Hydrotechnical structures

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Abstract. When using modern methods of analyzing information about accidents at hydrotechnical structures, one can make forecasts of the probability accidents and calculate the possible consequences. Estimation of qualitative and quantitative characteristics of the accident at HTS barrage regulatory structure on the river Bolshoy Uzen near the village Alexandrov Gai of Alexandrov-Gai district Saratov region, the emergency situations and their consequences was carried out in accordance with the decree of the Government of the Russian Federation dated 21.05.07 № 304 "On the classification of emergency situations of natural and technogenic character" (with amendments and additions of May 17, 2011). According to the decree of the Government dated 21.05.07 № 304 "On the classification of emergency situations of natural and technogenic character" the accident at HTS barrage regulatory structure of Alexandrov-Gai district refers to the emergency situation of municipal character, as in the breakout barrage regulatory structure the emergency zone does not extend beyond the territory of the municipality; in the case of hydrodynamic accident the life of people, property of individuals and legal persons, the environment will not damage, and the total amount of detriment caused by damage to the health of 1 person and water supply disruption (the most difficult situation), will not exceed 5 million rubles. The object is not potentially dangerous.

1. Introduction

Analysis of the risk accidents at a dangerous object (at hydrotechnical structures) is an integral part of its safety management during operation [1-8].

The main task of analysis risk accident at hydrotechnical structures is to use all available information about the technical condition of the structure, about the most dangerous weak points from the point of view of safety.

The purpose of the methodology for estimation risk accidents at hydrotechnical structures is to develop recommendations for reducing the risk of HTS [9-13].

At the stage of operation of the HTS, the purpose of risk analysis can be: checking the meeting of operating conditions with safety requirements; verifying the information about the main possible emergency situations at the facility; improving the instructions for operation and maintenance of the facility, plans for liquidation and localization of emergency situations at the facility.

The process of risk analysis includes the following stages: determining the probability of identifying possible emergency situations; the risk estimation of possible emergency situations; and developing recommendations to reduce the risk of accidents at the HTS [14-16].

When choosing methods for conducting an accident risk analysis of HTS, it is necessary to take into account the goals of risk analysis, the type, class, purpose and stage of the life cycle of the
analyzed HTS, the nature of hazards, the volume and quality of initial data, the availability of time and financial resources for conducting a risk analysis, the experience and qualifications of performers [17-26].

To analyze the risk of HTS accidents, it is recommended to use well-developed and proven methods of risk analysis of complex technical systems in other industries of technogenic activity, but their application in hydraulic engineering is possible only taking into account the full range of differences between HTS and mechanical, electrical, and technological systems.

The purpose of research is to conduct an estimation methodology of the risk accidents at hydrotechnical structures of the barrage regulatory structure on the Bolshoy Uzen river based on the predicted results of the development hydrodynamic accident.

2. Materials and methods

Methods of analysis the risk of accidents at hydrotechnical structures must meet the following general requirements [27-29]:

- methods must be scientifically based and meet the objectives of the risk analysis and analyzed structure;
- methods should give results which help to better understanding the level of risk and to outline the most effective ways to reduce it;
- results of methods applying must be reproducible

At the hazard identification stage, it is necessary to use one or more of the following methods of the risk analysis:

1. What would happen if...?;
2. Check sheet;
3. Hazard and work capacity analysis;
4. Type analysis and consequences of failures;
5. Type analysis, consequences, and criticality of failures, and other equivalent methods

These methods provide structured logical schemes for systematic use of expert estimations and construction data for a visual and reproducible analysis of the risk of HTS accidents [7].

The application of these methods is particularly effective in identifying hydrotechnical structures that are subject to mandatory safety declaration [30].

In table 1 the recommendations for choosing a method or combination of methods of risk analysis of HTS accidents when conducting hazard identification, taking into account the stage of the life cycle of structures are presented. Methods can be used in isolation or in addition to each other, and qualitative and quantitative estimates can be combined.

Table 1. Recommendations for choosing methods of risk analysis at hydrotechnical structures at the stage of hazard identification.

| Method                          | Stage life cycle of HTS |
|---------------------------------|-------------------------|
|                                 | design    | commissioning | operation | liquidation | reconstruction |
| What would happen if…?          | +  | *            | *         | *          | +            |
| Check sheet                     | +  | +            | *         | +          | +            |
| Hazard and work capacity analysis | *   | +            | +         | +          | *            |
| Type analysis, failures          | *  | +            | +         | +          | *            |
### Table 1: Consequence Type Analysis

| Type analysis, consequences, failures criticality | * | + | + | + | * |

Note: + - recommended method; * - the most appropriate method.

At the stage of risk estimation accidents at hydrotechnical structures, it is advisable to use one or a combination of the following methods to determine the qualitative or quantitative indicators of the frequency predicted undesirable occurrences, processes and events:

- analysis of the «failure tree»;
- analysis of the «event tree»;
- mathematical modeling of the state structures (statistical, deterministic, mixed models).

Risk estimation of an accident at a hydroelectric power plant should be carried out by analyzing the combined influence of factors that reflect the degree of danger and vulnerability of HTS [31].

At the same time, the degree of danger determining the characteristics of processes at the HTS and in the zone of their influence, the threat to the life or living conditions of people, facilities and the environment, is expressed by the accident hazard coefficient $\lambda$. The degree of vulnerability determining the HTS property to lose the ability to perform specified operational functions as a result of negative impacts is expressed by the vulnerability coefficient $v$.

Accident risk at the HTS is a hazard measure characterizing the accident possibility at the hydrotechnical structure and the severity of its consequences. Risk estimation of an accident at HTS is a process used to determine the frequency (probability) and severity of consequences implementation of HTS accident hazards for health, people life, property and the environment [32-33].

Risk estimation of an accident at HTS also includes a comparison obtained results with the acceptable level of the risk accident at HTS regulated by current normative documents.

A complex characteristic of an object is the estimation of the total risk, making it possible to fulfil the comparative estimation of the situation from the possible losses for existing or projected facilities.

The risk estimation is based on the results of monitoring and analysis of the hazard factors that are most significant for this facility and its operating conditions.

Hazard indicators are divided into 4 groups:

1. 1 - exceeding the natural loads and impacts accepted for calculated substantiation of the HTS design;
2. 2 - validity and accordance of design solutions with modern normative requirements;
3. 3 - accordance with the design of HTS structures, construction technology and operating conditions;
4. 4 - possible consequences and damage during an accident at HTS.
5. At the same time, in each group of indicators, the expert assessment analyzes the main factors of influence.
6. Vulnerability indicators are also divided into 4 main groups:
7. 1 - condition of the structure according to visual and instrumental observations, accordance of the main parameters with the maximum permissible values (HTS safety criteria);
8. 2 - environment state in HTS influence zone (according to monitoring data);
9. 3 - organization of HTS operation, observance of standards and requirements for safe operation;
10. 4 - facility readiness for localization and liquidation of emergency situations

The values of hazard and vulnerability codes are determined on the basis of expert assessment in
accordance with the Methodology for the risk estimation of accidents at hydrotechnical structures of water management and industry [34].

Based on the received integrated codes of hazard and vulnerability indicators, in accordance with the formalized ranked assessment, the hazard and vulnerability coefficients are determined, and then the magnitude of the accident risk.

3. Results

Risk estimation of an accident at HTS barrage regulatory structure was carried out in accordance with Gost R 22.2.09-2015 «Safety in emergency situations. Expert assessment of safety level and risk of accidents of hydrotechnical structures. General regulations» [35].

Risk estimation of an accident is based on an expert analysis of the accident hazard level and the vulnerability level of HTS.

To assess the level of accident risk, the risk coefficient is calculated based on the principle of intersection of these events, i.e.:

\[ D_a = \lambda \cdot v \]  

(1)

where: \( \lambda \) - hazard coefficient for HTS; \( v \) - vulnerability coefficient of HTS.

The physical meaning of the coefficient \( D_a \) is a measure (dose) of a dangerous impact on a given HTS with a specified degree of vulnerability. The safety level of HTS is estimated by the value of the risk coefficient \( D_a \) in accordance with the data given in table 2 according to GOST R 22.2.09-2015 [35].

**Table 2. Classification of the HTS safety level by the value of the accident risk coefficient.**

| Level safety of HTS | Accident risk coefficient, \( D_a \) |
|---------------------|-------------------------------------|
| Normal level of safety | no more 0.15 |
| Reduced level of safety | more than 0.15, but not more than 0.30 |
| Unsatisfactory level of safety | more than 0.30, but not more than 0.50 |
| Dangerous level of safety | more than 0.50 |

Change ranges of the coefficient \( D_a \) in table 2 are assigned in such a way as to practically connect the accident risk characteristics with the qualitative characteristics of the safety level regulated by the decree of the Government of the Russian Federation dated 21.05.07 No. 304 "On the classification of emergency situations of natural and technogenic character" (as amended on May 17, 2011) [32].

Determining the accident risk coefficient \( D_a \) makes it possible to estimate the probability (frequency) of an accident \( P_a(HTS) \) in accordance with the formula:

\[ P_a(HTS)=0.5erfc x \]  

(2)

where: \( D_c \) — catastrophic value of the risk coefficient \( D_a = 1 \); \( r_{ad} \) — acceptable value of the risk coefficient, above which the normal level safety of HTS is not provided \( D_{add} = 0.15 \); \( \beta \) — probability coefficient that depends on the HTS class; \( erfc x \) - probability function (table 13 GOST R 22.2.09-2015 [32]).

The value of the coefficient \( \beta \) for class IV structures, corresponding to the permissible value of the accident probability \( P_a(HTS) \), equal to \( 5 \cdot 10^{-3} \) 1/year, is \( \beta = 1.8 \) (table 14 GOST R 22.2.09-2015 [32]).

Tables 3 and 4 present the results of an integrated expert assessment of the accident hazard and vulnerability of HTS barrage regulatory structure for the situation with the most severe consequences.
Table 3. Integrated assessment of the accident hazard level.

| №  | Hazard indicator                              | Hazard level       | Code | Distinguishing features that are used to determine the hazard degree (level) for the considered hazard indicator                                                                 |
|----|-----------------------------------------------|--------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Danger of exceeding natural loads             | Small hazard       | 1    | Only local damages to structural elements and constructions (comb and slopes of the dam, places of interfaces with the concrete fastening), which can be eliminated in the course of current (planned) repair works |
| 2  | Validity and accordance of design solutions   | Hazard is absent   | 0    | All technical decisions are made in accordance with the current SNiP and SP                                                                                                       |
| 3  | Accordance with structure design, its operating conditions, properties materials of the structure and the foundation | Small hazard       | 1    | Dam is in good condition. Minor deviations from the project that cannot lead to disruption of the normal operation of the structure (due to the installation of water level boards in the reservoir (14.23 m) above the design level of the NPU, equal to 13 m) |
| 4  | Possible consequences and damage in the event of an accident | Average hazard     | 2    | During operation, in the event of a dam break, a municipal emergency may occur in the estimated flood zone (the flood zone does not extend beyond the territory of the municipality where the structure is located); possible material damage consists of the costs of dam damage (costs of the operating organization), and water supply violations |

The integral code of hazard indicators in accordance with the data in table 3 is 1012. Hazard coefficient $\lambda = 0.3125$.

Table 4. Integrated vulnerability assessment.

| №  | Vulnerability indicator                       | Vulnerability Level | Code | Distinguishing features that are used to determine the hazard degree (level) for the considered vulnerability indicator                                                                  |
|----|-----------------------------------------------|---------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Condition of the dam according to visual and instrumental observations state environment in the zone influence of the hydrotechnical structure | Small vulnerability  | 1    | According to observations and surveys in general, the structures are in good condition, local damages can be eliminated in the course of current (planned) repairs.                        |
| 2  | Reservoir does not affect the state environment and the living conditions of the population in the area where the hydroelectric facility is located |
| 3  | Organization of dam operation                 | Small vulnerability  | 1    | Day and night duty is not provided. Minor deviations from the requirements for safe operation do not impose                                                                       |
According to table 4, the integral vulnerability code of the dam is 1011, which determines the vulnerability coefficient \( v = 0.2833 \).

According to the obtained hazard coefficients \( \lambda \) and vulnerability \( v \) the dam accident risk coefficient is:

\[
D_a = 0.3125 \times 0.2833 = 0.0885
\]

Thus, the safety level of the dam, in accordance with the classification of the Russian HTS Register [36], is estimated as normal, corresponding to the accident risk coefficient, which is within the established limits, namely, \( D_a < 0.15 \).

Then, taking into account the obtained results for determining the accident risk coefficient \( D_a = 0.0885 \) in this case, the probability of an accident: \( P_a = 3.6 \times 10^{-4} \) 1/year. Thus, according to the classification of the risk level (table 15 GOST R 222.09-2015 [32]), the risk of a HTS accident is estimated as acceptable (possible), since the obtained values of the probability of accidents at HTS class IV are less than \( 5 \times 10^{-3} \) 1/year.

Similarly, the result of calculating the integrated expert assessment of the hazard and vulnerability at HTS accident according to the situation with the most likely accident is given.

For the situation with the most severe consequences, the integral hazard code is estimated as 2111, which corresponds to the hazard coefficient \( \lambda = 0.4063 \).

The dam's vulnerability code is 1111, which determines the vulnerability coefficient \( v = 0.3333 \).

According to the obtained hazard coefficients \( \lambda \) and vulnerability \( v \) the dam accident risk coefficient is:

\[
D_a = 0.4063 \times 0.3333 = 0.1354
\]

Thus, the safety level of the dam, in accordance with the classification of the Russian HTS Register, is estimated as normal, corresponding to the accident risk coefficient, which is within the established limits, namely, \( D_a < 0.15 \).

Then, taking into account the obtained results for determining the accident risk coefficient \( D_a = 0.1354 \) in this case, the probability of an accident: \( P_a = 3.6 \times 10^{-3} \) 1/year. Thus, the risk of a HTS accident probability is estimated as acceptable (possible), since the obtained values of the probability of accidents at HTS class IV are less than \( 5 \times 10^{-3} \) 1/year.

4. Discussions

For HTS barrage regulatory structure, the maximum value of the accident probability that may lead to an emergency situation are:

- for the case of a flood of rare occurrence, water level raising over the comb of the overflow dam above the design values, clogging of the outlet structure, erosion of the protecting shaft, the formation of a flood zone (most likely) - \( 3.6 \times 10^{-3} \) 1/year;
- for the case of dam failure due to mechanical damage by water flow, ice, abrasive materials, the formation of a hole with further destruction of the dam, the emergence of a break wave and flooding zone (the most severe) - \( 3.5 \times 10^{-4} \) 1/year.
In accordance with SP 58.13330.2012 [33], probabilistic estimation is allowed to be carried out in order to more fully disclose the uncertainties in the factors determining the reliability and safety of constructions and structures, to clarify the calculated characteristics, calculated schemes, combinations of loads and impacts, as well as limit states. For hydrotechnical structures class IV the calculated value of the probability accident should not exceed the value $5 \cdot 10^{-3}$ 1/year.

In our case, the maximum calculated value of the probability accident is $3,6 \cdot 10^{-3}$ 1/year that does not exceed the permissible value and corresponds to the normal level of safety of hydrotechnical structures. The object is not potentially dangerous.

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