Calculation of strength of stilling basins and pressure in downstream water outlet structures

Abstract. Calculations performed to determine the strength of the stilling basin and apron of the downstream zone should mainly be carried out, considering the conditions of their stability and strength. When calculating the elements of the fastening zone for strength and stability, it is advisable to consider vertical and moment hydrodynamic stresses. Conducting targeted research on developing scientific methods for calculating the interface between the spillway and downstream outlet structures, mitigating kinetic energy in the downstream toe, choosing designs for protecting downstream of the structure, and determining hydrodynamic loads is particularly important. In this regard, one of the important tasks is to conduct scientific research on improving the design of the downstream toe, working out methods for determining hydrodynamic loads while calculating the thickness of the stilling basin and apron, which ensures the strength of the downstream toe.

1 Introduction

The possibility of determining the stability of stilling basin and apron in the downstream water outlets of low–medium-head reservoirs by comparing their vibrational oscillations with the spectral characteristics of pulsating stresses is substantiated by the authors of the article considering the results of experiments carried out by other researchers [1–7]. However, unfortunately, it was impossible to measure these structures' partial vibrations in actual operating and field conditions. Therefore, in these calculations, we restrict ourselves to statically setting stresses, not considering the dynamics of their foundations.

The unstable state of the downstream part of water structures is explained by the inconstancy of the hydraulic modes of operation. Structures often operate in the absence of flooding from the downstream side, which causes undesirable hydraulic phenomena, forms of conjunction—a repulsed jump or a hydraulic wave jump with an uneven distribution of velocities and significant pressure fluctuations, especially during the start-up period; design flaws and deviations from the design during anchoring and construction, taking into account...
Based on the analysis of existing problems, when designing a stilling basin and an apron for low and medium pressure water outlet structures, scientific solutions are given to the following problems: calculation of the conjunction of pools, selection of forms and parameters of various energy absorbers, ensuring the absence of unfavorable modes of a repulsed jump, failure, etc. with various schemes of maneuvering shutters. In addition, it is required to determine the laws of distribution of flow velocities, averaged, and pulsating pressures of the water flow in the structure for various water flow regimes.

Based on these experimental data, it is possible to determine the dimensions of the length and thickness of the slabs of the stilling basin and apron. These solutions increase the level of strength and stability of the structures.

2 Methods

\[ |G_{пл}| \geq P_b \]

\[ l_{пл}^n \geq |P| \]

\[ f_{b}P_{ф} \geq \frac{\sqrt{\pi}n_{м}}{K_{и}m} \]

Here, \( f \) is the coefficient of friction; \( P_{ф} \) is the horizontal force affecting one absorber.
\[ P_u \leq \left| n_2 \right| P \leq \left| n_2 - P \right| \]

\[ P = \bar{P} + P' \]

\[ P'_{max} = \max \left( \bar{P} + P' \right) \]

\[ P''_{max} = \max \left( \bar{P} + P' \right) \]

\[ K_A = 3.0 \div 6.0 \]

3 Results and discussion

\[ \mathcal{E} + p = \frac{\alpha \nu}{\rho} + p \]
Using the data obtained, the time-averaged value of the vertical component of the hydrodynamic stress affecting the slab of the water well is determined:

For the selected absorber, the resistance coefficient is determined by the expression

\[
\frac{\tau}{\alpha v_r} = \frac{g_p \omega_1}{\mu}
\]

In the next stage, the formula determines the average horizontal stresses over time, which affects the energy absorber.

3. The pulsation components of stresses are determined:

- Taking into account the length of the slab and the total specific energy of the flow \(\frac{g_p \omega_2}{\mu}\), determined on their basis, we accept the specific standard value of the pulsation stress

\[
\frac{\tau}{\alpha v_r} = \frac{g_p \omega_1}{\mu}
\]

- The ratio of the horizontal component of the stress pulsation to the average stress \(\bar{\sigma}\) is determined. For certain values of the average horizontal stress component \(\bar{\sigma}\), the pulsation horizontal component is determined on the basis of part b of paragraph 2.

General hydrodynamic stresses are determined using the following formulas, respectively:

\[
P_{\text{max}} = \bar{P} + P'
\]

\[
P_{\text{M}} = \bar{P}_M + P'_M
\]

\[
P_{\omega_{\text{max}}} = \bar{\omega} + \omega'
\]

\[
\frac{\tau}{\alpha v_r} = \frac{g_p \omega_1}{\mu}
\]

The thickness of the slabs under vertical stress is determined based on the following condition: the total hydrodynamic load for conditions where the slab can float to the water surface about the top and bottom edges is determined in stages.

Ensuring the stability of the slab for overturning is realized when the following condition is met:

\[
\frac{b_{\text{pl}} P_g}{G} \geq \frac{b_{\text{pl}} P_{\text{M}} \gamma_0}{\gamma - \gamma}
\]
In this case, the average vertical \( \bar{\tau} \) and pulsation \( \bar{\gamma} \) loads are determined as functions of quantities without units of measurement, depending on the absorber schemes used in the downstream.

The thickness required to provide resistance against the ascent to the water surface of the slab of the stilling basin concerning the upper and lower edges is determined by the following condition:

\[
\gamma \geq \frac{5.0}{\gamma}
\]

Based on the above method, calculations of the strength of the outlet structures of the downstream of several reservoirs were performed. Calculations were made for a flat stilling basin with energy absorbers of water outlet structures and a deep stilling basin; the results were compared and analyzed.

Discharge at the water outlet structure \( Q = 50 \text{ m}^3/\text{s} \), the average flow velocity in the compressed section 3.0 m/s, average flow velocity in front of the first row of absorbers 2.5 m/s, flow velocity in front of the stilling basin wall 2.0 m/s, the first conjugate depth \( h_1 = 1.0 \text{ m} \). The design of the stilling basin shown in Fig. 3.1, which consists of two slabs 10 m long each. The difference between the bottom of the pipe and the bottom of the downstream \( p = 1.0 \text{ m} \). Downstream depth \( h_2 = 2.0 \text{ m} \).

1. Using the following formula, the total specific energy of the flow is calculated:

\[
E = \frac{1}{2} \rho v^2 + g h + \alpha \varphi
\]

2. Calculate the average stress.

3. Based on the design scheme shown in Fig. 1., in a non-drainage state, the thickness of the slab is determined by the following formula based on the condition of stability against its ascent (1) (the calculation is carried out for a slab thickness of 1 m).
Fig. 1. The downstream structure of the reservoir spillway structure selected for calculations (dimensions in m):

\[ \sum P = P_{\text{in}} - P = 1 \left( \frac{P}{B} \right) + \frac{P}{B} \]

Medium stresses exerting the walls of the stilling basin and the energy dissipator

\[ \omega = 1 \left( \frac{P}{B} \right) + \frac{P}{B} \]

Here, \( m \) is the upwind surface of one absorber located above the slab; \( C = 1.2 \) is the absorber resistance coefficient in the design mode; \( v = 2.5 \text{ m/s} \) is the speed in the front part of the 1st row of the absorber.
\[ \bar{P}_c = \gamma \omega C_e \nu_{\max} / \gamma \omega C_e \nu_{\max} = \frac{\gamma \omega C_e \nu_{\max}}{\gamma \omega C_e \nu_{\max}} = \frac{\gamma \omega C_e \nu_{\max}}{\gamma \omega C_e \nu_{\max}} \]

\[ \bar{P}_c = \gamma \omega C_e \nu_{\max} / \gamma \omega C_e \nu_{\max} = \frac{\gamma \omega C_e \nu_{\max}}{\gamma \omega C_e \nu_{\max}} = \frac{\gamma \omega C_e \nu_{\max}}{\gamma \omega C_e \nu_{\max}} \]

\[ L_e = t + 1.4/2 - \bar{P}_c \]

\[ \sum \bar{P}_c = \bar{P}_c \quad \bar{P}_c = \frac{\gamma \omega C_e \nu_{\max}}{\gamma \omega C_e \nu_{\max}} \]

**Fig. 2.** Scheme for calculating the hydrodynamic stress on the slabs of the stilling basin of the water outlet.
Determination of pulsation stress components. Relative standard of vertical stress pulsation (from the graph in Fig. 2).

\[ P' = \frac{\gamma v}{\gamma} = \frac{\gamma v}{\gamma} \]

\[ P'_m = \frac{\gamma v}{\gamma} = \frac{\gamma v}{\gamma} \]

\[ P'_c = \frac{\gamma v}{\gamma} = \frac{\gamma v}{\gamma} \]

We define the following:

\[ \frac{K_A}{\tau_0} = 10^6 \text{ and } p_0 = 0.95 \]

\[ T / \tau_0 = 6 \cdot 0.127 = 0.141 \]

\[ K_A = 6 \]

\[ \tau_0 = \pi \sqrt{\int_0^\infty \overline{\omega}^2 \omega} \]

Putting all the calculation formulas in place, we get the following:

\[ P' = \sum \bar{P}_i \]

\[ \gamma_0 - \frac{\gamma_0}{\gamma} = \frac{\gamma_0}{\gamma} = \frac{\gamma_0}{\gamma} = \frac{\gamma_0}{\gamma} \]
According to the condition of ascent, having overturned the resistance of the slab, we accept the first condition as the main one since it is greater than the shear condition. That is, the accepted slab thickness is 0.5 m.

### 4 Conclusions

According to the calculation results, the main stresses are vertical and overturning moment stresses, consisting of the average and pulsation components of the stability of the slabs of the stilling basin. Horizontal stresses, to which a small value of the overturning moment is added, have an imperceptible influence in determining the thickness of the stilling basin slab. This allows us to think that it is possible to increase the efficiency of energy absorbers without increasing the thickness of the slab of the downstream stilling basin for water outlet structures of reservoirs.

### References


