Research on Human Reliability Model of a Reservoir Dam

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Abstract. The safety of reservoirs has a great impact on the social and economic life of the country, and human factors in modern life occupy an increasingly important position. This paper uses the prediction technology of human error probability, establishes the reliability model of human factor cognition based on Bayesian network, quantifies the influencing factors of human factor, and actually uses the calculation in a certain reservoir dam.

1. Introduction
In the large-scale human-machine system of modern life, humans are playing an increasingly important role. Many accidents are directly or indirectly caused by human errors [1-2]. Water conservancy systems are no exception. Reservoir dams, while storing water and preventing floods for exerting economic and social benefits, also pose a certain threat to the lives and property of downstream[3-5]. Dam failures in the history of our country were mainly due to quality factors such as engineering defects and environmental factors such as floods. After entering the new era, with the improvement of scientific and technological level and management capabilities, dam-break accidents caused by over-standard floods and other problems have gradually decreased, and dam-break accidents caused by human error have increased [6-7].

Domestic research on human reliability is mainly concentrated in the fields of nuclear power, electricity, transportation, etc. The human factor reliability of dam safety is still in its infancy. By referring to the existing results of other industries at home and abroad, this paper introduced human factor reliability analysis into the field of dams, build a model based on Bayesian networks, and applied it to the analysis of a certain reservoir dam.

2. Commonly used human factor reliability analysis methods
2.1. Technique For Human Error Rate Prediction (THERP)
The first generation of personnel error probability prediction technology (Performance Shaping Factor, THERP) is a representative method in human reliability analysis (Human Reliability Analysis, HRA), and is a relatively complete personnel reliability based on task analysis. The analytical model is a function of the human performance shaping factor (Performance Shaping Factor, PSFs), which is a linear model of the probability of human error. It not only provides a mechanism for analysing human error, but also provides quantitative values and methods [8-11].

The method is mainly based on the human factor reliability event tree model. According to the development process of the event, all the behaviours of the human factor involved in the human factor
event are analysed, and the failure path is determined in the event tree for quantitative calculation. The HRA event tree describes the behaviour sequence of a person in the process of performing a task. It is based on task analysis, and expands along two-state branches in the order of time. Each fork represents a necessary operation in the execution of the task. There are two possible ways of success and failure. Therefore, according to the event tree of a certain operation process, all possible human error modes and their effects can be described in the operation process. Assign the probability of occurrence to each branch of the tree, and then the probability of success or failure of the job can be finally derived.

2.2. Dam Human Reliability Model Based on Bayesian Network

2.2.1. Bayesian network overview
Bayesian network is a mathematical model based on probabilistic reasoning\cite{12}, which is the process of obtaining the probability information of other variables through the information of some variables. Use the symbol B(G, P) to represent a Bayesian network. B(G, P) consists of two parts:

A directed acyclic graph with N nodes, the nodes in the graph represent random variables, and the directed edges between the nodes represent the correlation between the nodes.

A table of conditional probabilities associated with each node. The conditional probability table can be used to describe, it expresses the correlation relationship between a node and its parent node—the conditional probability relationship. The probability of a node without any parent is a prior probability.

2.2.2. Probabilistic causal model construction
To establish a causal model of a person's behavior, we must first determine the variables and explanations in the model, and establish the causal link between the variables. The model must have good feasibility, can be applied to engineering practice, and must have good adaptability and scalability, and be easy to modify and update. Combining the existing research and engineering practice experience, some modeling principles are proposed as follows\cite{13-14}.

1. A person's behavior is directly affected by his own state, including knowledge, skill level, physical and psychological state, etc. These are called internal influence factors. At the same time, it is affected by factors such as management system and site environment. These are called external influence factors. Therefore, the established causal model is a hierarchical model.

2. Reduce network complexity in the modeling process. Determining the conditional probability distribution of each variable involves a huge amount of calculation. When the number of parent nodes of a node is k, the parameters that need to be determined are at least $2^k$. Therefore, when the value of k exceeds 10, it is difficult to handle in real applications, and it is necessary to make full use of conditions to simplify calculations independently.

According to the above description, the hierarchical causal model shown in Figure 1 is obtained. Such a hierarchical causal model is easy to adjust.
2.2.3. Quantification of the causal model

To establish the network model shown in Figure 1, it is necessary to further determine the parameters of the model, that is, to determine the conditional distribution of each node in the Bayesian network. The following rules are adopted for this.

1. The value of each node is 2 values and these binary states are collectively referred to as "yes/no" (although the two values are used, the probability connected to it can also be regarded as a measure of "degree" to accurately reflect the actual situation deemed).

2. If a node in the model has n parent nodes, according to some event data from the application background, combined with the opinions of domain experts, each root node is given a weight of 0~1, denoted as \( w_i \) (\( i = 1, ..., n \)), which indicates the degree of influence of the root node on the node. The larger the value, the greater the degree of influence.

When the value of each node is "Yes" and the other nodes have the value of "No", the probability of the node taking "Yes" is:

\[
P(Y/X_1, X_2, L, X_n) = \frac{w_{11} + w_{12} + L + w_{1n}}{\sum_{i=1}^{n} w_i}
\]

The above are only general rules for node value. In the application field, more specific value rules can be formulated based on actual conditions.

3. Dam Human Reliability Sub-model in Engineering Application

In the field of dam engineering, human error often occurs in links such as forecasting, early warning and dispatching, and emergency intervention. In order to facilitate engineering applications, the following three types of human reliability sub-models in dam risk analysis are established:

3.1. Human Reliability Model in Prediction, Early Warning and Scheduling

In the early warning, forecasting and dispatching links, the reliability of people is mainly related to the management, individuals and systems, and is particularly closely related to the “day-to-day management” of the “management” superior indicator. Therefore, four three-level indicators of
inspection, dispatch, operation, maintenance and monitoring, and observation data analysis are established for "daily management". In the specific calculation process, the weights of these are all taken as 1/3, and the details are determined by experts based on experience.

3.2. Human reliability model in emergency intervention

Emergency intervention means that when an emergency occurs in a reservoir dam, relevant departments take emergency management measures to control the dangerous situation and avoid the occurrence of dam breach. The success of manual rescue intervention is mainly related to the following aspects:

1) Environment. Hazards are generally accompanied by disasters, especially when there is a huge earthquake or flood that exceeds the standard. If there are hidden engineering hazards in the dam itself, the probability of manual rescue success is low;

2) Reservoir management. After the occurrence of a danger, the management needs to check and judge the characteristics, nature, potential, possible development and hazards of the danger in a timely manner to take reasonable and effective rescue measures.

3) Individuals. Reservoir site management personnel should understand and master the rescue knowledge and repair methods, and the reservoir should be equipped with necessary rescue materials and obtain the support of technical experts for timely use in emergency situations.

It can be seen that the reliability of people in the rescue intervention should mainly consider the three-tier indicators of management, individual and environment.

4. Case studies

4.1. Project overview

A reservoir is located in a low mountain and hilly area in my country. It is a large-scale reservoir mainly used for flood control and irrigation, as well as water supply and aquaculture. The pivotal project is composed of the main dam, auxiliary dam, spillway and irrigation culvert. The reinforcement project was completed in April 2011.

The main dam is a homogeneous earth dam. The spillway is composed of a diversion channel, a control section, a drainage channel, a stilling basin, a connection section with the downstream spillway, and a water drop. There are 3 irrigation culverts, namely the west irrigation culvert, the middle irrigation culvert and the east irrigation culvert.

4.2. Human Reliability Analysis of a Reservoir Dam

Combining the flood data, project status, management department organization setting, system construction, inspection inspection, dam safety monitoring, emergency plan and other aspects of the reservoir over the years, the 12 secondary indicators are graded and the probability of failure is determined.

1. Human factor reliability analysis in prediction, early warning and dispatch

There are three levels of indicators in this sub-model, so the levels and error probability of the three levels of indicators should be determined first. See Table2 for details.

According to formula (1), calculate the probability of errors in the "daily management" node:

\[
\frac{1/4 \times 0.05 + 1/4 \times 0.05 + 1/4 \times 0.05 + 1/4 \times 0.25}{1/4 + 1/4 + 1/4 + 1/4} = 0.10
\]

The remaining secondary indicators use the results determined in Table 1, and the human error probabilities of the three secondary indicators for management, individuals, and the environment are...
calculated to be 0.1720, 0.0412, and 0.2327 respectively. The probability of error is:
\[
\frac{(0.3588\times0.1542+0.1738\times0.0412+0.3572\times0.2327)}{(0.3588+0.1738+0.3572)}=0.1520
\]

2. Human factor reliability analysis in emergency intervention

According to the error probability values of the twelve secondary indicators determined in Table 1, formula (1) is used to calculate the human error probability of the three secondary indicators of individual, system, and environment as 0.0412, 0.2327, 0.3111, then the probability of human error in emergency intervention is:
\[
\frac{(0.1738\times0.0412+0.3572\times0.2327+0.1102\times0.3111)}{(0.1738+0.3572+0.1102)}=0.1246
\]

5. Conclusions and recommendations

1) The selected reservoirs are general and representative. The analysis concluded that the probability of human error in forecasting, early warning and scheduling is the highest, followed by emergency intervention, and finally in daily management, which is consistent with cognition. Therefore, this method has certain applicability and can be promoted after further improvement.

2) Human factor reliability analysis data sources are mainly database data, expert analysis, etc. The former are mostly derived from simulator data, while the latter is subjective, and more objective real data should be introduced in practical applications.

3) Good and detailed index classification needs to be further rigorous.

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