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Application of geoinformation technology methods for researching the morphodynamics of river and coastal processes

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Abstract—**This report is devoted to aspects of the application and improvement of methods of geoinformation systems and information technologies to solving problems of hydromorphodynamics for the development of measures to ensure the stable state of the sea approach channels looking on the example of the deepwater Danube-Black Sea shipping channel. Mathematical numerical methods with a GIS database were used for modeling river and coastal processes, creating calculation grids and postprocessing the numerical results.**

Keywords—geoinformation systems; bathymetric and hydrological data base; binding of grids and bathymetry nodes to maps; numerical methods of hydromorphodynamics; cartographic methods of space images and results analysis.

I. Introduction

The analysis of the state in the zones of recreational and industrial use of riverbeds and banks of rivers, deltas, seas and water reservoirs showed that the lack of regulation and coastal protection structures leads to the depletion of beaches and restraining the development of coastal infrastructure. Designed modern engineering protective structures must prevent the reduction of the area and length of territories along the water cut and comply with the principle of environmental sustainability. Currently, the principle of natural analogues, developed at the National Academy of Sciences Hydromechanics Institute by B.A. Pyshkin in 1954[1] and improved and implemented in many developments by Yu.M. Sokolnikov, V.V. Khomytskyi. [4, 5] and others. The generalization of methods of calculation and research of structures in the form of natural analogues was developed in the works of L. van Rijn, N. Christensen, K. Mangor [2, 3, 6, 7], as well as by authors based on CFD complexes [12, 13]. A possible option for ecologically safe development and protection of coastal areas can be the creation of natural bays by the construction of intermittent breakwaters [4, 5].

One of the more effective means of researching the condition of coastal zones in the conditions of wide application of technical, space and computer technologies arose due to the development of geoinformation technologies (GIS) as a basis for saving and processing the results of bathymetric, geological, hydrological, meteorological measurements for the analysis of hydromorphodynamic processes using mathematical modeling methods [8, 9, 12]. Currently, GIS software complexes such as ArcGIS, MapInfo, QGIS and others have been created for open use for applied tasks.

The application of geoinformation systems and technologies takes place in the following areas of hydromorphodynamics:

- Use of GIS to compile a geolocation database of signs of morphodynamic changes and linking to special space images and research objects;
- Conducting a geo-informational analysis of the results of bathymetric measurements and comparison of space images to determine the morphological changes of riverbeds, mouths and banks of rivers and shipping channels;
- Mathematical numerical methods of modeling river and coastal processes using a GIS database for creating calculation grids and postprocessing the results of numerical calculations taking into account boundary conditions.

In fact, in recent years, a new field has been created - mathematical geography.

With the help of GIS, a database is created that contains hydrological, geological characteristics and geolocation, as well as their properties or attributes [13, 14]. A GIS database can be stored in various forms such as a set of individual data files or spatially supported data, or part of a project, for use as input data and for analysis and visualization of results.

As an example, we will consider here aspects of the application of GIS and IT for drawing up a numerical model of analysis and substantiation of measures to ensure the stable condition of the Sea Approach Channel (SAC) at the Danube-Black Sea Deep-Navigation Channel (DNC). The current state of the dynamics of the marine approach channel (see the in Fig. 1) shows the zone of flow spreading from the mouth of the Bystroy and siltation of the SAC between the protective dam (left flooded bank of the SAC) and Ptashina Kosa (right flooded bank of the SAC). At the same time, there is a significant deviation of the canal route from the design IPC. Preliminary observations of channel, bar, and estuarine processes along the canal route showed that the amount of suspended and entrained sediments carried by the Bystry estuary onto the SAC route which is wider than the Bystry arm, there is siltation of the channel route, pushing and simultaneous erosion of the flooded left bank bank, and even signs of meandering are observed (see Fig. 1). In order to get rid of such negative phenomena during the implementation of the scientific support of the GSH project, the Institute of Hydromechanics of the National Academy of Sciences (IGM, Department of Hydrodynamics of Channel and Wave Flows) proposed measures at the mouth of the Bystroy arm, which are based on the method developed by the institute for the anticipatory creation of natural analogs of river and sea coastal forms. These proposals were substantiated by scientific research, field observations and analysis of bathymetric surveys of dredging operations at the IPC over a long period. Creation of the proposed measures will ensure a significant reduction in the amount of repair excavations. At one time, they were provided to the project organizations to be implemented in the navigation channel project. Structural elements are taken into account in the modeling - protective dams, the presence of natural formations in the form of a right-bank spit and an estuarine bar, on which the dam and the opening of the SAC are located (Fig. 2).

Figure 1. Current space image of the SAC

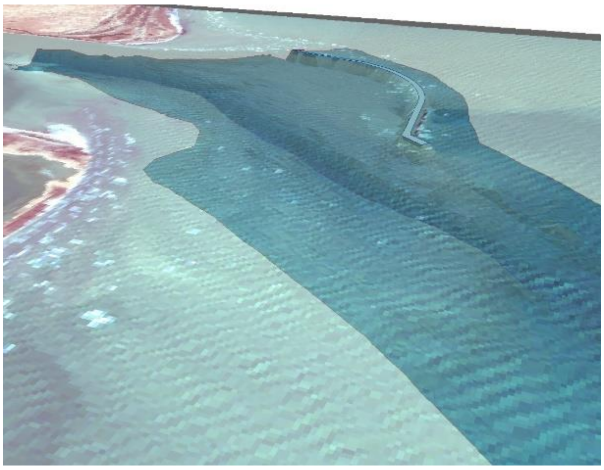

Figure 2. Spatial image of the research area

Modeling was carried out on the basis of bathymetry measurements (Fig. 2, 3). It can be seen from the pictures that the bottom has a complex topography. The meandering of the stream and the formation of a slot basin with a depth of more than 8 *m* are observed.

II. Mathematical model of the morphodynamic process

To calculate flow dynamics and morphodynamics, the FST2DH (2D Depth-averaged Flow and Sediment Transport Model) program [14] is used, which implements the finite element method for calculating non-stationary depth-averaged surface water flow. The system of calculation equations includes mass and momentum transfer equations, bottom deformation equations, and drag and suspended sediment transfer. The mass transfer equation, taking into account the deformation of the bottom, has the form

$$\frac{\partial z_w}{\partial t}+\frac{\partial q_1}{\partial x}+\frac{\partial q_2}{\partial y}=q_m ,$$

where $z_w = z_b + H$ is water surface level, z_b – depth of erosion zone; q_1, q_2 –volumetric flow rates in x, y per unit of flow width; q_m – inflow (flow) per unit area.

Equations of momentum transfer in specific costs have the form

$$\frac{\partial q_1}{\partial t}+\frac{\partial}{\partial x}\left(\beta\frac{q_1^2}{H}+\frac{1}{2}gH^2\right)+\frac{\partial}{\partial y}\left(\beta\frac{q_1q_2}{H}\right)+gH\frac{\partial z_b}{\partial x}$$
$$+\frac{1}{\rho}\left[\tau_{bx}-\frac{\partial\left(H\tau_{xx}\right)}{\partial x}-\frac{\partial\left(H\tau_{xy}\right)}{\partial y}\right]=0$$

$$\frac{\partial q_2}{\partial t}+\frac{\partial}{\partial y}\left(\beta\frac{q_2^2}{H}+\frac{1}{2}gH^2\right)+\frac{\partial}{\partial x}\left(\beta\frac{q_1q_2}{H}\right)+gH\frac{\partial z_b}{\partial y}$$
$$+\frac{1}{\rho}\left[\tau_{by}-\frac{\partial\left(H\tau_{yx}\right)}{\partial x}-\frac{\partial\left(H\tau_{yy}\right)}{\partial y}\right]=0$$

where τ_{bx},τ_{by} – bottom shear stresses are stresses caused by flow turbulence, which are considered to be proportional to the gradients of the depth-averaged velocity; β — the correction factor of the flow momentum, which takes into account the change in velocity in the vertical direction.

Changes in the bottom surface during erosion and deposition are determined by the equation

$$(1-\eta_s)\frac{\partial z_b}{\partial t}+\frac{\partial q_{s1}}{\partial x}+\frac{\partial q_{s2}}{\partial y}=0$$

where η_s is the porosity of the bottom material, q_{s1}, q_{s2} is the volume flow rate of entrained and suspended sediments per unit width of the current. The sediment concentration is described by the transport equation

$$\frac{\partial\left(C_sH\right)}{\partial t}+\frac{\partial\left(C_sq_1\right)}{\partial x}+\frac{\partial\left(C_sq_2\right)}{\partial y}=C_{es}\left(C_s^*-C_s\right)$$

where C_s^* –is the equilibrium concentration, which describes the state of equilibrium of sediments rising from the bottom and settling.

Boundary conditions. In the upper part of the flow, the flow rate Q is set, in the lower part – the level of the water surface z_w. The elements of the calculation grid are directed parallel to the supports and have a rectangular shape of 20*40 *m*, in the zone of IPC the grid thickens to 20*20 m (Fig. 3). The effect of compression of the flow by structures is taken into account by the uniform distribution of hydrodynamic resistance across the grid element containing impermeable parts of the structure (pillars, dams).

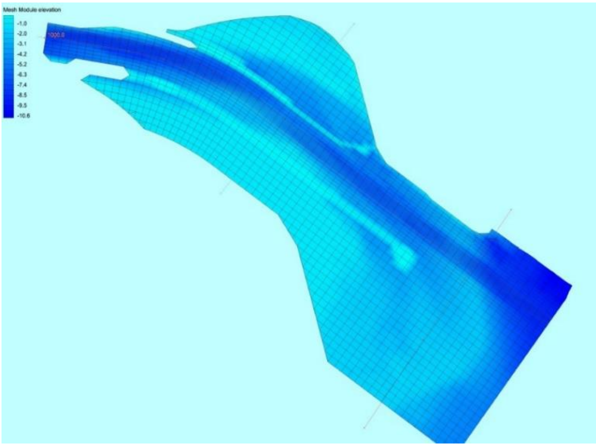

Figure 3. Bathymetric data over calculation grid

III. RESULTS OF THE NUMERICAL EXPERIMENT

Modern calculation complexes based on numerical calculation methods make it possible to evaluate the kinematics of the flow and erosion of the river. Figure 4 shows the calculation results steady flow with channel-forming flows Q = 1000 m^3/s with boundary conditions $z_w = 0.2$ *m*. Flow speed of 1.0-1.5 *m/c* is observed on a straight section of the channel.

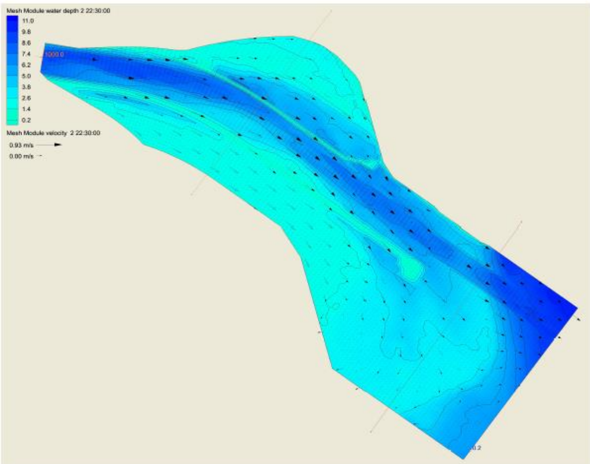

Figure 4. Kinematic picture of the flow on the SAC

The use of GIS tools makes it possible to estimate the extent and location of erosion of bedforms eroded noncohesive soil (Fig. 5) and underwater elements of structures made of local materials.

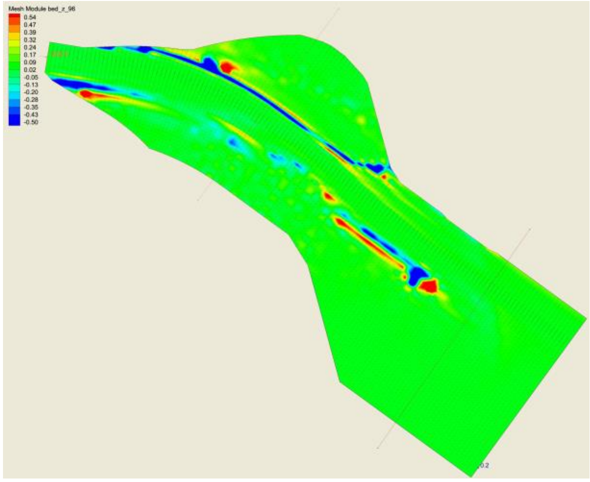

Figure 5. Зміни глибин в результаті ерозії брівок МПК

IV. CONCLUSIONS

A program for calculating hydromorphodynamic processes was created using computer modeling tools. On the basis of morphodynamic analysis with the help of GIS of the results of mathematical modeling, measures to stabilize the design profile of the DNC SAC were developed and substantiated, which are proposed to be carried out in stages:

– **The first stage** :

– Carrying out of load washing in the indicated in fig. 6 places of the shallow water of the directing jetties with scooping materials during the dredging of the channel by the method of gradual extension starting from the left bank of the canal with the simultaneous attachment of ridges with bushy plants (possibly in gabions) to avoid erosion, which will occur in the case of creating submerged jetties structures. This measure is practically ecological, does not have a negative impact on the environment, but complements the existing natural form - the right-bank Bird Spit and the left-bank shoal - with sustainable natural analogues in the form of coastal bars, which reduces the time and volume of dredging and does not require significant additional costs. After the natural overgrowth of the braids and jet directing groins, the amount of dredging will be minimized.

The second stage:

– After the completion of the first stage, the dredged materials may be used to backfill the protective embankment (permanently, instead of dumping on the sea dump) of the natural bar beach slope type on the seaward side of the capital jet-directing protective dam (Fig. 2, 6), which will significantly increase its reliability.

Figure 6.

The proposals remain relevant even now in connection with the violation of grain agreements by the occupiers and the need for reliable transport of goods by sea vessels to the Danube ports. They can be carried out in parallel with the dredging works, which speeds up their execution, practically does not require significant additional costs and will ensure a further reduction in the amount of repair dredges and the stability of protective structures and IPC. We offer to consider and take into account our proposals during the discussion and design of measures for gradual deepening over to 7 *m* and reliable operation of the deep-sea shipping passage through the mouth of the Bystry and other arms of the Cylia delta with representatives of the design and operation organizations.

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