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Modeling of unsteady water movement in open channels during the construction of transport facilities

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Abstract. The article considers the simulation of the planned unsteady movement of water in open channels using the finite element method in the construction of bridges and tunnels in the transport system. A system of two-dimensional equations, boundary conditions of unsteady water movement in isoparametric spatial coordinates, as well as results of computer simulation of unsteady water movement in two-dimensional simulated areas of open channels are presented. The processes occurring in water management objects occur in a multidimensional spatial domain and in time. The complexity of these processes does not allow researchers, designers and operators to quickly assess the qualitative and quantitative parameters of the operation of sections of river beds, canals and hydraulic structures to implement the required water resource management regime [5]. Currently, with the widespread development of numerical methods for solving complex mathematical problems using modern computer technologies, there is a real opportunity to obtain specific qualitative and quantitative characteristics of various complex dynamic processes. Numerical finite difference and finite element methods are used to model fluid dynamics problems. Finite-difference methods for modeling two-dimensional water motion were considered in [1-4].

INTRODUCTION

In the Republic of Uzbekistan, the Karshi Main Canal (KMC) is a large and important hydraulic structure, which, together with the Talimarjan Reservoir, provides water to more than 350 thousand hectares of cultivated area in the region. It should be noted that the Talimarjan reservoir provides drinking water to large industrial enterprises, as well as a population of more than 400 thousand people in four districts of the Kashkadarya region. Water intake into the Karshi cascade of pumping stations develops the complex hydraulic process of erosion of the river banks by dump currents, which creates difficult conditions for supplying the Karshi cascade of pumping stations. The above allows us to conclude that the problem of delivering water to consumers in the required volume is in demand; accuracy of water supply is required through optimal control of water distribution in the canals of irrigation systems [6-40].

Mathematical methods, algorithms and corresponding software, obtained adequate modeling results will ensure a reduction in unproductive losses of water resources in canals, which is of great economic importance for the republic. The use of modern high-performance computers and information technologies will make it possible to obtain timely information about water resources, to use modeling results for the purpose of managing water resources in all water management systems and objects, which include river sections, reservoirs and canals (gravity flow and with mechanical water lifting systems) [8, 41-56]. Computer modeling allows you to simulate the behavior of various elements of engineering structures, devices, including individual water management facilities, their interaction, taking into account all influencing factors in conditions close to real ones, during their operation

EXPERIMENTAL RESEARCH

The planned unsteady movement of water in open channels is described by the two-dimensional system of Saint-Venant equations. [5]

$$\begin{gathered}\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}+\frac{\partial(vh)}{\partial y}+i=0,\\ \frac{\partial(uh)}{\partial t}+\frac{\partial(u^2h)}{\partial x}+\frac{\partial(uvh)}{\partial y}+g\frac{\partial\left(\frac{h^2}{2}\right)}{\partial x}=gh\left(S_{ax}-S_{fx}\right),\\ \frac{\partial(vh)}{\partial t}+\frac{\partial(v^2h)}{\partial y}+\frac{\partial(uvh)}{\partial x}+g\frac{\partial(h^2/2)}{\partial y}=gh\left(S_{ay}-S_{fy}\right).\end{gathered} \tag{1}$$

Where is $h=h(x,y,t)$ – water surface depth; $u=u(x,y,t)$ – longitudinal component of water flow velocity; $v=v(x,y,t)$ – transverse component of water flow velocity; v_t – fluid viscosity, S_{ax} – bottom slope along the axis x, S_{ay} – bottom slope along the axis y, S_{fx} – slope of the free water surface along the axis x, S_{fy} – slope of the free water surface along the axis y; g – acceleration due to gravity; $i(x,y,t)$ – water flow rate, x – axis coordinate along length; y – width axis coordinate; t – time.

The ordinate of the channel bottom is given by the function $z_o(x,y)$, then the bottom slopes at the corresponding coordinates are determined

$$S_{ax}=\frac{\partial z_0}{\partial x},\qquad S_{ay}=\frac{\partial z_0}{\partial y}, \tag{2}$$

Using Manning's formula, it can be obtained the slopes of free surfaces along the ordinates.

$$S_{fx}=\frac{n^2u(u^2+v^2)^{1/2}}{h^{4/3}};\qquad S_{fy}=\frac{n^2v(u^2+v^2)^{1/2}}{h^{4/3}} \tag{3}$$

Let us introduce the change of variables $p=uh$, $q=vh$. Then equation (1) has the form

$$\begin{gathered}\frac{\partial h}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}+i=0\\ \frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}+\frac{gh^2}{2}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial z_0}{\partial x}+gn^2\frac{p(p^2+q^2)^{\frac{1}{2}}}{h^{\frac{7}{3}}}=0\\ \frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q^2}{h}+\frac{gh^2}{2}\right)+gh\frac{\partial z_0}{\partial y}+gn^2\frac{p(p^2+q^2)^{1/2}}{h^{7/3}}=0\end{gathered} \tag{4}$$

Writing these equations in vector form, we get

$$\frac{\partial U}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}+D=0 \tag{5}$$

where U, F, G and D are function vectors

$$U=\begin{pmatrix}h\\p\\q\end{pmatrix},\qquad \mathrm{F}=\begin{pmatrix}p\\ \frac{p^2}{h}+\frac{gh^2}{2}\\ \frac{pq}{h}\end{pmatrix},\qquad \mathrm{G}=\begin{pmatrix}p\\ \frac{pq}{h}\\ \frac{q^2}{h}+\frac{gh^2}{2}\end{pmatrix}, \tag{6}$$

$$D(p,q,h)=\begin{pmatrix}i\\ gh\frac{\partial z_0}{\partial x}+gn^2\frac{p(p^2+q^2)^{1/2}}{h^{7/3}}\\ gh\frac{\partial z_0}{\partial y}+gn^2\frac{q(p^2+q^2)^{1/2}}{h^{7/3}}\end{pmatrix} \tag{7}$$

Since the functions F(U) and G(U) depend on the function U, we write equation (5) in the following form

$$\frac{\partial U}{dt}+\frac{\partial F}{dU}\frac{\partial U}{dx}+\frac{\partial G}{dU}\frac{\partial U}{dy}+D=0 \tag{8}$$

Let us finally write equation (8) in vector-matrix form.

$$\frac{\partial U}{\partial t}+A\frac{\partial U}{\partial x}+B\frac{\partial U}{\partial y}+D=0 \qquad (9)$$

where are the matrices

$$A(p,q,h)=\frac{\partial F}{\partial U}=\begin{pmatrix} 0 & 1 & 0\\ -\frac{p^2}{h^2}+gh & \frac{2p}{h} & 0\\ -\frac{pq}{h^2} & \frac{q}{h} & \frac{p}{h}\end{pmatrix}$$

$$B(p,q,h)=\frac{\partial G}{\partial U}=\begin{pmatrix} 0 & 0 & 1\\ -\frac{pq}{h^2} & \frac{q}{h} & \frac{p}{h}\\ -\frac{q^2}{h^2}+gh & 0 & \frac{2q}{h}\end{pmatrix} \qquad (10)$$

To make the solution unique, it is necessary to set the initial and boundary conditions.

Initial conditions characterize the entire movement at some point in time t_0, taken as the initial.

$$\mathrm{U}(\mathrm{x},\mathrm{y},\mathrm{t}_0)=\mathrm{U}_0(x,y), \qquad (x,y)\in\Omega, \qquad (11)$$

Where is $U_0(x,y)$ – given distribution functions of flow depth and flow rates, Ω – two-dimensional region. The domain of definition of variables where the movement of water flow occurs has a complex geometric shape in the case of sections of rivers and natural canals [6].

A significant difficulty in formulating a two-dimensional problem lies in specifying the boundary conditions. We will consider the border $d\Omega$ areas Ω, consisting of liquid and impermeable solid parts, i.e.$d\Omega=\{d\Omega_{ж}, d\Omega_{т}\}$, moreover, these parts of the border can consist of several parts [8].

On the liquid part of the boundary, a change in depth or a change in water flow is specified

$$\begin{aligned} &h_i(x,y,t)=H_i(t),\\ &q_i(x,y,t)\cos\alpha+p_i(x,y,t)\sin\alpha=Q_i(t),\\ &\alpha=(\widehat{n,Ox}),\quad (x,y)\in d\Omega_{жi},\quad i=1,n_{ж}, \end{aligned} \qquad (12)$$

Where is $q_i(x,y,t)$ and $p_i(x,y,t)$ unknown longitudinal and transverse components of flow rates, $H_i(t)$ и $Q_i(t)$ - specified functions for changing the depth and flow rates on the corresponding liquid part, α – angle between the normal to the boundary and the axis x [4].

On the solid part of the boundary is given in the form

$$\begin{aligned} &\mathrm{q_i}(\mathrm{x},\mathrm{y},\mathrm{t})\cos\alpha+\mathrm{p_i}(\mathrm{x},\mathrm{y},\mathrm{t})\sin\alpha=0,\\ &\alpha=(n,Ox),(x,y)\in d\Omega_{ti} i=1,n_t \end{aligned} \qquad (13)$$

The physical meaning of (12) means that the total component of the longitudinal and transverse water flow rates normal to the boundary will be equal to zero.

Then the common boundary of the region is the union of the solid and liquid parts of the boundary [20].

$$d\Omega=d\Omega_{ж}\bigcup d\Omega_{т},\quad d\Omega_{ж}=\bigcup_{i=1}^{n_{ж}} d\Omega_{жi},\quad d\Omega_{т}=\bigcup_{i=1}^{n_{ж}} d\Omega_{тi}, \qquad (14)$$

Thus, to simulate two-dimensional water flow in open channels, it is necessary to solve the system of equations (9) with boundary conditions (12)-(13).

System of equations (9) refers to quasilinear partial differential equations with complex boundary conditions of the domains of definition of the variables. An exact solution to the formulated problem cannot be obtained, so it is necessary to use various numerical methods for an approximate solution based on the finite element method, which uses isoparametric transformation of the equations and the used (triangular and quadrangular) elements. The domain of definition of Ω variables is divided into N finite subdomains consisting of triangular or quadrangular elements [5].

Enter curvilinear coordinates $x=x(\xi, \eta)$, $y=y(\xi, \eta)$ and determine the elements of the isoparametric transformation. The relationship between the derivatives of the transformation is determined [6]

$$\frac{\partial}{\partial x}=\frac{\partial\xi}{\partial x}\frac{\partial}{\partial\xi}+\frac{\partial\eta}{\partial x}\frac{\partial}{\partial\eta}, \qquad \frac{\partial}{\partial y}=\frac{\partial\xi}{\partial y}\frac{\partial}{\partial\xi}+\frac{\partial\eta}{\partial y}\frac{\partial}{\partial\eta} \qquad (15)$$

or in vector-matrix form

$$\begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{pmatrix} = \begin{pmatrix} \xi_x & \eta_x \\ \xi_y & \eta_y \end{pmatrix} \begin{pmatrix} \frac{\partial}{\partial \xi} \\ \frac{\partial}{\partial \eta} \end{pmatrix} \tag{16}$$

Where is

$$\xi_x = \frac{\partial \xi}{\partial x}, \qquad \xi_y = \frac{\partial \xi}{\partial y}$$
$$\eta_x = \frac{\partial \eta}{\partial x}, \qquad \eta_y = \frac{\partial \xi}{\partial y} \tag{17}$$
$$0 \le \xi \le 1 \qquad 0 \le \eta \le 1,$$

Likewise

$$\frac{\partial}{\partial \xi} = \frac{\partial x}{\partial \xi}\frac{\partial}{\partial x} + \frac{\partial y}{\partial \xi}\frac{\partial}{\partial y} \qquad \frac{\partial}{\partial \eta} = \frac{\partial x}{\partial \eta}\frac{\partial}{\partial x} + \frac{\partial y}{\partial \eta}\frac{\partial}{\partial y} \tag{18}$$

or in vector-matrix form

$$\begin{pmatrix} \frac{\partial}{\partial \xi} \\ \frac{\partial}{\partial \eta} \end{pmatrix} = \begin{pmatrix} x_\xi & y_\xi \\ x_\eta & y_\eta \end{pmatrix} \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{pmatrix} \tag{19}$$

$$x_\xi = \frac{\partial x}{\partial \xi}, \qquad x_\eta = \frac{\partial x}{\partial \eta}, \qquad y_\xi = \frac{\partial y}{\partial \xi}, \qquad y_\eta = \frac{\partial y}{\partial \eta}, \tag{20}$$

$$\begin{pmatrix} \frac{\partial}{\partial \xi} \\ \frac{\partial}{\partial \eta} \end{pmatrix} = \frac{1}{\xi_x \eta_y - \xi_y \eta_x} \begin{pmatrix} \eta_x & -\eta_y \\ -\xi_y & \xi_x \end{pmatrix} \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{pmatrix} = \begin{pmatrix} x_\xi & y_\xi \\ x_\eta & y_\eta \end{pmatrix} \begin{pmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{pmatrix} \tag{21}$$

Introducing the Jacobian notation $J = \xi_x \eta_y - \xi_y \eta_x$, let's write the connections in a different form

$$\frac{1}{J} \begin{pmatrix} \eta_y & -\eta_x \\ -\xi_y & \xi_x \end{pmatrix} = \begin{pmatrix} x_\xi & y_\xi \\ x_\eta & y_\eta \end{pmatrix} \tag{22}$$

	(22)

Relationship between derivatives of spatial variables with fundamental and isoparametric coordinates

$$x_\xi = \frac{1}{J}\eta_y \qquad y_\xi = -\frac{1}{J}\eta_x$$
$$x_\eta = -\frac{1}{J}\xi_y \qquad y_\eta = \frac{1}{J}\xi_x \tag{23}$$

Or

$$\eta_y = J x_\xi \qquad \eta_x = -J y_\xi$$
$$\xi_y = -J x_\eta \qquad \xi_x = J y_\eta$$
$$J = \xi_x \eta_y - \xi_y \eta_x = J^2 (x_\xi y_\eta - x_\eta y_\xi) \tag{24}$$
$$J = \frac{1}{x_\xi y_\eta - x_\eta y_\xi}$$

The relationship with the main and isoparametric variables will be written as follows

$$p^\xi = \xi_x p + \xi_y q$$
$$p^\xi = \eta_x p + \eta_y q$$
$$p = \frac{1}{J}(\eta_y p^\xi - \xi_y p^\xi)$$
$$q = \frac{1}{J}(-\eta_x p^\xi + \xi_x p^\xi) \tag{25}$$

or in vector-matrix form

$$\begin{pmatrix} p^\xi \\ p^n \end{pmatrix} = \begin{pmatrix} \xi_x & \xi_y \\ \eta_x & \eta_y \end{pmatrix} \begin{pmatrix} p \\ q \end{pmatrix}$$

$$\begin{pmatrix} p \\ q \end{pmatrix} = \frac{1}{J} \begin{pmatrix} \eta_y & -\xi_y \\ -\eta_x & \eta_x \end{pmatrix} \begin{pmatrix} p^\xi \\ p^\xi \end{pmatrix} \quad (26)$$

We substitute the elements of the isoparametric transformation into the main equation, and after simple algebraic transformations we obtain the following vector-matrix equation in curvilinear coordinates [18].

$$\frac{\partial V}{\partial t} + A^{\xi\eta}(V)\frac{\partial V}{\partial \xi} + B^{\xi\eta}(V)\frac{\partial V}{\partial \eta} + D^{\xi\eta}(V) = 0 \quad (27)$$

Next, the initial (11) and boundary conditions (12)-(13) are also translated into curvilinear coordinates $x=x(\xi,\eta)$, $y=y(\xi, \eta)$.

Transforming quadrilaterals. For a quadrilateral with vertices (x_i,y_i, $i=1,2,3,4$) we will carry out the transformation elements according to the formulas

$$x = x(\xi,\ \eta) = x_1 + (x_2 - x_1)\xi + (x_3 - x_1)\eta + A\xi\eta,$$
$$y = y(\xi,\ \eta) = y_1 + (y_2 - y_1)\xi + (y_3 - y_1)\eta + B\xi\eta \quad (28)$$

Where is

$$A=x_4-x_3-x_2+x_1 \qquad B=y_4-y_3-y_2+y_1$$

$$I(\xi,\ \eta) = det\begin{bmatrix} x_2 - x_1 + A\eta & x_3 - x_1 + A\xi \\ y_2 - y_1 + B\eta & y_3 - y_1 + B\xi \end{bmatrix}$$

Derivatives are determined by the formula

$$\frac{\partial x}{\partial \xi} = x_\xi = x_2 - x_1 + A\eta, \quad \frac{\partial x}{\partial \eta} = x_\eta = x_3 - x_1 + A\xi,$$
$$\frac{\partial y}{\partial \xi} = y_\xi = y_2 - y_1 + B\eta, \quad \frac{\partial y}{\partial \eta} = y_\eta = y_3 - y_1 + B\xi \quad (29)$$

The inverse transformation for quadrilaterals can be constructed based on formula (1), but during implementation you can do without the explicit form of the inverse transformation.

Transforming triangles. For a triangle with vertices (x_i,y_i, $i=1,2,3$) transformation elements using the bilinear transformation method have the form

$$x = x(\xi,\ \eta) = x_1 + (x_2 - x_1)\xi + (x_3 - x_1)\eta,$$
$$y = y(\xi,\ \eta) = y_1 + (y_2 - y_1)\xi + (y_3 - y_1)\eta \quad (30)$$

$$I(\xi,\ \eta) = det\begin{bmatrix} x_2 - x_1 & x_3 - x_1 \\ y_2 - y_1 & y_3 - y_1 \end{bmatrix} = (x_2 - x_1)(y_3 - y_1) - (x_3 - x_1)(y_2 - y_1) \quad (31)$$

$$\frac{\partial x}{\partial \xi} = x_\xi = x_2 - x_1, \quad \frac{\partial x}{\partial \eta} = x_\eta = x_3 - x_1, \quad \frac{\partial y}{\partial \xi} = y_\xi = y_2 - y_1, \quad \frac{\partial y}{\partial \eta} = y_\eta = y_3 - y_1 \quad (32)$$

The inverse transformation to (2) has the form

$$\xi = \frac{(y_3 - y_1)(x - x_1) - (x_3 - x_1)(y - y_1)}{(y_3 - y_1)(x_2 - x_1) - (x_3 - x_1)(y_2 - y_1)}; \qquad \eta = \frac{(y_2 - y_1)(x - x_1) - (x_2 - x_1)(y - y_1)}{(y_2 - y_1)(x_3 - x_1) - (x_2 - x_1)(y_3 - y_1)} \quad (33)$$

Numerical solution method. As an algorithm for the numerical solution of equation (26) with boundary conditions, we use the finite element method based on the Galerkin-Petrov scheme [6, 7]:

1. Domain of definition Ω variables is divided into N finite subareas

Ω_i (i – 1, 2,…, N (for example, irregular triangles and quadrilaterals having areas of the same order) so that $\bigcup_{i=1}^{N} \Omega_i$, $\Omega_i \cap \Omega_i=0$, at $i \neq j$ and go to isoparametric coordinates using the bilinear transformation;

2. Choosing bases $\{\varphi_i(\xi,\eta)\}$ and $\{\psi_i(\xi,\eta)\}$ - for sub-areas $\Omega_{i.}$;

3. The bases for the elements are selected from the approximation conditions, for example, for a triangular element - linear approximation;

4. Second basis $\{\psi_i(\xi,\eta)\}$ we choose as the characteristic function of the region Ω_i:

$$\psi_i(\xi,\eta) = \begin{cases} 1, & (x,y) \in \Omega_i, \\ 0, & (x,y) \notin \Omega_i. \end{cases} \quad (34)$$

5. An approximate solution V $(\xi,\eta,\ t)$ is sought in the form

$$V^j(\xi,\eta,t) = \sum_{i=1}^{n_i^j} Q_i^j(t)\phi_i^j(\xi,\eta) \quad (35)$$

Where is $Q_i^j(t) = \begin{pmatrix} h_i^j(t), & 1,\dots,n_i^j \\ p_i^{\xi j}(t), & 1,\dots,n_i^j \\ p_i^{\eta j}(t), & 1,\dots,n_i^j \end{pmatrix}$- vector-matrix of unknown coefficients and number of functions in approximations of elements of the domain of definition of variables and φi(ξ,η) – linear or quadratic basis functions on a triangle and quadrilateral [3,4].

6. To determine the coefficients $Q_i^j(t)$ at internal points of the domain of definition of variables, a system of equations is used

$$\left(\frac{\partial V^j}{\partial t} + A^{\xi\eta}(V^j)\frac{\partial V^j}{\partial \xi} + B^{\xi\eta}(V^j)\frac{\partial V^j}{\partial \eta} + D^{\xi\eta}(V^j),\ \ \psi_j\right), \qquad j = 1,2,\dots N \tag{36}$$

or

$$\iint_{\Omega_j}\left(\frac{\partial V^j}{\partial t} + A^{\xi\eta}(V^j)\frac{\partial V^j}{\partial \xi} + B^{\xi\eta}(V^j)\frac{\partial V^j}{\partial \eta} + D^{\xi\eta}(V^j)\right)\partial\omega_j = 0, \qquad j = 1,\dots.,N_j \tag{37}$$

Where is scalar product *(u, v)*.

7. Based on the given boundary conditions (12) – (13), additional equations are compiled for unknown boundary points;

8. Substituting solutions into the equation and calculating the integrals in (41), we obtain a matrix system of nonlinear ordinary differential equations at each node of the element, using the quasi-linearization method, we obtain

$$\frac{dQ_i^j}{dt} + G_i^j F_i^j\left(Q_i^j\right) = U_i^j \tag{38}$$
$$j = 1,\dots.,N_j$$

Where is G^j and U^j - vectors of coefficients obtained as a result of numerical integration.

9. Solving the resulting system of matrix differential equations based on the finite-difference method, we obtain the functions $Q_i^j(t)$ for all grid nodes, then passing to the main variables using the inverse isoparametric transformation, we obtain the final solution [8].

10. Next, points 6-9 of the algorithm are repeated cyclically for subsequent time steps [8].

The above algorithm is implemented in the form of a software package and modeling of unsteady water movement in open channels is carried out using model examples [8].

RESEARCH RESULTS

A rectangular section of the canal bed (Fig. 1) with a spur on the right side along the flow. The parameters of the rectangular channel are 50.0 m in width and 1000.0 m in length. The channel is divided into 1960 quadrangular elements, the approximate area of each quadrangle is 25 square meters. m, channel slope 0.00001, bottom mark at the end of the channel was 4.0 m.

The initial conditions were assumed to be equal to zero along the entire channel and the water surface elevation at the end of the channel was equal to 5.0 m, i.e. there was standing water in the riverbed. At the solid upper and lower boundaries, the conditions for zero water flow normal to the canal side are accepted.

As boundary conditions, a liquid boundary with a constant water flow rate of 6 m^3/s, was adopted on the left side of the rectangular channel, and a constant water horizon of 5.0 m was selected on the right side of the section.

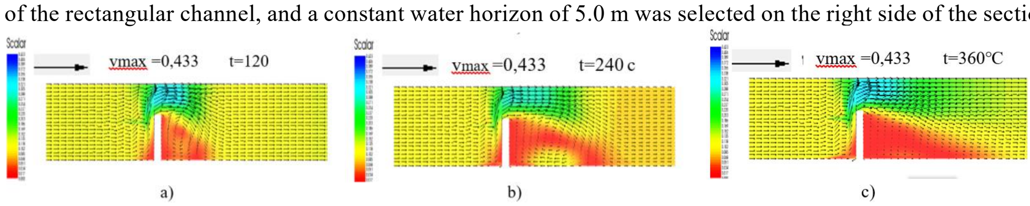

FIGURE 1. Section of a rectangular channel with a spur. a) shows the velocity diagram in time 120 seconds after the start of the process; b) shows the velocity diagram in time 240 seconds after the start of the process; c) shows the velocity diagram in time 360 seconds after the start of the process

From the moment the numerical experiment began, water began to flow from the right boundary evenly across its width at a water flow rate of 6 m^3/s and changes in the parameters of the water flow began. On the left side of the figures are scales for water flow rates. The figures show how the velocity diagrams of the water flow along the length and width change over time and how the whirlpool zone behind the spur changes, which changes along the length over time.

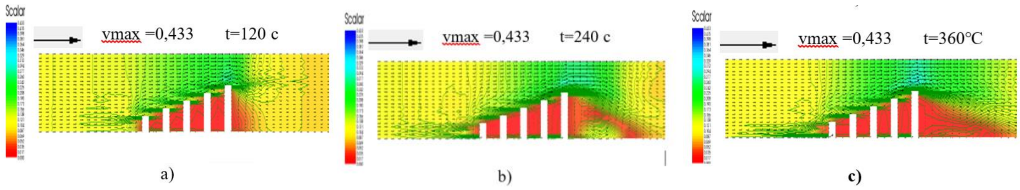

FIGURE 2. Section of a rectangular channel with sequentially located one-sided spurs. In Fig. 2 a, b and c show velocity diagrams at various times after the start of the process 120 seconds later.

A rectangular section of the channel (Fig. 2) with successively located one-sided spurs on the right side along the flow. The parameters of the rectangular channel, initial, boundary and other conditions are similar to Example 1. On the left side of the figures are scales for water flow rates. The figures show how the diagrams of water flow velocities along the length and width change over time. The whirlpool zone behind the spur is almost absent in this case [13-15].

A zigzag rectangular river bed (Fig. 3) 30 m wide and 400 m long. The bed is divided into 600 quadrangular elements, the approximate area of each quadrangle is 15 to 30 square meters. m, channel slope 0.0001, bottom mark at the end of the channel was 5.0 m.

The initial conditions along the entire channel are such that the water flow is zero and the elevation at the end of the section is 6.0 m. Changes in water flow are specified at the right liquid boundary 10 m^3/s, and on the left liquid boundary there is a change in the elevation of the free water surface equal to 6.0 m.

From the moment the numerical experiment began, water began to flow from the right boundary evenly across the width at the rate of water flow 10 m^3/s and changes in water flow parameters began. In Fig. 1 a, b and c show velocity diagrams at various times after the start of the process 100 seconds later. On the left side of the figures are scales for water flow rates. The figures show how the velocity diagrams of the water flow along the length and width change over time and how the maximum values of velocities occur at the bends of the zigzag channel, and at the humps of the zigzag channel they have minimum velocities [16-17].

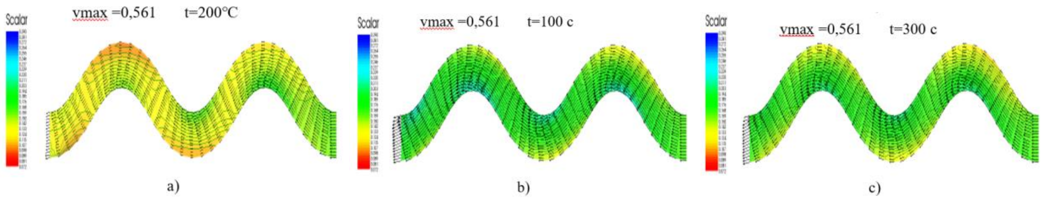

FIGURE 3. Section of a rectangular zigzag canal. a) shows the velocity plots at different points in time 200 seconds after the start of the process; b) shows the velocity plots at different points in time 100 seconds after the start of the process; c) shows the velocity plots at different points in time 300 seconds after the start of the process

At the beginning of the numerical experiment, water began to flow evenly across the width from the right boundary with a water flow rate of 10 m3/s, and changes occurred in the parameters of the water flow. The scales of the water flow velocity are shown on the left side of the figures. As can be seen from the figures, the water flow velocity plots change over time along the length and width and reach maximum values of velocities at the bends of the zigzag canal and minimum velocities at the irregularities of the zigzag canal.

CONCLUSIONS

Thus, based on modeling the planned unsteady movement of water in open channels using the algorithm and software package described above, it is possible to determine changes in the main parameters of water flow in space and time and the associated dynamics of transient processes of water resources.

The development of a modeling system based on finite element methods makes it possible to evaluate qualitative and quantitative changes in water flow parameters along the length and width of the channel, and also makes it possible to determine the design parameters of protective, regulating water flow structures and improve the operational parameters of existing hydraulic structures.

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