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Field Studies of the Dispersed Flow

I.E.Makhmudov
Doctor of Technical Sciences, Professor, Head of the laboratory. "Modeling of hydrodynamic processes of hydraulic engineering and land reclamation" Scientific Research Institute of Water Problems, Tashkent, Uzbekistan.
Email address: ismiti@minwater.uz

B.Khamdamov
Ph.D., Associate Professor of the Department of Tashkent State Technical University named after I.A. Karimov. Email:_khamdamov_55@mail.ru

N.K.Murodov
Senior Researcher at the Scientific Research Institute of Irrigation and Water Problems, Tashkent, Uzbekistan.
Email: ismiti@minwater.uz

M.O.Ruziev.
Doctoral student. Scientific Research Institute of Irrigation and Water Problems, Tashkent, Uzbekistan.
Email: ismiti@minwater.uz

J.E.Shonazarov
Doctoral student. Scientific Research Institute of Irrigation and Water Problems, Tashkent, Uzbekistan.
Email: ismiti@minwater.uz

Abstract

Based on the analysis of previous research, there appears to be insufficient understanding regarding the maintenance of the main water intake structure connecting the Amu Darya River to the Karshi main canal, particularly regarding hydraulic processes leading to erosion and structural damage at connecting points of the channel protection system. Along the water intake segment from Cape Pulizindan on the Amu Darya to the Karshi mainline, there exists a protective structure for the canal banks, functioning not only to shield against adverse water flow effects but also to direct water flow from the river into the canal. To ensure the reliable and efficient operation of supply channel NS-I and the adequate provision of water, a coastal protection structure was constructed within the Amu Darya River bed at an angle of 107 degrees relative to the river's water flow axis. However, this positioning results in water velocity exceeding critical erosion thresholds, leading to deformation of the

embankment's protective structure. During high-water months (June and July), the average water flow rate interacting with this structure reaches approximately 1.7 m/s.

Keywords: Pumping station, canal, structure, flow, hydraulics, deformation, flow rate.

INTRODUCTION

The erosion of the stone surface of the coastal protection structure, constructed from durable rocks and concrete, is attributed to the movement of solid clay particles carried by water flow. This erosion compromises the stability of the rocks, leading to their degradation and ultimately causing damage to the coastal protection structure.

This phenomenon is intricately linked to several hydraulic factors: the erosion of a solid surface boundary layer by the water flow and suspended sediment particles within it; the formation of turbulent and vortex regions near the eroded surface; and the mutual alteration of flow parameters affecting the dispersed water flow interacting with the solid surface. It's important to note that the inertia of clay particles suspended in the liquid and the solid surface's particles is directly influenced by their geometric shapes and flow patterns, with variation occurring particularly for uniform particles across different conditions.

The interaction between the dispersed flow and the solid surface results in significant alterations in the concentration of clay particles within the flow compared to its initial calm state. As these dispersed flow particles move along the boundary regions of the solid surface, there are substantial changes in velocity gradient and clay liquid particle concentration, making their distribution across the surface a highly intricate process.

Main body. In order to derive the Stokes criterion, we formulate the forces exerted on solid surface particles (constituting elements of a coastal protective structure) by the dispersed water flow using the following equations:

$$\left.\begin{aligned} F &= F_1 + F_* \\ F_* &= F_2 + F_3 \end{aligned}\right\}$$

Where:

- F represents the total forces exerted on a solid surface (comprising elements of a coastal protection structure) by dispersed water.
- F_1 denotes the force of hydrostatic pressure.
- F_2 represents the frictional force.
- F_3 signifies the force exerted on solid surface particles by particles of turbid liquid within the dispersed water mixture (acting in the opposite direction to the shear force acting on solid surface particles).
- λ stands for the coefficient of hydraulic friction.

These forces are defined within the system of equations by the following expressions [1,3]:

$$
\left.\begin{aligned}
F = \frac{4\pi \cdot a^3}{3}\rho_1^0\left(\frac{dw_{12}}{dt} - g\right), F_1 = \frac{4\pi \cdot a^3}{3}\rho_1^0\left(\frac{dV_1}{dt} - g\right)\\
F_2 = C_\mu \pi a^2 \frac{\rho_1^0 \omega_{12}^2}{2}\frac{W_{12}}{\omega_{12}},\\
F_3 = \frac{2\pi \cdot a^3}{3}\rho_1^0\left(\frac{dV_1}{dt} - \frac{dV_2}{dt} + \frac{3}{a}\frac{da}{dt}w_{12}\right),\\
C_\mu = C_\mu(R_e, C_2) \text{ ёки } C_\mu = Stk = \lambda\psi\\
R_e = \frac{2a\rho_1^0 W_{12}}{\mu},\\
W_{12} = V_1 - V_2
\end{aligned}\right\}
$$

In the context of the equations provided, C_μ denotes a dimensionless coefficient or Stokes number, which characterizes the resistance encountered by particles flowing on a solid surface due to the presence of dispersed flow. Additionally, a represents the displacement of shore protection elements resulting from the influence of dispersed water flow, with measurements expressed in centimeters.

When considering equations (1) and (2) together, we derive the following equation:

$$\frac{dV_2}{dt} = \frac{3}{4}C_\mu \frac{\omega_{12}}{a} \cdot W_{12} + \frac{dV_1}{dt} + \frac{3}{a}\frac{da}{dt}W_{12}$$

With respect to the initial conditions, where $-\omega_{12} = \omega_0$ and $W_{12} = V_0$, equation (3) assumes the following form

$$\frac{dV_2}{dt} = \frac{3}{4}C_\mu \frac{\omega_0}{a} \cdot V_0 + \frac{dV_1}{dt} + \frac{3}{a}\frac{da}{dt}V_0 \quad (4)$$

$$\frac{d\omega_2}{dt} = \frac{3}{a}\frac{da}{dt}V_0 + \frac{3}{4}C_\mu \frac{\omega_0}{a}V_0 \quad (5)$$

we solve the differential equation (5) with equation (4) in the form of a single system

$$\frac{dW_{12}}{dt} = \frac{3}{a}\frac{da}{dt}V_0 + \frac{3}{4}C_\mu \frac{\omega_0}{a} \cdot V_0$$

$$\frac{da}{dt} = \omega_0 - \frac{j_{21}}{4\pi a^2 \rho_1^0} \quad (6)$$

From the system of equations (6) we obtain the following simple differential equation:

$$\frac{dW_{12}}{dt} = 3 \cdot \frac{V_0}{a}\left[\omega_0 - \frac{j_{21}}{4\pi a^2 \rho_1^0}\right] \cdot t + \frac{3}{4}C_\mu \frac{\omega_0}{a} \cdot V_0 \cdot t + C \quad (7)$$

integrating a simple differential equation (7);

$$W_{12} = 3 \cdot \frac{V_0}{a}\int \left[\omega_0 - \frac{j_{21}}{4\pi a^2 \rho_1^0}\right] dt + \frac{3}{4}C_\mu \frac{\omega_0}{a} \cdot V_0 \cdot t + C$$

Assuming that j_{21}=const, we get the following expression:

$$W_{12} = 3 \cdot \frac{V_0}{a}\left[\omega_0 - \frac{j_{21}}{4\pi a^2 \rho_1^0}\right] \cdot t + \frac{3}{4}C_\mu \frac{\omega_0}{a} \cdot V_0 \cdot t + C \quad (8)$$

where C=const.

Field measurements were conducted along the river section using a SONTEC S5 Doppler profiler coupled with a GPS device. The analysis revealed that within the channel segment (1d-1d), the water flow rate amounts to 993.5 m3/s, covering a total area of 1219.55 m2, with an average water velocity of 1.7 m/s and a maximum depth of 3.66 m.

At the gate (1k-1k), measurements were taken across the channel's cross-section at PC0+50 using a SONTEC S5 Doppler profiler and GPS device. The examination indicated a water flow rate along the channel alignment (1k-1k) of 182.3 m3/s. The cross-sectional area (live shear surface) was found to be 236.75 m2, with an average water velocity of 0.77 m/s and a maximum depth of 6.5 m.

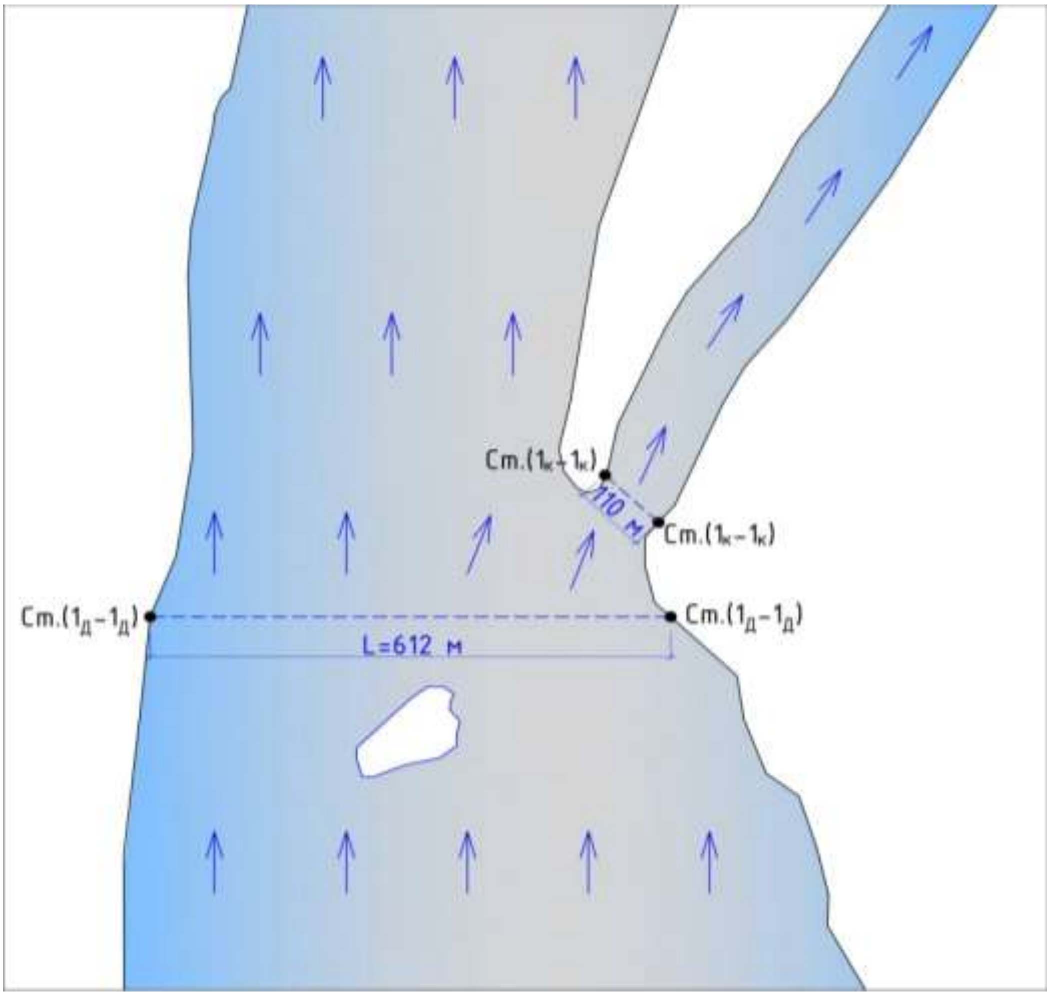

Fig.1.Gates made in field studies (1d-1d)-gate.

As a consequence, we have derived the equation governing the motion of dispersed water flow.

Figure 1 illustrates graphs depicting field studies conducted during May-June 2023 to ascertain the hydraulic parameters of the water flow.

A numerical experiment based on equation (8) was conducted using data from the field studies. From the experiment's results, the average value of W12 was determined to be 0.93 m/s. Utilizing the average value of W12p obtained from equation (8), we deduce the following empirical expression:

$$\mathrm{Stk} = \frac{4}{3}\frac{a}{t}\cdot\frac{W_{12\mathrm{cp}}}{W_0\cdot V_0} - \frac{4}{W_0}\left[W_0 - \frac{j_{21}}{4\pi a^2\cdot\rho_1^0}\right] \quad (9)$$

Consequently, we have derived a novel expression for the Stokes criterion.

Upon considering the expression Stk = λψ within the system of equations (2), we derive a semi-empirical expression for determining the coefficient of hydraulic resistance in the quadratic resistance region:

$$\lambda = \frac{1}{\psi}\left\{\frac{4}{3}\frac{a}{t}\frac{W_{12\text{cp}}}{\omega_0 V_0} - \frac{4}{\omega_0}\left[\omega_0 - \frac{j_{21}}{4\pi a^2 \rho_1^0}\right]\right\} \quad (10)$$

[2,4] in the literature, the expression ψ is presented in the following form:

$$\psi \approx \frac{3}{2} C_2^{\frac{1}{3}}$$

Conclusion:

1. Several scientific research endeavors have been conducted to investigate the intricate hydrological, hydraulic, and morphological processes within the Amu Darya River region, particularly concerning the presence of substantial damless water intake structures and river flow regulation infrastructure. Nevertheless, there remains a notable gap in research addressing the assurance of safe and dependable operation for the primary water intake structure connecting the Amu Darya River to the Karshi main canal. Additionally, insufficient attention has been given to understanding the hydraulic processes leading to erosion and structural degradation along the protective structure of the riverbed in adjacent sections.
2. Through application of the law of conservation of mass, hydraulic models have been developed. These models accurately depict the phase density of surrounding mediums, the volume concentration of clay sediment particles, and alterations in particle velocity at the interface between dispersed water and solid surfaces (constituting elements of a coastal protection structure)

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