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ANALYSIS OF NUMERICAL METHODS OF MODELING UNSTEADY WATER MOVEMENT IN WATER MANAGEMENT FACILITIES, TAKING INTO ACCOUNT THE MULTIDIMENSIONAL DISTRIBUTION OF THEIR PARAMETERS IN SPACE

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Abstract: *In the article, the problems of analyzing the numerical methods of modeling the unsteady water movement in the water management objects, taking into account the multidimensional distribution of their parameters in space, are discussed. According to the author, finite difference and finite element methods are usually used to model hydrodynamic problems. The use of the finite difference method for modeling two-dimensional unsteady water flow in open channels is effectively used if the field of determination of flow variables has a regular shape. In the work process, the finite difference method was used to model the two-dimensional movement of water. If the field of detection does not have a regular shape, the application of the finite-difference method becomes complicated in the construction of the differential mesh and the determination of the boundaries according to the boundary conditions.*

Key words: *water management objects, unsteady water movement, modeling, numerical methods, multidimensional distribution in space, hydrodynamic problems, determination of flow variables, finite-difference method.*

Mathematical modeling of unsteady water movement in open streams was studied in the researches of Saint-Venan, S.A.Khristianovich, A.A. Arkhangelsky, J. Stoker and others[1].

The method of characteristics was proposed by S.A. Khristianovich and developed by A.A. Arkhangelsky [2] and others. The essence of this method is to replace the system of Saint-Venant equations with four equivalent systems of ordinary differential equations, that is, two characteristic (direct and inverse) equations and two equations connecting the flow elements along these characteristics. The four-equation system is solved by the finite difference method and allows to calculate the t and x coordinates of the characteristic grid nodes in the wave plane. Then, the values of flow parameters are determined according to the calculated coordinates: Q(x,t), z(x,t).

The method of characteristics makes it easier to obtain the boundaries of the domain of existence of a given solution (a given wave), in particular, it tracks the momentum and goal of a continuous transition of a wave. In addition, mesh methods are used to calculate the mode elements in the boundary region of the characteristic equations.

The variational method was developed by N.A. Kartvelishvili and is based on the application of the Bubnov-Galerkin method to calculate the unsteady motion of water. This method allows to bring the solution of the system of equations in partial derivatives (in this case, the system of Saint-Venant equations) to the initial solution of the system of ordinary differential equations, and then to the system of algebraic equations [3]. It is convenient to use modern computers for calculation work.

Some of the difficulties of this method are evident in the selection of variation coefficients based on careful processing of topographic and hydrometric materials.

The method of straight lines is considered as the endpoint of the mesh method, when a rectangular mesh is used, one of its linear dimensions tends to zero, and the set of boundary nodes represents some system of straight line parallel sections. fills In this case, differential equations with particular derivatives are reduced to a system of ordinary differential equations by replacing the derivatives with appropriate unknown differential ratios [2].

The main function of this method is that all changes of parameters are assumed to be small compared to their values in the initial steady state, so the squares and multiples of these quantities are ignored. The successful use of this method was proposed by academician E.E. Makovsky [3], the analytical solution of the linear Saint-Venant equation obtained by him is now widely used in engineering calculations.

V. I. Koren and L. S. Kuchments conducted research on creating mathematical models of unstable water movement [3]. In their research, a wide range of issues related to the creation of mathematical models of the river flow were considered.

Many works are dedicated to the mathematical description of boundary problems, the creation of numerical methods of solving mainly using definite differential schemes, the development of methods for determining morphometric and hydraulic properties, their approximation, and exact equalization and determination by solving inverse problems. N.A. Kartvelishvili [4] developed the main issues of deriving one-dimensional equations from multi-dimensional equations of motion in connection with the one-dimensional scheme of the flow, which made it possible to clarify the theoretical aspects of the one-dimensional scheme of the process. Many authors have considered the possibilities of determining the mathematical meaning of the corrections for momentum and energy introduced by various methods to the equations of motion, simplifying and schematizing the movement of water flows.

The main advantage of the open scheme is the relative simplicity of the construction of the solution algorithm and the implementation of its software. But this does not allow to perform calculations on large calculated time steps, because for the scheme to be stable, a certain relationship between the time step and the calculated length step, i.e., the Courant-Friedrichs-Levy condition, must be fulfilled.

$$\Delta t = \frac{\Delta x}{|v| + \sqrt{gh}} \qquad (1.34)$$

This limits the use of disclosure schemes.

S.K. There is another limitation indicated by Godunov [9]:

$$\Delta t \le \frac{c}{g}\sqrt{\frac{R}{i}} = \frac{K}{g\omega\sqrt{i}}, \qquad (1.35)$$

where v is the flow rate; *g* – gravitational constant; h – ordinate of the free flow surface; c – Shezi coefficient; R is the wetted channel perimeter; *i* – lower slope; ω – flow field; K is the consumption module.

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According to experts, the finite element method is the most effective method for solving hydraulic problems, but it is little studied [11, 25].

In the early 60s, the works of professors related to the results of mathematical modeling of unstable water movement [2, 3]. Here, the equation of motion is derived in a more general form, and mathematical formulas of problems of uniformly variable and continuous unsteady motion of water in water streams and their systems are given. A number of methods for solving one-dimensional problems without separation and separation of discontinuities on stationary and moving grids, methods for calculating and determining many parameters of equations have been developed. These scientists conducted research on increasing the level of automation of mathematical modeling. Expression of analytical and numerical methods of solving problems, including the movement of water along an open channel, is given great attention. Methods of solving two-dimensional problems have been developed and software tools have been created.

Approximation of differential equations using implicit differential schemes leads to the solution of a differential boundary value problem at each time layer with essentially the same structure as the basic boundary value problem. Algorithms for solving differential equations that take this structure into account are the most successful [4]. In solving similar problems, linear differential equations are used, as well as using one of the variants of the method in which unknown coefficients are given, through which the parameters of the studied system state are determined using balance equations.

Hydraulic models almost always allow obtaining, interpolating and extrapolating process characteristics with the desired detail and acceptable errors within wide limits. Therefore, despite the high cost of their creation, they are widespread. This applies primarily to one-dimensional mathematical models [2, 3].

According to experts, the finite element method is the most effective way to solve hydraulic problems, but the finite element method was used to solve one-dimensional problems only in the 80s of the last century.

When using numerical methods for two-dimensional problems, the main problem is to determine the dependence of the solution of the equations on the dominant factors of the physical process that determine the initial and boundary conditions of the right side of the equation. The use of a numerical model requires the description of initial morphological and hydrological data in space and time. The effect of the model on this description largely reflects the accuracy of the calculation method.

Finite difference methods have become the most widely used method for numerically solving differential equations in two-dimensional problems, which is explained by the universality of these methods and the ease of their implementation on computers. Currently, there is considerable experience in the application of discretization methods to various problems of atmospheric, oceanic hydro and thermodynamics, based on which the rapid use of the results of the prediction of hydrometeorological phenomena and the path related to important theoretical studies based on the numerical integration of the shallow water equation directions are being developed because the hydrostatic approximation implies a certain filtering approximation that isolates a certain type of motion.

In order to successfully apply differentiation methods, in any case, it is necessary to know the main elements of the theory of finite difference approximations and to understand its situation. These are the concept of convergence of a differential equation to a differential equation in a certain space, the concept of stability of differential equations, according to the norm of solving differential equations, convergence to the solution of a differential equation when the step of the space-time grid tends to zero, stability and convergence given by Lax's equivalence theorem the relationship between; different types of schemes and practical calculation algorithms; effective (easily tested in practice) criteria for the stability of differential equations in the simplest case; and finally, the adoption and methodology of heuristic expansion of the scope of such criteria. The study of the listed elements of the theory, the issues considered here, has ten years of study experience, and it is necessary and relevant to use a wide variety of methods to analyze them.

A review of the relevant results shows the evolution of the penetration of quantitative methods into this area of mesoscale oceanology. The first attempt at the numerical integration of shallow water equations to calculate long-wave oscillations of the sea, a series of studies on storm forecasting in Lake Michigan, Platzman N.A. performed by [4]. The researcher proposed a linear model of the motion induced in a stormy situation over the lake. Central difference scheme was used to solve the equations. During storm tracking, the log books formed the basis of Chicago's later flood warning system. Calculation of fluctuations of the North Sea level was carried out by G. Fischer [5], using the "open - hidden" scheme. The well-known "crest" approximation for the wave equation leads to this, according to which the approximation of differential equations Courant R, Friedrichs K.O. and Lewy H. [4] studied in the article.

It should be noted that at this stage of the research, the work of G. Fischer was the only work in which the convergence of the discrete problem was analyzed taking into account the friction force. The analysis is based on the method of Lax P.D., R.D. Richtmyer [4], which led to the verification of some effective criteria for the stability of the developed scheme. In the one-dimensional case, A. Swansson [4] used the transparent-non-revealing scheme to calculate the level and currents of the Baltic Sea.

S.Uusitalo [5] made an attempt to integrate the initial equations with the help of the simplest non-revealing scheme obtained by averaging the required functions for two time layers. Despite the linearization of the equations, if the spatial operator is not used in the smoothing of the solution, the variability of the coefficients and the effect of the boundaries lead to computational instability. The calculation of a large number of storm surges caused by moving typhoons on the coast of Japan was carried out by M. Miyazaki M., Ueno T., Unoki S. according to the central-difference scheme in the Eliassen modification [5]. The researches of Japanese authors are distinguished by their attention to the functional appearance of the considered physical factors, but they do not introduce any innovations in the work from the point of view of calculation.

The second stage of the research determines the transition from the simple modeling of hydrometeorological situations that occurred in the 60s of the last century to the extensive application of numerical experiments to analyze the mathematical model itself and explain its accuracy.

Discussions of the formulation of boundary value problems and their numerical integration, as well as the scope of problems related to the calculation of flood patterns caused by tropical storms, can be found in Harris D., Jelesnianski C. [5] and Ch. Jeleshianski [6] is presented in scientific works. The applied difference scheme is checked for invariance of the total energy of fluctuations in the closed basin, and its stability is analyzed with the nine-point spatial operator.

After the work of W.Hansen and R.O.Reid [6], the first attempt to numerically integrate the shallow water equations for the calculation of long-wave sea oscillations, studies on the prediction of storm conditions in Lake Michigan were carried out by G. Platzman increased, he proposed a linear model of the motion induced by the storm front over the lake. He used the central difference scheme to solve the equations. Account books based on the observation of storms formed the basis of the forecasting method that was created later.

In order to create a method for predicting sea floods in Leningrad, comprehensive research was carried out for several years, including hydraulic modeling, meteorological research and observations in natural conditions. To optimize the hydrodynamic method, a large number of floods that occurred in Leningrad were calculated and a number of different experiments were conducted according to the scheme proposed by P. Laks. The analysis of the possibilities of the mathematical model prompted us to study a number of schemes other than those mentioned above, as well as to conduct a number of special studies for comprehensive verification of the method.

A more general theory, which considers the development of the process over time, allows studying their attenuation, in addition to the spectrum of free oscillations. Comparison with complete data allows to determine the dependence of the nature of propagation on the dimensions of the basin and to determine the coefficient of friction. Interesting results can be obtained from analyzing the spectrum of solving a nonlinear problem. In addition to these physical problems, the free oscillations of closed water bodies are interesting as an object for studying the characteristics of discrete circuits, because it is easy to interpret the change in the total energy of such oscillations over time. A few relevant examples are discussed below.

For modeling hydrodynamic problems, finite difference and finite element methods are usually used. The use of the finite difference method for modeling two-dimensional unsteady water flow in open channels is effectively used if the field of determination of flow variables has a regular shape. In the work process, the finite difference method was used to model the two-dimensional movement of water. If the field of detection does not have a regular shape, the application of the finite-difference method becomes complicated in the construction of the differential mesh and the determination of the boundaries according to the boundary conditions.

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