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METHOD OF HYDRAULIC CALCULATION OF TRANSFORMATION OF WATER RESERVOIR BOWLS UNDER THE INFLUENCE OF NATURAL AND ANTHROPOGENIC FACTORS

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Abstract

Reservoirs are large hydraulic structures designed to perform functions such as managing water resources and their efficient use in economic sectors, as well as preventing or reducing the negative effects of catastrophic floods. Dams and weirs of reservoirs are designed to hold large masses of water, and during normal operation of reservoirs, processes such as the accumulation of water in the reservoir and its release during operation are observed, such as the accumulation of turbidity in the reservoir basin, erosion of banks and dams.

Natural disasters (floods, high-water periods, etc.) and catastrophic situations associated with the operation of reservoirs have a significant negative impact on socio-economic infrastructure facilities, the population, and the ecosystem. At the same time, as a result of the breach of the reservoir dam (overflow), a large mass of water flows downstream through the overflow, a sharp increase in the flow velocity occurs, which leads to macro-meso-shaped deformation processes associated with the washing out of certain parts of the reservoir basin or its filling with muddy water, which leads to the formation of a relief of the riverbed with complex geometry. This situation, in turn, raises issues regarding the determination of the volume of water resources in the reservoir and their accounting. This article presents a hydraulic method for calculating the state of the relief of a reservoir basin that has undergone severe deformation.

Keywords: Reservoir bowl, morphological and morphometric parameters, deformation and transformation of the riverbed, morphodynamic model, sedimentary and bottom turbidity, riffles in the riverbed, meso and macro forms.

Introduction

Situations associated with natural extreme events (floods, high-water periods, etc.) and accidents related to the operation of reservoirs (breakage of reservoirs and dams) have a significant negative impact on socio-economic infrastructure facilities, the population, and the ecosystem. At the same time, as a result of the breach of the reservoir dam (overflow), a large mass of water flows downstream through the overflow, resulting in a sharp increase in the flow velocity, which leads to the washing out of certain parts of the reservoir basin or its filling with muddy water, and the formation of a relief of the riverbed with complex geometry.

In the event of an accident related to a breach in a reservoir, the reservoir water is intensively released through the water outlet, in violation of the operational requirements. This situation negatively affects the stability of the reservoir dam and dams. In practice, after an accident related to a breach, conclusions are drawn up on the safety of reservoir structures through scientific research, technical and instrumental studies. Based on these conclusions, repair and restoration work is carried out in the section of the dam where the breach occurred. In some cases, a complete reconstruction of the dams along the perimeter of the reservoir is required. Of course, these measures require large-scale construction and installation work, a large amount of financial resources and time.

Analysis of literature on the topic

The processes of river deformation have been well studied in the works of V.M. Lokhtin, N.S. Lelevsky, V.N. Goncharov, M.A. Velikanov, N.A. Mikhailov, N.E. Kondratov, N.I. Makkaveev, A.V. Karaushov, K.I. Rossinsky, K.V. Grishanin, B.F. Snishchenko, V.S. Borovkov. At the same time, the formation and dynamics of morphological forms of various topologies that form at the bottom of river beds, including changes in the boundaries of meso- and micro-forms, have been sufficiently studied. However, scientific research issues related to the volume and changes in the boundaries of closed-contour meso-forms that form at the bottom of reservoirs as a result of dam or embankment failure have not been sufficiently studied.

Based on the research tasks, we aim to determine the morphological parameters of the relief of the bottom of the reservoir bowl by determining the elevation marks. Because the configuration of the relief formed at the bottom of the reservoir bowl and the determination of its elevations create opportunities to accurately calculate the volume of water resources in the strongly deformed reservoir bowl. This, in turn, creates favorable conditions for the organization operating the reservoir to maintain the volume of water resources of the reservoir and its accurate accounts.

Material and Methods

In arid regions, that is, in regions with extremely high water resource shortages, water resources are of great importance for economic sectors, including water and agriculture. Therefore, after accidents in reservoirs operated in these regions, the practice of collecting water in the reservoir bowl, up to the mark of the overflow mark, and using these water resources in economic sectors is being practiced. In particular, the Sardoba reservoir, located in the Syrdarya region, was built and put into operation in 2017. The length of the reservoir is 10 km, width is 6 km, the area occupied is 60 km^2 (6,000 ha), and the design volume is 922 million m^3. On May 1, 2020, the water level in the reservoir was at the 305 mark, and the volume is 957 million m^3, an accident occurred in the section of the dam between PK57+00-PK60+00 pickets (Fig. 1).

The accident resulted in the release of 627 million cubic meters of water from the reservoir, causing serious damage to settlements, social and economic infrastructure in

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the Sardoba, Aqaltyn, Mirzaabad regions of the Republic of Uzbekistan and the Zhittisuv district in the southern region of the Republic of Kazakhstan. At the same time, it dramatically changed the configuration of the reservoir basin's bottom relief.

Figure 1. The collapse that occurred in the dam section between pickets PK57+00-PK60+00 of the Sardoba reservoir

At present, despite the fact that the section of the reservoir where the dam was not leveled, water resources of an average volume of 290-300 million m3 are collected every year, and water is supplied to improve the water supply of 114,000 hectares of irrigated areas of Syrdarya and Jizzakh regions.

There are hydroposts at the relevant facilities of the reservoir. However, the transformation of the reservoir basin as a result of the accident has limited the ability to measure the volume of the reservoir and accurately measure the amount of water resources in the reservoir. This, in turn, poses serious scientific, technical and organizational issues for the reservoir operating organization related to water accounting and its operation.

In the article, we aim to develop and improve the methods of calculating the morphological parameters of the chasha bottom with a complex relief, which caused a strong transformation of the reservoir core due to the accident.

As part of the research, in order to develop hydraulic methods for determining the volume of water resources in the Sardoba reservoir, experimental studies were carried out in 2022, 2023, 2024 and 2025 on 47 km² of the reservoir's water area and 13 km² of dry land area using a modern Sontek S5 Doppler profiler, a Garmin striker vivid 7CV transducer ultrasonic device for determining the depth of the reservoir's bottom, and a South nts-362R6 electronic total station (Figure 2).

The results of experimental studies are presented in Chapter II of the dissertation.

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Figure 2. Modern measuring devices used in the experiment

The transformation of the cistern tank can be seen through the shapes presented in Figures 3 and 4.

Figure 3. Topological parameters of the chasha of the Sardoba reservoir in 2017

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Based on the results of experimental research conducted in 2024 and 2025 to determine the morphological parameters of the bottom of the Sardoba reservoir, we will use contour lines and elevation marks (marks) of the reservoir bottom relief formed after the accident (Figure 4).

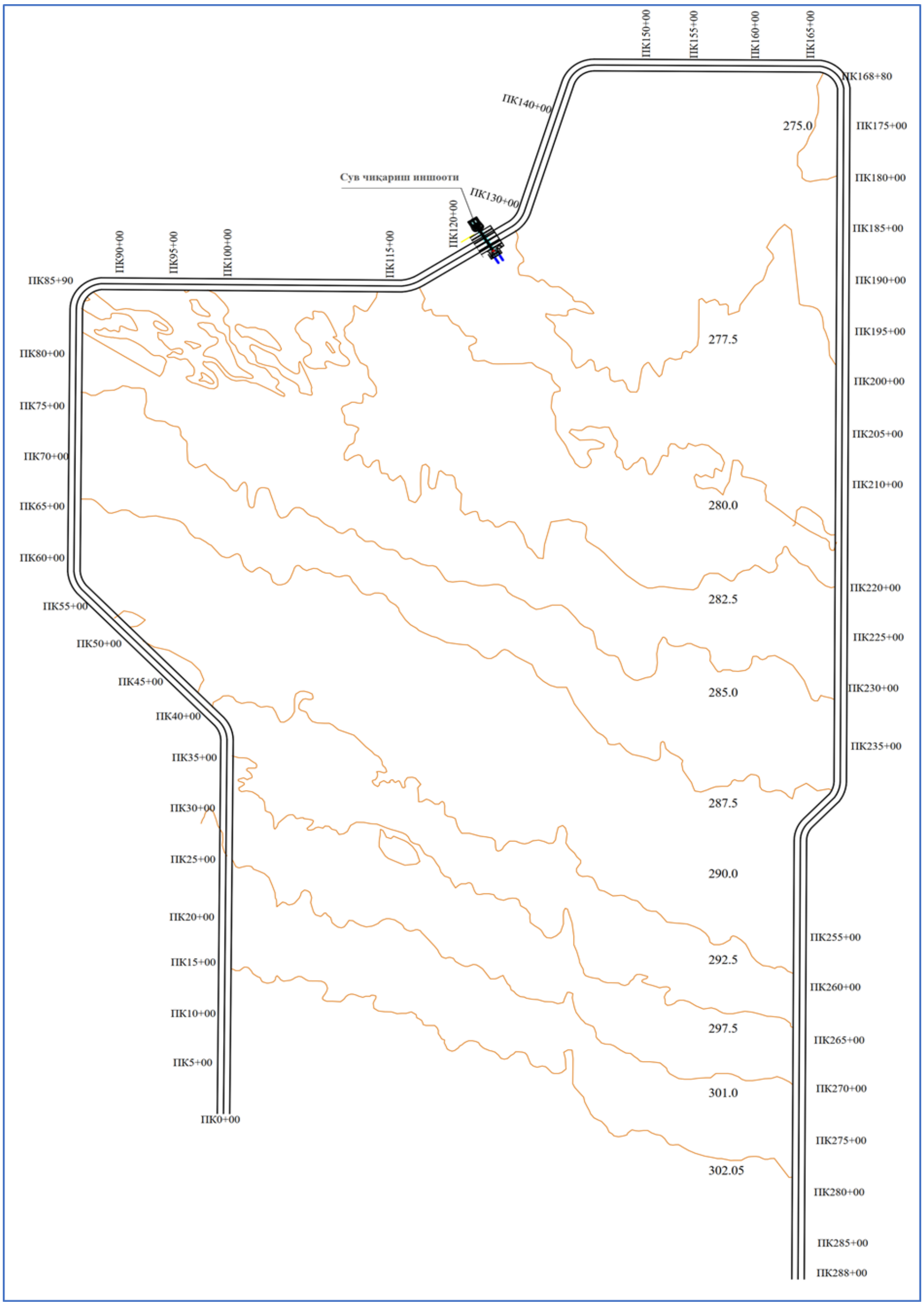

Figure 4. Reservoir basin contours and elevations determined based on experimental studies conducted at the Sardoba Reservoir in 2024 and 2025.

The results obtained. We connect the elevation marks of the complex relief of the bottom of the Sardoba reservoir, formed after the technogenic accident, with curved lines. As a result, we get a curved surface covered with a mesh consisting of Ξ non-orthogonal curved lines (Figure 5).

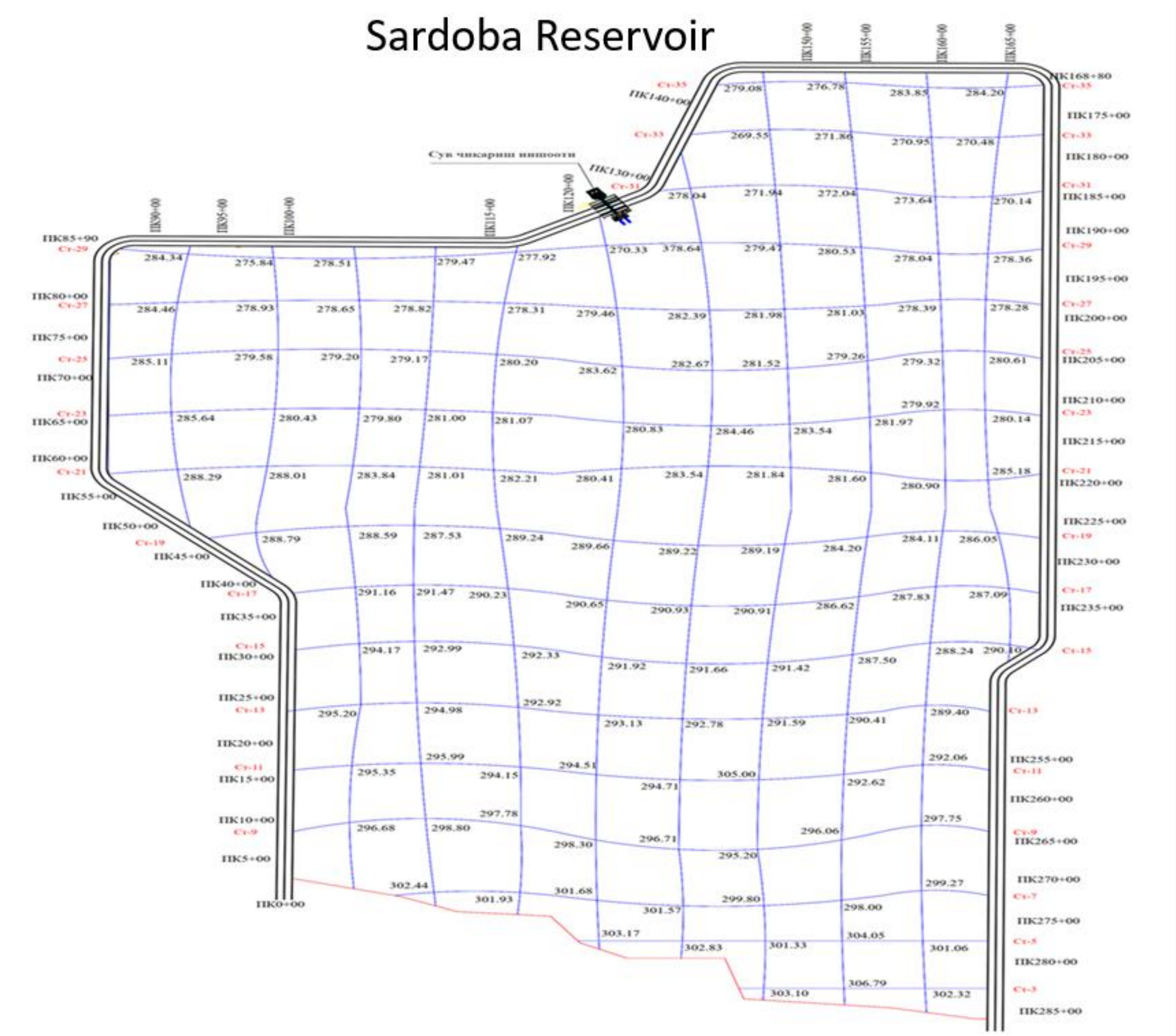

Figure 5. A curved surface covered with a mesh made up of Ξ non-orthogonal curved lines.

We define the nodes of a grid formed by non-orthogonal curved lines (non-orthogonal grid) as points of elevation marks of the reservoir bottom relief. Thus, our goal is to determine the coordinates of the points at the nodes of the non-orthogonal grid. To do this, we construct a non-orthogonal curved line grid.

Determining the position of points at the nodes of orthogonal grids is one of the most difficult scientific and technical issues. Optional to solve the problem $\Xi(x, y)$ corresponding to the configuration of the boundaries of this field on the surfacefind the linear coordinates. That is, of variables $\xi(x, y)$ ва $\eta(x, y) x, y \in \partial\Xi$and we can construct a system of elliptic equations that satisfy the boundary conditions defined by the corresponding values. In this case, one boundary coordinate line corresponds to each segment of the boundary, the corresponding curvilinear coordinate is constant, and the other coordinate is arbitrarily distributed and monotone.

Putting the problem in the condition mentioned above makes it possible to reflect the area in the initial coordinate axis to the computational area in the coordinate plane. That is, it is difficult to find the coordinates of the nodes of the non-orthogonal mesh formed by the intersection of the curves. Therefore, it is possible to map a non-orthogonal mesh to a linear orthogonal mesh area. It is more convenient to find the coordinates of a point on the nodes of a straight line orthogonal grid.

By keeping one coordinate value constant in the coordinate plane and distributing the other coordinates equally across the inverse boundary pairs, it is possible to map the curvilinear coordinate plane to a discrete analog coordinate plane (Figure 6).

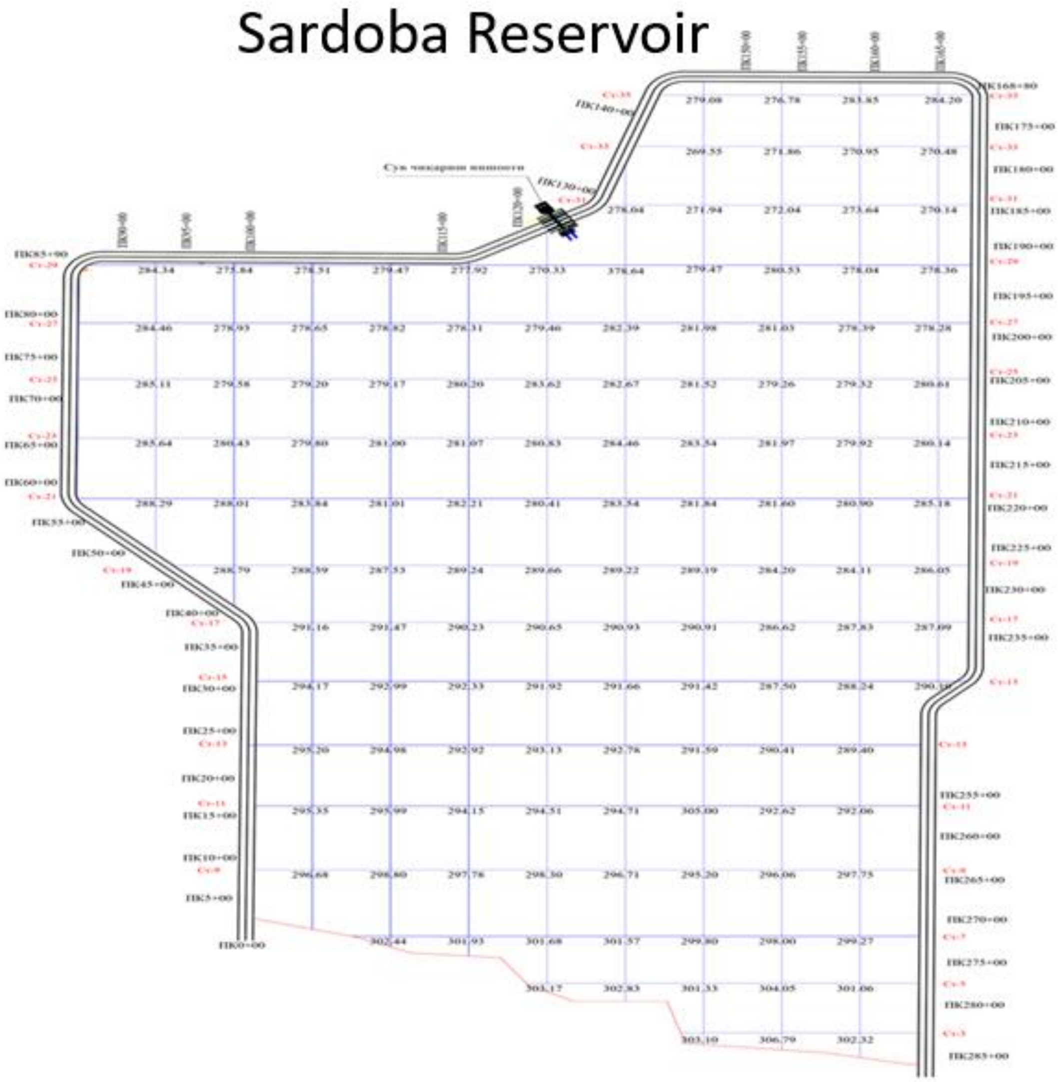

Figure 6. **Ξ a form of reflection of the domain into the Ξ^* discrete analog plane.**

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Discussion

The aforementioned nonorthogonal mesh is formed by solving the boundary value problem for the system of elliptic equations. A simple representation of this system of equations is Laplace's equation.

$$\begin{cases}\xi_{xx} + \xi_{yy} = 0, \\ \eta_{xx} + \eta_{yy} = 0.\end{cases} \quad (1)$$

To solve the system of equations (1), we set the following boundary conditions:

$$\begin{cases}\xi|_{\partial\Xi} = \xi_{0,} \\ \eta|_{\partial\Xi} = \eta_0\end{cases} \quad (2)$$

We find the Cartesian coordinates in a rectangular field using the conditions of mutual dependence of physical and computational fields. For this, we solve the system of equations (1). Differentiating the system of equations (1) twice in terms of variables, we get the following expression:

$$x = x(\xi, \eta), \; y = y(\xi, \eta) \quad (3)$$

By collecting matching results $r = (x, y)$we have the following equation for the vector:

$$(x_\eta^2 + y_\eta^2)r_{\xi\xi} - 2(x_\xi x_\eta + y_\xi y_\eta) \cdot r_{\xi\eta} + (x_\xi^2 + y_\xi^2)r_{\eta\eta} = 0 \quad (4)$$

Taking into account that in the polar coordinate system =(R,), we can write equation (4) in the polar coordinate system:$r \; \varphi$

$$\alpha\frac{D^2}{D\xi^2}r + 2\beta\frac{D^2}{D_\xi D_\eta}r + \gamma\frac{D^2}{D_\eta^2}r = 0 \quad (5)$$

Here:

$$\alpha = \xi_R^2 + (R^{-1}\xi_\varphi)^2, ,\beta = \xi_R\eta_R + R^{-2}\xi_\varphi \cdot \eta_\varphi$$

$$\gamma = \eta_R^2 + (R^{-1}\eta_\varphi)^2 \quad (6)$$

Taking into account equations (5) and (6), we obtain the following equation for the coordinate vector:$\psi = (\xi, \eta)$

$$\frac{D^2}{DR^2}\psi + \frac{1}{R}\frac{D}{DR}\psi + \frac{1}{R^2}\frac{D^2}{DR^2}\psi = 0 \quad (7)$$

$$\psi|_{R=R_1} = 0$$

We carry out a numerical experiment of equation (7) using the "partitioning of variables" method. To do this, I seek to solve equation (7) in the following form:

$$\psi(\xi, \eta) = K(\xi)\,\phi(\eta) \quad (8)$$

Substituting expression (8) into equation (7) and separating the variables, we get:

$$\frac{\phi^{\|}(\eta)}{\phi(\eta)} = -\frac{R^2K^{\|}(\xi) + RK^{|}(\xi) + R^2K(\xi)}{K(\xi)} = -V^2 \quad (9)$$

Condition (71) and the following boundary value problems in expression (8):

$$\phi_V^{\|}(\eta) + V^2\phi_V(\eta) = 0, \quad (10)$$

$$\phi_V(\eta + 2\pi) = \phi_V(\eta), \quad (11)$$

$$K_V^{\|}(\xi) + \frac{1}{R}K_r'(\xi) + (1 - \frac{V^2}{R^2})K_V(\xi) = 0 \quad (12)$$

$$K_V|_{R=R_1} = 0, \quad K_V|_{R=0} \neq \infty \quad (13)$$

The nontrivial periodic solution of problems (10) and (11) is only $V = n$(n-integer) exists under the condition and has the following form:

$\phi_n(\eta) = A_n \cos\varphi + B_n \sin\varphi, \quad n=0,1,2,$ (14)

Now we solve the equation (12). To do this, we introduce a variable of the following form:

$z = \lambda R$ (15)

If we consider the expression (15), the equation (12) will have the following form:

$K_n^{\parallel}(z) + \frac{1}{z} K_n'(z) + (1 - \frac{n^2}{z^2}) K_n(z) = 0$ (16)

Equation (16) is called Bessel's equation. Now we will perform a numerical experiment on Bessel's equation. We can write the general solution of Bessel's equation (16) in the following form:

$K_n(z) = aJ_n(z) + bN_n(z)$ (17)

Here: - Bessel function of the first kind, order n; $J_n(z)$

$N_n(z)$-Bessel function of the second kind, order n (or Neumann function);

a,b are equation parameters.

Bessel's first type $J_n(z)$ The function is a power series of the formаникқланади:

$J_n(z) = Z_{k=0}^{\infty} \frac{(-1)^k}{k!\Gamma(n+k+1)}$ (18)

G-gamma function in the denominator of the power series (18) is determined by the following integral:

$\Gamma(n) = \int_0^{\infty} e^{-x} x^{n-1} dx$ (19)

The Neumann function in expression (17) is defined by the following expression:

$N_n(z) = \frac{J_n(z)\cos n\pi - J_{-n}(z)}{\sin n\pi}$ (20)

For large values of the argument of the Bessel function, it is convenient to express functions (18) and (20) in the following form, namely:

$$\begin{cases} J_n(z) \approx \sqrt{\frac{2}{\pi z}} \cos(z - \frac{n\pi}{2} - \frac{\pi}{4}) \\ N_n(z) \approx \sqrt{\frac{2}{\pi z}} \sin(z - \frac{n\pi}{2} - \frac{\pi}{4}) \\ \quad |z| \gg n, \; z \to \infty \end{cases} \quad (21)$$

(21) From the system of equations (17) we find the expression ():

$K_n()+bz \approx a\sqrt{\frac{2}{\pi z}} \cos(z - \frac{n\pi}{2} - \frac{\pi}{4}) \sqrt{\frac{2}{\pi z}} \sin(z - \frac{n\pi}{2} - \frac{\pi}{4})$ (22)

From equations (14) and (22), we get the solution of expression (8):

$$\Psi_{mn}(\xi,\eta) = \left[a\sqrt{\frac{2}{\pi z}} \cos\left(z - \frac{n\pi}{2} - \frac{\pi}{4}\right) + b\sqrt{\frac{2}{\pi z}} \sin\left(z - \frac{n\pi}{2} - \frac{\pi}{4}\right) \right] \cdot$$

$\cdot\, [A_{nm} \cos n\varphi + B_{mn} \sin n\varphi]$ (23)

Conclusion

As a result, we have obtained a solution to equation (7). That is, we have derived an equation that determines the coordinates (state) of points at the joints (height marks) of an orthogonal type in the computational domain or expresses the morphological state of the stream. Based on the parameters of the research object Ξ^*Equation (23) was solved. The results of the numerical solution of equation (23) were compared with the results of measurements carried out in nature. Based on the comparison of the results, a numerical model of the reservoir relief was developed (Fig. 7).

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