

ANALYSIS OF TYPES OF MATHEMATICAL MODELING OF MORPHODYNAMIC PROCESSES OCCURRING AS A RESULT OF BREACHES IN RESERVOIR DAMS AND EMBANKMENTS

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Reservoirs are considered important hydraulic engineering structures for various sectors of the economy worldwide. The design and construction of reservoirs require significant financial resources. At the same time, scientific and technical issues related to their operation, reliability and safety conditions, as well as service life, are of great importance.

For example, in countries such as Russia, China, Kazakhstan, Uzbekistan, and others, from two to ten reservoirs have been constructed and are currently in operation on large and small rivers, each with a catchment area of at least 100 km². However, the majority of these reservoirs were constructed and commissioned during the 1965–1970s. At present, at least 8–10 percent of them have fully exhausted their operational lifespan and have reached a potentially авария-prone condition. This situation may lead to negative consequences such as the breach (proran) of earth dams and embankments of reservoirs.

In the works of scientists such as Alekseyuk A.I., Belikov V.V., Bogoslavchik P.M., Vasilyeva E.S., Vinogradova T.A., Voltsinger N.E., Militeev A.N., Fedorova T.A., Cristofan Eugene A., Fedorova T.A., Fread D.L., and others, five types of modeling approaches have been identified for

simulating the formation and development of breaches caused by technogenic accidents in reservoir dams and embankments, as well as the transformation of the bottom relief of the reservoir basin.

The first type of modeling methods. Mathematical models of this type have a relatively simple structure, where the initial shape of the damaged section of the dam is represented as either triangular or trapezoidal. The calculations of processes related to the growth of the geometric dimensions of the breach are carried out using empirical or semi-empirical expressions.

The second type of modeling methods. These mathematical modeling approaches are well described in the works of Cristofan Eugene A., Fedorova T.A., and Fread D.L. Despite different methodological approaches in their studies, the content and essence of these models are very similar. In particular, the authors assume that the erosion processes in the reservoir basin and in the breach are proportional to the average mobilization state of the soil.

The third type of modeling methods. These modeling approaches have been thoroughly studied in the works of Hanson G.J., Froehlich D.C., Govindaraju R.S., Pikalova I.F., and Naumova T.V. In this type of modeling, the water flow near the breach is assumed to have maximum transport capacity, and the processes of reservoir basin erosion and breach widening are modeled based on the law of mass conservation.

The fourth type of modeling methods. Mathematical approaches of this type have been sufficiently studied in the works of Aleksyuk A.I., Belikov V.V., Macchione F., Sirangelo B., Ponce V.M., Reiter P., Tsivoglou, Benoist G., Benslama E., and Herledan R. In these models, the processes related to the dynamic movement of water in the reservoir are simulated using two-dimensional unsteady flow equations, while the deformation processes in the reservoir basin and the breach are modeled based on the Exner equation.

The fifth type of modeling methods. These methods have been extensively studied in the works of Fread D.L. In this type of modeling, the erosion processes occurring at the bottom of the reservoir basin and within the breach are modeled in two phases: the initial phase and the developed phase.

A comparative analysis of the most widely used practical methods of all modeling types is presented in **Table 1**.

Table

1

Comparison and evaluation of forecasting models for breach erosion in reservoir dams or embankments and deformation processes in the reservoir basin.

No.	Model Name	Morphological Processes	Calculation Form	Model Limitations
1	D.L. Fread – NWS BREACH model	Deformation of the reservoir basin relief and dynamics of breach erosion	Semi-empirical model	The error when comparing numerical results of the semi-empirical model with experimental results exceeds 25%.
2	Reiter P. – BEED model	Deformation of the reservoir basin relief	Semi-empirical model	Morphometric parameters are considered, but the hydraulic parameters of the flow are not taken into account.



3	Benslama E., Herledan R. – SITES model	Parabolic parameters are accepted as the breach shape	Empirical expression	Only parameters describing the initial state of the breach are considered.
4	Tsivoglou and Benoist G. – NCP BREACH model	State of the reservoir basin relief at a specific time	Empirical expression	The error of the empirical expression exceeds 30%.
5	Aleksyuk A.I., Belikov V.V. – EDBREACH model	Deformation of the reservoir basin relief	Morphodynamic model	A relationship model between morphometric and hydraulic parameters has been developed. Numerical solutions were compared with laboratory experiments but not with field studies.
6	Pikalova I.F., Naumova T.V. – BRES model	Trapezoidal shape accepted as the initial breach shape	Empirical expression	Only parameters describing the initial state of the breach are considered.
7	Macchione F., Sirangelo B. –	Triangular shape accepted	Empirical expression	Only parameters describing the

	DEICH No.1/No.2 model	as the initial breach shape		initial state of the breach are considered.
8	Renard and Rupro model	Breach erosion	Empirical expression	Only parameters describing the initial state of the breach are considered.
9	Benslama E., Herledan R. – Flood Levee Breaches model	Dynamics of the reservoir basin bottom configuration	Hydraulic model	The hydraulic model was developed for one-dimensional unsteady water flow.
10	V.V. Belikov – Cemagref model	Deformation of the reservoir basin relief	Hydrodynamic model	The model does not take into account the existing volume of water in the reservoir basin during an авария caused by a breach.
11	D.C. Froehlich and R.S. Govindaraju – SOBEK model	Breach deformation	Semi-empirical model	A functional relationship equation between the linear geometric parameters of the



				breach and the dam has been developed.
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According to the analysis of scientific research and sector-related materials, more than **52,000 high-head dams** have been constructed worldwide over the past **100 years**, of which more than **37,000** have been built and put into operation during the last **50 years**.

From the **1970s to the present day**, technogenic accidents have occurred in **98 reservoirs** constructed during this period. More than **30 percent** of technogenic accidents in reservoirs have occurred due to violations of operational standards and regulations for the use of reservoirs.

At the moment of a dam or embankment failure, the water resources stored in the reservoir basin begin to be forced out through the damaged section, resulting in a sharp increase in the velocity of the water flow. As a consequence, **intensive erosion of the damaged section of the dam (breach)** occurs.

Various mathematical modeling methods have been developed to accurately describe the **hydrodynamic and morphodynamic processes** that occur as a result of breaches in reservoir dams and embankments.

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