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Formations of Ventilated Caves and Their Influence on the Safety of Engineering Structures

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Abstract*—the article discusses the formation of honest turbulence on the walls of the cavity, which lose the transparency of the walls of the caverns. In the feed part, the flow is a two-phase medium, a zone without pronounced longitudinal vortices. A flow pattern with a return flow is given. In direct cavitation flow, a return stream characterizes the resistance value. In the reversed flow, the body will experience a craving of magnitude. Analytical formulas are given for determining the shape with a certain minimum number of cavitation..*

Keywords— gas envelope, gas flow rate, gas ablation curve, Froude numbers, the coefficient, around, a disk,; river flow; aquifer; pulsating caverns, periodic drawdown; thermodynamic conditions; heterogeneous conditions on the contours;.

I. Introduction

In many engineering structures, the formation of ventilated cavities leads to pipe aggression, cavitation erosion begins, which is the beginning of the destruction of the entire system. In this article, we consider the formation of ventilated caverns and the effect on the safety of engineering structures. The term ventilated defines caverns, the existence of which is associated with the forced supply of gas into the liquid stream. In other words, ventilated caverns refer to artificial cavitation [1-4]. The need for ventilated cavities most often arises in laboratory studies of developed cavitation currents, when it is necessary to obtain caverns at low and moderately high flow rates. Gas injection allows increasing the pressure in the cavity and thereby reducing the number of cavitation to a predetermined value.

The positions of the boundaries' points which are relative to the plane of comparison are variable. Using the Brillouin Paradox for a heavy fluid, conditions are selected for which a stationary cavity of finite length, in particular a cavern with a sharp edge floats to the top of the liquid and is extinguished. He gives algorithms and numerical methods for determining the forces of cavitation.

II. Main part

Formations of ventilated caverns**.** The formation of a gas envelope around the body by ejecting a gas jet in the bow towards the water stream, leads to ventilated caverns. However, this scheme has significant drawbacks. In fact, at the nasal critical point of the cavity, the gas pressure is equal to the water stagnation pressure. From the Bernoulli equation, it is possible to establish the boundary value V_{gas} of the gas outflow velocity at which the existence of the flow in question is possible

$$V_{gas} \succ V_{\text{water}} \sqrt{\frac{\rho_{\text{water}}}{\rho_{gas}}(1+\sigma)}$$

What gives an approximate ratio for air

$$V_{air} \succ 28{,}6\left(1+\frac{\sigma}{2}\right)V_{water}$$

As you can see, even with moderate values of the water flow rate, the speed of the gas stream should be significant. In addition, with the flow scheme under consideration, a zone of increased pressure arises in the head of the cavity, which, in turn, causes a gas flow in the cavity at high speeds. Honest turbulence forms on the walls of the cavity, the walls of the cavity lose transparency. In the feed part, the flow is a two-phase medium, a zone without pronounced longitudinal vortices. L.I. Sedov proposed replacing the oncoming gas stream with a water stream, and blowing gas into the stagnant zone (Fig. 1). This flow pattern is a reversed cavitation flow with a return flow. In direct cavitation flow, a return stream characterizes the resistance value. In a reversed flow, the body will experience a craving of magnitude [2-4];

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$$R = \rho S V_{jet} V_{\infty} \quad (1)$$

where S -is the area of the jet; V_{jet} - jet speed. From a physical point of view, this phenomenon is explained by the fact that the force arising from the restoration of pressure in the stern exceeds the reactive force of the jet. In real flows, it is difficult to achieve a smooth closing of the jets in the stern. Therefore, the considered effect will be less. The experiments confirmed the proposed flow pattern. In a hydrodynamic pipe, flows were obtained with an oncoming liquid stream in which a thrust was created. It turned out that a stable flow pattern is observed at a certain ratio of velocities in the jet and in the oncoming flow: $1{,}1 \le \frac{V_{jet}}{V_{\infty}} \le 1{,}3$ The combined method of creating ventilated caverns, in which the discontinuity of the aqueous medium is achieved on the sharp edge of the cavitator with simultaneous gas flow to place of break. The most stable detachment of free jets and a smoother cavity surface are observed for plate cavitators.

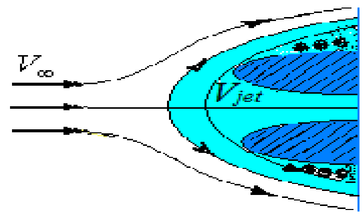

Fig. 1. The formation of a gas envelope near the body by ejecting a gas jet in the bow towards the water stream.

Gas flow rate. The amount of gas required to create and maintain an artificial cavitation flow is characterized by a dimensionless flow coefficient:

$$C_Q = \frac{Q}{V_{\infty} d_n^2} \quad (2)$$

where Q - is the volumetric flow rate of the blowing gas reduced to the pressure in the cavity, m^3/s; d_n -nozzle diameter, m; V_{∞} - the speed of the oncoming flow, m/s. There are two modes of gas entrainment: along longitudinal vortices and in the form of periodically breaking off portions. The portions sometimes take a toroidal form and therefore the second regime of gas entrainment is called ablation along circular vortices.

Using dimension theory, we can write

$$Q = f\left(\rho, g, V_{\infty}, d_n, p_{\infty}, p_{\kappa}, X, \nu, \chi\right) \quad (3)$$

and further

$$C_Q = f_1\left(\sigma, Eu,, Fr_n, C_{xn}, \mathrm{Re}_{\kappa}, We_n\right) \quad (4)$$

standard definitions of similarity criteria. The index means that the cavitator diameter is taken as the linear dimension. The Reynolds and Weber numbers are practically uncontrollable during the experiment. Their influence has not yet been fully studied. Therefore, for simplicity of analysis, let us drop from consideration. In relation (4), the influence of a free surface is discarded, which could be reflected by the depth of the cavitator immersion [5, 6]. So,

$$C_Q \approx f_1\left(\sigma, Eu,, Fr_n, C_{xn}\right) \quad (5)$$

The first regime of gas entrainment is observed only during artificial cavitation and is characteristic of regimes of strong influence of weight $\left(\sigma^2 Fr_n^2 \le 3\right)$. With $Fr = const$ longitudinal vortices, they form at lower cavitation numbers. The second mode exists at higher cavitation numbers. It is characterized by high non-stationarity. The cavity is periodically filled with foam. Then, under the influence of the return stream, large gas-liquid formations come off from the cavity, the cavity recovers its size, and then the process of destruction of the cavity is repeated.

It is not possible to create a unified theory C_Q of gas entrainment from the cavity, which would allow calculating in all flow regimes. An approximate assessment lends itself to individual flow regimes.

More simple for analysis is the case of gas entrainment along longitudinal vortices, which is characteristic of small Froude numbers and, correspondingly, large Euler numbers. The first attempts to create a semi-empirical calculation scheme C_Q belong to Cox and Klaiden (1956), as well as L. A. Epstein, A. F. Bolotin, I. T. Egorov.

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The most reasoned from a physical point of view is the theory of L. A. Epstein. Suppose that as the body moves, more and more new sections of the vortex are formed

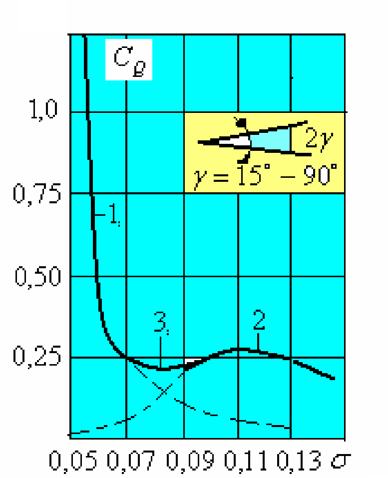

Fig. 2. Types of branch of gas ablation curve.

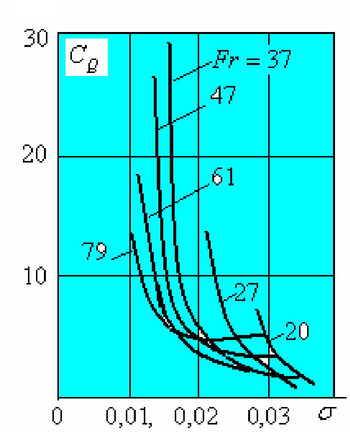

Fig.3. The effects of Froude numbers on the coefficient flow around a disk.

tubes. The pressure in the cavity and in the pipes is the same. Therefore, the gas is at rest relative to the liquid particles. Let the tube formation rate be equal to the oncoming flow velocity, then the volumetric gas flow rate in the vortex tubes will be equal to

$$Q = 2\frac{\pi d_{\text{vortex}}^2}{4}V_\infty \quad (6)$$

in dimensionless form.

$$C_Q = \frac{\pi}{2}\left(\frac{d_{\text{vortex}}}{d_н}\right)^2 \qquad (7)$$

Let us express the square of the ratio of d_{vortex} the diameter of the vortex tubes $d_н$ to the diameter of the cavitator from the Bernoulli equation. Moreover, we take into account that the distance between the vortices "b" is much larger than the diameter of the vortices. Let h be the height of the ascent of the end of the cavity, which is determined by the formula:

$$p_\infty = p_к + \rho g h + \frac{\rho}{2}\frac{\Gamma^2}{\pi^2 d_B^2}$$

Further

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$$\left(\frac{d_н}{d_B}\right)^2 = \frac{\Gamma^2}{\pi d_н^2\left(\sigma - \frac{2gd_н}{V_\infty^2}\frac{h}{d_н}\right)} \tag{8}$$

The value for [] (1.3.6), we obtain:

$$C_Q = \frac{\left(\frac{S^*}{d_н^2}\right)^2}{2\pi(1+\sigma)\left(\sigma Fr_н^4 - 2\frac{h}{d_н}Fr_н^2\right)} \tag{9}$$

Here S^* is the area of the vertical projection of the cavity. We take it equal to the area of the ellipse corresponding to the cavity in the weightless liquid, and we obtain h the value from (8). Then we get the final formula of L. A. Epstein:

$$C_Q = \frac{0{,}42C_{xн}^2}{\sigma\left(\sigma^3 Fr_н^4 - 2{,}5C_{xн}(0)\right)} \tag{10}$$

It is easy to see that if instead of introducing $d_н$ a new characteristic linear size $d_1 = d_н\sqrt{C_{xн}(0)}$, it will C_Q not depend on $C_{xн}(0)$. A generalized experimental curve of a similar type for a fixed value of the number $Fr_н$ for a family of cones with solution $2\gamma = 30^\circ ... 180^\circ$ angles is shown in Fig. 2. As you can see, there are both types of gas entrainment. The left branch of curve 1 corresponds to the entrainment of gas along the longitudinal vortices, the right branch 2 to the annular vortices, the middle part 3 corresponds to the intermediate regime, in which both forms of gas entrainment can sometimes be observed simultaneously. The left branch 1 is well described by formula (10). The family of experimental curves $C_Q(\sigma, Fr_н)$ in Fig. 3. gives an idea of the effect of large Froude numbers on the gas flow coefficient of the blowing gas during cavitation flow around the disk. [1,2,5,6]

The formula of L. A. Epstein does not reflect the influence of the Euler number. Meanwhile, it is clear that for small Euler numbers $Eu = \frac{p_\infty}{\frac{\rho V_\infty^2}{2}}$ comparable with the number of natural cavitation

$$\sigma = \frac{p_\infty - p_\vartheta}{\frac{\rho V_\infty^2}{2}}$$

the ventilated cavity will differ little from the natural one, and the flow coefficient.

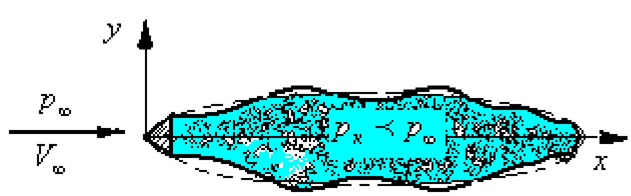

Figure 4. pulsating caverns.

gas blowing will tend to zero. In view of this consideration, another formula was proposed for calculating the flow rate of the gas blowing [15]:

$$Q = \mu_0 S_\kappa V_\infty \left(\frac{\sigma_\vartheta}{\sigma} - 1 \right) \qquad (11)$$

where Q is the volumetric flow referred to environmental pressure; $\mu_0 = 0{,}08,\ldots 0{,}1$-coefficient determined experimentally. The last formula can be given a different look:

$$C_Q = \mu_0 \frac{C_{xн}}{\sigma} \left(\frac{Eu}{\sigma} - 1 \right) \quad (12)$$

because $Eu \approx \sigma_\vartheta$. From formula (12) it can be seen that $C_Q \to \infty$ if the denominator tends to zero. With a fixed Froude number, this is achieved with a certain minimum number of cavitation

$$\sigma_{\min} = \sqrt[3]{\frac{2{,}5 C_{xн}(0)}{Fr_н^4}} \qquad (13)$$

case disk

$$\sigma_{\min} = \sqrt[3]{\frac{2}{Fr_н^4}} \qquad (14)$$

This implies the conclusion that no increase in gas flow gives a decrease in the number of cavitation below a certain minimum value.

III. CONCLUSIONS

Under certain conditions, the walls of the cavity acquire wave-like deformations and then they speak of pulsating caverns (Fig. 4). On the length of the cavity can be one, two ... five waves. Sometimes a cavern loses its general stability and it changes its volume stepwise or a portion separation of a cavity occurs. According to the theory of caverns, interesting results were obtained by E. V. Paryshev, D. I. Dianov [1,4].

IV. ACKNOWLEDGMENT

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