UDC – 626.823.69:626.823.6.4

ECONOMIC DAMAGE FROM ACCIDENTS AT HYDRAULIC STRUCTURES – WORLD EXPERIENCE AND PREVENTIVE METHODS OF PROTECTION IN THE REPUBLIC OF ARMENIA

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https://doi.org/10.56243/18294898-2025.2-3

Bulletin Of High Technology N 2 (34) 2025.-pp. 3-26. **WATER SYSTEMS**

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Abstract

Hydraulic failures are a global problem where engineering, ecology, economics and social responsibility intersect. Development of monitoring technologies, improvement of design solutions and implementation of international safety standards are the key to reducing risks and protecting the population.

Given the large number of dams existing in the world, the safe operation of these structures takes on important social, economic and environmental significance. A dam failure can have extremely negative consequences, including large human casualties. For countries with a large number of dams, the issue of ensuring their safety becomes especially acute.

The failure of dams and other hydraulic structures causes enormous economic losses, including the costs of rebuilding infrastructure, eliminating the consequences of floods, compensating for damage to property and businesses, as well as long-term environmental costs and the costs of economic recovery. Physical modelling is a powerful tool that can be used at the end of the design phase to check that all the design criteria have been met and thus guarantee the long-term structural soundness of the structures and ensure that they will function efficiently from the hydraulic standpoint, whatever the conditions. Physical modeling is also very useful in the rehabilitation of hydraulic structures after accidents.

Keywords: dam failure, hydraulic modeling, laboratory testing, safety of facility operation.

Introduction

The socio-ecological consequences of dam failures, caused mainly by the impact of the breakthrough wave, exceed the consequences of accidents at many other engineering structures. The number of human casualties and material damage from dam failures and accidents at large hydraulic structures are comparable to the consequences of natural disasters and accidents at nuclear power plants.

Physical modelling offers a means of obtaining a technically and economically optimised design of the hydraulic structures associated with dams and hydropower schemes. In particular, it allows vortices, strong turbulence, and complex flows involving air/water mixtures to be replicated. The principal objective of the studies that on physical models is to validate and optimise the various hydraulic aspects of a dam project (new or rehabilitation), with a view to guaranteeing the degree of safety whilst avoiding any excessive oversizing. Optimisation and validation of the design of dam safety structures (flood spillways, downstream stilling basin, surge shaft, etc.) Determination of the stage/discharge relations for complex structures. Study of 3D flows on the approaches to structures to structures and in their vicinity (for example formation of vortices at the inlets to water intakes or in forebays). Study of sedimentation risks in reservoirs and with regard to water intakes, and validation of structural or operational solutions (bypasses, sediment deposition areas, flushing structures) [1].

A comprehensive analysis of international experience allows us to draw the following conclusions:

1. Damage from accidents at hydraulic structures is large-scale and multi-layered, especially in densely populated and industrial areas.

2. Prevention is cheaper than elimination of consequences – investments in monitoring, modernization and risk management are justified in the long term.
3. New challenges – climate change, increasing number of extreme weather events, etc. require revision of design standards.
4. International cooperation and data exchange (e.g. through ICOLD) help to develop common approaches to dam safety.

The most common causes of accidents at hydraulic structures are:

- Natural disasters (floods, mudflows, earthquakes, etc.);
- Technical defects and aging of structures;
- Violations of operating rules and insufficient supervision;
- Failure of engineering systems;
- Human factor: from negligence to deliberate actions (including military ones).

The economic consequences of dam failures and accidents at large hydraulic structures include:

- **Damage to infrastructure**:

Destruction of roads, bridges, buildings, dams, power plants, water pipes and other infrastructure.

- **Losses in agriculture**:

Flooding of agricultural land, crop damage, loss of livestock, disruption of agricultural production.

- **Damage to industry**:

Destruction of industrial enterprises, stoppage of production, loss of jobs.

- **Long-term recovery costs**:

Expenses to eliminate the consequences of the flood, restore infrastructure, provide assistance to victims, compensate for damage.

- **Environmental damage**:

Water and soil pollution, disruption of ecosystems, loss of flora and fauna.

- **Social costs:**

Deaths, injuries, population displacement, psychological trauma.

The Kakhovka Dam failure affected more than 100,000 people, and long-term recovery costs are estimated at several billion dollars.

The 2010 Indus River dam collapse in Pakistan caused $6.2 billion in damage, destroyed thousands of homes and flooded millions of hectares of farmland. Up to 895,000 homes were destroyed and more than 2 million hectares of farmland were flooded. More than 1,700 people died. The flooding affected up to 20 million people in the country, according to the UN.

The collapse of the Brumadinho Dam (Brazil, 2019), which held waste from iron ore mining (tailings pond), resulted in the death of 270 people. The environmental disaster and the shutdown of the mining company Vale S.A. cost more than US$7 billion. This includes: payments to the families of the deceased and injured; fines and compensations; environmental costs; reputational damage; and a drop in the market value of shares. What makes this case special is the combination of environmental, economic, and legal damage, which illustrates the growing demands for business responsibility for man-made risks.

As a result of the accident at the Sayano-Shushenskaya hydroelectric power station (Russian Federation, August 2009), 75 people died, the equipment and premises of the station were seriously damaged. The work of the station for the production of electricity was suspended. The consequences of the accident affected the environmental situation of the water area adjacent to the hydroelectric power station, and the social and economic spheres of the region. The amount of damage amounted to more than 40 billion Russian rubles.

One of the most tragic man-made disasters of the 20th century occurred in Henan Province (Banqiao, China, 1975). As a result of the failure of the Banqiao Dam after Typhoon Nina and the cascading destruction of neighboring dams, more than 170,000 people died. The damage was estimated at more than $1.5 billion (in 1975 prices), which is equivalent to over $10 billion today. Millions of homes were destroyed, crops were destroyed, and transport infrastructure was destroyed. The disaster demonstrated the vulnerability of design solutions to extreme climatic events and the lack of early warning systems.

The Orroville dam (California, USA) in 2017 was at risk of failure due to erosion of the main and emergency spillways. The accident was avoided, but more than 180,000 people were evacuated, and the costs of repairs, temporary accommodation, logistics and strengthening of infrastructure amounted to about $ 1.1 billion. This case showed that even in highly developed countries, rapid deterioration of hydraulic structures is possible if risk assessments are not carried out in time and modernization is not invested in.

Assessing economic damage is an important tool not only for analyzing the consequences, but also for justifying investments in the safety of water infrastructure.

World practice offers the following approaches to assessing economic damage from accidents at hydraulic structures:

- Modeling destruction scenarios;
- Inventory of assets in the flood-prone area;
- Estimate of restoration costs (repairs, compensation);
- Calculation of long-term losses (downtime of hydroelectric power station, crop loss, reduction of tourism).

Indicators of indirect losses, such as declining property values, deteriorating investment climate, and rising prices for utilities and food products, should also be taken into account.

Research Results

Considering that hydraulic structures are not subject to precise calculations, physical modeling plays an important role in their construction, restoration, technical diagnostics and emergency response. In this regard, hydraulic modeling laboratories are of great importance for ensuring the safety of hydraulic structures.

Model studies of structures allow to increase the safety of water facilities and reduce the costs of construction and operation.

Hydraulic modeling is carried out for the following hydraulic structures:

- Dams;
- Catastrophic spillways;
- Water intakes;
- Artificial and natural canals, aqueducts;

- Anti-mudflow structures;
- Pumping stations, hydraulic rams;
- Hydro turbines;
- Hydraulic locks;
- Water conduits, water diversion structures;
- Water treatment facilities;
- Drainages, melioration systems,
- Fish passages.

Hydraulic modeling laboratories in several countries

The world's leading scientific centers and universities, successfully combining educational and scientific research processes in the field of water issues and hydraulic engineering, have achieved tangible successes. In particular, the hydraulic research laboratories operating within them, along with the implementation of scientific research and experimental programs, are used to organize training courses and student research work. Information about a number of such laboratories is provided below.

The University of Utah is ranked 62nd in the list of the best universities in the United States. The university is rightfully considered the heart of innovation. It combines engineering, medicine, and economics. Fig. 1 shows some models of the hydraulic research laboratory of the University of Utah, USA.

Fig. 1 Hydraulic Modeling Laboratory at the University of Utah (USA)

In particular, in 2024, the University of Utah Hydraulics Lab developed a device (AWH) to extract water molecules from the air and then release them into liquid form under the influence of heat. The device uses hygroscopic materials, such as metal-organic frameworks, which have high selectivity and the ability to absorb water vapor. Even a small amount of this material can hold a lot of water.

The research and design potential of the VNIIG named after B.E. Vedeneyev (RF) is in demand by a variety of industries, but the main focus of work is on topics related to hydropower [1]. The VNNIG hydraulic laboratory has an experimental hall measuring 140 x 48 m. The room contains a 5,000 cubic meter basin with a pumping station that provides water circulation for the laboratory. In the center of the experimental hall there is a free space for placing spatial models (Fig. 2).

Fig. 2 Hydraulic Research Laboratory of the B.E. Vedeneyev Institute of Hydraulic Engineering (St. Petersburg, Russia)

For research of fragments of hydraulic structures on flat and semi-spatial models of large scales, as well as for conducting methodological research, the laboratory has eight stationary hydraulic trays. The laboratory of the institute houses cavitation, aerodynamic, high-pressure and other stands.

The Hydraulic Research Laboratory of the Technical University of Athens deals mainly with wave modelling problems (Fig. 3).

The study of wave action on structures in laboratory conditions is carried out in wave trays on a two-dimensional model (plane problem) and in wave pools on a three-dimensional model (spatial problem). In the case of spatial modeling, all three dimensions of the object under study are introduced into the study to the fullest extent possible: its height, width and the third dimension, for example, the profile of the coast and its orientation in relation to the wave beam at different non-frontal approaches to the coastline, in particular, the entire actual relief of the coast and the bottom of the reservoir is fully reproduced.

Fig. 3 Hydraulic Research Laboratory of the Technical University of Athens (Greece)

Hydraulic structures built on rivers must be able to withstand mudflows and flash floods.A mudflow is one of the most dangerous natural phenomena. It is a sudden, rapid flow of mud, rocks and water. A mudflow poses a threat not only to human life, but also leads to material damage and destruction of infrastructure. Unlike ordinary flows, mudflows do not move continuously, but in separate shafts (waves), which is due to the mechanism of their formation and the jam nature of the movement - the formation of accumulations of solid material in narrowings and on bends of the channel with their subsequent breakthrough. Mudflows move at a speed of up to 10 meters per second or more. The volumes of one-time removals reach hundreds of thousands, and sometimes millions of cubic meters, the size of the transferred debris is 3-4 meters (in diameter), with a mass of 100-200 tons. Having a large mass and speed of movement, mudflows destroy structures, infrastructure facilities, and destroy agricultural lands.

Flood waters, overflowing their channels or changing their natural channel, inundate coastal agricultural and other lands. Floods cause significant damage to coastal buildings and engineering structures, including bridges, roads, irrigation networks, etc. Large-scale landslides occur.

The laboratories of the Moscow Hydrodesign Institute named after N.E. Zhuk (Fig. 4), Moscow State University of Civil Engineering (Fig. 5) and Novocherkassk Engineering and Reclamation University (Fig. 6) specialize in hydraulic studies of river hydraulic structures.

Fig. 4 Hydraulic research laboratory of the Moscow Hydrodesign Institute named after N.E. Zhuk (Russia)

Fig. 5 Hydraulic Research Laboratory of Moscow State University of Civil Engineering (Russia)

Fig. 6 Hydraulic research laboratory of Novocherkassk Engineering and Meliorative University (Russia)

The center of leading hydraulic modeling laboratories "Artelia" is located in Grenoble (France) (Fig. 7).

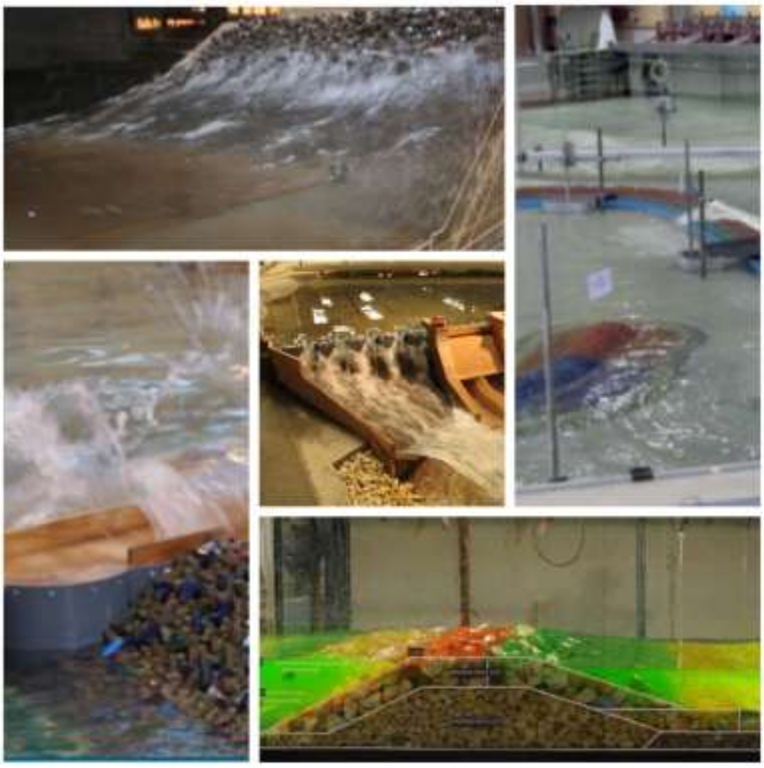

Fig. 7 Hydraulic research laboratories "Artelia", Grenoble (France)

The Scientific and Educational Center for Hydraulic Research in Tajikistan was closed for more than 30 years, and its restoration was a significant step in the development of the scientific research and educational base in the field of water management (Fig. 8). The laboratory is equipped with modern equipment. The Ministry of Energy and Water Resources of Tajikistan considers the opening of the laboratory one of the key goals of the strategy for scientific, technical and personnel support of the water industry. The renewal of this laboratory creates the necessary conditions for the training of highly qualified specialists in demand both in Tajikistan and abroad [3].

Fig. 8 Hydraulic research laboratory of the Tajik Agrarian University

The hydraulic modeling laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov is one of the best in the South Caucasus. In terms of its capabilities, it is not inferior to similar laboratories in many leading countries. The laboratory has existed for about 30 years since its denationalization, having been replenished with a number of new structures (Fig. 9).

In the laboratory of hydraulic research, models of the culvert were built, on which the structural features, types and sizes of coastal protection measures of mountain rivers were determined based on the results of the tests. A large amount of theoretical and experimental research was carried out on the protection of pipelines against non-stationary fluid movement, in particular, hydraulic shock.

In 1997-98, an automatic system for protecting against hydraulic shock in the 1st stage of the Mkhchyan pumping station's pumping pipelines was developed, designed and installed, which is still in operation today. The implementation of this system eliminated frequent pipeline ruptures in the event of emergency power outages.

Fig. 9. Hydraulic research laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov (Armenia)

Modeling of water intake structures

Whether in a marine or river environment, on an urban or industrial site, the design of a water intake for a process (hydropower, irrigation, drinking water, industrial use, cooling, etc.) or an outfall discharging effluent into the environment raises issues that are often examined using physical modelling. Water intake structures must comply with a certain number of hydraulic design criteria, such as: uniform intake velocity; absence of vortices; limitation of head losses; low sensitivity to floating debris; fish-friendliness; etc. Similarly, to minimise environmental impacts, effluent discharged from the outfall must be well diluted in the receiving environment. The energy from the flow must be dissipated efficiently in order to limit risks of scour. The structural stability of intake and outfall structures exposed to hydrodynamic stresses from their environment must also be checked. [1].

In the area of water intake and sanitation, the following tasks must be solved:

- dimensional design and hydraulic optimisation of intake and outfall structures;
- checking of different operating configurations and identification of operating limits (flow rate, water level, obstruction, head loss);
- characterisation of hydraulic behaviour, velocity field and risk of air entrainment;
- checking of efficient effluent dilution following release from an outfall
- checking of the hydraulic stability of intake and outfall protection structures.

An example of a model of a shaft-type water intake structure is shown in Fig. 10, Scale 1:20.

Fig. 10 Water intake in a vortex drop shaft (Scale 1:20) [1]

An example of a model of a water intake structure for a hydroelectric power station (Morocco) is shown in Fig. 11, Scale 1:68.

Fig. 11 Wave propagation on the outfall structure of the Safi thermal power plant (Morocco) - Scale: 1:68 [1]

An example of a model of a water intake structure hydroelectric power station (Portugal) is shown in Fig. 12, Scale 1:33.

Fig. 12 Upstream water intakes of the Venda Nova III (pumped storage) hydropower scheme (Portugal) - Scale: 1:33.33 [1]

Spillway structures

Optimising and validating the design (new or rehabilitation) of flood spillways: a critical issue with regard to dam risk management.

The flood spillway of a dam built for any purpose (hydroelectricity, irrigation, flood protection, etc.) is a safety component designed to avoid an uncontrolled rise in reservoir level during a flood in the catchment basin, a water overflow over the dam crest, and the potential subsequent failure of the dam and all the ensuing catastrophic consequences for the population living downstream. For this reason, correct spillway dimensional design and operation are fundamental aspects of risk management.

Physical modelling is the best tool for checking and optimising the hydraulic design of these structures, and the entire profession (project owners, engineering consultants, control authorities, funding agencies) has used it continuously for more than 100 years, in spite of the emergence since the early 2000s of numerical modelling, which still tends to remain insufficient for certain technical aspects [1].

Physical modelling contributes a guarantee of satisfactory operation over the full range of the expected flow rates, detecting and correcting any possible hydraulic malfunctions that would not be seen in an analytical approach, and if necessary searching for the geometrical configuration that will be sufficient to ensure an adequate degree of safety, without excessive oversizing.

The physical model allows all the hydraulic aspects of the operation of a spillway to be explored, in particular the following main points:

- Discharge capacity of the structure: the "stage-discharge" relation for various degrees of opening of any movable components. This point in particular can be of great interest:
  - for the dam design, potentially generating significant savings,
  - providing discharge charts for the future operator of the prototype structure;
- Determination of water level profiles and changes in flow conditions (free surface, pressurised);
- Evaluation of energy dissipation and risk of scouring at the downstream toe;
- Mesurement of forces and pressures;
- Evaluation of sensitivity to floating debris;
- Identification of areas of negative pressure on training walls or aprons;
- etc.

Physical modelling provides substantial technical added value for all spillway construction or rehabilitation projects:

- involving large dimensions or conveying large floods;
- where there is potential to make real budget savings, but a need for reliable verification;
- with a complex geometry and in which the dam - even if it is small - presents a particularly high safety concern.

The following structures are systematically tested using a hydraulic model:

- spillway equipped with fusegates;
- nonlinear spillways, for example labyrinth or semi-labyrinth configurations;
- spillways equipped with gates or flaps;
- high-velocity pressure spillways;
- morning glory spillways;
- lateral spillways with the risk of submersion of the weir from the downstream side;
- high velocity chute;
- flip bucket spillway with a natural or concrete-faced stilling basin;
- etc.

To increase the useful volume of the reservoir, a water-retaining structure can be installed on the head of a concrete dam or on the crest of the head of a spillway structure – an additional barrier that, if necessary (dangerous), opens and allows the water level, which has risen above the design level, to be lowered.

The increase in the useful volume of the reservoir may vary from the normal backed up level of the reservoir to the fared backed up level. However, in the case of an increase in flood flows, an unacceptable increase in the water level in the upper pool of the reservoir may occur, requiring the operator's intervention to open the gates of the spillway structure.

It is necessary to take into account that in emergency situations the valve control equipment may fail.

In particular, due to the lack of backup power supply for the electric motors of the pre-turbine gates of the Sayano-Shushinskaya hydroelectric power station, the turbine penstock was not automatically closed, which resulted in an increase in the development time of the disaster, which led to further destruction.

The «Hydroplus» system gates are free from the above-mentioned drawbacks, which is why they have found wide application at many hydroelectric power plants [4]. The «Hydroplus» system gates are installed on the upper part of the spillway of the dam and are designed to increase the useful volume of reservoirs and ensure safe passage of flood discharge. Their first prototype is a sand embankment erected along the entire length of the spillway structure. If the water level in the reservoir does not exceed a specified value, the embankment is stable, and an additional volume of water accumulates in the reservoir. When the water level on the spillway exceeds a specified value, the embankment is destroyed and washed away by the flow of water.

The appearance of the "Hydroplus" system is shown in Fig. 13.

Fig.13 Retaining structure of the "Hydroplus" type

In particular, the design of the «Hydroplus» system was modeled in France (Fig. 14).

Fig. 14 Development of piano-key weirs on the existing spillway at the Charmine dam (France) [1]

The design of the stationary automatic gate was developed and tested by professors Albert Margaryan and Vache Tokmajyan in the laboratory of hydraulic modeling of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Egiazarov (Fig. 15) [5].

The purpose of the experimental study was:

1. checking its operability;

2. determining the value of the opening angle of the gate shield depending on the amount of water supplied to the pool;

3. checking the operability of the seals, changing their design or material if necessary;

4. determining the effect of the hydroballast regulator on all phases of the gate operation;

5. checking the functionality of the softener , adjusting the opening-closing speed (if necessary, changing the type of throttle unit by increasing or decreasing the throughput capacity of the valve).

Fig. 15. Testing of the model and prototype of a stationary automatic gate in the hydraulic laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov

When constructing the theory of hydraulic calculation of the gate, the main initial data are the estimated maximum flow rate of the river flowing into the reservoir, and the maximum flood level determined for the reservoir. The use of a stationary automatic gate allows to significantly increase the accumulation of additional water in the reservoir, ensuring the safety of the dam operation. Only by installing the already developed gate with a height of 1 m, on the Akhuryan, Azat and Kechut reservoirs, it is possible to accumulate an additional 46 million m3 of water per year. Since this volume is at the highest existing mark of the reservoir mirror, it creates the possibility of irrigating an additional 9,000 hectares of land by gravity [5].

Fig. 16. Catastrophic spillways of the Kechut and Azat Dams, modeled in the hydraulic laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov

In 1995, as a result of an accident caused by a sudden flood, the power unit and the main building of the Argel HPP (Gumush HPP) were so damaged that foreign experts recommended building a new one next to the old one. However, a decision was made to restore the structure and a project was developed. The proposed designs were modeled in the hydraulic research laboratory of the I.V. Yegiazarov Institute of Water Problems and Hydraulic Engineering. The hydroelectric power plant was put into operation again in 1999.

A model of an earth dam breakthrough was built and tested in the hydraulic research laboratory of the I.V. Yegiazarov Institute of Water Problems and Hydraulic Engineering under the supervision of Professor Pargev Baljyan (Fig. 17).

Research has shown that, contrary to popular belief, the dam does not completely collapse during a breakthrough. Significant fragments of the dam banks (more than 50% by volume) remain undamaged. Experiments also show that the expansion of the initial dam breakthrough toward the river bed occurs more than 2 times faster than toward the walls. This fact is confirmed by world experience of natural disasters.

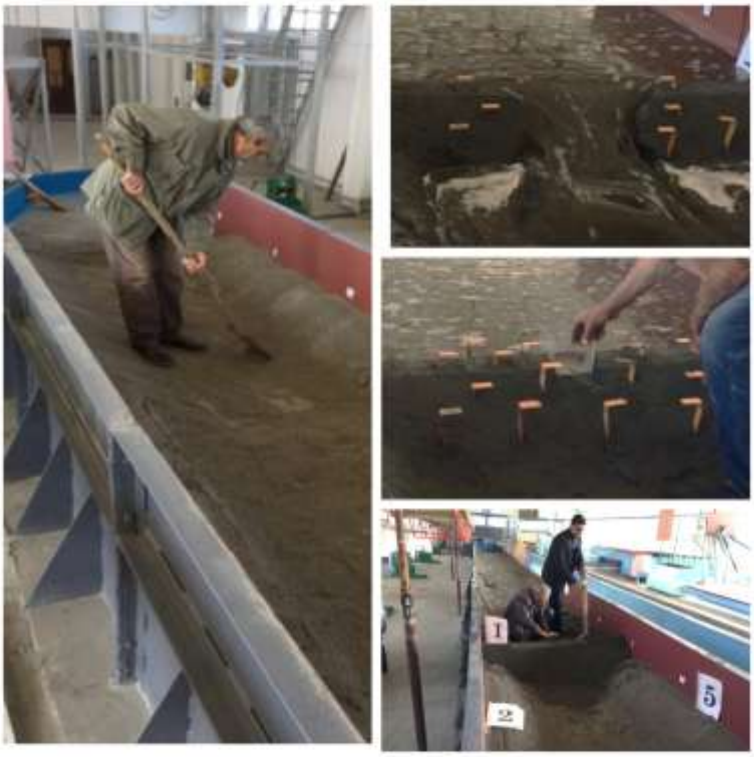

Fig. 17 Model of the collapse of an earthen dam in the Hydraulic Research Laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yeghiazarov

Mudflows. Sedimentation in rivers and reservoirs

The goal - Finding ways to manage the sedimentary impact of river structures, in particular sedimentation in dam reservoirs, to operate them sustainably in the long-term and limit their ecological impact. This sedimentary aspect of hydraulic projects is now rightly considered to be a serious environmental and sustainable management issue. In particular, the risk of sedimentation in dam reservoirs is an essential component of the dimensional design : sediments from the catchment basin can rapidly fill up part of the reservoir and thereby reduce its water storage capacity.

In the hydraulic modeling laboratory, it is possible to study the mechanisms of sedimentation of sediments in rivers and reservoirs. The physical model replicates these complex mechanisms and provides a means of testing various solutions to limit the impact of sediment on projects, such as by-passes, sediment flushing, or full gate opening during floods, in order to propose durable structures. In addition, these studies are paired with an operational study of the various hydraulic components of the structure (flood spillway, outlet structure, operation of the water intake, etc.) (Fig. 18 and 19).

World experience in hydraulic modeling to define and study [1]:

- Extremely precise physical modelling;
- Sediment transport: bed-load or suspended transport;
- Phenomena in steady and unsteady flow conditions.

Fig. 18 Modelling of sedimentation in the Inga dam headrace channel
Scales: 1:140 (horizontal), 1:100 (vertical)

Fig. 19. Model studies of erosion of accumulated sediments in the hydraulic laboratory of the Institute of Water Problems and Hydraulic Engineering named after I.V. Yrgiazarov (within the framework of the European program: Greece, Turkey, Georgia, Armenia)

High pressure water systems

In mountainous terrain, the pipelines of irrigation, gravity water pipelines for drinking water, and pumping stations have numerous siphon sections in the vertical plane, in which air accumulations are formed. The main reason for the formation of air accumulations in high-altitude sections of gravity pipelines is the entry of aerated currents arising in the head structures into the pipe. The upstream and downstream branches of high-altitude sections of the pipeline in most cases have large slopes, due to which the air accumulations formed in siphon sections are not carried away by the liquid flow under the conditions of the hydraulic regime of operation. As a result of all this, the amount of output released through the pipeline decreases. Not infrequently, in particular, in the case of relatively small diameter pipes, air accumulations become the cause of complete blockage of the pipe. The phenomenon of air emissions is extremely dangerous during the operation of the pipeline, which can lead to a loss of strength and stability of the structures of the head of the pipeline.

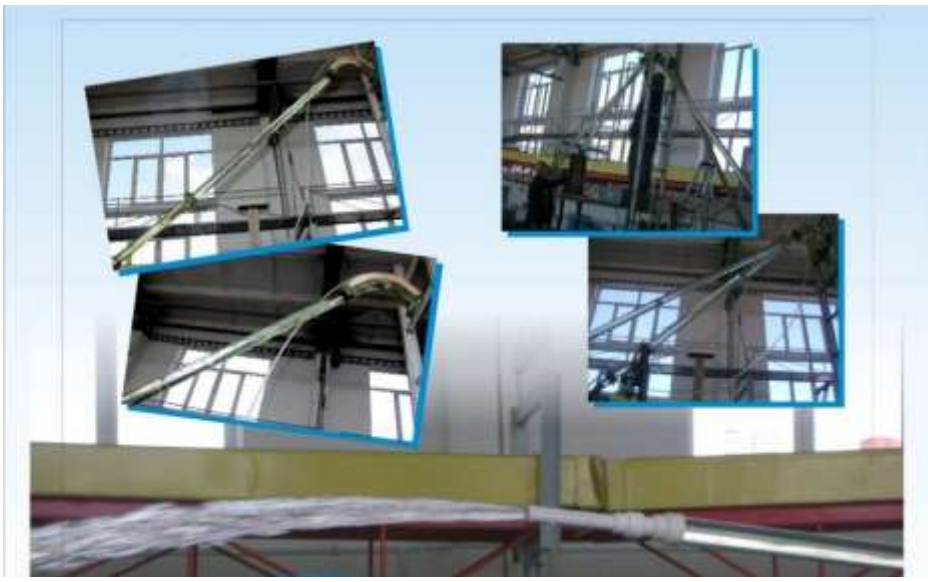

Fig. 20. Experimental setup for studying air accumulations in the hydraulic laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov

Preventive methods of protection of hydrotechnical structures

In order to take appropriate measures to prevent emergency situations and mitigate the consequences of possible accidents at hydraulic structures, it is necessary to predict all types of emergency situations that may arise and assess them taking into account the scale of the consequences in the event of a dam break [6].

During the design, construction, commissioning, operation, decommissioning, reconstruction or major repairs of hydraulic structures, as well as in cases of temporary cessation of activity, the owner or, on his behalf, the user draws up a declaration of safety of hydraulic structures, which is the main official document containing information on the compliance of hydraulic structures with safety standards [7, 8].

The preparation of a safety declaration for hydraulic structures in operation is preceded by their inspection. The safety declaration for hydraulic structures is prepared by their owner or user, and the declaration for hydraulic structures under design and construction is prepared by the customer. The Water Committee ensures that the safety declaration for hydraulic structures submitted by the declarant is examined and, based on the conclusion, approves it, which is subject to registration in the state water cadastre [7].

The Water Committee, in agreement with the interested state bodies, forms a technical commission to conduct an inspection of hydraulic structures. The Technical Commission establishes [8]:

1) Control over the activities of organizations operating hydraulic structures in terms of ensuring compliance with safety rules and regulations;

2) Assessment of the technical condition of hydraulic structures.

According to the decision of the Government of the Republic of Armenia, inspections and declarations of safety of hydraulic structures are carried out at least once every three years [9].

The declaration of safety of hydraulic structures may be supplemented and amended at the initiative of the declarant [7]:

- In the event of a change in conditions affecting safety;
- In the event of detection of new damage;
- After reconstruction, major repairs, restoration or termination of operation, before acceptance of the relevant construction and installation works.

Visual inspection may be accompanied by verification measurements and, if necessary, by decision of the technical commission, verification tests and calculations. The composition of special instrumental examinations is determined taking into account the purpose of the structure, its design features, natural, climatic and technological conditions, operating requirements, and the nature of defects in the structure [9]. Tests may be carried out in research laboratories that have the appropriate capabilities.

The hydraulic laboratory of the Institute of Water Problems and Hydraulic Engineering named after Academician I.V. Yegiazarov has the appropriate capabilities to conduct the necessary hydraulic tests.

A comprehensive assessment of observations to identify the genesis of anomalies in hydraulic structures can sometimes lead to radical inaccuracies, so it is necessary to separate possible violations and try to separately build cause-and-effect relationships for each violation. A scenario of possible failure development can be presented by constructing a so-called "failure tree", which will allow predicting the further course of development of phenomena and assessing its impact on the reliability of the structure.

The scope of work to assess the safety of a dam must be proportionate to the significance and complexity of the hydraulic structure, as well as the nature of the consequences of a possible accident.

Conclusions

1. The processes of investigating faults identified during the operation of dams and other large hydraulic structures should be based on the use of modern calculation methods and comparison of the results of hydraulic modeling.
2. Physical modelling is a powerful tool that can be used at the end of the design phase to check that all the design criteria have been met and thus guarantee the long-term structural soundness of the structures and ensure that they will function efficiently from the hydraulic standpoint, whatever the conditions (floods, screens blocked by waste, etc.). Physical modeling

is also very useful in the rehabilitation of hydraulic structures after accidents. In this regard, the issues of preserving and modernizing the relevant hydraulic modeling laboratories are relevant.

3. The solutions proposed on the basis of the study should ensure the safety of further operation of hydraulic structures, based on the following priorities:

- Physical safety of the population;
- Prevention of economic losses;
- Environmental protection;
- Prevention of transboundary impact.

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ՀԻԴՐՈՏԵԽՆԻԿԱԿԱՆ ԿԱՌՈՒՑՎԱԾՔՆԵՐԻ ՎԹԱՐՆԵՐԻ ՏՆՏԵՍԱԿԱՆ ՎՆԱՍԸ. ՀԱՄԱՇԽԱՐՀԱՅԻՆ ՓՈՐՁԸ ԵՎ ՊԱՇՏՊԱՆՈՒԹՅԱՆ ԿԱՆԽԱՐԳԵԼԻՉ ՄԵԹՈԴՆԵՐԸ ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆՈՒՄ

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[3]*Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ*

Հիդրոտեխնիկական կառուցվածքների վթարները գլոբալ խնդիր են դարձել ամբողջ աշխարհում: Այստեղ հատվում են ինժեներական, բնապահպանական, տնտեսագիտական և սոցիալական շահերը: Մոնիթորինգի նոր տեխնոլոգիաների մշակումը, նախագծային լուծումների կատարելագործումը և միջազգային անվտանգության ստանդարտների ներդրումը ռիսկերի նվազեցման և բնակչության պաշտպանությանն ուղղված երաշխիքներից են:

Հաշվի առնելով աշխարհում գոյություն ունեցող ջրամբարների մեծ թիվը, պատվարների անվտանգ շահագործումը ձեռք է բերում կարևոր սոցիալական, տնտեսական և բնապահպանական նշանակություն: Պատվարի փլուզումը կարող է հանգեցնել ծայրահեղ բացասական հետևանքների, այդ թվում՝ մեծ մարդկային զոհերի: Մեծ թվով ջրամբարներ ունեցող երկրների համար պատվարների անվտանգության ապահովման հարցը հատկապես կարոր է դառնում:

Պատվարների և հիդրոտեխնիկական այլ կառուցվածքների փլուզումը հանգեցնում է նաև հսկայական տնտեսական կորուստների, այդ թվում՝ ենթակառուցվածքների վերականգնման, ջրհեղեղների հետևանքների վերացման, գույքին և բիզնեսին հասցված վնասի փոխհատուցման, ինչպես նաև բնապահպանական և տնտեսության կայունացման

ուղղված երկարաժամկետ ծախսերի: Ֆիզիկական մոդելավորումը հզոր գործիք է, որը կարող է օգտագործվել հիդրոհանգույցների նախագծման վերջնական փուլում՝ ստուգելու համար կառուցվածքների նախագծային լուծումների ճշտությունը, որով երաշխավորում է դրանց անվտանգ աշխատանքը: Ֆիզիկական մոդելավորումը կարող է կիրառվել նաև վթարված հիդրոտեխնիկական կառուցվածքների վերականգնման գործընթացում արդյունավետ լուծումներ գտնելու համար:

Բանալի բառեր. պատվարի փլուզում, հիդրավլիկական մոդելավորում, լաբորատոր փորձարկումներ, կառուցվածքների շահագործման անվտանգություն

ЭКОНОМИЧЕСКИЙ УЩЕРБ ОТ АВАРИЙ НА ГИДРОТЕХНИЧЕСКИХ СООРУЖЕНИЯХ – МИРОВОЙ ОПЫТ И ПРИМЕНТИВНЫЕ МЕТОДЫ ЗАЩИТЫ В РЕСПУБЛИКЕ АРМЕНИЯ

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Аварии гидротехнических сооружений являются глобальной проблемой, где пересекаются вопросы инженерии, экологии, экономики и социальной ответственности. Развитие технологий мониторинга, совершенствование проектных решений и внедрение международных стандартов безопасности — ключ к снижению рисков и защите населения. Учитывая большое количество плотин, имеющихся в мире, безопасная эксплуатация этих сооружений имеет важное социальное, экономическое и экологическое значение. Авария плотины может повлечь за собой крайне негативные последствия, включая большие человеческие жертвы. Для стран с большим числом плотин вопрос обеспечения их безопасности приобретает особую остроту. Разрушение плотин и других гидротехнических сооружений наносит огромный экономический ущерб, включающий в себя затраты на восстановление инфраструктуры, ликвидацию последствий наводнений, компенсацию ущерба имуществу и бизнесу, а также долгосрочные экологические издержки и затраты на восстановление экономики. Физическое моделирование — мощный инструмент, который можно использовать на заключительном этапе проектирования для проверки соблюдения всех проектных критериев, что гарантирует долгосрочную прочность конструкции и гарантирует её эффективное функционирование с точки зрения гидравлики в любых условиях. Физическое моделирование также весьма полезно при восстановлении гидротехнических сооружений после аварий.

Ключевые слова: прорыв плотины, гидравлическое моделирование, лабораторные испытания, безопасность эксплуатации сооружений.

Submitted on 29.05.2025
Sent for review on 03.06.2025
Guaranteed for printing on 29.07.2025