A Fuzzy Comprehensive Assessment System of Dam Failure Risk Based on Cloud Model

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Abstract—At present, more and more attentions have been paid to dam risk management around the world. In order to deal with the fuzziness and randomness of dam failure, the cloud model was introduced into the risk assessment of dam failure, which was combined with Analytic Hierarchy Process(AHP) method and fuzzy theory, and then the multi-level fuzzy comprehensive assessment of dam failure risk was realized based on the cloud model. The improved AHP based on the judgment scaled with cloud model was proposed, and the cloud model was also used to determine the membership function in fuzzy assessment of dam failure risk, finally the group decision can be made with the improved algorithm that integrated methods of AHP and fuzzy with cloud model. The application shows that the improved algorithm can reflect both the fuzziness and randomness in dam failure, and therefore has much more stronger robustness than the traditional AHP and fuzzy assessment methods.

Index Terms—Risk Assessment System, Cloud Model, Fuzzy Method, Analytic Hierarchy Process (AHP), Dam Failure

I. INTRODUCTION

In the research field of dam failure, it is very difficult to effectively quantify the risk with only collecting and counting data that are full of different kinds of fuzziness and randomness [1]. At present, many methods, such as system analytic method, logic analytic method, operational simulation method, grey method, hierarchy analytic process method, fuzzy method and so on, are adopted to assess the risk of dam failure. But these methods usually ignore the uncertainties presented in the assessment processes, meanwhile, they lack of an effective and simple transition model between quality and quantity. The different risk factors reflect different status and importance, which make different contributions to the dam failure, so each factor in the index system has its own weight and risk degree.

The traditional methods to determine the relative weight of each factor in the index system is Analytic Hierarchy Process(AHP), which uses paired comparisons to derive a scale of relative importance for alternatives and then construct a pair-wise comparison matrix using a scale of relative importance. In the judgment matrix, the integer and reciprocal are usually used to express the different importance between two factors, however it can not describe the fuzziness and randomness of the judgment accurately.

As a main tool to deal with the fuzzy problem, the fuzzy sets theory curves the fuzzy things’ uncertainty by the degree of membership. However, once the fuzzy sets are described by a membership function, the concept of fuzziness will be no longer fuzzy. The cloud model can realizes the transition between precise value and quality value by combining the fuzziness and randomness. So, cloud model can be introduced to reflect the fuzziness and randomness of the judgment more obviously and to reduce the subjectivity of the judgment more effectively. For the problem of interval multi-attribute group decision-making in AHP and fuzzy method, the risk values and the preference importance are expressed in the form of cloud model, which can be calculated with the comprehensive cloud and the floating cloud methods.

In this paper, the cloud model is combined with AHP and fuzzy method so as to give an assessment of dam failure risk. This algorithm discards the hard division methods which are used in previous studies. As a result, the concepts obtained by this way can reflect the data distribution characteristics more obviously and more objectively. According to the proposed algorithm, a fuzzy comprehensive assessment system of dam failure risk based on cloud model was designed and developed, the application of this system shows that the improved algorithm is feasible and effective in the practice of dam failure risk assessment.

II. THEORY AND METHODOLOGY

A. Cloud Model

Cloud model theory proposed by Prof. Li Deyi, an academician of Chinese Academy of Science, is an effective method with the functionality of qualitative and quantitative conversion [2]. Cloud is combined by many cloud drops, and a cloud drop may be footy, but the
whole shape of the cloud reflects the important characters of the quantity concept \(^3\). The digital character of cloud can be expressed by \(Ex\) (Expected value), \(En\) (Entropy) and \(He\) (Hyper entropy).

Expectation \(Ex\) is a value that best represents the qualitative concept, which is completely subordinated to the qualitative concept and usually is the value of \(x\) corresponding to cloud centre.

Entropy \(En\) is an uncertainty measure of the qualitative concept and is decided by both the concept randomness and the concept fuzziness. On the one hand, entropy is a measure of qualitative concept randomness which reflects the dispersion degree of cloud drops; on the other hand, it is a measure of the qualitative concept with double-sided property which reflects the value range of cloud drops that can be accepted by concept in the domain space.

Hyper entropy \(He\) is the uncertainty measure of entropy namely the entropy of entropy, which reflects the dispersion degree of cloud and the size of the cloud’s thickness. The larger the hyper entropy, the greater the cloud drops’ dispersion degree and membership randomness and the thicker the cloud is.

B. AHP-Cloud Model

According to the above theory of cloud model, in this paper, we adopt nine cloud models to get the quantitative judgment matrix to compare one factor to the other in the AHP index system as shown in Fig.1, which is called AHP-cloud model. The \(En\) and \(He\) of each cloud model are confirmed with golden section method \(^4, 5\).

After the AHP-cloud model is constructed, it is used to express the different importance between two factors in the AHP index system, and the experts’ linguistic judgments are synthesized with the built floating cloud method (red cloud shown in Fig.2)\(^6\). If we have two neighbor clouds such as \(C_1 = (Ex_1, En_1, He_1)\) and \(C_2 = (Ex_2, En_2, He_2)\), over the same universe of discourse \(U\), a virtual floating cloud \(C(Ex, En, He)\) can then be defined by the following equation:

\[
Ex = \beta_1 Ex_1 + \beta_2 Ex_2 \\
En = \frac{En_1(Ex_2 - Ex) + En_2(Ex - Ex_1)}{Ex_2 - Ex_1} \\
He = \frac{He_1(Ex_2 - Ex) + He_2(Ex - Ex_1)}{Ex_2 - Ex_1}
\]

(1)

Where \(\beta_i\) is the adjustment coefficient.

Suppose we have three neighbor clouds \(C_1 = (Ex_1, En_1, He_1)\), \(C_2 = (Ex_2, En_2, He_2)\) and \(C_3 = (Ex_3, En_3, He_3)\). Firstly, a virtual floating cloud \(C’(Ex', En', He')\) which is between \(C_1\) and \(C_2\) can be synthesized with the floating cloud method. Then, the floating cloud \(C(Ex, En, He)\) between \(C_3\) and \(C’\) can also be synthesized.

The cloud of the importance between two factors in the AHP index system can be synthesized with the floating cloud model, and the comparison matrix can be constructed as follows:

\[
C = \begin{bmatrix}
C_{11} (Ex_{11}, En_{11}, He_{11}) & C_{12} & \cdots & C_{1n} \\
C_{21} (Ex_{21}, En_{21}, He_{21}) & \cdots & \cdots & \cdots \\
\vdots & \vdots & \ddots & \vdots \\
C_{n1} (Ex_{n1}, En_{n1}, He_{n1}) & \cdots & \cdots & C_{nn}
\end{bmatrix}
\]

(2)

The relative normalized weight of each factor can be obtained by calculating the geometric mean (GM) of the \(i^{th}\) row and normalizing the geometric means of rows in the comparison matrix. This can be represented by using Equation (3):
After the examination on consistency of all the factors in the AHP index system, the relative weights of the factors can be acquired as follows:

\[
GM_j = \frac{\sum_{i=1}^{n} C_{ij}(E_{x_{ij}}, E_{n_{ij}}, H_{e_{ij}})}{\sum_{i=1}^{n} \sum_{k=1}^{n} C_{ij}(E_{x_{ij}}, E_{n_{ij}}, H_{e_{ij}})}
\]

\[
w_j = GM_j / \sum_{i=1}^{n} GM_j, i, j = 1, 2, \cdots, n
\]

So the experts’ opinions can be expressed as an integrated value of \( C_i = (E_{x_i}, E_{n_i}, H_{e_i}) \), \( C_m = (E_{x_m}, E_{n_m}, H_{e_m}) \). After that, we can get the judgment matrix \( V \) as \( V = \{C_1, C_2, \cdots, C_m\} \). Finally, the cloud eigenvalues of the fuzzy comprehensive assessment result of potential dam failure risk can be obtained as the following equation:

\[
R = V \times W = C(E_x, E_n, H_e)
\]

In addition, according to the algorithm of cloud drops generation, the cloud chart of the final assessment results can be obtained, in which the risk of dam failure is simply and visually displayed.

III. DESIGN OF THE RISK ASSESSMENT SYSTEM

A. Requirement Analysis of the System

According to the theory and method mentioned above, Fig.3 describes the flows of dam failure risk assessment by integrating fuzzy set concept and cloud model. So, the fuzzy comprehensive assessment system of dam failure risk based on cloud model must meet three aspects of requirements. Firstly, the user can input the risk data of the candidate dam such as name, weights, values and etc. into the system. Secondly, all the input data should be managed in the system exactly, and the risk assessment results can be gained correctly. Thirdly, the results of dam failure risk assessment can be shown to the user intuitively.

C. Fuzzy-Cloud Model

In this study, we establish the membership clouds of the standard risk states of dam failure, replacing the membership curves in the traditional fuzzy method [7]. The qualitative remarks of factors in the AHP index system given in this paper all have bilateral constraints. For the factor remark that has bilateral constraint \([C_{min}, C_{max}]\), its cloud processing can use the expectation as the intermediate value of constraints to approximate the remark, and then we can use Equation (4) to calculate the eigenvalues of the cloud[8]:

\[
\begin{align*}
Ex &= (C_{min} + C_{max}) / 2 \\
En &= (C_{max} - C_{min}) / 6 \\
He &= k
\end{align*}
\]

Where \(k\) is a constant number and can be adjusted according to the fuzzy threshold degree of the variable.

The comprehensive assessment set of dam failure risk is \( V = \{V_1, V_2, \cdots, V_m\} \). If we assume that there are \(k\) experts to judge the importance of each factor in the AHP index system, there will be \(k\) remarks for each factor. Then \(V_i = \{C_{i1}, C_{i2}, \cdots, C_{im}\}\) can be used to represent the assessment set of factor \(i\), among which \(C_{ij}\) is the cloud model of the factor \(i\) with the remarks of expert \(j(i=1, 2, 3, \ldots, m; j=1, 2, 3, \ldots, k)\).

For factor \(i\), we use a comprehensive cloud to express its qualitative variables represented by \(k\) cloud models, and the corresponding cloud eigenvalues can be drawn from Equation (5):
B. Main Modules of the System

According to its requirements and operation flow, the system for fuzzy comprehensive assessment of dam failure risk based on cloud model should be consisted of integration control module, risk indexes input module, floating cloud model module, weight calculation module, comprehensive model module, fuzzy assessment module, assessment output module and project database. Fig.4 shows the structure of the designed system’s main modules.

IV. DEVELOPMENT OF THE MAIN MODULES

There are two important modules in the designed system for dam failure risk fuzzy comprehensive assessment based on cloud model, just as weight calculation module and fuzzy assessment module. Their developments are most essential to the implementation of the system.

A. Development Environment of the System

In this paper, the programming language of VB was used to develop the designed risk assessment system, and the database system of SQL Sever 2000 could provide data managing services.

B. Development of Weight Calculation Module

The weight calculation module is used to calculate the weights of each factor in the AHP risk index system. In this paper, the AHP-cloud model mentioned above which combines Analytic Hierarchy Process with cloud model are applied to develop the weight calculation module. The flow chart of weight calculation can be shown in Fig.5.
C. Development of Fuzzy Assessment Module

After all risk data are put into the system and the indexes’ weights are calculated, the result of dam failure risk can be assessed and shown with the Matlab tools. As mentioned above, in this paper, the fuzzy-cloud model is adopted to assess the dam failure risk. The flow chart to develop the fuzzy comprehensive assessment module is described as Fig.6.

V. APPLICATION

According to the proposed algorithm and corresponding design and development, a fuzzy comprehensive assessment system of dam failure risk based on cloud model is implemented. It can be applied to assess the failure risk for a candidate dam.

The fault tree of logical relation between dam risk and genesis is drawn in Fig.7. The potential risk of the candidate dam named Wangjiaba in Hubei Province of China is divided into four ranks in this paper: very dangerous, dangerous, slight dangerous and safe. When the comprehensive assessment value of potential risk respectively falls in \([9,10], [7,9], [4,7] \) and \([0,4] \), the four risk ranks can be expressed as four corresponding clouds (the four blue clouds shown in Fig.12) such as \(C_1(9.5,0.167,0.1) \), \(C_2(8,0.33,0.1) \), \(C_3(5.5,0.5,0.1) \) and \(C_4(2,0.667,0.1) \).
After all the factors in the AHP index system of the candidate dam are input into the risk assessment system, the corresponding comparison matrices can be constructed by using the floating cloud module (Fig.9).

Based on the corresponding comparison matrix, the weights of each factor in the AHP index system of the candidate dam can be calculated in the weight calculation module, as demonstrated in Fig.10.

When the weights of index are obtained, we can use the judge matrix module to calculate the eigenvalues of the assessment result cloud for the candidate dam. Fig.11 shows the weights vector of the comprehensive assessment result cloud. Finally, we can obtain the cloud of risk assessment result for the candidate dam, and the Matlab tool can be used to visually display the result (the red cloud shown in Fig.12):

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From Fig.12, it is shown that the cloud of assessment results (the red cloud) is close to the third cloud (5.5, 0.5, 0.1) of the four ranks of potential dam break risk clouds (the third blue cloud from right to left), so we can easily and visually determine that the potential failure risk of this candidate dam tends to be “slight dangerous”.

VI. CONCLUSIONS

In this study, the analytic hierarchy process is combined with floating cloud to calculate the weights of the factors related to dam failure. Firstly, the experts’ linguistic judgments are synthesized with the built floating cloud method, which can reduce the experts’ subjective preference. Secondly, the scale of weights of two factors is depicted by cloud model, and the synthetically aggregated cloud obtained by group decision is viewed as the value of judgment matrix instead of integer and reciprocal. Therefore, the synthesized comparison matrix can combine fuzziness with randomness much better.

On the other hand, the AHP index system of dam failure risk assessment is established and the cloud model is introduced into it. The clouds of four ranks of dam failure risk are set up, which transform the one-to-one mapping of membership into the one-to-several mapping of cloud drops. All the experts’ qualitative remarks are depicted by the cloud models. Through the quantitative transformation of qualitative factors, the assessment procedure can be simplified, and in addition, the arbitrary of experts can be obviously reduced. So, the proposed approach reflects both the fuzziness and randomness of dam failure risk which is more reasonable, objective, effective and robust.

Conclusively, this algorithm is a great improvement of the traditional analytic hierarchy process and fuzzy method in dam failure risk assessment. It is also a new attempt to apply the cloud theory into the area of dam failure risk assessment. The fuzzy comprehensive assessment system of dam failure risk based on cloud model proposed in this research has shown to be quite valuable in practice. The system can be used to increase the modernization level of dam risk management, which can lessen the burdens of managers’ job. It is believable that the cloud theory will bring great promotion in the risk assessment of dam failure in the future.

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