Flow calculations in intake structures of hydropower plants

Alexander Gazaryan^{1*}, and Oleg Glovatskii^{1,2}

¹Research Institute of Irrigation and Water Problems, Tashkent, Uzbekistan

²Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

Abstract. Research is carried out for design institutes in which the structures of pumping stations are designed. In the regional conditions of the Republic of Uzbekistan, when operating pumping stations, the problem of protecting equipment from pumps and fin is of particular importance, as well as the stability of water supply structures and the creation of favorable hydraulic conditions for supplying flow to the pumps. The main factors in the flow conditions are the calculations associated with suspended particles. The purpose of the research was to study the kinematics of the flow of intake structures in the problem of protecting equipment from pumps and fin. The research subject was to identify the regularities of the operation of intake structures depending on the structure of the flow supply. Experimental methods of hydraulic research of intake structures of pumping stations are used in the work. The analysis of the current state of water supply to the intake structures of pumping stations is carried out based on calculation schemes, which make it possible to establish the nature of the influence of flow parameters and soil particles on this process.

1 Introduction

Based on the operating conditions of pumping stations (PS), scientific research is being carried out in the world to improve their designs and ensure the efficiency of their operation. The Hydroelectric stations (HES) are a responsible complex. Their designing and usage require the acquaintance with broad around of hydromechanical discipline. The scheme of the count of the energy potential HES in a certain fold with consumption Q and pressure H must consider that part of pressure gets lost when a motion of water from the fence of water before unit [1-7].

In this direction, ensuring a normal water level in intake structures to prevent the operation of pumping units in the cavitation mode is of particular relevance.

Scientific research on intake structures is carried out in the fundamental research of the authors to study the problems of improving the theory of unsteady water movement in the "channel - pumping station" system to improve their interconnections [1-4]. It is the

* Corresponding author: gazaryan.lex@gmail.com

investigation of the laws of change in the kinematic characteristics of the flow in the intake structures of large pumping stations, mainly of the chamber and block type, and assessing the influence of the design of the intake structures on the hydraulic conditions for supplying water to the pumps, in particular, extreme ones, and on the operational parameters of the pumps during unsteady processes [8-18].

2 Methods

When performing the work, methods of hydraulic study of the flow structure based on well-known measurement methods were used. The reliability of the data obtained in the course of theoretical research is proved by mathematical methods of checking the adequacy of experimental results and field studies of a quantitative assessment of the conditions of water intake from the middle and extreme water intake chambers and objective data of these conditions on the reliability and efficiency of operation of the pumps [5, 6].

3 Results and Discussion

By intake structures, we mean structures that ensure the functioning of the main pumping equipment at the boundary sections of the flow before and after building the PS and HES. There are many descriptions of design schemes that allow us to establish the nature of the influence of flow parameters in these sections and suspended foreign particles (sediment) on this process (figure 1).

Fig. 1. The scheme of weighing particles of bottom soil

However, to this day, the question remains unanswered whether the weighing of soil particles is directly related to their flow over a time-averaged flow and the action of vertical turbulent velocity pulsations or the attracting force arising between a moving stream and a fixed bottom. The proposed schemes are not brought to a complete calculation of the weighing conditions and usually end with criteria-type relations [2, 7].

The dynamic effect of the flow on the particle of the bottom soil determines the separation of the particle from the system of surrounding particles and its weighing by the flow. Currently, it is believed that the action of the following forces determines the

weighing of particles of bottom soil [19-30]:

- Gravity

$$F_G = a_G \left(\frac{\rho_\tau}{\rho} - 1 \right) \frac{\pi d^3}{6} ; \quad (1)$$

- frontal pressure forces
-

$$F_x = \rho a_x C_D \frac{\pi d^2}{4} - \frac{u_k^2}{2} ; \quad (2)$$

- lifting power

$$F_z = \rho a_z C_n \frac{\pi d^2}{4} \frac{u_k^2}{2} ; \quad (3)$$

- adhesion forces

$$F_\sigma = \sigma_p \frac{\pi d^2}{4} ; \quad (4)$$

- hydrostatic loading forces

$$F_p = \rho g h a_p \frac{\pi d^2}{4} ; \quad (5)$$

Here a_G , a_x , a_z are the coefficients of the form of soil particles with a diameter d ; a_p is coefficient taking into account the area over which unbalanced hydrostatic pressure acts; C_D is coefficient of hydrodynamic resistance; C_n is the coefficient of lifting force; σ_p is soil resistivity to rupture (referred to the unit area of the midsection of the particle); u_k is current (instantaneous) speed at the level of the peaks of the roughness protrusions.

Let us consider in more detail each of the active forces.

Gravity F_G can be calculated correctly if the particle volume and density are known. Since the real particle, as already noted, differs in the shape of the ball, its real volume V_p will differ from the volume of the ball V_b with the same size

$$\frac{V_p}{V_b} = a_G . \quad (6)$$

Considering the forces acting on the particle, we note that the frontal pressure force can cause the rolling of single particles lying on a smooth surface or significantly protruding from the layer of surrounding particles; however, in this case, the horizontal directional frontal pressure force cannot cause the particle to weigh.

In a system of equal-sized particles, the force of frontal pressure F_x will be balanced by the reaction of the surrounding soil grains. Therefore, the only active force that determines

the separation of a particle under these conditions is the lifting force F_z .

The lifting force is determined by the highest actual velocity of flow around the particle u_k (velocity at the height of the roughness protrusions), the nature of the pressure distribution over its surface, the shape of the particle, and the lifting force coefficient C_n .

Among the forces holding the particle in the system, in addition to gravity, are adhesion forces. Cohesive forces act both in cohesive and dispersed soils, determining the mutual attraction of particles to each other. The adhesion forces of fine-grained dispersed soils and their effect on the erosion resistance of particles are considered earlier [8].

The hydrostatic pressure acting on a particle will not affect its stability only if the pressure is applied to all points of its surface and, thus, is balanced. This happens when the particle is surrounded by a layer of water of considerable thickness. However, there are suggestions that particles of bottom soil are affected by hydrostatic loading, increasing with depth [2].

To illustrate, we consider the effect of hydrostatic pressure forces on a rectangular particle with a "contact spot" with an area of ω on the lower face. The hydrostatic pressure forces acting along the lateral faces of the particle are balanced and do not affect its stability. Under the conditions of a free particle, the force $\rho gh d^2$ acts on its lower face, and the force $(h-d)d^2 \rho g$ acts on the upper face. The difference between these forces determines the strength of buoyancy (figure 2.). If the particle on the lower face has a "contact spot" that does not transmit hydrostatic pressure, then the force $\rho gh(d^2 - \omega)$ will act on the lower face (minus the area of the "contact spot"), and the buoyancy force will be equal

$$\rho gh(d^2 - \omega) - \rho g(h-d)d^2 \quad (7)$$

Fig. 2. Scheme for calculating hydrostatic loading

The resulting vertical force acting on the particle in the liquid at rest will be determined by the difference between the particle weight (in the air) $p_t g d^3$ and the buoyancy force. This force is greater than the force of gravity acting on a particle in water

$$(p_t - p)gd^3 + \rho gh\omega. \quad (8)$$

The second term in this expression is the force of the hydraulic load acting on the particle. Its value is determined by the area of the "contact spot" ω and the depth of immersion of the particle under level h . The above data on the thickness of the water layer make it possible to estimate the hydrostatic loading with the loading force $\Pi = pgh\omega$ and the force of gravity acting on the particle in the water $G = (p_r - p)gd^3$.

The calculation according to this ratio at $h=1$ m for particles of various sizes shows that the ratio of hydrostatic loading to the force of gravity acting on the particle increases with decreasing particle diameter (table.).

Table - The ratio of hydrostatic loading to particle weight

d mm	1.0	0.3	0.1	0.03	0.01
P/G	5·10-7	1.6·10-5	5·10-4	1.6·10-2	5·10-1

The calculation data show that for full-scale watercourses, the hydrostatic loading for particles $d>0.03$ mm is small compared to the force of gravity acting on the particle. It may not be taken into account in calculations of soil resistance to erosion. This conclusion is consistent with the measurement data of C. E. Mirtskhulava and the authors of [8, 9].

Let us consider in more detail the factors determining the lifting force F_z . The value of this force depends on the square of the actual speed at the top of the protrusion of the roughness u_k . Therefore, the success of the quantitative determination of the particle weighing conditions largely depends on the accuracy of the speed calculation. The speed is determined differently depending on the resistance mode. The resistance mode of the river flow is known to be determined by the parameter uk_s/v . In the absence of bottom channel forms, the value of k_s is close to d , and in this case, the parameter uk_s/v determines the regime of flow around the soil grains [31-35].

In the presence of bottom channel forms, the channel resistance increases sharply. The equivalent roughness k_s determined by the resistance significantly (sometimes by several orders of magnitude) exceeds the value d . Therefore, at high values of uk_s/v , the parameter ud/v may remain small. In quadratic resistance mode with $ud/v>50$

$$u_k/u=6.75.$$

(9)

The vertices of particles oriented vertically with the average diameter (at $z_{\kappa} = \frac{d}{2}$) will flow around at a lower speed equal to $6.75u$.

Initial weighing of protruding particles will occur during periods of action of the largest longitudinal velocity pulsations.

The measurement data show that the standard of longitudinal ripples near the wall is close to an average of $2.7u$, while the largest ripple is $8.1u$, which is close to the average velocity.

The data obtained show that the maximum recorded speeds when cleaning from bottom sediments near the bottom are on average 1.5 times higher than the average value of the rate during siltation [5, 8].

The calculation of the free cross-sections in the flowing part of the pumps according to the existing methods is determined by the high-speed pressure calculated from the average speed and does not consider the changes in the velocity diagram when changing the pump modes. The proposed new elements eliminate the disadvantages of these techniques [10-13]. The authors have created new pump designs with reduced wear and increased ability to control the modes [14-17]. Vortex zones are formed at the walls in the spiral chamber, in

the suction nozzle, and the discharge nozzle, and when installing the separating spiral planes, the transit flow speed increases, and, accordingly, the vortex zones are practically eliminated. At values $\sigma_y < \sigma_{kp}$, the vortex bundle breaks up into smaller ones, which leads to a change in the period and shape of the pressure pulsation. The range of pulsations at values σ_y of y close to σ_y increases and then decreases.

For high-frequency pulsation, the process proceeds somewhat differently. The main difference lies in the fact that the pressure pulsation frequency decreases near the cavitation stall, and the swing increases (figure 3 b).

Fig. 3. Combined oscillograms of pressure pulsations: a) - $a_0=14$ mm, $n_1'=110$ r/m; б) - $a_0=18$ mm, $n_1'=90$ r/m; в) - $a_0=22$ mm, $n_1'=80$ r/m.

4 Conclusions

1. Studies carried out at RIWP with the participation of the authors have shown that the obtained ratios make it possible not only to use scientifically grounded methods for calculating the known intake structures of the PS (front chambers, water intakes), but also to analyze the design schemes of dynamic and kinematic flow supply conditions, which allow to establish the nature of the influence of flow parameters and soil particles of bottom and suspended sediments on the process of their layout [18,19].
2. For natural watercourses of the intake structures of the PS and HES, the hydrostatic surcharge for particles $d > 0.03$ mm turned out to be small in comparison with the gravity acting on the particle and may not be taken into account in the calculations of soil resistance to erosion. The data obtained show that the maximum recorded velocities when cleaning from bottom sediments, on average, are 1.5 times higher than the average value of the velocity during silting.
3. Recommendations for selecting rational designs and operating modes of intake structures and main equipment of the PS allow making technical and economic comparisons of options at the design stage of pumping stations and take into account during operation.
4. The developed method for calculating the flow paths of pumps based on applying the formulated methods of applying the theory of hydrodynamics makes it possible to design PS and HES with optimal characteristics [20,21]. The method allows for the modernization of the flow parts of hydrounits of various types and different parameters.

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