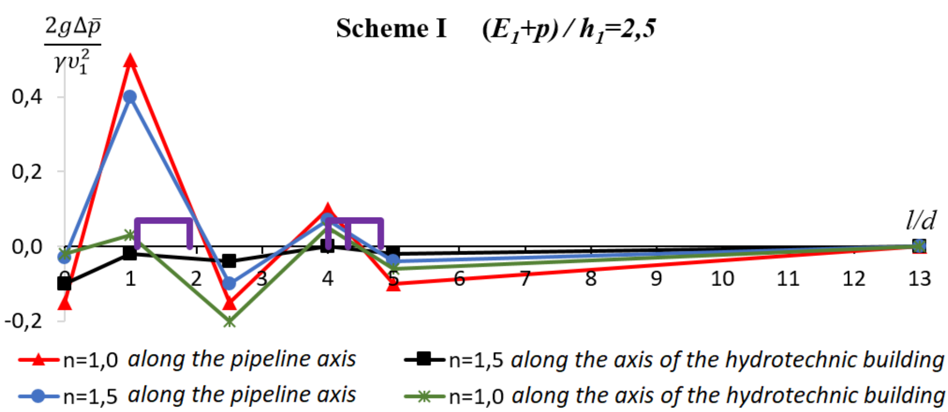
For them, it was observed that the change in the value of the energy parameter $(E_1 + p)/h_1$ has very little effect on the change in the shape of the befs connection. Based on the location boundary condition of the hydraulic jump, it was observed that the extinguishers' design features, placement, and location are affected by the degree of burial from the lower pool side.

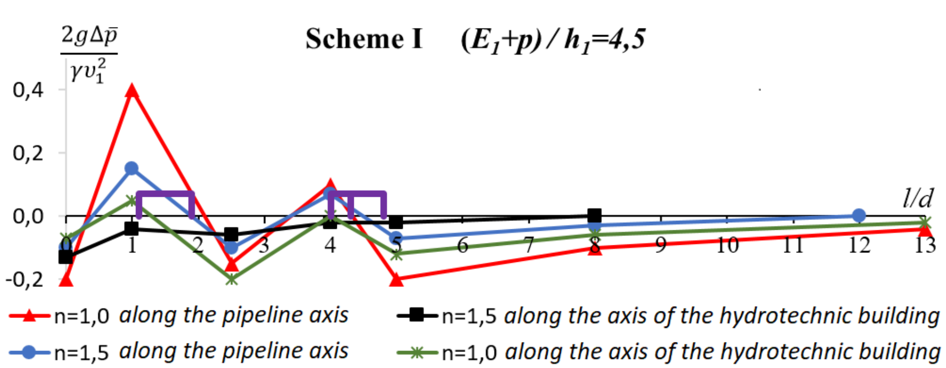
For all the studied variants, a reduction in the area of the bottom hydraulic jump connection was observed when the positions of the valves were changed. An increase in the burial height was observed when a pipe was operated $(E_1 + p)/h_1 \geq 3{,}5$ unstable currents were observed when the condition was met. In this case, the dynamic axis of the flow is tilted towards the open pipe. As a result, the energy quenching efficiency is significantly reduced, and the extinction of the average flow velocities is slowed down. Several studies have also observed this result [140, 142, 143]. It is also necessary to ensure that the switches are installed strictly symmetrically for the circuits studied. Otherwise, in the case of $E_1/h_1 > 1{,}5$, it was observed that a slip current occurs throughout the entire structure.

For both schemes in a four-pipe spillway structure, the water flow velocities $\bar{\upsilon} = (0{,}7 \div 0{,}9)\upsilon_2$ in the area close to the bottom are l=(11÷16)d is formed for length

As the water flow over the energy extinguishers increases, the pressure at the front of each energy extinguisher increases, leading to a significant increase in the average compressive strength at the bottom.

In the front part of the extinguishers of the first row, depending on the relationship $(E_1 + p)/h_1$ and n, if the average pressure in the water tank changes to $\bar{p}_i = (1{,}0 \div 1{,}2)\gamma h_1$, this amount is equal to $\bar{p}_i = (0{,}5 \div 1{,}0)\gamma h_1$was observed to change. By aligning the water in the water tank with the percussion walls, the installation of the percussion cups increased the mean pressure by 25÷35% (Fig. 3). In smooth watercress, the stability of the entire fortified area is reduced to 40÷50%.





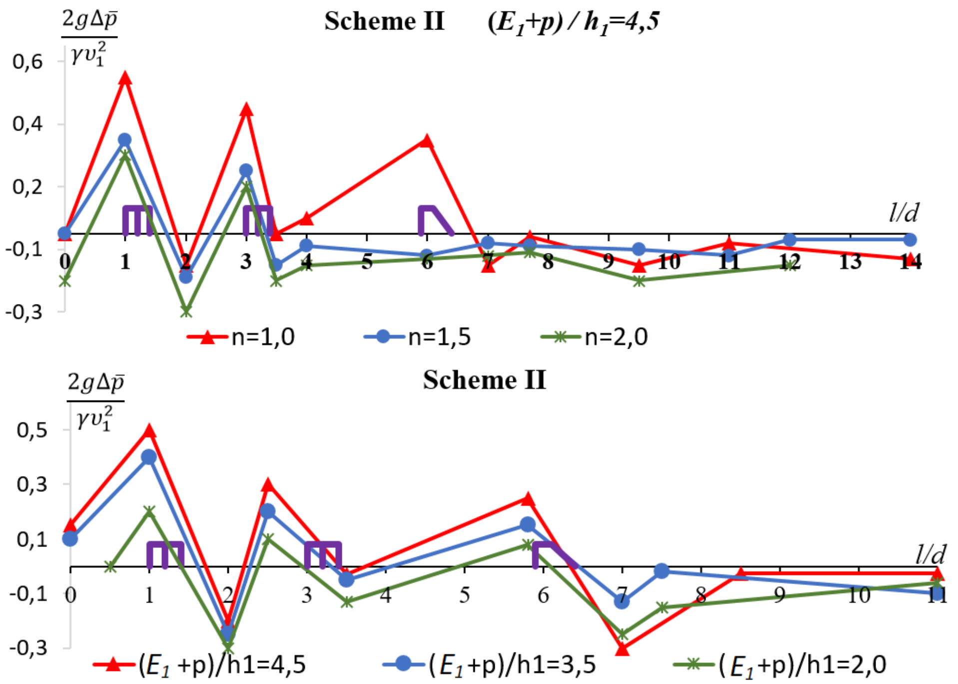


Fig. 3. According to Schemes I and II, pressure changes in the aquifer and risberme at the bottom of the spillway structure

For the observed schemes, starting from the end section of the expanding water tank, the pressure acting on the bottom gradually increases with the recovery of the potential energy pressure. At the end of the risberme is equal to the lower pool pressure. $l = (11 \div 13)d$ when the pressure difference tends to zero $\Delta\bar{p}_i = \bar{p}_i/\gamma - h_2$ (Figure 3).

4 Conclusions

Studies to determine the hydrodynamic pressure characteristics in the direction of the pools junction were analyzed.

By observing the hydraulic modes of low-and medium-pressure pools in the discharge structures, hydrodynamic pressure distribution in the expanding apron and their parameters in the fortified fields were determined.

The location of the extinguishing structures in the reservoirs, which are built to extinguish the full energy of the flow in the lower reaches of the discharge structures of low and medium-pressure reservoirs, evenly distributes the impact force of the flow. To the lack of pressure in aprons without energy extinguishers, the strength stability of the apron is reduced to 30-50%. An increase in the expansion angle does not affect the average pressure distribution in the expanding apron and subsequent areas at the outlet of the structure.

Connection graphs were obtained to determine the calculated plot and velocity of the average pressure voltage in the front area for the studied schemes of the flow extinguishers moving in the lower part of the spillway structure.

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