Justification for the culverts' design with joint operation of a water cylinder with a side weir

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Abstract. The article is devoted to the actual topic of the substantiation of the culverts' design with the joint operation of a water cylinder with a lateral flow outlet. In the article, the advantages and disadvantages of gravity and pressure flow are considered. Under catastrophic conditions, structures with a non-pressurized regime are safer since they have a high reserve of carrying capacity, and structures with a pressurized regime have a large carrying capacity. Today, there is a tendency to use energy dissipation methods using a water cylinder with a side outlet of the water flow in the bottom reach. It is necessary to use water flows when increasing the construction territory of hydraulic structures in mountainous and foothill sections of rivers. A design diagram of a water cylinder with a lateral water outlet when using water cylinder is proposed; the work shows a cylinder with a zero-bottom slope of a rectangular section. A roller with a rotation axis is considered in the article; the flow follows to the wall of the water cylinder along the length of the side walls, a water flow approaches with the expansion in the vertical plane of the side cutout; a flow is formed in the cylinder in the area of the tunnel joining to the cylinder, the outlet channel design and energy dissipation are also considered.

1. Introduction

The culverts are one of the main elements of the hydroelectric complex, and the creation of a water cylinder is definitely an effective energy dissipation in the volume of costs passed by culverts.

On average, about 52% of the object's cost falls on a part, since culverts have the most important value of engineering structures. Large financial values of culverts are determined by the traditional approach to the technical and design justification.

For many years, it has been important to resolve the issue of energy dissipation of spillway structures. Each of the flow modes of open and closed culverts has both positive and negative sides. As practice shows, the pressure regime has a good flow capacity with the same geometric dimensions of the structure. Structures operating in a free-flow mode guarantee the reliability of the structure. At the same time, they provide a reserve of carrying capacity.

2. Materials and methods

In an open culvert there is a higher concreteness of the flow regime than in a closed one. The gravity mode will operate at off-design flow rates with the maximum flow rate. The formation of transients can be avoided. The load on structures is increasing and there is a possibility of a risk of cavitation phenomena. In order to prevent flooding of the structure in the bottom reach, it is necessary to provide
for the height of the energy dissipation devices, which in turn affects the volume, cost and production of work [1].

A variety of driving modes sometimes help to find the correct flow design through culverts for low pressure culverts. Long-term construction skills provide established methods for calculating and constructive justification of culverts. Does not suggest the methods' use for low-pressure structures on low-water streams in cases of effective solutions [2].

With the help of a water cylinder with a side cut, we are currently using new methods of energy dissipation in the bottom reach low- and medium-pressure structures. This scheme is used in mountainous and foothill sections of rivers with an increase in the geographic zone during the construction of hydraulic structures in cramped terrain. The construction of medium and low-pressure hydrounits becomes more complicated in the constrained conditions of the mountainous and foothill terrain, with the placement of hydraulic structures for the energy-dissipating water flow.

For the construction of a discharge channel, a place is needed when using water cylinders. A flow transition from a mode with increased characteristics to a domestic mode is formed.

The use of a water cylinder requires a discharge channel, which in turn increases the volume of excavation. This, in turn, increases the cost of production work and subsequently affects the cost of the object as a whole.

Since there is not enough area to accommodate the outlet channel, the mountainous and foothill terrain needs a large amount of excavation volume. As a result, it becomes necessary to use the design of energy-dissipating devices with a lateral flow outlet [3].

We will consider a retaining hydraulic jump in a water cylinder with a lateral water outlet. The design is shown in Figure 1.

![Figure 1. Structural layout of a water cylinder with a side weir.](image)

1 - discharge tunnel; 2 - ramp; 3 - water cylinder; 4 - end wall of the cylinder; 5 - side walls of the cylinder; 6 - cutout in the side wall; 7 - weir crest; 8 - outlet channel.

The flow is formed with the rotation axis of the roller in the area of the discharge tunnel connection to the cylinder, which enters the well energy is dissipated.
The flow moves along the length of the side walls to the wall of the water cylinder, then reaches the side cutout and follows into the discharge channel [4].

A weir that is made in the side wall of the well is called a side weir. The weir is located parallel to the bottom of the water cylinder. The water follows longitudinal flow along the axis, in the cylinder parallel to the crest of the weir. Due to the action of the structure, the specific flow rate at the weir crest changes, and the water level and pressure in the water cylinder can also change. Overflowing water through a weir, which is parallel to the ridge, has a directed velocity. The structural layout is considered in Figure 2.

![Figure 2. Structural layout.](image)

From the normal weir to the lateral weir, there are transitions in the structures of the lateral weir.

The current velocity vector represents the characteristic direction relative to the crest of the cylinder's weir. In a classic water cylinder, the flow velocities are perpendicular to the weir ridge. At an approach angle of the flow other than 90°, it is called an oblique weir. An angle of up to 15° created by the ridge with the flow is called a lateral weir [5].

3. Results and Discussion
Let us consider a rectangular cross-section water cylinder of a non-prismatic type with a zero slope for a steady motion. The weir ridge is parallel to the bottom of the cylinder. The flow velocities are constant in direction and magnitude. At a constant flow rate, the energy line is parallel to the bottom of the structure at flow depths close to domestic ones.

Despite the change in flow rate, the energy line remains unchanged parallel to the bottom and at the weir of the water cylinder. A gradual change at the weir should not affect additional energy losses, except for the losses corresponding to the natural flow.

For further calculations, we can assume that the energy line is parallel to the bottom of the cylinder at the baffle wall ridge [6].

By indicating the depth $h$ through $v$, average velocity in the section can be found by the Bernoulli equation:
where the values are determined by the index \( I \), they refer to the section at the beginning of the draining section, \( i \) is the bottom slope, \( I \) is the average hydraulic slope between the observed sections on the section \( l \), and is also equal to the total energy of the section, the sum \( h + \frac{v^2}{2g} = H \), whence we take the stability of the total energy in the cross section with the equality \( i = I \). It has been observed that the loss at the weir crest depends on the decrease in speed. In this regard, expression (1) becomes conditional. Due to that the energy of all streams at the beginning and end of the water cylinder is the same, then in each section the energy of all points is the same. At the weir, we observe an increase in speed and a decrease in water levels caused by suction from the bottom reach. The specific energy is taken to be equal for the points that do not fall under the influence of the suction. Consequently, the unevenness of the weir speeds obtained as a result of suction is not taken into account when determining the energy.

For further conclusions, for each channel cross section, we have that \( I > i \) specific energy is not constant

\[
H = h + \frac{v^2}{2g} = \text{const}
\]  

(2)

Let's consider the speed correction \( \alpha = 1 \).

We consider the depth \( h \) in equation (2) as the average velocity to be constant and do not take into account the effect of suction when calculating the entire section. An error can become large if the height of the crest \( h_0 \) is small compared to the depth \( h \), in this case the error is insignificant.

Further, we determine the change in the water level within the weir. From equation (2) we determine:

\[
v = \sqrt{2g(H - h)} ; Q = w\sqrt{2g(H - h)}
\]  

(3)

For \( Q \), we differentiate the expression and find

\[
dQ = \frac{\sqrt{2g}}{2\sqrt{H - h}} \left[ 2(H - h) \frac{dw}{dh} - w \right] dh
\]  

(4)

For \( Q_{\text{max}} \) determine the value of \( h_k \), determined from the equation

\[
h_k + \frac{w_x}{2} = H
\]  

(5)

Through the width \( B_k \) we replace here \( \frac{dw}{dh} \), we find

\[
h_k + \frac{w_x}{2B_k} = H
\]  

(6)

Further, comparing with equation (2), we find

\[
\frac{v^2}{2g} = \frac{w_x}{2B_k}
\]  

(7)
Belongs to the critical depth of the flow at the specified value $Q_{\text{max}}$ of the specific energy. Equations (5) and (7) have the condition that if there is one solution for $h_k$, then this implies the continuity, finiteness of the values of $B$ in the region $0 < h < H$.

The speed is determined through the weir from the pool, which can be found in the ratio of the flow through the weir. In the absence of approach speed, if there is a speed in the flow that is close to the weir, it has an oblique direction of the jets overflowing through the weir. Despite the element of the weir edge, the water level must be in the pool at rest in cross-section, corresponding to the level of water flowing through the cylinder [7].

Equation (8) takes the form

$$dq = \frac{\sqrt{2g}z}{f} \cdot df$$

Through the elementary area $f$ for the flow rate, we determine

$$dQ = m_g \frac{\sqrt{2g} (h - h_0)^{\frac{3}{2}}}{l} \cdot dl$$

where $dQ$ is the flow rate in a section of length $dl$

$m_g$ - consumption coefficient,

$p$ - the height of the weir crest.

4. Conclusion

Drawing a conclusion, we see that $m_g$ does not affect the speed of water flow in the cylinder, the oblique direction of the flowing streams. The crest height should not affect the flow rate, if the compression of the jet at the bottom decreases, is small, equal to zero [8].

If there is an influence at the beginning of the lateral compression of the weir, then the lateral weir is not taken into account. We consider the introduction of the static stream $h$ into the calculation of equation (9), if the jets expressing has an oblique direction, which has a velocity in the cylinder.

It is possible to give a recommendation for the $m_g$ value of the discharge coefficient if it is close to the value and does not consider the approach speed of a conventional weir [9].

It is also possible to neglect mutual influence of the overflowing stream elements through the weir. With a short length of the weir, it gives action, a decrease in velocities in the well and high streams. We can summarize the results of the experiment in practice, and this makes it possible to understand the experimental studies [10].

It is worth highlighting that a lateral weir is a weir made in the side wall of a water cylinder. The longitudinal flow of water is directed along the axis parallel to the weir crest in the cylinder [11]. The topics of solving the problem of excess flow energy dissipation, its interface with the bottom reach, open and closed culverts, and the reduction of erosion behind the end sections, do not lose its importance. Also, culverts are one of the main elements of the hydrounit. It should be emphasized that the flow regime in an open culvert is characterized by high certainty in an open culvert, rather than in a closed one. It should be noted that existing structures with a non-pressure mode have a large reserve of throughput than of with a pressure mode.

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