Computer Intelligent Comprehensive Rapid Risk Assessment System of Barrier Dam by Fuzzy Analytic Hierarchy Process and Big Data

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Abstract. Barrier dam overall stability and dam break influence degree are the two risks. In order to comprehensively and quickly evaluate the risk of barrier dams, the dam height, the capacity of the barrier lake and the material composition of the dam body are selected as the stability evaluation indexes; the dam failure degree and the risk population and the potential economic loss are taken as the evaluation indexes. Based on the fuzzy hierarchy theory, this comprehensive and rapid risk assessment system of barrier dam is obtained, which is clear, intuitive and rapid, combining qualitative indexes and quantitative indexes.

1. Introduction
Barrier dam is a natural dam body formed by unstable bodies such as volcanic eruptions, landslides, debris flows and glacial deposits. In the past, most of the studies on the risk of dammed dams paid more attention on judging the stability of dammed dams other than the impact of flood after dam break [1-4]. Besides, a few researches, considering the impact after dam break, took the total reservoir capacity of dammed lake as the evaluation index. However, this index is not accurate. In actual cases, the dam body usually did not break to the end, and some reservoir water remained in the dammed lake after dam break, which would lead a real impact on the downstream area. The research on the change of dam break of Deng Pengxin et al. [5] also shows this point. Therefore, this paper proposes to use the ratio of breach depth and dam height to characterize the degree of dam breach, so as to more accurately analyze the impact of outflow on downstream.

The project team collected a large amount of data of the existing dams, basing on the theory of Fuzzy AHP, determined a set of rapid risk assessment system of the dam, which can quickly judge the stability of the dam and its impact on the downstream by combining qualitative indicators with quantitative indicators. The research results are used to judge the risk of the dam in the shortest possible time, select the corresponding emergency response measures, provide reference and guidance for the subsequent rescue or development and utilization, and avoid the occurrence of secondary disasters.

2. Comprehensive and Rapid Risk Assessment Model of Barrier dam
Barrier dam is a natural dam, and its lifetime from formation to break is different. Among the 276 dams with detailed break time, 67% of them have a life span of less than one month, while 50% of
them have a life span of less than one week. Most of them broke in a short time after formation, especially in the area where multiple dams are formed at the same time. Therefore, it is very important to comprehensively and rapidly evaluate the risk of dammed dams.

In order to quickly assess the risk, this paper establishes a comprehensive and rapid risk assessment system of barrier dam, as shown in Figure 1. Evaluate index selection based on the actual case, and evaluate grade classification; after weight calculation and membership degree calculation, weight calculation needs to have consistency check, then results can be used; the final weight and membership degree is used to calculate the results of first evaluation and second evaluation, in order to decide the grade of barrier dam risk.

![Figure 1 Comprehensive and rapid risk assessment system of barrier dam](image)

2.1. Selection of Evaluation Index

Different from man-made dams, the material heterogeneity of barrier dams is significant, and it is difficult to obtain the physical and mechanical properties and material gradation of most barrier dams. Therefore, the risk assessment should select the factors that can be obtained accurately and quickly and have great influence. This article divided the risk evaluation of barrier dams into stability evaluation and influence evaluation (see figure 2). According to the research of Cui Peng [4], Yang Qigui [6] and other scholars at home and abroad, risk evaluation took dam height, barrier lake capacity and material composition of dam body, which can be obtained quickly and have great influence, as its evaluation indexes. The severity of dam break influence evaluation regarded dam break degree, risk population and the potential economic loss as its evaluation index.
2.2. Classification of Evaluation Grade
The risk level of barrier dam is divided into four levels: low risk $V_1$, medium risk $V_2$, high risk $V_3$, and extremely high risk $V_4$. Table 1 is the classification of risk assessment index.

Table 1. Indicator classification of barrier dam risk assessment

| Criterion layer | Index layer | Low risk | Medium risk | High risk | Extremely high risk |
|-----------------|-------------|----------|-------------|-----------|--------------------|
| Stability index | Dam height (m) | $\leq 15$ | 15~30 | 30~70 | $\geq 70$ |
|                 | Storage capacity (10000 m$^3$) | $\leq 102$ | 102~103 | 103~104 | $\geq 104$ |
|                 | Material composition of dam body | mainly boulders | boulder with soil | soil with boulders | mainly soil |
|                 | Dam break degree (%) | $\leq 0.1$ | 0.1~0.3 | 0.3~0.5 | $\geq 0.5$ |
| Impact index    | Risk population (10000 people) | $\leq 1$ | 1~10 | 10~100 | $\geq 100$ |
|                 | Potential economic loss | commonly loss | more loss | major loss | extra-large loss |

2.3. Construction of Membership Function
Membership degree refers to the membership degree of the factor set to the evaluation set. For the dam risk, it is the membership degree of the evaluation index to the evaluation grade interval, which represents the contribution of each evaluation index to the risk judgment, which is a single factor evaluation.

2.4. Determination of Weight and Consistency Test
It is very important to determine the weight according to the principle of AHP, when evaluating the risk of dammed lake. It compares the importance of the evaluation index in pairs, on the basis of the existing literature of the dammed lake and the actual investigation of the dammed body on site, combining with the opinions of experts. As a result, the comparison matrix is constructed.

The comparison matrix of each column (or row) is normalized after geometric average according to formula (1), which can be used as weight.

$$w_i = \frac{1}{\sum_{k=1}^{n} \left( \prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}}} \quad (i = 1, 2, \cdots, n)$$

Figure. 2 Indicator system of barrier dam risk assessment
In the application of AHP, it is very important to keep the consistency of judgment thinking. When \( a_{ij} \cdot a_{jk} = a_{ik}, 1 \leq i, j, k \leq n \), A is a completely consistent pairwise comparison matrix. But in fact, it is impossible to satisfy the above equations when constructing the pairwise comparison matrix, so it is necessary to carry out consistency test.

2.5. Comprehensive Evaluation

The comprehensive evaluation includes the first level evaluation and the second level evaluation. According to the single factor evaluation matrix and the weight set, the first level and the second level comprehensive decision-making vectors are calculated hierarchically.

The rapid risk assessment of the dam is divided into the following three steps. Firstly, calculating the membership degree of different evaluation indexes. Secondly, according to the fuzzy relationship between the weight of the first level index and the membership degree, carrying out the first level assessment of the dam. Thirdly, bringing the results of the first level assessment into the second level assessment process to carry out the comprehensive risk assessment of the dam.

3. Application of Comprehensive and Rapid Risk Assessment Model for Barrier dams

3.1. General Situation of Tangjiashan Barrier Dam

The XiaoGangJian (upstream) barrier dam (see figure 3) formed by Wenchuan earthquake is located about 300m upstream of XiaoGangJian hydropower station on Mianyuan River in Mianzhu City. The reservoir capacity of Saihu is about 11 million m³, the height of weir plug is about 72m, and the total volume is about 2 million m³. The material of weir plug body is mainly composed of solitary and fragmental rocks. XiaoGangJian dammed lake reservoir [15] has large capacity, high dammed body, thin dammed body and steep terrain downstream. Large flow and high-speed scouring may cause local collapse of dammed dam, which may result in great possibility of collapse. It poses a great threat to Hanwang town and the towns along Mianyuan River downstream. After the dam break of XiaoGangJian (upstream) weir, a residual weir plug with a breach depth of 30m was formed. See Table 2 for details.

Table 2. General Situation of XiaoGangJian (upstream) Barrier dam

| Parameter                          | Value         |
|------------------------------------|---------------|
| Dam height (m)                     | 72            |
| Dam length (m)                     | 120           |
| Dam width (m)                      | 172           |
| Storage capacity (10000 m³)        | 1100          |
| Backwater length (m)               | 400           |
| Breach depth (m)                   | 30            |
| Material composition of dam body   | Mainly block stone |
| Risk population (10000 people)     | 21            |
| Potential economic loss            | Huge loss     |

Figure 3 XiaoGangJian (upstream) barrier dam
3.2. Membership Calculation
According to the membership function, the single factor evaluation matrix $R_i$ is determined. Bring the first level evaluation index value into the membership function of different intervals, the matrix is achieved as follows.

$$
R_{u1} = \begin{bmatrix}
0 & 0 & 0 & 1 \\
0 & 0 & 0.99 & 0.01 \\
1 & 0 & 0 & 0
\end{bmatrix},
R_{u2} = \begin{bmatrix}
0 & 0 & 0.4 & 0.6 \\
0 & 0 & 0.8 & 0.2 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

3.3. Weight Vector Calculation
The weight vector of each grade evaluation index is as follows according to formula (1):

$$A_u = (0.33, 0.67); \quad A_{u1} = (0.54, 0.30, 0.16); \quad A_{u2} = (0.11, 0.63, 0.26)$$

3.4. First Level Evaluation
The single factor evaluation matrix $R_i$ multiply the weight set $A_i$ the first level comprehensive decision vector $B_i$ is obtained.

$$B_{u1} = A_{u1} \circ R_{u1} = \begin{bmatrix} 0.16 & 0 & 0.297 & 0.543 \end{bmatrix}$$

$$B_{u2} = A_{u2} \circ R_{u2} = \begin{bmatrix} 0 & 0 & 0.548 & 0.452 \end{bmatrix}$$

From the first level evaluation, the first level comprehensive decision vector $B_{u1}$ obtained, $b_4 = \max_{1 \leq j \leq n} \{b_j\} = 0.543$, the stability of the dam is in a very dangerous state. Besides, $B_{u2}$ obtained $b_3 = \max_{1 \leq j \leq n} \{b_j\} = 0.548$, the dam break influence degree is in a high dangerous state.

3.5. Secondary Level Evaluation
The result of the second level evaluation is determined by the weight matrix $A_u$ and evaluation matrix $R_u$. From the first level evaluation, the decision vector evaluation matrix $R_u$ is obtained:

$$R_u = \begin{bmatrix}
B_{u1} \\
B_{u2}
\end{bmatrix} = \begin{bmatrix}
0.16 & 0 & 0.297 & 0.543 \\
0 & 0 & 0.548 & 0.452
\end{bmatrix}$$

The secondary comprehensive decision vector $B_u$ is obtained from $B_u = A_u \circ R_u$

$$B_u = A_u \circ R_u = \begin{bmatrix}
\text{low risk} & \text{medium risk} & \text{high risk} & \text{extremely high risk}
\end{bmatrix}$$

$$= \begin{bmatrix}
0.0528 & 0.4652 & 0.4820
\end{bmatrix}$$

It gets $b_4 = \max_{1 \leq j \leq n} \{b_j\} = 0.4820$. According to the principle of maximum membership degree, the risk level of the dammed lake is Grade 4, which is extremely high risk. This evaluation result is
basically consistent with the actual engineering situation, the stability is extremely dangerous, and the impact after collapse is high risk.

4. Conclusion

Most of the barrier dams would break down in a short time after they are formed. It is particularly important to quickly and accurately judge the risk degree of barrier dams, in the area where many barrier dams are formed at the same time due to natural disasters, to determine the disposal order and method. This paper puts forward a comprehensive and rapid assessment system for the risk of barrier dams to solve this problem.

In this paper, the risk assessment of barrier dams is divided into two aspects, the stability of the barrier dam and the degree of influence after the dam break. On the basis of Fuzzy AHP, this article, combining with qualitative index and quantitative index, divided the risk level of the dam into four grades. The index classification is reasonable and effective. The interval value of quantitative index is selected according to the specification, and the qualitative index is divided according to the experience. The risk level of the dam can be comprehensively and quickly evaluated. Through the example of the evaluation of XiaoGangJian (upstream) dam, the evaluation results are consistent with the actual situation. It shows that the evaluation system proposed in this paper has a certain theoretical basis and practical significance, and can provide reference and guidance for subsequent rescue, development and utilization.

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