EVALUATION OF THE PERMITTED RISK LEVEL FOR AGED DAMS DURING SURVEY AND EXPERTISE

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ABSTRACT

Most Russian dams operate 50-70 years. We have investigated the formal risk assessment of aged dams using the results of monitoring and regular examinations of 130 dams.

For aged dams not only quantitative but qualitative information assessment is essential. The analysis uses the observational scale of accidents and highlights three groups according to different processes: filtration, destruction, and overflow over the crest. We have also included a more detailed scale. We introduce condition index I, which signifies the degree of deviation of the conditions from the norms and project. We give a method to quantify (digitize) the index I.

The monitoring is automated as follows. The description of the accidents is matched with the scale. One then chooses a "dam-analog" corresponding to the specified accident. Finally, the index I for the analog is given to the damaged dam.

The permitted risk level is evaluated according to the "damage from a failure" – "index of the condition" ("G – I") diagram. This diagram is similar to the well-known "F – N" diagram. The diagram provides regions: "acceptable risk", "conditionally acceptable risk", "elevated risk" and "unacceptable risk".

***Keywords** : dam survey, expert estimates, quantification, acceptable risk, diagram "I - G".*

1. EVALUATION OF THE PERMITTED RISK LEVEL FOR AGED DAMS DURING SURVEY AND EXPERTISE

A dam database of 180 dams was used in the preparation of this report. Most dams (75%) have been in operation for over 50 years. The lifetime and types of dams are characteristic for Russia. The purpose of the study is to develop a methodology for assessing permissible risk. The risk is characterized by the possibility of an accident and associated damage. Consideration of not only quantitative, but also qualitative initial information is necessary when assessing the risk of old dams. In this regard, the formalization of expert information on the condition of dams is important. The following methods are presented in the report: (1) formalized assessment of the condition for old dams; (2) digitization of initial ordinal estimates of the dam condition; (3) assessment of the acceptable risk level. The proposed methodology for assessing the acceptable level of risk is focused on the operational application in monitoring, survey and expertise of reconstruction projects of old dams.

Assessment of the condition of old dams (in this case, the assessment of the possibility of a hydrodynamic failure) is carried out in the form of a condition index I. Index I characterizes the deviation of the dam condition from the project. Estimates of index I vary on an ordinal scale from 0 to 5 as the dam approaches the limit (emergency) condition. All available quantitative and qualitative information on the dam condition as a whole (index I), as well as on individual indicators (indices Ii), is reduced to a single scale.

The quantification (digitization) of the initial ordinal estimates of the index I is necessary, as is known, for performing mathematical operations. In this paper, the authors use a method of I.F. Shakhnov (Shakhnov, 2005) based on the application of local ternary ordinal and quantitative scales.

The process to clarify (digitize, quantify) the proposed assessment scale of the structures' conditions is as follows:

- the initial quality scale is divided into triples (hence the term "ternary") A_{p-1}, A_p and A_{p+1};
- for each triple an expert evaluates on the scale from 0 to 1 the parameter r_k, which "may be interpreted as relative distance" or remoteness of A_p from A_{p-1};
- by (1) one evaluates (on the relative scale from 0 to 1) the quantitative assessments of the levels of damage:

$$V_p = \left[1+\sum_{t=p}^{m-2}\prod_{k=t+1}^{m-1}\frac{1-r_k}{r_k}\right]*\left[1+\sum_{t=1}^{m-2}\prod_{k=t+1}^{m-1}\frac{1-r_k}{r_k}\right]^{-1} \quad ...(1)$$

$$\sum_a^b = 0,\ a > b,\ p = 1, \dots, m-1,\ V_1 = 1,\ V_m = 0$$

If the expert believes the assessments have to be further clarified, one repeats the procedure with clarified parameters r_k.

The functional dependence we get after digitization has two inflection points with sharp (almost linear) growth of the index I^q between them. Many tested psychophysical dependencies (for example, known desirability function Harrington) have similar behavior and are widely used to formalize subjective expert assessments in psychology, medicine, sociology, etc. This confirms the expedience of this method of digitization and enables us to trust in the obtained quantitative assessments Iq. The adjusted quantitative graph (Figure 1) is universal; one can be applied to the practice of dam survey and in the mathematical processing of the obtained assessments of the structures' conditions.

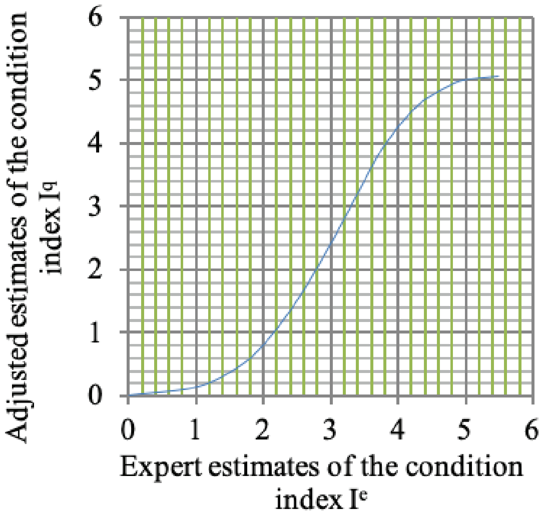

Figure 1 : Digitization chart of expert assessments I^e.

The majority of the initial expert assessments of the index Ie used in this paper is obtained according to the described method that is based on the direct evaluation during the dam survey. To clarify the obtained results we have also used the results of inspections of the safety declarations and the constructions' safety criterions by the committees of certified experts.

Three main conditions of hydraulic structures in operation are identified: "normal", "potentially dangerous" and "pre-emergency". The indicated conditions of the structure correspond to ranges of changes in the index Ie from 0 to 3, from 3 to 4, and from 4 to 5. The achievement by index I of a value of 5 corresponds to an "emergency" condition. The process of transitioning the structure from the "pre-emergency" to the "emergency" condition (and reaching the level $I^e = 5$ is clearly demonstrated, for example, by the recent (2017 year) accident at the 235-meter Oroville dam (USA, California) (BBC News). The accident developed from February 7 to February 14. The passage of the rain flood caused erosion of the concrete spillway and erosion of its foundation. There was a real threat of an uncontrolled release of water from the reservoir. Urgent emergency measures taken - inclusion of all openings of the main spillway into operation (despite the ongoing process destruction), dropping of large rock blocks from helicopters into a deep 14-meter hole in the spillway and at its base led to stabilization of the situation.

The initial information is combined for state indicators corresponding to the most "dangerous" of the entered states of the structure. Within the same range, for calculating the index I, formula (2) is used, the conclusion of which is made (Ivashchenko, Lavrov, Chernilov, Ivashchenko, 2008) based on the application of some provisions of the theory of fuzzy sets:

$$I = (I_{max} + q) - \prod_{i}^{n} \left[(I_{max} + q) - I_i] / I_i + q) - I_{min}\right]^{n-1}, \quad (2)$$

Where Ii - meaning of condition index for quantitative or qualitative indicators of structure or its components; Iмах, Imin - maximum and minimum of the condition index, which correspond to the borders of each band; q - parameter input to the expert-based (in the range from 0.1 to 0.15); $\prod_i^n$ - multiplication sign.

The use of formula (2) allows us to evaluate the influence of all factors affecting the assessment of the dam condition within each range. Any available (quantitative and qualitative) additional information may also be used. Taking into account the mutual influence of factors enhances the reliability of the assessment of factors of a higher level of the hierarchy and the final assessment of the dams' damage level. Note the analogy with the Bayes formula known from probability theory.

Detailed descriptions of the damages of each dam and their individual condition indices Ie are presented in the database. The initial values of these indices, assigned by experts based on the results of the dam survey, were refined by the method of pair comparisons. Several types of damage scales are applied. In the composition of the scales, three groups of damage characteristic of the processes are identified: filtration (index S), destruction (index D) and overflow over the crest (index F). The indicated groups contain subgroups corresponding to the previously identified dam conditions: normal ("minor" damage; damage levels vary from 2 to 5), potentially dangerous ("noticeable and medium" damage - levels from 6 to 7) and pre-emergency ("Serious - Very heavy "destruction - levels from 8 to 9). For each subgroup, a verbal description of characteristic lesions and corresponding average assessments Ie are also provided. A more detailed classification for the indicated 9 levels of damage is presented in a separate section of the database (table 1). The same section provides a list of keywords used to identify dams - analogues for the dam under study.

Two options are possible for estimating I^e for a specific dam. Option A: 1) the members of the commission formulate a preliminary qualitative assessment of the dam's condition on the basis of the usual expertise and agreement of opinions (column 1 of table 1); (2) a group of dams from the database is identified by keywords (column 4 of table 1); (3) damages of the surveyed dam are compared with descriptions of dam damages from the selected group and an analog dam is selected; (4) the Ie index of the analog dam is assigned to the dam under investigation. If it is not possible to select a suitable analogue, then option B is applied: a direct comparison of the dam condition with the aforementioned verbal description of the characteristic damages presented in the database.

Table 1 : Scale for estimation of dam condition

Dam Damage	**Damage level**	**Average assessment index I**	**Damage code; keyword; numbers "dam-analogues" in the database**
1	**2**	**3**	**4**
Low Damage	2 - 5	1,22	3; Control device; 25; 26; 46; … 64-67; 75-79 (n=14) 4; Safety criteria; 46.1; 47.1; 50; 57; 64-67; 75-77
"Marked – Average" Damage	6 – 7	3,35	D.7.2.1; Spillway; 23.2; 27.1; … 55.2; 69.2; 85.2 (n=8) F.7.3; Machinery; 22.3; 27.2; … 87.1; 87.2 (n=14)
"Severe - Very severe" destructions	8 - 9	4,43	S.9.1; Suffusion; 26.4; 76.1; 76.2 D.9.1; Deformations; 26.1; 66.3; 76.3; 76.4; 76.5 D.9.3; Apron; 54.1; 54.2; 81.2
Emergency	10	5	

An initial assessment of the potential for a dam accident is done by comparing the survey (or monitoring) results with a scale. If the index I is less than or equal to 3, then the dam condition is assessed as "normal". No serious measures are required. Relevant activities are carried out as part of maintenance. If the index is I> 3, it is necessary to analyze not only the dam condition, but also the consequences of a possible failure (G). In determining the criteria for the admissibility of the risk level the "F-N" diagram is used, as well as the risk matrix. In this report, assessments of the acceptable level of risk are carried out on the basis of the "I - G" diagram (Figure 2). When creating the chart, the results of surveys of 14 dams were used. For this sample, both estimates of the possibility of an accident (in the form of index I) and estimates of damage from a possible hydrodynamic failure were available (estimates were made mainly by S.Ya. Shkolnikov).

On the diagram "I - G", the experts identified the risk zones: unacceptable (A), elevated (B), conditionally acceptable (C), acceptable (D), acceptable for unique structures (E). The boundary of the "unacceptable risk" zone (Figure 2) is drawn through the "dangerous" zone, which presents data on I and G for the most damaged structures. These facilities are in a "potentially dangerous" or "pre-emergency" condition, but their operation continues. The assignment of structures to the "dangerous" zone and fixing the position of its border was carried out on an expert basis, taking into account the definition of "acceptable risk" given in: "Permissible risk is the risk within the range with which the society can live in order to provide benefits provided by the dam " Thus, when concretizing the position of the border of the zone of

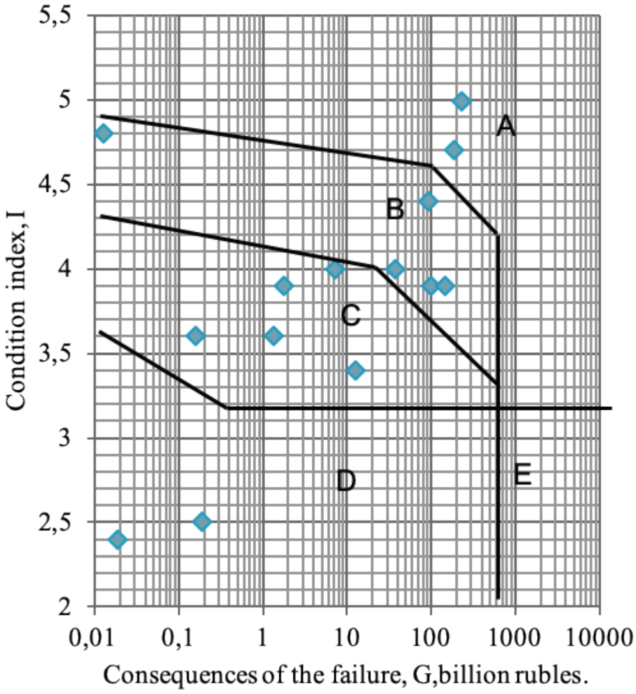

Figure 2 : Diagram " I – G"

"permissible risk", the premise was adopted: "serious damage and the dangerous condition of the structure have already been achieved, but no destruction has occurred - therefore, continued operation is possible subject to urgent repair work."

Practical application of the developed methodology is carried out in the course of the following types of work:

1. Commission inspection and monitoring of the operating dams condition. The survey is carried out in two stages. At the first stage, the dam condition is assessed based on the application of the proposed condition index Ie and a descriptive database scale. For structures in "potentially dangerous" and "pre-emergency" states (that is, when $I^e > 3$), at the second stage of the commission's work, a risk assessment should be performed (either based on the search for dams - analogues, or based on diagram "I - G"). At the second stage of the survey should be proposed preliminary reconstruction or repair options.
2. Expertise of project options and economic justification for the effectiveness of major repairs or reconstruction of the "old" structure. The "I - G" diagram is used to justify the best option based on varying combinations of index I (the possibility of the failure) and failure-related damage.

2. CONCLUSION

1. Two interconnected methods are considered: a) a formalized assessment of the "old" structure condition; b) creating a diagram of the connection between the risk components "failure possibility I - damage G" (diagrams "I - G").
2. A scale is proposed for expert assessment of the dam condition I, which summarizes the experience of surveys and expertise for safety declarations of 180 hydraulic structures in Russia. On an expert basis, appropriate marks of the scale, ranked by increasing level of damage, are proposed.
3. The possibility of failures and possible damage to 14 dams was assessed. These data were used to illustrate the proposed methodology for creating the "I - G" diagram. The application of the proposed "I - G" diagram (Figure 2) is an element of the risk assessment procedure. The diagram "I - G" is similar to the well-known diagram "F - N". The combined use of these diagrams defines the safety criteria for structures - risk assessments should not be in the zone of "unacceptable" risk.
4. The diagram "I - G" can be used to monitor, evaluate and regulate the safety level of the "old" structures during the survey, safety declaration, development and expertise of the project for reconstruction and repair of structures. The search of the optimal engineering solution for the repair and reconstruction of "old" structures is based on a more flexible variation of the combinations "condition index I - damage G".
5. The methodology used to assess the condition of the "old" hydraulic structures (including through the application of formula (2)) and to refine the "I - G" diagram allows you to quickly carry out risk assessment during operation.

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