A prediction method for salt frost resistance of dam rock foundation based on improved BP neural network

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Abstract. Hydraulic resources can be utilized in a cascade manner, with the advantages of energy conservation, economy, and environmental protection. In order to study the anti salt freezing performance of rock foundation in hydroelectric power dams and accurately predict the degree of rock and soil freeze-thaw damage under salt freezing conditions, this paper proposes a prediction method for the anti salt freezing performance of dam rock foundation based on an improved BP neural network. Firstly, freeze-thaw cycle tests were conducted on the rock foundation materials of dams poured with different proportions of fiber reinforced concrete to study the changes in soil mass loss rate and dynamic elastic modulus; Then, based on BP neural network and particle swarm optimization algorithm, a prediction model for rock and soil freeze-thaw damage is established; Finally, using the historical data of the Baihetan hydropower station, optimization was carried out and model prediction errors were compared and analyzed. The method proposed in this article has been verified to have good accuracy and stability, providing guidance for the operation and construction design of hydropower projects.

Keywords: Geotechnical engineering, Hydroelectric power generation, Freeze thaw damage, Improving neural networks

1. Introduction

In hydraulic engineering, dams are the foundation. In winter in mountainous areas, after low-temperature freezing and erosion by molten salt water, the rock and soil will experience surface peeling and steel bar corrosion. Due to the combined effects of freeze-thaw cycles and chloride erosion on the rock and soil of the dam, material degradation leads to the degradation of its structural performance. This will greatly affect its durability performance, making it unable to reach the expected service life and creating significant safety hazards. Therefore, it is very important to conduct in-depth research on the salt frost resistance of dam rocks [1-2].

Dams are usually made by pouring concrete and bedrock. Compared with the first generation of ordinary concrete, the new type of concrete with certain fibers added is more powerful, and scholars are

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also more concerned about it [3-8]. Concrete with added fibers, which has been studied, is definitely more effective. But adding only one type of fiber has a mediocre effect, and the vast majority of current research is also in this situation. It is obvious that adding different types of fibers can complement each other's shortcomings and further improve their characteristics. But now few people are studying this direction.

In order to enhance the strength of rocks, the project involves adding different proportions of carbon fiber and glass fiber to concrete. This article investigates the salt freezing resistance of mixed fiber soil samples. The establishment of a prediction model for rock and soil salt freezing damage provides guidance and reference for the on-site application of dam construction. Meanwhile, it will be tailored to different scenarios. Angles with different temperatures, corrosion conditions, salt concentrations, and corrosion durations. Further conduct testing research. And continue the idea of combining experiments with artificial intelligence methods. Continuously improving the research content of this paper.

2. Performance test

2.1. Test materials and proportions

To ensure the quality of the experiment, this article uses rock samples from hydroelectric engineering sites Both coarse aggregate and fine stones in the experiment are of high quality. Select Class I fly ash manufactured by Tianjin Thermal Power Plant as the fly ash. The anhydrous sodium sulfate and anhydrous sodium chloride used in the experiment meet the specification requirements.

To ensure the universality of the experiment. Our laboratory first conducted a lengthy, serious, and comprehensive investigation and research on mainstream domestic fiber manufacturers. The system has sorted out 162 fiber manufacturers. They all have national production qualifications. The products produced are highly consistent with the overall product series. So our laboratory conducted a systematic selection from inside. After 6 rounds of 24 rounds of screening. We have compiled a total of 6 types of fiber samples to be used. Corresponding to the 6 manufacturers mentioned above. It has also undergone many comprehensive considerations and trade-offs. Taking into account the technical and economic viability of each fiber. In the end, our laboratory used carbon fibers produced by Jiangsu Boshi Continuous Fiber Co., Ltd. After the same screening criteria, six types of glass fibers have also entered our field of vision. In the end, our laboratory used glass fiber from Hebei Antai Chemical Fiber Co., Ltd. In order to more intuitively and clearly characterize the technical indicators and physical properties of each fiber. Now summarize their main performance. And it is presented in the table 1 below.

Table 1. Performance parameters of fiber

Fiber type	Density / (g·cm-3)	Length / mm	Tensile strength /MPa	Elongation rate /%
Carbon	1.8	10	780~1000	2~2.5
Glass	2.6	10	>600	2.4-3

Identify applicable sponsor/s here. *(sponsors)*

The designed rock mix ratio is w (rock): w (water): w (fine aggregate): w (coarse aggregate)=477:194:688:1 032. To ensure the applicability of the experiment. We need to have as many parameters as possible for the testing conditions under different ratio parameters. However, the method of traversal cannot cover all working conditions. Therefore, we set a testing condition every 0.05% interval. Our laboratory conducted experiments on the above content. Representative working conditions will now be organized.This experiment used ordinary rock (OC) as the control group, kept the concrete mix ratio unchanged, and formed each experimental group by adding fibers with different dosages, named CF** GF**. CF represents concrete doped with carbon fiber, GF represents concrete doped with glass fiber, and the number after the letter represents the fiber content. CF10 represents the addition of carbon fiber concrete with a volume fraction of 0.10%. The mixing ratio parameters of the experimental group are shown in Table 2.

Table 2. Design parameters of rock mix proportions

Type	Volume fraction /%		Type	Volume fraction /%	
	Carbon	Glass		Carbon	Glass
OC	0	0	CF10GF15	0.10	0.15
CF10	0.10	0	CF10GF20	0.10	0.20
CF15	0.15	0	CF15GF10	0.15	0.10
CF20	0.20	0	CF15GF15	0.15	0.15
GF10	0	0.10	CF15GF20	0.15	0.20
GF15	0	0.15	CF20GF10	0.20	0.10
GF20	0	0.20	CF20GF15	0.20	0.15
CF10GF10	0.10	0.10	CF20GF20	0.20	0.20

2.2. Test project

The volume of rock used for testing is 0.20 meters × 0.20 meters × 0.10 meters. A total of 3 pieces were used in the experiment. The chemical reagent used in the experiment is a sodium chloride solution. The duration of the experiment is 48 hours. The mass fraction of sodium chloride solution is 3.5%. When conducting experiments, each experiment should have 25 full freeze-thaw cycles. After thoroughly drying the specimen, weigh the mass of the specimen and calculate its dynamic elastic modulus [9-10]. The two important indicators for evaluating rock freeze-thaw damage are the mass loss rate and the relative dynamic modulus of elasticity. After N freeze-thaw cycles. The mass loss rate and relative dynamic modulus of elasticity of rock are:

$$W_N = \frac{m_0 - m_N}{m_0} \times 100\% \quad (1)$$

m_0 is the mass of rock before freeze-thaw cycles. With a dimension of grams; m_N is the mass of rock after N freeze-thaw cycles. With a dimension of grams.

$$P_N = \left(\frac{f_N}{f_0}\right)^2 \times 100\% \quad (2)$$

f_0 is the initial transverse fundamental frequency of the rock before freeze-thaw cycles, with a dimension of Hz; f_N is the transverse fundamental frequency of the rock after N freeze-thaw cycles, measured in Hz.

3. Test results and Analysis

3.1. Rock quality loss rate

The quality loss rate of OC. And each group of fiber reinforced rock varies. With the cycles number N. Is shown in Figure 1.

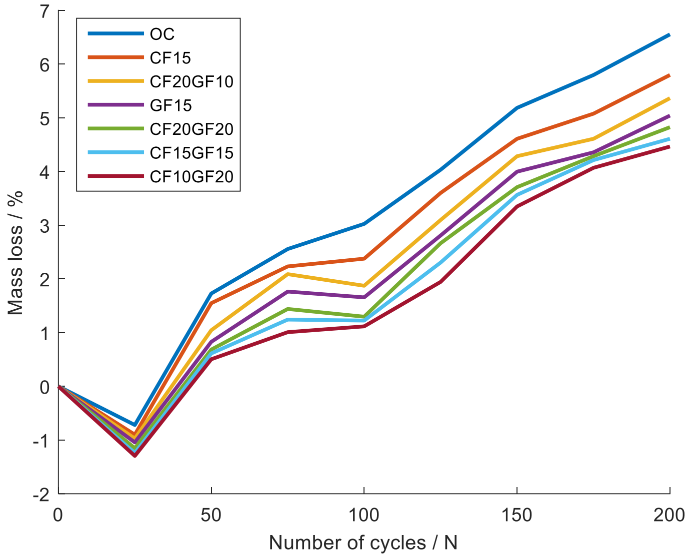

Figure 1. Mass loss rate of rock

As shown in Figure 1, when N ≤ 25. All curves are in a downward trend. This is due to the rock of micro cracks inside the rock during the initial stage of the experiment. The traces of rock are becoming increasingly prominent. All the ions in sodium chloride have gone in. The moisture absorbed by rock. The overall quality has improved. When N = 25, the degree of injury becomes even more severe. The mass of sodium chloride solution absorbed by rock is less than the weight of weight loss. When N>125, the degree of injury intensifies on the original basis.

3.2. Rock elastic loss rate

The relative dynamic elastic modulus of OC. And each group of fiber reinforced rock varies. With the number of freeze-thaw cycles N. Is shown in Figure 2.

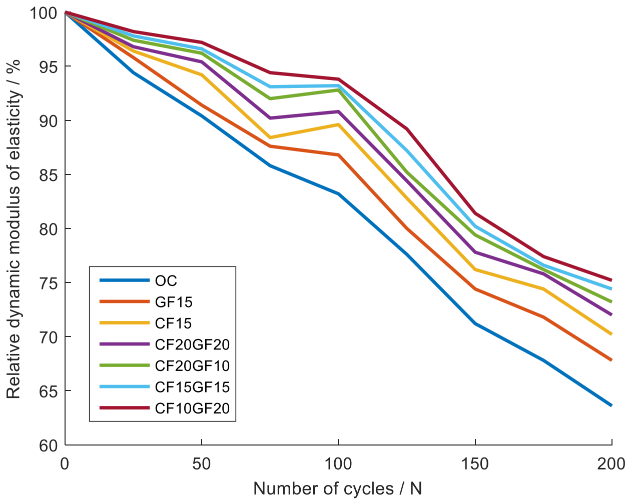

Figure 2. Elastic loss rate of rock

As shown in Figure 2, as the number of freeze-thaw cycles increases, the dynamic elastic modulus of rock shows a decreasing trend to varying degrees. When N≤75, the dynamic elastic modulus of each group of rock decreases slowly; When 75<N ≤125, the elastic loss rate increases. N>125, the rate of decrease in the dynamic elastic modulus of rock increases sharply. During the entire freeze-thaw test, the degree of OC damage was the highest.

When subjected to 200 freeze-thaw cycles, the relative dynamic elastic modulus of each group of rock is: OC<GF15<CF15<CF20GF20<CF20GF10<CF15GF15<CF10GF20. Among them, the relative dynamic elastic modulus of CF10GF20 is 75.2%, which reduces the loss by 11.4% compared to ordinary rock. In summary, the best solution is CF10GF20.

4. Performance Prediction

4.1. Freeze thaw damage model

To accurately describe the damage caused by rock under freezing and saline conditions. We have consulted literature on temperature and electrolytes. Part of it is to consider the quality loss of rock[11-13]. Part of it is to consider the cumulative damage caused by freeze-thaw of rock. Here we balance both. Provided a comprehensive definition. For the first type of loss rate. When it is greater than equal to 5%. We position it as causing irreversible structural damage. For the second type of loss rate. When it is greater than equal to 40%. We position it as causing irreversible structural damage. During the process of rock salt freezing damage, the mass of rock increases due to the absorption of moisture in the early stages of the test. The modified prediction model for rock freeze-thaw damage under freeze-thaw cycles and chloride salt coupling is as follows:

$$D = 1 - \frac{E_N}{E_0} = e^{aN^2+bN+c} \tag{3}$$

D represents the cumulative damage of rock during freeze-thaw cycles, which is dimensionless. E_0 is the initial dynamic modulus of elasticity, with a dimension of MPa. E_N is the dynamic elastic modulus of the test block after *N* freeze-thaw cycles, with a dimension of MPa. *N* is the number of freeze-thaw cycles. a. b and c are the correlation coefficients of fiber content [14].

4.2. Improved BP neural network prediction method

BP neural network is an intelligent sample training method mainly used for optimizing and predicting nonlinear variables, similar to the biological neural response method. When dealing with prediction problems, it does not have high requirements for the original input parameters and has strong data processing capabilities. It mainly calculates the output layer function and inverse error function values of the training samples continuously, and compares and analyzes them with the original parameter requirements until the relevant requirements are met [15-18]. The sample training is stopped and the optimal output result is output.

The revised mathematical calculation expression is as follows:

$$v_{id}^{(k+1)} = wv_{id}^{(k)} + c_1 r_1 \left(p_{id}^{(k)} - x_{id}^{(k)}\right) + c_2 r_2 \left(g_d^{(k)} - x_{id}^{(k)}\right) \tag{4}$$

$$x_{id}^{(k+1)} = x_{id}^{(k)} + v_{id}^{(k+1)} \tag{5}$$

w is the inertia weight; v is the velocity of the particle; x is the position of the current particle; c_1 and c_2 is the acceleration factor; r_1 and r_2 is the random numbers between B (0,1); $p_{id}^{(k)}$ is the *d*-th dimensional component of the optimal position vector for the *i*-th particle at time *k*; $g_d^{(k)}$ is the *d*-th dimensional component in the optimal position vector of the population at time *k*.

The performance improvement of neural network algorithms mainly comes from two aspects. On the one hand, it improves the rationality of the input data of the model, and on the other hand, it improves the model itself, thereby reducing the limitations of algorithm optimization and improving the optimization ability of the algorithm to handle high-dimensional complex data. This article adopts the momentum gradient method with variable step size to improve the learning factor of neural networks, reduce the oscillation of algorithm optimization, and improve the reliability of network training samples.

The calculation expression for adjusting the learning factor of neural networks based on variable step size is as follows:

$$lr(t) = \begin{cases} 0.7lr(t-1), E(t-1) > E(t-2) \\ 1.05lr(t-1), E(t-1) \le E(t-2) \end{cases} \tag{6}$$

On this basis, the momentum term influence factor of the reverse error calculation bias in the neural network training samples is taken into account.

The flowchart is shown in Figure 3.

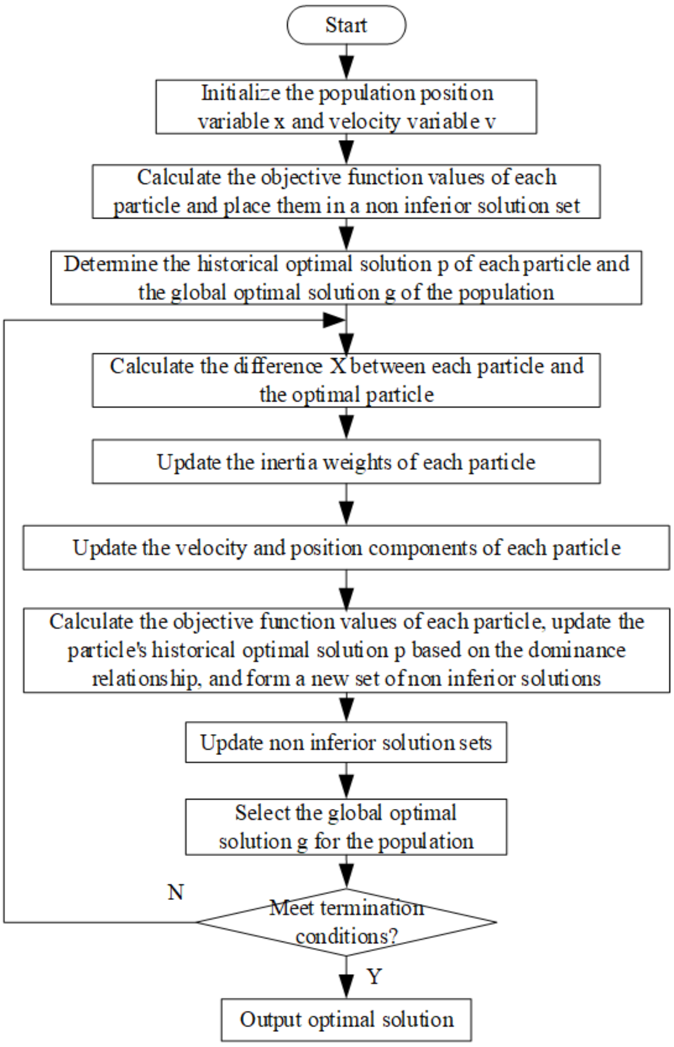

Figure 3. Improved BP neural network method flowchart

Calculate based on measured data. The convergence curve is shown in Figure 4.

From Figure 4, it can be seen that the established prediction model has high accuracy and reliability in predicting the degree of rock salt frost damage. As can be seen from the figure, the simulation curve with the application of particle swarm optimization algorithm. Its fitting effect is very close to the actual working conditions. In more than ten actual testing conditions. All can correspond to it. The overall trend is consistent with the summarized pattern obtained from the experiment. At the same time, in terms of convergence, it can converge quickly. No divergence occurred. In terms of iteration times, it also maintains overall controllability. The simulation time is fast. Provide guidance for the practical engineering applications.

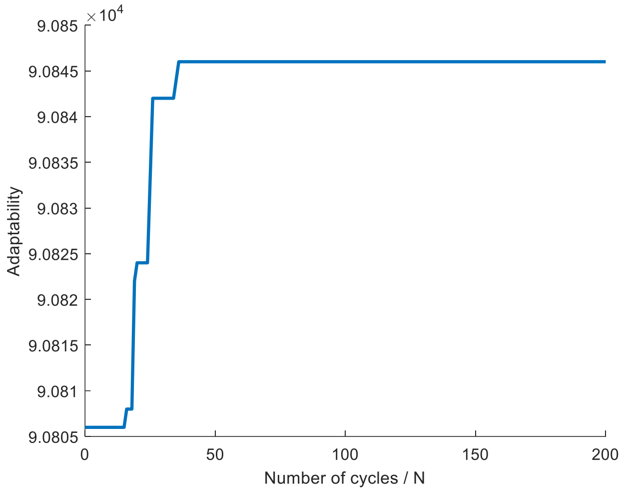

Figure 4. The convergence process of BP neural network

5. Conclusion

This article proposes a method of adding carbon fiber and glass fiber to improve salt frost resistance when pouring cement into dam rocks. This method can improve the frost resistance of rock. A large number of the basic experiments were conducted on the text. Explore the possibilities of various combinations between cement and fibers. The method proposed in this article has been verified to have good accuracy and stability.

The research results of this paper have potential applications in many fields in the future. Firstly, the main focus of this paper is on the impact of adding fibers to dam rock cement. This paper only studied two types of fibers. One type is carbon fiber. Another type is fiberglass. Further research can be conducted on the types, quantities, proportions, and other aspects of added fibers in the future. For example, carbon fiber, glass fiber, polypropylene fiber, organic synthetic fiber, natural fiber, and so on. This paper is based on experience. Only experiments with a mixing ratio not exceeding 0.2% were conducted. The reason is to balance the economy of cement rock. But from the scientific research perspective. You can study the addition of various percentages and conduct corresponding tests. In the future, our laboratory will also conduct research on the economy of dam rock cement project. Find a balance between technical and economic characteristics. Provide a more reasonable solution. This can provide a theoretical guidance for the practical application of fiber cement rock in the future. Meanwhile, it will be tailored to different scenarios. Angles with different temperatures, corrosion conditions, salt concentrations, and corrosion durations. Further conduct testing research. And continue the idea of combining experiments with artificial intelligence methods. Continuously improving the research content of this paper.

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