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TECHNICAL SCIENCE

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SPILLWAY PROTECTION AGAINST CAVITATION EROSION

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ЗАХИСТ ВОДОСКИДІВ ВІД КАВІТАЦІЙНОЇ ЕРОЗІЇ

Abstract

Aerators are designed to saturate water with air to protect spillways from cavitation erosion. The method of calculation of the aerator on the spillway is offered. The presence of a boundary layer of pressure reduction under the jet is taken into account, which influences the distance of the jet flow down the springboard. The dependencies for the calculation of air concentration are given.

Анотація

Трампліни-аератори призначені для насичення води повітрям з метою захисту водоскидів від кавітаційної ерозії. Пропонується методика розрахунку аератора на водозливній межі. Враховується наявність приграничного шару зниження тиску під струменем, що впливає на дальність відльоту струменя за трампліном. Наводяться залежності для розрахунку концентрації повітря.

Keywords: *algae, springboard aerator, boundary layer, two-phase flow, air concentration.*

Ключові слова: *водозлив, трамплін-аератор, приграничний шар, двофазний потік, концентрація повітря.*

Introduction

For the vast majority of foreign and domestic waterworks, calculations show that with natural roughness, the actual cavitation coefficients are more than unity, and according to the calculation, there is no cavitation.

However, it should be noted that in some cases the law of distribution of the heights of roughness protrusions can sharply differ from the "normal" one, and this can change the cavitation situation. In addition, model tests, on the basis of which the cavitation parameters recommended in practice are obtained, do not provide a reserve in comparison with nature.

The main text

As experience shows, cavitation erosion in nature is more intense. It is also possible that even with careful monitoring of the inspection of the concrete surface, some irregularities, surface defects may not be noticed or they may appear subsequently during operation, as a result of various destructive processes. Therefore, at flow rates of more than 25 ... 28 m/s and the absence of concrete defects (natural roughness), it is recommended to install a springboard-aerator on the spillway path. Its main purpose is to saturate the bottom layer of the stream with air, in which the occurrence of cavitation becomes impossible. The design scheme of the aerator is shown on the figure 1.

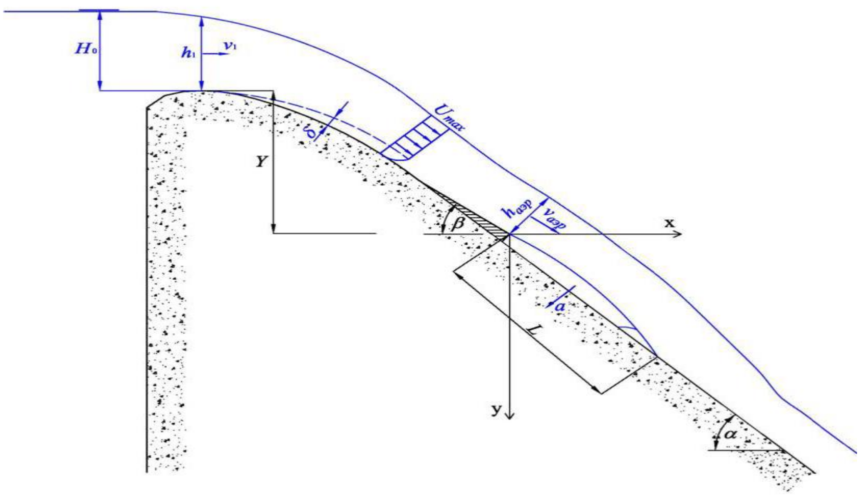

Fig. 1 The scheme of calculation of the aerator at the edge of the spillway

The location of the aerator is determined in accordance with the cavitation situation on the spillway. The determining criterion for choosing the location of the aerator is compliance with the conditions

$$v_{хар} \le v_{пор}\,, \qquad (1)$$

where $v_{хар}$ – the characteristic speed, for which it is recommended to take the flow rate at the height of the roughness protrusion equal to z∆≈10∆ [1], here ∆ is the value of the equivalent heterogeneous roughness; vpor is the threshold velocity, i.e. flow rate at which cavitation erosion does not occur for a long time, depending on the characteristics of concrete.

A characteristic feature of the spillway face is the presence of a boundary layer, the speed of movement in which is significantly lower than the average speed. The boundary layer originates at the head and develops downstream. Its thickness can be determined by theoretical dependence [2]

$$\frac{\delta}{h_0} = 0{,}7\lambda\left(\frac{X}{\lambda}\right)^{\frac{1}{1+1{,}5\sqrt{\lambda}}}, \qquad (2)$$

or empirical formula [3]

$$\frac{\delta}{X} = 0{,}08\left(\frac{X}{\Delta}\right)^{-0.233}, \qquad (3)$$

where δ - is the thickness of the boundary layer, at a distance X from the top of the input head; h_0 - is the normal flow depth; λ - coefficient of hydraulic friction.

The turbulent boundary layer significantly affects the kinematic characteristics of the flow. The velocity distribution over the depth of the boundary layer can be described by a power law dependence

$$\frac{v_z}{v_{\max}} = \left(\frac{Z}{\delta}\right)^n, \qquad (4)$$

where v_{max} - is the velocity of the flow core outside the boundary layer. Its value is determined by the law of free fall, since at the upper boundary of the boundary layer the velocity gradient is zero [2]

$$v_{\max} = \sqrt{v_1^2 + 2g\left(Y + \frac{h_1}{2}\right)}, \qquad (5)$$

where v_1, h_1 - average velocity and depth of flow in a vertical section at the threshold of the spillway head; Y - is the vertical distance from the tip of the tip to the center of gravity of the flow section in question; n - is an exponent

$$n = \frac{1}{\ln\frac{\delta}{\Delta} + 2}.$$

As a rule, the aerator location target is preassigned 20.0...25.0 m below the mark of the spillway head. In this section, the thickness of the boundary layer δ is determined from dependence (2) or (3), and from the expression (4) the flow velocity in the boundary layer is found at the height of the maximum roughness protrusion z_Δ. Based on the above assumptions $v_{z\Delta} = v_{\max}\left(\frac{10\Delta}{\delta}\right)^n$. Taking $v_{хар}=v_{z\Delta}$, the fulfillment of condition (1) is checked, and if necessary, the location of the aerator is adjusted.

The height of the aerator ledge and the slope of its upper face relative to the spillway surface is determined from the conditions necessary to ensure the jet take-off distance L 1:7...1:15 (γ=4...8) [2].

In the aerator section, the average flow velocity v_{aer} and water depth h_{aer} are calculated

$$v_{аэр} = \varphi\sqrt{2g\left(H_0 + \nabla_{ог} - \nabla_{аэр} - h_{аэр}\cos\beta\right)}, \qquad (6)$$

$$h_{аэр} = \frac{Q}{b_{аэр} v_{аэр}} \qquad (7)$$

where φ - is the velocity coefficient; H_0 - full head on the top of the spillway; $\nabla_{ог}$ - mark of the spillway head; $\nabla_{аэр}$ - mark the alignment of the aerator; β - is the angle of inclination of the upper face of the aerator relative to the horizon; Q - water consumption; b_{aer} - the width of the spillway face in the alignment of the aerator.

The calculation according to dependences (6) and (7) is performed by the method of successive approximations, assuming $h_{aer}=0$ in the first approximation.

The main characteristic of the aerator is the amount of air supplied under its ledge. Its value depends both on the hydraulic parameters of the flow and directly on the design parameters of the aerator. By summarizing the numerous experimental and field data N.L. Pinto obtained the following empirical relationship to determine the air drawn into the sub-jet space [3]

$$Q_{аэр} = 0{,}29 \cdot Q\left(\sqrt{Fr} - 1\right)^{0{,}62}\left(\frac{D}{h_{аэр}}\right)^{0{,}59}, \qquad (8)$$

where $Fr = \frac{v_{аэр}^2}{g h_{аэр}}$ - is the Froude number; $D = \frac{\mu_{аэр} F_{аэр}}{b_{аэр}}$ - effective duct area referred to the width of the aerator; $\mu_{аэр}$ - the flow coefficient of the duct path is determined by the known dependencies in accordance with its geometry. From the experience of the developed and implemented aeration systems for preliminary calculations, it is possible to take the value of the flow coefficient $\mu_{аэр}$=0,6; $F_{аэр}$ - the area of the duct, which approximately can be assigned equal to

$$F_{аэр} = \left(0{,}08...0{,}12\right)\frac{Q}{v_a}, \qquad (9)$$

where v_a - is the air velocity in the duct path. Usually taken no more than 60 m/s.

Thus, when calculating the aerator, it is necessary to determine the cross-sectional area of the air ducts according to dependence (9), and then, using (8) to determine the amount of air drawn in, to find the magnitude of the pressure decrease in the under-junction space behind the ledge

$$h_{вак} = \frac{\rho_{возд}}{2g\rho_{вод}}\left(\frac{Q_{аэр}}{\mu_{аэр}F_{аэр}}\right)^2, \qquad (10)$$

where $\rho_{вод}$, $\rho_{возд}$ - respectively, the density of water and air.

The most important task characterizing the efficiency of the aerator is to determine the junction of the stream thrown off the springboard to the spillway face. The jet departure range behind the aerator step should be at least 10.0...15.0 m, which will ensure the absence of water in the duct path [1]. This calculation can be performed according to the equations of motion of the stream in free fall after it leaves the springboard-aerator, taking into account the decrease in pressure under the stream,

$$\begin{cases} x = vt\cos\beta - \frac{at^2}{2}\sin\alpha \\ y = vt\sin\beta + \frac{gt^2}{2} + \frac{at^2}{2}\cos\alpha \end{cases} \qquad (11)$$

and the equation of the surface of the spillway

$$y = \frac{h_1}{\cos\alpha} + xtg\alpha, \qquad (12)$$

where x, y - are the coordinates of the system with the origin located on the exit edge of the springboard; v - is the flow rate taken for the lower surface of the jet equal to the flow velocity at the height of the maximum protrusion of the roughness $v_{z\Delta}$; t is the flow time from the moment the aerator descends from the springboard to where it adjoins the spillway face; β - the angle of inclination of the jet to the horizon in the alignment of the output edge of the springboard-aerator; α - the angle of inclination of the spillway face below the aerator; h_t - is the total height of the springboard and ledge; g - is the acceleration of gravity; a - additional acceleration directed normal to the weir plane and caused by the pressure force on the area of the lower surface of the aerated stream with the depth of the aerated stream h_a and average air concentration C at a vacuum in the subjet region h_{wack}

$$a = \frac{h_{вак}}{h_a(1-C)}g = \frac{h_{вак}}{h_{аэр}}g . \qquad (13)$$

The calculation of the jet departure distance L is recommended to be carried out graphically when solving parametric functions (11) and equation (12) together. In this case, a series of values of the time parameter t are set with a certain step until the jet boundary intersects the spillway face.

In the process of jet departure, it will be saturated with air. The entrained air is mainly concentrated in the boundary layer. The concentration of air at the bottom $\overline{C}_1$ in the alignment of the lower surface of the jet to the spill face is determined by the following dependence

$$\frac{q_a}{q_{погр}} = \frac{\overline{C}_1}{1-\overline{C}_1}, \qquad (14)$$

where q_a - is the specific consumption of entrained air, $q_a = \frac{Q_{аэр}}{b_{аэр}}$; $q_{погр}$ - the specific water consumption in the boundary layer, based on the power law of the distribution of speeds, is

$$q_{погр} = v\int_0^{\delta}\left(\frac{z}{\delta}\right)^n dz . \qquad (15)$$

Having completed the integration of expression (15) and after carrying out the corresponding transformations, we obtain an expression for determining the initial bottom air concentration

$$\overline{C}_1 = \frac{Q_{аэр}}{Q_{аэр} + \frac{v_{\max}\delta}{n+1}b_{аэр}}. \qquad (16)$$

After the aerated stream adjoins the spillway, its deaeration begins. The decrease in bottom air concentration along the length of the spill face is determined by the dependence

$$\overline{C} = \overline{C}_1 - \sum \Delta C_i l_i , \qquad (17)$$

where ΔC - is the specific decrease in air concentration by 1 running meter, according to field data, $\Delta C_{пр}$=0.15...0.5% in the prismatic section and $\Delta C_{п}$=0.5...1.2% in the turn [5]; l_i - is the length of the corresponding section of the spillway surface.

Conclusion

Dependence (17) allows us to estimate the change in air concentration along the length of the spillway. In the alignment, where it will decrease to a critical value, an aerator device of the next stage will be required.

Aerators, calculated according to the above methodology, were built on the spillways of the Karun I waterworks (after reconstruction) (Iran), Kapanda (Angola), Teri (India), on the coastal spillway of the Sayano-Shushenskaya hydroelectric power station. Field tests have shown the reliable operation of these aeration systems.

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