Prediction of soft soil foundation settlement in Guangxi granite area based on fuzzy neural network model

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Abstract. At present, the prediction of soft foundation settlement mostly use the exponential curve and hyperbola deferred approximation method, and the correlation between the results is poor. However, the application of neural network in this area has some limitations, and none of the models used in the existing cases adopted the TS fuzzy neural network of which calculation combines the characteristics of fuzzy system and neural network to realize the mutual compatibility methods. At the same time, the developed and optimized calculation program is convenient for engineering designers. Taking the prediction and analysis of soft foundation settlement of gully soft soil in granite area of Guangxi Guihe road as an example, the fuzzy neural network model is established and verified to explore the applicability. The TS fuzzy neural network is used to construct the prediction model of settlement and deformation, and the corresponding time response function is established to calculate and analyze the settlement of soft foundation. The results show that the prediction of short-term settlement of the model is accurate and the final settlement prediction result has certain engineering reference value.

1. A fuzzy neural network overview
Artificial neural network is neural network for short, which is a kind of mathematical model [1] that imitates the behavioral characteristics of animal neural network to carry out distributed parallel information processing algorithm. Neural network has a strong ability of autonomous learning and association, high computational accuracy, but cannot process and describe fuzzy information, cannot make good use of the existing empirical knowledge, especially learning and problem solving have the characteristics of a black box, and its work does not have Explanatory, while it requires a higher sample. Compared with neural network, fuzzy system has many advantages such as easy to understand reasoning process, better use of expert knowledge and lower requirement on samples, but it also has many shortcomings of manual intervention, low speed of reasoning and low accuracy. It is difficult to realize the function of adaptive learning, and how to automatically generate and adjust membership
functions and fuzzy rules is a thorny problem. If the two organically combined, can play a complementary effect.

1.1. TS fuzzy neural network principle
The main advantage of the TS Kagi-Sugeno fuzzy logic system is that its output can be precisely determined by the membership functions of variables in the rule base and the output of the rules [2]. TS fuzzy neural network is a multi-layer network which has five layers.

(1) Input layer: this layer has n nodes directly with the input vector \( x = [x_1 ... x_n]^T \). The connection will be entered \( x \) Pass to the next level.

(2) Fuzzy layer: this layer has a total of \( n \times m \) nodes. The input of m nodes in i group is \( x_i \), the \( \mu_i(x) \) represent j fuzzy set. If it is Gaussian function, then:

\[
\mu_i(x_j) = \exp \left[ -\left( \frac{x_j - c_j}{b_j} \right)^2 \right]
\]  

Where: \( c_j \) and \( b_j \) is the center and width of \( \mu_i(x) \) membership function.

(3) Rule layer: each node represents a fuzzy rule whose role is to match the antecedent of the fuzzy rule and calculate the cost of each rule that is:

\[
\omega = \mu(x_1) \mu(x_2) \cdots \mu(x_n) = \prod_{i=1}^{n} \mu_i(x_i)
\]  

If \( \mu_i(x) \) for the Gaussian function, there are:

\[
\omega = \exp \left[ -\sum_{j=1}^{m} \left( \frac{x_j - c_j}{b_j} \right)^2 \right]
\]  

(4) To the fuzzy layer: the role of this layer is to achieve normalized computing.

\[
p = \frac{\omega}{\sum_{i=1}^{m} \omega}
\]  

(5) Output layer: it is to achieve the clarity of technology, that is

\[
y = \sum_{j=1}^{m} (p h_j) = p^T h
\]  

Where: \( h = p_1 x_1 + p_2 x_2 + \cdots + p_n x_n \)

1.2. TS fuzzy neural network calculation procedure
The calculation steps of TS type fuzzy neural network are as follows [3]:

First, the given input and output sample are divided into two parts. Part is used to train the network, and the other part is used to test and evaluate the performance of the system.

Secondly, according to the training samples, the input samples are clustered by the clustering method. Suppose that the clustering is divided into m groups, that is, there are m fuzzy rules.
Finally, train neural networks. The matrix composed of the membership function values is obtained by calculation. Then, the algorithm is updated and iteratively.

According to the fuzzy neural network, the MATLAB program can be compiled according to the operation of fuzzy neural network matrix to predict the settlement of foundation. [4-5].

2. Relying on engineering research

2.1. Overview of the project
The project Guihe Road has a total length of 143 km and a bi-directional four-lane highway is designed with a 28 m subgrade width. The line mainly passes through the granite area and granite gully soft soil develops very typical along the line. It has the characteristics of wide range of soft soil, large thickness and poor physical and mechanical properties. It is mainly distributed in the negative terrain such as valley gully [6].

2.2. Granite gully facies soft clay formation and distribution

2.2.1 Soft soil formation and evolution. The soft soil in granite area mostly develops in hills and valleys dominated by weathering and denudation, hill valleys in the topographic terrain area, or foot of hilly hills. Generally, groundwater is exposed along with perennial water, Water is rich.

2.2.2 Soft soil distribution and characteristics. Guangxi granite gully soft soil is mainly distributed in southeastern Guangxi area, humid and rainy climate, rich surface and groundwater, soft soil area of about 15,100 square kilometers, accounting for about 6.4% of Guangxi area, the distribution area shown in Figure 1.

![Fig. 1 Distribution of granite soft soil in Guangxi](image)

Guigang to Hepu Highway mainly through the granite area, the granite gully soft is mainly silt clay and silt, granite quartz granule is more difficult to weathering, so the granite area is quartz sand with gravel composition, fine sand and coarse sand, soft soil has the following characteristics [7]:

1. Muddy clay and silt: brown ash, gray, black, soft plastic shape, local flow plastic shape, containing a small amount of silty fine sand and organic matter, with rotten odor.

2. Silt mixed fine sand to gravel: gray brown, dark gray, gray white, soft plastic, containing 20 ~ 30 % fine sand and gravelly sand, the distribution is very uneven, the local area is mainly sand layer, with lenticular or fossa distribution.

3. Loose medium coarse sand or gravelly sand: gray, gray-white, grayish yellow, loose shape mainly, local for slightly dense, uneven distribution, generally mixed with about 30 % silt or clay.
2.3. Design, treatment and optimization of soft soil foundation
Relying on the engineering of complex road granite soft soil replacement site test section of the pile for the K72 +300 ~ K72 +700, is denuded hilly valley topography, terrain ups and downs, the ground elevation of 83 ~ 126 m.

The original design adopts cement mixing pile treatment, then it is found that the average thickness of soft soil is about 4.0m, which basically meet the conditions for soft foundation replacement. Based on the principle of “local conditions and local materials ”, the original scheme is optimized as composite replacement method of rubble, crushed stone and granite residual soil [8], and the soft foundation pit bottom is 0.5 ~ 1.5 m filled with rubble, the above riprap stones are filled with 0.3 m crushed stone.

2.4. Evaluation on treatment of soft soil foundation
The monitoring data of soft soil subgrade settlement is an important basis for controlling the subgrade fill rate. It is of great significance to guide the subgrade construction in a reasonable way to analyze the trend of settlement of subsidence during loading. Settlement plates were installed on the left of K72 + 660 and the right of K72 + 660, respectively, for monitoring settlement of subgrade in Fig.2.

![Fig. 2 The settlement results by replacement method](image_url)

From the subgrade load-time-settlement relationship curve, it can be seen that the settlement value increases with the increase of fill height, and reflects the increasing trend of settlement of foundation under graded loading. When the soil is first filled, the settlement rate of the foundation is developed rapidly, and the later rate tends to be gentle, with the fluctuation in the smooth, indicating that the soft soil foundation load increases initial settlement deformation is larger, and the settlement change of roadbed filling period is relatively slow, which is consistent with the characteristics of consolidation deformation of soft soil.

Through the settlement observation data, the monthly settlement of the soil filling thickness are obtained, as shown in Table 1.

| Monitoring section | Settlement amount / mm during 24 hours | The monthly settlement amount / mm |
|--------------------|----------------------------------------|-----------------------------------|
| K72 +660 Left 11m  | 0.1-3.8                                | 4.70 (July - August)              |
|                    |                                        | 4.18 (August - September)         |

According to the Technical Specification for Design and Construction of Highway Soft Soil Embankment, it is stipulated that the ground subsidence rate during embankment construction should not exceed 10-15 mm per day during the construction period; The pavement construction must be
carried out after the settlement has stabilized and the monthly sedimentation value less than 5mm. As can be seen from Table 1, the sediment values are less than 10 mm per day, and the maximum monthly sedimentation value observed for two consecutive months is 4.94 mm and less than 5 mm. Therefore, the control indexes meet the rules and regulations during the construction, meanwhile, the method is used to reduce the construction cost a lot, speed up the construction progress, and meet the engineering requirements.

3. Calculation and analysis of soft soil foundation settlement based on fuzzy neural network

In order to predict the settlement of soft ground for replacement of Guahe Road and evaluate the effect of treatment under soft soil with time, the fuzzy neural network is used to calculate and analyze the settlement. The MATLAB program is compiled and the optimization convergence effect is achieved. Firstly, 500 days of data is differentiated, then the iterative step size is reduced to 0.0003, the maximum number of iterations increased to 500. Predict N using N-1, N-2, and N-3. Input layer 3 points, classification 4, hidden layer 4 points.

Adopting the fuzzy neural network to calculate and analyze the data of settlement data, the result of K72 + 660 left section of Guihe Road is shown in Fig. 3-6.

![Figure 3](image1)

**Figure 3** Total settlements of left in Guihe Road K72 + 660

![Figure 4](image2)

**Figure 4.** Neural network test prediction of Guihe Road left K72+ 660
Figure 5. Neural network training prediction of Guihe Road left K72 + 660

Figure 6 Neural network training error with time of Guihe Road left K72 + 660

Through the calculation of the settlement of soft foundation on the left sides of K72 + 660, the error of TS fuzzy neural network prediction is smaller, and as the iteration step increases, the error value approaches zero wirelessly. The accuracy of the prediction settlement increases with the increase of the sample size. The results of the test show that the fuzzy neural network has strong predictive ability and the algorithm has a fast convergence speed. The method can provide a reference for engineering design.

4. Conclusion

How to correctly predict the settlement of soft foundation is a common problem faced by the technical personnel of design and construction. The analysis of settlement of soft soil foundation in the soft soil in the granite area of Guangxi Guihe Road K72 + 660 segment is taken as an example, the prediction settlement is discussed by using the TS fuzzy neural network multilayer system model, and compared with the actual observation value, the calculation is consistent with the test. From this, it can be concluded that:
The TS fuzzy neural multilayer network model is used to predict the settlement of soft soil foundation. This method mainly perfects the application of the model in the settlement prediction of soft foundation, and the prediction accuracy of the model is satisfactory. Compared with the traditional method, this method can avoid the shortage of the use of the data in the actual application process, and also avoid the data of random disturbance caused by the nonlinear model such as the standard method in the process of model linear change.

Using TS fuzzy neural multilayer network model, approximation nonlinear interpolation method, compared with the traditional linear interpolation method, the results and the actual curve fitting degree is high. Neural network can establish the best mapping mode through adaptive learning, has strong stability and fault tolerance ability. It has no strict requirements for the number of samples and variables, is very suitable for the nonlinear field such as soft soil, but the complexity of the TS fuzzy neural multilayer network needs to be further simplified.

The calculation example shows that the short-term prediction accuracy is high by using this model, and the prediction value could show the settlement amount of soft soil foundation, which can provide reference for settlement control and corresponding construction measures, and also has certain engineering reference value for the prediction of settlement.

Acknowledgments

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