RESEARCH ON THE PREDICTION OF DEFORMATION PROPERTIES BASED ON NEURAL NETWORK

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Abstract: The direct analysis method based on deformation properties needs to predict the lateral deformation of the steel frame-support structure in advance, but it takes time and labor to use both finite element numerical simulation and experimental research. In this paper, the BP neural network receives the parameters of the steel frame-support structure, such as the aspect ratio, the second-order effect parameters, the slenderness ratio of frame columns, the rigidity ratio of beam-column bus and the deformation limit, with the lateral displacement of the column as the output layer, the second-order lateral deformation properties of the steel frame-support structure can be quickly obtained. Comparing the prediction results of BP neural network with those of the existing fitting formulas, the absolute difference and the relative error ratio between them are very small, which shows that the accuracy of the second-order column top migration using the BP neural network prediction is high. The BP neural network can be used to judge the applicability of the direct analysis method based on the deformation properties of the steel frame-support structure under various parameters.

1. Introduction

The current design code of steel structure in China and abroad about the direct analysis of bearing capacity ultimate state design method is based on the whole process of analysis directly, but in practice, the high-flexible steel frame-support structure with small lateral stiffness is designed according to the ultimate state of bearing capacity. When checking the overall deformation, most of them do not meet the deformation requirements of the normal limit state specified in the specification. At this time, it is necessary to increase the section of the component to recalculate the ultimate bearing capacity and deformation, which virtually increases the workload of design [1]. In order to predict whether the allowable bearing capacity of the structure is controlled by the deformation properties before engineering design, it is necessary to predict the second-order column top displacement of the whole structure. According to the results, a more suitable direct analysis method based on deformation properties can be selected. However, whether through finite element numerical simulation or experimental research will be time-consuming and laborious, and the efficiency is low. In this paper, BP neural network is adopted. Through learning and testing the samples [2], the magnitude of the second-order column top displacement of the structure can be estimated according to the established accuracy requirements, so as to directly select the appropriate and reasonable direct analysis method, and the design efficiency will be significantly improved [3].

2. Neural network structure

Artificial Neural Network (ANN) is a kind of network system which imitates the human brain information processing mechanism. Because of its advantages of information processing such as...
parallelism, self-learning, self-organization, associative memory function and high fault tolerance, ANN has been widely used in many fields such as civil engineering. The application of ANN does not require prior knowledge, and the implicit relationship between input and output hidden in the sample data can be obtained through training and learning [4]. In this paper, ANN is used to predict the application range of a direct analysis method based on deformation properties of steel frame-support structure under the influence of various parameters of steel frame-braced structure (the structure aspect ratio, second-order effect parameters, slenderness ratio, beam-column bus stiffness ratio, etc.). Back Propagation (BP) neural network, one of the most popular ANN algorithms, is used in this paper. It is a multilayer feedforward network and adopts a typical supervised learning method [5].

Artificial neural network method has a strong capability of multi-dimensional nonlinear mapping. A three-layer network can approximate any given continuous function with arbitrary accuracy, which is suitable for dealing with nonlinear problems with poor regularity [6], including receiving external data and a large number of information input layers. Implement the hidden layer of internal calculation and operation; The output layer that expresses the results of data processing. In this paper, the MATLAB neural network toolbox is used to build a neural network model with three-layer topology [7], and its logical structure is shown in Figure 1. The node parameters of the input layer are the second-order effect parameter \( c \), the height-width ratio \( H/L \), the beam-column linear stiffness ratio \( KZ \), the slenderness ratio \( \lambda \) and the deformation limit \( v \), respectively. The node parameters of the output layer are the second-order column top lateral displacement of the frame-support structure.

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\begin{align*}
\text{Fig. 1 Neural network structure} \\
\text{Fig. 2 Network training error curve}
\end{align*}
\]

The formula 1 shows the calculation of second-order effect parameter \( c \); Formula 2 shows the calculation of beam-column line stiffness ratio \( KZ \) [8]; Formula 3 shows the calculation of frame column slenderness ratio \( \lambda \) [9]:

\[
\begin{align*}
(c &= \frac{\sum N \Delta u}{\sum H \cdot h} \\
(KZ &= \frac{\sum F_{3D}}{\sum F_{1D}} \\
(\lambda &= \frac{\mu}{l})
\end{align*}
\]

Where, \( \Delta u \)——Interlayer sidesway of frame; \( N \)——Design value of concentrated wind load on top of column; \( H \)——The horizontal load of calculation layer and above layers; \( h \)——Calculation of frame height; \( E \)——Elasticity modulus; \( I_b \)——The moment of inertia of beam section; \( I_c \)——Moment of inertia of column section; \( l \)——Beam length; \( h \)——Column length; \( \mu \)——Factor of length; \( l \)——Calculated length; \( i \)——Radius of gyration.

3. Second-order lateral displacement prediction of steel frame-support structures

3.1 Model training

Due to the great randomness of the samples predicted by the neural network, more training samples
should be selected and distributed discretely within the calculation range in order to more accurately discover the internal relations and rules between things. Therefore, in order to make the training data scientific and reasonable, this paper selected a total of 30 sets of data for neural network training. The selection range and combination of each parameter involved the orthogonal design distribution.

The following 11 groups of data were selected as the test samples, including various factors, through reasonable screening and at the same time to prevent the occurrence of local over-optimization. H/L: 4.5, 5.5, 6; c: 0.21, 0.30, 0.33; $K_z$: 0.5, 0.54, 0.75, 0.8, 0.35, 0.55, 1.05, 1.2, 0.30, 0.33, 0.53; $\lambda$: 20, 25; $\nu$: 231.6, 337.2, 421.2.

The number of hidden layer nodes is determined to be 120, the transfer function is Sigmoid function, the training algorithm is L-M algorithm, and the network structure at this time is 5-120-1. The training error set by the network is 0.001, as shown in Fig. 2. After seven training sessions, it meets the requirement, i.e. 0.00017 less than 0.001, indicating that the established network model has a better prediction accuracy.

3.2 Compared with the results of finite element analysis
After learning 30 sets of data and taking 11 sets of test data as validation samples, the neural network model of output parameters is obtained, which can be used to predict and analyze the second-order column top displacement of steel frame-support structure, so as to verify whether the training performance is good, and its prediction ability and accuracy.

It can be seen from Figure 3 that the maximum absolute error is 22.1 mm between the finite element results and the predicted values of BP neural network in the fifth group of test data, and the minimum absolute error is 0.7 mm between the finite element results and the predicted values of BP neural network in the seventh group of test data, and the test values are all greater than the deformation limits.

According to Figure 4, the relative error rate of the fourth group of test data is 5.77%, which is the maximum relative error, while the relative error rate of the second group of test data is 0.04%, which is the minimum relative error, and the average relative error ratio is 2.15%, indicating that the BP network neural prediction results are stable.

Fig. 5 shows the generalization ability of the neural network. It can be seen that the predicted results of the BP neural network for the second-order displacement are basically consistent with the finite element results, indicating that the predicted value of BP neural network for the second-order column top displacement is accurate.
In conclusion, after training, the BP neural network can truly reflect the relationship between the four parameters of the steel frame-support structure and the lateral displacement of the second-order column top, and the results are similar to those of the finite element simulation with high accuracy. Through the study of 30 groups of training samples, even the data without training can be well predicted, with high accuracy, and the average prediction accuracy reaches 97.85%. Therefore, the second-order column top displacement predicted by BP neural network can be directly used as the discriminant basis before structural design. Therefore, the applicability and feasibility of using the direct analysis and design method based on deformation properties to analyze the steel frame-support structure can be quickly judged.

4. Conclusions
In this paper, the BP neural network is used to predict the second-order lateral displacement of the column top of the steel frame-support structure with small lateral stiffness, which can quickly determine the size of the second-order column top lateral displacement of the steel structure and whether the second-order lateral displacement of the structure is used as the basis for section control. Thus, the scope of application of the direct analysis method based on deformation properties can be reasonably selected. The following conclusions are obtained:

For the high-flexible steel frame-bracing structure, the BP neural network can quickly predict the lateral deformation of the second-order column top with high prediction accuracy, so as to determine whether the direct analysis design method based on deformation properties can be used for the structural modification design.

Acknowledgement
The work presented in this paper was supported by the natural foundation guidance program of Liaoning province, China (2019-ZD-0678) and the program for “Xing Liao Talent” of Liaoning province, China (XLYC1807188).

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