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CALCULATION OF HYDRAULIC PARAMETERS OF WATER FLOW IN THE WATER SUPPLY CHANNEL OF PUMPING STATIONS

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Abstract. This article presents the calculation of hydraulic parameters of water flow in the water supply channel of pumping stations. The water flow of the supply channel and the channel parameters were assessed through mathematical modeling, and the results are presented.

Keywords: Flow, pumping station, water discharge, water level, sediment, depth, level, riverbed, river, channel.

The old water supply channel for the Amu-Zang-1 and temporary pumping stations, which draws water from the Amu Darya River, was built in 1972. However, due to a significant decrease in the water level of the Amu Darya over the years and the rapid silting of the water supply channel with sediment (filling up within one week when the pumping units were turned off), a new water supply channel for the Amu-Zang-1 pumping station was excavated in 2005.

The length of this channel is L=1702 meters, width B=60 meters, depth H=10 meters, slope m=1.5 meters, gradient i= 0.0002÷0.0003, and water conveyance capacity Q=120 m³/sec.

The calculations are carried out based on the scheme presented in Figure 3.1.

We aim to improve the method for calculating the average velocity, which is the main parameter of the water flow in the section of the Amu Darya River where the water intake structure for the Amu-Zang-1 pumping station is located (Fig.1).

In the river cross-section (1-1), let the width of the riverbed along the water surface be B_1, and the average velocity of the water flow in this section be V. In cross-section (2-2), let the width along the water surface be B_2, and the average velocity of the water flow in this section be V_1.

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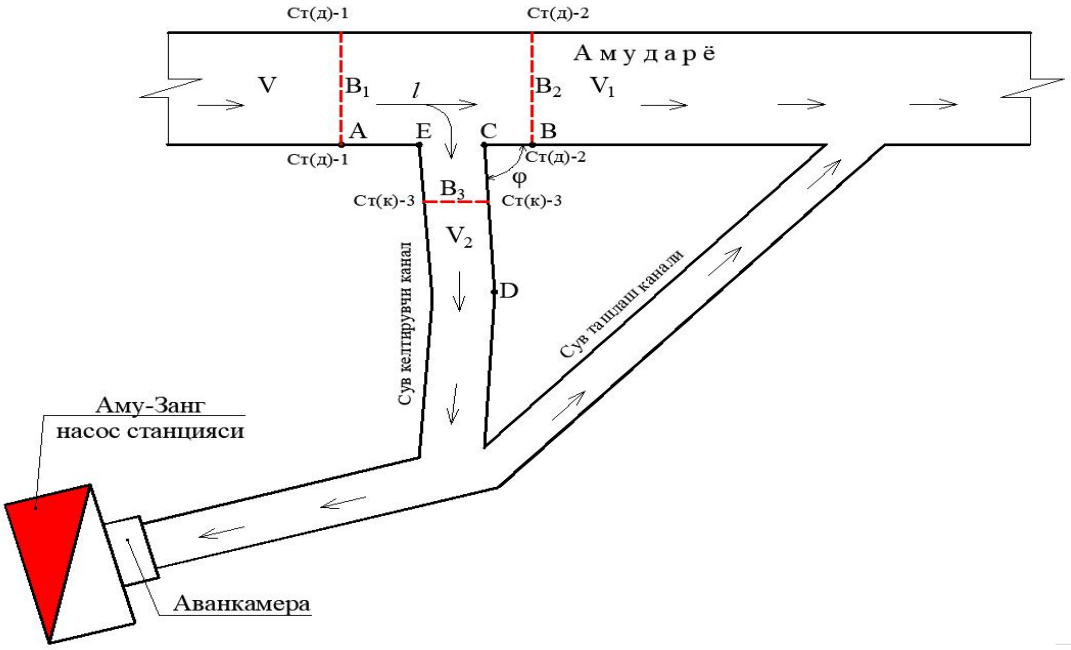


Figure 1. Pattern of water flow movement.

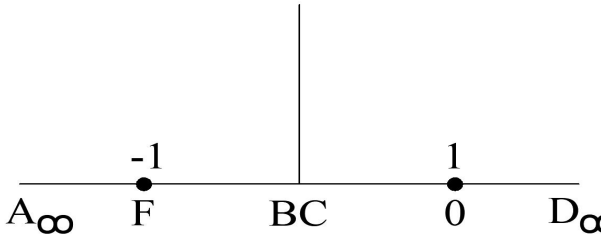
We denote the width of the riverbed along the water surface in cross-sections (1-1) and (2-2) of the river, and the average velocities of the water flow in these sections, as V, V_1 and B_1, B_2, respectively. We designate cross-section (3-3) at the beginning of the water supply channel for the Amu-Zang-1 pumping station. In cross-section (3-3), the width of the channel along the water surface is denoted as B_3, and the average velocity of the water flow in this section as V_2. Let the angle between the river and the water supply channel be φ.

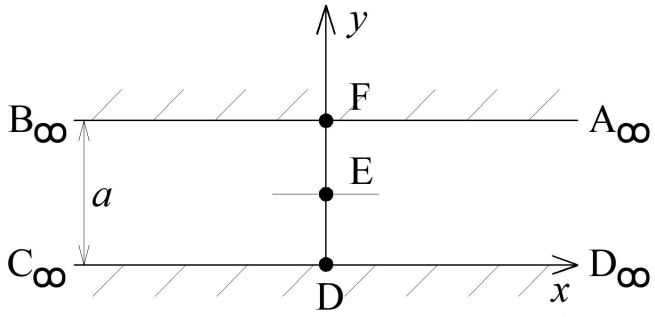
The results of long-term studies carried out on the water supply channel of the Amu-Zang-1 pumping station show that due to the incorrect selection of the angle φ between the water supply channel and the riverbed, the presence of a structure with 30 metal debris-catching screens fixed with a long cable at the river entrance of the water supply channel, or factors related to the operating mode of the units at the Amu-Zang-1 pumping station, the intensity of sediment deposition in the water supply channel is high, which negatively affects the channel's water conveyance capacity.

Therefore, we set the goal of systematically and consistently solving the above-mentioned scientific and technical problems.

Before solving this problem, we consider a new method of mapping the planes of complex functions from the theory of "Complex Variables".

a) z – plane





б) ξ - plane

Figure 2. Mapping of complex function planes to new planes.

In the z – plane shown in Figure 2, A_∞ B_∞ C_∞ D_∞– the width of the infinite plane is *a* and we assume that points B_∞ and C_∞ pass as images at point $\xi = 0$, respectively.

Then we assume that the origin of coordinates 0 – goes to point $\xi = 1$, point F(z=*ai*) goes to point $\xi = -1$, and point D_∞ in turn, goes to point $\xi = \infty$ (Figure 3.2). As a result, the angle at the edge B_∞ C_∞ becomes equal to "zero", and we obtain the following expression:

$\frac{dz}{d\xi}=K\xi^{-1}$, $z=K\cdot\ln\xi+L$

We choose the coordinate axes as shown in Figure 2. Then we define the logarithm such that when $\xi = 1$, the quantity z equals "zero". Then

$0=K\cdot\ln 1+L$, $ai=K\cdot\ln -1+L$

Thus, L=0 and $iK\pi=ia$. As a result, we obtain:

$$Z=\frac{a}{\pi}\cdot\ln\xi \text{ or } \xi=e^{\pi z/a} \qquad (1)$$

The coordinate lines, i.e., the straight lines *x*=const, transform into circles around $|\xi|$ =const, while the straight lines *y*=const transform into rays (i.e., half-lines) argξ=const emanating from the origin of the ξ-plane. If the points $A\infty$ and $D\infty$ map to ξ=0, then the mapping takes the following form:

$$\xi=-e^{-\pi z/a}$$

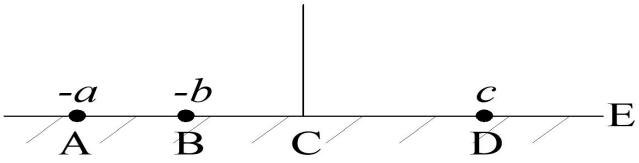
In some cases, it is advisable to place the origin of coordinates in the z -plane at point E.

Then the corresponding mapping is performed by replacing the quantity z with ***z+i a/2*** Then from expression (1) we obtain:

$$z=\frac{a}{\pi}\ln\xi-\frac{ia}{2}, \text{ ёки } \xi=ie^{\frac{\pi z}{a}} \qquad (2)$$

Now let's consider the scheme shown in Figure 1. The flow line ***l*** shown in the diagram splits at the critical point C into flow lines CB and CD. That is, along line ***l*** the water flow moves along the main riverbed, while the flow on the right side moves along the water supply channel for the Amu-Zang-1 pumping station. On the flow line AED, the water flow rapidly changes its configuration at point E, and the flow velocity values change rapidly.

In the next stage, applying the above-mentioned method of mapping complex function planes to a new form, we consider the shape of the water flow shown in Figure 3 as the ***z*** plane and map it conformally onto the ξ plane. In performing these operations, it is necessary to ensure that point E tends along the riverbed and point C coincides with point $\xi = 0$ (Figure 3).



ξ–plane

Figure 3. Image of the shape in the *z* plane on the *ξ*– plane.

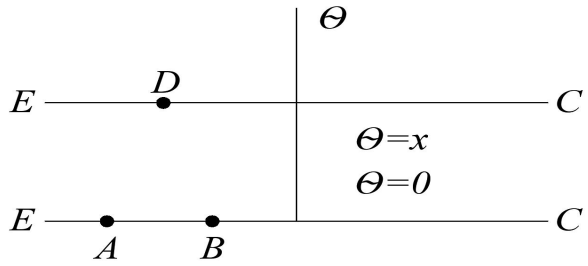
We assume that points A, B, D correspond respectively to points ξ=-*a*,-*b*,*c* in the ξ plane. Considering the above, we consider the following expression:

$$Q=ln\frac{V}{u}=ln\frac{V}{q}+i\theta \quad (3)$$

Here*:* $u=qe^{-i\theta}$

Along the river, the angle θ is equal to zero, i.e., θ=0, while along the water supply channel, $\theta=\varphi$. At point C, q=0, and the quantity Q tends to infinity at that point.

Thus, in the complex Q-plane, we obtain the shape shown in Figure 4:



θ–plane

Figure 4. Shape of water flow movement in the Q-plane.

Conformally mapping the θ–plane to the ξ-plane, as shown in Figure 2, we obtain:

$$\xi=e^{-\theta\frac{\pi}{\varphi}}=-(\frac{u}{V})^{\frac{\pi}{\varphi}} \quad (4)$$

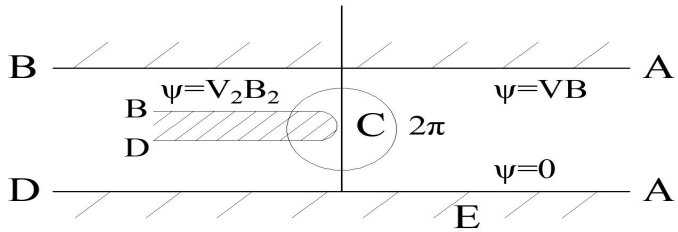
To construct the corresponding region in an arbitrary ω-plane, we assume that the straight line ψ=0 corresponds to the line AED. Then we have the following condition:

$$\begin{cases} If\ AB,\ then\ \ \psi=VB \\ If\ CD,\ \ then\ \psi=V_2B_3 \\ If\ CB,\ then\ \psi=V_2B_3 \\ \ \ IfAB,\ then\ \psi=V_2B_2+V_1B_1 \end{cases} \quad (5)$$

From condition (5), we obtain:

$$VB=V_2B_2+V_1B_1 \quad (6)$$

Bringing $\varphi=\infty$ to point A, we have $\varphi=-\infty$ at points B and D. As a result, we obtain the region shown in Figure 5.



ω–plane

Figure 5. Shape of water flow movement in the river and channel in the *ω*-plane.

To map the ω -plane to the ξ-plane, we have the following expression:

$$\frac{d\omega}{d\xi}=k_1\xi(\xi+a)^{-1}(\xi+b)^{-1}(\xi-c)^{-1}=-\frac{k_1a}{(a-b)(a+c)}\frac{1}{k_1+a}=$$
$$+\frac{k_1b}{(a-b)(b+c)}\frac{1}{k_1+b}+\frac{k_1c}{(a+c)(b+c)}\frac{1}{k_1-c} \quad (7)$$

After integrating expression (7) and performing relevant mathematical operations, we obtain:

$$\omega=\frac{k_1a}{(a-b)(a+c)}\ln\frac{\xi+a}{\xi-c}+\frac{kk_1,b}{(a-b)(a+c)}\ln\frac{\xi+b}{\xi-c}+L_1 \quad (8)$$

On line DE, $\psi = 0$, and the quantities $(\xi + a)$, $(\xi + b)$ and $(\xi - c)$ have the same sign, the corresponding logarithm values belong to the set of real numbers, and the quantity L_1 also has certainty. Furthermore, at point C, $\varphi = 0$, $\psi = V_2B_2$, and $\xi = 0$. Thus, the constant L_1 pertains to the imaginary part of the complex number. Hence, $L_1 = 0$, and at $\xi = 0$ we obtain:

$$-v_2B_2=\frac{k_1\pi}{(a-b)(a+c)}+\frac{k_1b\pi}{(a-b)(a+c} \quad (9)$$

As a result, along line FI, we have $\psi = VB$. In this case, the quantity $(\xi + a)$ is positive, while $(\xi + b)$ and $(\xi - c)$ are negative. Then we obtain:

$$-VB=\frac{k_1a\pi}{(a-b)(a+c)} \quad (10)$$

From expressions (10) and (6), we obtain:

$$\frac{k_1b\pi}{(a-b)(b+c)}=V_2B_2-VB=-V_1B_1, \text{ or}$$
$$\omega=\frac{VB}{\pi}l_n\frac{\xi+a}{\xi-c}-\frac{V_1B_1}{\pi}l_n\frac{\xi+b}{\xi-c} \quad (11)$$

Considering the above expression, from expression (4) we obtain:

$$-\frac{d\omega}{dz}=u=V^{-i\varphi}\xi^{\frac{a}{\pi}} \quad 12)$$

From equation (10), we find:

$$\frac{d\omega}{d\xi}=\frac{VB}{\pi}\cdot\frac{1}{\xi+a}-\frac{V_1B_1}{\pi}\frac{1}{\xi+b}+\frac{V_1B_1-VB}{\pi}\cdot\frac{1}{\xi-c} \quad (13)$$

At y=0, u=0. From equation (13), $\frac{d\omega}{d\xi}=0$, resulting in the following equality from equation (13):

$$\frac{VB}{a}-\frac{V_1B_1}{b}+\frac{VB-V_1B_1}{c}=0 \quad (14)$$

Substituting expressions (4) and (5) into equation (14):

$$VB=V_1B_1\left(\frac{V_1}{V}\right)^{-\frac{\pi}{\varphi}}-V_2B_2\left(\frac{V_2}{V}\right)^{-\frac{\pi}{\varphi}}, \text{ or}$$
$$\left(\frac{V_1}{V}\right)^{1-\frac{\pi}{\varphi}}\frac{B_1}{B}-\left(\frac{V_2}{V}\right)^{1-\frac{\pi}{\varphi}}\frac{B_2}{B}=1 \quad (15)$$

We introduce the following notations into equation (15):

$$\frac{B_1}{B}=M_1,\ \frac{B_2}{B}=M_2,\ \frac{B_1V_1}{BV}=M_3 \quad (16)$$

Then we obtain the following system of equations:

$$\left.\begin{array}{l} M_3+M_2\frac{V_2}{V}=1, \\ \frac{V_2}{V}=\frac{1-M_3}{M_2}, \\ \frac{V_1}{V}=\frac{M_3}{M_1}. \end{array}\right\} \quad (17)$$

From the system of equations (17), we find the first equation via expression (6), and substitute the remaining two equations into expression (15), obtaining:

$$M_1\left(\frac{M_3}{M_1}\right)^{1-\frac{\pi}{\varphi}}-M_2\left(\frac{1-M_3}{M_2}\right)^{1-\frac{\pi}{\varphi}}=1 \quad (18)$$

According to the experimental results conducted at the research site, M_1, M_2 and φ are known, and the value of M_3 is determined from the transcendental equation (18).

Thus, the influence of the hydraulic structure at the head of the water supply channel for the Amu-Zang pumping station on the water flow was calculated.

Scientific and technical problems related to the operational regime of channel banks and the silting of channels with sediment in damless water intake channels on large rivers have not been sufficiently studied. Among the factors causing a decrease in the water flow's sediment transport capacity are the changes in water flow parameters due to the interaction of the water flow with debris-catching structures during water intake in irrigation channels.

The environment or structures resisting the water flow in the channel constitute a complex hydraulic process dependent on changes in the configuration of the water flow in the channel. Specifically, inertial forces of the flow, forces lifting elements of structures in the flow direction, and various characteristics of forces acting on the obstacle manifest themselves. Among these, the lifting forces exerted by the water flow on the structural elements in the flow direction are dissipative in nature, depending on the interaction of various forces related to the overall effective velocity of the water flow.

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