IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Haoping Li *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **490** 032024

IOP Conf. Series: Materials Science and Engineering **490** (2019) 032024 doi:10.1088/1757-899X/490/3/032024

Study on safety evaluation model of small and medium-sized earth-rock dam based on BP - AdaBoost algorithm

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Abstract. The security characteristics of the small and medium-sized earth-rock dam was analysed , the dominant factors which were significant and high contribution on dam safety evaluation were selected by Delphi method combined with grey relational analysis, then constituted the evaluation index system of the small and medium-sized earth-rock dam. The dam safety evaluation model was constructed by BP neural network combined AdaBoost algorithm, the strong classifier was composed of several BP neural network weak classifiers, the network error was effectively reduced, and the network convergence speed was improved. The safety evaluation model of the small and medium-sized earth-rock dam based on BP- AdaBoost was feasible and can provide a new way for researching on the quantitative and intelligent safety evaluation.

1. Introduction

The dam safety evaluation has the characteristics as multi-level, multi-index and uncertain [1].To solve the uncertain problems, at present, some modern theory and system engineering method such as: fuzzy mathematics, chaos theory, grey system theory are mainly used. These methods have subjectivity and randomness, mainly depend on the expert's experience and local quantitative indexes, it is difficult to comprehensively evaluate the deterministic and uncertain safety factors. The methods couldn't meet the quantitative, dynamic and intelligent demands of dam safety evaluation [2]. This paper mainly explores the method to establishing the evaluation index system of small and medium-sized earth-rock dam, studies the way of establishing safety evaluation model based on BP neural network combining with AdaBoost algorithm, and realizes the quantitative, intelligent comprehensive evaluation of dam safety.

2. Construction of safety evaluation index system of small and medium-sized earth and stone dams

2.1. Screening method of evaluation index

There are three aspects should be taken into account when screening indexes: 1) importance of indicators; 2) correlation among indicators; 3) discrimination of index data[1].For the case of large quantity and complicated correlation of the dam safety factors, this paper puts forward a "qualitative + quantitative" index selection method, which combines expert knowledge with grey relational degree.

Firstly, according to the influence degree of the index on the dam safety, which is determined by Delphi and literature analysis and statistics, the initial indicators are screened. Then grey relational analysis is used to determine the influence degree of evaluation index on evaluation result, and the final evaluation index is determined based on this.

2.2. Primary election of evaluation index

More than 96% of the small and medium-sized dams are earth-rock dams, which generally have such problems as: low design standards, low construction standards, poor structural safety and project aging. According to the literature, the cause of dams accident has mainly 5 types: ①flood crest, accounting for 50.6%.②poor design and construction quality, accounting for 38%.③poor operation management, accounting for 5.3%.④others(including the flood diversion in crisis, the failure of discharge flood facilities, etc.) accounting for 4.6%.⑤unknown cause, accounting for 1.5% [3,4].

According to "guideline" [5], combining literature research, on the basis of that refine 7 primary indicators and 27 secondary indicators [6], in combination with the safety features of earth-rock dam, a questionnaire survey is carried out for n experts by Delphi, m indicators are set, whose mean value is $\overline{x_j}$, the importance W_{1j} is been as primary basis.

$$\overline{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij},\ j = 1, 2, \ldots, m \tag{1}$$

$$W_{1j} = \frac{x_j}{\sum_{l=1}^{m} x_l},\ j = 1, 2, \ldots, m \tag{2}$$

Finally, the six indexes of the least importance degree are deleted, and the primary 21 indicators are preserved and constitute the index set R.

$$R = \{X_1, X_2, X_3, \ldots\ldots X_{21}\}$$

$$= \left\{\begin{array}{l}\text{operation management, the dam anti-seepage,protection slope, termites,foundation and slope,}\\ \text{concrete intensity, carbonization, concrete surface quality,flood control capacity, discharge capacity,}\\ \text{downstream scour, displacement rate, relative tensile strain, dam anti-sliding stability, sluice}\\ \text{foundation anti-sliding stability,anti-seismic stability,water pressure potential, spill point,}\\ \text{drainage facilities, hydraulic hoist, gate structure}\end{array}\right\}$$

2.3. Grey relational degree analysis of indexes

The basic steps of calculating the influence degree of index by grey relational degree [7,8] are as follows:

(1) The raw data standardizing.

(2)Calculate the correlation coefficient of reference sequence and comparison sequence by using

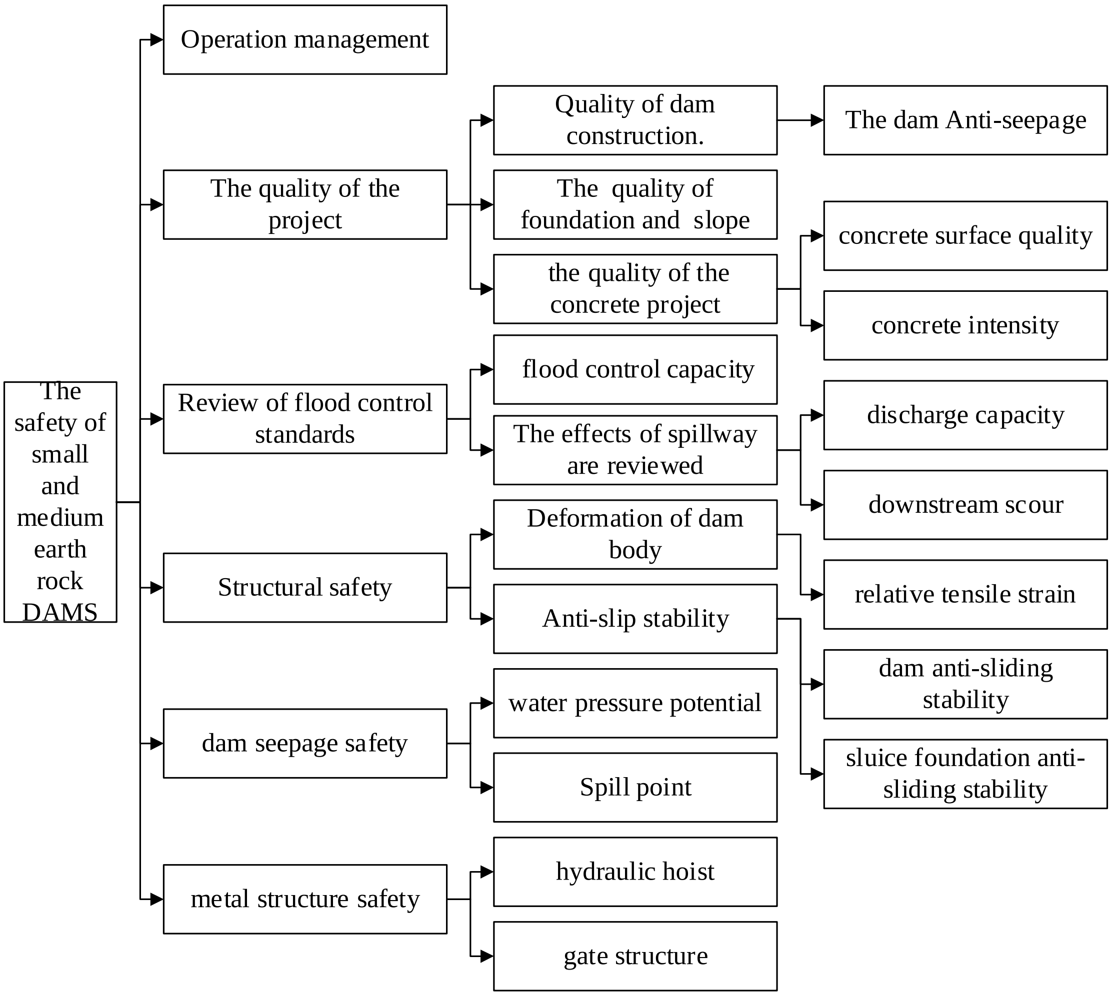

Figure 1. Safety evaluation index system of small and medium-sized earth-rock dams

the formula of correlation coefficient of Deng's grey relational theory, the resolution coefficient of the formula is 0.5.

(3) Calculate the correlation degree by using Deng's correlation degree formula.

By MATLAB, program is written for calculating index correlation and screening index. The principle for screening index is that these indexes would be kept which cumulative correlation degree are in the first 85%, so 6 indexes are deleted. The evaluation index system is composed of other 15 indexes, it is shown in Figure 1.

3. Safety evaluation model based on BP - Adaboost algorithm

3.1. Structure design of BP network model

BP network is a multi-layer feedforward neural network with strong function approximation ability and adaptive learning ability. It is the most widely used network form in artificial neural network [9], and often used for evaluation or prediction [10]. In this paper, the BP network evaluation model of small and medium-sized earth-rock dam is a one-way transmission and three-layer forward network: input layer, output layer and hidden layer, without coupling in the same layer nodes, the structure is shown in figure 2 .The evaluation network is designed as follows:

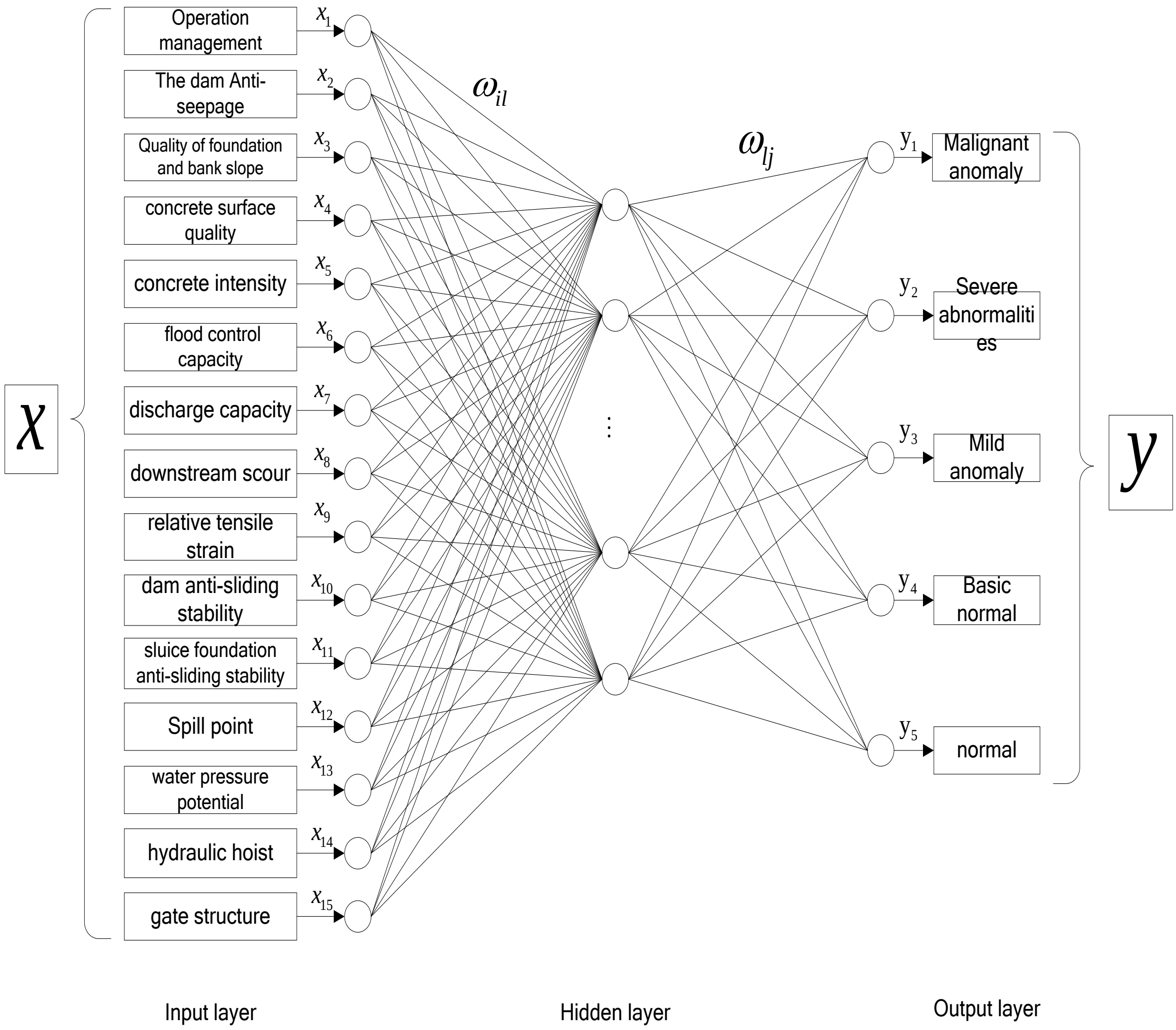

Figure 2. Structure diagram of dam safety evaluation neural network model

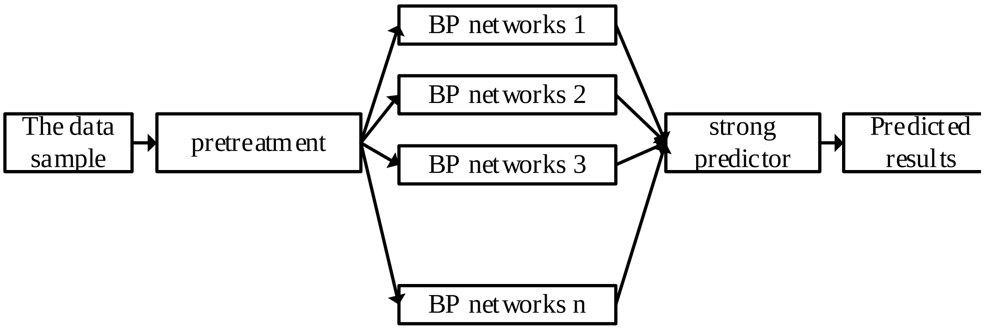

Figure 3. Flowchart of BP - AdaBoost algorithm

(1) Input layer: the input layer node number is 15, which is 15 evaluation indicators. The input vector is $X = [x_1, x_2, ...x_{15}]$.

(2) Output layer: system evaluation result is as the output layer. According to the partition of safety levels, the output vector is divided into five components, respectively indicate five safety states such as: malignant abnormal, serious abnormal, light abnormal, basic normal, normal by [1,0,0,0,0]、[0,1,0,0,0]、[0,0,1,0,0]、[0,0,0,1,0]、[0,0,0,0,1] . Output layer node number is 5, output vector is $Y = [y_1, y_2, y_3, y_4, y_5]$.

(3) Hidden layer: because the number of hidden layer nodes determines the convergence speed of the neural network, the determination of the number is critical. In this paper, the test method is chosen, firstly, according to the empirical formula: $l = \sqrt{n+m} + a$,(l: the number of hidden nodes; *n*: the number of input nodes; *m*: the number of output nodes; *a*: the adjustment constant between 1 and 10),the number of hidden layer nodes is calculated, between 5 and 15. By changing l and analyzing the average errors E, the number of hidden layer nodes is determined as 10.

(4) Transfer function: the intermediate layer transfer function is set to s-type tangent function tansig, its formula is as follows: $n = \frac{2}{1+e^{-2n}} - 1$. The s-type logarithm function logsig is set as the transfer function of output layer, its function formula is as follows: $n = \frac{2}{1+e^{-2n}}$. The gradient descent momentum learning function is set as the learning function of BP neural network. The rate of change of weight or threshold is calculated by using neuron input and error, momentum constant and learning rate of threshold or weight. ω_{il} is the weight between the *ith* neuron of input layer and the *lth* neuron of hidden layer, ω_{lj} is the connection weight between the *lth* neuron of hidden layer and the *jth* neuron of output layer.

3.2. Generation of learning samples

Put the initial index data of multiple reservoirs as the training sample of networks, as shown in Table 1, these dams are the small and medium-sized earth-rock dams that have been evaluated, whose index data is complete, accurate and scientific. The raw data of the following table is standardized processing and transformation to eliminate the dimensions of the original data. Enter the sample data into BP neural network, and the network will be trained by many rounds of learning. When the error between actual output values and the desired output reached the preset objectives, nonlinear mapping relationship between the safety of dam system and evaluation index will be established accurately. When the training is mature, the network can be used as a safety evaluation model for evaluation.

Table 1. Raw data of evaluation indexes (part)

Indexes	Dam1	Dam2	Dam3		DamN
1Quality of foundation and slope	83.710	68.534	77.386	…	91.978
2 The dam anti-seepage	98.124	97.904	96.948	···	99.678
…	…	…	…	…	…
14 Flood control capacity	0.691	0.445	0.450	…	1.304
15 relative tensile strain	0.330	0.682	0.859	…	0.098

3.3. Model of BP - AdaBoost network

The traditional BP algorithm correct weights and thresholds from the negative gradient direction of network prediction error by adopting the gradient correction method. It does not take into account the accumulation of previous experience, so the learning process of it converges slowly [2]. In this paper, AdaBoost and BP are combined to build a safe evaluation model to solve the above problems.

The central idea of AdaBoost algorithm is to combine the output of multiple weak classifiers to produce effective classification [11, 12]. Its main steps as follows: first of all, weak learning algorithm and the sample space (x, y) is given, and m sets of training data are found from the sample space, the weight of each set of training data is 1 / m, and then the weak learning algorithm is used to iterate T operations, according to the classification results, the weight distribution of training data was updated

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after each operation, give greater weight for training individuals who fail in classification, pay more attention to the training of individual when the next iteration compute. The better the weak result, the bigger the corresponding weight is, the strong classification function F is finally weighted by the weak classification function after the T iteration. That is to say, BP neural network is regarded as a weak classifier in the BP-Adaboost model, and the output of predicted sample of BP neural network is repeatedly trained, and a strong classifier composed of several BP neural network weakly classifiers is obtained by Adaboost algorithm.

The process of dam safety evaluation prediction algorithm based on BP- AdaBoost model is shown in Figure 3.The above training samples are substituted into the BP-AdaBoost model to train and generate 10 BP neural network weak classifiers, and finally a strong classifier composed of 10 weak classifiers is used to predict dam safety. The absolute error values of strong predictor classification and weak predictor classification are shown in Figure 4 below. It showed that the classification error of strong predictor is lower than that of weak predictor, and the error of BP - AdaBoost algorithm model are lower than those of error of BP network as a whole, therefore the BP - AdaBoost algorithm evaluation effect is better and more accurate.

4. Case verification

4.1. Basic information

A hydropower project is located in the lower reaches of the river section. The main task of the project is to generate electricity. The total capacity of the reservoir is 4.17 million m^3 and its effective storage capacity is 3.49 million m^3, it has annual adjustment performance and its normal water level is 499.70 m. The total installed capacity of the power station is $2\times1000\,kW$, and its average generation capacity is 36.4958 million $kW\bullet h$. Size of engineering is small (1) type, engineering level is IV, main building is four level. Other data is ignored.

4.2. Process of evaluation

The quantitative results (part) of the dam safety evaluation index are shown in Table 2 below.

Table 2. Quantitative results of dam safety evaluation index (part)

The index	1 Quality of foundation and slope	2 The dam anti-seepage	…
data	92	81.3	…
The index	…	14 Gate structure safety	15Hydraulic hoist structure safety
data	…	96	97

The data is standardized and is entered into the mature BP-AdaBoost safety evaluation network model established in MATLAB. The evaluation result was shown in Figure 5. The conclusion is normal, which is consistent with the conclusion of expert group. That indicates the safety evaluation model proposed in this paper is reasonable and effective.

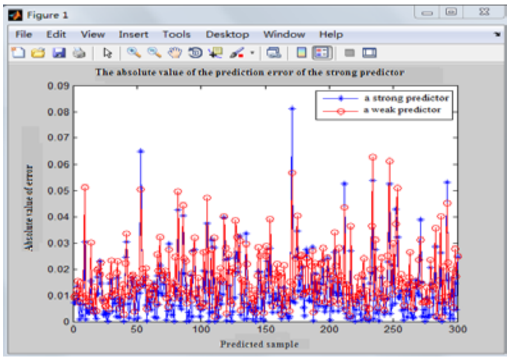

Figure 4. The error contrast between strong predictor and weak predictor

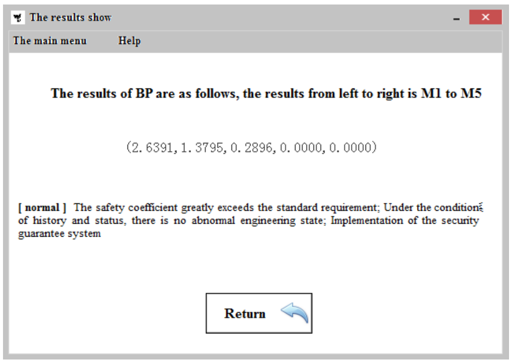

Figure 5. Safety evaluation results of the dam

5. Conclusion

(1) The safety evaluation index system of the dam is constructed by combining the method of Delphi with grey correlation analysis, so the index system is simplified, which makes the evaluation more refined and efficient.

(2) A safety evaluation network model is constructed based on BP-AdaBoost algorithm, new method for quantitative and intelligent safety evaluation is studied.

(3) The validity of network model of security evaluation is verified by an example.

Safety evaluation of dam is a complicated system engineering. Dam safety evaluation model based on BP - AdaBoost algorithm is scientific, rational, efficient and high application value, and it provides a new method for quantification and intelligent evaluation.

Acknowledgment

This work was financially supported by the fund of the Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin (China Institute of Water Resources and Hydropower Research),(IWHR-SKL-201413).

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