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IMPROVED HYDRAULIC ASSESSMENT OF BANK DEFORMATION IN IRRIGATION CANALS AND OPTIMIZATION OF RECONSTRUCTION PARAMETERS (CASE STUDY OF THE AMU-BUKHARA MACHINE CANAL)

Xolmamatov Islom Komil ugli[1]
Associate Professor at Karshi State Technical University, Doctor of Philosophy in Technical Sciences (PhD), ORCID: 0009-0001-2837-048X, E-mail: ixolmamatov93@gmail.com
Sobirov Feruz Choriyevich[2]
Senior Lecturer at Bukhara Engineering Technological Institute
E-mail: sobirovferuzbek874@gmail.com
Dilshodova Dilsuz Dilshod kizi[1]
Assistant Karshi State Technical University
Raimova Nodira Jo`ra kizi[1]
Assistant Karshi State Technical University
[1]Karshi State Technical University, Karshi city, Uzbekistan.
[2]Bukhara Engineering Technological Institute, Bukhara, Uzbekistan.

Abstract: This article presents an improved hydraulic calculation method for accurately assessing erosion and deformation processes on the banks of earthen irrigation canals, taking into account the uneven distribution of flow velocities and bed shear stresses across the cross-section. Results from field studies and laboratory experiments on the Amu-Bukhara Machine Canal (ABMC) are provided. A multi-objective optimization model based on the NSGA-II genetic algorithm has been developed to determine optimal geometric parameters for canal reconstruction, ensuring minimal filtration losses and overall costs. This approach contributes to improving the technical reliability of canals in Uzbekistan's water management sector.

Keywords: earthen canal, bank deformation, bed shear stress, velocity distribution, secondary flows, hydraulic model, reconstruction, NSGA-II algorithm, Pareto front, Amu-Bukhara Machine Canal.

1. Introduction

Uzbekistan's irrigation system is the backbone of the country's agriculture. There are over 196,000 km of irrigation canals in the republic, the majority of which have earthen beds. During operation, processes such as bank erosion, deformation, and sediment accumulation pose serious problems. In particular, intensive bank erosion is observed in certain sections of the Amu-Bukhara Machine Canal (ABMC) (e.g., PK 950–1200), which reduces the canal's water conveyance capacity, increases water losses, and raises operational costs.

Figure 1. Bank deformation and erosion in an irrigation canal (similar conditions to ABMC).

Existing calculation methods, including the permissible velocity method based on ShNQ 2.06.03-12, consider only the average flow velocity as the criterion. However, flow in open channels is three-dimensional, with uneven velocity distribution across the cross-section, the presence of secondary flows, and locally high shear stresses on the banks. This leads to deformation occurring in practice even when canals are deemed stable by traditional methods [1, 2].

The relevance of the study is linked to the tasks outlined in the Concept for the Development of Water Management in the Republic of Uzbekistan for 2020–2030 and the New Uzbekistan Development Strategy for 2022–2026. These documents emphasize efficient use of water resources, reduction of filtration losses, and reconstruction of irrigation canals as key directions.

This article presents methods developed based on research on the ABMC: (1) a fragment-based hydraulic verification method for bank stability; (2) an NSGA-II-based model for determining optimal reconstruction parameters.

2. Literature Review

Numerous studies have been conducted on bed shear stress and velocity distribution in open channels. The classical approach calculates shear stress using the formula:

$$\tau = \rho g R i \qquad (1)$$

where ρ is water density (1000 kg/m³), g = 9.81 m/s², R is hydraulic radius, and i is slope.

However, in trapezoidal sections, τ values are not uniform along the wetted perimeter. Due to secondary flows on the banks, velocities approach maximum values, and local τ can be 2–3 times higher than the average [3, 4].

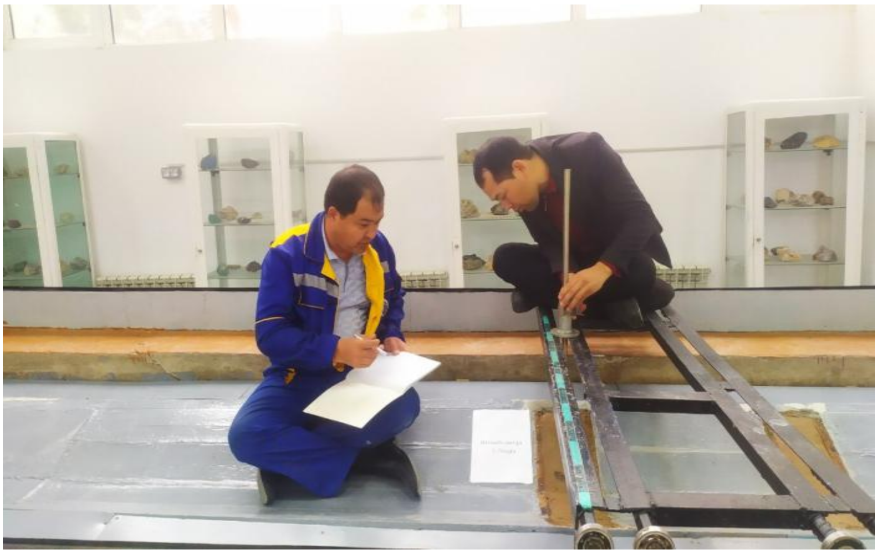

Figure 2. Cross-section of a trapezoidal channel with scouring (erosion) on the side walls and bottom.

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Foreign researchers (V.T. Chow, P.Y. Julien, T.W. Sturm) and CIS specialists (S.E. Mirskhulava, K.V. Grishanin, D.R. Bazarov) have proposed methods based on logarithmic law or Prandtl's formula for velocity distribution. Nevertheless, in the republic's conditions, deformation cases remain frequent, and existing methods lack sufficient accuracy.
Studies show that increasing bank slope and flow curvatures intensify shear stress. Higher τ values have been observed on convex banks in curved sections of the ABMC [5].

3. Research Object and Methods

The Amu-Bukhara Machine Canal in Bukhara Region was selected as the research object. The canal is over 150 km long, with a design discharge of 300–500 m^3/s. It has a trapezoidal earthen cross-section with side slope coefficients m=2–3.

Methods:

- Field measurements (velocity profiling using ADCP acoustic Doppler current profiler, 2024);
- Laboratory experiments (scaled 1:50 hydraulic flume);
- Mathematical modeling (NSGA-II algorithm in Python).

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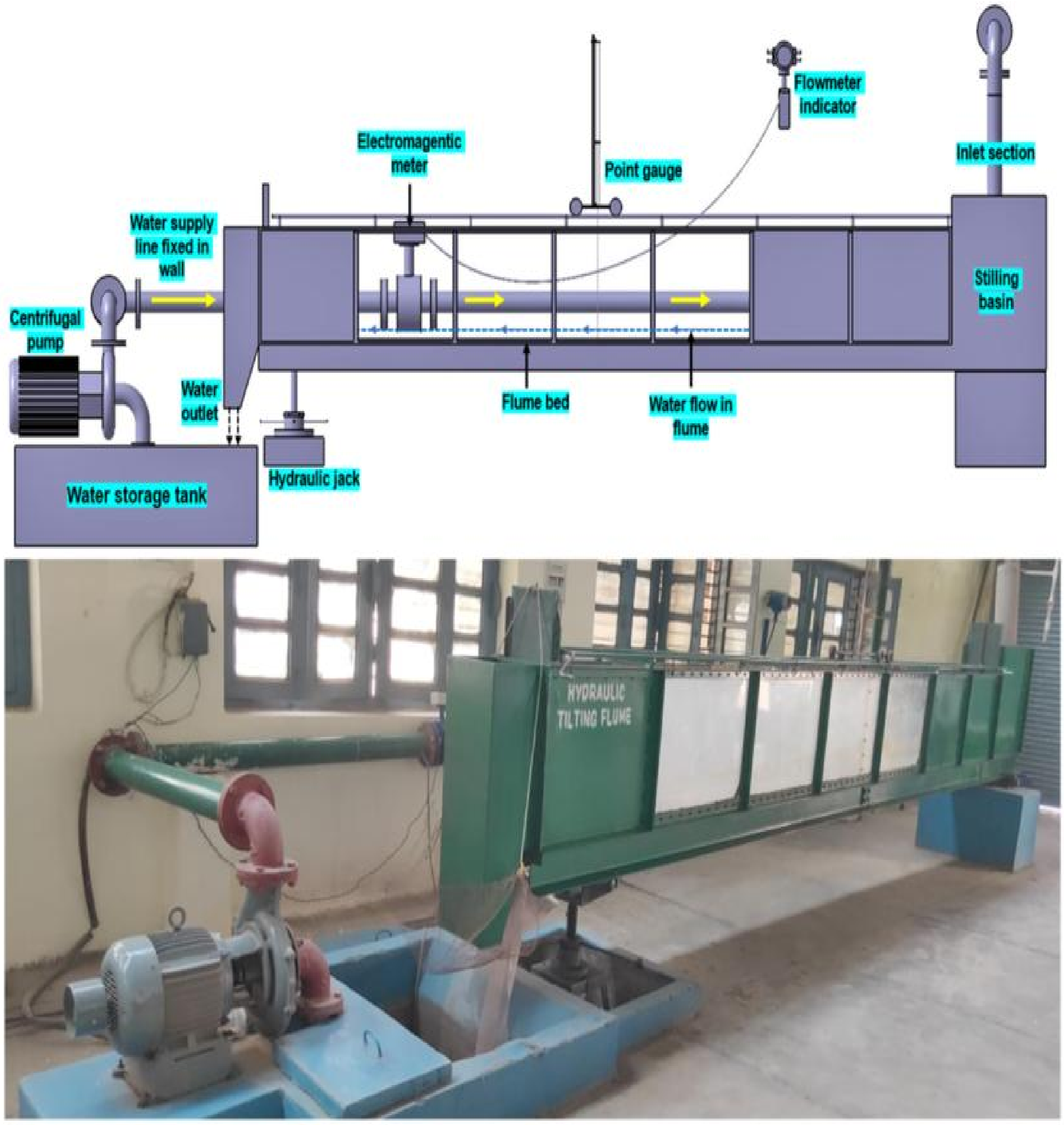

Figure 3. Schematic of laboratory hydraulic flume for studying canal erosion.

4. Improved Hydraulic Calculation Method

The proposed method involves dividing the cross-section into vertical fragments (Δb=1–2 m) and performing separate calculations for each:

1. Determine average velocity v_{fr} and depth h_fr in the fragment.
2. Calculate hydraulic radius $R_{fr} = A_{fr} / \chi_{fr}$.
3. Apply correction coefficient for velocity distribution $k_v = (v_{max} / v_{avg})^2\alpha$ (α=0.8–1.2 depending on experiment).
4. Actual shear stress $\tau_{fr} = \rho g R_{fr}$.
5. Compare with permissible τ_{perm} (according to S.E. Mirskhulava's formula, depending on soil particle size d{50}).

Field measurement results (PK 1201–1202) are presented in Table 1.

Table 1. Measured velocity ratios in ABMC (selected fragments)

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Fragment	H/H_{max}	V_{max}/V (left)	V_{max}/V (right)	V_{max}/V (bottom)	τ_{fr} / τ_avg
1	0.18	2.56	2.56	1.53	2.4
2	0.27	1.91	1.91	1.38	1.8
3	0.50	1.55	1.55	1.20	1.4
4	0.78	1.28	1.28	1.10	1.2
5	0.93	1.32	1.32	–	1.3

Results showed that near the banks (H/H_max < 0.4), τ_{fr} is 2–2.6 times higher than the average.

Laboratory experiments validated the method, showing agreement with field data within 15%.

5. Model for Calculating Optimal Reconstruction Parameters

Reconstruction objectives: (1) minimal filtration losses; (2) minimal total costs (construction + operation).

The multi-objective problem was solved using the NSGA-II algorithm. Model parameters: b, h, m, lining type.

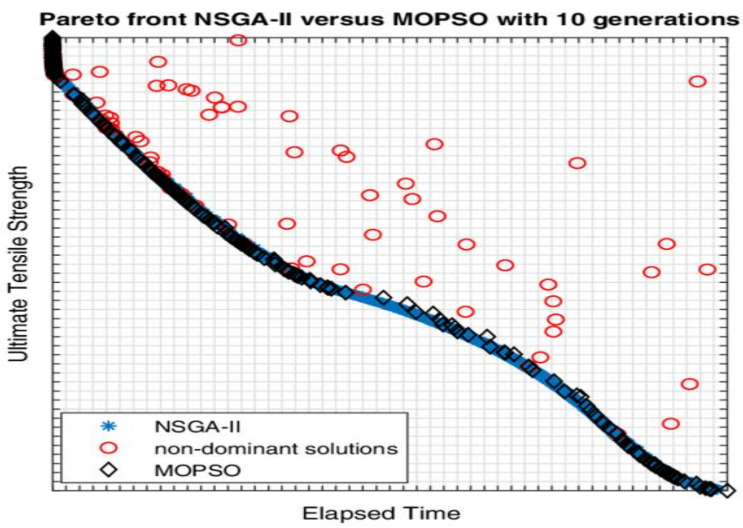

Figure 4. Pareto front obtained with NSGA-II algorithm (set of optimal solutions between cost and filtration losses).

Calculation results: For ABMC, the optimal variant with concrete lining – b=28–30 m, h=4.0–4.5 m, m=2.5–3.0. This reduces filtration by 40–50% and costs by 25–30%.

6. Experimental Results and Discussion

In ABMC, the classical method deemed the canal stable, while the improved method identified erosion risk in 70% of bank sections. This fully corresponds to observed deformations.

In the laboratory, changing the slope from 1:2 to 1:3 reduced τ by 20–25%.

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Implementation of the model in practice (according to the Ministry of Water Resources reference) improved canal reliability.

7. Conclusions and Recommendations

1. Accurate prediction of bank deformation in earthen canals requires accounting for uneven distribution across cross-section fragments.
2. The improved method provides more accurate results than traditional ones and detects local high stresses.
3. The NSGA-II-based model ensures resource-efficient solutions in reconstruction.
4. Recommendation: Apply this method and software in the design and reconstruction of irrigation canals in the republic.

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