Experimental studies of horizontal flow effects in the presence of cavitation on erosion – free dampers

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Abstract. Based on cavitation studies, the obtained graphical dependencies for determining the horizontal hydrodynamic effect of the cavitating flow on erosion-free dampers at various stages of cavitation. These data supplement the results obtained earlier. Based on studies, the effect of cavitation on the work of erosion-free dampers was revealed. On average, horizontal ripple loads in the zone of the developed stage of cavitation increase by 1.7...2 times. Such a significant increase in loads necessitates taking into account the influence of cavitation when designing the downstream fastening plates with erosion-free dampers. The values of the horizontal hydrodynamic loads on the erosion-free dampers given in the work make it possible to establish the shear loads on the slabs of the water cube under cavitation. The results of this work can be used in design practice to assess the stability of slabs of waterfall fasteners with cavitating erosion-free dampers.

1. Introduction

For the first time in hydraulic engineering, the force effects of a cavitating flow on erosion-free dampers were studied by us. Based on cavitation studies, it was possible to obtain quantitative regularities of horizontal, averaged, and pulsating loads on absorbers as cavitation develops. During the experiments, a decrease in the resistance coefficients with the development of cavitation was recorded. The marked decrease in the resistance coefficients during cavitation, especially in the conditions of a frolic stage and supercavitation, is explained by the fact that with the development of cavitation the character of the diagrams of the distribution of pressure on the streamlined body changes.

In the second stage, the authors studied the ripple loads on the dampers. The analysis of the research results showed that during the operation of the absorbers under cavitation conditions (initial and frolic), the pulsation component of the load increases compared to the cavitation-free mode.

As far as we know, the question of the effect of cavitation on the pulsation characteristics of the flow acting on the slabs of the water cullet and energy absorbers under the cavitation mode has not been investigated. However, qualitative ideas about pressure pulsations behind energy absorbers can be obtained by the example of studies studying the pulsation characteristics behind various kinds of obstacles (protrusions, gates), since both are essential sources of cavitation, turbulence and pressure pulsations.

In laboratory tests of a flat shutter operating in a high-speed flow at pressures up to 200 m were carried out. One aspect of the work was the study of the dynamic effect of the cavitating flow on the shutter. According to the authors, the value of the standards of pressure pulsation on the shutter in the presence of developed cavitation is twice the value of the standards in its absence. In supercavitation...
mode, such data are not presented because the authors of the work were not able to obtain supercavitation.

In the works of V.M. Lyatkher and L.V. Smirnov [1–5] obtained data on the characteristics of pressure pulsation in the separation zone at different absolute pressures, according to which there is an increase in dispersion and significant deformation of the pulsation spectrum towards high frequencies as cavitation develops. In the separation zone, a change in the spectrum during cavitation is natural since the most intense pulsations occur in the presence of cavitation [6, 7].

A.Locher and E.Naudater conducting systematic studies, received the intensity of pressure pulsation on the protruding walls depending on the number of cavitation. To obtain information about flow-induced structural vibrations in common cases, pressure pulsations were measured on a protruding wall. It was found that the pressure pulsation intensity, linear correlation, and wall pressure fluctuation spectra strongly depend on the application of the flow around the wall.

In the beginning, the case of the absence of cavitation and without sticking was investigated $\frac{d}{b} = 1$. At $\frac{d}{b} = 1$ no principal frequency was found in the spectrum of pressure pulsations and the intensity of this load was comparatively low $\frac{0.078\rho U_0^2}{2}$. In the case of unstable adhesion of the flow to the wall for $\frac{d}{b} = 3$, the force influences of the flow differs in the high-frequency spectrum and pronounced peaks, while the rems pressure pulsation is much larger $\frac{0.13\rho U_0^2}{2}$. Cavitation in the early stages leads to an increase in flow pulsations, thereby leading to more intense pressure pulsations in the low – frequency part of the spectrum, but only in cases where the flow does not adhere to the streamlined wall.

For a flow with unstable adhesion, cavitation works in an antiphase with it, which leads to a decrease in the relative intensity of low-frequency oscillations. High-frequency oscillations, as shown by the spectra of pressure pulsations, increase in wallpaper cases. In connection with the ultrasonic spectrum of the cavitation phenomenon itself. With supercavitation $K = 1.8$, the pulsation standard decreases significantly. The authors of the reports explain the discovered phenomenon by the damping effect of air bubbles released from water in the zone of low pressure and accumulated in the displacement zone. A similar effect is also exerted by especially cavitation vapor-gas caverns (torches).

The authors also note an increase in the standard of pressure pulsations in the zones of separation of the flow and beyond the projections of structures. So in the studies were conducted on the model of the construction spillway of the second tier of the Sayano-Shushensky hydroelectric power station. A two-dimensional protrusion was installed on the ceiling of a curved discharge and simulated the displacement of one of the elements of a precast concrete floor. The spillway model was made of Plexiglas at a scale of $1:30$ n.v. The height of the protrusion was 6 mm, and the length of the stream 100 mm. The ledge was a source of cavitation, various stages of cavitation, which were recorded visually [8–14].

The studies were performed under pressure mode of water flow. The water flow rate in the protrusion range was 5–7 m/sec. Pressure pulsations were recorded on an oscillogram, both at atmospheric pressure inside the test bench and at a different vacuum, providing a change in the cavitation process from the moment of its occurrence to its developed stages. The authors note that the pressure pulsation intensity with developed cavitation $\beta = 0.3$ is significantly higher than with the cavitation-free regime of flow around the protrusion.

With cavitation-free flow around the protrusion, the main share of the pressure pulsation energy falls on low frequencies (up to 3 Hz). With cavitation, a change in the shape of the spectrum occurs. The contribution of low-frequency components decreases, the maximums of the spectrum shift to frequencies of 20 – 30 Hz, the frequency range extends to the high-frequency region.
S. Wigander and U. Chi found an increase in pressure fluctuation by 6 times observing the transformation of the spectrum of action in the field of re-attachment of the flow.

K. Petrikat, A. Kadyr, M. Knoll studied horizontal loads on checkers. In this case, the drag coefficient of the dampers in the hydraulic jump turned out to be equal to $c = 0.98$. The authors note that with a cavitation number of 0.9 (a developed stage of cavitation), the pulsation amplitudes increase 5.5 times. In this case, the dominant frequencies in the cavitation-free mode on the absorbers are 40 Hz, and in the super-cavitation mode – 80 Hz.

For the first time in hydraulic engineering, the force effects of a cavitating flow on erosion-free energy absorbers were studied by N.P. Rozanova [15]. Based on cavitation studies, the author of the work was able to obtain quantitative regularities of horizontal averaged and ripple loads on absorbers as cavitation develops (fig. 1). During the experiments, a decrease in the resistance coefficients with the development of cavitation was recorded. The resulting graphical dependence $\frac{c_{kav}}{c_0} = f(\beta)$ for a jump in the limiting state indicates a change in the resistance coefficients of erosion-free dampers and the dependence $\frac{c_{kav}}{c_0} = \beta^{0.6}$ (fig. 2) the noted decrease in the drag coefficient during cavitation, especially in the conditions of a frolic stage and supercavitation mode, the author explains by the fact that with the development of cavitation the character of the diagrams of pressure distribution on the streamlined body changes.

![Figure 1. Dependence $C = f(\beta)$ for energy absorbers: a is for absorbers № 1, № 3, b or absorbers № 2, are shown in figure 5; 1 is limiting state of a hydraulic jump, 2 is distilled hydraulic jump](image-url)
As is known from the literature, experimental studies of the flow around a stream of various bodies (cylinder, plate, and disk) show the presence of a change in the drag coefficient of the body, its reaction with the development of cavitation. Moreover, with significant development of cavitation, the drag coefficient “C” of elliptical nozzles of the number of cavitation [16]. It can be seen from the figure that a decrease in the “C” values begins from the moment of the formation of developed cavitation (figure 3) and a decrease in “C” occurs in direct proportion to a decrease in the cavitation parameter.
In the second stage, the author studies the ripple loads on the dampers at maximum magnitudes. Analysis of the research results showed that cavitation (initial and frolic), there is an increase in the instantaneous pulsating component of the load compared with the cavitation-free regime (figure 4). For example, in cavitation-free mode, the ripple coefficient $\delta_n$ constant and equal to 0.14, and in the developing stage $\beta=0.5 \; \delta_n=0.65$ – also increased by 4.6 times, and when $\beta<0.5$ there is a tendency towards its decrease.

![Figure 4](image)

**Figure 4.** Waving of the cavitation stage on the ripple coefficient $\delta_p$: 1 is for a damper according to the scheme of figure 5; 2 is spillway spreaders of the Chirvak hydroelectric complex

2. Methods
Cavitation studies of erosion-free energy absorbers were carried out in a vacuum cavitation stand of the laboratory of hydraulic structures of MGMI.

It is known that when modeling the operation of energy absorbers in the downstream in the presence of cavitation, as well as in its absence, it is necessary to observe the Froude similarity criterion ($Fr = idem$) and conduct research in the automotive field at Froude numbers calculated for the compressed section $Fr = 16 – 64$ and Reynolds numbers $Re > Re_{gr}$.

To observe the approximate similarity of cavitation phenomena, it is necessary to fulfill the condition:

$$K_n = \eta K_m$$

here: $K_n$ and $K_m$ are cavitation parameters for nature and model;

$\eta$ is the correction factor for the scale of the model (assumed $1.0 = 1.0$, given the scale of the model $Re > 105 – 106$.

No cavitation will be ensured provided

$$K > K_{cr}$$

The cavitation parameter is usually written in the following form:

$$H_{char} = H_a + h$$
(at is the pressure created above the free surface in the cavitation installation, in meters of water, for nature - atmospheric pressure);

here: $h$ is the height of the water column above the quencher, in meters of the water column; $v_{\text{char}}$ is the characteristic flow rate (taken on the velocity distribution diagram at the top of the damper), m/s; $g$ is gravity acceleration, m/s$^2$; $H_{cr}$ is pressure (in meters of water) vaporization (taken as for pure water).

A hydraulic jump in the installation was created when water flowed out from under the shutter.

The fragment model was water well with two rows of extinguishing devices: in the first row, erosion-free absorbers, in the second, water wall (figure 5).

![Figure 5. Study of the shape of model erosion-free energy absorbers (dimensions in mm)](image)

### 3. Results and Discussion

In the work, four types of erosion-free dampers were studied with water bore (figure 5). The drag coefficients and ripple components of the horizontal load were measured using a plate sensor. The natural frequency of the plate sensor was about 100Hz.

It is obvious that, in addition to vertical hydrodynamic loads, horizontal slabs, caused by both static and dynamic components of the flow effect, act on those slabs where dampers are installed, in addition to vertical hydrodynamic loads. In this regard, studies of revealing the contribution of the dynamic component to the total horizontal load in cavitation-free and cavitation modes are of some interest. In cavitation-free regimes, this question was posed in [16], where it was noted that the contribution of the dynamic component to the total horizontal loads is significant, amounting to $25 = 30\%$. The study of the static component (resistance coefficient) of the horizontal load for three absorbers (№ 1, 2, 3), as well as the ripple load for the absorber № 2 are given in [15, 17, 18].

The goal of our research was to study the effect of the cavitation stage on additional changes in the pulsation component for the four types of erosion-free dampers. Along the way, we determined the resistance coefficients for the indicated types of absorbers, gave a comparative graph of their dependence on the cavitation stage (Figures 6 and 7). It can be seen from the figure that the results of our studies almost coincide with the above [19]. The dependence of the resistance coefficient on the cavitation stage for the newly studied erosion-free damper – spreading agent was also clarified. It should be noted that the nature of the change in the drag coefficient for the rest of the absorbers, and in the cavitation-free mode, its value was 0.85.

For all studied types of dampers, a decrease in drag coefficient ($s$) was observed with the development of the cavitation stage. Based on measurements of the average pressure on the absorbers using a plate sensor, their resistance coefficients are determined as a function $rac{C_{kav}}{C_0} = f(\beta)$. 

![Figure 5. Study of the shape of model erosion-free energy absorbers (dimensions in mm)](image)
Figure 6. Change in resistance coefficient № 1 depending on the cavitation stage ($\beta$): 1 is data of the author; 2 is data of N.P. Rozanov.

Figure 7. Change in the coefficient of resistance of absorbers Figure 5 № 2 and 3 depending on the stage of cavitation: 1 is for the damper № 2; 2 is for damper № 3, 3 and 4 data are for damper № 2.

Figure 8 shows a graph of the change in the drag coefficient for all the studied erosion-free dampers $\frac{C_{\text{cav}}}{C_0}$ depending on the stage of cavitation. The decrease in “$C$” can be explained by the fact that with the development of cavitation, the nature of the diagrams of the distribution of pressure on the streamlined body changes. At the initial stage of cavitation, one should expect the proximity of the values of $C_0$ and $C_{\text{cav}}$, which was obtained in the experiments. Since the marginal vacuum on the rear surface of the energy absorber does not occur at all points of the vacuum zone. A noticeable decrease in $C_{\text{cav}}$ occurs during the frolic stage and supercavitation. The explanation for the decrease in “$C$” during cavitation is consistent with the physics of the phenomenon and is given in [16, 20].
4. Conclusions

These studies have shown that the drag coefficients of the investigated erosion-free energy absorbers significantly decrease with the development of cavitation. In the calculations to ensure the necessary energy-extinguishing ability, the change in resistance coefficients should be taken into account.

1. The study of the horizontal pulsation mode of the studied energy absorbers showed that the presence of cavitation further increases the horizontal pulsation loads. For the studied types of dampers, the ripple load in the developed stage of cavitation $\beta = 0.5$ increases by 1.5-1.7 times in relation to the ripple loads without cavitation.

2. Studies have shown that the horizontal pulsating hydrodynamic component is approximately one-fourth of the static.

3. The specific horizontal pulsation load is largely determined by the stage of cavitation.

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