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# METHODS FOR CALCULATING OPTIMAL CONDITIONS FOR PREVENTING BED EROSION AND SEDIMENT DEPOSITION IN IRRIGATION CANALS

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**Abstract**
This paper presents the results of research based on field (in-situ) investigations in irrigation canals that divert water from a river without a dam (run-of-river intakes), carried out to substantiate the optimal hydraulic parameters for preventing bed erosion and sediment deposition in the canal.

**Keywords**: Canal, irrigation, channel bed, sediment, velocity, flow, turbulent motion, pumping station, discharge, water level.

## Introduction

Numerous methods and measures exist for preventing bed erosion and sediment deposition in irrigation canals.

In particular, the calculation of the optimal conditions for preventing bed erosion and sediment deposition in irrigation canals employs methods that are widely used in practice and offer high accuracy.

Taking the above into account, for the canal supplying water to the Amu-Zang-1 pumping station we perform the following steps:

- Side-slope coefficient of the canal (depending on the soil of the canal slopes and bed), “m”.
- Roughness coefficient of the canal slopes and bed, “n”.
- Permissible (non-eroding) flow velocity depending on the canal-bed soil, “$V_{perm}$”.
- Maximum flow velocity in the canal, “$V_{max} = V_{perm}$”.

To calculate the optimal conditions for preventing bed erosion and sediment deposition in the canal supplying water to the Amu-Zang-1 pumping station, four cross-sections were selected and the calculations were carried out for them (Table 1).

**Table 1. Selected cross-section numbers and their locations (picket marks).**

| No. | Design cross-sections | Location | PK |
|---|---|---|---|
| 1 | Cross-section 1 | Supply canal | 0+55 |
| 2 | Cross-section 2 | Supply canal | 3+89 |
| 3 | Cross-section 3 | Supply canal | 12+03 |
| 4 | Cross-section 4 | Supply canal | 13+18 |

All of the above data are presented in Table 2.

**Table 2. Hydraulic parameters of the canal supplying water to the Amu-Zang-1 pumping station**

| No. | Cross-sections, pickets | Side-slope coefficient, "m" | Roughness coefficient, "n" | Permissible velocity, "$V_{perm}$". | Maximum flow velocity, "$V_{max} = V_{perm}$" | Channel bed slope, i |
|---|---|---|---|---|---|---|
| 1 | Cross-section 1, PK-0+55 | 1.5 | 0.025 | 1.62 | 1.62 | 0.0002 |
| 2 | Cross-section 2, PK-3+89 | 1.5 | 0.025 | 1.67 | 1.67 | 0.00025 |
| 3 | Cross-section 3, PK-12+03 | 1.5 | 0.025 | 1.73 | 1.73 | 0.0003 |
| 4 | Cross-section 4, PK-13+18 | 1.5 | 0.025 | 1.58 | 1.58 | 0.00028 |

**Table 3. Cross-sectional area, mean velocity, discharge and maximum depth of the canal cross-sections**

| Cross-section No. | Reach name | Picket No. | Cross-sectional area ($m^2$) | Mean velocity (m/s) | Discharge ($m^3/s$) | Maximum depth (m) | Max. width, m |
|---|---|---|---|---|---|---|---|
| 1 | Supply canal | 0+55 | 53.19 | 0.65 | 34.57 | 4.6 | 66.5 |
| 2 | Supply canal | 3+89 | 47.27 | 0.73 | 34.51 | 5.3 | 39.9 |
| 3 | Supply canal | 12+03 | 41.51 | 0.82 | 34.04 | 5.8 | 35.8 |
| 4 | Supply canal | 13+88 | 29.32 | 0.88 | 25.80 | 4.2 | 29.5 |

*Next, we perform the calculations using the Chézy function ($C\sqrt{R_{perm}}$). For this purpose, the data of Table 2 are used.*

$$C\sqrt{R_{perm}} = \frac{V_{perm}}{\sqrt{i}} \qquad (1)$$

Where: $i = 0.0003$

"$V_{perm}$" is the permissible velocity (non-eroding for the canal-bed soil), 1.62 m/s.

***Calculation for cross-section 1:*** $C\sqrt{R_{perm}} = \frac{1.62}{\sqrt{0.0002}} = 114.55$

***Calculation for cross-section 2:*** $C\sqrt{R_{perm}} = \frac{1.67}{\sqrt{0.00025}} = 105.62$

***Calculation for cross-section 3:*** $C\sqrt{R_{perm}} = \frac{1.73}{\sqrt{0.0003}} = 99.88$

***Calculation for cross-section 4:*** $C\sqrt{R_{perm}} = \frac{1.58}{\sqrt{0.00028}} = 94.42$

To determine the permissible hydraulic radius, we use the values obtained through the function $CC\sqrt{R_{perm}}$ by the following expression (1):

$$R_{perm} = \frac{\omega}{C\sqrt{R_{perm}}} \qquad (2)$$

***Calculation for cross-section 1:*** $R_{perm} = \frac{\omega}{C\sqrt{R_{perm}}} = 8.64$ m

***Calculation for cross-section 2:*** $R_{perm} = \frac{\omega}{C\sqrt{R_{perm}}} = 6.12$ m

***Calculation for cross-section 3:*** $R_{perm} = \frac{\omega}{C\sqrt{R_{perm}}} = 4.53$ m

***Calculation for cross-section 4:*** $R_{perm} = \frac{\omega}{C\sqrt{R_{perm}}} = 3.76$ m

Next, we perform the following operation:

$$F(R_{opt}) = \frac{Q_{max}}{4m_0\sqrt{i}},\ m^3/s \qquad (3)$$

- Where: $Q_{max}$ – maximum design discharge of the canal, 120.0 m³/s
- $i$ – side-slope coefficient of the canal (depending on the soil of the canal slopes and bed), "m". Cross-section 1 – $i$ = 0.0002, cross-section 2 – $i$ = 0.00025, cross-section 3 – $i$ = 0.0003, cross-section 4 – $i$ = 0.00028.
- $4m_0$ = 7.42.

***Calculation for cross-section 1:*** $F(R_{opt}) = \frac{Q_{max}}{4m_0\sqrt{i}} = 1143.57$

***Calculation for cross-section 2:*** $F(R_{opt}) = \frac{Q_{max}}{4m_0\sqrt{i}} = 1022.84$

***Calculation for cross-section 3:*** $F(R_{opt}) = \frac{Q_{max}}{4m_0\sqrt{i}} = 933.72$

***Calculation for cross-section 4:*** $F(R_{opt}) = \frac{Q_{max}}{4m_0\sqrt{i}} = 966.49$

Next, using the values of $R_{perm}$ and $R_{opt}$, we find the design hydraulic radius; for this we use the expression $R_{perm} - R_{opt} = R$. Here $R_{opt}$ = 1.14.

***Calculation for cross-section 1:*** $R = 7.50\ m$

***Calculation for cross-section 2:*** $R = 4.98\ m$

***Calculation for cross-section 3:*** $R = 3.39\ m$

***Calculation for cross-section 4:*** $R = 2.62\ m$

For each cross-section we determine the expression $\frac{R}{R_{opt}}$:

***Calculation for cross-section 1:*** $\frac{R}{R_{opt}} = 6.58$ m

***Calculation for cross-section 2:*** $\frac{R}{R_{opt}} = 4.37\ m$

***Calculation for cross-section 3:*** $\frac{R}{R_{opt}} = 2.97\ m$

***Calculation for cross-section 4:*** $\frac{R}{R_{opt}} = 2.30\ m$

Next, we determine $\frac{h_{max}}{R_{opt}}$:

***Calculation for cross-section 1:*** $\frac{h_{max}}{R_{opt}} = 7.0$

***Calculation for cross-section 2:*** $\frac{h_{max}}{R_{opt}} = 8.8$

***Calculation for cross-section 3:*** $\frac{h_{max}}{R_{opt}} = 7.0$

***Calculation for cross-section 4:*** $\frac{h_{max}}{R_{opt}} = 6.1$

Next, to achieve a flow velocity in the canal that prevents bed erosion and sediment deposition, we calculate the optimal bottom width of the canal. For this we use the following expression.

$$b_{calc} = \left(\frac{b}{R_{opt}}\right) \qquad (4)$$

***Calculation for cross-section 1:*** $\frac{b}{R_{opt}} = 51.11$

***Calculation for cross-section 2:*** $\frac{b}{R_{opt}} = 32.39$

***Calculation for cross-section 3:*** $\frac{b}{R_{opt}} = 27.77$

***Calculation for cross-section 4:*** $\frac{b}{R_{opt}} = 24.82$

**Determination and assessment of sediment infilling (siltation) of the canal**

We calculate the minimum mean flow velocity in the canal using expression (5).

$$V_{min} = \left(\frac{Q_{min}}{(b_{cs}+mh_{min})}\right) \quad (5)$$

$$\textbf{Calculation for cross} - \textbf{section 1}: V_{min} = \left(\frac{Q_{min}}{(b_{cs}+mh_{min})}\right) = 0.53\ m/s$$

$$\textbf{Calculation for cross} - \textbf{section 2}: V_{min} = \left(\frac{Q_{min}}{(b_{cs}+mh_{min})}\right) = 0.77\ m/s$$

$$\textbf{Calculation for cross} - \textbf{section 3}: V_{min} = \left(\frac{Q_{min}}{(b_{cs}+mh_{min})}\right) = 0.84\ m/s$$

$$\textbf{Calculation for cross} - \textbf{section 4}: V_{min} = \left(\frac{Q_{min}}{(b_{cs}+mh_{min})}\right) = 0.75\ m/s$$

At the selected canal cross-sections, we determine the minimum hydraulic radius of the flow (live) cross-section.

$$R_{min} = \frac{\omega_{min}}{X_{min}} = \frac{(b_{cs}+mh_{min})*h_{min}}{b_{cs}+2h_{min}\sqrt{1+m^2}} \quad (6)$$

$$\textbf{Calculation for cross} - \textbf{section 1}: R_{min} = 0.87$$
$$\textbf{Calculation for cross} - \textbf{section 2}: R_{min} = 0.80$$
$$\textbf{Calculation for cross} - \textbf{section 3}: R_{min} = 0.77$$
$$\textbf{Calculation for cross} - \textbf{section 4}: R_{min} = 0.80$$

For the known particle diameters of the fractions in the water, we determine the hydraulic size (settling velocity) of the sediments.

**Table 4.Composition of sediments by fractions.**

| Fractions | Cross-section 1 | Cross-section 2 | Cross-section 3 | Cross-section 4 |
|---|---|---|---|---|
| Diameter, mm. | 0.08 | 0,04 | 0.03 | 0,01 |
| P, %. | 1 | 12 | 28 | 59 |
| Hydraulic size. | 7.6 | 5.4 | 4.7 | 2.7 |
| $W_d$, cm/s. | 7.6-5.4 | 5.4-4.7 | 4.7-2.7 | 2.7 |

During the field investigations, the experimental values of the hydraulic parameters were determined on the basis of the above-mentioned methodology. In particular, the settling velocity of sediment particles toward the channel bed under the turbulent flow regime, as a function of particle fraction, was determined using the empirical expression [7]. That is:

$$w = 1.22\sqrt{\frac{\rho_s-\rho}{\rho}gd} \quad (7)$$

Where: $\rho_s$ – sediment density, $(\frac{kg}{m^3})$; $\rho$ – density of water, $(\frac{kg}{m^3})$, $g$ – gravitational acceleration, $(\frac{m}{s^2})$ and $d$ – sediment particle fraction (diameter), (mm).

Within the field experiments, the settling velocities of sediment particles toward the channel bed under the turbulent flow regime were determined experimentally in the particle-size range of 0.001÷0.1 mm (Fig. 1).

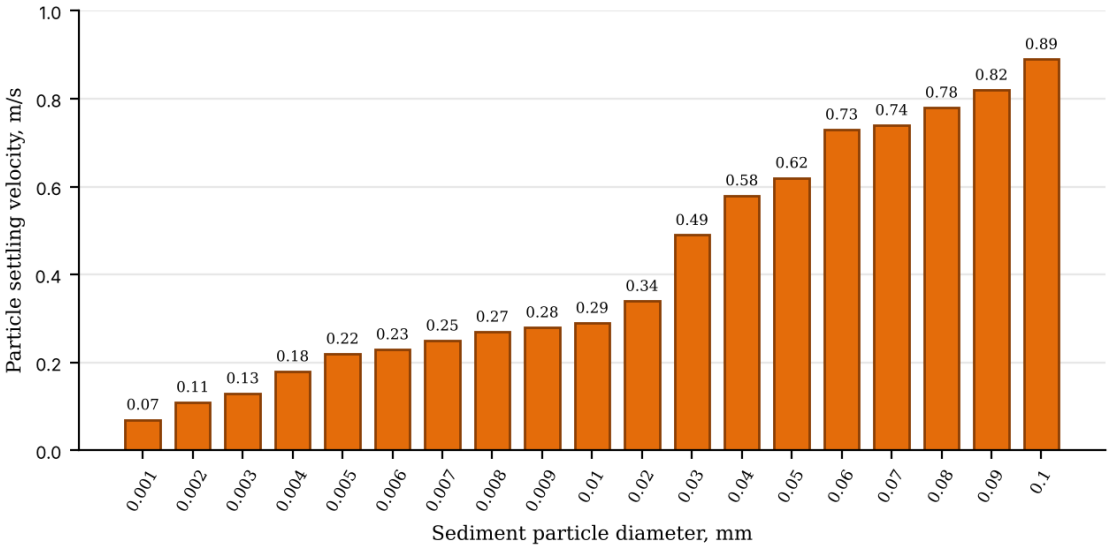



**Fig. 1. Settling velocity of sediment particles toward the channel bed as a function of particle fraction.**

In accordance with the field-research methodology, the experimental values of the initial (threshold) velocity $v$ that sets the sediment particles on the channel bed in motion were determined (Fig. 1). For this purpose, we used the empirical expression of I. I. Levi:

$$v_{init} = 1.4\sqrt{g d_{avg}}\, ln\frac{h}{7d_{avg}}\left(\frac{d_{max}}{d_{avg}}\right)^{1/7} \quad (8)$$

Where: $d_{avg}$ – mean fraction diameter of the sediment particle, mm; $d_{max}$ – maximum fraction size.

As a result, the method for calculating the hydraulic parameters of the water flow in the canal supplying water to the Amu-Zang-1 pumping station was improved, and a method was developed for the hydraulic calculation of the effect of the hydraulic structure at the head reach of the canal supplying water to the Amu-Zang pumping station on the water flow.

Practical implementation of the research results will make it possible to prevent bed erosion and sediment deposition in irrigation canals.

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