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Research Article

Hydraulic Modeling Of Water-Air Flow In A Tubular Spillway With Local Hydraulic Resistance

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Abstract:

A hydraulic model was established for dynamics of changes in the hydrodynamic pressure of the water-air flow in the water supply path with various local hydraulic resistances (swirler, diffuser, confuser) of high-pressure hydraulic structures. By the using of this model, it is possible to predict the hydrodynamic pressure of the water-air mixture in high-speed water supply paths with various absorbers of the excess kinetic energy of the flow.

Key words: spillways, flow energy absorbers, swirler, diffuser, confuser, hydraulic model.

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Introduction

Spillways of high dams are carried out in the form of overflows, deep or bottom holes (in the form of channels of closed section, tubular spillways). The greater the pressure, the higher the flow rate that affects the elements of the structure, the more difficult the flow control, and the greater the excess kinetic specific energy of the water must be extinguished in the downstream of the spillway. The flow within the spillway structures of high-pressure waterworks is called high-speed. However, a number of features attributed to the high-speed flow also appear at relatively low speeds.

At pressures of 35-45 m, which correspond to speeds of 25-28 m / s, special measures have to be taken to ensure the normal operation of culverts. In particular, when designing high-pressure spillways, it is necessary to take into account the constructive solution for installing various types of damper.

Research indicate that during the movement of water in spillway structures with various devices for damping the flow energy, the velocity fields are continuously deformed, as a result of which the velocity fields in the cross sections of the corresponding channels almost always turn out to be uneven. In addition, in complex constructions of spillways, where it is practically impossible to maintain an uninterrupted flow in the aquatic environment, the velocity fields turn out to be unsteady as well, and the pressure fields turn out to be unsteady. In [1], amplitudes of pressure pulsations reaching 10% of the absolute pressure in front of the shutter were obtained in front of the segmented gates. As a result, unacceptably large dynamic loads arise, acting on all elements of various devices and spillway walls.

At the same time, swirls of the flow sharply increase or axisymmetric and asymmetric deformations of the velocity diagram leads to the occurrence of cavitation processes. Accordingly, to eliminate this problem, The first way is to provide a long linear spillway source behind the disturbance source, or install a damper of the diffuser and confuser type between the disturbance source in order to reduce the length of the indicated section of the pipeline and ensure uniform distribution of velocity over the cross section.

In view of the foregoing, it is difficult to overestimate the relevance of suppressing the unevenness and non-stationarity of velocity fields generated in various devices and corresponding pipelines. When solving the indicated problem, two ways of suppressing the non-uniformity and non-stationarity of the velocity fields are possible.

The first way is reduced to purely constructive changes in the flow parts of the corresponding devices in order to eliminate the causes of the unsteady flow with large vortex formations.

The second way provides for the suppression of already arising unsteady flows with a pronounced unevenness of the velocity fields in the cross sections of the water supply path. In practical terms, it is much more often necessary to quench an already unsteady flow with a very complex velocity field in the cross sections of the water supply path, where the vector velocity field can contain areas with the return movement of the working media. In this case, any method of suppressing the non-uniformity of velocity fields is accompanied in most cases by an increase in hydraulic resistance due to the introduction of an additional device — a non-uniformity damper (diffuser, confuser, etc.) into the flow.

But we have to not forget that cavitation is of a general nature, i.e. to develop in sections of the conduit with reduced pressure, regardless of the state of the solid boundaries, and local, when even with excess pressure in this section there is a local decrease in pressure on the flow energy absorbers (like a diffuser and confuser).

In this case, there is a need to develop a hydraulic model of the dynamics of the pressure change in the tubular spillway. To simulate dynamic processes in the water supply path, the equation of the balances of the mass flow of water in the nodes of the transitional sections of the tubular spillway structure was made [1]:

$$Q = Q_{swirl} + Q_{dif} + Q_{conf} + Q_{comp\,vol} \quad (1)$$

where: Q is the mass flow through the glass conduit;

Q_{swirl} – mass flow rate of water through the swirl chamber;

Q_{dif} – mass flow rate of water in the diffuser;

Q_{conf} – mass flow rate of water in the confuser;

$Q_{comp\,vol}$ – mass flow rate, taking into account the compressibility of the volume of water in the pipeline.

The calculation of the flow of water-air flow through a water supply path with various hydraulic resistances (swirl, diffuser, confuser) is reduced to solving the energy conservation equation [2]:

$$\frac{Q_2}{Q_1}-1=\left[(\frac{p_1}{p_2})^b-1\right] \quad (2)$$

where: Q_1, Q_2 -:, is the mass flow rate at the sections (1-1) and (2-2), p_1, p_2 - is the hydrodynamic pressure at the sections (1-1) and (2-2), b - is a constant.

The hydrodynamic parameters Q and p in section (1-1) are not initially known. Their calculation is performed iteratively with the known flow parameters in sections (1-1) and (2-2). If the flow is single-phase or two-phase, then, as a rule, one iteration is sufficient. In our case, the flow is two-phase, in connection with this one step iteration will be performed.

In this case, the initial approximation is performed as follows:

$$p_0=\frac{(p_1+p_2)}{2} \quad (3)$$

Next, at the selected pressures, we determine the flow rates in the transition sections $Q_{swirl}, Q_{dif}, Q_{conf}, Q_{comp\ vol}$:

$$Q_{swirl}=\frac{\mu_{swirl}Q_0}{(a_1^b-1)tg\alpha+1} \quad (4)$$

where: Q_0 -: is the initial flow rate of the water-air mixture flow, μ_{swirl}- is the flow coefficient of the swirl chamber, $a_1=\frac{p_{swirl}}{p_0}$- , is the empirical coefficient characterizing the change in the hydrodynamic pressure in the swirl chamber, b - is the empirical constant.

$$Q_{dif}=\frac{\mu_{dif}Q_0}{l_1}\int_{l_1}(a_2^b-1)dl_1 \quad (5)$$

where: μ_{dif}- is the diffuser flow coefficient, $a_2=\frac{p_{dif}}{p_0}$- is the empirical coefficient characterizing the change in the hydrodynamic pressure in the diffuser, l_1 - is the length of the diffuser channel.

$$Q_{conf}=\frac{\mu_{conf}Q_0}{l_2}\int_{l_2}(a_3^b-b+1)dl_2 \quad (6)$$

where: μ_{conf}- is the flow coefficient of the confuser, $a_3=\frac{p_{conf}}{p_0}$- is the flow coefficient of the confuser,, l_2 -,, is the length of the confuser channel.

$$Q_{comp\ vol}=Q_0\beta_{comp\ vol}l\frac{dp}{dl} \quad (7)$$

where: $\beta_{comp\ vol}=-\frac{1}{W}\frac{dW}{dp}$- is the compression ratio, l - is the length of the tubular spillway or the length of the water supply path, $\frac{dp}{dl}$ - is the change in hydrodynamic pressure along the length of the water supply path.

We put formulas (4), (5), (6), (7) in equation (1), we obtain:

$$Q=\frac{\mu_{swirl}Q_0}{(a_1^b-1)tg\alpha+1}+\frac{\mu_{dif}Q_0}{l_1}\int_{l_1}(a_2^b-1)dl_1+\frac{\mu_{conf}Q_0}{l_2}\int_{l_2}(a_3^b-b+1)dl_2+Q_0\beta_{comp\ vol}l\frac{dp}{dl}$$

(8)

And then we will we get:

$$p=\int_l\left[\frac{Q}{Q_0\beta_{comp\ vol}l}-\frac{\mu_{swirl}}{\beta_{comp\ vol}l(a_1^b-1)tg\alpha+1}-\frac{\mu_{dif}}{l^2\beta_{comp\ vol}}\int_{l_1}(a_2^b-1)dl-\frac{\mu_{conf}Q_0}{l^2\beta_{comp\ vol}}\int_{l_2}(a_3^b-b+1)dl_2\right]dl \quad (9)$$

Conclusions: an expression is obtained for changing the pressure of a water-air flow in a water path with various hydraulic resistances (swirler, diffuser, confuser). Based on the experimental results, equation (9) was numerically solved. The results of a numerical experiment are shown in Figs. 1 and 2.

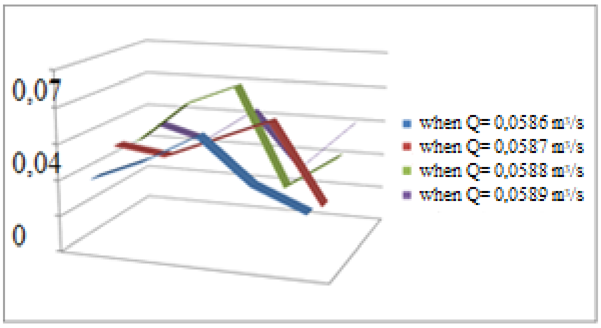

Fig. 1 Graph of changes in hydrodynamic pressure.

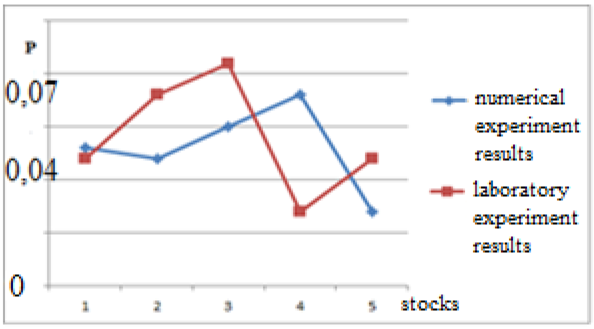

Fig. 2 Comparison of laboratory and numerical experiments, the error is 4%.

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