Safety and risk categories of water reservoir hydrosystems

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Asror Yangiev, Furkat Gapparov, Dilmurat Adjimuratov and Sherzod Panjiev

Tashkent Institute of irrigation and agricultural mechanization engineers

E-mail: yangiev_asror_63@mail.ru

Abstract. The article provides an analysis of accidents and their main causes in existing reservoir hydro-systems in the world. Besides, the article presents the diagram for accident causes in reservoirs. Risk category assessment is given for Langar, Kizilsuv and Kalkamaflood-reservoirs. According to available data from the Congress on large dams, currently there are no regulations on risk assessment for water reservoir hydro-systems in Uzbekistan. In addition, major security challenges and recommendations are presented to improve the operation of water reservoir hydro-systems.

1. Introduction

Currently in Uzbekistan there are more than 4.2 million hectares of irrigated land. In practice, all agricultural crops are grown by artificial irrigation. Nearly 300 large hydrotechnical facilities operate for irrigation of these lands, including 59 reservoirs with total capacity of 20 billion m^3, nearly 65 large hydrosystems, more than 1000 small hydrotechnical facilities, more than 60 main and interfarm water canals. Total water consumption of half of the existing land comes from over 1.5 thousand, including 24 large pump stations with total capacity of 6.4 million m^3/s. The age of these structures is 50-60 years or more, there are cases of decrease in their technical condition and capacity due to their long-term use, insufficient amount and quality of repair works on them. In addition, the lack of attention to environmental factors in the process of operation leads to a decrease in the level of reliability of hydro-technical facility operation [1].

In Uzbekistan, large scale measures are being taken to effectively organize the operation and reconstruction of reservoirs. The Law of the Republic of Uzbekistan "On the safety of hydrotechnical structures", Decree of the Cabinet of Ministers of the Republic of Uzbekistan №499 "On measures for implementation of the Law of the Republic of Uzbekistan" dated November 16 1999, define the important tasks, governing the relations on ensuring the safety of hydrotechnical structures, arising in the implementation of activities associated with their design, construction and operation. Therefore, particular attention is paid to provision of their reliable and safe operation in the designing, construction and operation of water reservoir hydrosystems [2].

2. Research methods and results

Statistical data from literature reviews, data from field surveys, and theoretical processing of research results were used in the research process.

According to the International Commission on large dams, more than 45 thousand large dams have been built around the world, more than 60% of them are earth-fill dams. Approximately 45% of dams of various types have had accidents, as well as breakouts of the pressure front. Major catastrophic dam accidents have occurred in the United States, France, Italy, India, Brazil, South

Korea, Russia and other countries. Usually the most dangerous emergencies by their consequences occur when passing amounts of water, exceeding design spillway capacities through hydrotechnical structures. This is evidenced in material of the International Commission on large dams, according to which about 3 thousand accidents occur annually in the world at hydrosystems [3, 4, 5, 6]. The ratio of accidents on different types of dams is shown in Table 1.

Table 1. Accidents on various types of dams

Types of dams	**Frequency of accidents, %**
Earth-fill dam	53
Concrete gravity dam	23
Protective dams made of local materials	4
Arched reinforced concrete dam	3
Other types of dams	17

As seen in Table 1, every second accident is associated with earth-fill dams, and the accidents in concrete gravity dams occur two times less frequently.

The analysis show that the main causes of accidents are the base damage and insufficient capacity of the spillway when water flows over the dam crests [7, 8] (Table 2).

Table 2. Causes of accidents on the Hydro-technical structures.

Causes of destruction	**Frequency of accidents, %**
Damage of the dam base	40
Insufficient spillway capacity	23
Cavitation erosion	22
High pressure on the dam	5
Military action	3
Slope damage	2
Material defects	2
Improper operation	2
Earthquake	1

Schematic illustration of water reservoir accident causes is shown Figure 1.

The analysis show that the main causes of damage and accidents at the reservoir include technical failure of hydropower stations, water outlet, earth dam, spillway, and reservoir overflow.

Possible reasons for the failure of an earth dam due to loss of static stability or filtration strength may be the loss of static stability of the lower prism, dam, design-exceeded earthquake, terrorist attack, suffusion at the base of the dam, suffusion in the body of the dam, improper water resistance of the dam's anti-filtration devices [9, 10, 11 and 12].

Typical types of damage in spillway structures include corrosion of metal parts, jamming of gates, damage to gate support and motion devices, cavitation-erosive damage to the spillway, unacceptable filtration through cracks in the concrete lining, destruction from hydrodynamic loading and cavitation erosion of damping devices in the tailrace, deformation from an earthquake. The reasons for reducing the capacity of the spillway can be mechanical damage to the gates, mechanical damage in the slots of the gates, malfunctions of drive devices, loss of external power supply, malicious actions - a terrorist act. Hydrological data, collected during the operation of hydropower station indicate the need to adjust the values of a number of river regime characteristics, especially the maximum flow rates, which differ most significantly from those previously designed and determine the capacity of spillways [13, 14, 15, 16, 17, 18, 19, 20].

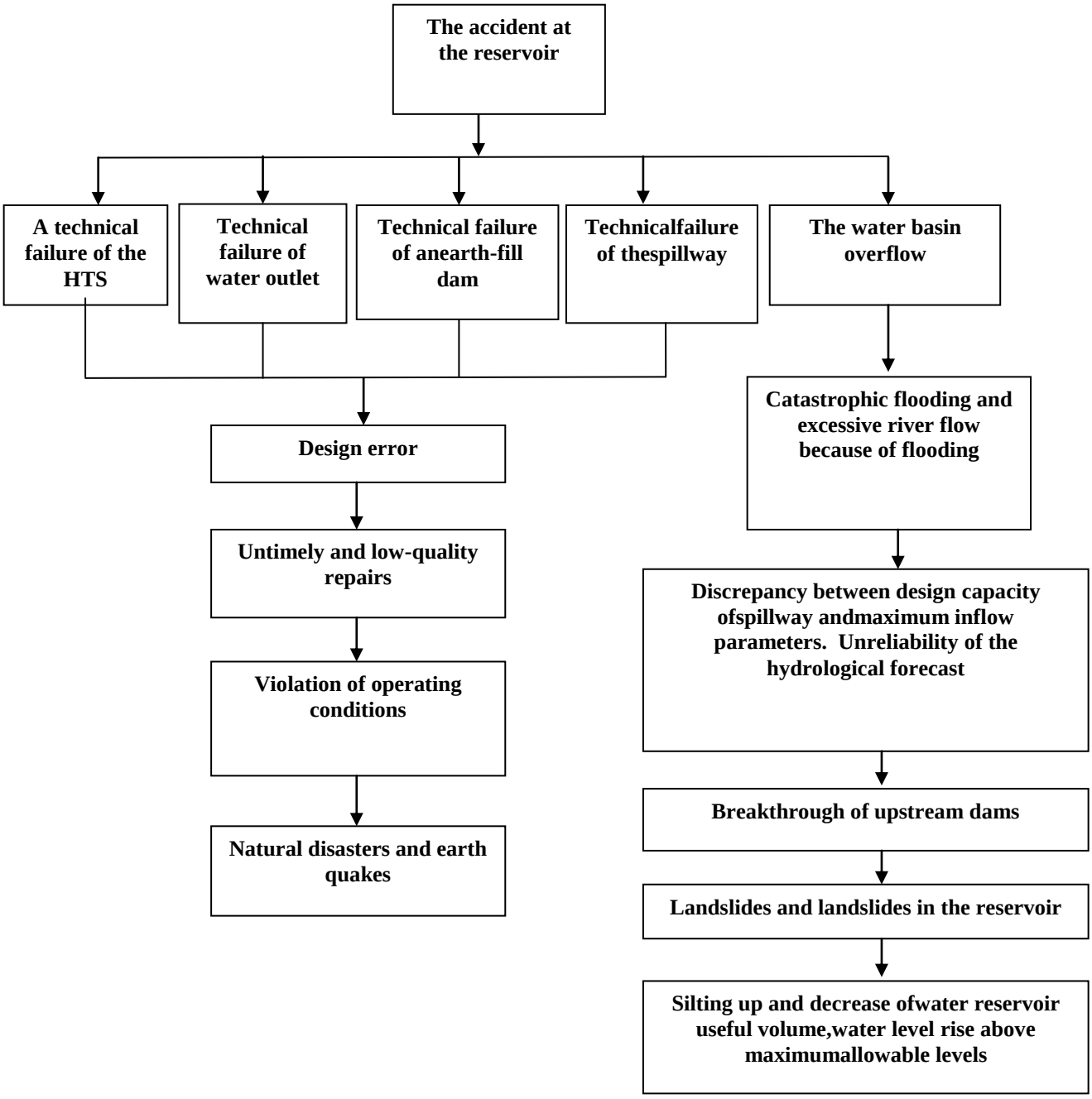

Figure 1. Water reservoir accident causes.

Because of global climate change on our planet, the frequency of natural hazard occurrence in nature is increasing. Such natural phenomena can be cited with the example of floods. In particular, in Central Asia, including the regions of the Republic of Uzbekistan, flooding and other dangerous natural phenomena have often occurred in the last decade because of climate change. As a result, short-term flood flows for several minutes to several hours causing damage to bridges, roads, canals, fields, crop fields and hydrotechnical structures. In order to study and analyze the factors that affect

the safety of operating reservoirs in the Republic, field observations were also conducted at number of reservoirs in 2019. In particular, Kashkadarya, Guzardarya, Tankhozdarya, Yakkabagdarya basins were considered to be the major flood centers in the Kashkadarya region. Therefore, because of floods in the water reservoirs, which is located in the basins of these rivers, many malfunctions are found. In other words, this is the cause of a large accumulation of sediments in reservoirs of restored water and floodwaters in river basins. During floods that occur randomly, there are violations in the operation of drainage and drainage structures (Figure.2).

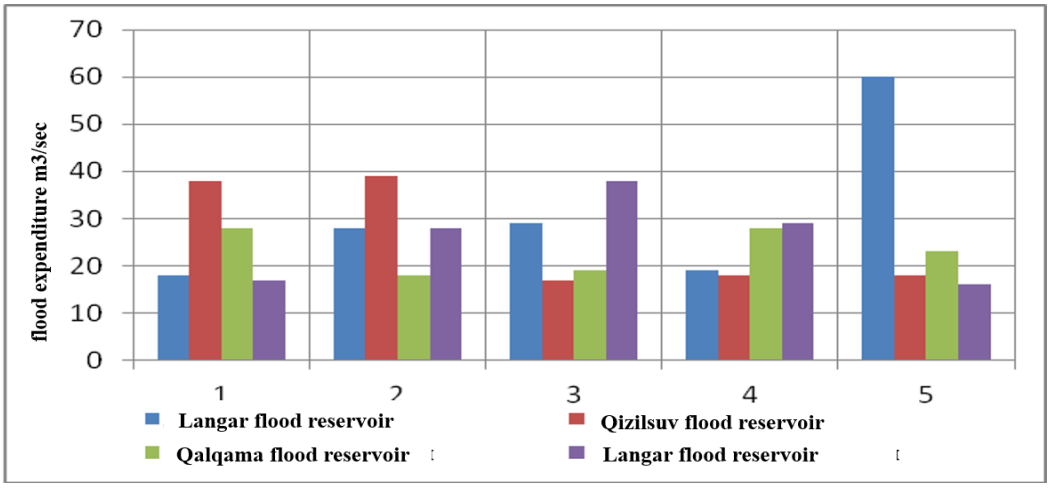

Figure 2. Changes in the maximum water consumption during flooding in the Kashkadarya River Basin

As the result of observation of the current technical condition of all hydro-technical structures in Langar reservoir the signs of damage were determined which are shown in Figure 3.

Figure 3. Damage caused by the flood in Langar reservoir.

The flood had negative impact on the technical condition of the water intake structure due to the fact that floods carry large amount of sediment.

The following are the safety categories of Langar, Kyzylsuv and Kalkam reservoirs according to the system for assessing the safety of hydro-technical structures proposed in the Bulletin of the 72nd Congress of the International Commission on large dams (ICOLD 72).

Table 3. Classification factors and points of assessing the safety of hydro-technical structures

Classification factors	**Base values for classification**			
Volume, (mln.m^3)	>120	120 – 1	1 – 0,1	<0,1
	(6)	(4)	(2)	(0)
Height of dam, (m)	>45	45 – 30	30 – 15	<15
	(6)	(4)	(2)	(0)
Population evacuation (number of people)	>1000	1000 – 100	100 – 1	-
	(12)	(8)	(4)	(0)
Potential damage to tailrace	High	average	low	-
	(12)	(8)	(4)	(0)

Based on the characteristics of the reservoir facilities, the scores of the flood-reservoirs determined in accordance with the recommendations of the Congress were determined in the tables below.

Table 4. Parameters and points of Langar flood reservoir

Parameters	**Size**	**Points**
Volume, (mln.m^3)	7.35	4
Height of dam, m.	34	4
Population evacuation (number of people)	1500	12
Potential damage to tailrace	Average	8
Total		28

Table 5. Parameters and points of Kizilsuv flood reservoir

Parameters	**Size**	**Points**
Volume, (mln.m3)	20.4	4
Height of dam, m.	56	6
Population evacuation (number of people)	2000	12
Potential damage to tailrace	Average	8
Total		30

Table 6. Parameters and points of Kalkama flood reservoir

Parameters	**Size**	**Points**
Volume, (mln.m3)	12	4
Height of dam, m.	21	2
Population evacuation (number of people)	1500	12
Potential damage to tailrace	Average	8
Total		26

Table 7. Determination of the category of the dam

Determining the dam category	
The sum of classification factors	**Dam category**
(0 – 6)	I
(7 – 18)	II
(19 – 30)	III
(31 – 36)	IV

According to evaluation results of the safety of hydro-technical structures proposed in the 72-Bulletin of the Congress of the International Commission on large dams (ICOLD 72) Langar, Kizilsuv and Kalkama flood-reservoirs in the Kashkadarya region were determined as the third category of facilities in the system.

Main problems in operation of water reservoir hydrosystems include low level of availability of modern control and measurement equipment, lack or unsufficient amount of control and measurement equipment in operating hydraulic structures. Only few of them are fully equipped with control and measurement equipment, exiting equipment for certain types of observations have physically worn out or are morally out of date, partially out of order, preventive measures to maintain operability and repair of control and measurement equipment are carried out not frequently enough, operational rules are not complied with and there is lack of information-analitical data, showing the whole cycle of dam operation, certain hydraulic structures don't have service instructions. Most hydraulic structures keep observation logs irregularly, measurements are not accurate and irregular, operational staff has low level of qualification and knowledge. Hydraulic structure maintenance specialists have insufficient amount of qualification, especially dealing with control and measurement equipment. Qualification promotion courses are not held regularly, there is insufficient financing of operational measures. Repair and reconstruction works, related with dam safety and reliability, are not done sufficiently in hydraulic structures and dams due to insufficient financing.

In this regard, the most important issue of ensuring the safety of water reservoir hydrosystems is the development of their risk category standard. In order to develop the risk category standard for water reservoir hydro-systems it is necessary to:

- carry out field observations and diagnostics of the technical condition and reliability of hydraulic structures;
- identify the list of risks that can lead to the destruction of individual elements or the whole dam;
- formulate the cadaster of hydro-technical structures;
- adjust the criteria for the safe condition of dams, taking into account the duration of the operating period.

3. Discussion

In Uzbekistan there is a large amount of collected informative data technical characteristics of objects, defects and factors affecting the safety of structures. Until recently, all this was recorded in logs, survey reports, inventories and reports of field observations, which made it very difficult to quickly analyze and predict the operational safety of the structure, as well as making decisions to prevent accidents under extreme operating conditions of hydro-technical structures. To solve these problems, computer information and analytical system for monitoring the technical condition of hydraulic structures was developed. The computer system is designed for collecting, storing, processing, convenient and easy access to all information, including graphics, obtained during special surveys. The system allows you to control the dynamics of the development of defects and damage to structures

and the effectiveness of their recovery during operation with the use of proper materials and technologies.

The database includes project data on the object, results of instrumental and visual observations of the state of structures, results of repair and restoration work and reference section.

The computer system functionally provides insertion of data on the results of observations of structures and on the repair and restoration work carried out, organization of user requests for information about the state of structures stored in the database, providing the user with tools for compiling documentation on the state of structures. Recommendations for prevention of accidents and reliable, safe operation of the reservoir-hydro system are necessary to perform a set of tasks related to the following issues:

- step-by-step restoration of out-of-order control and measuring equipment at hydraulic structures of reservoir hydro-units for continuous monitoring of their condition;
- continuous professional development of responsible personnel for the safety of hydraulic structures to ensure compliance with the standards and rules of their qualification;
- study of the world's best practices on modern methods and technologies for ensuring the safety of reservoir hydroelectric units and their implementation, as in recent years there have been major changes in scientific and technical progress, new approaches to solving certain problems have appeared;
- not allowing power outages at culverts without warning, leading to sharp wear of expensive equipment and accidents;
- compliance with the requirements of operating organizations based on legal acts on mandatory Declaration of safety of hydraulic structures during their design, construction and reconstruction, approval of their construction and reconstruction projects to justify safety and develop measures for their safe operation of structures;
- increasing the amount of funds allocated for the repair and reconstruction of reservoir hydroelectric units to ensure phased work to ensure the reliability of the technical condition and safe operation of structures for the long term;
- improving the regulatory and technical framework for evaluating and assigning dam safety criteria;
- specification of the norm of the risk category of reservoir hydroelectric units.

4. Conclusions

Implementation of the state regulation of safety of hydro-technical structures in our country, implementation of diagnostic works of the technical condition of structures with an assessment of their safety, specification of the norm of the risk category of reservoir water units, monitoring the safety of large and especially important water facilities, and other functions to ensure their safe operation allow to minimize the level of risk of their accidents.

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