Prediction on Steel Corrosion Amount After the Concrete Cracking Due to Corrosion Expansion Based on Generalized Neural Network

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**ABSTRACT:** Generalized neural network is applied to establish the network model of steel corrosion amount after the concrete cracking due to corrosion expansion, crack width along the ribs, bar diameter, concrete compressive strength and concrete cover thickness are used as the neurons of the input layer of network, and the loss rate of steel corrosion section is used as the output layer of network. The research results show that the predicted results of generalized neural network are in good agreement with the measured data, and the precision can meet the requirement of engineering practice, which provides an effective solution for the prediction of steel corrosion amount after the concrete cracking due to corrosion expansion.

**KEYWORDS:** Generalized neural network; Concrete cracking due to corrosion expansion; Steel corrosion amount; Prediction; Fuzzy mathematics

1. INTRODUCTION

For a long time, affected by the concept that concrete is a building material with good durability, people neglect the durability problem of reinforced concrete structure, resulting in a lagging of research on the durability of reinforced concrete structure as well as heavy losses[1]. Steel corrosion process after the concrete cracking due to corrosion expansion is affected by the concentration of carbon dioxide in the air, the relative humidity of the environment, water-cement ratio of concrete and compressive strength of concrete, and the formation mechanism is very complex, with a high degree of uncertainty[2]. Japanese scholar Guan Xiaoyi, and Chinese scholars Niu Ditao[3], Jin Weiliang[4] presented their own prediction models of steel corrosion amount. However, one difficulty of the calculation problems of steel corrosion amount in concrete elements is the incomplete and uncertain information, the complex of uncertain information like randomness, unpredictability, gray property and model property instead of only randomness, so these prediction models all have certain limitations[5]. Applying modern fuzzy mathematical knowledge to build an artificial neural network of steel corrosion amount is an effective way to solve this problem.

2. INTRODUCTION TO GENERALIZED NEURAL NETWORK

2.1 Overview of GRNN Neural Network

Generalized regression neural network (GRNN) was proposed by American scholar Don-ald F. Specht in 1991, which is one of RBF neural networks.

2.2 Network Structure of GRNN

GRNN structure is similar to the structure of RBF network. It consists of four layers, namely, input layer, pattern layer, summation layer and output layer, as is shown in Figure 1. The corresponding network input is $X = [x_1, x_2, \ldots, x_n]^T$, and its output is $Y = [y_1, y_2, \ldots, y_n]^T$. 

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Neuron transfer of pattern layer in Figure is 

\[ p_i = \exp\left[-\frac{(X - X_i)^2 (X - Y_i)^2}{2\sigma^2}\right] \quad i = 1, 2, ..., n \quad (1) \]

The output of neuron i is the exponential square of Euclid distance square between input variable and its corresponding sample X. In the formula, X is the network input variable and \( X_i \) is the corresponding learning sample of i-th neuron.

In the summation layer, two types of neurons are used for summation.

One type of computational formula

\[ S_D = \sum_{i=1}^{n} P_i \quad (2) \]

is the connection weight of its pattern layer and each neuron is 1, and the transfer function is

\[ S_{Nj} = \sum_{i=1}^{n} y_i P_i \quad j = 1, 2, ..., k \quad (3) \]

Output of neuron is corresponding to the result \( \hat{Y}(X) \) of No. j element, namely

\[ y_i = \frac{S_{Nj}}{S_D} \quad j = 1, 2, ..., k \quad (4) \]

2.3 Theoretical Basis of GRNN

The theoretical basis of generalized regression neural network is non-linear regression analysis, that is, the condition mean is

\[ \hat{Y} = E(y/X) = \frac{\int_{-\infty}^{\infty} y f(X, y)dy}{\int_{-\infty}^{\infty} f(X, y)dy} \quad (5) \]

\( y \) is the predicted output of \( y \) under the condition that the input is \( X \).

Apply Parzen nonparametric estimation to estimate the density function \( \hat{f}(X, y) \) by the sample data set.

\[ \hat{f}(X, y) = \frac{1}{n(2\pi)^{p/2}\sigma^n} \sum_{i=1}^{n} \exp\left[-\frac{(X - X_i)^2 (X - Y_i)^2}{2\sigma^2}\right] \quad (6) \]

In the formula, \( X_i \) and \( Y_i \) are the sample observations of random variables x and y; n is the sample size; p is dimension of random variable x; \( d \) is the width coefficient of Gaussian function, referred to herein as smooth factor.

\( \hat{f}(X, y) \) is substituted into Formula(6) to replace \( f(X, y) \), and the order of integral and plus is exchanged:

\[ \hat{Y}(X) = \frac{1}{n(2\pi)^{p/2}\sigma^n} \sum_{i=1}^{n} \exp\left[-\frac{(X - X_i)^2 (X - Y_i)^2}{2\sigma^2}\right] \quad (7) \]

As \( \int_{-\infty}^{\infty} ze^{-z^2} dz = 0 \), calculating the two integrals can obtain the output of network \( \hat{Y}(X) \)

\[ \hat{Y}(X) = \frac{\sum_{i=1}^{n} y_i \exp\left[-\frac{(X - X_i)^2 (X - Y_i)^2}{2\sigma^2}\right]}{\sum_{i=1}^{n} \exp\left[-\frac{(X - X_i)^2 (X - Y_i)^2}{2\sigma^2}\right]} \quad (8) \]

3. PREDICTION NETWORK MODEL OF STEEL CORROSION AMOUNT

3.1 Generating Training Sets / Test Sets

Because there are many uncertainties of steel corrosion after the concrete cracking due to corrosion expansion, the steel corrosion in actual project is greatly discrete[3].

A large number of project surveys and research results show that steel corrosion amount after the concrete cracking due to corrosion expansion is
directly related to crack width along the ribs $w$, bar diameter $d$, concrete compressive strength $f_{cuk}$ and concrete cover thickness $c$ [3]. Therefore, in the construction of generalized neural network, the above four factors are used as neurons of network input layer. The output layer is the predicted value of steel corrosion amount after the concrete cracking due to corrosion expansion. Relevant literature[3] collect 31 sets of test data and actual data, as are shown in Table 1. This paper applies these sets of data as the training sets and test sets of generalized neural network. The specific approach is that 21 sets of data are randomly selected as training sets, and the remaining 10 sets are used as training sets to detect the generalization ability of network.

![Figure 2. Modeling Procedure.](image)

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3.2 Network Training

Applying the newgrnn toolbox of scientific computing software MATLAB can construct generalized neural network. Since data samples used in this paper are relatively few, taking into account the accuracy of predicted value, cross-validation is conducted on the 20 sets of samples randomly selected in constructing training sets. MATLAB training results are shown in Figure 3. Figure 3 shows that the predicted accuracy of the network achieves 0.009mm after 33 iterative computations, meeting the requirement of pre-set error of 0.01mm.

![Figure 3. Training Result of Generalized Neural Network.](image)

3.3 Evaluation on Network Generalization Ability

While MATLAB is applied to build generalized neural network, spread setting of expansion coefficient of the network has a greater impact on the prediction accuracy[6]. This paper applies the cross-validation of data in building the neural network, and as the training samples are randomly selected, the result of each training is not the same. The relation curve of the predicted value and measured value of steel corrosion section’s loss rate is shown in Figure 4, and the difference between the predicted value and the measured value is shown in Figure 5.
4 CONCLUSION

This paper takes 31 sets of collected data consisting of crack width along the ribs $w$ on the surface of concrete, diameter $d$ of the bar in concrete, concrete compressive strength $f_{ck}$ and concrete cover thickness $c$ as engineering examples, applies generalized neural network in the prediction on the steel corrosion amount after the concrete cracking due to corrosion expansion, and obtains the following conclusions.

(1) Generalized neural network has good nonlinear approximation computing power, and compared with other neural network, has higher prediction accuracy and fewer iterations.

(2) This paper converts the prediction problem of the steel corrosion amount after the concrete cracking due to corrosion expansion into a network containing four input layer neurons, and proposes a computation method that can effectively predict steel corrosion amount after the concrete cracking due to corrosion expansion. The prediction accuracy can meet the requirement of practical engineering and also can be applied into engineering practice.

(3) The value of expansion coefficient Spread and the number of neurons in hidden layer have a greater impact on the prediction accuracy of generalized neural network, so the application of neural network in the actual project requires analysis and calculation on specific data, otherwise it may cause failure of network prediction. How to reasonably determine the value of the expansion coefficient still needs further research and improvement.

It is worth noting that generalized neural network is dynamic, and with the accumulation of actual engineering data, the network can continue to be trained, to make the prediction accuracy more closer to the actual test result.

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6. OTHERS

University Research Project of Guangxi Department of Education, Project Number: 201106LX665

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