CHARACTERIZATION OF HYDRAULIC RESISTANCE IN TURBULENT FLOWS WITHIN CONCRETE-LINED CHANNELS

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Abstract: Accurate evaluation of hydraulic resistance in turbulent open flows within concrete-lined channels plays a crucial role in determining energy losses and ensuring the reliability of hydraulic calculations. In many practical applications, empirical formulas assume the resistance coefficient to be constant; however, under turbulent flow conditions, hydraulic parameters interact and vary simultaneously.

In this study, the resistance coefficient is treated as a variable quantity influenced by the flow regime, hydraulic radius, and channel slope. Based on experimental data, a mathematical generalization was performed to derive a parametric relationship applicable to both turbulent uniform and gradually varied flows. The results demonstrate that hydraulic resistance cannot be considered a universal constant, as it is highly sensitive to varying flow conditions in concrete-lined channels. The proposed model provides a more accurate estimation of energy losses in turbulent open flows.

Key words: Turbulent flow, hydraulic resistance, concrete-lined channel, open-channel hydraulics, energy losses, resistance coefficient.

Introduction.

The determination of energy losses in open channels is one of the key factors that define the accuracy of hydraulic calculations and the structural reliability of hydraulic systems. Under turbulent flow conditions, the increasing complexity of flow structure leads to the variable nature of the hydraulic resistance coefficient. Although empirical formulas such as those of Manning's equation and others provide practical convenience in solving many engineering problems, they do not ensure consistent accuracy across all flow regimes.[1]

Concrete-lined channels are widely used, particularly in irrigation and drainage systems, which creates a strong need for a deeper analysis of their hydraulic behavior. Under turbulent open flow conditions, clarifying the dependence of the resistance coefficient on the hydraulic radius, channel slope, and surface roughness is of both scientific and practical importance.

The aim of this study is to refine the determination of hydraulic resistance in turbulent flows within concrete-lined channels using a parametric approach and to identify the applicability limits of existing empirical methods.

Materials and Methods.

The study was aimed at the quantitative assessment of hydraulic resistance patterns in turbulent flow conditions in concrete-lined open channels. The calculations were carried out based on the Shézy equation $V = C\sqrt{Ri}$ adopted for open-channel flows, where $R = \frac{\omega}{x}$ denotes the hydraulic radius, i - represents the hydraulic slope, and c - is the hydraulic resistance coefficient. The flow discharge was determined using the continuity equation $Q = \omega V$, with velocity and cross-sectional area considered in their interdependence [3].

The calculations were performed within the practical range of the hydraulic radius (typical values for concrete channels), and the sensitivity of the resistance coefficient to R and i was evaluated through parametric analysis.

This approach makes it possible to determine the variability of the resistance coefficient across the cross-section and to quantitatively compare the differences between uniform flow and gradually varied flow conditions.

The accuracy of empirical formulas was verified through comparative analysis. In this process, the calculated velocity values were compared, and the relative deviation was evaluated as follows [2]

$$\delta = \frac{(V_M - V_p)}{V_p} \quad 100\%$$

Here, V_p - represents the velocity calculated using the Pavlovsky expression,

while V_M -denotes the velocity determined according to the Manning formula.[8]

In addition, the deviation arising from the use of a universal value of the resistance coefficient was evaluated under turbulent flow conditions. The results of the parametric analysis made it possible to determine the sensitivity of the resistance coefficient to the flow regime and to identify the applicability limits of empirical formulas [5].

This methodology serves to systematically verify the accuracy of existing formulas for assessing hydraulic resistance in turbulent flow conditions in concrete-lined channels and to substantiate their practical applicability.[7]

Results

The experimental results demonstrated that the hydraulic resistance coefficient in concrete-lined channels under turbulent flow conditions changes as a function of the flow regime, hydraulic radius, and slope. Moreover, the calculated values revealed distinct trends for uniform and gradually varied flows, indicating that it is not appropriate to treat hydraulic resistance as a constant parameter in all cases.[6]

In the calculation process, λ - is first determined using experimental data, after which the transition to the Shézy coefficient is carried out through the relationship [3].

$$c = \sqrt{\frac{8g}{\lambda}} = \frac{8.86}{\sqrt{\lambda}}$$

For smooth-walled flumes, the constants are determined as follows:

$z = -1$ $a = 0.0065$, $K = 0.00125$, $x = \frac{1}{6}, z = -1$

In the calculation results, the root means square deviation obtained from the calculation results was

$$\Delta C_{ck} \pm 1.8\%$$

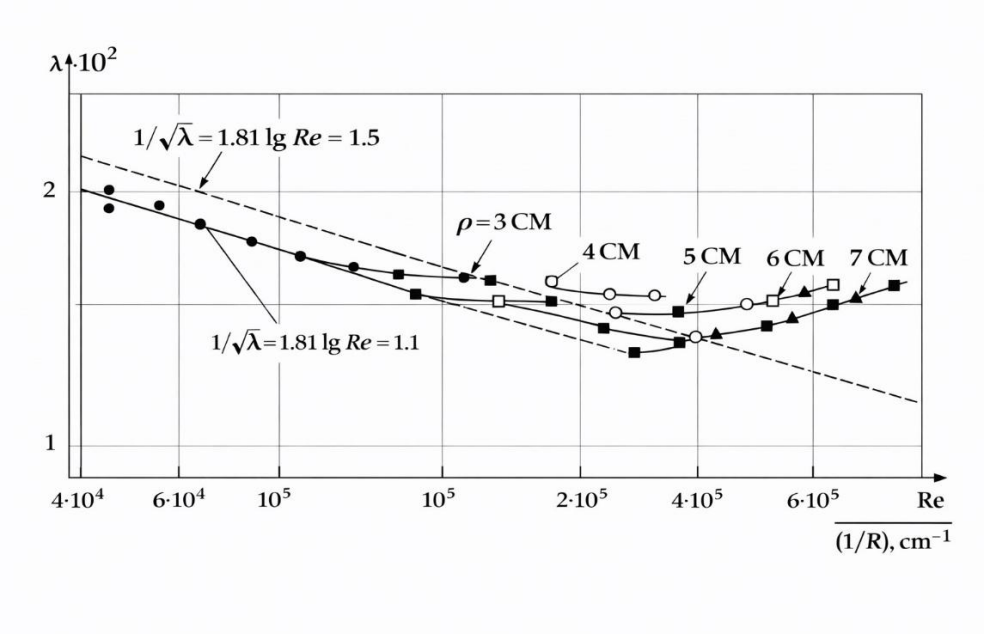


Figure 1. Relationship graph of $\lambda = f(\mathrm{Re})$.

The calculation results showed that the value of λ varies depending on the Reynolds number and the slope, and differs according to the type of cross-section. It was noted that the deviation determined for smooth flumes did not exceed 1.8%.[4]

Conclusion.

The results indicate that hydraulic resistance in turbulent open-channel flow within concrete-lined channels cannot be consistently treated as a constant across all flow regimes. Instead, the resistance coefficient should be considered a variable parameter influenced by the flow regime, hydraulic radius, and channel slope. The parametric relationship derived from experimental data has improved the accuracy of energy loss estimation in turbulent flows. These findings contribute to enhancing and refining existing methodologies for open-channel flow calculations.

Further research is recommended to investigate, on a broader experimental basis, the dependence of key parameters on the Reynolds number, relative roughness, and cross-sectional geometry. Such efforts will increase the general applicability of the model and facilitate its effective integration into practical hydraulic computation systems.

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