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ANALYSIS OF THE CONSEQUENCES OF BREAKDOWNS OF HYDRAULIC STRUCTURES AND THE OCCURRENCE OF EMERGENCY SITUATIONS

The problem of prevention and elimination of emergencies remains very urgent. The prediction of area flooding as a result of seasonal floods, or due to emergency situations is important and is solved on the basis of various technologies. Computer modeling methods based on direct hydrodynamic calculations of surface water dynamics seem to be an effective direction. Of particular interest is modeling the dynamics of filling of hydraulic structures in mountainous terrain.

In this article, features of destruction of hydraulic structures in emergency situations on water bodies. The article also mentions the methods of monitoring water levels in the reservoirs. A description of flood monitoring technology is given, the results of its practical use in some regions are discussed, and directions for further development are outlined. This information is subsequently used to predict the emergency situation.

Key words: *dam, reservoir, flooding, mathematical model, monitoring, forecast, breakthrough, environmental safety.*

Introduction. According to the report of the United Nations Commission, the damage caused by natural disasters, particularly floods, has been increasing over the years, and the economic losses caused by floods have led to a decrease in the gross domestic product. To select a set of measures to minimize damage, it is advisable to forecast the main characteristics of floods that affect the amount of damage. Their magnitude affects the degree of severity of the consequences of floods for the population, economy, agriculture, etc. [1, 2].

In the last century in the world there have been more than a thousand cases of failure of hydraulic structures, the causes of which, among the meteorological phenomena were also factors of geological and geophysical nature [3, 4].

Based on statistics for the 15,000 large dams that exist in the world, there has been an average of 1.5 failures per year, which means that the probability of dam failure is approximately 1-4 cases per year [5].

Modern information technology provides powerful tools for collecting, storing and processing data. Integrated application of mathematical modeling and geographic information systems is the most effective strategy for solving the problem of adequate, rapid monitoring and analysis of threats of water body breaches. It will make it possible to assess the environmental risk, predict the possibility and the expected time of the dam break of the wave arrival to the settlements, as well as competently manage the hydraulic situation in the region.

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Existing hydraulic safety systems are mainly designed for large bodies of water, and their software and technical operation requires large staff and appropriate conditions. Therefore, development of autonomous hardware-software complexes for monitoring of filling in real time is urgent for reservoirs with volume up to 100 mln. m^3.

Lakes and rivers of Kazakhstan are sources of fresh water and are used in the life support of the country's population, for irrigation of agricultural land. Currently, there are 1,665 hydraulic structures in the republic, including 443 large dams and 125 dike. The main problem in Kazakhstan is that many of them are remote, disconnected from power supply systems and pose some threat to the population.

In the spring of 2010, Almaty Oblast was hit by a tragedy: the flooding, with human casualties and devastation. The natural disaster was caused by a dam break. In 2014, the tragedy repeated itself in the Karaganda region.

Only the creation of an automated information system to monitor and prevent the hydraulic situation in the regions of Kazakhstan will solve the problem of minimizing the cost of preventing floods and eliminating their negative consequences.

Hydraulic structures are complex technical objects that create a whole range of environmental and nature-user problems even in normal operating conditions. The zones of influence of a hydraulic structure on adjacent areas (reservoirs and downstream areas) are quite long and can occupy hundreds of square kilometers.

There are now many known examples of flooding emergencies caused by the spread of floodwaters and breakwaters. At this time in our country is the task of protecting agricultural land and settlements from flooding. Flooding of agricultural land occurs both during the passage of large-scale floods and natural, man-made factors.

The problem of floods is becoming more and more acute. The situation when settlements in different regions of the country literally go under water has already become the norm. At the same time, the budget is still spent on floods, instead of preventing them. Flood is a phase of the water regime characterized by an intense, usually short-term increase in discharge and water levels caused by rainfall or snowmelt during thaws. Springtime flooding is a seasonal phenomenon, and, in fact, it's a recent phenomenon that cannot be avoided to any degree.

Attempts to resolve the conflict between the need to use floodplains and coastal lands and losses from possible flooding have been made repeatedly by many experts. But so far this conflict has not been resolved. To solve the problem of the possibility of using coastal land, it is necessary to analyze the possible damage from floods.

In the event of a flood or breakthrough wave, the quality of the land is significantly degraded. Even a short-term rise in river water during a flood can cause flooding of coastal lands, which will invariably lead to significant losses associated with both the possible loss of crops and deterioration of land quality.

As measures to prevent damage caused by possible flooding, it is necessary to carry out engineering measures such as:

– monitoring and regulation of flood flow using various engineering structures: dams, dikes, riverbank reinforcement, straightening river channels, etc.;

– design and rational placement of infrastructure elements and residential buildings in accordance with the potentially dangerous areas of possible flooding; in areas with frequent cases of flooding it is possible to build houses on piles, or to transfer the first floors of buildings into non-residential housing;

– ensuring the sustainability of operations, taking into account the possible occurrence of emergencies, important infrastructure elements: bridges, communication lines, etc.

The occurrence of emergency situations on hydraulic structures leads, in particular, to such hydrodynamic accidents as the destruction of a hydroelectric complex and the formation of a breakthrough wave with catastrophic consequences in the tailrace - the destruction of dams, dikes, power, industrial and civil facilities, flooding territories, loss of human life. The main causes of emergencies are natural or man-made factors, such as overflow of the reservoir head or a terrorist act. Man in the modern world is becoming more and more dangerous to live in. While natural disasters such as earthquakes, floods, and forest fires have always posed a threat, they have recently been joined by man-made disasters. The most dangerous are accidents at large environmentally sensitive facilities, which include many water management structures (dams, reservoirs, levees). Every day we hear about dam and dam failures, accidents at nuclear power plants, gas and oil pipelines, resulting in floods, toxic gas discharges into the atmosphere, and tons of oil spills. All of this can even be due to the slightest breach of technology and safety technology, negligence, oversight, and finally, because of the notorious “human factor”. Dams have been built for thousands of years - for flood control, power generation, drinking, industrial and agricultural water supply. By 1950, many governments, and in some countries private companies as well, were building more and more dams in response to growing populations and growing national economies. The construction of dams was seen as an important means of meeting water and energy needs and as a long-term strategic investment capable of producing multifaceted benefits. Some of these benefits are typical of large social projects involving infrastructure development, while others are either unique to all dams or specific to some of them.

Experimental. The research will address the following scientific questions: Based on the results of hydraulic data (signals) processing, development of mathematical models and algorithms for their calculations. Depending on the class of mathematical model different sections of mathematics will be applied: differential equations, difference equations, etc.

Scientists have concluded that the effects of dams have a major impact on the environment, since flow rates and soil erosion are directly related. Dams prevent sediments accumulated in rivers (mud, waste, etc.) from reaching the sea. Therefore, near the confluences of rivers, accumulations of such wastes are formed, leading to the formation of erosion.

Nevertheless, the past 50 years have revealed many characteristics of dams and their impact on society and the environment. Large dams have fragmented and transformed the world’s rivers. Dam failure has catastrophic consequences. First, the flow destroys the structures created by human hands on the land below the dam. Secondly, the powerful streams of water squander their energy not only uselessly, but also with great harm to humans. Thirdly, formerly flourishing lands are ravaged, piled with stones.

As we enter the twenty-first century, the world faces many challenges, foremost of which is the need to create a sustainable way of life that will not endanger future generations. Fresh water is an important element of life on our planet. Therefore, sustainable development requires the sustainable use of the world’s limited freshwater resources. The role of water resources in the development of the productive forces of our society, in solving national economic and socio-cultural problems is increasing every year. Water resources predetermine the development of individual regions, location of industrial facilities and settlements, play a paramount role in the formation of natural and technical complexes, such as water management nodes, irrigation and drainage systems, energy, agro-industrial and other complexes.

According to various scientists, in the future there may be serious disagreements and contradictions between countries in the use of fresh water, which can escalate into military conflicts [6].

Clog dams have disrupted the natural flow of rivers, led to the development of stagnant processes, reduced the ability of "self-purification," drastically changed water quality, etc. Increasing pressure in dams and their deplorable condition can lead to their destruction. A natural disaster or sabotage explosion could result in a devastating flood.

In the operation of hydraulic structures, in particular dams, the destruction of the pressure front of hydroelectric installations is one of the most dangerous cases of accidents, leading to significant economic, environmental and social consequences, as well as affecting significantly the ecology of the tailrace of hydroelectric installations.

Based on statistics for the 15,000 large dams that exist in the world, there has been an average of 1.5 failures per year, which means that the probability of dam failure is approximately 10 cases per year. The accuracy of prediction of the spill hydrograph depends on the reliability of forecasting the parameters of the spill wave (change in time of the flow depth, flow velocity, etc.) in various flood areas, information about which is necessary to select the location of economic facilities, development of flood control measures, drawing up an action plan in case of a breach, assessment of the consequences of the wave passage and the subsequent environmental situation, insurance of retaining structures, etc. [7].

The basis for the formation of population protection is the zoning of the territory according to the types and degree of possible danger in case of catastrophic flooding by a breakthrough wave. To predict the engineering situation during the passage of the breakthrough wave, it is necessary to calculate its main parameters, which include: the maximum height of the breakthrough wave; the maximum velocity of the body of the wave; the speed of the breakthrough wave front; the tail speed of the breakthrough wave; time of reaching characteristic points of the breakthrough wave (front, crest, tail) to the design sections.

To effectively protect the population, objects and territories, a methodology and program for calculating the parameters of the breakthrough wave and flooding zones, as applied to the hydromorphometric conditions of our country are needed.

Result and discussion. The theoretical basis is based on the study of the movement of the breakthrough wave during hydrodynamic accident on the hydraulic structures of the pressure front.

We consider a slowly changing unsteady fluid flow on the section dl of some channel with the live cross-section area at the beginning of the flow S. The calculation scheme of the breakthrough wave motion is shown in Fig. 1.

The coordinate of the free surface of the flow at the initial section is denoted by z, and the average velocity at this section by v. At distance dl, coordinate z and velocity head $\alpha v^2/2g$ will receive the following increments: dz and $d(\alpha v^2/2g)$, respectively (α is the Coriolis coefficient) [8].

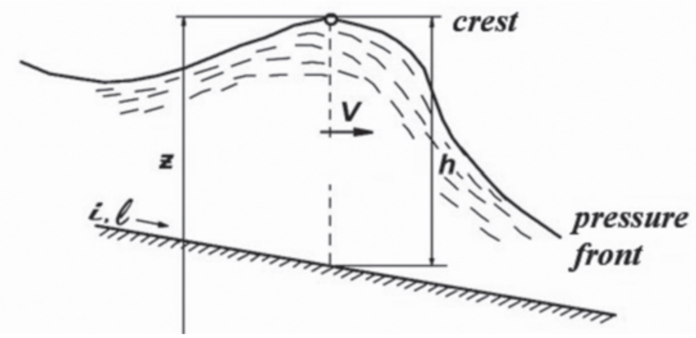

Figure 1 – Calculation scheme of the breakthrough wave motion

For rivers, the longitudinal gradient for channels is relatively small, so for the breakthrough wave flow, the acceleration equal to $\frac{\alpha_{0\partial v}}{\partial t}$ (taking into account the irregularity of velocity distribution in the section) acts along the axis l (α_0 is the Boussinesq factor; t is the time of flow, s).

In accordance with Fig. 1, taking into account the work of inertial force per unit weight of the fluid at section dl, the equation of conservation of total specific energy for the section with coordinate z and the section at the increment dl at unsteady motion of the breakthrough wave body is

$$z+\frac{\alpha v^2}{2g}=z+dz+\frac{\alpha v^2}{2g}+d\left(\frac{\alpha v^2}{2g}\right)+i_{TP}dl+\frac{\alpha_0}{g}*\frac{\partial v}{\partial t}dl \quad (1)$$

or

$$d\left(z+\frac{\alpha v^2}{2g}\right)=-i_{TP}dl-\frac{\alpha_0}{g}*\frac{\partial v}{\partial t}dl \quad (2)$$

where i_{TP} is the slope of friction:

$$i_{TP}=\frac{Q^2}{K^2} \quad (3)$$

where Q – flow rate in the section, m^3/s; K – flow characteristic, m^3/s, $K=SC\sqrt{R}$; R – hydraulic radius, m; S – live cross-sectional area of the flow, m^2; C – Shezi coefficient, $m^{0,5}/s$, $C=\frac{1}{n}R^y$, n – roughness coefficient of the watercourse, $s/m^{0,25}$.

For calculation of open channels it is recommended values y = 0,2...0,25. For the calculations in the work took y = 0,25.

Dividing both parts of equation (2) by dl with the friction slope taken into account, we obtain the following equation:

$$\frac{\partial z}{\partial l}+\frac{av}{g}*\frac{\partial v}{\partial l}+\frac{\alpha_0}{g}*\frac{\partial v}{\partial t}+\frac{Q^2}{K^2}=0 \quad (4)$$

where $\frac{\partial z}{\partial l} = I = i - \frac{\partial h}{\partial l}$ – free surface slope; *i* – stream bottom slope; *h* – flow depth, m.

After transformations, equation (4) takes the form of the Saint-Venant equation [8, 9]:

$$i - \frac{\partial h}{\partial l} = \frac{av}{g} * \frac{\partial v}{\partial l} + \frac{\alpha_0}{g} * \frac{\partial v}{\partial t} + \frac{Q^2}{K^2} \qquad (5)$$

or

$$i - \frac{\partial h}{\partial l} = \frac{av}{g} * \frac{\partial v}{\partial l} + \frac{\alpha_0}{g} * \frac{\partial v}{\partial t} + \frac{v^2}{C^2 R} \qquad (6)$$

The complexity of the equations in question and the impossibility of obtaining analytical solutions required the use of numerical methods based on the approximation of derivatives by finite differences [10]. Systems for real-time monitoring of water bodies, based on automation of information collection and processing, are being developed for practical application.

The main concepts of this work is to identify ways to establish a monitoring system, in particular, predicting the risks of accidents due to dam breaks, analyzing data, the characteristics of objects falling into the flood zone and obtain instructions for an immediate response to prevent emergencies. The objectives of the work are to analyze the consequences of a dam break and the immediate response to these events, to predict possible flood zones, the destruction of downstream dams, recommendations for rescue operations.

To solve the problem of obtaining flood zones as a result of flooding, the following ways of obtaining results are possible:

1. Physical models;
2. Conducting analytical calculations;
3. Numerical modeling.

To date, it has been shown that it is possible to determine the parameters of flood and breakout wave propagation only by using numerical computer modeling. Fluid flows are divided into two very different types: laminar (smoothly varying, regular) and turbulent (disordered). In cases of flood and breakthrough wave propagation, the fluid flow will be turbulent [11].

All existing software packages can be divided into one-dimensional, two-dimensional and three-dimensional. Numerical modeling in one-dimensional and two-dimensional cases greatly simplifies the model under study, and does not give a complete picture of the processes occurring during the propagation of the breakthrough wave or flood wave, which will be shown below. Thus, the most accurate would be to use three-dimensional numerical modeling to perform flood and breakout wave calculations.

In most cases, the basic system for hydrodynamic modeling is a three-dimensional system of Navier-Stokes evolutionary equations.

Let's analyze the necessary input data for different ways of modeling.

Saint-Venin's system of differential equations for unsteady fluid motion, assuming flow in a channel with a sufficiently large bottom slope, can be reduced to the form:

$$\frac{\partial h}{\partial t}+\frac{1}{b}\frac{\partial Q}{\partial x}=0, \tag{7}$$

$$\frac{\partial Q}{\partial t}+\left(\frac{Q}{bK}\frac{dK}{dh}\right)\frac{\partial Q}{\partial x}-\frac{K^2}{2bQ}\frac{\partial^2 Q}{\partial x^2}=0, \tag{8}$$

where: t – time, $0 \le t \le T = \text{const}$, s; x – spatial coordinate in the direction of motion, and $0 \le x \le l$, m; J – bottom slope, m/m; b – width σ of the channel, m; $h(x, t)$ – channel depth, m; $K(h)$ – flow characteristic of the channel ($K(h)=\frac{bh^{\frac{5}{3}}}{n}$, where n – is the roughness coefficient); $v(x, t)$ – average flow velocity in the channel cross section, m/s; $Q(x, t)$ – flow rate in the selected cross-section, $\frac{m^3}{s}$.

To calculate by these equations describing unsteady nonuniform movement of water masses, it is necessary to set initial and boundary conditions on the river section. Initial conditions require to set the state of the flow, its velocity or flow rate at all points of the channel at the time $t = 0$. Boundary conditions determine the water level, its velocity or flow in the upper and lower sections of the river at any time.

The initial conditions will be of the form:

$$(x,0)=\sigma_0(x), \quad b(x,0)=\gamma_0(x), \tag{9}$$

Boundary conditions:

$$Q(0,t)=\sigma_1(t), \quad h(0,t)=\gamma_1(t), \tag{10}$$

$$Q(l,t)=\sigma_2(t), \quad h(l,t)=\gamma_2(t). \tag{11}$$

The problem can be solved by dividing the interval [0, T] into segments and calculating on them all the characteristics of the flow, because for real river channels in a non-uniform movement area of the cross section varies depending on x, and since the motion unsteady, then the area also depends on time. Thus, it is necessary to divide the section into segments with unchanged hydraulic characteristics, then solve the system of Saint-Venin equations for the segments, where for the first segment the input hydrograph is taken from the initial data, then the flow parameters in this segment are calculated and the output hydrograph, which serves as the output hydrograph for the second segment, and so on.

The task of modeling river flow is an important problem. Currently, there is no single solution for predicting river flow. The constant desire to simplify methods leads to a loss of quality in the results of the study. But more complex models require numerous observational data, which are often not available, so we have to resort to simplifying models. One-dimensional models of river flow modeling can be used only for preliminary calculations. One-dimensional models of river flow modeling can be used only for preliminary calculations [12].

Conclusions. The paper shows that it is possible to determine the parameters of flood and breakthrough wave propagation only with the use of numerical computer modeling. All considered methods do not allow to quickly obtain baseline data to justify flood protection measures and require significant material and time resources. Thus, there is an obvious need to create a simplified technology for engineering justification of flood control measures, comparable in terms of reliability of obtaining results with existing ones, but with the advantage of speed of modeling and ease of implementation. The technology should, with a minimum set of input data, make it possible to simulate the propagation of the flood wave or breakthrough wave, which results in a two-dimensional map of the study area with flood zones, ranked by depth, as well as other parameters that characterize the propagation of waves.

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[1]Қазақстан Республикасы Ғылым және жоғары білім министрлігі Ақпараттық және есептеуіш технологиялар институты, Алматы, Қазақстан,
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ГИДРОТЕХНИКАЛЫҚ ҚҰРЫЛЫСТАРДЫҢ БҰЗЫЛУЫНЫҢ САЛДАРЫН ЖӘНЕ АВАРИЯЛЫҚ ЖАҒДАЙЛАРДЫҢ ТУЫНДАУЫН ТАЛДАУ

Төтенше жағдайлардың алдын алу және оларды жою мәселесі өте өзекті болып қала береді. Маусымдық су тасқыны немесе төтенше жағдайлар нәтижесінде аумақты су басуды болжау өте маңызды болып табылады және олар әртүрлі технологиялар негізінде шешіледі. Жер үсті сулары динамикасының тікелей гидродинамикалық есептеулеріне негізделген компьютерлік модельдеу әдістері қашан да тиімді бағыт болып көрінеді. Таулы жерлерде гидротехникалық құрылыстарды сумен толтыру динамикасын модельдеу ерекше қызығушылық тудыратыны рас.

Бұл мақалада су объектілеріндегі төтенше жағдайларда гидротехникалық құрылыстардың бұзылу ерекшеліктері қарастырылған. Сонымен қатар мақалада су қоймаларындағы су деңгейін бақылау әдістері де айтылады. Су тасқынын бақылау технологиясының сипаттамасы келтірілген, оны кейбір аймақтарда практикалық қолдану нәтижелері талқыланып, одан әрі даму бағыттары ұсынылған. Бұл ақпарат кейіннен төтенше жағдайды болжау үшін қолданылады.

Түйін сөздер: *бөгет, су қоймасы, су тасқыны, математикалық модель, бақылау, болжау, серпіліс, экологиялық қауіпсіздік.*

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АНАЛИЗ ПОСЛЕДСТВИЯ РАЗРУШЕНИЯ ГИДРОТЕХНИЧЕСКИХ СООРУЖЕНИЙ И ВОЗНИКНОВЕНИЕ АВАРИЙНЫХ СИТУАЦИЙ

Проблема предупреждения и ликвидации чрезвычайных ситуаций остается очень актуальной. Прогнозирование затопления территории в результате сезонных паводков или в результате чрезвычайных ситуаций имеет важное значение и решается на основе различных технологий. Методы компьютерного моделирования, основанные на прямых гидродинамических расчётах динамики поверхностных вод, представляются эффективным направлением. Особый интерес представляет моделирование динамики заполнения гидротехнических сооружений в горной местности.

В данной статье рассмотрены особенности разрушения гидротехнических сооружений в чрезвычайных ситуациях на водных объектах. В статье также упоминаются методы мониторинга уровня воды в водохранилищах. Приведено описание технологии мониторинга наводнений, обсуждены результаты её практического использования в некоторых регионах, намечены направления дальнейшего развития. Эта информация впоследствии используется для прогнозирования чрезвычайной ситуации.

Ключевые слова: *плотина, водохранилище, наводнение, математическая модель, мониторинг, прогноз, прорыв, экологическая безопасность.*