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ASSESSMENT OF VULNERABLE INFRASTRUCTURE SECURITY RISKS IN THE FORMATION OF ANTICIPATED DISASTERS

Tbilisi
2022

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UDC (უაკ) 338.49+574.23
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Ministry of Education and Science
Shota Rustaveli National Science Foundation
of Georgia
Tsotne Mirtskhulava Water Management
Institute of Georgian Technical University

The monograph has been published with the financial support of Grant Project #FR17_615 „Assessment of Vulnerable Infrastructure Security Risks in the Formation of Anticipated Disasters" of Shota Rustaveli National Science Foundation of Georgia

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ISBN 978-9941-8-4175-0

Tbilisi, 2022

The monograph develops a National Security Strategy and Risk Management Action Plan, assesses the risks of vulnerable infrastructure in light of the threats posed by predictable natural and anthropogenic (including terrorist acts) disasters. The active cooperation of governmental and non-governmental organizations in the modern level risk management and its implementation is presented, which will enable us to create an effective, integrated and consistent risk management platform for the prevention and mitigation of natural and anthropogenic disasters.

The monograph discusses the following tasks: Analysis and assessment of the anticipated threats in case of a possible breakdown as a result of a natural, anthropogenic or terrorist act on the example of Zhinvali high-earth dam in Georgia; Based on the Sustainability and Management Risk Framework - the Memorandum of Understanding with the University of Maryland (USA) (2011), the development of the critical asset and portfolio risk analysis (CAPRA) model which provides for the quantitative assessment, testing and implementation of all expected risks.

Based on the theory of small amplitude waves, the numerical formulation of two- and three-dimensional mathematical models of nonsteady wave boundary problems is discussed in order to study the extreme waves formed in the Zhinvali Reservoir and to predict the risks.

Digital maps of infrastructure-occupied and populated areas affected by floods and avalanches have been created using Global Positioning System (GPS) and Geographic Information Systems (GIS) software.

The effects of the impending catastrophe on the population living in the risk zone have been developed and evaluated, as well as recommendations for the promotion of ecological awareness of the local population and the development of precautionary warning measures have been developed. A new method is proposed to determine and implement the disaster-caused loss assessment, registration and rehabilitation plan for the affected population.

According to UN standards, control questions have been developed for persons working in public and competent local self-government to plan for actions in the event of an emergency. On the example of a possible breakdown at the Zhinvali High Dam, a methodology has been developed to determine risk mitigation and sustainability management strategies.

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Preamble

The reason for the breakdown of hydraulic structures can be natural disasters (earthquake, landslide, hurricane, mudflow, etc.), technogenic factors (corrosion and rupture of construction of structures, disturbance of water intake, filtration flows, etc.), as well as diversion-terrorist attacks and the use of dam-destroying weapons during wartime.

The main function of the Zhinvali earth dam is to protect the environment, agricultural facilities, human life from the floods and mudflows formed in the Aragvi riverbed, however, under the conditions of improper operation and extreme phenomena of nature (earthquakes, catastrophic freshets, etc.) the Zhinvali earth dam itself can become the cause of a major catastrophe.

Destructive tsunami-type waves shall be potentially generated when the hydrodynamic facility of our study - 102-meter-high Zhinvali dam breaks. Their power depends on the amount and velocity of water. This is why hydrodynamic facilities with the reservoirs containing a large amount of water, having a significant difference in height between the head-water and tail-water- high pressure, are dangerous.

The breakthrough wave and the huge mass of water can destroy everything in its path - buildings, agricultural lands, cause human casualties and great material damage [4,10].

Depending on the safety risk category of the hydraulic structure (technological, ecological and social) and the safety declaration of the structure owner, the conditions of operation of the dam must be observed, taking into account the safe operation of the structure nodes and all ancillary structures, buildings, equipment and checking their normal operation.

Based on the EU Flood Risk Assessment Directive (January 1, 2012, http://www.slovakaid.sk/), it is necessary in Georgia to develop a mechanism for harmonization and implementation of the EU Flood Risk Assessment Directive [10] in the country's legislation, which includes:

- Development of a roadmap for harmonization and implementation of the EU Flood Risk Assessment and Management Directive in Georgian legislation;
- Prepare a draft Responsibility and Action Directive for the relevant Ministries in the field of flood forecasting and early warning, which includes:
  - ✓ Development of anti-disaster methodologies and hydrological monitoring in the area of flood risks;
  - ✓ Preparation of methodology for determining the area of flood risks;
  - ✓ Preparation of a map in GIS format of flood risk zones in river basins for the whole country;
  - ✓ Introduction of modern hydrological models for flood prediction;
  - ✓ Arrangement of automatic hydrological stations in river catchments;
  - ✓ Training young experts in flood forecasting matters, etc.

Chapter 1.

High hydroengineering complexes and the causes of their breakdown

1.1. A brief overview of dam breakdowns around the world

In practice, the reliability of dams of various purposes has been of interest to mankind since ancient times, when several thousand years ago water-retaining structures of different heights were built in Babylon, China, Egypt and Italy.

According to the specialists, the main reason for the dam breakdown was that the specialists often considered the shallow depth of the material embedded in the foundation, and the second reason was - more load to earth dams than the allowed one, etc. [10].

The cases of man-made disasters around the world, with huge human casualties are discussed below [4-7]:

- In 1864, the Bradfield Earth Dam collapsed in the United States. The head-water of the dam was paved with concrete slabs, and clay-clayey soil was placed in the heart of the dam. 239 people died in the result of the dam breakdown;
- On May 31, 1889, a 92-m-high earth dam of South Fork, (Pennsylvania) collapsed in the United States, killing 2,500 people;
- On February 22, 1890, a 33.6 m high rockfill dam collapsed in Arizona, USA, killing 129 people;

- On April 27, 1895, Buzeisk 22 m high rockfill dam was collapsed in France, killing 156 people;
- On September 30, 1911, a concrete dam collapsed near Austin, Pennsylvania. 100 people died in the result of the disaster;
- On August 13, 1935, a 16.5 m high concrete dam collapsed in the village of Zerbino (Italy), killing more than 100 people.

Dam breakdowns have also occurred in the former Soviet republics, but due to well-known policies, this information was closed to the public. Therefore, information about the victim is also unknown:

- In 1955, there was a breakdown at the Gorki Hydroelectric Power Plant - Guri Dam;
- In 1956 on the Luzhsk Dam (Leningrad region);
- In 1958 on the Irkutsk Dam;
- In 1960 in Tsageri Reservoir, Georgia
- In 1989, in the borough of Tskneti - on a 10 m high earth dam, killing 3 people;
- On August 17, 2009 in Russia, a breakdown took place on the Saino-Shushensky dam, which killed 12 people (newspaper "Vzglyad"), etc.
- In January 2019 in Brazil, an earth dam collapsed near Brumadinho, killing 58 people and leaving 300 missing. Traffic was made impossible in some areas as the height of sand and gravel transported reached 15 m in some areas.
- On October 19, 2019, 5 dams were broken on the river Saiba in the Krasnoyarsk region of Russia, during which at least 15

people were killed. Five people are still missing in the village of Shotkino. After the dam broke, a mudflow was formed, which reached a depth of 4-5 meters and filled the villages with sand and gravel.

1.2. Review and analysis of aging processes in hydraulic structures

In order to strengthen the country’s economy, including developing countries such as Georgia, measures to extend the life of buildings in general and hydraulic structures in particular are vital. There is practically no state - even the most economically strong - that would prefer to repair an old building, no matter how difficult it may be, and build a new one in its place. This is evidenced by the fact that the International Committee for Dam and Reservoir Damage (which also covers the entire infrastructure of these facilities) has been established and is functioning successfully worldwide, which implements the condition of these facilities at a high scientific level, starting from their designing, supervising the construction process and operating conditions; Analyzes and evaluates the obtained results, generalizes them and gives appropriate recommendations.

From the materials collected by this committee, which includes 1150 cases of damage, it is confirmed that the concrete dams and their foundations; Stone dams and their foundations; Earth-fill dams and their foundations have been damaged; there are damages in the reservoir zone in the tail-water of the structures. Analysis of these and other data shows that the largest number of breakdowns occurred on earth-fill dams during the period 1900-1919. Under-washing is the most dangerous for these types of dams. Over the past 200 years, observations of more than 2,000 earth-fill dams in the UK have confirmed that under-washing is taking place here as well, which is due to aging and is a major cause of breakdowns. The causes of the breakdown are divided as follows: Under-washing - 55%; Water flow overflow - 14%; other factors - 31%; Processes related to aging should be overcome [10, 22, 28, 32].

Field observations were carried out on the hydraulic structures along the Georgian military road on the Aragvi tributaries in order to fix the modern condition of these structures. It is noteworthy that the hydraulic structures in this ravine are not in a quiet operating condition. Their condition is especially aggravated during the floods passage, both above and below the Zhinvali Reservoir, as the latter section of the river is characterized by quite strong left and right tributaries, which are characterized by great destructive force during the floods.

Zhinvali Reservoir - The upper and lower slopes of the dam are in normal condition, the previously damaged baffle hollow structure has been repaired. A shoreline within the limits of reservoir level fluctuations undergoes deformation, resulting in an accelerated increase in dead volume.

1.3. Some possibilities about increasing the service time of structures

In the ecological sense, dams are the most dangerous structure for humans, population and the environment. No other field of construction takes on such great responsibilities to the people as the construction of dams. In foreign literature, the threat of dams, and especially large dams, is referred to as the „hydrological bomb” and therefore the focus is on the safety of operation of these facilities. Declaring the absolute reliability of these dangerous (often quite reliable) objects has long been accepted as a myth and can lead to disorientation of service personnel and the entire population. Safe operation of the structure, parts of which are put in difficult engineering-geological, hydrological, climatic and other conditions, is mentioned. High seismic areas require surveys to develop a methodology for their rational operation.

Population living in dam impact zones in both developed and developing countries are troubled by the answer to the question: What is the probability of dangerous objects malfunction at a given point in time? It is not so easy to answer it, but one thing is certain; with the increase of the non-incidental, cloudless period, the age of the object increases unnoticed, thus increasing the risk of its demolition and malfunction. This problem was especially aggravated in the countries of the Soviet Union, due to the reduction of adequate funding for the normal operation of the facilities and the prevention of breakdowns. Intense growth of defects is caused by damage to various parts, malfunctions and requires repair.

It is noteworthy that disasters occur not only in developing countries, but also in countries where the quality of designing, construction and operation is high. According to the data obtained [28, 37, 39] the number of breakdowns and emergencies has decreased in many countries, although so far in no economically highly developed country has a complete eradication of breakdowns been achieved.

- **Quantitative assessment of safe operation of facilities**

When analyzing the safe operation of technological systems, it is necessary to determine not only the numerical value of security, but also to know appropriate level of its security.

As the security level, we take the relevant security feature, which is based on the final cost of the security indicator and the basic characteristics.

When assessing the level of safety, it is advisable to use analog methods. In this case, the purpose of such an assessment is first formed and the appropriate nomenclature of the safety indicator is selected. An analog is then selected - a „basic pattern" having the same safety indicator and a comparison method is assigned – for the values of the safety indicators. Analogs are compared for the object under consideration and as a result of this comparison the given issue is solved up to the level of security achieved.

Differential, complex and mixed methods of safety level assessment can be emphasized by using the safety indicator and timely assessment of the safety level.

In the case of the differential method, the unit characteristics of both safety and the corresponding analogs are determined and the relative values are calculated:

$$q_i = \frac{P_i}{P_{ia}} \tag{1.1}$$

or

$$q_i = \frac{P_{ia}}{P_i} \tag{1.2}$$

where P_i is the i–safety indicator of the technical system to be evaluated; P_{ia} – is the basic indicator, i=1…n (n – is a number of statistical indicators). From these 2 equations, the one that guarantees more security for the object is chosen. The limitation of using differential methods is that it is difficult at this time to decide on multiple unit safety indicators.

A complex method can be used when security can be characterized by a single value - the generalized value of the security indicator. There are several variants of this method:

1. If we can single out the main indicator of safety. In this case, it is possible to plot a functional relationship between the generalized W safety indicators and the unit Pi ... Pn values, which looks like this:

$$W = \varphi(P_1, P_2 ... P_n) \tag{1.3}$$

The generalized W safety indicator is calculated and equals to the corresponding values of the analogs.

2. If it is not possible to single out the main security indicator, then we use the floating arithmetic mean method. In this case the generalized relative characteristic $q_{\text{r.ch.}}$ is calculated by the following formula:

$$q_{\text{r.ch.}} = \frac{1}{n}\sum_{i=1}^{n} v_i q_i; \quad \sum_{i=1}^{n} v_i = 1 \tag{1.4}$$

where v_i –is the weight coefficient of the unit characteristic of the relevant q1 relative characteristic; n – is a unit characteristic number that includes a generalized safety indicator.

This variant of the complex method is intended to be used for P_i

and P_{ia} - small deviations when the safety of all characteristics is within the purpose limits. In case of large deviations of the basic indicators, there are cases when the generalized values are higher than the safety indicators even in the case of some significant small indicators.

1.4. Breakdown on hydrodynamic facilities

Hydraulic structures. From the hydraulic structures of different purposes, we consider the types in which it is more probable to trigger a dangerous hydrodynamic event and create an emergency situation.

These types are: a) Dams, dikes, stop-gates, the purpose of which is to create water inflow and consequently the hydrostatic pressure appropriate for its levels. 2) Aqueducts, canals, hydraulic tunnels, which supply water from one point to another at the expense of natural pressure. In view of emergencies, water escape and intake hydraulic structures should be considered as mitigation elements, and natural reservoirs in the mountains should be considered as an increased hazard due to high pressure in case of breaks. Thus, a dangerous hydrodynamic object is both an artificial hydraulic structure and natural reservoir that, in the event of a breakthrough, could potentially generate destructive tsunami-type waves.

The power of the waves depends on the amount of water and its velocity. Thereafter, the hydro-dynamic facilities that contain a large amount of water, have significant height differences between the tail-water and head-water (high pressure) and insufficient strength of the dam or natural resistance or the latter is not checked periodically, are hazardous. A breakthrough wave and a huge mass of water can destroy everything in its path - buildings, farmlands, causing casualties and great material loss.

The reason for the break of hydraulic structure or natural reservoir can be natural disasters (earthquake, hurricane, mudflow, etc.), technogenic factors (corrosion and rupture of construction of structures, disturbance of water intake regime, etc.), as well as diversion-terrorist attacks and the use of dam-destroying weapons during wartime.

Hydraulic structures are divided into 4 classes according to the construction norms effective in the world, including in our country. The most important facilities, such as the Enguri HPP Dam, belong to the 1st class, and the temporary structures - to the 4th class.

There are 4 main groups of dams: solid gravity, arched, buttressed and anchored. The constructions of these groups of dams are shown in Figures 1.1 - 1.4.

Solid gravity dams

1.1. Solid gravity
(Fedaia Lake, Rentino, Italy)

1.2. Solid gravity-arched dam
(Kurobo, Japan)

Buttressed dams

1.3. Anchipa, Italy **1.4. Kirov Dam, Kyrgyzstan**

As for the construction materials used to build the dam: concrete, reinforced concrete, timber, stone, soil, the material is selected according to the class of the dam. The dams' construction differs according to the principle of operation. An anchored dam resists shaking with an anchored base. The water level from the water inflow side is called the head-water, the lowest water level on the other side is called the tail-water, and the difference in vertical distance between the water races is called the dam pressure. Pressure can be measured by the height of the water column (m) or any other unit of pressure.

According to the pressure, dams, like other hydraulic structures, are still divided into 4 groups: low-pressure (up to 10 m), medium-pressure (up to 40 m), high-pressure (up to 100-150 m) and ultrahigh-pressure (more than 150 m).

Embankment dams are the most common and oldest ones. About 60% of the total number of dams is embankment dams. The highest pressure embankment dams are Nurek (305 m) and Chirvak (168 m) in the former Soviet Union and Oroville (235 m) in Canada.

Safety of hydraulic structures. The safety of a hydraulic structure is its feature, to protect the environment, agricultural facilities, human life, health and legitimate interests, and the operating condition of the structure must be appropriate and meet this feature.

The safety of hydraulic structures is characterized by three main categories of risk, which include: technological, natural (including ecological) and social hazards. The latter is due to sabotage-like internal and terrorist-like external attacks. Therefore, all hydraulic structures must have an owner who excludes unauthorized access to the facility.

In addition, the owner of the hydraulic structure must have a safety declaration of the structure, which will include all its technical parameters and data monitoring procedure during the operation of the structure, as well as the periodicity of inspection the normal operation conditions of all ancillary buildings, premises and equipment and their safe operation terms. The principles of protection of the territory in the area of influence of the structure and the surrounding area should also be developed.

In all cases, the hydraulic structure needs ongoing repairs and overhaul at intervals specified by the owner.

In order to protect the population, it is forbidden to settle in the area of impact of originated waves in case of break of a hydraulic structure or natural reservoir, and the lands can be used for annual crops.

From operative measures to protect the population and the territory, it is necessary to continuously monitor the strength of the structures and eliminate the observed defects, timely and quality performance of planned repair works, forecast of snowmelt and expected floods, risk assessment, safety of staff, raising qualification level of staff, strict compliance with safety rules, etc.

Notwithstanding the above, if there is still a high risk of an emergency, the population should be warned and preparations for evacuation should begin. In the event of an unpredictable sudden break of the dam, it is necessary to sound the alarm by all means, and the evacuation of the population, depending on the situation, must take place in a very short time.

In general, as mentioned above, all man-made breakdowns are preceded by the accumulation of defects in the structure, equipment, production line, deviation from the normal course of technological processes, etc., which in themselves cannot be the cause of the breakdown, but facilitate the development of the breakdown in case of its initiation. This stage, which can be conditionally called the stage of accumulation of defects, is very important, because at this stage it is possible to eliminate the causes of the breakdown and, in most cases, to avoid the breakdown.

In the second stage of the breakdown, some initiating event is triggered, which is always unexpected, and to avoid it, the person has no time to be evicted and the breakdown moves to the third stage, i.e. the negative results of the first two stages are realized. Therefore, it is clear that only in the first stage it is possible to execute the preventive human intervention in order to achieve a sustainable result.

Population action during floods. During the break of large reservoirs, tsunami-type waves are triggered in the ravine, the only means of protection of which is the organized evacuation of the population. However, the breakthrough does not happen suddenly, it is preceded by the accumulation of defects in the structure, which is a forecast indicator.

Consequently, the proper headquarter has enough time to notify and evacuate people. One of the forecast indicators is also the conditions (long rains, heavy snowfall in the mountains), which should be taken into account to assess the risk of flooding. This is especially necessary in the case of rivers.

In the river gorge, the regulation of water flow gives good results, which is manifested by the cleaning of the bed, in some cases by the removal of deposits, and sometimes - by the correction of the bed. These measures help to increase the water velocity and duty of water in the riverbed and prevent the negative consequences of flooding.

Chapter 2.

Prediction methodology in case of possible breakdown of Zhinvali earth dam

2.1. Loss assessment method in case of earth dam breakdown

For the development of energy and amelioration in Georgia it became necessary to build water economy dams of different heights. In order to solve the task set, in the 20th century, the construction of dams of various purposes and types intensively began, the height of which varies from 10 to 274 meters. As for the volume of reservoirs, their size exceeded several tens of millions of m^3 [4-8].

According to the census conducted in the 60s and 80s of the 20th century, 64 large and small reservoirs were recorded in Georgia, which are located in mountainous and foothill landscapes.

High-rise dams, which form large-capacity reservoirs, in addition to their main agricultural purpose, play a special role in the regulation of natural disasters (floods and freshets), as well as in the field of energy [6,15].

In Georgia, high-rise dams have a complex purpose and they minimize the risk of flooding the population and surrounding areas.

Scientists’ observations of climate have made it clear that we are experiencing an increase in temperature on the planet, which contributes to the intense melting of snow cover and glaciers, which is one of the main components of the formation of floods, freshets and mudflows.

In view of all the foregoing, during the period of floods and freshets, the load on water economy facilities, including dams, increases. We should also take into account the research of Academician Tsotne Mirtskhulava [21,22], which is related to the so-called "aging" of dams, which greatly reduces the reliability of operation of dams and increases the likelihood of a man-made disaster.

Based on the analysis of the scientific literature [4-19] and the theoretical and field surveys conducted, it was possible to determine the risks of flooding of the population and the territory in case of a man-made disaster of the Zhinvali earth dam.

In order to computer imitation of the possible man-made disasters of the Zhinvali Dam, the existing algorithm [26] has been refined, which allows us to calculate the wave velocity, mileage and, most importantly, the geometric dimensions of the flooded area in the event of a possible dam collapse.

We have divided the initial data into two parts: the first - constant, and the second, variable; Constant values include parameters that do not depend on any of the conditions; as for the variables, they depend on the flood, the degree of dam collapse, and so on.

The volume of water in the reservoir (W_0) was calculated as follows [26]:

$$W = \frac{H_B S_B}{3} \text{ , (mln m}^3\text{)} \qquad (2.1)$$

where H_B is the water depth at the normal water inflow height of the dam (m); S_B Reservoir slickenside area (million m^3).

The slope of the Aragvi riverbed is calculated as follows:

$$i = \frac{B_w h_G^2}{W_R M (M+1)}, \qquad (2.2)$$

where H_R is the water depth in the head-water of Zhinvali Reservoir (m), h_G - the water depth in the tail-water of the dam, W_R - slickenside area of Zhinvali Reservoir (m^2),

Reservoir width in the reporting section of the dam (m), M - the coefficient of the cross-section of the river, the value of which is given in Figure 2, B_W - the average width of the river bed at h_G - depth (m).

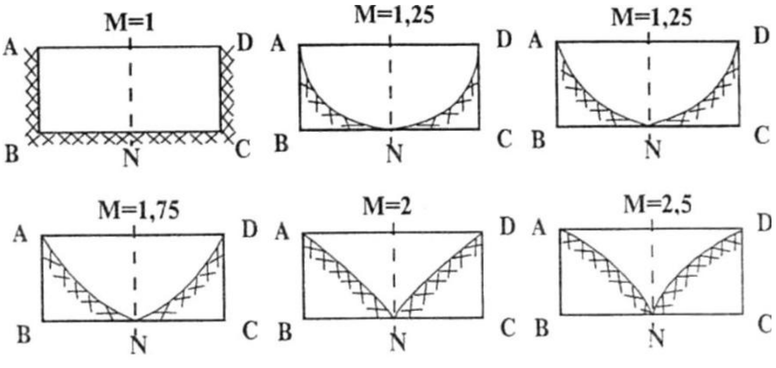


Fig. 2.1. Cross-section forms of the river Aragvi

The width of the river is taken from topographic maps, and as for the number of points, according to the existing methodology, it should not exceed 3-3 points on both sides of the river axis, a total of 6 points, and should cover the entire catchment area. To determine the area of flooded territory, the number of sections from the dam should not exceed 8, the distance between which should be pre-marked on the topographic map.

During floods, the wave velocity (V) in the tail-water of the structure is calculated by the following formula [26]:

$$V = V_0 (H_1 / H_0)^{2/3}, \qquad (2.3)$$

where V_0 is the water velocity of the river in the tail-water of the structure (m/sec); H_1 - river water level in the tail-water of the dam (m); H_0 - water level in the river during flood - (m).

The degree of dam collapse (Ep) is determined by the following dependence [26]:

$$E_p = \frac{F_B}{F_0}\ , \qquad (2.4)$$

where FB is the area of shore rupture (m2); F_0 - surface area (m^2).

2.2. Flood wave calculation sequence in case of Zhinvali dam collapse

In case of collapse of Zhinvali dam, the height of flood in the sections is calculated as follows:

$$H_{BI} = 0.6H - h_G \quad \text{(m)}\ , \qquad (2.5)$$

where H is the depth of the reservoir in the head-water (m) near the dam body, h_G - water depth in the tail-water (m) of the dam, in case of Zhinvali dam collapse the time of the destructive wave movement is calculated with the following dependence (time of complete emptying of Zhinvali reservoir):

$$T_1 = \frac{W_R A}{3600 \mu B_i H \sqrt{H}} \quad \text{(hr)}, \qquad (2.6)$$

where W_R is the maximum volume of the Zhinvali reservoir (million m^3), A - the coefficient of curvature of the Zhinvali reservoir, according to the preliminary calculation it is equal to 2, μ - is a characteristic parameter of the shape of the river bed; $B\ i$ - width of demolition on Zhinvali dam (m), H - depth of reservoir in the head-water (m) near the dam body.

In case of the Zhinvali dam collapse, the arrival time of the destructive wave in the first reporting section is calculated as follows:

$$t_1 = \frac{L_1}{V_1} \quad \text{(hr)}\ , \qquad (2.7)$$

where L_1 is the distance (km) from the Zhinvali Dam to the first design section (km), and V_1 is the maximum wave velocity (km / h) from the Zhinvali Dam to the first design section.

The time of arrival of the destructive wave in the 2nd section is calculated as follows:

$$t_2 = \frac{L_2}{V_2} + t_1 \quad \text{(hr)}, \qquad (2.8)$$

where L_2 is the distance of the second section (km), i.e. distance from 1st section to 2nd section (km); V_2 - Destructive wave velocity in the 2nd section (km / h).

In the other design sections, the destructive wave velocity and wave motion time are calculated using the same approach discussed above.

In addition to the above, the algorithm includes: height of the river bank threshold (m), number of sections along the river, distance between sections (km), river bed width (m), water flow velocity in the river bed (m / s), former river bed width (m), values of river bed marks (m) and so on.

2. 3. Hydrodynamic report and analysis of dam destructive wave

For the purpose of computer imitation of the possible man-made disasters of the Zhinvali Dam, the existing algorithm was refined and field surveys were carried out (Figs. 1 and 2), which allow us to calculate the hydro-dynamic parameters of the dam-destroying wave in the event of possible dam collapse, in particular – wave velocity, mileage and, most importantly, the geometric dimensions of the flooded area.

We have divided the initial data into two parts: the first - constant values and the second - variables; Constant values include parameters that do not depend on any of the conditions; as for the variable values, they depend on the flood, the degree of dam collapse, and so on.

The construction height of Zhinvali dam is 102 m, and the operating height (water inflow) is 96 m. The width of the dam on the threshold is within 415 m. The volume of Zhinvali Reservoir is 520 million m^3 and the slickenside area is 733 million m^3.

Destructive tsunami-type waves shall be potentially generated when the hydrodynamic facility of our study - Zhinvali earth dam breaks. Their power depends on the amount and velocity of water. This is why hydrodynamic facilities with the reservoirs containing a large amount of water, having a significant difference in height between the head-water and tail-water (high pressure) are dangerous.

The breakthrough wave and the huge mass of water can destroy everything in its path - buildings, agricultural lands, cause human casualties and great material loss.

Fig. 2.2. During field surveys by boat in Zhinvali Reservoir

Fig. 2.3. General view of colloidal and sand-silt material deposited in Zhinvali Reservoir

Figure 2.4 shows the longitudinal profile of the tsunami-type wave generated in case of the Zhinvali earth dam collapse.

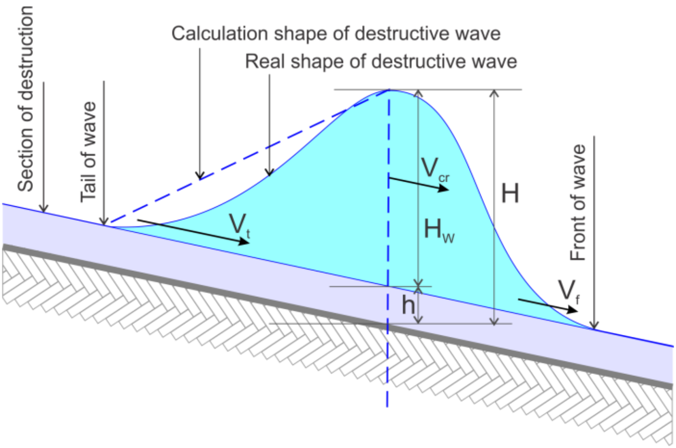


Fig. 2.4. Longitudinal profile of the tsunami-type wave

The volume of water in the reservoir (W_0) was calculated as follows (W_0):

$$W = \frac{H_B S_B}{3} \quad (\text{mln m}^3) \qquad (2.9)$$

where H_B is the water depth at the normal water intake height of the dam (m); S_B - slickenside area of the reservoir (million m^3);

The width of the river is taken from topographic maps, as for the number of points; it should not exceed 3 points on one side of the river axis, a total of 6 points on both sides, and should include the entire catchment area. To determine the area of flooded territory, the number of sections from the dam should not exceed 8, the distance between which should be pre-marked on the topographic map.

During floods, the wave velocity (V) in the tail-water of the structure is calculated by the following formula:

$$V = V_0 (H_1 / H_0)^{2/3}, \qquad (\text{m/sec}) \qquad (2.10)$$

The degree of dam collapse (E_p) is determined by the following dependence:

$$E_p = \frac{F_B}{F_0} \ , \qquad (2.11)$$

where FB is the shoreline rupture area (m^2); F_0 – surface area (m^2).

In addition to the above, the algorithm includes: height of the river bank threshold (m), number of sections along the river, distance between sections (km), river bed width (m), water flow velocity in the river bed (m/s), former river bed width (m), values of river bed marks (m) and so on.

Zhinvali Reservoir, the dam of which is a clay-hearted structure, is located in Zhinval Village, Dusheti Region (the construction height of Zhinvali dam is 102 m, and the operating height (water inflow) is 96 m. The width of the dam on the threshold is within 415 m. The volume of Zhinvali Reservoir is 520 million m^3 and the slickenside area is 733 million m^3 (See Fig. 4).

Fig. 2.5. Head-water of Zhinvali earth dam with water intake structure

In order to predict the consequences of the Zhinvali Dam catastrophe, the number of sections at the riv. Aragvi and Mtkvari before Rustavi is 8 units (Fig. 2.6).

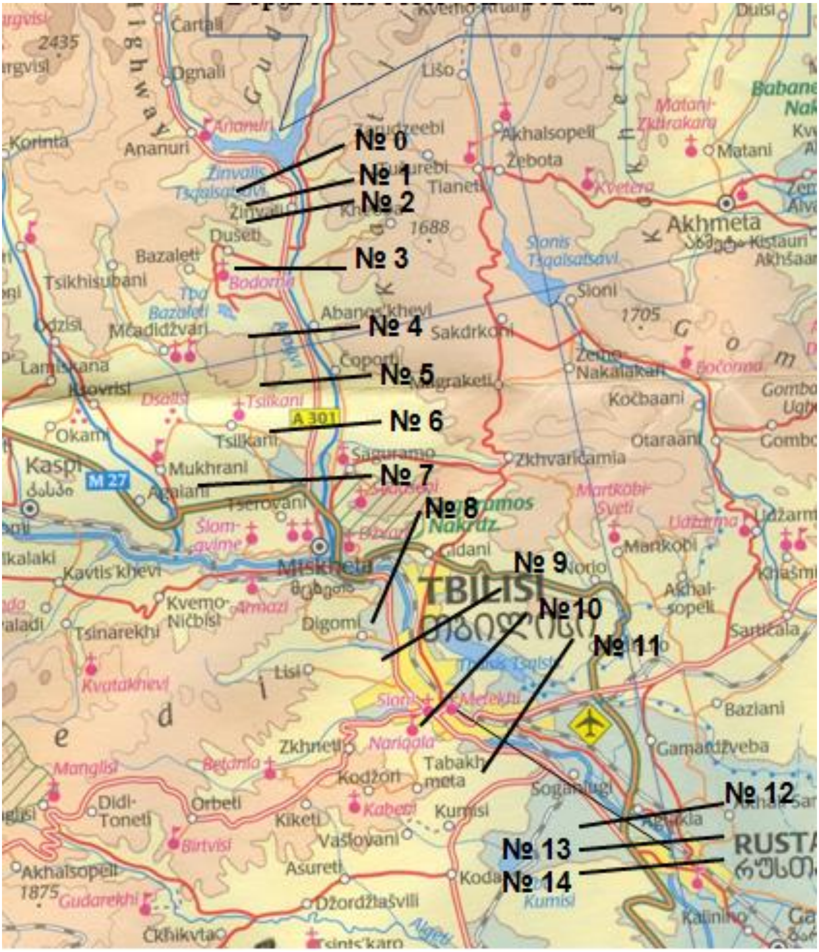


Fig. 2.6. Scheme of layout of design sections

Sections are taken in populated areas at different distances from the dam, namely:

1. Village Misaktsieli - 30.0 km;

2. Avchala settlement - 35.0 km;
3. Digomi (Shalikashvili) bridge - 44.5 km;
4. King Tamar (Cheluskin) Bridge - 48.0 km;
5. Ortachala Bridge - 54.2 km;
6. New settlement of Rustavi - 74.0 km;
7. Center of Rustavi - 77.0 km;
8. End of Rustavi - 80.0 km.

The first stream of water wave after the breakdown of Zhinvali dam will flow in the relevant sections at the following time:

1. Village Misaktsieli - 47.1 minutes;
2. Avchala settlement - 57.74 minutes;
3. Digomi (Shalikashvili) Bridge - 76.34 minutes;
4. King Tamar (Cheluskin) Bridge - 90.1 minutes;
5. Ortachala Bridge - 107.0 minutes;
6. New settlement of Rustavi - 172.6 minutes;
7. Rustavi center - 183.3 minutes;
8. End of Rustavi - 197.3 minutes.

As for the geometric dimensions of the area flooded by Zhinvali Reservoir to the left and right sides of the river axis, they are as follows:

1. The village of Misaktsieli
   Left - 319 m, right - 322 m,
   Water depth - 21 m, wave velocity - 11 m / s;
2. Avchala settlement
   The canyon is flooded on both sides;
3. Digomi (Shalikashvili) bridge

Left - 649 m, right - 1603 m,

Water depth - 9 m, wave velocity - 5 m / s;

4. King Tamar (Cheluskin) Bridge

Left - 88 m, right - 715 m,

Water depth - 18 m, wave velocity - 10 m / s;

5. Ortachala Bridge

Left - 239 m, right - 629 m,

Water depth - 10 m, wave velocity - 7 m / s

6. New settlement of Rustavi

Left -- 115 m, right - 570 m,

Water depth - 11 m, wave velocity - 7 m / s;

7. Center of Rustavi

Left - 293 m, right - 786 m,

Water depth - 6 m, wave velocity - 5 m / s;

8. End of Rustavi

Left - 1055 m, right - 110 m,

Water depth - 7 m, wave velocity - 5 m / s.

Detailed material reflecting the Zhinvali Dam is given in Tables (Tables 2.1 - 2.12), while the geometric dimensions of the flooded areas in the river bed and the surrounding area are given in Figures 2.7-2.42.

Table 2.1

Report on work performed

Time: 27.09.2019, 18:24:00

Name: Zhinvali Dam (with degree of collapse $E_p = 1,0$)

Hydroengineering complex initial data:	Meas. unit	Q-ty
1. Reservoir volume at normal water inflow level	mln m^3	520
2. Reservoir depth at the dam at normal water inflow level	m	96
3. Slickenside area at normal water inflow level	mln m^3	7,33
4. Dam width at normal water inflow level	m	415
5. The depth of the river in the tail-water of the dam	m	1
6. The width of the river in the tail-water of the dam	m	25
7. The speed of the river in the tail-water of the dam	m/s	1
8. Reservoir depth at the time of the dam breakdown	m	96
9. Degree of dam collapse	m	1
10. The height of the rupture of the river bed shoreline	m	1
11. Benchmark of normal water inflow into the reservoir	m	816
12. Number of transverse profiles in the river bed	pcs	8

Table 2.2

Characterization of cross sections	Meas.unit	Section#1	Section #2	Section #3	Section #4	Section #5	Section #6	Section #7	Section #8
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
i-like section distance from the dam	km	30	35	44,5	48	54,2	74	77	80
Specific flow:									
Water inflow benchmark	m	480	425	398	393	375	327	322,7	313
Depth	m	1	3	2	2	1	2	1	1
Width	m	70	60	80	82	80	150	100	93
Flow velocity	m/s	1	1	1	1	1	1	1	1
Left bank									
The height of the river bank rupture	m	7	2	3	5	4	2,5	3	0,5
The width of the former river bed	m	50	10	50	20	20	5	5	40
Benchmark #1	m	490	435	402,5	400	383	330	327,5	315
Distance from the river axis to # 1 benchmark	m	137	50	440	71	180	100	60	225
Benchmark #2	m	520	440	405	405	385	340	330	320
Distance from the river axis to # 2 benchmark	m	687	70	670	371	280	125	1310	1295
Benchmark #3	m	680	490	410	415	388	350	332,5	322,5
Distance from the river axis to # 3 benchmark	m	2437	340	970	800	720	265	1610	1345
Right bank									
The height of the river bank rupture	m	15	8	3	5	4	1	1	5

Table 2.3

Dam collapse parameters	**Meas.unit**	**Section #0**	**Section #1**	**Section #2**	**Section #3**	**Section #4**	**Section #5**	**Section #6**	**Section #7**	**Section #8**
Section distance from the hydroengineering complex	km	0	30	35	44,5	48	54,2	74	77	80
Maximum duty of water at the section	ten. m^3/s	137	31,9	28,18	22,98	21,7	19,6	15,19	14,59	14,16
Time:										
Wave front lowering	min	0	47,1	57,74	76,34	90,1	107	172,6	183,3	197,3
Wave lowering	min	0	75,3	93,07	135,6	149	171	273	285,7	297,3
Wave tail lowering	min	90,3	590	673,7	832	890	994	1324	1374	1424
Flooding	min	90,3	543	615,9	755,7	800	886	1151	1190	1226
Maximum speed of flow	m/min	18,7	11,5	14,52	5,25	9,78	6,99	7,33	5,06	5,45
Wave height	m	56,6	19,9	32,32	6,77	16	8,98	9,01	5,27	5.88
Maximum depth of flooding	m	57,6	20,9	35,32	8,77	18	9,98	11,01	6,27	6,88
Maximum flood benchmark	m	778	500	457,3	404,8	409	384	336	328	318,9
Maximum flow height:										
On the left bank of the river	m	152	319	1005	649	715	239	115	293	1055
On the right bank of the river	m	152	232	648,9	1603	87,6	629	570	785,6	110,3

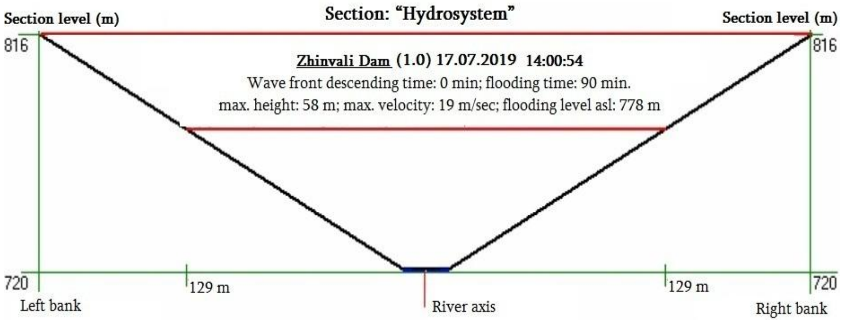


Fig. 2.7. Zhinvali hydroengineering complex

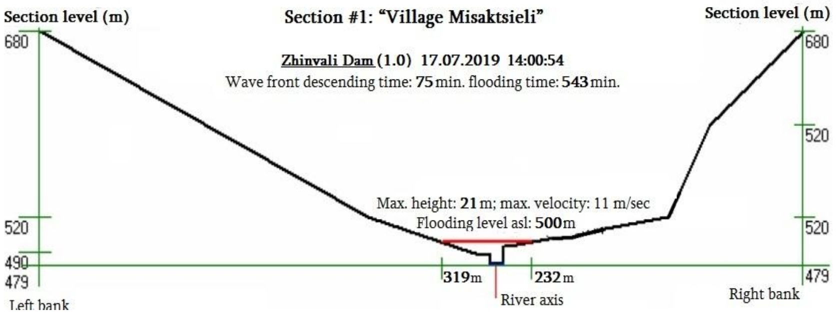


Fig. 2.8. Design section №1

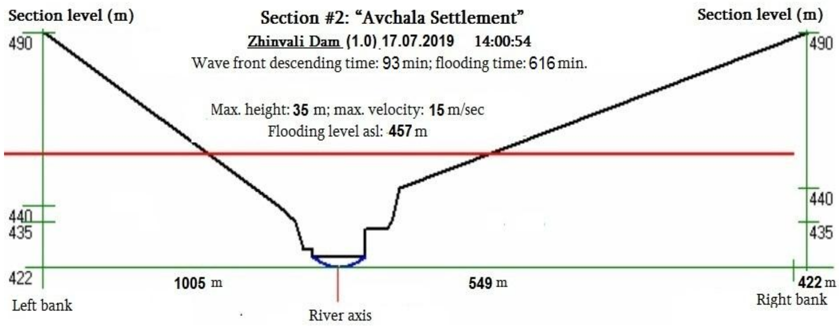


Fig. 2.9. Design section №2

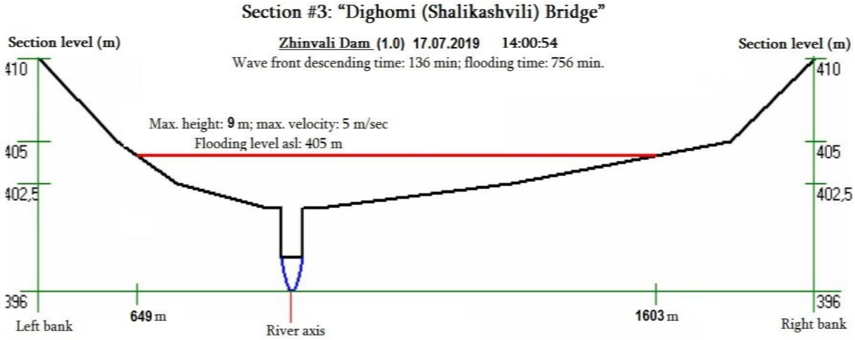


Fig. 2.10. Design section №3

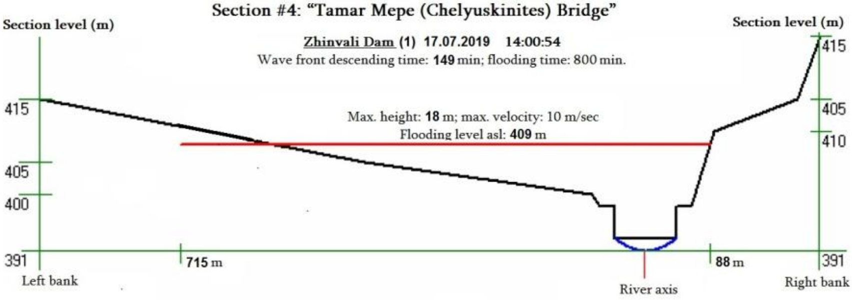


Fig. 2.11. Design section №4

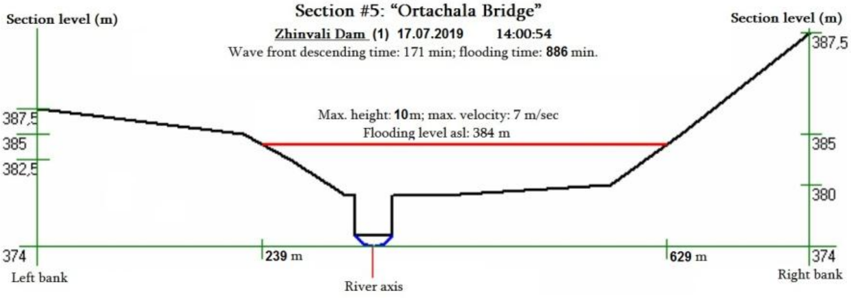


Fig. 2.12. Design section №5

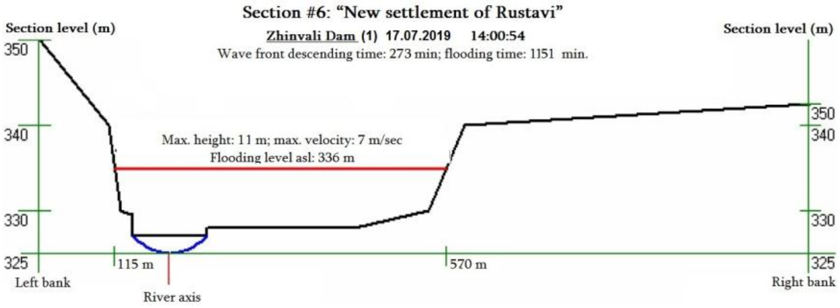


Fig. 2.13. Design section №6

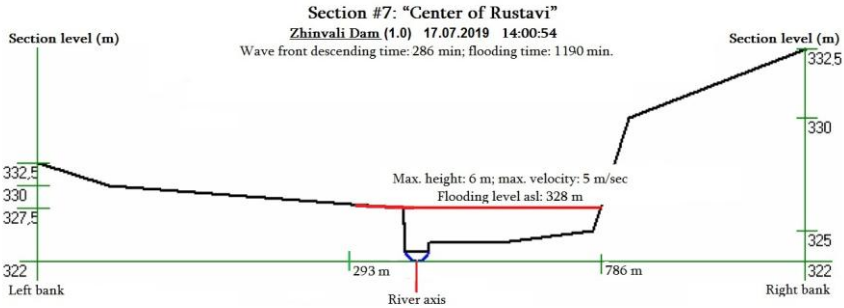


Fig. 2.14. Design section №7

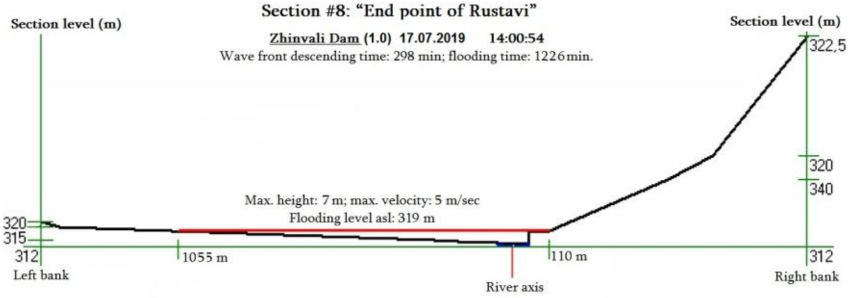


Fig. 2.15. Design section №8

Table 2.4

Report on work performed

Time: 27.09.2019, 18:02:40

Name: Zhinvali Dam (with degree of collapse E_p = 0,75)

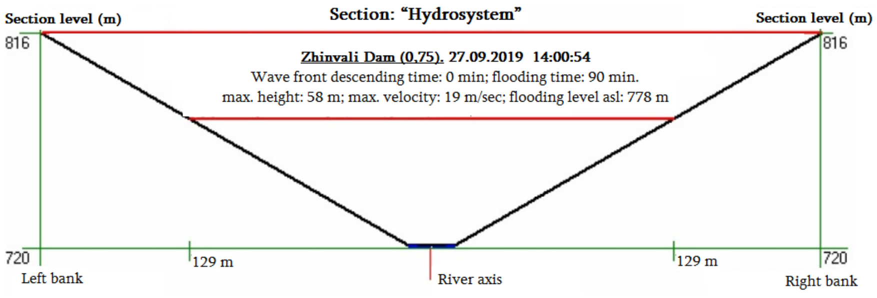
Hydroengineering complex initial data:	Meas. unit	Q-ty
1. Reservoir volume at normal water inflow level	mln m^3	520
2. Reservoir depth at the dam at normal water inflow level	m	96
3. Slickenside area at normal water inflow level	mln m^3	7,33
4. Dam width at normal water inflow level	m	415
5. The depth of the river in the tail-water of the dam	m	1
6. The width of the river in the tail-water of the dam	m	25
7. The speed of the river in the tail-water of the dam	m/s	1
8. Reservoir depth at the time of the dam breakdown	m	96
9. Degree of dam collapse	m	0,75
10. The height of the rupture of the river bed shoreline	m	24
11. Benchmark of normal water inflow into the reservoir	m	816
12. Number of transverse profiles in the river bed	pcs	8

Table 2.5

Characterization of cross sections	Meas.unit	Section#1	Section #2	Section #3	Section #4	Section #5	Section #6	Section #7	Section #8
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
i-like section distance from the dam	km	30	35	44,5	48	54,2	74	77	80
Specific flow:									
Water inflow benchmark	m	480	425	398	393	375	327	322,7	313
Depth	m	1	3	2	2	1	2	1	1
Width	m	70	60	80	82	80	150	100	93
Flow velocity	m/s	1	1	1	1	1	1	1	1
Left bank									
The height of the river bank rupture	m	7	2	3	5	4	2,5	3	0,5
The width of the former river bed	m	50	10	50	20	20	5	5	40
Benchmark #1	m	490	435	402,5	400	383	330	327,5	315
Distance from the river axis to # 1 benchmark	m	137	50	440	71	180	100	60	225
Benchmark #2	m	520	440	405	405	385	340	330	320
Distance from the river axis to # 2 benchmark	m	687	70	670	371	280	125	1310	1295
Benchmark #3	m	680	490	410	415	388	350	332,5	322,5
Distance from the river axis to # 3 benchmark	m	2437	340	970	800	720	265	1610	1345
Right bank									
The height of the river bank rupture	m	15	8	3	5	4	1	1	5
The width of the former river bed	m	30	25	50	20	100	300	300	50
Benchmark #1	m	520	435	402,5	410	380	330	325	340
Distance from the river axis to # 1 benchmark	m	912	60	840	90	510	525	750	440
Benchmark #2	m	600	445	405	415	385	340	337,5	350
Distance from the river axis to # 2 benchmark	m	1137	70	1680	200	660	600	900	570
Benchmark #3	m	680	490	410	425	395	343	345	400
Distance from the river axis to # 3 benchmark	m	1637	540	2000	230	940	1300	1650	840

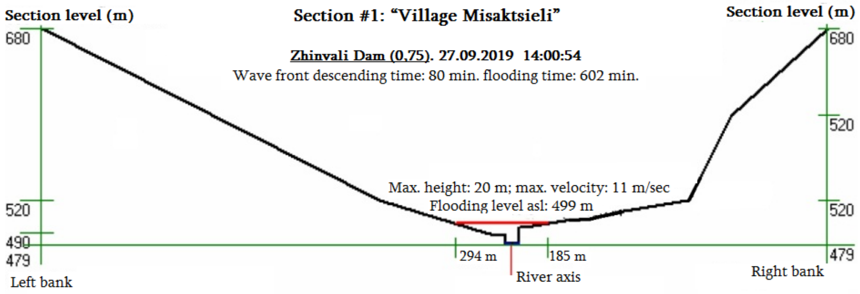
Table 2.6

Dam collapse parameters	**Meas.unit**	**Section #0**	**Section#1**	**Section #2**	**Section #3**	**Section #4**	**Section #5**	**Section #6**	**Section #7**	**Section #8**
Section distance from the hydroengineering complex	km	0	30	35	44,5	48	54,2	74	77	80
Maximum duty of water at the section	ten. m^3/s	137	24,4	21,9	18,12	17,2	15,59	12,32	11,84	11,5
Time:										
Wave front lowering	min	0	47,1	57,8	76,9	90,9	108,5	175,5	186,7	201
Wave lowering	min	0	80,2	99,1	143,4	158	180,7	288,7	301,9	314,8
Wave tail lowering	min	149	649	732	890,4	949	1052	1382	1432	1482
Flooding	min	149	602	674	813,5	858	943,6	1207	1245	1281
Maximum speed of flow	m/min	18,7	11,2	14,1	5,03	9,53	6,77	6,86	4,91	5,26
Wave height	m	56,6	18,6	29,7	6,15	14,8	8,29	7,88	4,88	5,41
Maximum depth of flooding	m	57,6	19,6	32,7	8,15	16,8	9,29	9,88	5,88	6,41
Maximum flood benchmark	m	778	499	455	404,2	408	383,3	334,9	327,6	318,4
Maximum flow height:										
On the left bank of the river	m	152	294	862	591,6	614	211,7	112,2	97,83	955,8
On the right bank of the river	m	152	185	524	1394	84,8	608,8	561,6	780,9	103


Section: "Hydrosystem"

Zhinvali Dam (0.75). 27.09.2019 14:00:54
Wave front descending time: 0 min; flooding time: 90 min.
max. height: 58 m; max. velocity: 19 m/sec; flooding level asl: 778 m

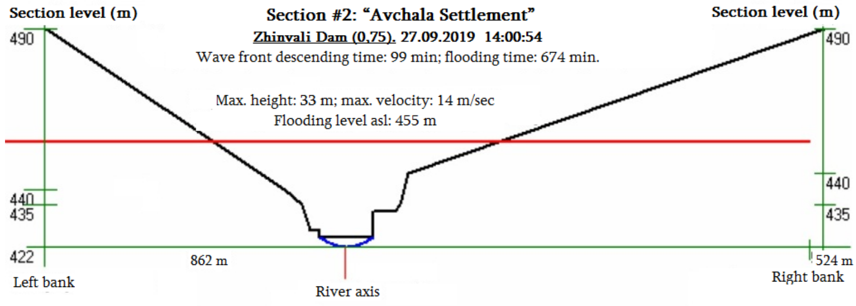
Fig. 2.16. Zhinvali hydroengineering complex


Section #1: "Village Misaktsieli"

Zhinvali Dam (0.75). 27.09.2019 14:00:54
Wave front descending time: 80 min. flooding time: 602 min.

Max. height: 20 m; max. velocity: 11 m/sec
Flooding level asl: 499 m

Fig. 2.17. Design section №1


Section #2: "Avchala Settlement"
Zhinvali Dam (0.75). 27.09.2019 14:00:54
Wave front descending time: 99 min; flooding time: 674 min.

Max. height: 33 m; max. velocity: 14 m/sec
Flooding level asl: 455 m

Fig. 2.18. Design section №2

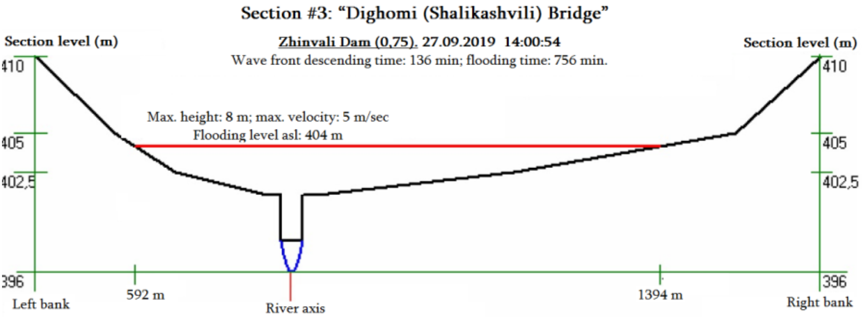


Fig. 2.19. Design section №3

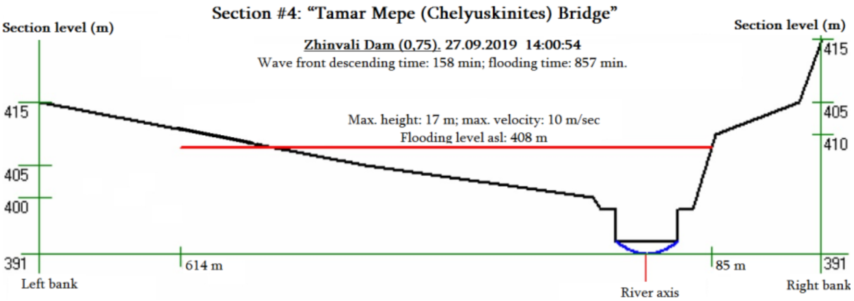


Fig. 2.20. Design section №4

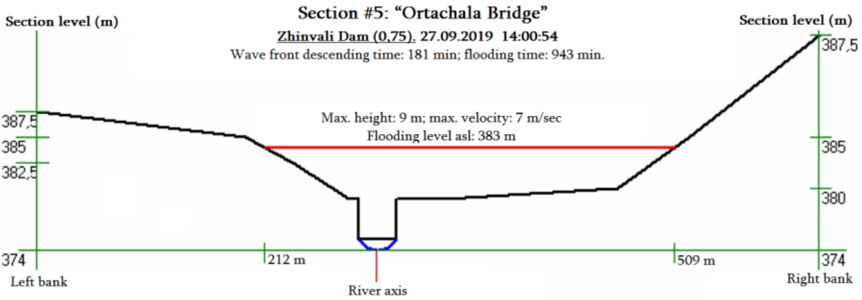


Fig. 2.21. Design section №5

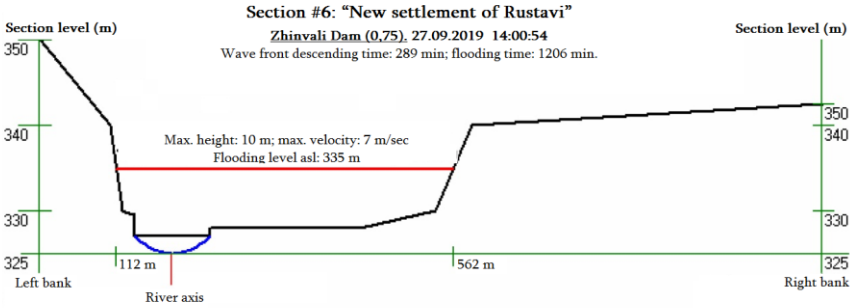


Fig. 2.22. Design section №6

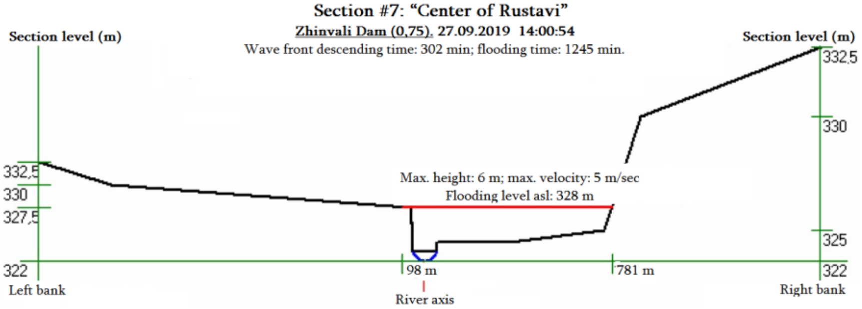


Fig. 2.23. Design section №7

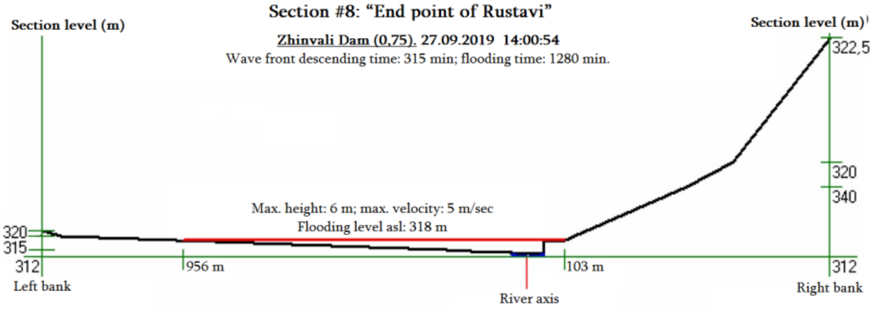


Fig. 2.24. Design section №8

Table 2.7

Report on work performed Time: 27.09.2019, 18:28:04

Name: Zhinvali Dam (with degree of collapse $E_p = 0{,}5$)

Hydroengineering complex initial data:	**Meas. unit**	**Q-ty**
1. Reservoir volume at normal water inflow level	mln m^3	520
2. Reservoir depth at the dam at normal water inflow level	m	96
3. Slickenside area at normal water inflow level	mln m^3	7,33
4. Dam width at normal water inflow level	m	415
5. The depth of the river in the tail-water of the dam	m	1
6. The width of the river in the tail-water of the dam	m	25
7. The speed of the river in the tail-water of the dam	m/s	1
8. Reservoir depth at the time of the dam breakdown	m	96
9. Degree of dam collapse	m	0,5
10. The height of the rupture of the river bed shoreline	m	48
11. Benchmark of normal water inflow into the reservoir	m	816
12. Number of transverse profiles in the river bed	pcs	8

Table 2.8

Characterization of cross sections	Meas. unit	Section # 1	Section #2	Section #3	Section #4	Section #5	Section #6	Section #7	Section #8
1	2	3	4	5	6	7	8	9	10
i-like section distance from the dam	km	30	35	44,5	48	54,2	74	77	80
Specific flow:									
Water inflow benchmark	m	480	425	398	393	375	327	322,7	313
Depth	m	1	3	2	2	1	2	1	1
Width	m	70	60	80	82	80	150	100	93
Flow velocity	m/s	1	1	1	1	1	1	1	1
Left bank									
The height of the river bank rupture	m	7	2	3	5	4	2,5	3	0,5
The width of the former river bed	m	50	10	50	20	20	5	5	40
Benchmark #1	m	490	435	402,5	400	383	330	327,5	315
Distance from the river axis to # 1 benchmark	m	137	50	440	71	180	100	60	225
Benchmark #2	m	520	440	405	405	385	340	330	320
Distance from the river axis to # 2 benchmark	m	687	70	670	371	280	125	1310	1295
Benchmark #3	m	680	490	410	415	388	350	332,5	322,5
Distance from the river axis to # 3 benchmark	m	2437	340	970	800	720	265	1610	1345
Right bank									
The height of the river bank rupture	m	15	8	3	5	4	1	1	5
The width of the former river bed	m	30	25	50	20	100	300	300	50
Benchmark #1	m	520	435	402,5	410	380	330	325	340
Distance from the river axis to # 1 benchmark	m	912	60	840	90	510	525	750	440
Benchmark #2	m	600	445	405	415	385	340	337,5	350
Distance from the river axis to # 2 benchmark	m	1137	70	1680	200	660	600	900	570
Benchmark #3	m	680	490	410	425	395	343	345	400
Distance from the river axis to # 3 benchmark	m	1637	540	2000	230	940	1300	1650	840

Table 2.9

Dam collapse parameters	**Meas. unit**	**Section #0**	**Section #1**	**Section #2**	**Section #3**	**Section #4**	**Section #5**	**Section #6**	**Section #7**	**Section #8**
Section distance from the hydroengineering complex	km	0	30	35	44,5	48	54,2	74	77	80
Maximum duty of water at the section	ten. m^3/s	67,2	14,6	13,3	11,38	10,87	9,97	8,13	7,81	7,61
Time:										
Wave front lowering	min	0	53,7	64,8	85,4	99,92	118,2	188,9	201,4	216,3
Wave lowering	min	0	90,6	112	160,5	176,8	202,1	322	366,5	350,6
Wave tail lowering	min	277	777	861	1019	1077	1181	1511	1561	1611
Flooding	min	277	724	796	933,7	977,5	1063	1322	1359	1394
Maximum speed of flow	m/min	16	10,8	12,9	4,69	9,08	6,33	6,01	4,58	4,95
Wave height	m	41,1	16,2	23,8	5,15	12,74	7,01	6,01	4,13	4,64
Maximum depth of flooding	m	42,1	17,2	26,8	7,15	14,74	8,01	8,01	5,12	5,64
Maximum flood benchmark	m	762	496	449	403,2	405,7	382	333	326,8	317,6
Maximum flow height:										
On the left bank of the river	m	125	251	316	500	434,1	163,2	107,5	58,12	788,9
On the right bank of the river	m	125	105	73,8	1059	79,69	570,3	547,9	771,9	46,5

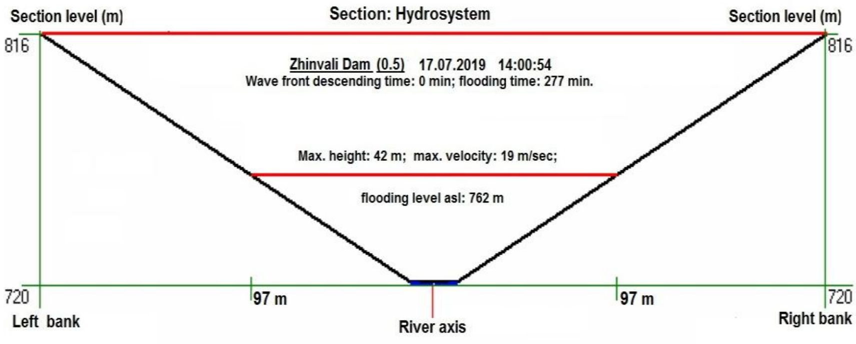


Fig. 2.25. Zhinvali hydroengineering complex

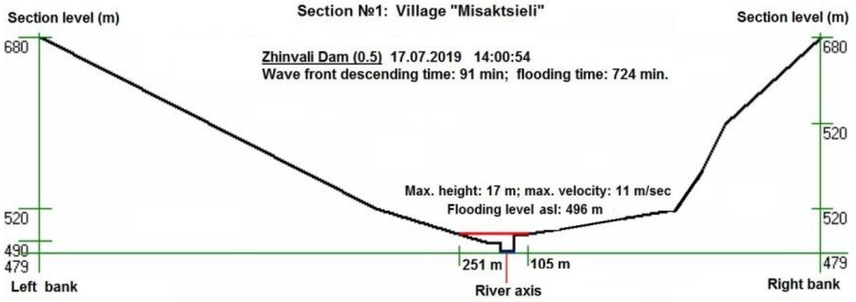


Fig. 2.26. Design section №1

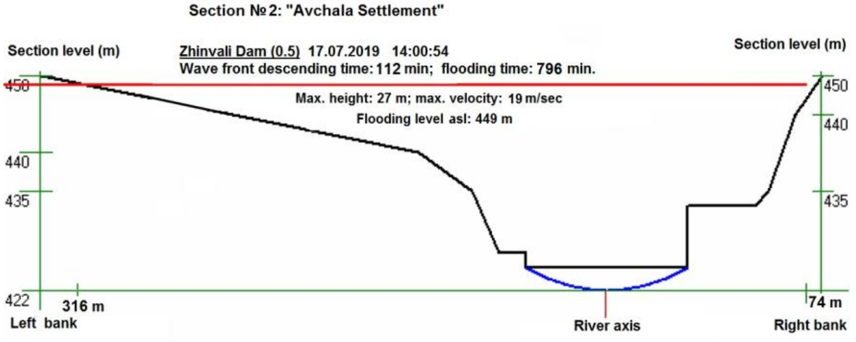


Fig. 2.27. Design section №2

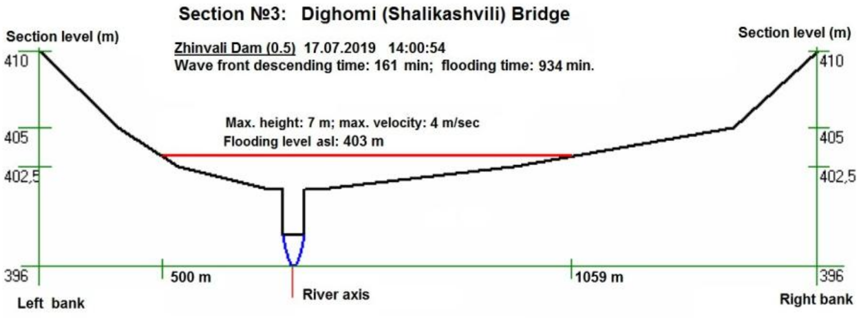


Fig. 2.28. Design section №3

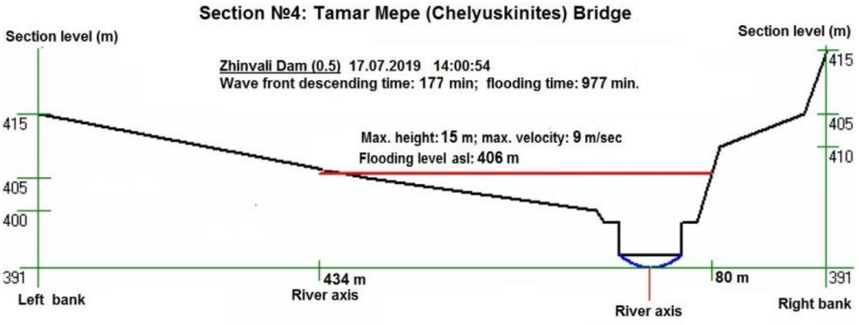


Fig. 2.29. Design section №4

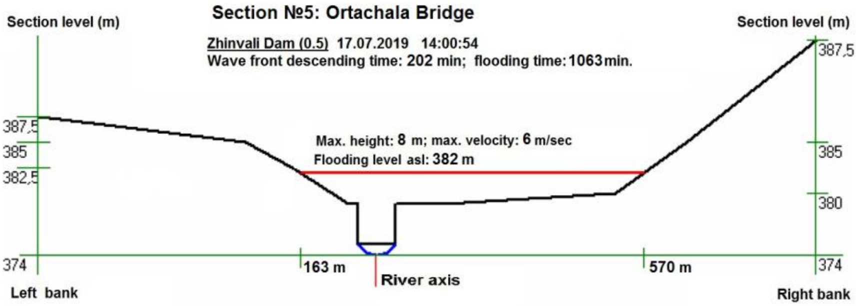


Fig. 2.30. Design section №5

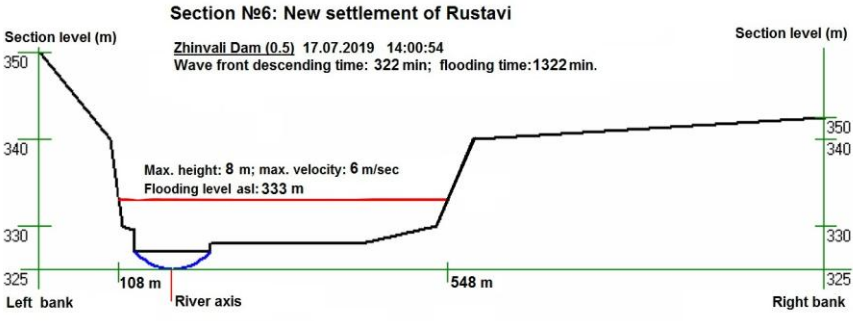


Fig. 2.31. Design section №6

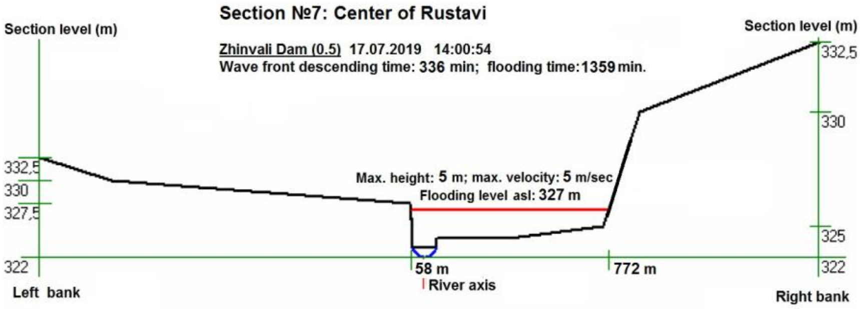


Fig. 2.32. Design section №7

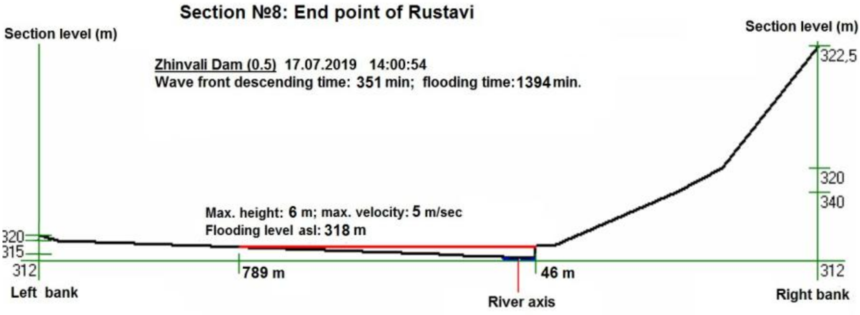


Fig. 2.33. Design section №8

Table 2.10

Report on work performed

Time: 27.09.2019, 18:28:04

Name: Zhinvali Dam (with degree of collapse E_p = 0,25)

Hydroengineering complex initial data:	**Meas. unit**	**Q-ty**
1. Reservoir volume at normal water inflow level	mln m^3	520
2. Reservoir depth at the dam at normal water inflow level	m	96
3. Slickenside area at normal water inflow level	mln m^3	7,33
4. Dam width at normal water inflow level	m	415
5. The depth of the river in the tail-water of the dam	m	1
6. The width of the river in the tail-water of the dam	m	25
7. The speed of the river in the tail-water of the dam	m/s	1
8. Reservoir depth at the time of the dam breakdown	m	96
9. Degree of dam collapse	m	0,25
10. The height of the rupture of the river bed shoreline	m	72
11. Benchmark of normal water inflow into the reservoir	m	816
12. Number of transverse profiles in the river bed	pcs	8

Table 2.11

Characterization of cross sections	**Meas.unit**	**Section#1**	**Section #2**	**Section #3**	**Section #4**	**Section #5**	**Section #6**	**Section #7**	**Section #8**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
i-like section distance from the dam	km	30	35	44,5	48	54,2	74	77	80
Specific flow:									
Water inflow benchmark	m	480	425	398	393	375	327	322,7	313
Depth	m	1	3	2	2	1	2	1	1
Width	m	70	60	80	82	80	150	100	93
Flow velocity	m/s	1	1	1	1	1	1	1	1
Left bank									
The height of the river bank rupture	m	7	2	3	5	4	2,5	3	0,5
The width of the former river bed	m	50	10	50	20	20	5	5	40
Benchmark #1	m	490	435	402,5	400	383	330	327,5	315
Distance from the river axis to # 1 benchmark	m	137	50	440	71	180	100	60	225
Benchmark #2	m	520	440	405	405	385	340	330	320
Distance from the river axis to # 2 benchmark	m	687	70	670	371	280	125	1310	1295
Benchmark #3	m	680	490	410	415	388	350	332,5	322,5
Distance from the river axis to # 3 benchmark	m	2437	340	970	800	720	265	1610	1345
Right bank									
The height of the river bank rupture	m	15	8	3	5	4	1	1	5
The width of the former river bed	m	30	25	50	20	100	300	300	50
Benchmark #1	m	520	435	402,5	410	380	330	325	340
Distance from the river axis to # 1 benchmark	m	912	60	840	90	510	525	750	440
Benchmark #2	m	600	445	405	415	385	340	337,5	350
Distance from the river axis to # 2 benchmark	m	1137	70	1680	200	660	600	900	570
Benchmark #3	m	680	490	410	425	395	343	345	400
Distance from the river axis to # 3 benchmark	m	1637	540	2000	230	940	1300	1650	840

Table 2.12

Dam collapse options	**Meas.unit**	**Section #0**	**Section #1**	**Section #2**	**Section #3**	**Section #4**	**Section #5**	**Section #6**	**Section #7**	**Section #8**
Section distance from the hydroengineering complex	km	0	30	35	44,5	48	54,2	74	77	80
Maximum duty of water at the section	ten. m^3/s	13,2	4,78	4,56	4,11	3,99	3,73	3,32	3,15	3,10
Time:										
Wave front lowering	min	0	71,51	83,09	105,8	120,7	139,8	217,5	232,9	250,2
Wave lowering	min	0	122,4	151,8	209,4	230,6	262,6	407,7	425,4	442,2
Wave tail lowering	min	751	1251	1334	1492	1551	1654	1984	2034	2084
Flooding	min	751	1179	1251	1386	1430	1514	1766	1801	1834
Maximum speed of flow	m/min	11,2	9,78	11,38	4,28	8,52	5,68	4,54	3,66	4,39
Wave height	m	19,6	11,51	15,96	3,7	9,38	5,03	3,24	2,52	3,29
Maximum depth of flooding	m	20,6	12,51	18,96	5,7	11,38	6,03	5,24	3,52	4,29
Maximum flood benchmark	m	741	491,5	441	401,7	402,4	380	330,2	325,2	316,3
Maximum flow height:										
On the left bank of the river	m	80,5	164,7	87,19	252,4	213,9	95,22	100,6	50	500,3
On the right bank of the river	m	80,5	35	65,96	438	71,59	510,8	526,8	752,7	46,5

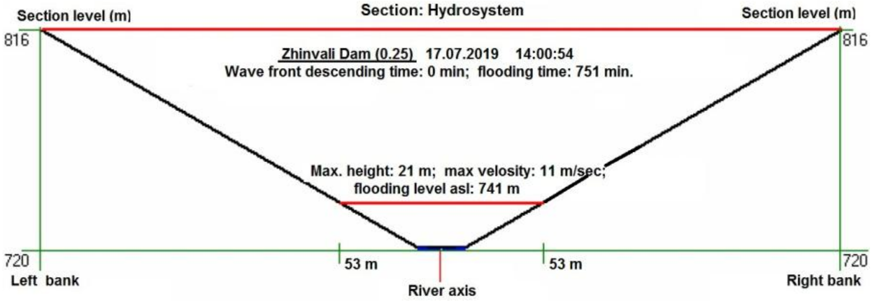


Fig. 2.34. Zhinvali hydroengineering complex

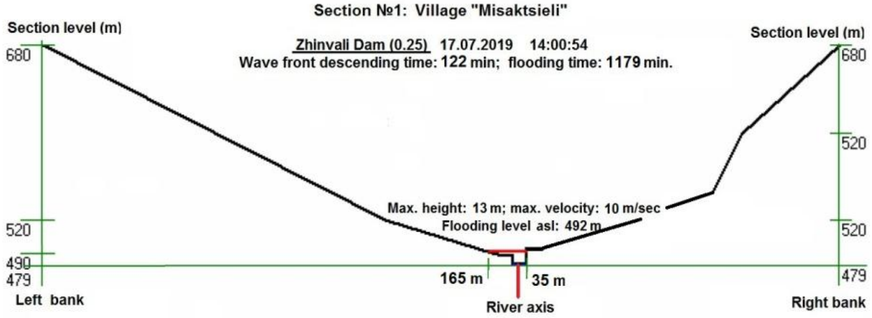


Fig. 2.35. Design section №1

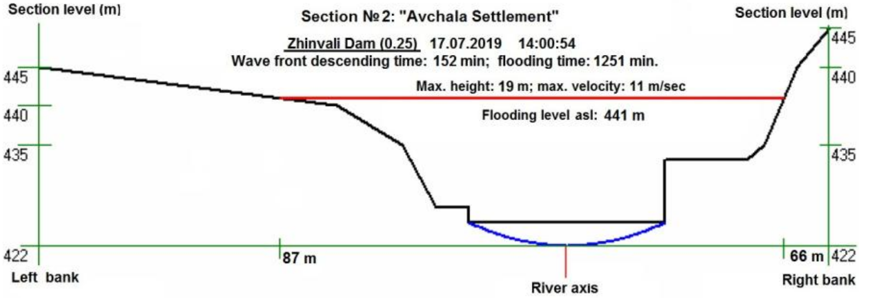


Fig. 2.36. Design section №2

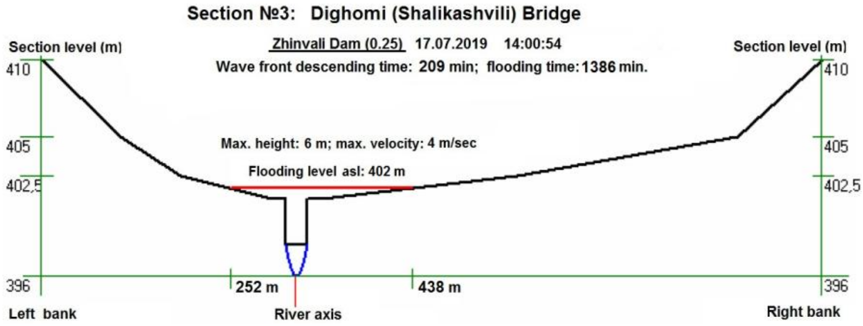


Fig. 2.37. Design section №3

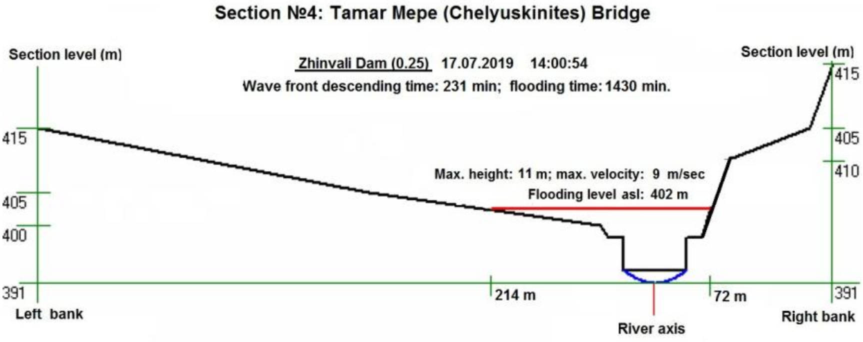


Fig. 2.38. Design section №4

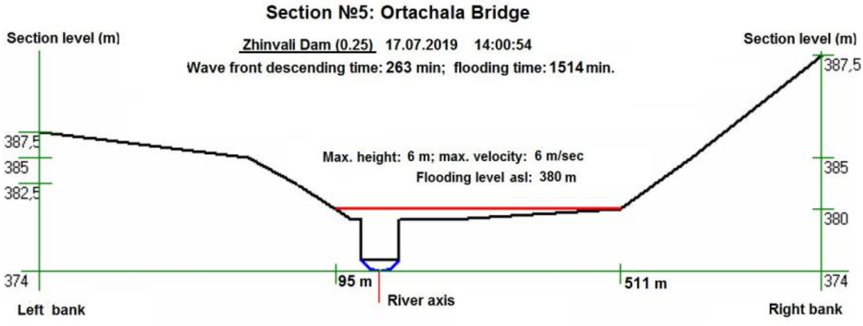


Fig. 2.39. Design section №5

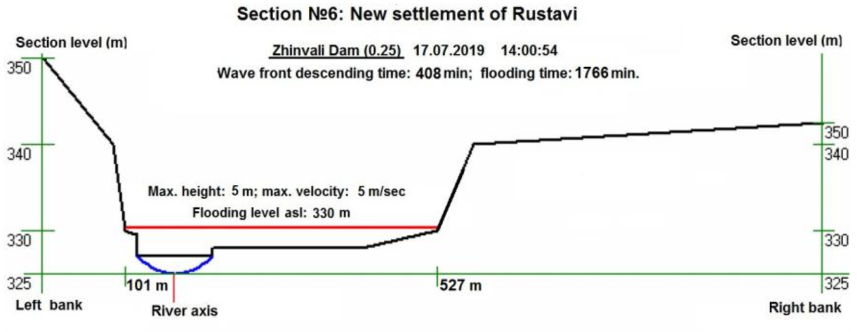


Fig. 2.40. Design section №6

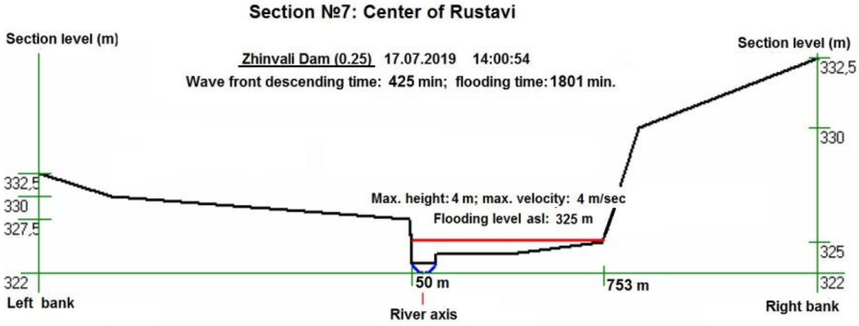


Fig. 2.41. Design section №7

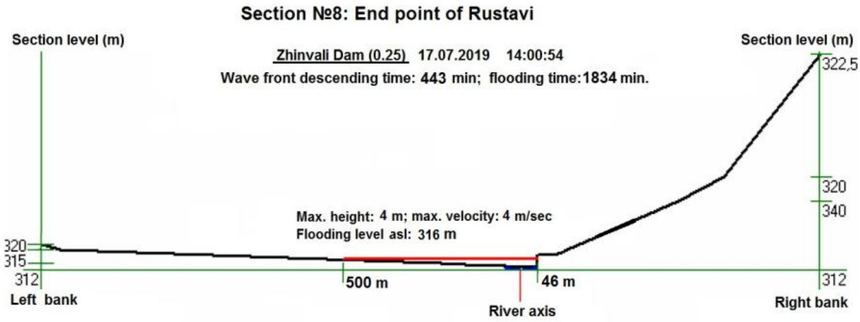


Fig. 2.42. Design section №8

Thus, we propose a methodology for predicting the hydrodynamic parameters of a tsunami-type wave in case of a possible breakdown with different degree of collapse of the Zhinvali earth dam (E_p = 1.0; 0.75, 0.50; 0.25) and determine the contours of the flooded areas (Dusheti and Mtskheta municipality territories, the territories of Tbilisi and Rustavi) taking into account the relevant risk factors.

2.4. Fixing the contours of the territories flooded as a result of the Zhinvali earth dam breakdown

Using the methodology for forecasting the possible breakdowns of the dams discussed in the previous paragraphs of the monograph, the Global Positioning System (GPS), absolute marks of Aragvi riverbed and the corresponding coordinates of former riverbed were observed in the head-water of the Zhinvali earth dam. [4], absolute marks were measured here at the threshold of the dam section and at its foot, which were 816 m and 714 m, respectively.

In the event of a possible break of the Zhinvali earth dam, tsunami-type waves will be triggered in the Aragvi riverbed, and the only way to protect the population is an organized evacuation. Although the Zhinvali earth dam does not break suddenly, it is preceded by the accumulation of defects in the structure, which is a forecasting indicator. As well as technical parameters of the dam, hydrological indicators of the reservoir and topographic characteristics of the river Aragvi, which allow forecasting the area of the territory flooded as a result of the Zhinvali dam breakdown.

Field surveys, GPS, Geographic Information Systems (GIS) and computer software have determined the maximum widths in the Aragvi riverbed where flooding can occur in the event of a possible breakdown at the Zhinvali Dam, which will cause great damage to our country including huge casualties and victims of animals. The results of the report are given in the form of a table, and the contours of the flooding are plotted on a digital map.

As a result of the analysis of the studies, it was found that as a result of a possible breakdown of the Zhinvali earth dam, the following villages of Dusheti and Mtskheta municipalities given in Table 2.13 with a total population of 14,823 people are included in the high risk zone of flooding, added by the population of Tbilisi and Rustavi living in the high flood risk zone (see Figure 2.42).

Table 2.13

Villages at high risk of flooding in case of Zhinvali earth dam breakdown

№	Name of the settlement	Number of the population (Person)
1	Chinti	188
2	Zhinvali	121
3	Bichignauri	424
4	Aragvispiri	907
5	Bodorna	140
6	Tsiteli sopeli	546
7	Navazi	
8	Misaktsieli	2100
10	Natakhari	1234
11	Mtskheta	7 940
12	Zahesi	546
	Total:	**14 823**

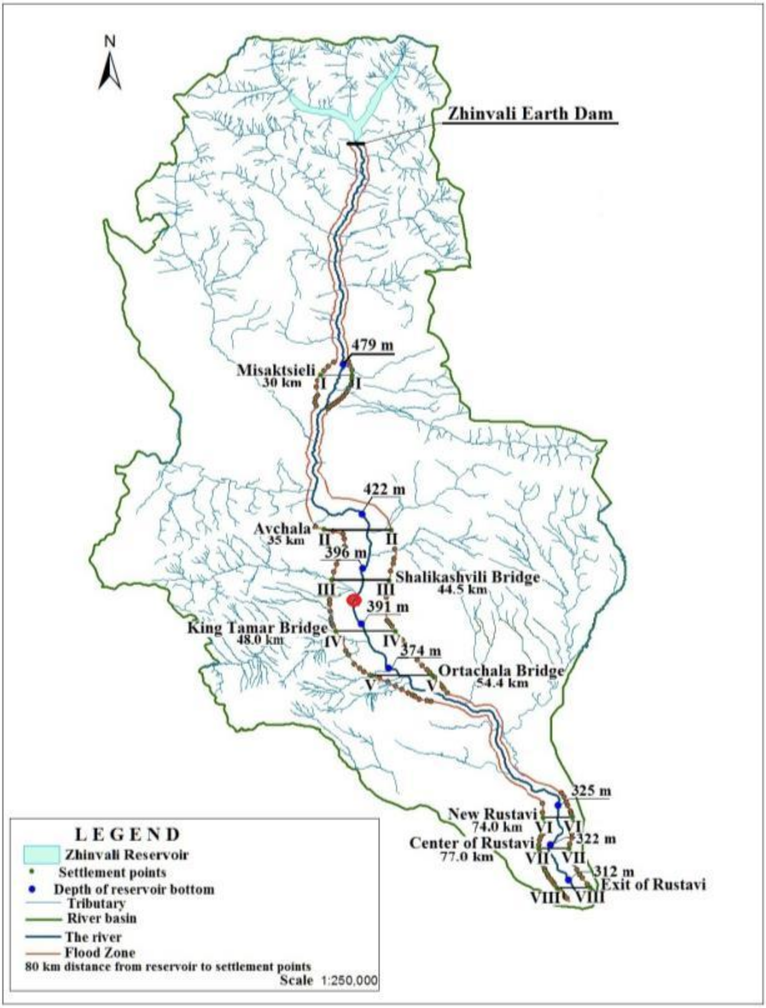


Fig. 2.42. Digital map of the flooded area with GIS system

Thus, according to the first forecast data, the area of the high-risk zone flooded as a result of the possible breakdown of the Zhinvali earth dam and the number of the population settled there, who are in great danger, have been determined.

Chapter 3.

Mathematical modeling of tsunami-type waves

3.1. 2D and 3D mathematical modeling of small amplitude waves formed in a reservoir

Based on the analysis of the scientific-research works carried out on the Zhinvali Dam it was found that erosion-mudflow and landslide processes are activated in the Aragvi river catchment, which further reduces the useful volume of the Zhinvali reservoir and, consequently, its duration of operation.

In view of the above, attention was also focused on mudflow or landslide activation in the Zhinvali Reservoir waters (due to landslide process activation, a major disaster occurred in Italy at the Vayonti Arched Reinforced Concrete Dam in 1963, resulting in more than 2,000 peoples death), also on development of a mathematical model to determine the hydrodynamic characteristics of a wave generated by a terrorist attack on an earth dam, where the overflow of current through the dam is considered in a wave mode.

In this case, in the hydrodynamic model, we consider the following cases: 1. With the model of one-dimensional (1D) fluid motion, using the nonlinear theory of the shallow water; 2. With the two-dimensional (2D) (vertical plane) motion model using the theory of linear small-amplitude waves; 3. With the two-dimensional (2D) motion model, using nonlinear water theory; With a 4-dimensional (3D) motion model [2, 3, 12, 13].

In the case of a wave over a dam, it is perfectly acceptable to assume that the movement is non-vortical. Such motion can be characterized by introducing a velocity potential of $\varphi=(x,y,z,t)$. According to the small-amplitude wave theory, if the corresponding amplitude of the generated waves $\eta = \eta(x,y,z,t)$ is numerically small than other corresponding characteristics, e.g. wave length or mean depth, then the derivatives of η and their multiplications are also second-order small values that can be neglected in the equations (Fig. 3.1).

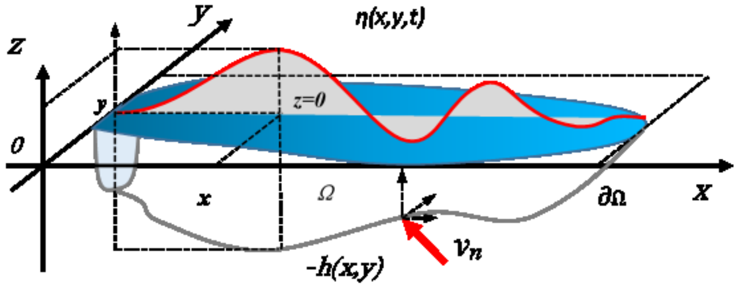


Fig. 3.1. Calculation scheme for the study of a three-dimensional (3D) wave problem in a bordered area using the theory of small amplitude waves

In the second case, when the wave flows over the dam, we can assume that the vertical velocities are quite small with respect to the horizontal velocities $w \ll u,\ v$ and the horizontal velocities are practically independent of the vertical coordinate $u = y,\ u,\ u,\ t,\ t,\ v = v\ (x,\ y,\ t)$. Additionally, if the vertical determinant of the vector $\vec{F}$ is equal to the force of gravity $fw = -\rho g$, and the horizontal determinants are only the frictional forces, which also do not depend on the vertical coordinate, then the motion of the flow can be considered on the plane X_oY (Fig. 2).

Mathematical model of a flood or a viscous stream wave over the Zhinvali earth dam, which is mainly related to the unsteady flow motion of the stream, at any moment of the wave motion, its hydraulic elements are variable values. In formation of a viscous stream in the tail-water of the Zhinvali Dam and its unsteady movement to the lower areas of the sluice, the flow systematically changes its hydraulic values, which must be taken into account when calculating the flow [1,2,3].

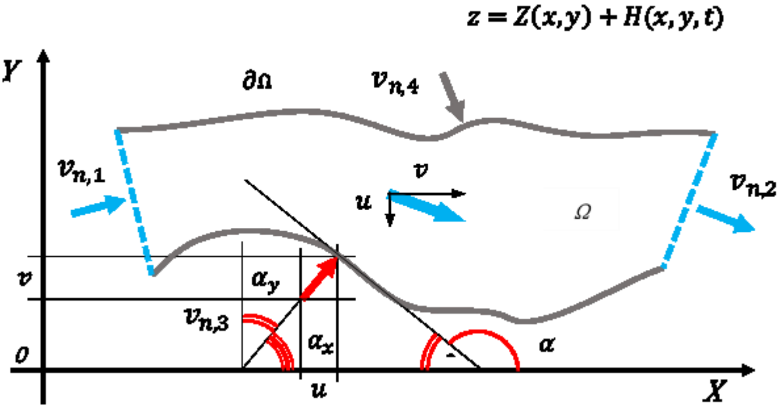


Fig. 3.2. Calculation scheme for studying a two-dimensional (2D) plane boundary problem using shallow water theory

Numerical methods for calculating the unsteady motion of a viscous stream are based on the solution of the system of Saint-Venant equations [1-10], the implementation of which is based on a computer-based exact selection of boundary conditions; These data must have fixed boundaries, without which the task set will not be solved with the desired accuracy.

In the tail-water of the Zhinvali Dam, the motion of the viscous stream in the Aragvi riverbed can generally be represented by the following scheme: the onset of motion, the motion in the transit zone, and stopping in the riverbed while reducing the kinetic energy.

In particular case, due to the physical-mechanical and rheological properties of the viscous stream, it is possible to stop the flow even in the transit areas of the river. Each of these phases has its own peculiarities, from a mathematical point of view of problem solving. In particular, in the design of the algorithm, in the development of the program, etc., when solving the problem taking into account all these phases, the values of the boundary conditions must be taken into account, which will allow to calculate the main indicators of the viscous stream taking into account the hydraulic friction (K_1) and frontal air resistance coefficients (K_2) in these phases.

As for the viscous stream movement taking into consideration variable flow, taking into account the coefficient of hydraulic friction and air resistance, it is still less studied and requires refinement of these methods [2-13].

The aim of the study is to study the unsteady movement of viscous stream in any section of the Aragvi riverbed when the average flow velocity is V> 5.0 (m / s).

As it is known, the viscous stream formed in the riverbed slowly gains velocity in the sluice and enters the phase of „movement", which takes the form of a single wave in the riverbed. The wave moves to the transit area of the bed according to the scheme discussed above, its velocity increases and hydraulic friction and air resistance forces are formed against the flow (Fig. 3.3).

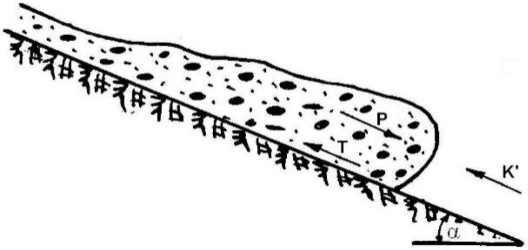


Fig. 3.3. Viscous stream motion calculation scheme

In the case of a viscous stream caused by the flow of water on the Zhinvali Dam, let’s consider the unsteady flow motion in the case of variable flow in the Aragvi Riverbed inclined at the α angle, the system of differential equations of motion of which is as follows [2,3]:

$$\begin{cases} B\dfrac{\partial h}{\partial t}+B\dfrac{\partial (hV)}{\partial x}=q_{*} \\ \dfrac{\partial V}{\partial t}+V\dfrac{\partial V}{\partial x}=g\sin\alpha-g\cos\alpha\dfrac{\partial h}{\partial x}-V^{2}\left(\dfrac{K_{\text{ხ}}}{h}+\dfrac{K_{\text{ჰ}}}{\ell}\right)-\dfrac{q_{*}V}{\omega} \end{cases} \tag{3.1}$$

where B is the width of the river (m), h - is the depth of the mudslide (m), V- is the average velocity of the mudslide (m / s), x - is the length of the river bed (m), q_*- is the intensity of the mudslide rate due to the inflow-outflow of phases on the river length; g - acceleration of free fall (m / s ^{2}), i - slope of the river bed, K_1 - hydraulic friction coefficient, K_2- frontal air resistance coefficient, l - flow movement length (m), ω - mudslide live sectional area (m^2).

To solve the system of equations (3.1) we use the numerical method for solving the differential equation, namely the „flow vector splitting scheme” [2, 15-17]. The flow vector, according to the system of equations, differs from the Euler and aerodynamic vectors, it is not considered as a single function. In this case, it is based on the use of the properties of hyperbolic equations, with the help of which it is possible to construct a vector splitting scheme, which allows making a report with great accuracy.

One of the main problems when determining a viscous stream velocity based on air and friction resistance coefficients is to construct a „flow vector splitting scheme". Steiger and Worming [2] used the fact that the flow vector f (G) was considered to be the only vector function of G for the dependence of the system of equations (3.1).

In view of all the above, let's to write the system of equations (3.1) in divergent form for conservative variables (J - momentum, h - depth of flow) in vector form;

$$\frac{\partial G}{\partial t}+\frac{\partial}{\partial x}f(G)=W(G),\quad f(G)=W(G), \qquad (3.2)$$

where Q = $(J,h)^T$, $J = hV$

$$\begin{cases} f(G)=\left(\bar{J}^2/h+gh^2/2;\bar{J}\right)^T; \\ W(G)=\left[\dfrac{1}{h}\left\{g\sin\alpha-V^2\left(\dfrac{K_{\text{б}}}{h}+\dfrac{K_{\text{з}}}{\ell}\right)-\dfrac{qV}{\omega}\right\};q_*B\right]^T. \end{cases} \qquad (3.3)$$

The process of viscous stream formation is considered as a case of natural boundary or earth dam collapse, when the boundary conditions have the following values:

a) For flow depth:

$$\begin{cases} 1; & t<0{,}12 \\ 1+\dfrac{(t-0{,}12)}{0{,}3}; & 0{,}12\le t\le 0{,}72 \\ 3{,}0; & 0{,}90<t<2{,}40; \\ 1{,}0; & t\ge 2{,}40. \end{cases} \qquad (3.4)$$

b) For flow rate:

$$V_0(x) = 0{,}2;\ h_0(x) = 1{,}0; \tag{3.5}$$

In the process of realization of the problem, the main hydrological and hydraulic properties of the flood mass, as well as the geological-topographic characteristics of the riverbed are taken into account. To do this, we use eigenvalues of matrix $\nabla F = \dfrac{\partial F}{\partial Q}$ which is as follow:

$$\lambda_1 = V + \sqrt{gh\cos\alpha}\ ;\ \lambda_2 = V - \sqrt{gh\cos\alpha}\ . \tag{3.6}$$

Let’s introduce the mark $C_0 \equiv \sqrt{gh\cos\alpha}$, which indicates the value of the velocity impulse in the viscous storm. In view of all the above, a mudslide can be represented as follows:

$$f(G) = \frac{h}{2}\begin{bmatrix} V(\lambda_1+\lambda_2)+C_0(\lambda_1-\lambda_2)/2; \\ \lambda_1+\lambda_2 \end{bmatrix}, \tag{3.7}$$

and the numerical values λ_1 and λ_2 can be represented as:

$$\lambda_1 = \lambda_1^+ + \lambda_1^-;\ \lambda_2 = \lambda_2^+ + \lambda_2^-. \tag{3.8}$$

values λ_1 and λ_2 can be selected in different ways, for example:

$$\begin{aligned} \lambda_1^+ &= 0{,}5(V+|V|)+C_0; \\ \lambda_1^- &= 0{,}5(V-|V|)+C_0; \\ \lambda_2^+ &= 0{,}5(V+|V|); \\ \lambda_2^- &= 0{,}5(V-|V|). \end{aligned} \tag{3.9}$$

If we enter the values of expression (3.8) in the expression (3.7), we get:

$$\tilde{\mathrm{f}}(\Pi) = a^{+}(\Pi) - a^{-}(\Pi) = p\begin{bmatrix} V(|V| + C_0; \\ |V| + C_0 \end{bmatrix} \tag{3.10}$$

Let us write a completely conservative difference diagram with a nonlinear regulator and, given (3.1) to the right of the system of equations, we get:

$$G_t + \mathrm{f}(G, \alpha, \sigma) = R_{xx}(G) + W(G) \tag{3.11}$$

where, $G = (\bar{j}, h)^{\mathrm{T}}$; $\bar{j} = hV$. i.e.

$$\left\{\begin{array}{l} f(G,\alpha,\sigma) = \left(\bar{J}^{(\alpha)} \cdot V^{(\sigma)} + 0{,}5\cos\alpha\left(h^2\right)^{\alpha}; \bar{J}^{(\alpha)} \cdot V^{\sigma}\right)^{T} \\ R(G) = \dfrac{h\Delta x}{4}\begin{bmatrix} \left(|V + C_0| + |V - C_0|\right) \cdot V + 0{,}5C_0 h|V + C_0| - |V - C_0|; \\ |V + C_0| - |V - C_0| \end{bmatrix}^{T} \\ W(G) = \left[\dfrac{1}{h}\left\{g\sin\alpha - V^2\left(\dfrac{K_x}{h} + \dfrac{K^h}{\ell}\right) - \dfrac{g_* V}{\omega}\right\}; g_* B\right] \end{array}\right\} \tag{3.12}$$

when $\alpha = 0$ and $\sigma = 0$, he difference diagram (11) changes its appearance and viscous stream „vector splitting scheme” is obtained, i.e.

$$G^{n+1} = G^{n} - \tau'\left[\mathrm{f}(G)_x + 0{,}5\Delta x\, \mathrm{f}\left(G_{xx}\right)\right] + \tilde{W} \tag{3.13}$$

where τ' is a time variability step; X - grid step with equal space, n - temporary layer number, and, $\tilde{W}$ - is a discrete analog of the right part of the equation system.

For the realization of the scheme it is necessary to fulfill the condition of Courant, Friedricks and Lewy [7]:

$$\tau' \le \frac{\mathrm{Cr} \cdot \min \Delta x}{\max(|V| + C_0)} \tag{3.14}$$

where Cr is a Courant number.

Expressing the dependence (11) in an expansive form, we get:

$$
\begin{aligned}
(hV)_i^{n+1} = (hV)_i^n - \tau'\Bigg[& \frac{1}{2\Delta x}\left\{\left(hV^2 + \frac{gh^2\cos\alpha}{2}\right)_{i+1}^{n} - \left(hV^2 + \right.\right. \\
& \left.\left. + \frac{gh^2\cos\alpha}{2}\right)_{i-1}^{n}\right\} - \frac{1}{2\Delta x}\left\{\left[hV\left(|V| + C_0\right)\right]_{i+1}^{n} - 2\left[hV\left(|V| + C_0\right)\right]_{i-1}^{n}\right\} + \\
& + \frac{1}{h_i^n}\left[g\sin\alpha - \left(V_i^n\right)^2\left(\frac{K_{\text{x}}}{h} + \frac{K_{\text{h}}}{\ell}\right) - \frac{q_* V_i^n}{\omega}\right];
\end{aligned}
\tag{3.15}
$$

$$
\begin{aligned}
h_i^{n+1} = h_i - \tau'\Bigg[& \frac{1}{2\Delta x}\left\{\left((hV)_{i+1}^{n} - (hV)_{i-1}^{n}\right)_{n+1}^{n}\right\} - \frac{1}{2\Delta x}\left\{\left[h\left(|V| + \right.\right.\right. \\
& \left.\left.\left. + C_0\right)\right]_{i+1}^{n} - 2\left[h\left(|V| + C_0\right)\right]_i^n + \left[h\left(|V| + C_0\right)\right]\right\}_i^n + q_* B\Bigg].
\end{aligned}
\tag{3.16}
$$

The report on unsteady motion of the viscous stream is implemented on the computer taking into account the coefficients of resistance to air and hydraulic friction.

The values of the initial data changed in the following boundaries: the slope of the Aragvi riverbed i = 0,01 ... 0,12; The former riverbed width B = 20,0 ... 300,0 (m); Intensity of change in flow rate of flood or viscous stream q* = 38.0 ... 457.0 (m^2 / sec); Hydraulic friction coefficient K_1=0,1...0,05; Frontal air resistance coefficient K_2 = 0,01...0,05.

Chapter 4.

Determining the Flood Risk Zone in the Event of a Possible Breakdown of a Zhinvali Earth Dam According to the Risk Portfolio Analysis (CAPRA) Model

4.1. The essence of risk and its definition

Risk is the likelyhood of the result that is a deviation from the planned/expected result and negatively affects the achievement of the objectives of the research object.

Risk is defined by a combination of the following characteristics:

a) Probability of occurrence;

- The probability of occurrence is the possibility of a specific outcome, where the frequency of occurrence of the outcome should be taken into account.

b) Impact (if occurred).

- Impact is the effect obtained in the event of a specific outcome. Impact involves four elements:
- Time;
- Quality;
- Benefits;
- Human and other resources.

The combination of probability of occurrence and impact determines the level of significance of a particular risk and allows the risk to be categorized according to the priorities depending the institution’s targets.

First of all, the risks, the probability of occurrence and impact of which are the highest, must be considered and managed. In sequence, each subsequent risk must be less likely to occur and have a less impact. In practice, this process is much more difficult because there are risks that are high likely to occur but have a low impact and/or vice versa. In such cases, risks should be prioritized according to the goals and objectives of the institution to avoid mistake (see Table 4.1).

Table 4.1

Probability	High	Is a priority
Impact	High	
Probability	High	The sequence should be determined based on the goals and strategy of the institution
Impact	Low	
Probability	Low	The sequence should be determined based on the goals and strategy of the institution
Impact	High	
Probability	Low	Is less of a priority
Impact	Low	

4.2. Risk management

Risk management is the process of taking the necessary control measures to identify, assess, monitor and maintain the risk at an acceptable level, which affects the achievement of the goals and objectives of the institution and involves the implementation of necessary measures to mitigate the risk.

Risk management is a unified, continuous and evolving process in which each employee of the institution participates within his/her powers.

Risk management is one of the important components of the strategic management of the institution.

The main task of risk management is to identify risks and take response measures. Through risk management it is possible to identify potential positive or negative factors that affect the performance of the research object.

Risk management covers actually all risks related to the activities of the research object in the past, present and future (see Table 4.2).

The management ensures the establishment and operation of a proper risk management system of the research object, and the duty of the internal audit entity established in the research object is to evaluate the existing risk management system and make relevant recommendations for its improvement. Risk management should be permanent and carried out in accordance with the risk management strategy approved annually by the head of the research object.

Risk management assists and strengthens the research object, ensuring that it performs its tasks effectively, including:

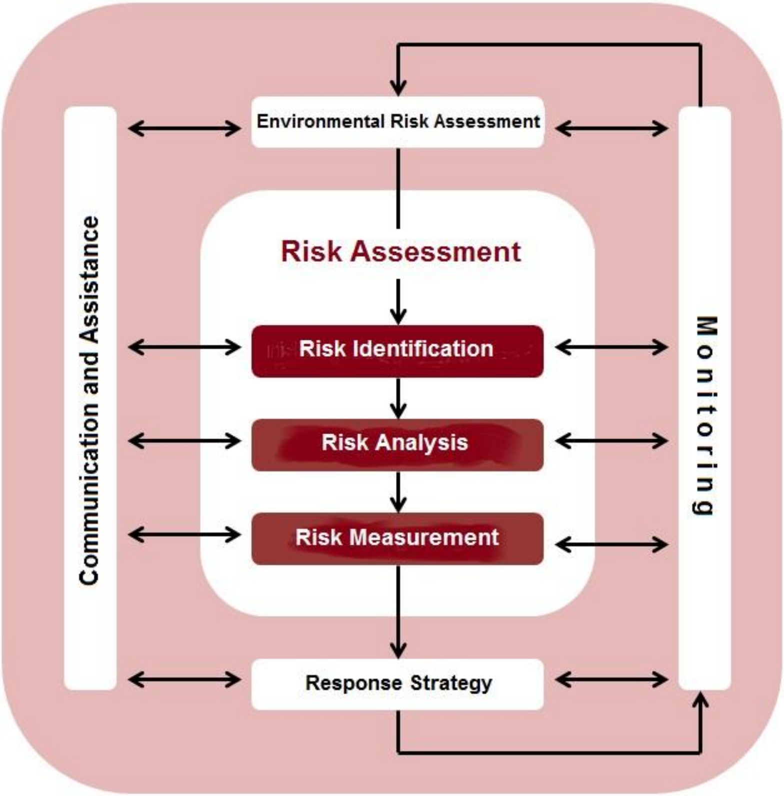
- Establish general directions of the research object, which allows future activities to be conducted in a smooth and controlled manner;
- Improving a number of processes - decision making, planning and prioritization;

- Facilitate the fruitful distribution and use of the existing property and resources of the research object;
- Protecting and strengthening the reputation and assets of the research object;
- Development and strengthening of the human resources and institutional knowledge base;
- Optimization of operations, etc.

The risk management process is a combination of coordinated and consistent continuous actions.

Table 4.2

Risk management process (according to ISO 31000)



4.3. Risk identification

Risk identification is the process by which risk is identified and described in detail (see Table 4.3 for an example). It is important that the identification should be a well-established and continuous process involving all risks as much as possible. Otherwise, the unidentified so-called „missed” risk can no longer be subject to the risk management process and may adversely affect the achievement of the objectives of the research object.

Table 4.3

Risk categories

Strategic risks	This category refers to the agency’s long-term strategic goals, which may be “affected” by the following risks, such as political, legislative and regulatory changes, and the institution’s reputation risks.
Operational risks	This category includes the daily risks that the agency faces in carrying out its tasks and functions.
Financial risks	This category includes the risks related to effective financial management and control, as well as external factors: credit availability, exchange rate, interest rate fluctuations, and other ongoing processes.
Knowledge management	This category includes the risks associated with the effective management and control of knowledge resources. External factors in this category may be the unauthorized use or misuse of intellectual property, competing technologies. Internal factors - may be system malfunction or outflow of necessary staff.
Compliance	This category includes issues such as health and safety, access to databases, regulatory issues.

Each agency should divide the risks into categories based on their specifics and objectives, from which the source of the risk is clearly identified (see Table 4.4 for an example).

Table 4.4

Detailed description of the risk		
1	Risk Name	• Unique Identifier or Risk index.
2	Scope of risk	• Qualitative description of events, their size, type, number, etc.
3	Risk category	• Strategic, operational, financial, knowledge management, compliance, etc.
4	Stakeholders	• Both internal and external stakeholders and their expectations.
5	Risk conditions	• Significance and probability.
6	Experience of loss	• Previous similar incidents and risk-related loss experiences.
7	Risk „appetite" / tolerance	• Potential loss and financial impact of risk exposure • Probability of potential losses • The purpose of risk control
8	Response measures and control mechanisms	• Through which a risk is dealt with • The degree of reliability of existing controls • Establishing the procedures for monitoring and analysis
9	Potential ways to improve	▪ Recommendations to mitigate risk
10	Strategy and policy development	• Identify the person responsible for risk strategy and policy development

Risk identification involves defining the consequences of an impact in order to avoid as much as possible the expected negative consequences.

Risk identification methods are:

- ✓ Interviews and discussions with groups of people with different specializations;
- ✓ Completion of questionnaires;
- ✓ Analysis of events of the previous period;
- ✓ Analysis of available risk databases;
- ✓ Analysis of various potential development of events;
- ✓ Systematization and structural analysis of the function performed by various structures and/or persons in the institution;
- ✓ Operational modeling.

4.4. Risk analysis

Risk analysis is performed by examining the probability and impact of identified risks to determine how they should be managed. As a result, risk analysis involves identifying the factors that may affect the likelihood and consequences of risk.

Preliminary analysis is performed at the initial stage, which involves the grouping, consolidation and exclusion of low-impact risks (it should be noted that exclusion does not imply to neglect, as they were accounted for at the risk identification stage).

The next step is to determine the level of risk based on its scale. The level of risk is determined not only by studying the probability and impact of risk, but also by considering the interrelationships of risks and other factors.

The level of risk may be acceptable to the agency and is called the risk „appetite”.

It is also possible to identify not any specific risks but combined risks.

Risk analysis can be performed in different ways, depending on the specific risk, the purpose of the analysis, the available information, data, resources, etc.

Risk analysis can be:

- Quantitative;
- Qualitative;
- Combined.

❖ Quantitative analysis

If there are quantitative data on the probability and impact of the risk, then the best way is to conduct a quantitative risk analysis. Non-quantitative assessments are less reliable, especially when assessing the likelihood of occurrence of a risk.

The following methods may be used in quantitative analysis:

- Probability analysis;
- Impact analysis;
- Computer modeling;
- Statistical analysis, etc.

❖ Qualitative analysis

Qualitative analysis is widespread in the public sector, where the outcome of accountability and impact on society is crucial, often making it impossible or costly to quantify risks. Such analysis is based on subjective evaluation and in such cases decisions are made based on the experience, knowledge, judgment and intuition of management. This type of analysis verbally describes the likelihood of the risk occurring and the extent of the impact (see Appendix 2).

Qualitative analysis is used:

- When there are no data and resources needed for quantitative analysis;
- At the initial stage of risk analysis as a means of risk research;
- When this type of analysis is sufficient to carry out proper analysis and decision making.

A common practice in the risk analysis process is to develop a risk matrix that allows us to rank and identify risk. The matrix is formed by the relationship between risk probability and impact, according to which we take a risk rating and categorize it (see Table 4.5 for an example).

Table 4.5

Example of a risk matrix

Probability	High	3	6	9
	Medium	2	4	6
	Low	1	2	3
		Low	Medium	High
		Impact		

where,

High	• Financial impact is high; • There is a significant impact on the research object’s strategy and operations; • There is a significant interest of stakeholders

Medium	• Financial impact is medium; • There is a moderate impact on the research object’s strategy and operations; • There is a moderate interest of stakeholders
Low	• Financial impact is low; • There is a low impact on the research object’s strategy and operations; • There is a low interest of stakeholders

In the example of the risk matrix the risks with the unacceptable rating are bolded and measures must be taken to reduce or prevent them.

4.5. Risk measurement

Risk measurement is the process by which the results and criteria of its analysis are compared.

Risk measurement takes into account the relationship of the assessed or rated risk with the existing control mechanisms and the level of risk acceptable to the institution. The purpose of risk measurement is to take appropriate measures based on specific criteria, goals and objectives of the institution. Risk measurement involves the following three steps:

- **Qualitative characterization of the control mechanisms in the facility,** in particular, what are the processes, policies and other existing factors aimed at neutralizing the risk. The quality of the control mechanisms in the facility is assessed using the following terms:

a) non-existent;

b) inadequate;

c) adequate;

d) strong;

e) excessive (implies the existence of over-strong control mechanisms, which in itself will lead to a waste of both material and other resources).

- **Characterization of risk in relation to the level of risk accepted in the institution**, in particular, it is possible to characterize the risk as follows: unacceptable, acceptable, but with the need to use appropriate response measures and acceptable. It is also possible to have an acceptable zero level of risk (if it can be avoided). Risk is acceptable when responsive measures are impossible or the risk itself is intangible and insignificant, in which case it is not advisable to spend resources on responsive measures.

In agencies, risk criteria, risk-taking measures and other risk-related parameters may be established (for example, setting an acceptable level of unexpected loss beyond which the loss will be considered as unacceptable and within which it will be accepted).

Decision making on responsive measures is based on the first and second stages of risk measurement, namely, responsive measures are: Avoidance (e.g if the risk is unacceptable, it can be avoided by not making the decision and not taking the action that results in risk occurrence), specific responsive actions, adaptation and monitoring (e.g risk is accepted and adapted and monitored when specific responsive actions are impractical or impossible. We also adapt and monitor such risks, level of impact of which is insignificant, but characteristics of which may change in the future), etc.

4.6. Responsive measures

As a result of the risk assessment, a decision is made as to what kind of measures should be taken in response to the identified risks and what is the most effective responsive measures strategy. The purpose of the responsive measures is to mitigate the negative impact of the risks facing the agencies, which is reflected in the reduction of the threat and the proper achievement of the goals set by the institution. Responsive measures mainly include risk control, however, there are also measures such as risk prevention, risk sharing, risk financing and others.

Selecting the best of the responsive measures involves comparing the costs and benefits of each type of measure. The value of risk management should be commensurate with the benefits that will accrue from that management. When comparing costs with benefits, the specific surrounding and circumstances must be taken into account. It is important to consider all direct and indirect costs and benefits (both tangible and intangible) and to evaluate them financially or otherwise. Factors such as political and social factors must be taken into account when selecting responsive measures.

In the event that the responsive measures’ budget is limited, the risk response plan should accurately reflect the priorities on which the risk response plan will be based. It is important that the full value of the responsive measure be compared with the resulting benefits.

The following are the types of risk responsive measures with a negative potential outcome. They can also be used in combination.

Against most of the risks the following four main types of control measures are implemented, which aim to mitigate the risks to an acceptable level:

- Preventive control
- Corrective control
- Directed control
- Discovery control.

Responsive measures plan

The purpose of the response plan is to document the selected plan, which should include:

- Control measures required to minimize the level of risk (action planning);
- Indicators required for risk level monitoring, control systems evaluation and responsive measures;
- Persons responsible for the implementation of the plan;
- Determining the type of resources needed (financial, human resources, information, technology, etc.);
- Determination of the outcome of responsive measures;
- Execution deadlines;
- Monitoring and reporting requirements.

Chapter 5.

Assessment, accounting for the damage caused by the disaster and elaboration-analysis and sustainability of the rehabilitation plan of the affected population

When determining the economic efficiency and appropriateness of the construction of reservoirs, it is necessary to determine the estimated magnitude of the possible damage as a result of the collapse (breakdown) of the reservoir dam. In this case, the losses can be represented as the sum of the damage directly to the hydraulic facility, industry, agriculture, forestry, utilities and human casualties.

The above-mentioned technical requirements must also be met by the current condition of the Zhinvali earth dam, as there are various facilities mentioned by us in the tail-water of the dam, and when assessing their risks, it is necessary to take into account the loss incurred to all facilities that may be damaged or completely out of order as a result of a possible breakdown at the Zhinvali Earth Dam.

Let’s consider the loss assessment methodology for each item.

5.1. Damage caused by the collapse of a hydraulic facility

Damage caused by the collapse of a hydraulic facility is determined by the formula:

$$D_h = \sum_{1}^{3} K_i = K_1 + K_2 + K_3 \qquad (5.1)$$

where: K_1 is the carrying amount of the collapsed part of the hydraulic structure; K_2 - Capital costs of restoration of the demolished part of the hydraulic structure; K_3 - Repair costs of the damaged part of the hydraulic structure.

5.2. Losses to industry

Losses to industry are determined by the formula:

$$D_m = \sum_{i=1}^{7} d_i = d_1 + d_2 + d_3 + d_4 + d_5 + d_6 + d_7 , \qquad (5.2)$$

where d_1 is the loss caused by the loss of production equipments; d_2 - damage caused by demolition of industrial and non-industrial buildings; d_3 -costs related to the repair of damaged production installations and buildings; d4 - Expenses related to the repair of damaged non-industrial installations and buildings; d5 - Loss caused by destruction of raw materials and supplies, as well as stored finished products; d6 - losses related to the reduction of labor productivity; d_7 - Loss caused by reduction of products is determined by the formula:

$$d_7 = \sum_{i=1}^{t} \frac{d_{i7}}{(1+\alpha)^t} \qquad (5.3)$$

where $(1+\alpha)^t$ is the discount rate, t - the length of the recovery period (years).

5.3. Damage to agriculture and forestry

Damages include destruction of agricultural and forest lands, livestock destruction, demolition of industrial and non-industrial buildings, destruction, damage of agricultural machinery, etc. This loss is determined by the formula:

$$D_{sm} = D_{mc} + D_{mx} + D_{tk} \ , \tag{5.4}$$

where D_{mc} is the loss of horticulture; D_{mx} - livestock losses, including pond farming; D_{tk} - forestry loss.

Horticulture losses include the losses of both annual and perennial crops, agricultural costs.

5.4. Expenditures on restoring the fertility of agricultural lands

Expenditures on restoring the fertility of agricultural lands are calculated by the formula:

$$D_{mc} = \frac{d_{mc1} + d_{mc2} + \ldots + d_{mck}}{(1+\alpha)^1} + \frac{d_{mc1} + d_{mc2} + \ldots + d_{mck}}{(1+\alpha)^2} + \ldots$$

$$.. + \frac{d_{mc1} + d_{mc2} + \ldots + d_{mck}}{(1+\alpha)^t} \tag{5.5}$$

where: d_{mck} is a k-type loss in horticulture; $(1+\alpha)^t$ - is the discount rate (t is an agricultural recovery period, years).

5.5. Damage to cattle-breeding

Damage means the losses related to the death of livestock, costs of restoring their population, as well as repairs and restoration of buildings and equipment of livestock complexes, costs of repair and restoration of ponds and buildings of pond-farming, costs of on sanitary-epidemiological measures. In cattle-breeding, the loss is calculated by the formula:

$$D_{mx} = \frac{d_{mx1} + d_{mx2} + \ldots + d_{mxk}}{(1+\alpha)^1} + \frac{d_{mx1} + d_{mx2} + \ldots + d_{mxk}}{(1+\alpha)^2} + \ldots$$

$$.. + \frac{d_{mx1} + d_{mx2} + \ldots + d_{mxk}}{(1+\alpha)^t} \tag{5.6}$$

where, d_{mxk} is a k-type loss in cattle-breeding; $(1+\alpha)^t$ - is the discount rate (t is an agricultural recovery period, years).

5.6. Damage to forestry

Losses arise from deforestation, declining productivity, and the costs of reforestation. Losses to forestry are calculated by the formula:

$$D_{tk} = \frac{d_{tk1} + d_{tk2} + \ldots + d_{tkk}}{(1+\alpha)^1} + \frac{d_{tk1} + d_{tk2} + \ldots + d_{tkk}}{(1+\alpha)^2} + \ldots$$

$$\ldots + \frac{d_{tk1} + d_{tk2} + \ldots + d_{tkk}}{(1+\alpha)^t} \tag{5.7}$$

where, d_{mxk} is a k-type loss in forestry; $(1+\alpha)^t$ - is the discount rate (t is an agricultural recovery period, years).

5.7. Loss to utilities

Loss (D_{km}) is the sum of costs for cleaning the flooded area and restoration and repair of infrastructure (d_{km1}), destroyed water supply facilities (d_{km2}), public transport (d_{km3}), restoration and renovation of demolished and damaged residential and public buildings (d_{km4}), planting destroyed green plants (d_{km5}):

$$D_{km} = \sum_{i=1}^{n} d_{kmi} \qquad (5.8)$$

where d_{kmi} is the i-like loss of the utility.

5.8. Loss caused by human casualties

Human life in general is invaluable, but in this context the loss caused by human casualties can be roughly determined through insurance funds:

$$D_a = n * C\,, \qquad (5.9)$$

where n is the number of victims; C - Maximum insurance sum for human life.

Thus, in the first approximate calculation, the damage caused by a tsunami-type wave as a result of a possible dam breakdown can be calculated as – the sum of the losses caused by human casualties, destruction of hydraulic facility, damage to industrial facilities, agricultural, pond-farming, forestry and utilities.

The development-analysis and sustainability of the rehabilitation plan of the affected population shall be considered in accordance with the rules of conduct of the population in case of emergency.

The owner of the dam must have developed the principles of protection of the surrounding area and the area of influence of the structure.

The safety of a hydraulic structure as a water economy complex is its feature, to protect the environment, agricultural facilities, human life, health and legitimate interests, and the operating condition of the structure must be appropriate and meet modern requirements.

Therefore, all hydraulic structures must have an owner who excludes unauthorized access to the facility. In addition, the owner of the hydraulic structure must have a safety declaration of the structure, which will include all its technical parameters and data monitoring rules during the operation of the structure. It must also provide for the safe operation of all ancillary buildings, premises and equipment and the periodicity of inspections of their normal operating conditions.

Thus, the development-analysis and sustainability of the rehabilitation plan of the affected population should be assessed taking into account the factors discussed above.

Chapter 6.

Assessment of the rules of conduct of the population living in the flood risk zone as a result of a possible breakdown at the Zhinvali earth dam

The safety of a hydraulic structure is its ability to protect the environment, agricultural facilities, human life, health and legitimate interests, and the operating condition of the structure must be appropriate and meet that requirement.

Due to the security risk of the hydraulic structure (technological, natural and social, as well as sabotage and terrorist act-like external attacks) it is necessary for all hydraulic structures to have an owner who prevents unauthorized access to the facility and has a safety declaration of the dam, which will include all its technical parameters and data monitoring rules during the operation of the structure. Great attention should also be paid to the conditions of safe operation of all ancillary buildings, premises and equipment and the periodicity of their inspection [21-24].

The owner of the dam must also have developed the principles of protection of the surrounding area and the area under the sphere of influence of the structure. In all cases, the hydraulic structure needs ongoing repairs and overhaul, and the owner must specify its periodicity.

The safety of hydraulic structures is characterized by three main categories of risk, which include: technological, natural (including ecological) and social hazards. The latter is due to sabotage-like - internal and terrorist act-like - external attacks.

The principles of protection of the surrounding area and the area of influence of the structure should also be developed. In all cases, the hydraulic structure needs ongoing repairs and overhaul, and the owner must specify its periodicity.

Consequently, the appropriate emergency headquarter has sufficient time to alarm and evacuate people. One of the forecast indicators is also the climatic conditions (long rains, heavy snowfall in the mountains), which should be taken into account to assess the risk of flooding.

In the river gorge, the regulation of water flow gives good results, which is manifested by the cleaning of the bed, in some cases - by the removal of deposits, and sometimes - by the correction of the bed. These measures help to increase the water velocity and duty of water in the riverbed and prevent the negative consequences of flooding.

Floods, as a disaster, are known to be caused by snowmelt, torrential rains, windy water, or as a result of rising rivers, lakes or seawater levels during river blocking, floods can also be caused by hydrotechnical breakdowns and sea fluctuations, the latter along with flooding of areas as a result of a tidal wave, causes large-scale destruction (of bridges, buildings), and at high velocity water (> 4 m/s) and high water levels (> 2 m) - victims of humans and animals, the country's economy is suffering. The main cause of collapse is the high-velocity movement of water masses on buildings and hydraulic shocks. Floods can occur suddenly and last from a few hours to 2-3 weeks [20,23,24].

- **How to prepare for a flood:**

If your region is frequently affected by flooding, explore and remember the possible boundaries of flooding, as well as the elevated areas (which are rarely flooded) in the immediate vicinity of your home and the shortest access roads to them. Introduce your family members to the rules of evacuation as well as those of conduct in the event of a sudden and rapid flood. Remember the storage areas for boats, rafts, and building materials needed to make them. Make a list of necessary documents, items and medicines to take with you during the evacuation. Put the necessary warm clothes, supplies of products, water and medicines in a special suitcase or backpack.

- **How to conduct during a flood:**

Upon receipt of a flood and evacuation alert, immediately leave a potentially catastrophic flood zone and move to a safe area or elevated location, carrying your documents, valuables, personal belongings, and two-day supplies of food. Register at the evacuation point. Pets are also subject to evacuation.

When leaving the house, turn off the electricity and gas, extinguish the fire in the oven, attach all floating objects outside the building or place them in auxiliary storage. If time allows, move valuables to the upper floors of the house, or to the attic. Close the doors and windows, and if necessary and when time allows, board up the windows and doors of the first floor with planks from the outside.

In the event of a catastrophic flood, in order to protect yourself from a breakthrough wave impacts, you need to quickly take an elevated place, climb a large tree, on the upper tiers of solid buildings, if you are in the water, when the wave approaches, do not get confused and do not panic, dive deep into the water and after some delay - surface to the surface of the water by underwater swimming.

When in the water, by swimming or using swimming equipment go to a dry place, preferably on a road pile or dam - in a non-flooded area. Self-evacuation of people by walking or by available swimming means is permissible in the following cases: If you see an un-flooded area directly, you have run out of food, getting outside help is becoming unpromising or you need urgent medical attention. Show restraint during the flood and do not panic.

You should bring the boats in order, and if you do not have them, prepare them from local materials.

If you find yourself in the water, try to discard heavy clothes and shoes, swim to un-flooded places. Be careful of objects floating on the surface of the water to avoid possible injury.

If there is no organized evacuation, climb to the top floors, roofs, trees, or other elevated objects before rescuers arrive or the water level drops. At the same time, constantly send a distress signal: during the day - by exposing or shaking a piece of well-visible fabric attached to a stick, and at dusk with a light signal and periodic contact. When rescuers approach, calmly, without panic, carefully go to the swimming equipment. At the same time, strictly follow the requirements of the rescuers, do not allow the swimming equipment to be overloaded. Do not leave your seat while traveling, do not sit on the outer boundary, exactly follow the instructions of the crew.

- **If a person drowns,** throw a floating object, encourage it, and call for help. When approaching the victim by swimming, take into account the flow of the river, if the drowning person cannot control his actions, approach him from behind, grab him and swim to the shore.

- **How to act after a flood.**

Before entering the buildings, check if there is a danger of them falling down or any objects falling; Air out them; Do not turn on the electric lights; Do not use electrical appliances until you are sure they are well dried; Do not use open fire sources; Do not light the match until the building is fully ventilated and the gas supply system is checked. Check electrical wiring, gas supply pipes, water pipes, sewers and do not use them until you are sure they are working properly; Do not take food that may have been in contact with water; Do not drink unboiled water from local water sources.

6.1. General measures to fight against floods

There are basically four types of work to be done to fight against floods:

1. Flood forecasting and warning the population about anticipated threats;
2. Evacuation of the population from the flooded area and providing assistance to them;
3. Fighting against the flood itself;
4. Providing medical care to the victims.

Particular importance is attached to flood prediction. It should be noted that the staff of the National Environment Agency has been successfully coping with this very difficult task in recent years.

In order to avoid a large part of the damage, human casualties and livestock death, we first need to timely warn the population about the impending disaster. In such a case, the population will be able to leave the lowlands in time and take their property, livestock to a safe place. If flood control organizations are aware of the expected floods in advance, they will be able to prepare for effective flood response in a timely manner and begin construction of anti-flood structures in areas that are primarily exposed. Flood information must be comprehensive, accurate and, most importantly, timely, as this information is less useful if it is not provided in a timely manner [25].

Currently, the following means are used to protect cities, industrial and agricultural territories from floods: Avoiding flood flows from the protected area through bypass (unloading, discharge) canals (as is done for the city of Poti), arrangement of piles, so called dams, improvement of permeability of certain river sections (riverbed leveling and cleaning) and their artificial regulation, agro-amelioration, forest-amelioration, hydrotechnical, anti-erosion measures, arrangement of foothill canals, reducing and retaining of runoff, struggle against forest fires, and reduce rainfall intensity through impacting weather (among these measures, the latter is at the experimental stage).

Most of the named flood control measures are already used on the rivers of our country and their constructions comply with the generally accepted standards and norms in flood control practice.

Many examples of flood control, taken from the practice of foreign countries, show that fertile agricultural lands and settlements can in principle be saved from the destructive force of floods, if it is possible to re-direct the freshet using various hydraulic structures, at which time less valuable and untapped lands will be flooded. Unfortunately, such opportunities are very limited.

Most flood control measures are effective for frequent and moderately recurrent floods, but - almost ineffective for floods that occur infrequently, so the best measure to fight against flooding is to regulate runoff in the reservoirs and to embound them. These two measures are not alternative in most cases and their implementation is complex.

It should also be noted that the embounding carried out on rivers such as the Rioni, Khobi, etc., significantly reduced the frequency of freshets of meandering rivers, while the reduction of meandering led to increased accumulation of sedimentary and bottom alluvions, gradual increase of the bottom mark and, consequently, gradual decrease of the permeability of the embounded bed.

6.2. Organizational and technical preventive measures and organization of the flood control service

Taking measures against floods that would give us absolute reliability of the protection of the facilities is unfortunately practically unrealistic, and their construction is economically unprofitable. Thus, when carrying out flood control measures, we should be aware that there is still a risk of impending catastrophic floods.

In addition, it should be borne in mind that scientists and designers are not always able to accurately predict the course of the flood process. The multifactorial process of flood protection and its consequences are often unforeseen. Therefore, despite all possible measures to be taken to protect this or that area from floods, we must always be ready to fight against floods and not to ignore emergencies (natural disasters, man-made, breakdowns of dams and weirs). This will allow us to drastically reduce the scale of the loss.

Those who have taken up territory near the river believe that the land on which they live and work is safe, that there will be no flooding, and that they are reliably protected from it. In most cases, the trouble is largely due to such irresponsibility when safety measures are not taken in advance against the expected floods.

Flood control services are especially important to reduce the damage caused by the disaster. Special services allow us to carry out all the work planned to repair all the buildings, as well as to protect other anti-flood structures. The person in charge of this service shall draw up a map of the flood-prevention works to be carried out, which shall indicate all the embankments indicating dangerous places, etc.

Flood control service responsibilities include:

- Distribution of the entire area between the brigades;
- Attaching material and transport resources to each brigade;
- Supply of necessary materials for immediate liquidation of the breakdown;
- Organization of all necessary works. Particular attention should be paid to the night, in heavy rains and windy weather, when there is a greater chance of a breakdown.

Good organization of works during the flood period ensures the avoidance of the damage of embankments and structures and will make it possible to completely exclude or greatly reduce the damage caused by the expected breakdown.

Security measures need to be considered and processed in a timely and thorough manner so that they can be implemented sooner or later as soon as the disaster situation requires it. Naturally, in order to carry out such measures, we must preliminarily take into account the natural conditions of the area where their implementation will be required. Thus, in order to prevent disaster or reduce the damage caused by it, in all areas where flood risk is expected, we must have a plan for the protection of the area, population and victim assistance, as well as a plan of long-term measures to avoid great material and other losses, or, in extreme cases, to significantly reduce it [20,23,25].

Success in the fight against floods depends to a large extent on the coordination of the work of all the services that carry out the planned measures. Disagreement between those involved in flood control, or those who need to be evacuated from flooded areas, or areas at risk of flooding, or who have taken care of the victims, will lead to disruption of the measures. Developing a well-thought-out program, providing timely information to the public about impending floods, and measures that can be taken to save citizens' lives and property are crucial.

After the flood, first of all, the area needs to be cleared of rubble and silt; Tidy up the area to alleviate the grief caused by the devastation and casualties, identify the causes of the disaster, and address any issues that may arise.

One reliable way to solve problems is to include it in our multi-year plans for economic and social development. There are no universal methods for compiling such a program. Of great importance is the position of those who did not fall into the flood zone. Recent years have shown that those who live and work in areas where there is a risk of flooding are well aware that their well-being, the social and economic situation of the whole country, depends significantly on how successful the fight against flood is and how its consequences are liquidated.

Experience has shown that flood-caused damage increases in most cases as a result of neglecting the expected hazards. For example, many people who live in areas where there is a risk of flooding think that the flood will not happen again and if it does, it will happen again after a long time and with not enough power to touch it.

When discussing flood control methods, it is important to remember that in small rivers, especially at the head-waters of river catchments, water levels can rise rapidly due to heavy rains, and floods can begin before the rains stop. In such a case, there is almost no time left to predict the flood and the peak of the freshets. It is necessary to immediately take measures to save people, livestock and property.

In order for the structures that regulate freshets to work well, it is necessary to ensure their normal maintenance. Well-maintained hydraulic structures do not require special care in critical cases. In case of poor maintenance, these buildings need urgent repairs in complicated flood conditions.

Inspection and maintenance works of dams, embankments, reservoirs, water pumping stations are specific and are detailed in the service and maintenance instructions of these facilities.

The most common anti-flood structures - dams - usually face two dangers: first, the fact that the water level in the river during the flood can rise above the dam, and second, the resorption of water in the dams can cause ruptures, which can lead to leaching of the dam. Of course, if the water flows over the dam, there is nothing to do here. To avoid ruptures, it is often necessary to take measures in advance, which are as follows:

Usually plants grow on the sides of the dam and along the river banks - the roots of trees and shrubs loosen the soil; In loose soil, water begins to leak. In addition, during floods, the river brings with it bulky trees and various types of debris that can mesh of the dam walls, trees and shrubs growing on the banks of the river and uproot them, resulting in the collapse of the dam banks. That is why we need to pay attention to the fact those trees and shrubs do not grow on the banks of the river and on the sides of the dams (on the river side).

Sometimes, the material from which the dam is built is compacted, which causes the dam to lower, which can also be caused by the regular movement of cattle on it, or a weak foundation and other reasons, in which case it is necessary to change the dam material and/or strengthen the base. If the lowering of the dyke is insignificant, we may not even change the material, but add a new one and bring it to the height provided by the dam project. In this case, to ensure the connection of old and new materials, it is recommended to remove the dam gleby cover at the connection point in advance. Nor should it be neglected that rats and various rodents often make holes in the dams, from which water can then easily leak out. Thus, old dams require strict maintenance and control.

Timely detection and examination of weak areas is of great importance. Areas at risk of flooding and for which protection measures need to be developed fall into two categories:

1. Areas protected by dams are already damaged and in need of reconstruction;
2. Lowland areas that are not protected by dams and the need to build a dam may arise during floods.

In order to detect deformed places, it is necessary to carry out regular monitoring of dams at any time of the year. It is better to restore them as they were before the flood. In any case, the locations of the dam should be identified so that in case of danger, we can eliminate them immediately - preventive measures should be taken.

The Preliminary Flood Control Plan shall provide for the timely supply of materials and equipment that may be required during the flood control. We must also have a constant supply of timber, sandbags used for the rapid construction of fortifications.

Particular attention should be paid to dam accesses that are prone to leaching and that are not protected by a gleby or other cover. Also, the ends of old dams and intersections require attention. If we notice signs of leaching, the quality of leaching should be determined and appropriate repairs should be carried out. Sandbags or bulk stones are usually used for this purpose.

Elimination of leaching and ruptures in dams is not easy. This requires early implementation of measures to prevent ruptures. If there are any ruptures in the dam, we must take appropriate measures to prevent them immediately.

When we have built reservoirs, then we have to create a working regime there that would limit the unplanned flow of water in the tail-water. This in turn means that it is necessary to develop a schedule for the work of the stop-gates and to keep it strictly adhered to. Recommendations for creating such a schedule are given in the reservoir maintenance and operation instructions.

Demolition of buildings and structures during floods can be reduced at the expense of constructional modifications. Among the various types of constructional modifications we can name the walls made of waterproof material, the closing of windows and other holes, which are located on low levels, the construction of buildings on a reinforced foundation. If necessary, buildings may be erected on piles.

Constructional modifications are acceptable when the flood continues for an insignificant period of time and the water velocity is low. This measure is most effective when the depth of flooding is less than one meter, although it is possible to build buildings that can withstand floods up to three meters deep.

Constructional modifications and earth level upgrades contribute to the steady settlement of the area - as well as reducing potential losses.

At the same time, the measures taken should not lead to indifference of people and belief in the absolute reliability of their houses, neglect of the measures needed to protect them from floods.

6.3. Selection of anti-flood measures

There are many measures to fight against floods, from which the most appropriate type of flood prevention for the given region and territory should be selected. There is a whole range of opportunities available to reduce flood-caused damage. We cannot avoid damage if we do not use every effort, every means and do not take the necessary measures. Any action aimed at mitigating the loss requires material costs (for example, to build a structure, to relocate a flood-affected enterprise). Such costs are reimbursed in profit gained after reduction of loss. The level at which income should exceed the maximum amount of expenses incurred should be clarified.

The analysis of incomes and expenditures will allow us to determine the list of measures against floods and select the optimal set of effective measures from them.

The damage caused by the flood to the national economy can be measured by the cost of restoring it to return it to its original form.

To do this, you need to determine the cost that will be spent on replacing or repairing the damaged property.

Where floods pose a serious threat to human life, the cost of building a dam can be compared to the cost of building a high-rise building, relocating roads, and improving a notification system. [20].

It is of great importance that the constructed structures be quite reliable so that they do not contain unreasonable expenditure of construction material, which would lead to further increase in the cost of the building and large capital costs.

➢ Medical aid

During the floods, in addition to the collapse of the existing medical care system in the disaster area, a number of other serious problems also arise.

The demolition of buildings disables vital facilities such as electricity and water treatment plants - unsanitary conditions can be created, which poses a risk of spreading infectious diseases. Therefore, these issues should be under the constant attention of the health services of the respective regions.

Chapter 7.

Necessary control questions according to UN standards for competent state and local self-government officials when planning emergency actions

In the methodological guidelines, manuals and other normative documents prepared by the United Nations in the last 2000-2019, special importance is attached to the quality of information of the control questions that are necessary for competent state and local self-government officials to have in case of emergency planning in the country. Emergencies in one or another country can occur during natural and man-made disasters (weirs breakdowns, dams demolition, etc.), terrorist acts, epidemics or other special cases [3].

The participation of Professor Givi Gavardashvili, Project Manager at the UNECE-sponsored international conference "Accidental transboundary water pollution prevention - contingency planning, early warning, mitigation" held in Budapest, Hungary on 2-4 November 2019, has highlighted the importance of governments, local governments, awareness of population living in the disaster zone and the knowledge of the rules of their conduct, the efficiency and effective use of their implementation in the announcement of a state of emergency in different countries of the world [3].

The following is a list of control questions and three criteria for assessing their knowledge („yes", „to some extent" and „no") according to the EU Standards Guidelines when planning operations in a state of emergency in a country (see Table 7.1).

Table 7.1

List of control questions when planning actions in a country during a state of emergency (For competent organizations) [3]

№	**Questions and description when planning actions in case of announcement of a state of emergency**	**Questions to check**	**Response of a competent person**		
			yes	**to some extent**	**no**
1	The country should ensure appropriate action, which will be approved by legislation, water and industrial facilities breakdown conventions.	Are the actions in line with the water and industrial facilities breakdown conventions?			
	Description of the river catchment basin				
2	Geographical location	Do you have a territory map in case of a potential pollution accident?			
3	Basic characteristics of the catchment basin	Do you have a basic description of the catchment basin?			
4	Topographic and other aspects	Do you have a basic topographic descript-tion: relief, flora, hydrographs, urban and district transport communications?			
5	Geology and soil structure	Do you have a description of the soil structure and its geological description?			
6	Climatic conditions	Do you have a description of climatic conditions (especially precipitation)?			

7	Groundwater and its horizons	Do you have a description of the groundwater status of the respective region and its horizons?			
8	List of potential pollutants of water resources	Is there a list of water polluting companies?			
9	Dissemination of pollution	Does the above list include the following facilities: Wastewater treatment facilities? Industrial organizations? Agrochemical enterprises? Carbon storage facilities? Are these objects marked on the map? Is the duration of their relocation in an extreme situation calculated in extreme hydrological conditions?			
10	Surface and groundwater quality	Do you have a classification related to water quality?			
11	Groundwater quality	Do you have information on groundwater in the emergency zone?			
12	Drinking water supply	Do you have a description of drinking water supply?			
13	Industrial water supply	Do you have a description of the industrial water supply?			
14	Agricultural water supply	Do you have a description of water use in agriculture?			
15	Recreation areas	Do you have a description of water use in recreational areas?			

16	Fish farms	Do you have a description of fish farms?			
17	Fish-passing facility	Do you have any description of fish-passing structures on water-barrier structures?			
	Water Management Organization / Competent Bodies				
18	Duties and activities of the competent bodies	Do you have a complete description of the activities of the Water Management Organization?			
19	Designation of competent bodies	• Do you have a list of competent organizations in the contingency plan? • Do you have a list of organizations whose purpose is to respond to an emergency? • Are the organizations responsible for preparing the contingency plan on the list?			
		▪ In case of a “positive” answer, check whether this organization is mentioned in the contingency plan?			
	Emergency preparedness				

20	Prior to the commencement of the construction of a capital strategic facility or the closure of the facility operation, the contingency plan must be agreed with the government of the country. Accordingly, it is necessary to calculate the duration of the evacuation in accordance with national or international laws.	• Is the time to act in an emergency set by national laws? • Does the contingency plan set out deadlines for initiating and completing actions in the event of a breakdown?			
21	The contingency plan shell be developed and verified by the operators from the list of hazardous objects and by the competent bodies. Finally, when it comes to the question of competent organizations, they should act in relation to each other and on the principle of mutual agreement.	• Does local laws provide for joint emergency monitoring in the contingency plan - in or outside the disaster zone?			
22	The contingency plan should always be revised as necessary, but not less than 5 years.	• In case of new hazards at the structure under construction? • If a new hazard is identified during the operation of the facility? • In case of additional irregularities at the facility using new diagnostic equipment or new technologies?			
23	The contingency plan must take into account	• Does the contingency plan			

	all types of natural disasters as additional causes of the breakdown. Therefore, additional information must be included in the action plan (e.g flood contours must be mapped during floods).	take into account natural disasters • Floods? • Mudflow? • Landslide? • Hurricane? • Fire? • The source of the disaster near a hazardous object?			
	Pre-warning systems and signals				
24	In case of emergency, it is necessary to have essential pre-warning systems and alarms. Pre-warning systems have two requirements: 1. Connection of measuring instruments in the hands of the organization, including communication between stations, etc.	• Do you have an accurate description of the pre-warning systems and signals? • Are there any explanations for the distribution of measuring instruments? • Is the cooperation between the measuring stations described? • Is the harmonious work of the technical elements agreed?			
	2. Appropriate technical equipment for catastrophic event detection and assessment of pre-warning systems and alarms	- Detection - Warning assessment - Purpose of the alarm			
25	Pre-warning systems are installed at hazardous facilities by the operator and by state authorities for the entire river catchment basin.	• Does each operator have a single warning station to the hazardous object connected to the national warning system?			
26	Are pre-warning systems attached to the International Plan of Action led by the Joint Bodies?	• Whether pre-warning measures and alert international plan is valid? If “yes”, are they included in the contingency plan?			

27	There is a need for continuous monitoring of hazardous objects, which will create a statistical series, continuous observations to develop pre-warning measures at different levels. These observations should be agreed with the competent authorities, in accordance with the relevant international action plan, for the development of pre-warning measures (e.g. Mtkvari River Catchment Basin, etc.).	• Is there continuous monitoring of the real dangerous object done by the operator? • Do you have access to an international warning plan? • Are there any barriers determined to reporting pre-warning activities? • Do you have access to the duration of natural disasters when calculating scenario modeling? • Are these scenarios included in the contingency plan?			
	Mutual assistance in an emergency				
28	In practice, how much mutual assistance is possible, which should be provided by the competent authorities with the help of other countries in case of emergencies?	• Has the transit cargo passage scheme been developed by the competent organizations? • Is there an agreement between states on mutual assistance in an emergency?			
29	Competent bodies should develop a special plan for the transit of rescuers and special equipments.	• Is there a normative regulation on the entry of technology and special equipments?			
30	Competent bodies should be able to exchange technologies related to accident elimination.	• Is it necessary to exchange technologies? • Exchange of experience and information? • Providing technical assistance?			

Chapter 8.

Raising the environmental education of the population living in flood risk areas

Knowledge of the rules of conduct and actions of the population in emergency situations, including floods, for each resident living in a high disaster risk zone, in addition to being a determinant of knowledge of specific methods and rational actions, it also contributes to extreme psychological resilience and self-confidence.

If the population lives in the tail-water of the dam, then they are in the high risk zone and should definitely know:

- Possible boundaries of flooding, as well as elevated areas in the immediate vicinity of the place of residing, which are rarely flooded, and the shortest access roads to them. Practice has shown that when large reservoirs break through, tsunami-type waves are triggered in the ravine (see Figure 8.1), the only means of protection of which is the organized evacuation of the population.

Fig. 8.1. Triggering the tsunami-type waves

- Each family member should know the evacuation plan, as well as the rules of conduct in the event of a sudden and rapid flood. Remember the storage places for boats, rafts and building materials needed for their construction.
- Make a list of necessary documents, items and medicines to take with during the evacuation. Put the necessary warm clothes, supplies of products, water and medicines in a special suitcase or backpack.
- Immediately leave the dangerous zone of possible catastrophic flooding and move to a safe area or elevated place, taking with them documents, jewelry, necessary items and supplies of products for two days as soon as they receive the warning signal for flood threat (Fig. 8.2) and evacuation notification. Get registered at the evacuation point. Pets are also subject to evacuation.

Fig. 8.2. Floods in the river bed

- When leaving the house, turn off the electricity and gas, extinguish the fire in the oven, attach all floating objects outside the building or place them in auxiliary storage. If time allows, move valuables to the upper floors of the house, or to the attic. Close the doors and windows, and if necessary and when time allows, board up the windows and doors of the first floor with planks from the outside.
- In the event of a catastrophic flood, in order to protect oneself from a breakthrough wave impacts, you need to quickly take an elevated place, climb a large tree, on the upper tiers of solid buildings (Fig.8.3), if they are in the water, when the wave approaches, do not get confused and do not panic, dive deep into the water and after some delay - surface to the surface of the water by underwater swimming. When in the water, by swimming or using swimming equipment go to a dry place, preferably on a road pile or dam - in a non-flooded area.

Self-evacuation of people by walking or by available swimming means is permissible in the following cases: If you see an un-flooded area directly, you have run out of food, getting outside help is becoming unpromising or you need urgent medical attention.

Fig. 8.3. Primary self-protection measures in case of flood

Show restraint during the flood and do not panic. They should bring the boats in order, and if they do not have them, prepare them from local materials. If one finds himself in the water, should try to discard heavy clothes and shoes, swim to un-flooded places. Be careful of objects floating on the surface of the water to avoid possible injury.

If there is no organized evacuation, climb to the top floors, roofs, trees, or other elevated objects before rescuers arrive or the water level drops. At the same time, constantly send a distress signal: during the day - by exposing or shaking a piece of well-visible fabric attached to a stick, and at dusk with a light signal and periodic contact. When rescuers approach, calmly, without panic, carefully go to the swimming equipment. At the same time, strictly follow the requirements of the rescuers, do not allow the swimming equipment to be overloaded. Do not leave their seat while traveling, do not sit on the outer boundary, exactly follow the instructions of the crew.

During the floods, in addition to the collapse of the existing medical care system in the disaster area, a number of other serious problems also arise. The demolition of buildings disables vital facilities such as electricity and water treatment plants - unsanitary conditions can be created, which poses a risk of spreading infectious diseases. Therefore, these issues should be under the constant attention of the health services of the respective regions.

Key Findings

With the financial support of Shota Rustaveli National Science Foundation of Georgia Grant Project - # FR17_615 "Assessment of Vulnerable Infrastructure Safety Risks in the Formation of Predictable Disasters" and according to the project plan-schedule, according to the theoretical researches and the field-scientific studies conducted during expeditions carried out on the Zhinvali earth dam in Dusheti region in the period 2019-2021, the following general and basic conclusions can be made:

- The role of high-rise dams in flood control and the need to determine the reliability and risk of working during their operation are presented and evaluated in the introductory section;
- The strengths and weaknesses of the CAPRA model are discussed and evaluated; The essence of the risks included in the (CAPRA) model and its management directions are discussed, taking into account the critical condition of the risk framework and the key determinants of the risk portfolio; Areas of risk identification and analysis, risk management and response measures and qualitative assessment directions are presented;
- Algorithms of computer programs (Volna-4 and MIKE-21) have been reworked and refined, and using GIS technologies, the methodology for forecasting the hydrodynamic parameters of a tsunami-type wave in case of a possible breakdown with different degree of collapse of Zhinvali earth dam (E_p = 1,0;

0.75, 0,50; 0,25) is proposed, taking into account the time factor and determining the contours of flooded areas (Dusheti and Mtskheta municipality territories, the territories of Tbilisi and Rustavi) taking into account the relevant risk factors.

- Based on the analysis of theoretical and field scientific researches, as well as in case of water flow over Zhinvali earth dam, when waves are provoked, for the purpose of studying the extreme waves formed in the reservoir and predicting the risks, numerical formulation of two- (2D) and three-dimensional (3D) mathematical models of non-stationary wave boundary problems based on small-amplitude wave theory is established;
- The speed of tsunami-type wave motion, the depth of flooding in flooded areas and the geometric dimensions of their dispersal from the axis of symmetry of the river bed to the left and right banks are determined; Data are entered on digital maps using GIS technologies;
- Based on the analysis of field scientific and theoretical studies conducted at the Zhinvali Reservoir during the expedition period in 2019-2021, the territories with high risk of flooded areas in case of a possible breakdown of the Zhinvali earth dam, and the population of Dusheti and Mtskheta municipalities have been identified, which at the first approximation constitutes 14,823 locals in Dusheti and Mtskheta municipalities;
- For the first time, a methodology was developed in this scientific paper, which focuses on the assessment, accounting

of the loss caused by the disaster, the development, analysis and sustainability of the rehabilitation plan of the affected population;

- The loss in case of a possible Zhinvali earth dam breakdown is represented at the first approximation as the sum of losses caused directly to a hydraulic facility, industry, agriculture, forestry, utilities and human casualties;
- In order to enhance the environmental education of the population living in flood risk zones, emergency knowledge, including knowledge of the rules of conduct and action during a flood, for the population living in a high disaster risk zone is reviewed and assessed;
- Areas of knowledge of specific techniques and knowledge that define rational actions, which at the same time contribute to a human’s psychological resilience and self-confidence in extreme conditions, are presented. It is noted that if the population lives in the tail-water of the dam, then it is in the high risk zone and the population should be aware of the possible boundaries of flooding, as well as elevated areas in the immediate vicinity of the residential place, which are rarely flooded and the shortest access roads to them.
- Locals living in the tail-water of the dam, e.g. in the high-risk flood areas, each member of the family should know the evacuation plan, the location of the medical care system, as well as the rules of conduct in case of sudden and rapidly formed floods and ways to implement it.

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