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SIMULATION OF FLOOD INFLAMMATION DUE TO DESTRUCTION OF HYDROTECHNICAL STRUCTURES

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The article presents the new results of scientific researches of technical aspects of forecasting the consequences of emergencies related to hydraulic accidents.Based on the analysis of statistical data, the relevance of the raised issue of the need to improve the existing scientific and methodological apparatus to justify the parameters of the breakthrough wave and the flood zone in the event of destruction of hydraulic structures is substantiated. The attention is focused on the need to take into account the condition of ensuring the consumption of bulk mass of water before the restoration of its domestic level in the lower reaches of the water barrier.This condition is the basis of an improved method for determining the parameters of active and passive flooding of the area, based on a three-dimensional model of the longitudinal section of the breakthrough of the hydraulic structure and the parameters of the breakthrough wave.Based on the results of verification of the proposed methodology, calculations and modeling according to the initial data in accordance with the developed situation of destruction of the hydro unit, a conclusion about the feasibility of its use for forecasting emergencies during hydraulic accidents was made.

Keywords: emergency situation, hydraulic structure, hydraulic accident, release wave, breakthrough wave, zone of active (passive) flooding, upstream and downstream, proran.

Formulation of the problem. As of the beginning of the 21st century, more than 30,000 artificial reservoirs with a total volume of 1 million m^3 have been created in the world as a result of technical regulation of river runoff with the help of damswhich caused flooding of 0.25% of the land area [1-4]. Most reservoirs were built to develop hydropower, irrigation, technical and drinking water supply, as well as to improve the work of the water water transport. The total number of large dams (over 15 m high), built in the twentieth century, reaches 46 thousand [5-6].

The urgency of the issue is exacerbated by global climate changes and the catastrophic floods caused by them on the Danube, Elbe, Rhine, Vistula, Dniester and other Carpathian rivers over the past 5 years [1-7]. For Ukraine, as a European country with a well-developed hydrographic network [8], the condition of hydraulic structures on the Dnieper River deserves special attention and is of concern [9-14].

Analyzing the information on the largest accidents of hydraulic structures should be mentioned the devastating effects of hydrodynamic danger in 1959. France [2]. Malpasse Dam on the Reyran River on the Cote d'Azur in the Mediterranean Sea, built in 1954. The height of the dam is 60 m, length - 222 m, width at the base - 6.8 m, purpose - irrigation and water supply.As a result of the breach of the dam, the city of Frejus was completely flooded. The causes of the accident were unsatisfactory quality of concrete, as well as the use of explosives a few hundred meters from the dam during the construction of the highway. Consequences - 423 deaths, economic losses - 68 million dollars [1].

In 1961 in the USSR in Kyiv city. Breakthrough of a temporary earth dam during the washing of Babyn Yar, which was to become part of a small ring road in Kyiv. Pulp - a mixture of sand with clay and water, which was pumped into the ravine, due to heavy rains broke through the earth dam. A stream 4 m high and 20 m wide at a speed of 5 m/s rushed to the densely populated area of Kurenivka.Within minutes, a tram park, residential buildings, and administrative buildings were buried under a 3-meter layer. Under the pressure of the pulp, the electrical wires broke and fell on the bus, which then caught fire.The fire killed all passengers.The volume of mud mass is 600 thousand m3, the total area of flooding is 30 hectares. The cause of the accident was a violation of the norms during the construction of the dam, the soil was not compacted properly, there was no drainage prism [2].

The accident on the Viont Dam in Italy, which occurred on October 9, 1963, when a 0.24 km^3 mountain massif collapsed into a 0.169 km^3 reservoir which led to the overflow of 5.0 million m^3 of water through the dam. A 90-meter-high water embankment washed away several settlements in 15 minutes, killing more than 2,000 people. The cause of the landslide was the rise in groundwater levels due to the construction of the dam.

1975. China. Typhoon “Nina” broke the dam in the peak of the river Ru.The giant wave that formed passed the Ru and Huai rivers, destroying 62 dams and hydroelectric dams, the largest of which was the Bainqiao Dam (height - 50.5 m, length - 3720 m), built in 1952.The causes of the accident - a natural disaster. As a result, 26,000 people died in the floods, the total number of victims, including famine and epidemics, was 340,000, and the economic damage was $ 513 millions [1].

1976 USA. A dam broke on the Teton River in Idaho. At that time, it was the second largest dam in the United States, its height - 93 m, length - 940 m, width at the base - 520 m. Construction was completed in 1976. The cause of the accident - a construction error. Consequences - 11 dead, 13 thousand injured, economic losses - 1 billion dollars [2].

1977 USA. In the state of Texas, the dam of the hydroelectric power plant, built in 1889, broke., height - 12 m, length - 120 m, width - 6.1 m. The cause of the accident - the obsolescence of the building, the negligence of the staff. Consequences - 40 deaths, economic losses - 2.8 million dollars [1].

1979 India. Breakthrough of a dam in Gujarat on the Machu River. The dam was built in 1972, height - 26 m. The cause of the accident - precipitation, which fell 55 mm per day, which is the annual norm for this arid region. Consequences - 15 thousand dead, 60% of the housing stock destroyed [1].

Breakthrough of the Tyrlyk Reservoir Dam in the Beloritsky District of Bashkortostan, which on August 7, 1994 caused a discharge of 8.6 million m^3 of water. As a result, 4 settlements were in the flood zone, 85 houses were completely destroyed, 200 houses were partially destroyed. During the flood 29 people died, 786 people were left homeless [2].

The destruction of 7 protective dams during the great flood of August 18, 2002 near the German city of Wittenberg on the river Elbe, when a water wave rushed into the city, urgently 40 thousand people were evacuated, 19 residents died, 26 people went missing [2].

2005 Pakistan. The 150-meter dam of Shakidor HPP on the Shadi River broke. Several settlements were flooded. The cause of the accident - heavy rains. The consequences are 130 dead and 500 injured. A 150-meter dam burst near the city of Pasni as a result of heavy rains on February 11, 2005 in Balochistan province in southwestern Pakistan. As a result, several villages were flooded, killing more than 135 people [1].

Dam burst during the construction of the Kiadag HPP after a sharp rise in water levels on October 5, 2007 on the Chu River in the province of Thancho in Vietnam. In the flood zone were 5 thousand houses, 35 people died [1].

2009 Brazil. Dam broke on the Algodoens Reservoir, a 50-meter section of the dam was destroyed, 2 settlements were flooded. The cause of the accident - heavy rains. Consequences - 54 dead, 80 injured [2].

On August 17, 2009, an accident occurred at the Sayano-Shushenskaya HPP in Russia [3], killing 77 people and rescuing 17 people. The 2nd hydro unit of the HPP was completely destroyed and the engine room was partially destroyed.n addition, the 7th and 9th hydraulic units were severely damaged. In total, the HPP consists of 10 hydro units that convert the kinetic energy of water flow into electricity. As a result, the engine room building was stopped, flooded and destroyed. After the accident, up to 10 tons of transformer oil spilled into the river and an oil slick ten of kilometers long was formed, mass deaths of hundreds of tons of fish were recorded.

2010 Poland. A dam broke on the Odra River near Wroclaw. In some areas of the city the water rose by 2 m. The cause of the accident - prolonged downpours - in mid-May for the week fell on January 2, the norm of precipitation. Consequences - 12 dead. In general, the 2010 floods in Central Europe affected Poland, the Czech Republic, Slovakia, Hungary, Ukraine, Austria and Serbia. The greatest devastation caused Poland - 22 dead, more than 20 thousand evacuees. The total economic damage from the flood was 2 billion euros [2].

2012 Bulgaria. The dam on the Ivanovo reservoir broke. Within minutes, the village of Biser disappeared under water, the city of Armanli was flooded, and the international highway was blocked. The cause of the accident - heavy rainfall, which led to overflow of the reservoir. Consequences - 8 victims [2].

In addition to this information, the consequences of hydrodynamic hazards on the state of ecological systems [4], hydrological component of flood runoff forecasting [5], mathematical model for monitoring the state of hydraulic structures to protect polder systems from flooding and inundation [6]. In Ukraine, a man-made accident was known at the Steblikov Chemical Plant in 1983 [7–8], when 4.5 million tons of highly mineralized water with a salt concentration of 240 grams per liter spilled into the Dniester River. Almost 600,000 tons of chlorides got into the Dniester Reservoir. At the end of 1983, 228,000 tons of chlorides had accumulated at the bottom of this reservoir, which accumulates pollution from upstream regions. They tried to cope with the consequences of the chemical accident by using a pumping unit, which lifted chlorides from the bottom of the reservoir, mixed them with water and dumped them into the lower reaches in acceptable doses.

It should be noted that the filling of the Dniester Reservoir [14] began in late 1981, and before the NDP it was completed in October 1987. Thus, the Dniester Reservoir prevented the spread of pollution downstream from the dam of the reservoir. It should be noted its positive environmental significance during this man-made accident. However, there are environmental problems of the Dniester complex hydropower unit's impact on the ecological status of the Dniester basin downstream from the buffer reservoir, from which water is taken to the upper reservoir for the operation of Dniester PSP hydroelectric units. These complex environmental problems need to be studied at all times: during the gradual commissioning of hydro units and after the commissioning of the Dniester PSP. The above problems are also complicated by the fact that the Dniester basin is flood-hazardous [15]. This is confirmed by the floods that occurred in the summer of 2008 in western Ukraine due to intense thunderstorms and a sharp rise in water levels in the rivers of the Dniester basin. This flood is called a natural disaster and is considered the largest in the history of Western Ukraine in the last 60 years. During the flood, the Carpathian Mountains, Prykarpattia and Zakarpattia were affected. The settlements in the Dniester and Prut river valleys suffered the most. On July 31, 2008, the Verkhovna Rada of Ukraine declared 90-day emergency zones in 6 regions of Ukraine: Lviv, Ivano-Frankivsk, Ternopil, Chernivtsi, Zakarpattia and Vinnytsia. The southern districts of Khmelnytsky region were also affected.30 people died, 6 of them were children. After the peak of the flood, on July 28, 2008, in the territories of Lviv, Zakarpattia, Ternopil, Chernivtsi and Ivano-Frankivsk regions 40 thousand 601 houses, 33 thousand 882 hectares of agricultural lands were flooded, 360 car and 561 pedestrian bridges were damaged, 6, 61 km of highways. The total damage from the flood is estimated at UAH 3-4 billion. In addition to the western regions of Ukraine, the neighboring regions of Moldova, Romania, Slovakia and Hungary were affected by the floods. The causes of the devastating consequences of this flood, according to many Ukrainian environmentalists, were mass deforestation in the Carpathians.

Thus, hydrodynamic danger may be caused by existing hydraulic structures subordinated to ministries and departments of various sectors of the economy of Ukraine or leased or privately owned by citizens, are existing or potential factors that endanger the vital interests of our country. This should always be borne in mind to ensure the safety of life, to prevent the negative consequences associated with the construction or reconstruction of water bodies to make the right decisions in the case of rational use of water and land resources and environmental protection measures.

Given the urgency of the issue in the theory and practice of civil safety, there is an urgent need to predict the consequences of emergencies on hydraulic structures, which in turn requires adequate scientific and methodological apparatus for calculating and modeling the development of hydraulic accidents.

Analysis of recent researches and publications has shown that they have explored a large number of aspects ofboth scientific and practical orientation. Among the open sources we can highlight the literature and publications devoted to the prediction of active and passive floods that occur as a result of hydrodynamic accidents of various kinds [15-19]. In addition, [20-21] the possible impact of active and passive floods that occur as a result of fightening is presented.

However, the results of research and methods of forecasting the consequences of floods presented in [15-19] relate mainly to floods or floods of a natural nature and are not fully adapted to the conditions of destruction of hydraulic structures. And the information and methods presented in [20-21] are outdated, they are based on analytical dependencies and do not allow to reliably calculate the basic parameters of the characteristics of the breakthrough wave, launch and zones of active and passive flooding. To solve this discrepancy in the theory of emergency forecasting, it is necessary to improve the existing methodological apparatus through the integrated use of analytical and graph-analytical methods for calculations and modeling of these processes.

The aim of the article is to highlight the theoretical foundations and improved methods for determining the parameters of active and passive flooding of the area due to the destruction of hydraulic structures, as well as an example of verification of the proposed method. Presentation of the main material of the study. According to the provisions discussed in [22], the following definitions are used in civil security practice.

Hydraulic structure (GTS) is an economic object located on or near the water surface and is designed to use the kinetic energy of water movement to convert it into other types of energy; cooling of spent steam at power plants; reclamation, water abstraction for irrigation, drainage and fish protection; water supply, coastal protection, water level regulation; ensuring the activities of river and sea ports, shipbuilding and ship repair enterprises, shipping; underwater mining, storage and transportation of minerals.

The reach is a part of a river, canal, reservoir or other water body adjacent to a hydraulic structure (dam, sluice, hydroelectric power station, etc.). A distinction is made between the upstream (WB), which is located upstream, and the downstream (NB), which is located on the other side (downstream) of the hydraulic structure.

Proran - a narrow passage (ravine) in the body (embankment) of the dam, through which water comes out, creating a wave of breakthrough. Depending on the rate of emptying the reservoir (WB), there are two types of waves: the release wave - slow emptying of the WB and the breakthrough wave - rapid emptying. The front part of the driving mass of water is called the breakthrough wave front.

Hydrodynamic accident (GDA) is an emergency that involves the failure and destruction of a hydraulic structure or part thereof, and the uncontrolled movement of large masses of water, causing the destruction and flooding of large areas. The causes of hydraulic accidents are shown in Figure 1.

(a) (b) (c)

Fig. 1. Causes of hydrodynamic accidents:
(a) - natural phenomena or natural disasters; (b) - man-made factors;
(c) - extraordinary consequences of a military nature and terrorist acts

The magnitude of population losses during the GDA may vary depending on population density in the flood zone, time of day (night increases significantly the number and severity of the affected), speed and wave height, water and air temperatures (low temperature severely limits the time during which it is possible to save the victims) [22].

The breach of the dam is the initial phase of the GDA, which is a proran and uncontrolled flow of water from the WB to the NB, which with great speed and pressure goes downstream. The wave height is from 2 to 12 m and the speed of movement is from 3 to 25 km/h (in mountainous areas it can reach 100 km/h).

The speed of propagation and the height of the wave are also significantly influenced by the nature of the terrain in which it moves. On the plains its speed will not exceed 25 km/h, and in the mountains, it can reach 100 km/h. Forests, hills, ravines and other relief elements reduce the speed of movement and the height of the breakwater.

Schematically, the longitudinal intersection of the GTS breakthrough and the breakthrough wave parameters can be represented as follows (Figure 2).

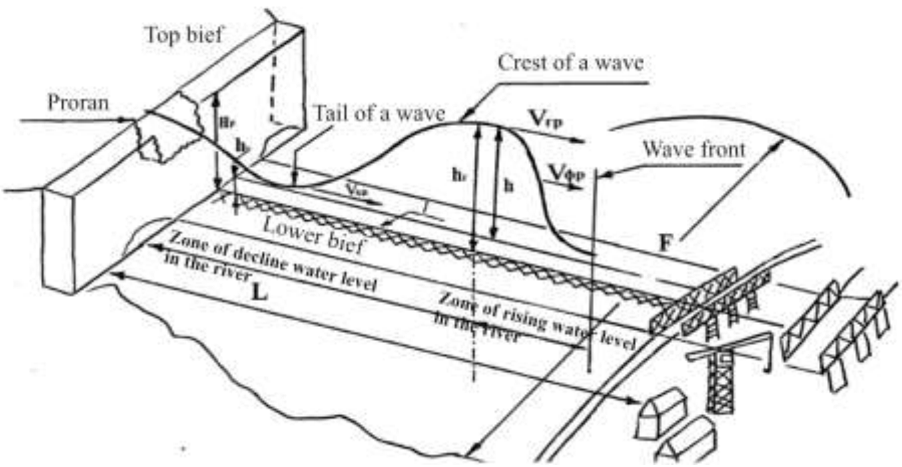

Fig. 2. Three-dimensional model of the longitudinal section of the GTS breakthrough
and breakthrough wave parameters

Taking into account [22] a catastrophic flood zone is a part of the territory that was flooded as a result of GTS, which occurred on the GTS and within which people, farm animals and plants were killed or damaged, buildings and various structures were significantly damaged or destroyed.

The improved method of determining the parameters of active and passive flooding of the area isdestined to predict the possible consequences of the breakthrough wave during the destruction of the GTS dams.

Initial data for calculations: reservoir volume W_B, million m^3; the width of the reservoir before the dam *B*, m; depth of the reservoir in front of the hydro node *H*, m; the depth of the river below the dam *h*, m; the shape of the valley in the river sections of sight; other characteristics of the river.

The sequence and formulas for calculations and modeling are as the following. Based on the data of large-scale maps, the longitudinal profile of the river section is formed (Figure 3), according to which the propagation of the breakthrough wave is possible. The obtained profile of the river is divided into calculated sections, the length of which depends on the same characteristics of the river and banks (slopes of the river bottom, depth, width, the nature of the forested valley). The boundaries of the sections are accepted as calculated river sectionscreatures. In this case, the destroyed dam is considered the first river sections, the boundary between the 1st and 2nd sections - the second river sections, and between the 2nd and 3rd - the third river sections, and so on. All wave parameters related to the calculated river sections are denoted by Roman indices I, II, III, and the calculated areas are indicated by Arabic indices 1, 2, 3, etc. (Figure 3).

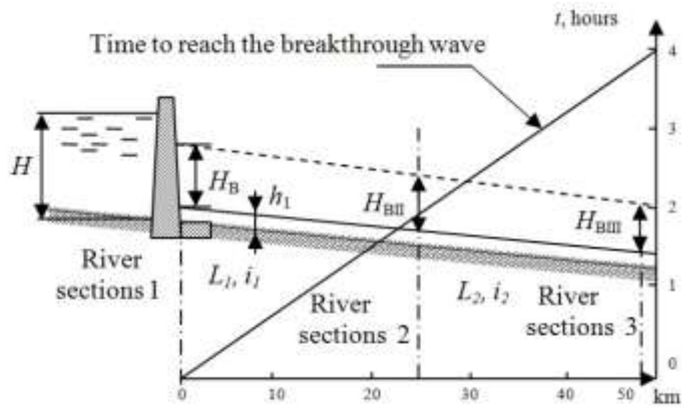

Fig. 3. Longitudinal profile and parameters of the breakthrough wave (example)

During the calculations of the parameters of the breakthrough wave in the area of the destroyed river sections GTS dam is determined(height of the breakthrough wave - H_B and time of its passage - T_B, then find the basic data of the breakthrough wave on the first section and subsequent, average speed - *V* and time to reach the calculated river sections - *t*). Next, determine the parameters of the breakthrough wave in all calculated river sections. The result of the calculations is a graph of the breakthrough wave and plotting a possible flood zone.

The procedure for determining the parameters of the breakthrough wave in the GTS river sections is as follows. During the destruction of the supporting structures of the dam, the height of the breakthrough wave in the first river sections of destruction is determined by the formula:

$$H_{BI} = 0,6H - h_1, \tag{1}$$

where H – is the depth of water in front of the dam at the time of its destruction, m; h_1 – is the depth of water in the river after the dam, m.

The time of the passage of the wave (T_I) through the river sections of the destroyed dam (I river sections) is equal to the time of emptying the reservoir and is determined by the formula:

$$T_I = \frac{W_B A}{3600\mu BH\sqrt{H}} \text{ (hours)}, \quad (2)$$

where W_B – is the total volume of the reservoir at the normal supported level, m^3; *A*– auxiliary coefficient which depends on the shape of the curvature of the reservoir (its value is in the range from 1 to 8 and for calculations in average conditions is taken equal to 3); μ – water consumption coefficient, which takes into account the shape of the riverbed and valley (Table 1); *B* – width of the reservoir along the water section in the river sections of the dam at the time of its destruction, m; *H* – depth of water in front of the dam at the time of its destruction, m.

Table 1

The value of the coefficient μ

Terra in type	Channel shape		
	Triangular	Parabolic	Rectangular
Plain	0,6	0,75	0,9
Hilly	0,5	0,6	0,8
Lowland	0,4	0,55	0,7
Alpine	0,2	0,3	0,45

The procedure for calculating the motion of the breakthrough wave in the first section and determining its parameters in he second river sections is as follows. First determine the time (t_1)reaching the crest of the wave from the first (I) to the second (II) river sections. Then determine the height of the breakthrough wave H_{BII} in thesecond (II) river section and determine the duration of the breakthrough wave through the second (II) river sections.

The time of reaching the cresto the wave from thefirst (I) to the second (II) river sections is determined by the formula

$$t_1 = L_1/V_1 \text{ (hours)}, \quad (3)$$

where L_1 –is the length of the first settlement section, km (determined for relatively identical slopes (*i*) and flood plains of the river); V_1 – averagespeedof breakthrough wave movement in the calculated section, km/h (Table 2).

The average speed of the breakthrough wave in the calculated area depends on the nature of the water barrier: the slope (*i*) of the river, the width of the river flood plain, the presence of vegetation.

Table 2

The value of the average velocity of the crest of the breakthrough wave

The type of river by the width of the flood plain and the slopes of the banks	Theaveragespeedofthecrestofthebreakthroughwave (V_1) when the slope of the bottom (s) on the calculated section of the river		
	0,01	0,001	0,0001
On rivers with a wide flood plain	4–8 (Average 6)	1–3 (Average 2)	0,5–1 (Average 0,75)
On winding rivers	8–14 (Average 10)	3–8 (Average 6)	1–2 (Average 1,5)
On rivers with a well-developed channel	14–20 (Average 17)	8–12 (Average 10)	2–5 (Average 3,5)
On under developed rivers	–	12–16 (Average 14)	5–10 (Average 7,5)

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The height of the (H_{BII}) in these cond calculated river sections and the duration of the breakthrough wave (T_{II}) through the calculated river sections of sight is determined depending on the relative coefficient:

$$K_1 = t_1 / T_1 \text{ (hours),} \quad (4)$$

where t_1 is the time of reaching the crest of the breakthrough wavefrom the destroyed dam to the second (II) river sections, hours (formula (3)); T_1 is the time of the breakthrough wave through the second (I) river sections, equal to the time of emptying the reservoir, hours (formula (2)).

The values of the coefficients K_H of the ralations of the height of the breakthrough wave and the duration K_T of its passage through the calculated river sections are shown in table 3.

The height of the breakthrough wave is determined by the formula:

$$H_{BII} = K_H H_{BI} \text{ (m),} \quad (5)$$

where K_H is the ratio of the wave height in the calculate driver sections (Table 3); H_{BI} is the height of the breakthrough wave in the first (I) river sections, m (formula (1)).

Table 3

The value of the ratio of the height of the breakthrough wave and the duration of its passage through the calculate driver sections

K_t	K_H	K_T
0,0	1	1
0,1	0,9	1,1
0,25	0,8	1,3
0,4	0,7	1,5
0,55	0,6	1,6
0,7	0,5	1,7
0,95	0,4	1,9
1,25	0,3	2,2
1,5	0,3	2,6

The duration of the breakthrough wave throughthe second (II) river sections is determined by the formula:

$$T_{II} = K_T T_I \text{ (hours),} \quad (6)$$

where K_T is the coefficient of the ratio of the duration of the breakthrough wave through the calculate driver sections (Table 3); T_I is the time of passage of the breakthrough wave through the second (II) river sections (formula (2)).

The procedure for determining the motion of the breakthrough wave and its parameters in the second and subsequent sections and river sections is as follows. Calculations of the motion of the breakthrough wave and its parameters in the second and subsequent sections and river sections are performed in the same way as during the calculations of the motion of the breakthrough wave and its parameters in the first section.

The time of reaching the breakthrough wave to the third and subsequent river sections is determined by the formula:

$$t_{2(i)} = L_{2(i)} / V_{2(i)} \text{ (hours),} \quad (7)$$

where $L_{2(i)}$ is the length of the second or subsequent calculation section, km (determined for relatively identical slopes (*i*) and river flood plains); $V_{2(i)}$ – the average speed of the breakthrough wave in the calculated sections, km/h (Table 2).

Theheightofthebreakthroughwave ($H_{BIII(j)}$) in the third calculated and subsequent river sections and the duration of the break through wave ($T_{III(j)}$) through the calculated river sections is determined depending on the relative coefficient, which, unlike the first section and the second river sections is determined by the formula

$$K_t = \frac{t_{2(n)}}{T_{II(j)} + \sum_{i=1}^{n-1} t_i} \text{ (hours)}, \tag{8}$$

where $t_{2(n)}$ – time of reaching the crest of the breakthrough wave from the previous to the next river sections, hours (formula (7)); $T_{II(j)}$ – time of passage of the break through wave through the previous calculated river sections, hours (formula (6)); $\sum_{i=1}^{n-1} t_i$ is the sum of the time of the breakthrough wave reaching the previous river sections, hours.

The height of the breakthrough wave in the following river sections is determined by the formula:

$$H_{BIII(j)} = K_H H_{BII(j-1)} \text{ (m)}, \tag{9}$$

where K_H is the ratio of the wave heights in the calculated river sections (Table 3); $H_{BII(j-1)}$ is the height of the breakthrough wave in the previous river sections, m.

The duration of the breakthrough wave through the calculated river sections is determined by the formula:

$$T_{III(j)} = K_T T_{II(j-1)} \text{ (hours)}, \tag{10}$$

where K_T is the ratio of the duration of the breakthroughwave through the calculated river sections; $T_{II(j-1)}$ – time of passage of the breakthrough wave through the previous river sections, hours.

The procedure for determining the parameters of the flood zone. The parameters of the flood zone include: the maximum level of the crest of domestic water flow in the *i*-th river sections; the average mark of the water level of the flooded *j*-th area of the i-th river sections; the average width of the flooded *j*-th area; consumption of household water flow in the *i*-th river sections; the total length of the flood zone; the total area of the flood zone during the destruction of the GTS support dam.

The maximum level of the crest of the breakthrough wave is determined by the formulas:

in the first river sections:

$$H_{\text{crest}1} = H_{h1} + H_{B1}, \text{ (m)}, \tag{11}$$

where H_{h1} is the mark of the household water level in the river, m; H_{B1} – breakthrough wave height in the first calculated river sections, m (formula (1));

in the following settlement river sections:

$$H_{\text{crest}(i)} = K_H H_{\text{crest}(i-1)} \text{ (m)}, \tag{12}$$

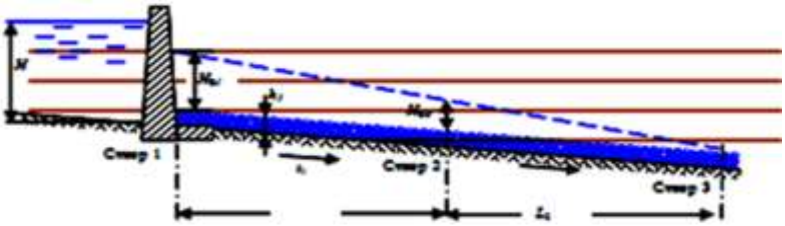
where K_H is the ratio of the wave height in the calculated river sections; $H_{\text{crest}(i-1)}$ is the maximum mark of the level of the crest of the breakthrough wave in the *i*–1 calculated river sections, m (formula (9)).

The mark of the water level of the flooded area of the settlement area calculated river sections is determined by the formula:

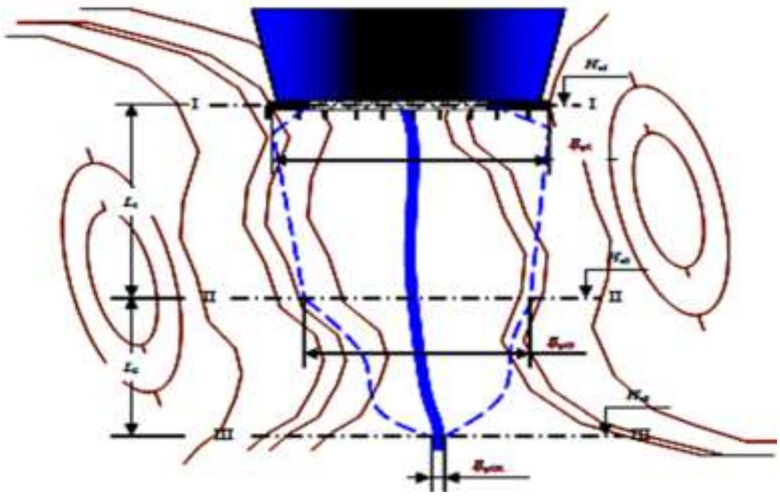
$$H_{\text{avg}i} = H_{\text{crest}(i)} \mu \text{ (m)}, \tag{13}$$

where $H_{\text{crest}(i)}$ – the maximum mark of the level of the crest of the breakthrough wave in the calculated river sections (formula (12)); μ – water flow factor, which takes in to account the shape of the channel and valley, is determined from the river database (Table 1).

The width of the flooded calculation sections (B_{pi}) in each of the calculated river sections is determined graphically by plotting the cross section of the river sections between the level of the flooded area and then measuring them (Figure 4).



(a)



(b)

Fig. 4. Graphic method of determining the width of the flood zone in the river sections of sight of the breakthrough wave: (a) - side view; (b) - top view

The average width of the flood zone in the calculated section of the breakthrough wave is determined by the formula:

$$B_{\text{avg}(j)} = \frac{B_{p(i)} + B_{p(i-1)}}{2} \text{ (m)}, \tag{14}$$

where $B_{p(i)}, B_{p(i-1)}$ is the width of the flood zones in the adjacent sections of the breakthrough wave, m (Figure 4).

The average value of the water level mark on the calculated flooded area of the breakthrough wave is determined by the formula:

$$H_{\text{avg}(j)} = \frac{H_{\text{avg}(i)} + H_{\text{avg}(i-1)}}{2} \text{ (m)}, \tag{15}$$

where $H_{\text{avg}(i)}, H_{\text{avg}(i-1)}$ are the average values of the water level mark in the adjacent river sections of motion of the breakthrough wave, m (Figure 4).

The consumption of domestic water flow in the calculation river sections is determined by the formula:

$$W_{B(j)} = B_{\text{avg}(j)} H_{\text{avg}(j)} L_j \ (\text{m}^3), \quad (16)$$

where $B_{\text{avg}(j)}$ is the average width of the flood zone at the calculated section of the breakthrough wave, m (formula (14)); $H_{\text{avg}(j)}$ is the average value of the water level mark at the calculated flooded section of the breakthrough wave, m (formula (15)), L_j is the width of the calculated section of the breakthrough wave, m.

The total area of the flood zone during the destruction of the GTS support dam is determined by the formula:

$$S_{gen.} = \frac{\sum_{j=1}^{J} B_{avg(j)} H_{avg(j)} L_j}{\frac{1}{J}\sum_{j=1}^{J} H_{avg(j)}} \ (\text{m}^2), \quad (17)$$

We introduce a condition, the fulfillment of which is final to determine the parameters of the flood zone:

$$\sum_{j=1}^{J} B_{avg(j)} H_{avg(j)} L_j \le W_B, \quad (18)$$

where $B_{\text{avg}(j)}$ is the average width of the flood zone at the calculated section of the breakthrough wave, m (formula (14)); $H_{\text{avg}(j)}$ is the average value of the water level mark at the calculated flooded section of the breakthrough wave, m (formula (15)); L_j is the width of the calculated section of the breakthrough wave, m (determined by the map); J is the number of calculated river sections.

The total length of the flood zone is determined by the formula:

$$L_{\text{tl}} = \sum_{j=1}^{J} L_j \ (\text{m}), \quad (19)$$

where L_j is the width of the calculated section of the breakthrough wave, m.

The total duration (estimated time) of flooding after the break of the dam to recovery to domestic water level is determined by the formula:

$$T_{\text{total}} = \sum_{j=1}^{J} T_j \ (\text{hours}). \quad (20)$$

Thus, the existing sequence of calculations and modeling of flooding processes due to the destruction of the GTS additionally takes into account condition (18) to predict possible total planar and temporal parameters of flooding after the break of the GTS dam to restore domestic water levels.

Verification of the proposed methodology based on the results of calculations and modeling. As an example, take the situation according to which, as a result of a terrorist act, the supporting structures of the hydroelectric power station were completely destroyed. Initial data for calculations: the volume of the reservoir W_B =72 millions m^3; the width of the reservoir before the dam B = 110 m; the depth of the reservoir in front of the hydro node H = 42 m; the depth of the river below the dam h = 3.2; the shape of the valley in the river sections of the hydro - parabolic; the river is flat with a well-developed channel, the floodplains of the river are narrow, in places medium, without large resistances. It is necessary to determine the main parameters of the breakthrough wave in the area 45 km from the hydraulic unit.

The problem is solved by formulas (1)-(19). Based on the study of a large-scale map, the 45 km long section is divided into two settlement areas and three river sections. In this example, we take the length of the first calculated section L_1=25 km (*i*-0.0012), and the second – L_2=20 km (*i*-0.001). The first river sections is the river sections of the destroyed dam, the second river sections between the 1st and 2nd sections and the 3d - at the end of the 3rd section (Figures 3, 4).

1. Determine the parameters of the breakthrough wave in the river sections of complete destruction of the supporting structures of the hydro unit (first river sections).

a) By formula (1) we find the height of the breakthrough wave H_{BI} in the first river sections:

$$H_{BI} = 0,6 \cdot 42 - 3,2 = 22\text{m}$$

b) Determine the time of passage of the breakthrough wave through the river sections of the destroyed dam (time of complete emptying of the reservoir). For approximate calculations of the time of complete emptying of the reservoir with the complete destruction of the hydroelectric structures in formula (2), the coefficient *A* is taken to be equal to 2.

With the parabolic formula of the channel and floodplain in the river sections of the destroyed hydroelectric factor the coficient μ=0,6 , then:

$$T_I = \frac{72000000 \cdot 2}{3600 \cdot 0,6 \cdot 110 \cdot 42 \cdot \sqrt{42}} = 2,22.$$

2. Determine the basic data of the motion of the breakthrough wave in the first section and the parameters that characterize it in the second river sections.

a) The time of reaching the crest of the wave to the second river sections is determined by formula (3).

In our example, for a river with a well-developed channel, with narrow floodplains without large resistances at a slope of the bottom *i*= 0.0012, the average speed of the wave in the first section is V_1=10 km/h. According to the data at an inclination of *i* = 0.0012 (*i*≈0.001), the speed of the wave is in the range of 8–12 km/h, and the average speed of the wave can be assumed to be equal to 10 km/h. The length of the first section L_1=25 km. With the specified characteristics of the first section, the time of reaching the breakthrough wave to the second river sections will be equal:

$$t_1 = \frac{25}{10} = 2,5\text{hours}.$$

b) Determine the height of the breakthrough wave in the second river sections. To do this, first determine the value of the ratio of the time of arrival of the wave to the second river sections t_1 at the time of complete emptying of the reservoir *T*. This ratio is equal to:

$$\frac{t_1}{T_1} = \frac{2,5}{2,22} \approx 1,1.$$

Then, according to Table 3, we determine the values of H_{BII}/H_{BI} and T_{BII}/T_{BI} , which corresponds to the ratio $t_1/T_1 = 1,1$. However, in the table the value of the ratio $t_1/T_1 = 1,1$ is missing. In such cases, the value of the ratio of the hight of the breakthrough wave H_{BII}/H_{BI} and the time of the passage of the wave T_{BII}/T_{BI} is determined by interpolation. In this example, the ratio $t_1/T_1 = 1,1$ is between 0,95 and 1,25, and it means that the corresponding ratio $t_1/T_1 = 1,1$ – is between 0,4 and 0,3 and is accepted H_{BII}/H_{BI} =0,35. Thus, the height of the breakthrough wave in the second river sections is equal to:

$$H_{BII} = 0,35 \cdot H_{BI} = 0,35 \cdot 22 = 7,7\,\text{m}.$$

c) Determine the time of passage of the breakthrough wave through the second river sections. Why in table 3 by interpolation we determine the value of the ratio T_{II}/T_I ; it is equal to 2,05, and then determine the time of flooding in the second river sections:

$$T_{II} = 2,05 \cdot T_I = 2,05 \cdot 2,22 = 4,55 \text{hours.}$$

Determine the parameters of the breakthrough wave during the movement of its second calculation section and in the third river sections.

a) By formula (3) determine the time of arrival of the breakthrough wave to the third river sections. The length of the second settlement section is 20 km (slope of the river bottom *i*=0.001). On rivers with medium floodplains without large resistances, the average speed of the wave is 8 km/h. With these data, the time of reaching the breakthrough wave to the third river sections will be equal to:

$$t_2 = \frac{20}{8} = 2,5 \text{hours.}$$

b) to determine the height of the breakthrough wave in the third river sections determine the value of the ratio $t_2/T_{II} + t_1$, it is equal to:

$$\frac{t_2}{T_{II} + t_1} = \frac{2,5}{4,55 + 2,5} = 0,355.$$

From table 3 by interpolation we determine the ratio $H_{BIII}/H_{BII} = 0,75$. From which it follows that the height of the breakthrough wave in the third river sections is equal to:

$$H_{BIII} = 0,73 \cdot H_{BII} = 0,73 \cdot 7,7 = 5,6 \text{m.}$$

b) The time of passage of the breakthrough wave through the third river sections is determined from the ratio $T_{III}/T_{II} = 1,43$ (Table 3)

$$T_{III} = 1,43 \cdot T_{II} = 1,43 \cdot 4,55 = 6,5 \text{hours.}$$

As a result of the calculation, the parameters of the breakthrough wave in the river sections of the destroyed hydro unit were set: the height of the breakthrough wave $H_{BI} = 22 \text{m}$; time of complete emptying of the reservoir $T_I = 2,22 \text{hours}$.

Data of the breakthrough wave movement on the first calculated section L_1 and its parameters in the second river sections: time of reaching the breakthrough wave to the second river sections $t_1 = 2,5 \text{hours}$; breakthrough wave height $H_{BII} = 7,7 \text{m}$; time of passage of a wave through the second river sections $T_{II} = 4,55 \text{hours}$.

Data on the movement of the breakthrough wave in the second section (L_2) and its parameters in the third river sections: the time of reaching the breakthrough wave to the third river sections $t_2 = 2,5 \text{hours}$; breakthrough wave height $H_{BIII} = 5,6 \text{m}$; time of passage of the wave through the third river sections $T_{III} = 6,5 \text{hours}$.

According to the data obtained on the basis of calculations, a graph of the breakthrough wave is constructed. For clarity, the scale of the breakout wave height is taken to be larger than the vertical scale of the longitudinal profile of the river (see Figure 4 for an example).

In conclusion, it should be noted that the article considers a three-dimensional model of flooding due to the destruction of the GTS, which improved the method of determining the parameters of active and passive flooding. The results of verification (calculations) using the original data are presented, which confirmed the feasibility of its use for forecasting emergencies during the GTA. As a direction of further research, the study of ways to protect low-water bridge structures from ice drifts can be chosen.

REFERENCES

1. Krupneyshiye avarii na gidrotekhnicheskikh sooruzheniyak hhttp://www.kommersant.ru/doc/ 1222760.
2. Krupneyshiye avarii na GES v mire za posledniye 50 let. – http://expert.ru/ratings/ table_531121/.
3. Avariya na Sayano-Shushenskoy GES v avguste 2009 godahttp://ria.ru/spravka/20130817/ 956779489.html.
4. Determination of Threshold Runoff for Flood EarlyWarning in Nepalese Rivers. Dilip Kumar Gautam,KhadanandaDulal, IDRiM 2012 Conference, RegularArticles, Special Issue: 2013,Vol 3, No 1.P.126-136.
5. Makarov O. Okovy dlya vody: gidroelektrostantsii – plyusy i minusy–http://www.popmech.ru.
6. Lyapichev YU.P. Gidrologicheskaya i tekhnicheskaya bezopasnost gidrosooruzheniy. – M.: RUDN, 2008. – 222 s.
7. DoslidzhennyaDnistra: 10 rokivhromadskoyiekolohichnoyiekspedytsiyi “Dnister” / RedaktorM.I. Zharkykh – Lviv-Kyyiv: 1998 r. – 216 s.
8. Vyshnevskyy V.I. Richky i vodoymy Ukrayiny, stan i vykorystannya. –K.: Vipol, 2000. – 376 s.
9. Denisova A. I., Timchenko V.M. i dr. Gidrologiya i gidrokhimiya Dnepra i yego vodokhranilishch. – K.: Naukova dumka, 1989. – 212 s.
10. Shvets G.I. Mnogovekovaya izmenchivost stoka Dnepra. – Leningrad: Gidrometeoizdat, 1978. – 84 s.
11. Dopolnitelnaya zashchita zemel ot zatopleniya na vodokhranilishche Kanevskoy GES. Tekhnicheskiyotchet. Knigi 1, 3. Arkhivnyyematerialy. – Kharkov: Ukrgidroproyekt, 1970.
12. Kaskad dneprovskikh vodokhranilishch // Podred. M.S. Kaganera. – Leningrad: Gidrometeoizdat, 1976. – 348 s.
13. Oksiyuk O.P., Timchenko V.M., DubnyakS. S. I dr. Sostoyaniye ekosistemy Kiyevskogo uchastka Kanevskogo vodokhranilishcha iputiy ego regulirovaniya. – K.: In – t gidrobiologii NANU, 1999. – 60 s.
14. Oksiyuk O.P., Timchenko V. M., Davydov O. A. i dr. Ekologicheskiye popuski Kiyevskoy GES. – K.: In – t gidrobiologii NANU, 2003. – 72 s.
15. Prohnozuvannya poveney: zahalnonatsionalna kompleksna systema. // https://www.nas.gov.ua/text/pdfNews/ poveni_prognoz.pdf. – 3 s.
16. Metodyka prohnozuvannya ta otsinky naslidkiv poveney // http://um.co.ua/11/11-7/11-70687.html.
17. Dubnyak S.S. Hidrodynamika milkovod dniprovskykh vodoskhovyshch, yiyi ekolohichna rol. Avtoreferat dys. nazdobuttyanauk. stup. kand. heohr. nauk. – K.: Vyd-vo Kyyivskoho natsionalnoho un-tu im. T. Shevchenka, 1997. – 18 s.
18. Timchenko V. M., Dubnyak S. S. Ekologicheskiye aspekty vodnogo rezhima Kiyevskogo uchastka Kanevskogo vodokhranilishcha // Gidrobiol. zhurn. – 2000. – 36, № 3. – S.57-67.
19. Shereshevskiy A. I. Naturnyye nablyudeniya I rezultaty raschetov rasprostraneniya voln popuskov v nizhnem byefe Kiyevskoy GES // Tr. UkrNIGMI. – 1972. – vyp.116, s. 60 – 78.
20. Lysukhin I. F. Metodika inzhenerno-takticheskikh raschetov. – M.: Voyenizdat, 1974. – 240 s.
21. Ivankov P. A., Zakharov G. V. Mestnost I yeyo vliyaniye na boyevyye deystviya voysk. – M.: Voyenizdat, 1969. – 207 s.
22. Mykhaylyuk V.O., Khalmuradov B. D. Tsyvilna bezpeka: navch. posibn. – K.: tsentruchb. lit., 2008. – 158 s.

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МОДЕЛЮВАННЯ ЗАТОПЛЕННЯ МІСЦЕВОСТІ В НАСЛІДОК ЗРУЙНУВАННЯ ГІДРОТЕХНІЧНИХ СПОРУД

У статті наведені нові результати наукових досліджень технічних аспектів процесів прогнозування наслідків надзвичайних ситуацій, що пов’язані із гідротехнічними аваріями. На основі аналізу статистичних даних обґрунтована актуальність піднятого проблемного питання щодо потреби удосконалення існуючого науково-методичного апарату обґрунтування параметрів хвилі прориву та зони затоплення місцевості у разі зруйнування гідротехнічних споруд. Акцентується увага на потребі врахування умови забезпечення витрати об’ємної маси води до поновлення її побутового рівня у нижньому б’єфі русла водної перешкоди. Вказана умова покладена в основу удосконаленої методики визначення параметрів активних та пасивних затоплень місцевості, що ґрунтується на об’ємній моделі повздовжнього перетину прориву гідротехнічної споруди та параметрів хвилі прориву. На підґрунді результатів верифікації запропонованої методики, розрахунків та моделювання за вихідними даними відповідно із розробленою ситуацією зруйнування гідровузлу зроблено висновок про доцільність її застосування для прогнозування надзвичайних ситуацій під час гідротехнічних аварій. Визначені напрямки подальших досліджень.

Keywords: надзвичайна ситуація, гідротехнічна споруда, гідротехнічна аварія, хвиля попуску, хвиля прориву, зона активного (пасивного) затоплення, верхній (нижній) б’єф, проран.

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Коцюруба В.І., Михайловський Д.В., ЧеревкоР.М., Камалов Є.В., Прощин І.В. **Моделювання затоплення місцевості в наслідок зруйнування гідротехнічних споруд** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 111. – С. 87-101.
Табл. 3. Іл. 4. Бібліогр. 22 назв.

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Kotsiuruba V.I., Mykhailovskyi D.V., Cherevko R.M., Kamalov Y.V., Proshchyn I.V. **Simulation of flood inflammation due to destruction of hydrotechnical structures**// Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2023. – Issue 111. – P. 87-101.
Tabl. 3. Fig. 4. Ref. 12.

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