E3S Web of Conferences **365**, 03044 (2023) https://doi.org/10.1051/e3sconf/202336503044
CONMECHYDRO - 2022

Increasing efficiency of flow energy damping with lateral water intake

Bekhzod Norkulov[1*], *Adkham* Mamataliev[1], *Umida* Kurbanova[3], *Shokhida* Nazarova[1], *Bobur* Shodiev[2], and *Iqboloy* Raimova[1,4]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, 100000, Uzbekistan
[2]Karshi Engineering Economics Institute, Karshi, Uzbekistan
[3]Samarkand State Architectural and Civil Engineering University, Samarkand, Uzbekistan
[4]Research Institute of Irrigation and Water Problems, Tashkent, 100187, Uzbekistan

Abstract. The paper presents the results of full-scale and experimental studies for applying a new design for damping the energy of the flow with a lateral water intake. In the article, the method for increasing the efficiency of flow energy damping with lateral water intake and a new calculation method have been improved. The proposed version of the calculation according to the method, compiled with several assumptions, demonstrated the possibility of using such a well and damper design with high operational reliability and the results aimed at damping the energy of the water flow of the lateral water intake structures. Recommendations were developed on calculating a water well with a lateral flow outlet.

1 Introduction

During the construction of River waterworks in mountainous and foothill sections of Rivers, the design and construction of water intake facilities are often complicated by the cramped conditions of the alignment, which significantly complicate the placement of their energy-extinguishing devices [1-4]. The construction of an average low-pressure hydroelectric complex is complicated by the difficulties in placing energy-extinguishing devices due to the complexity of the mountainous terrain. Extinguishing the energy of the water flow in the case of lateral water intake and preventing the phenomenon of the channel process per hectare of hydraulic structures requires the introduction of effective energy absorbers in practice [5-6]. In this regard, using effective means and devices that reduce the excess kinetic energy of the water flow in medium and low-pressure waterworks is particularly important. In the world, research work is being carried out aimed at developing scientifically based methods for damping the energy of the water flow in lateral water intake structures, choosing designs that dampen the energy of the flow, and eliminating the deformation of the conjugation of the pools at medium and low-pressure hydroelectric facilities. In this regard, special attention is paid to the determination of the relative values of the critical parameters of the location of energy absorbers, the choice of structural solutions for structures to dampen the kinetic energy of the water flow at the side water

*Corresponding author: behzod1983@mail.ru

intake structures, the determination of the hydrodynamic stresses of the water flow in the downstream of the structure, and the conduct of new experimental studies on the conjugation of the pools of spillways and their scientific justification. Currently, the problems of using various combined options for damping the energy of a water flow in side water intake structures, solving the issues of developing an experimental model, and applying them in practice to select the most advanced design have not been sufficiently studied. In this regard, there is a need to study and develop hydraulic processes in engineering practice using constructive solutions of various types of energy absorbers in the structure itself, taking into account the fact that in spillway structures, the energy of the water flow is extinguished at short distances, preventing the phenomenon of overturning the water flow [6-9].

Due to the difference in the level of the free surface of the water in the upstream and downstream of the hydrotechnical and hydropower structures, the flow at the outlet of the culvert acquires a high speed, the potential energy of the position is converted into kinetic energy of movement, which is dangerous for its destructive effect. The transition of a flow from a turbulent state to a calm one through a hydraulic jump is accompanied by an abrupt increase in its depth and a partial recovery of potential energy. Part of the kinetic energy the flow acquires when passing through the structure is spent on this.

The application for damping the energy of the flow with the help of water wells requires sufficient space to create a discharge channel that ensures the transition of the flow from a regime with increased pulsation characteristics to a domestic regime in the Riverbed. However, under certain conditions, this space is either insufficient to accommodate the outlet channel or completely absent. Therefore a large amount of excavation has to be performed [10-14].

2 Methods

In the research process, experimental and scientific research methods of field observations were used. The development of physical models based on the laws accepted in hydraulics and hydromechanics, as well as to improve of the design of the well and damper with a high degree of operational reliability, is the research method of this work.

3 Results and Discussion

A field study of the design with a lateral flow outlet conducted in the Akdarya reservoir is located in the Ishtykhansky district of the Samarkand region of the Republic of Uzbekistan. The Akdarya reservoir is located 50 km below the Karadarya hydroelectric complex, where the Zerafshan River divides into two permanent channels, the northern one (the Akdarya River) and the southern one (the Karadarya River). The channels form a winding island 100 km long and 15 km wide called Miankal. The reservoir was built on the Akdarya River. The Akdarya reservoir was built to use additional water resources - waste and runoff waters and is designed to irrigate 5.5 thousand hectares of new lands and increase water supply to 12.0 thousand hectares of old irrigated lands. The target of the dam was chosen in the narrowest part of the floodplain of the Akdarya River. The width of the section at the level of the dam's crest is 930 m. The relief of the flooded area is relatively calm, and the right bank of the Akdarya River is heavily indented by sais and ravines. The reservoir is filled with water from the Zerafshan River along the Akdarya due to spring nutrition and waste water when irrigated lands are irrigated [3, 4].

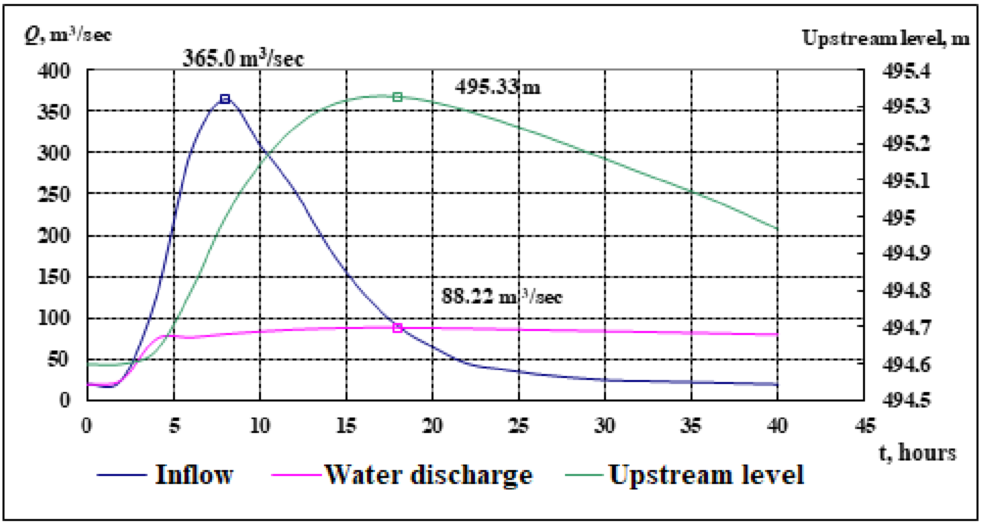

Fig 1. Flood transformation 0.5% probability with joint water flow through the outlet and surface spillway.

A tower-type water outlet with a capacity of 75 m^3/s is combined with a catastrophic discharge shaft arranged on the back side of the water outlet tower, with a cross-section of 3.15 x 8.0 m. According to the project, the spillway threshold level is 493.55 m, and the throughput is up to 173 m^3/s. The operational water outlet is mated with a high-speed water divider unit with increased roughness, expanding in plan with a dividing wall 1 m high and trapezoidal water well. The water divider node consists of 3 structures: a partitioning structure and two outlets (fig. 2).

Fig. 2. Water divider unit with side water outlet.

The process of water movement through spillway structures is carried out under gravity forces, which do not depend on the shape of the structures and their individual elements. To prevent the phenomenon of the channel process at hydraulic structures, effective energy absorbers must be put into practice. In this regard, we conducted an experimental study on the choice of structures that dampen the energy of the flow and eliminate the deformation of the conjugation of the pools [3].

https://doi.org/10.1051/e3sconf/202336503044

Experimental studies of hydraulic structures on models make it possible to predict the behavior of a future structure in nature and, when designing it, to find optimal solutions that meet reliability and efficiency. When conducting experimental studies, an experimental device was built, consisting of a metal tray with a slope of 0.00001, a width of 120 cm, a length of 1200 cm, overall dimensions of 1.35x0.3 and is connected to a neighboring structure of 6 m.

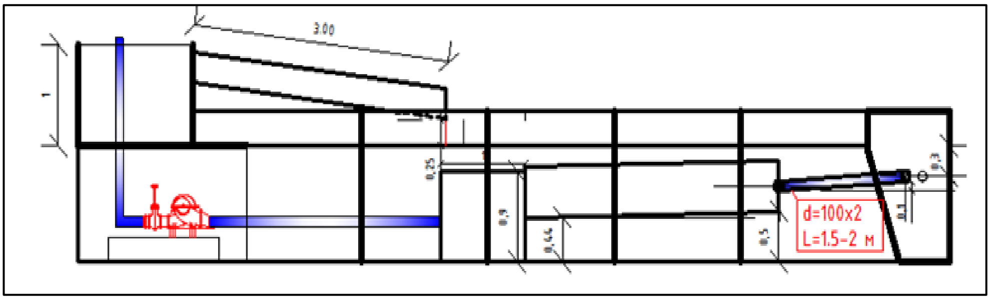

Fig. 3. Scheme of the installation design on which experimental studies are carried out.

In the first version, the Froude number and the kinetic parameters of the occurrence of hydraulic shocks were determined in the absence of energy absorbers in the spillway structure, depending on the flow velocity along the channel bottom.

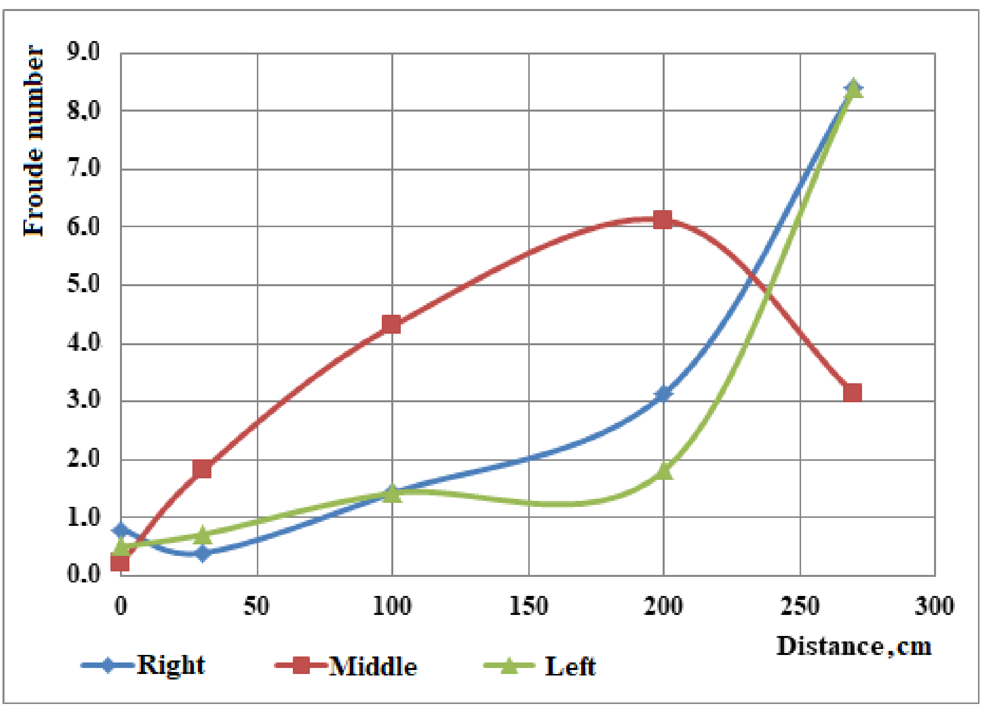

Fig. 4. Graph of the Froude number along the channel length in the absence of an energy absorber in the drainage structure. Water consumption $Q = 18.6\ l/s$.

According to the results of our experimental studies, it was found that when flowing out of the spillway at high speed, the flow in the spillway mainly connects with the flow in the lower part in the mode of movement at the bottom of the channel. It has been observed that the Froude number increases with increasing water consumption. We have conducted research with various energy fire extinguishers, rectangular, triangular, round, and crescent-shaped energy extinguishers have been installed, and the results have been compared.

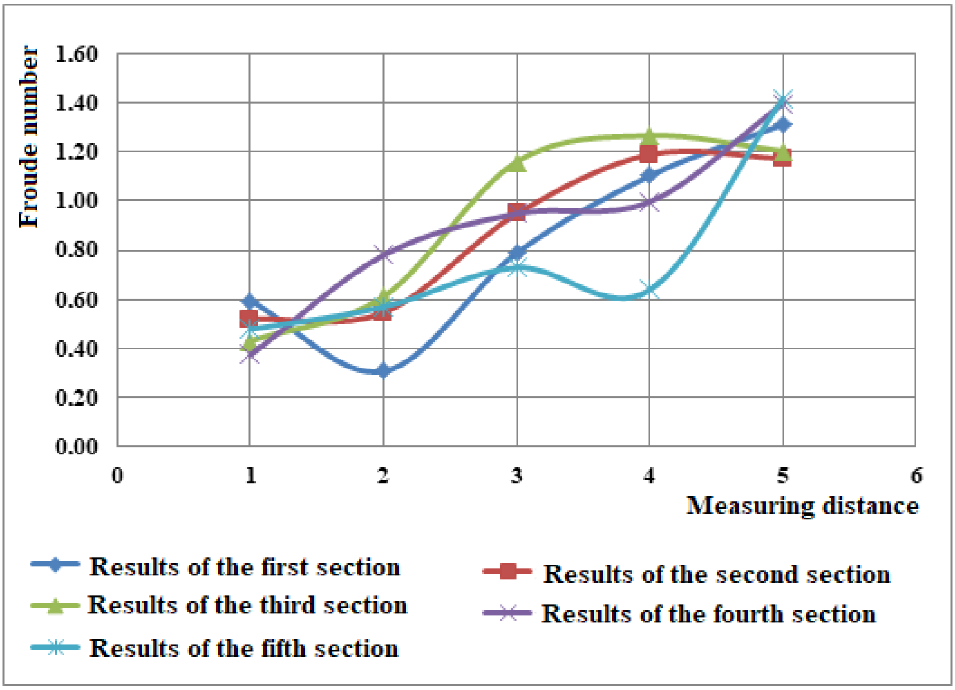

Fig. 5. Changes in the Froude number along the length of the channel after the installation of absorbers.

In the second variant, we experimented to extinguish energy in a water well. The water well is made of 0.55 mm thick galvanized iron with a 100 µm zinc coating layer applied by dipping it in a bath. With this coating method, the minimum coating thickness is 0.5 nominal, corresponding to the height of the roughness protrusions of 0.02 mm, which for nature is 1.2 mm. Since the roughness of the walls has no practical influence on the processes occurring in the water well, the material chosen for the water well model corresponds to concrete in natural conditions.

Thus, the adopted modeling scale of 1:60 natural size and the materials used provide hydraulically similar regimes over the entire range of the main spillway flow rates.

When installing the model, the height position of the main components and elements was controlled by a level using a steel ruler with a millimeter scale, according to which readings were also taken with an accuracy of 0.1 mm.

When installing the model, the width of the tunnel tray was maintained using templates installed in pairs along its entire length [15-22].

The parameters of the hydraulic modes of operation of the water well, measured on the model, are multi-parameter values, depending on the accuracy of direct measurement of the fixed values and the accuracy of the equipment used.

Fig. 6. Side outlet water well model.

The measurement of the water depth in the water well was carried out using a Spitzenscale. In the zone of strong wave motion and in the area where the hydraulic jump roller is located, the free surface mark was determined using the following method:

First, the minimum mark was taken, while the lower end of the Spitzenscale needle constantly touched the free surface, then the maximum mark, at which one contact of the Spitzenscale needle with the free surface, was observed. The experiment was repeated at several points along the alignment line. This made it possible to plot the line of the free surface of the hydraulic jump and the line of the water surface at the outlet of the water well using average values.

In the water well under study, the flow coming from the tunnel into the water well in the form of a submerged bottom jet, due to faster deceleration on the sides and in the upper part, was split into a system of independent jets. The experiments were carried out at flow rates Q=3.9 ... 18.6 l/s. Our study on the flow movement through the side cut was carried out with a horizontal bottom of the water well. The study of the nature of the flow in the water well was carried out by measuring the depths of water in the longitudinal and transverse sections of the water well (at the right and left sides of the well along the flow and along the axis of the well).

We used the ANSYS program to see the picture of the flow in the water well. With the help of these programs, it was possible to describe the movement of the flow not only in the water well but along the entire length of the experimental channel.

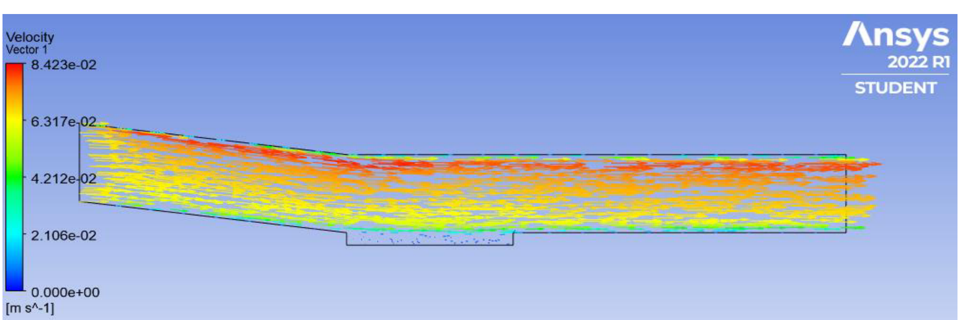

Fig.7. Dynamics of water consumption at depth $h = 5.5\ cm$.

Figure 7 shows the maximum water flow velocity $v = 0.084\ m/s$ at water consumption $Q = 3.9\ l/s$, channel slope $i = 0.06$.

We considered different designs of water well in different slopes to dampen the energy of the flow. Our study shows that low water consumption does not give optimal results. When the water level drops, the speed of the water flow increases. At a flow rate of 3.9 l / s, the water consumption decreases only at the bottom of the water well and increases in other areas.

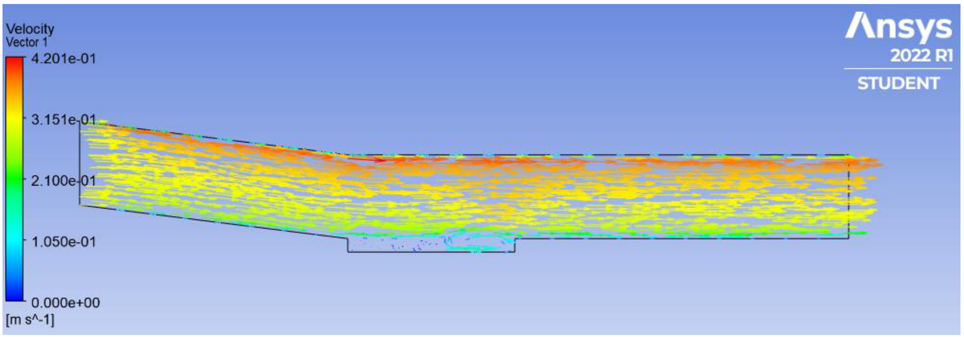

Fig. 8. Dynamics of water consumption at depth $h = 7.2\ cm$.Water consumption $Q = 18.6\ l/s$.

Within the cutout in the cross-section of the well, it was found that the depth of the curve at the starboard side is minimal, and the curve at the port side has maximum values. At the end wall of the well, there is a breaker with a horizontal axis, which caused a sharp rise in the water level. The maximum difference in water levels for the considered model of flow movement is 2.5 cm for a particular case of operation of a water well in kind.

As a result of studying the movement of the flow in the water well with lateral water intake, it can be said that partial energy losses occur due to the rotation of part of the flow to the lateral flow. The influence of the action of the lateral water intake does not extend to the entire width of the flow in the water well.

4 Conclusions

As a result of the experimental studies of a water well with a lateral outlet of water, the following conclusions can be drawn:

1. When calculating the conjugation of flows downstream when a catastrophic flood is skipped, the peak design discharge is taken into account, considering the reservoir's transformation of the flood.
2. Our studies have established that in a water well with a lateral outlet of water, the length of the hydraulic jump roll practically coincides with the length of the jump in straight-axis water well.
3. An analysis of the experimental results allows us to conclude that when designing energy-extinguishing devices for spillways in the downstream hydroelectric facilities, it is permissible to use non-prismatic water well at central wall expansion angles of $\beta = 14°\ ...\ 26°$ with a lateral water outlet.
4. It has been established that energy losses in a water well with a lateral outlet of water are less than in a water well with a direct outlet.

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