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METHOD FOR CALCULATING SEDIMENT TRANSPORT IN THE WATER SUPPLY CANAL TO THE AMU-ZANG PUMPING STATION

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Abstract. This article presents calculations for determining sediment transport in the canal supplying water to the Amu-Zang pumping station, with the aim of preventing sediment deposition in the canal and ensuring an optimal water-flow velocity.

Keywords: pumping station, canal, hydraulic structure, sediment, transport, river, flow, velocity.

Hydraulic structures built in canals have a significant effect on their operating regimes. In particular, a pontoon-shaped structure secured with a metal cable and installed at the head of the water supply canal to the Amu-Zang pumping station (hereinafter referred to as the structure) is positioned relative to the flow direction and considerably affects the flow's sediment-transport capacity (Fig. 1).γ~83°

As a result, although the canal was designed for a particular flow regime, the actual average flow velocity is lower, leading to sediment deposition in the water supply canal. V_{design}~0.9$^{m}/_{s}$ V_{actual}~0.6$^{m}/_{s}$

The studies of A. V. Karaushev, N. N. Kapitonov, K. V. Razumikhina, V. V. Romanovsky, A. D. Shvartsman, Z. G. Vorobyov, G. V. Lopatin, G. I. Shomov, V. M. Makkaveev and other researchers have examined water flow and sediment transport in rivers and canals. Suspended and bed sediments transported by water flow depend on the channel's morphometric characteristics and the hydraulic parameters of the flow. In turbulent flow, the velocity distribution across the flow section (u) depends on the



turbulent exchange coefficient (A), the sediment-transport capacity of the water flow, and other factors. Methods for calculating sediment transport in rivers and canals are mainly based on the semi-empirical theory of turbulence. One of the key parameters of this theory is the turbulent exchange coefficient. However, this coefficient is largely disregarded in empirical and semi-empirical formulas currently used in practice to solve sediment-transport problems.

Experimental results indicate that the turbulent exchange coefficient A varies with the flow's hydraulic parameters and the channel's morphometric parameters, and changes along the coordinate directions. In particular, it varies along the flow length.

In accordance with the objectives of this study, parameter A is taken into account when developing a semi-empirical expression for sediment transport in the water supply canal, considering the effect of the structure's elements on the hydraulic parameters of the water flow.

For this purpose, the XOZ plane is taken along the water surface, with the y-axis directed vertically downward, and an elementary flow volume in the shape of a parallelepiped is isolated from the flow.

The volume of the parallelepiped-shaped elementary flow is dw = dx dy dz, and its faces are assumed to be parallel to the corresponding coordinate planes. The faces of the parallelepiped are numbered as follows: face 1 is opposite to the flow direction; face 2 is in the flow direction; face 3 lies along the free surface of the water; face 4 lies on the channel-bed plane; and face 5 lies in the XOY coordinate plane. To simplify the calculations,

the water turbidity S is assumed to remain constant along the z-axis. In this case, the transport of sediment through faces 5 and 6 is equal to zero. We derive the balance equation describing the change in the mass of suspended sediment in the parallelepiped-shaped elementary flow.



q_{s1}, q_{s2}, q_{s3}Let the relevant quantities represent the unit sediment-discharge rates through faces 1, 2, 3, and so on, respectively. Then, over a time interval, the sediment transported through the entire area of the faces is as follows:δt

For face 1 – …; for face 2 – …$q_s, dsdy\delta t q_{s2}, dsdz\delta t$

As a result, expressions are obtained for the unit sediment mass flux passing through all faces of the elementary water-flow volume:

$$\begin{cases} q_{s1} = -\frac{A_1}{\rho}\left(\frac{DS}{Dx}\right)_1 + v_x\left[S - \left(\frac{DS}{Dx}\right)_1 \cdot \frac{dx}{2}\right], \\ q_{s2} = -\frac{A_2}{\rho}\left(\frac{DS}{Dx}\right)_2 + v_x\left[S - \left(\frac{DS}{Dx}\right)_2 \cdot \frac{dx}{2}\right] \\ q_{s3} = -\frac{A_3}{\rho}\left(\frac{DS}{Dx}\right)_3 + uS_3 \\ q_{s4} = -\frac{A_4}{\rho}\left(\frac{DS}{Dx}\right)_4 + uS_4 \end{cases} (1)$$

where: … is the sediment discharge; Ai is the turbulent exchange coefficient; S is water turbidity; … are the flow velocities in the corresponding directions [m/s]; and u is the velocity vector directed toward the channel bed along the y-axis under the action of gravity [m/s]. As a result, the change over an elementary time interval in the turbidity S of the water flowing through the entire volume w is obtained.$q_{si}\left[\frac{kg}{m^2 s}\right]\left[\frac{N \cdot s}{m^2}\right]\left[\frac{kg}{m^3}\right] v_x v_y \delta t \frac{DS}{Dx}\delta t$

The change in sediment concentration throughout the entire volume of the elementary flow can therefore be expressed as follows:

$$dw\frac{DS}{Dt}\delta t = (q_{s1} - q_{s2})dy \cdot \delta t + (q_{s3} - q_{s4})dzdx\delta t (2)$$

Dividing equation (2) by … and substituting into equation (2) the expressions for … from the system of equations (1), we obtain the following equation:$\delta t q_{si}$

$$-\frac{1}{2}\left[\left(\frac{DS}{Dx}\right)_1 + \frac{A_1}{\rho}\left(\frac{DS}{Dx}\right)_2\right] v_x dxdydz + (3)$$

According to the experimental results, coefficient A and water turbidity S vary monotonically with the coordinates. Therefore,

$$\begin{cases} A_2\left(\frac{DS}{Dx}\right)_2 - A_1\left(\frac{DS}{Dx}\right)_1 = \frac{D}{Dx}\left(A\frac{DS}{Dx}\right)dx, \\ A_4\left(\frac{DS}{Dx}\right)_4 - A_3\left(\frac{DS}{Dx}\right)_3 = \frac{D}{Dy}\left(A\frac{DS}{Dx}\right)dy, \\ \frac{1}{2}\left[\left(\frac{DS}{Dx}\right)_1 + \frac{A_1}{\rho}\left(\frac{DS}{Dx}\right)_2\right] = \frac{DS}{Dx}, \\ S_4 - S_3 = \frac{DS}{Dy}dy \end{cases} \quad (4)$$

$dw = dxdydzTaking$ *into account that … and substituting the expressions from the system of equations (4) into equation (3), we obtain the following equation:*

$$\frac{DS}{Dt} + v_x\frac{DS}{Dx} = \frac{1}{\rho}\left[\frac{D}{Dx}\left(A\frac{DS}{Dx}\right) + \frac{D}{Dy}\left(A\frac{DS}{Dy}\right)\right] - u\frac{DS}{Dy} \quad (5)$$

If A = const in equation (5) and the flow is considered one-dimensional, occurring only along the x-axis, the mass-transport equation takes the following form:

$$\frac{DS}{Dt} + V_0\frac{DS}{Dx} = \frac{A}{\rho}\frac{D^2S}{Dx^2} \quad (6)$$

Equation (6) describes the dissipation of water-flow energy in the supply canal due to the hydrodynamic resistance generated by the structure shown in Figures 2 and 3.

We now seek an analytical solution to equation (6) using the method of separation of variables. For this purpose, the following condition is adopted as the initial boundary condition for equation (6):

$$S = (x,0) = \sum_m b_m e^{imx} \quad (7)$$

Using the method of separation of variables, we seek a solution to equation (6) in the following form: $(8) S(x,t) = \sum_m b_m \lambda \cdot e^{imx} = \sum_m b_m S_m(x,t)$

Here, … is a harmonic function. We write the harmonic function in the following form:$S_m(x,t)$

We express the parameter in equation (9) in logarithmic form. Then the harmonic function in equation (9) takes the following form: $(10)\ \lambda\ln(\lambda) + aim = -\mu m^2 \quad or \quad \lambda = \exp(-aim)\cdot\exp(-\mu m^2) S_m(x,t) = \exp(-\mu m^2 t)\cdot\exp\big(im(x-at)\big)$

The qualitative characteristics of the solution (8) can be determined from the behavior of function (10). As a result, we obtain the solution to equation (6) in the

following form:

$$S_m(x,t) = \Sigma_m b_m exp\left\{im\left[x - \left(\frac{A}{\rho} - V_0 m^2\right)\cdot t\right]\right\}(11)$$

Based on the results of this study, a semi-empirical expression for sediment transport in the water supply canal was developed, taking into account the effect of the structure's elements on the hydraulic parameters of the water flow.

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