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DEVISING A PROCEDURE FOR INTEGRATED MODELING OF RIVERBED SHAPE IN THE AREA OF BRIDGE CROSSING IN ORDER TO AVOID DANGEROUS WASHING EROSION

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The object of research is a riverbed in the area of a bridge crossing, which is subject to the action of high water during the passage of a flood.

The selection of parameters and contours of the scheme of the river section was carried out using a mathematical model of the flow and deformation of the bed of the riverbed before and after the change of its shape. It was established that the assignment of parameters of the operational slot should be performed on the basis of the principle of creating natural analogs of riverbed shapes, riverbed and floodplain terraces, with the use of mathematical modeling.

To reduce erosion in the area of bridge crossings, it is proposed to regulate the riverbed by constructing a canalized riverbed. Modeling according to this option showed that the erosion in the span of a road bridge decreased and did not exceed 1.5 m. In addition, it was established that a significant role in ensuring the stability of the river is played by the vegetation cover in floodplain areas.

Using the method of mathematical modeling, it was established that the area near the convex bank with a width of 150 m is subject to the strongest erosion in the design of the supports. Siltation of the existing left-bank bottom basin is also observed.

It is recommended to make a decision to carry out restorative cutting of riverbed alignment annually after receiving a flood forecast from the local hydrometeorological station. In the case of a high flood warning, work should be carried out to clear the sleeves on the approach to the construction of the bridge deck.

It was established that the most stable shape of riverbeds is in the form of curvilinear incomplete meandering when the radii of curvature R and the width of the riverbed B satisfy the ratio R = (4…7) B at riverbed-forming flow rate. At the same time, radii of curvature R < 3.5 B should not be allowed, as this leads to separation of the flow from the convex bank and excessive erosion of the concave bank

Keywords: riverbed, bridge crossing, flood, hydromorphodynamics of riverbed flows, canalized riverbed, Google Earth systems

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1. Introduction

Under natural conditions, rivers rarely have a straight course. They are characterized by a tortuous outline in plan, and for some areas this tortuousness is extremely large. Of great interest are the problems of the influence of the curved flow on the deformation of the riverbed. As a result of the redistribution of velocities along the width, flow zones with increased velocities appear, where bottom erosion occurs, and zones of reduced velocities, where sediments are deposited.

Developed river systems include elements of multi-sleeve branches, occupying very large territories, which often do not have detailed geodetic and cartographic coverage, or it does not keep up with changes of a natural and anthropogenic nature. In such cases, instead of using cartographic materials, it is suggested to use space photographs of sufficient spatial resolution, as well as geographic information system (GIS) methods. In addition, modern methods of prospecting, especially the measurement of depths, current velocities, soil sampling, etc., are widely based on the use of GPS technologies, the results of which are conveniently processed by GIS methods [1].

With the help of corrective structures on rivers, it is possible to change the contour of the river flow, or as it is customary to say, the contour of the corrective route, within which bridge crossings are located. The stability of the track is usually enabled with the help of excavation slots, which are also given a curvilinear shape in plan according to established natural analogs [2]. It should be noted that the location and curvature of the corrective route can be correctly determined using mathematical modeling within the framework of the hydrodynamics of continuous media. In addition, it could make it possible to conduct a study into the influence of the curved flow on the deformation of the riverbed. The current work considers the improvement of devised methods through the use of GIS for the construction of grids of numerical modeling and analysis of the morphodynamics of riverbed processes. Solving this problem could have further practical application.

2. Literature review and problem statement

Modern methods of mathematical modeling of river processes are laid down in the works by many researchers based on the system of differential equations of the spatial movement of water within the boundaries of the free surface and banks. Of great interest are the problems of the influence of the curved flow on the deformation of the riverbed, as they were solved at various stages of the development of the theory of riverbed processes [3]. In numerous works, which consider riverbed processes, it is stated that the stability of the river and the formation of new river forms are affected by many factors, in particular, the presence of hydrotechnical structures. The main ones are the frequency and intensity of maximum precipitation and meltwater, which affect the change in the depth of rivers and the erosion of the stream bed. In some cases, this can lead to building accidents [4, 5].

At the same time, considerable attention was paid to the problems of pulsation of velocities and turbulence of flows, which under river conditions are concentrated mainly in the bottom layers and lead to the formation of bottom irregularities and distortion of the flow and deformation of the riverbed. These problems, which were solved at various stages of the development of the theory of riverbed processes, can be correctly determined with the help of mathematical modeling. The development of mathematical aspects of the hydrodynamic theory of river flows on the basis of field observations and experimental works ended with the formulation of a system of differential equations (Reynolds' equation), supplemented by sediment transport equations and the deformation equation. These equations accurately enough solve the problems of riverbed processes, in particular, hydromorphodynamics, but in such a statement the solution can be obtained only by numerical methods. For this purpose, calculation systems based on computer technologies were developed, one of which is presented in work [6] in the form of numerical calculation programs and programs for analysis and visualization of results. These programs are available for open use.

The first attempts to use such calculation systems are described in work [7], in which a numerical model of the kinematics of riverbed and flood flows was built, which made it possible to calculate the parameters of the flood passage and the breakthrough wave. It is also possible to determine their influence on the formation of erosion of underbridge structures, taking into account the factors of topographic and hydraulic conditions on the river. It should be noted that, in contrast to known models, the given model allows calculating bottom erosion in a planned approximation, taking into account the interaction with bank and riverbed hydrotechnical structures, including local erosion of bridge piers. The issues of the impact of flow distortion and the hydromorphodynamics of erosion of the bank elements of the river after the passage of the bridge crossing area remained unsolved.

In work [8], in order to determine the average depth of the flow under the bridge under the calculation conditions, the calculation of the total erosion is performed for the predicted cross-sections of the riverbed. The quasi-three-dimensional form of steady-state finite-difference flood flow equations proposed by the authors allows taking into account the law of distribution of the averaged hydrostatic pressure vertically and the distribution of suspended sediments, the influence of the cohesion of fine-grained soils and the resistance of vegetation on general and local erosion of the bottom, but it makes it difficult to determine the redistribution of water flows and sediments between river and floodplain sections of the river. The main problem of this approach is the impossibility of taking into account changes over time of the main parameters of the hydrodynamic riverbed flow, its distribution between the riverbed and the floodplain.

An urgent problem is the stability of river hydrotechnical structures, especially pressure dams of reservoirs. In work [9], a study of the breakthrough of the dam of the reservoir is reported; calculation formulas based on natural data were derived. Due to the approximation of the applied formulas to the analysis of complex hydromorphodynamic processes, the study did not conduct research into the change in the shape of the riverbed but only on the change in flow during the spreading of a breakthrough flow, which confirms the need to use numerical methods of the hydrodynamics of continuous media for such problems. Similarly, the simplified technique used in paper [10] allows for the calculation of the water level during a flood. However, it does not take into account the water balance in reservoirs along their length.

In paper [11] it is stated that it is necessary to calculate the general and local erosion of riverbeds by numerical solution of the two-dimensional (plan) equations of hydraulics and sediment balance. The problems of hydromorphodynamics related to the erosion of the bottom and shore elements of the river and the movement of sediments remained unsolved.

Our review of the literature [1–11] revealed that in the cases of solving complex problems of studying riverbed processes for the practical purposes of designing bridges and other important hydraulic structures, it is necessary to use and improve numerical methods that make it possible to simulate hydromorphodynamic processes in riverbeds. Therefore, it is expedient to study the specific problem of river processes, namely the hydromorphodynamics of bottom and bank changes, through the integrated application of modern computer technologies with the use of GIS for the grid approximation of the calculation area and analysis of the calculation results. Previously, this was achieved by constructing very expensive large-scale physical models [2, 5, 11]. Physical models, however, did not solve many problems, especially the specified problems of hydromorphodynamics, which are related to the erosion of the bottom and shore elements of the river and the movement of sediments.

3. The aim and objectives of the study

The purpose of our work is to devise a method for complex modeling of the riverbed shape in the area of the bridge crossing in order to avoid dangerous washouts. This will make it possible to evaluate the general deformations of the riverbed under different flow regimes in the area of bridge crossing construction, in the shipping area, and to determine parameters of the stable shape of the riverbed, which could minimize its deformation. This, in turn, will make it possible to solve the problem of hydromorphodynamics of bottom and bank changes, through the integrated application of modern computer technologies using GIS for grid approximation of the settlement area and analysis of calculation results.

To achieve the specified goal, the following tasks must be completed:

– to study the hydromorphodynamics of riverbed flows in the area of bridge crossing using the Google Earth system;

– to investigate deformation of the section of the natural riverbed before the application of the regulation, by the method of numerical modeling;

– to examine erosion in the area of bridge crossing by constructing a canalized riverbed.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of research is the section of the Amu Darya riverbed (Turkmenistan) in the zone of design and construction of bridge crossings (BC).

The research area (Fig. 1) is limited by the right-bank protective dam and the left-bank dam of the canal. The territory beyond the riverbed is occupied by dense infrastructure, characterized by small depths and velocities, and its influence on the general river flow during the passage of a flood can be neglected.

The simulation area has a length of 4000 m and a width of 1060 m in the area of bridge crossings and up to 1700 m in the entrance area.

The modeling takes into account structural elements – protective dams and supports (17 supports of the existing railway bridge, 9 supports of the railway bridge under construction, and 10 supports of the project road bridge). Modeling was carried out on the basis of bathymetry measurements (Fig. 2).

Fig. 2 shows that the bottom has a complex topography. The meandering of the stream and the formation of a right-bank basin with a depth of up to 12 m are observed. Therefore, data from the Google Earth system were used to conduct a study of natural changes in the dynamics of riverbed forms in the section of the Amu Darya River near the city of Turkmenabad. Such a tool effectively replaces field observations with the need for physical experiments.

Analysis of the hydromorphodynamics of the studied area was carried out based on the materials of space images for the years 2002–2015. Part of the photographs characterizing the dynamics of riverbed forms in the studied area for the period 2002–2007 are shown in Fig. 3 in chronological order with division by riverbed regimes.

Fig. 3 shows that the riverbed in the studied area has a meandering character (bifurcation area). This is due to the weak strength of the riverbed and banks, a large flow of sediments, and a sharp division of the flood and border regimes along the width of the riverbed. The result of this current pattern is the periodic formation and erosion of cells (temporary multi-armed) and laterals, which spread at a significant speed in the absence of riverbed alignment, which led to significant destruction during floods on the Amu Darya River.

A comparison of the visible boundaries of macroforms indicates significant dynamics of large forms (shoals and laterals), erosion and flooding of riverbeds. At the same time, large forms, which were strengthened by vegetation during the considered period, remain stable. As a result, they are characterized by a gradual rise in elevation due to the accumulation of sediments from flood waters (the density of sediments is indicated by the change in the color of the stream in Fig. 3). There are also changes in the width of the stream bed in places of compression in the spans of the existing bridge crossing (Fig. 4). Here, the method of imaging and analysis of the results is used, which is applied in the cases where regular data (solid curve) is compared with individual available data (markers).

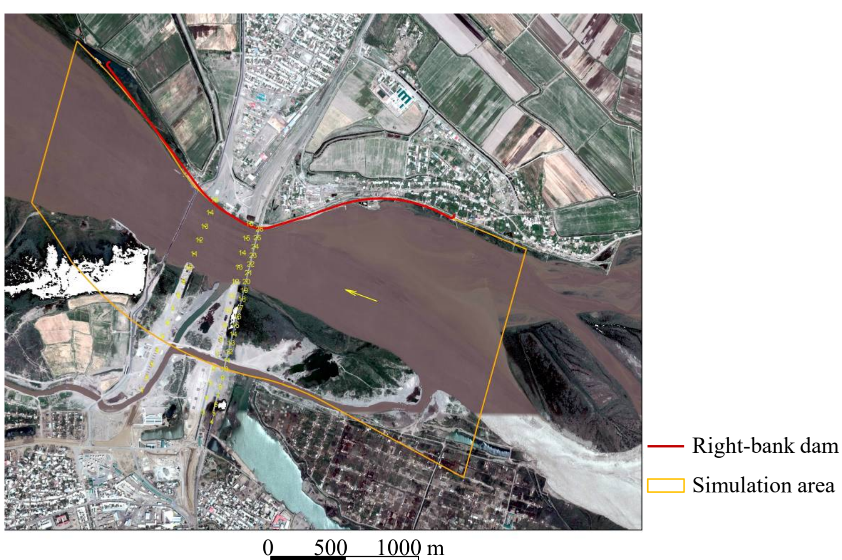

Fig. 1. Modeling area against the background of the GeoEYE-1 satellite image in the period close to the flood peak with the routes of existing and two projected BCs

Fig. 2. Bottom markings based on field measurements by GPS echo sounder

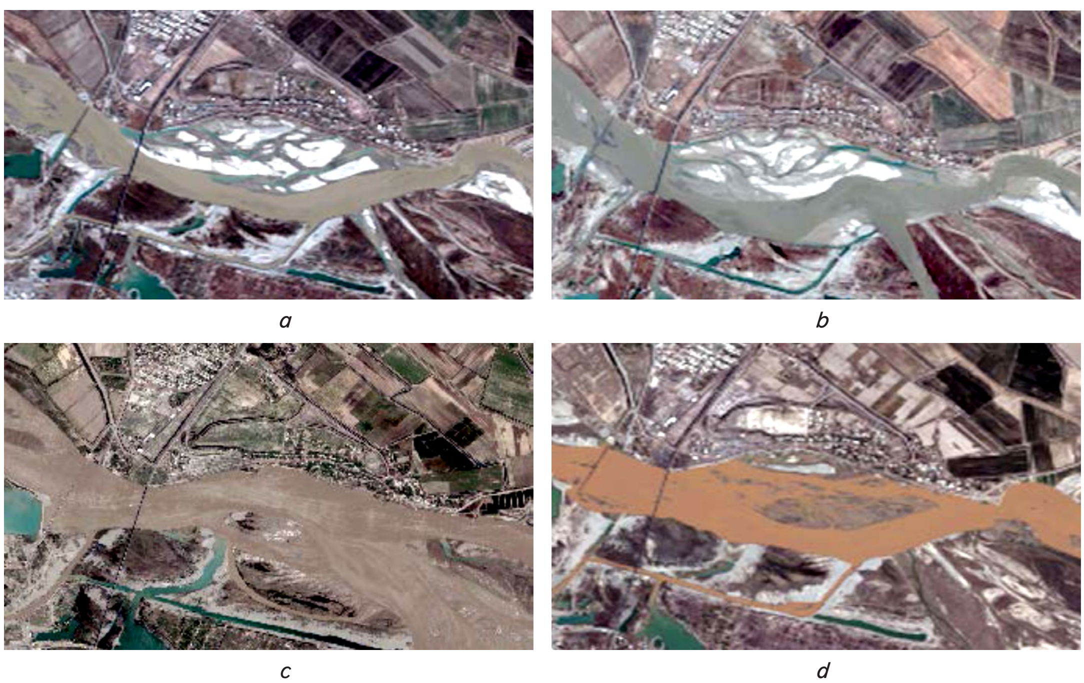

Fig. 3. Dynamics of riverbed shapes with division according to riverbed regimes: *a* – boundaries on December 1, 2006; *b* – boundaries on November 16, 2007; *c* – flood on July 25, 2002; *d* – flood on April 11, 2006

The images are numbered and arranged in chronological order at different intervals, and hydrological data on river flows are not available for every moment of the space images. The analysis of natural data shows the very active dynamics of hydromorphological processes in the study area depending on the flow of water in the river and confirms the need to apply flow regulation measures in the area of the construction of two transport crossings.

In addition, the photographs (Fig. 3) show the approach to the right-bank strait of a large and dynamic sidewall. It became the cause of the change in shape in the riverbed and will clog this riverbed in the future. This will also create a support, which may lead to a dangerous breakthrough of a new, left-bank arm and the formation of a new large cell and catastrophic erosion in the construction of supports of bridges and crossings.

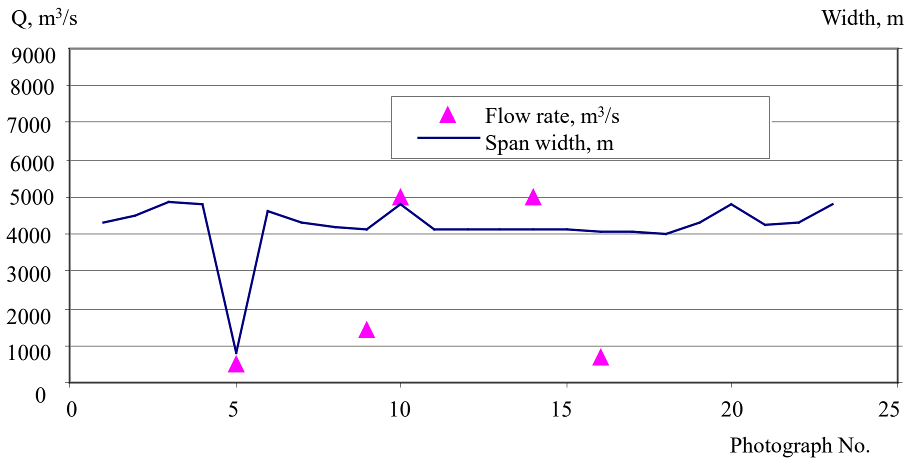

Fig. 4. Change in the width of the river in the span of the bridge in accordance with flow rate

Thus, the hypothesis of our study assumed that the data from the analysis of space images could be used to replace field observations of complex river processes that cause river instability. Appropriate numerical calculations based on simulations based on such data could be used to determine the necessary regulatory measures.

4. 2. Methodology for modeling the riverbed shape in the area of a bridge crossing

To calculate the flow dynamics and hydromorphodynamics of the riverbed, a numerical method is used that implements the finite element method for calculating the plan model of the non-stationary depth-averaged surface water flow within the deformable bottom and riverbanks (Fig. 5).

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, takes the form:

$$\frac{\partial z_w}{\partial t}+\frac{\partial q_1}{\partial x}+\frac{\partial q_2}{\partial y}=q_m, \quad (1)$$

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

Equations of momentum transfer in specific flow rate take the form of a system of differential equations:

$$\frac{\partial q_1}{\partial t}+\frac{\partial}{\partial x}\left(\beta\frac{q_1^2}{H}+\frac{1}{2}gH^2\right)+\frac{\partial}{\partial y}\left(\beta\frac{q_1 q_2}{H}\right)+gH\frac{\partial z_b}{\partial x}+ +\frac{1}{\rho}\left[\tau_{bx}-\frac{\partial(H\tau_{xx})}{\partial x}-\frac{\partial(H\tau_{xy})}{\partial y}\right]=0, \quad (2)$$

$$\frac{\partial q_2}{\partial t}+\frac{\partial}{\partial y}\left(\beta\frac{q_2^2}{H}+\frac{1}{2}gH^2\right)+\frac{\partial}{\partial x}\left(\beta\frac{q_1 q_2}{H}\right)+gH\frac{\partial z_b}{\partial y}+ +\frac{1}{\rho}\left[\tau_{by}-\frac{\partial(H\tau_{yx})}{\partial x}-\frac{\partial(H\tau_{yy})}{\partial y}\right]=0, \quad (3)$$

where τ_{bx}, τ_{by} are bottom shear stresses, τ_{xx}, τ_{yy} , $\tau_{xy}=\tau_{yx}$ are stresses caused by flow turbulence, which are considered to be proportional to gradients of depth-averaged velocity; β is the correction coefficient of the flow momentum, which takes into account the change in velocity in the vertical direction. Components τ_{bx}, τ_{by} are determined according to the procedure given in [6, 7].

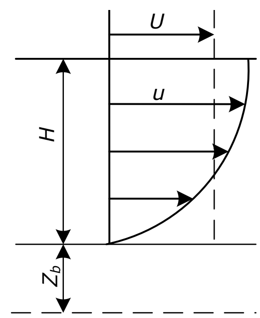

Fig. 5. Scheme of parameters for the computational model of riverbed flow [6, 7]

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

$$(1-\eta_s)\frac{\partial z_b}{\partial t}+\frac{\partial q_{s1}}{\partial x}+\frac{\partial q_{s2}}{\partial y}=0, \quad (4)$$

where η_s is the porosity of the bottom material, q_{s1}, q_{s2} are the volume flow rates of entrained and suspended sediments per unit width of the current.

The sediment concentration $C_s=q_s/q$ is described by the transport equation:

$$\frac{\partial(C_s H)}{\partial t}+\frac{\partial(C_s q_1)}{\partial x}+\frac{\partial(C_s q_2)}{\partial y}=C_{es}\left(C_s^*-C_s\right), \quad (5)$$

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

Boundary conditions are set on the calculation section: in the upper part of the flow, the water flow rate Q is set according to the calculated hydrograph, in the lower part – the water surface level Z_w. The effect of flow compression by bridge supports is taken into account by the uniform distribution of hydrodynamic resistance across the mesh element containing the support.

Solving the system of differential equations (1) to (5) by the finite volume method was performed using the *FST2DH* (2D Depth-averaged Flow and Sediment Transport

Model) software [6] in a combination with GIS to construct a calculation grid and analyze and visualize the results. The elements of the calculation grid are directed parallel to the bridge supports and have a rectangular shape of 20 m by 40 m, in the area of bridge transitions the grid thickens to 20 m by 20 m. The number of elements of the irregular grid is almost nine thousand.

5. Results of a numerical study of natural riverbed shape changes in the area of a bridge crossing under the influence of flooding

5. 1. Investigating the deformation of the section of a natural riverbed before the application of regulation

Fig. 6 shows the results of the calculation of steady-state flow along a natural riverbed with riverbed-forming flow rate Q=8000 m^3/s with boundary conditions on the water surface z_w=189.5 m at discharge.

Fig. 6 demonstrates that the current speed of 3.0–3.5 m/s is observed near the convex right bank and on the straight section of the riverbed.

Erosion modeling was carried out according to the flood hydrograph of 0.33 % of the Amu Darya River in the area of the city of Turkmenabad. To estimate the total erosion, a section of the calculated hydrograph at Q>8000 m$_3$/s, lasting 14 days, was determined (Fig. 7).

The image of the deformation of the section of the natural riverbed before the application of regulation, obtained as a result of numerical modeling, is shown in Fig. 8.

The section near the convex bank with a width of 150 m is subject to the strongest erosion in the design structure of the supports (shown in Fig. 8 by a solid line). Siltation of the existing left-bank bottom basin is also observed.

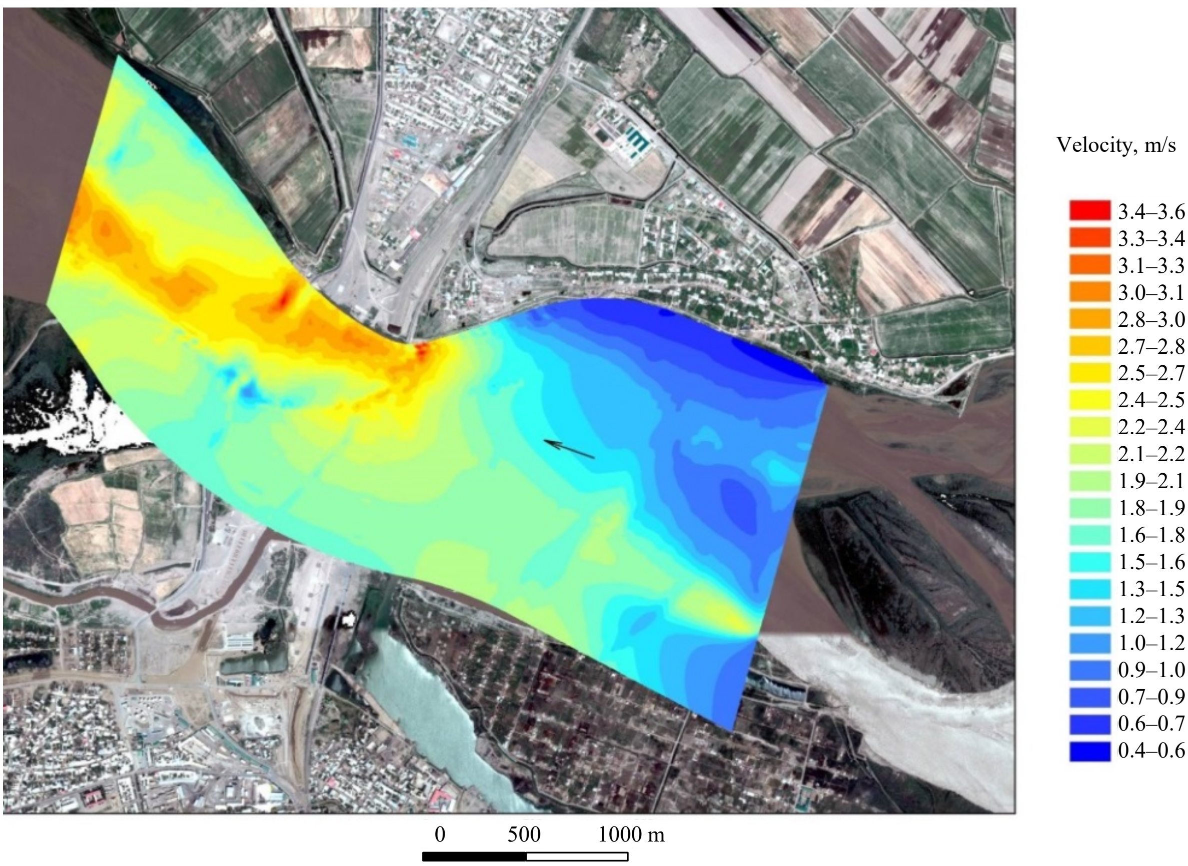

Fig. 6. Field of velocities of a stationary flow at flow rate Q=8000 m^3/s

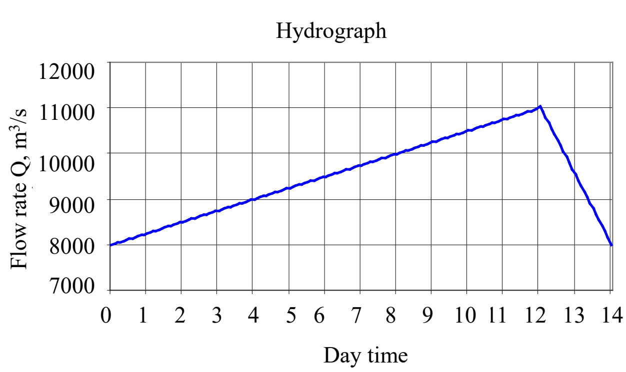

Fig. 7. Segment of the calculated hydrograph

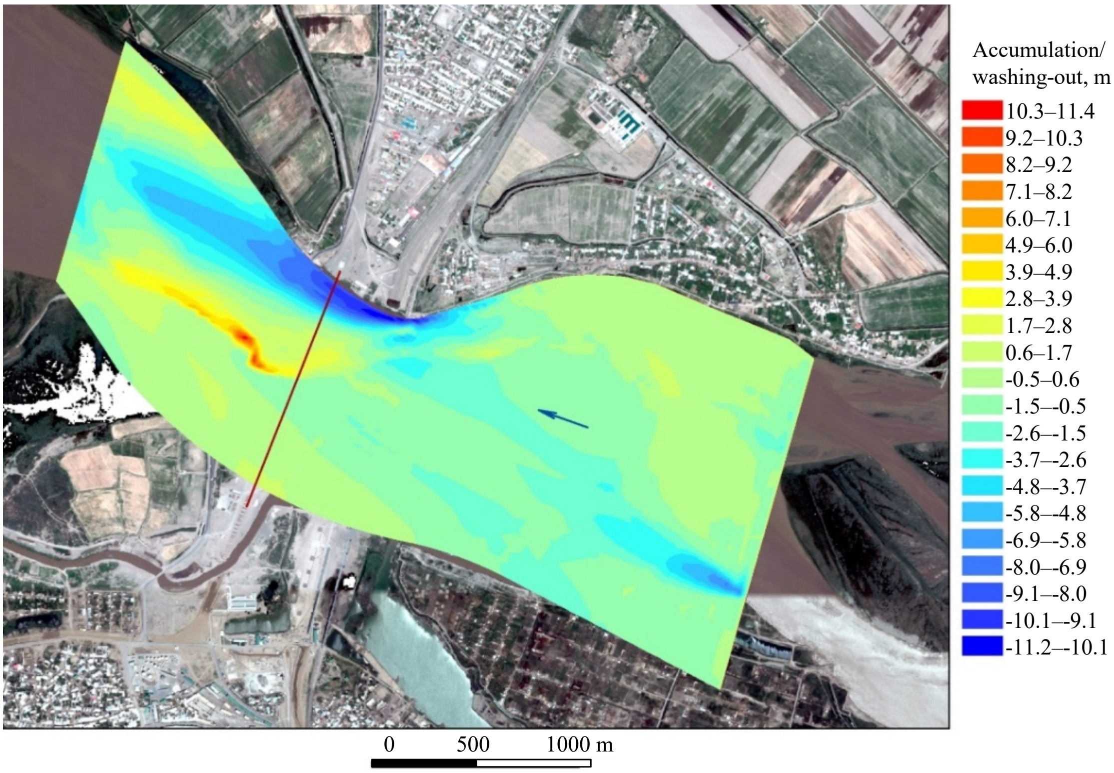

Fig. 8. Deformation of the bottom of dry riverbed over 14 days of the estimated flood

The deformation of the bottom in the design of the supports of the project road bridge is shown in Fig. 9 (location of the design supports is marked on the plots with a double vertical line). The plots are constructed with the help of a conventional graphic system based on the data obtained from the numerical calculations of the system of differential equations (1) to (5), represented in tabular form, for the option of a natural dry riverbed and the option of using a riverbed opening.

The maximum erosion is observed between the 13th pillar and the bank protection dam and reaches up to 10 m, which significantly exceeds the regulatory limits and confirms the results of the analysis of space images. At the same time, the minimum mark of the bottom surface is 178 m. Near the left bank between supports 10 and 12, siltation of the bottom basin is 3.0 m.

It is recommended to make a decision to carry out restorative cutting of riverbed alignment annually after receiving a forecast of a high flood from the local hydrometeorological station. In the event of a high flood warning, works should be carried out to clear the sleeves on the approach to the bridge deck, taking into account the cleaning of the right bank sleeve to the average mark H_{rb}=184 m and the filling of the straight between the islands. It is recommended to carry out restorative work on riverbed alignment during the border period. Thus, it is impossible to ensure the normative coefficient of erosion without the installation of an operational slot.

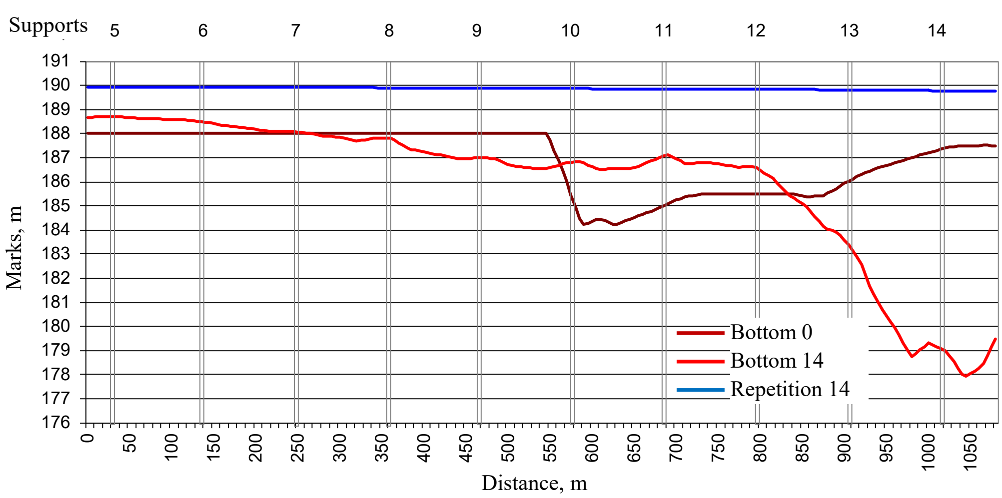

Fig. 9. Profiles of total bottom erosion over 14 days and water surface level in the span of supports of the road bridge (conditional marks: bottom 0 — initial marks of the bottom; bottom 14, rep.14 — parameters of the bottom and surface of the stream after a 14-day flood)

5. 2. Study of erosion in the area of a bridge crossing by constructing a canalized riverbed

To reduce erosion in the area of bridge crossings, it is proposed to regulate the riverbed by constructing a canalized riverbed. To determine the shape of the riverbed, we shall rely on the principles of laying stable riverbeds [2, 5]. The most stable form, according to the principles of application of natural analogs, is inherent in riverbeds in the form of curvilinear incomplete meandering, when the radii of curvature R and the width of the riverbed B satisfy the ratio R=(4...7) B at riverbed-forming flow rate. At the same time, radii of curvature R<3.5 B should not be allowed, as this leads to separation of the flow from the convex bank and excessive erosion of the concave bank.

One of the selected riverbed alignment options is shown in Fig. 10 with a comparison of the deformations obtained as a result of numerical modeling with previous flood conditions.

The right bank of the canalized riverbed starts from the island and stretches to the end of the existing right bank dam. The left edge runs parallel to the right edge. The right and left edges represent three connected arcs with radii of 4900 m, 2100 m, and 3300 m, respectively, and a total length of 4000 m. The distance between the edges along the bottom is 600 m, between the upper edges – 680 m, the bottom level is 183.5 m, the slopes are 1:10.

The volume of the excavation within the opening is 9,227,089 m^3, the area of the excavation is 3,556,582 m^2. The backfill volume of the bottom basin is 21,272 m^3, the backfill area is 28,861 m^2.

Modeling according to this option showed that the erosion in the road bridge span (Fig. 11) when adjusting the riverbed significantly decreased and did not exceed 1.5 m.

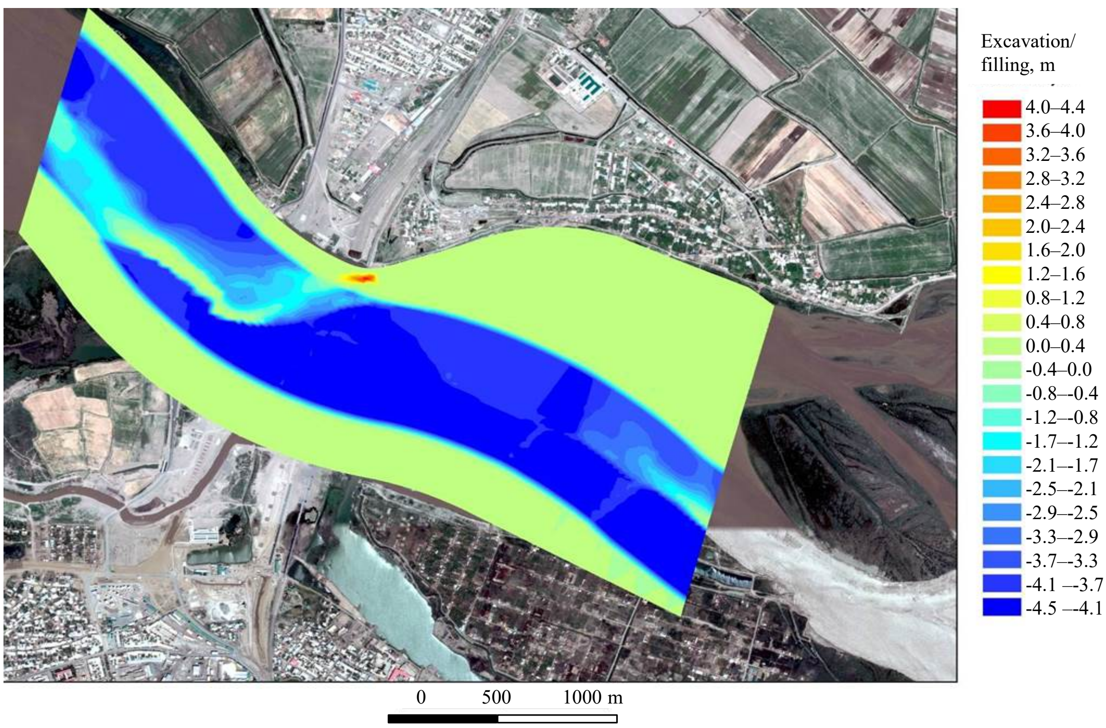

Fig. 10. Scheme of riverbed alignment in the area of bridge crossings

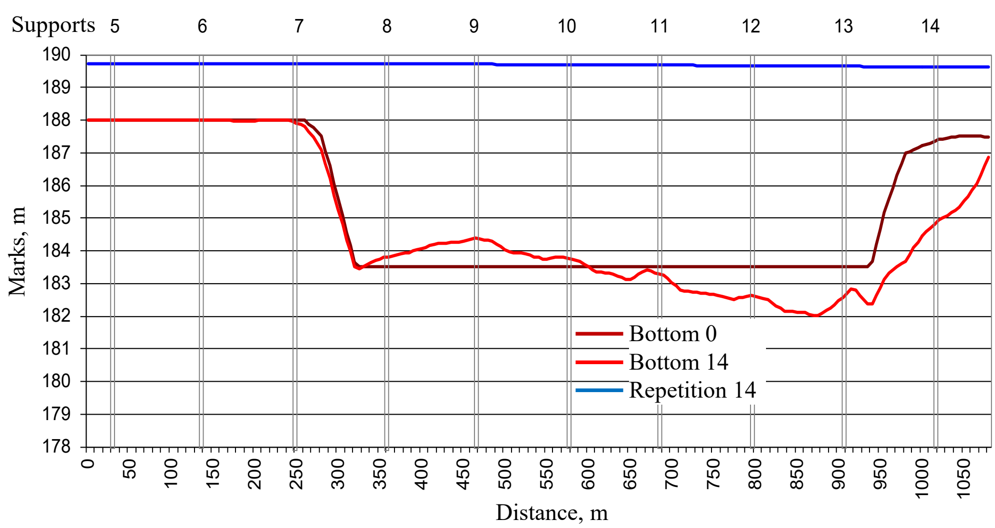

Fig. 11. Profiles of general erosion over 14 days during riverbed adjustment in the span of the road bridge supports (marks are the same as in Fig. 9)

A natural factor such as vegetation on floodplains plays a major role in ensuring the stability of the river. Therefore, during construction and operation, it must be stored or restored in case of damage. Carry out measures to strengthen floodplain terraces, slopes of the cut that protrude above the surface of the water or are located at a shallow depth. Activities can be carried out with green plantings made of local resistant grass, tree and shrub species.

6. Discussion of results of modeling the riverbed shape in the area of a bridge transition under the action of flood waters

Our numerical experiments and field observations allow us to suggest a number of practical recommendations. Analysis of the location and shape of the existing protective and stream-directing structures reveals that they should not be chosen based on situational considerations of protecting settlements and bank abutments of the bridge crossing by temporary measures but should be chosen based on a detailed analysis of the hydromorphodynamic situation of the riverbed section under consideration and adjusted to modern requirements building regulations and implemented by designing protective structures and riverbed alignment by arranging regulatory operational slots. The assignment of parameters of the operational opening should be performed on the basis of the principle of constructing natural analogs of riverbed shapes (riverbed and floodplain terraces) using mathematical modeling.

Applying the method of imaging and analysis of results, which is employed in the cases where regular data (solid curve) is compared with separate available data (markers) (Fig. 4), it was possible to establish the very active dynamics of hydromorphological processes in the study area depending on the flow of water in a dry riverbed. This also confirms the need to apply flow regulation measures at the construction site of two transport crossings.

In addition, significant dynamics of large shallows and laterals, erosion and flooding of riverbeds are observed. Moreover, the large forms, which were strengthened by vegetation during the considered period, remain stable and, as a result, are characterized by a gradual rise in elevation due to the accumulation of sediments from flood waters. One can see the approach to the right-bank strait of a large and dynamic tributary. It became the cause of change in the shape in the riverbed and will clog this riverbed in the future. It will also create a support, which could lead to the breakthrough of a new, left-bank arm and the formation of a new large cell. The same instability can be noted in relation to the width of the riverbed in places of compression, including in the spans of the existing and projected bridge crossing (Fig. 5).

The results of modeling the deformation of the bottom in the span of the supports of the automobile crossing (Fig. 9) showed that the maximum erosion occurs between the 13th support and the bank protection dam. It is 10 m, which significantly exceeds the regulatory limits and confirms the results of the analysis of space images. At the same time, the minimum mark of the bottom surface is 178 m. Near the left bank between supports 10 and 12, the siltation of the bottom basin is 3.0 m. Therefore, it is recommended to make a decision on carrying out restorative cutting of the riverbed alignment annually after receiving a forecast of a high flood from the local hydrometeorological station. In the event of a high flood warning, works should be carried out to clear the sleeves on the approach to the bridge deck, taking into account the cleaning of the right bank sleeve to the average mark H_{rb}=184 m and the filling of the strait between the islands. It is recommended to carry out restorative work on riverbed alignment during the border period. Thus, it is impossible to ensure the normative coefficient of erosion without the installation of an operational slot.

The results of modeling natural and regulated openings, together with the analysis of full-scale space photographs, prove the necessity of carrying out structural measures to regulate the flow to ensure the stability of the bottom in the span of bridge crossings that were designed.

Our solutions solve the problematic part of the design and justification of structural measures to ensure the stability of a dry riverbed with the help of a complex numerical method under the conditions of laying additional transport crossings in the research area.

A limitation of the current research is the two-dimensional method for calculating the shape of a riverbed in the area of a bridge crossing during a flood. This should be taken into account when trying to apply it in practice.

Advancing our research in the future may involve determining the regularities of the influence of the alignment of the flow riverbed on the hydromorphodynamics of the studied areas in the zone of bridge crossings, by means of the arrangement of regulatory operational slots.

7. Conclusions

1. Our studies on the hydromorphodynamics of riverbed flows in the area of a bridge crossing using the Google Earth system showed that the riverbed in the studied area has a meandering character. This is due to the weak strength of the riverbed and banks, a large flow of sediments, and a sharp division of the flood and border regimes along the width of the riverbed.

2. Using the method of numerical modeling, a study of the deformation of the section of the natural riverbed before the application of alignment was carried out. It was established that the maximum erosion is observed between pier 13 and the bank protection dam and reaches up to 10 m. At the same time, the minimum mark of the bottom surface is 178 m. Near the left bank between piers 10 and 12, siltation of the bottom basin is 3 m. The strongest erosion in the design span of the piers occurs in a 150 m wide section near the convex bank. Siltation of the existing left bank bottom basin is also observed.

3. The results of research into erosion in the area of a bridge crossing by constructing a canalized riverbed demonstrated that erosion in the road bridge span decreased significantly and does not exceed 1.5 m. It has been established that a major role in ensuring the stability of the dry riverbed is played by the vegetation cover in floodplain areas. Therefore, during construction and operation, it must be saved or restored in case of damage.

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Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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