Prediction Technology of Ground Surface Settlement under the Pipe Jacking Consyruction Based on Intelligent Algorithm

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Abstract. The ground settlement under pipe jacking is one of the key factors affecting construction safety and engineering quality. At present, domestic and foreign scholars have carried out a large number of studies on the prediction technology of surface settlement through pipe piercing. However, most of these studies are based on the simple combination of construction experience and prediction methods, and lack of systematic analysis and in-depth research on relevant influencing factors and parameters. Under this background, this paper discusses a prediction technology of surface settlement based on neural network, genetic algorithm and particle swarm algorithm. By combining relevant theoretical research and field monitoring data, the neural network model, genetic algorithm model, particle swarm algorithm model and improved BP neural network model are established, and the model is used to predict the surface settlement under the pipe top. The results show that the improved BP neural network model has higher prediction accuracy.

Keywords: Intelligent algorithm; Prediction of surface settlement under pipe jacking; Genetic algorithm

1 Introduction

In recent years, with the rapid development of underground engineering, there are more and more underground pipeline construction. As a new underground engineering construction technology, pipe jacking construction has been widely used in urban construction because of its advantages of low cost, fast construction speed and small impact on the environment. Because the surface settlement caused by pipe jacking construction is a complicated process, which is related to many factors, such as soil properties, material properties, groundwater and surrounding environment, it is necessary to accurately predict the surface settlement caused by pipe jacking construction.

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At present, domestic and foreign scholars have carried out a large number of studies on surface settlement prediction technologies for pipe penetration, such as empirical formula method, theoretical calculation method, numerical simulation method and on-site monitoring method, etc. However, most of these methods are based on empirical data and simple models, and lack systematic analysis of influencing factors and in-depth research on parameters. Therefore, in order to solve these problems, it is necessary to explore new methods of detection. This paper will carry out relevant research, aiming at providing new research ideas[1].

2 Basic Concepts of Intelligent Algorithms

Intelligent algorithm refers to the processing and analysis of data by imitating human thinking process. Intelligent algorithms usually include four main components in Figure 1: learning algorithms, neural network algorithms, evolutionary algorithms, and genetic algorithms.Among them, the learning algorithm is to find out the rules in the training data, so that the model has predictive function; Neural network algorithm is to simulate the operation mode of human brain by imitating the thinking process of human brain, so that the model has predictive function. Evolutionary algorithm refers to the use of information and knowledge generated in the process of evolution in optimization problems, so that the model has optimization function; Genetic algorithm Genetic algorithm is an algorithm that simulates the biological evolution process. Its basic idea is to optimize the model by using genetic algorithm and the information generated in the evolution process, so that the model has optimization function. Genetic algorithm can solve combinatorial optimization problems and is widely used in many fields, such as multi-objective decision making, production scheduling and fault diagnosis[2].

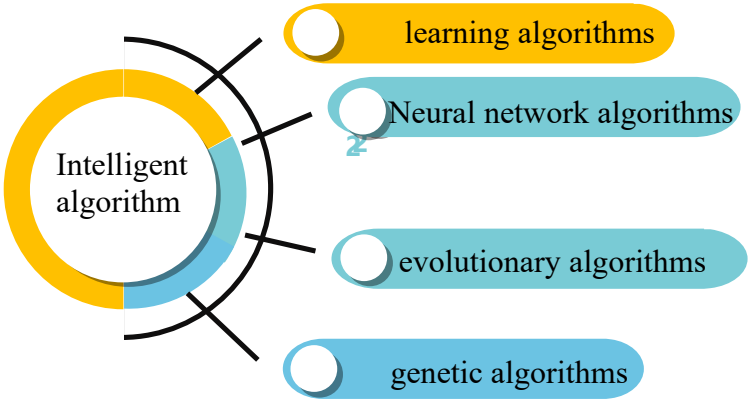

Fig. 1. Intelligent algorithm composition

3 Project Overview

3.1 Overview

The project starts at the south end of the former Meilin Main line toll plaza at K0+120 on the north side of Minle Interchange and ends at K2+353(right 363) at the starting point of Liuxian Interchange. The total length of the route is about 2. 24 km, with 2 interchange crossings, a total of 1, 977. 784 m/8 Bridges, 3 pedestrian Bridges, 1 bridge lanyway, 3 culverts and 4 passages. The west and east sides of the integrated pipe corridor are 4605m long, of which the west pipe corridor contains the integrated cabin and high voltage power cabin, and the standard section size is 8. 8mx4. 1m. The east corridor contains the integrated tank and the gas tank, and the standard section size is 7. 1mx4. 1m. Pass through Minle Road and Minkang Road respectively.

3.2 Overview of Pipe Jacking

As the project passes through Minkang Road and Minle Road, the integrated pipe corridor project on the east and west sides involves four underground excavation sections, all of which adopt the rectangular pipe pushing process of earth pressure balance. The outer contour of the west pipe section is 9. 1m×4. 4m, the internal clearance is 7. 9m×3. 2m, the wall thickness of the pipe section is 600mm, the width is 1500mm, and the weight of the single pipe section is about 57t. The outer outline of the eastern pipe section is 7. 4m×4. 4m, the internal headroom is 6. 2m×3. 2m, the wall thickness of the pipe section is 600mm, the width is 1500mm, and the weight of a single pipe section is about 48t. The strength grade of the pipe joint is C50, the impermeability grade is P8, the interface adopts the "F" type socket form, and the whole prestressed tension reinforcement is carried out after the pipe jacking forming. Table 1 shows the parameters of pile foundation in different construction sections of the project.

Table 1. Parameters of pile foundation in different construction sections of the project

Jacking position	Stake mark	Length (m)	Slope (‰)	Section size (m)	Section clearance (m)	Buried depth of pipeline(m)	Pipe gallery bottom elevation	Water table elevation
The west side of Hengling	GXK0+646. 6-GXK0+690	43. 4	5. 1	9. 1×4. 4	7. 9×3. 2	11. 9-13. 7	56. 25-56. 47	59. 21
The East side of Hengling	GDK0+626-GDK0+648	22	5. 3	7. 4×4. 4	6. 2×3. 2	12. 5-12. 8	56. 28-56. 42	65. 01
South China west section	GXK1+663. 9-GXK1+720. 4	56. 5	5. 4	9. 1×4. 4	7. 9×3. 2	9. 1-9. 3	67. 37-67. 57	74. 32
South China East section	GDK1+720-GDK1+775	55	2. 2	7. 4×4. 4	6. 2×3. 2	9. 0-9. 4	69. 61-69. 78	70. 09

3.3 On-Site Monitoring

In this project, in order to monitor the surface deformation during the construction of pipe jacking, 17 monitoring points were set up at the underpass of the jacking pipe, and one monitoring point was set up every 3~4m to monitor the surface settlement in this area in real time.

In this project, an improved BP neural network is used to predict land subsidence. First, the collected data of the monitoring points are converted into time series data[3-4]. Then, the BP neural network model is used to train and predict the sequence. Finally, the prediction results were compared with the actual monitoring values to verify the accuracy of the model. Specifically, in the field monitoring stage, a series of measures are taken to ensure the accuracy of monitoring data. In the training stage, the BP neural network model is trained by genetic algorithm and particle swarm algorithm respectively.

In the process of pipe jacking, the surface settlement is affected by many factors, including soil properties, surface load, grouting pressure and groundwater. Because of the nonlinear characteristics of settlement process, the traditional BP neural network prediction method can not get good results. In the process of BP neural network prediction, in order to improve the accuracy and reliability of the prediction results, genetic algorithm and particle swarm algorithm can be used to improve the BP neural network model. In order to improve the searching ability of genetic algorithm, crossover operator and mutation operator can be used to improve. Finally, the experimental results show that the predicted value obtained by using the improved BP neural network is in good agreement with the actual monitoring value, indicating that the method can effectively improve the accuracy of prediction results[5-6].

4 Method Selection and Implementation

4.1 Selection of Forecasting Methods

The prediction methods can be divided into probability-based method and statistics-based method. The probability-based method refers to using the function relationship between the surface settlement and soil layer parameters to predict the settlement amount. The prediction principle is to predict the newly input soil layer parameters according to the known soil layer parameters. This method has high prediction accuracy, but it requires a lot of calculation and is suitable for small deformation.

The method based on statistics is to process the data according to various relevant information collected through statistical analysis, cluster analysis and other technologies, and then predict the future results. This method has the advantages of less computation and is suitable for large deformation.

Combining the characteristics of the two methods, this paper adopts the method based on statistics, and establishes a gray prediction model according to the construction site monitoring data and various related factors in application, which is used to predict the surface settlement in this area. Finally, after verifying the grey model, the weight and threshold of the network are optimized by genetic algorithm to complete the

pre-processing. In addition, in order to reduce the noise problem in the training process of the model, the initialization data is cleaned before the application of the method, which can further improve the accuracy of the results[7].

4.2 Method Implementation

4.2.1 Model Establishment.

First, establish BP neural network model. BP neural network is a kind of nonlinear dynamic network, which uses artificial neural network method to nonlinear approach the problem studied, has strong self-learning ability, and is widely used in practical engineering. The model takes the measured data as the input variable and the ground settlement under pipe jacking as the output variable, and establishes the prediction model of ground settlement under pipe jacking. Three sets of 21 measured data were selected as sample data in the engineering example, and the BP neural network model was established by using MATLAB software. The model completes the training of the network through learning training, inspection testing and calculation output[8-9].

Second, genetic algorithm model. Genetic algorithm is a random search algorithm, which is mainly used to solve the optimal solution of nonlinear problems. The application of genetic algorithm to the prediction of surface settlement under pipe jacking can effectively improve the calculation speed and accuracy. The model mainly includes two parts, as shown in Table 2.

Table 2. Model composition

Model composition	The input and output variables are normalized
	Genetic algorithm is used to find the optimal solution

On the basis of Table 1, since the prediction model of surface settlement through pipe jacking is a nonlinear mapping relationship, it is necessary to find an optimal solution. In this paper, adaptive genetic algorithm is used to solve the optimal solution, and it is applied to the prediction of surface settlement.

Third, the forecasting process. The improved BP neural network is used in the prediction of the surface settlement through the pipe under the top: (1) The structure of the traditional BP neural network is optimized to reduce the number of input nodes and output nodes; (2) Introduce an adaptive adjustment mechanism to adjust weights and thresholds to avoid excessive convergence and over-learning; Then the initial weight and threshold of the network are optimized, and the maximum error principle is used to determine the number of hidden layers and the number of hidden layer nodes. (3) Optimize the performance of the network through continuous learning and training. According to the above steps, the surface settlement prediction model is optimized, and the optimized model is applied to the actual project. The results show that compared with the traditional BP neural network model, the improved BP neural network model can improve the prediction accuracy and calculation speed. In particular, the prediction effect of surface settlement under pipe jacking is significantly better than that of traditional BP neural network model and PSO algorithm model. Therefore, this algorithm is

suitable for the prediction of surface settlement under pipe jacking. Formula (1) is the algorithm expression[10].

$$1-\left(1-P_m\right)^{o(H)} \tag{1}$$

Where P is the genetic basis, m is the number of mutation paths of the genetic basis, and o (H) is the mutation probability of P on different mutation paths. The specific model is shown in Figure 2.

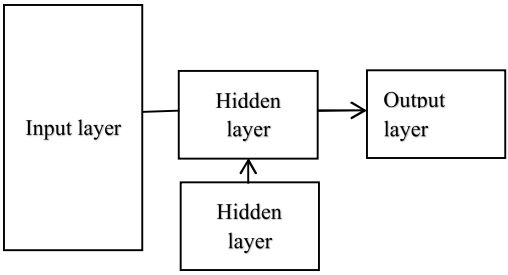

Fig. 2. Concrete model

4.2.2 Implementation.

Considering the uncertainties in the monitoring data, five times of model training were used in the prediction process, and the flow of the prediction model after training was shown in Figure 3.

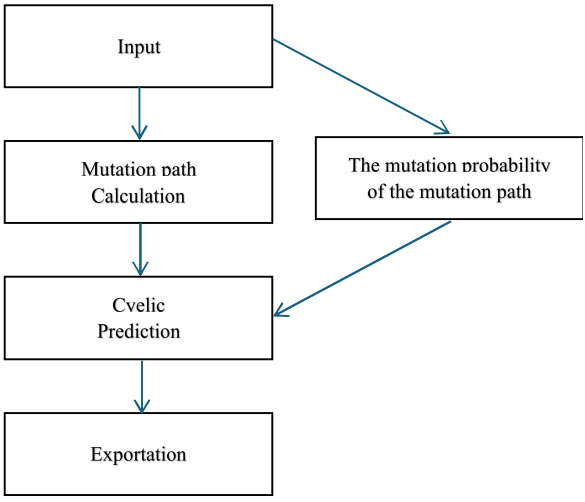

Fig. 3. Flow of prediction model

The model is the predicted value without considering the influence of factors, and the BP neural network can be output after training with genetic algorithm. As can be seen from Figure 3, after 5 times of model training, all the predicted results are in good agreement with the actual situation, but there are still some differences. According to the error analysis, when the BP neural network is used in the model, due to its slow convergence speed and easy to fall into the local extreme value, the prediction result will often have a large error. However, when genetic algorithm and particle swarm algorithm are added to the model, due to their respective advantages, they can better approximate the real value, so the prediction results are more accurate. When forecasting, we should not only take into account the influence factors of the surrounding environment, but also take into account the uncertainties existing in the monitoring data. Therefore, it is necessary to add a certain proportion of uncertain factors in the process of model training to ensure that the model can accurately predict the land surface settlement.

5 Analysis of Main Factors and Their Influence on Performance

5.1 Main Factors

In practical engineering, there are many factors affecting the ground settlement, such as construction technology, geological conditions and technical parameters, among which construction technology is the most important factor. In this project, the settlement of pipe jacking down through the surface is divided into four stages: excavation stage, grouting stage, pipe section installation stage and receiving stage. On this basis, according to the field monitoring data, the maximum surface settlement under pipe jacking is selected as the target variable, and the parameters affecting the surface settlement under pipe jacking are analyzed using Matlab software: First, when the parameter of the penetration depth under pipe jacking is greater than the standard value, the settlement depth will increase; when it is less than the standard value, the settlement value will remain unchanged; Second, when the top distance parameter is greater than or less than the standard value, the settlement area will change accordingly. Thirdly, when the top distance does not match the soil layer property parameters, the settlement depth will increase. Fourth, when the soil weight parameter is too large, the settlement depth will increase. Therefore, the influencing factors of ground settlement through pipe jacking are divided into the following four aspects, as shown in Table 3 for details.

Table 3. Influencing factors of surface settlement under pipe jacking

Influencing factor	Penetration depth under pipe jacking
	Top distance of pipe
	Top distance and soil properties
	Soil weight

Among the factors, the top distance has the greatest influence on the surface settlement under pipe jacking, followed by soil properties, top distance, jacking rate and

soil weight. Therefore, the top distance, soil properties and jacking rate should be reduced as much as possible.

5.2 Analysis of Factors Influencing Performance

5.2.1 Penetration Depth under Pipe Jacking.

According to the construction experience, it is generally believed that the ground settlement under the pipe jacking is zero, that is, the soil in the pipe jacking crossing section does not disturb. However, due to the influence of many factors, the soil in the pipe jacking crossing section is often disturbed. Such as soil layer properties, formation losses, grouting reinforcement effect. The influencing factors of surface settlement under pipe jacking include: (1) formation loss; ② Reinforcement effect of grouting. It can be seen from Fig. 3 that the penetration depth under pipe jacking has the greatest influence on the surface settlement under pipe jacking, and the surface settlement increases with the increase of penetration depth under pipe jacking, especially when the outer diameter of pipe jacking is large (for example, the diameter exceeds 1 200 mm), when the outer diameter of pipe jacking reaches 2 000 mm, and when the penetration depth under pipe jacking reaches 4 000 mm or more. The land subsidence value will be large. Therefore, in the construction should try to avoid the use of large diameter pipe jacking diameter. Too small penetration depth of pipe jacking is easy to cause large soil disturbance and poor reinforcement effect of grouting.

5.2.2 Top Distance and Soil Layer Properties.

The surface settlement is mainly composed of two parts: first, the surface settlement caused by groundwater seepage caused by the drop of groundwater table; Second, stratum movement caused by soil disturbance around excavation face. The ground settlement caused by the drop of groundwater table is mainly caused by the formation loss, and the disturbance of the soil around the excavation face will affect the formation loss. In the property of soil layer, it is expressed by the pore ratio. The smaller the pore ratio, the greater the density of the soil mass. The soil mass will form more pores under the action of compression, and the soil mass is less dense. The smaller the top distance is, the smaller the settlement value under the top pipe.

At the same time, the surface settlement value caused by pipe jacking construction has a close relationship with soil properties. When the soil properties are the same, the surface settlement value of pipe jacking construction increases with the increase of roof distance. This is because due to the friction between the pipe jacking machine and the formation during the jacking process, the disturbance deformation caused by the pipe jacking through the surface is mainly borne by the soil resistance, so the surface settlement value increases with the increase of the top distance under the same conditions.

5.2.3 Influence of Pipe Jacking Construction Parameters on Surface Settlement.

In order to analyze the influence of pipe jacking construction parameters on the surface settlement, the sensitivity analysis of pipe jacking construction thrust, grouting pressure and grouting volume was carried out.

With the increase of the top thrust, the surface settlement decreases gradually. With the increase of grouting pressure, the surface settlement decreases gradually. With the increase of grouting amount, the surface settlement increases gradually. This is because the jacking force of pipe jacking construction is mainly provided by the jacking machine, and the surface settlement decreases gradually with the jacking force increasing within a certain range. In addition, with the increase of grouting pressure in a certain range, the surface settlement also increases. This is because during pipe jacking construction, the jacking force is mainly provided by the pipe jacking machine. When the top thrust exceeds a certain range, the impact of the top thrust on the land surface settlement becomes larger.

The effect of grouting pressure on the surface settlement is obvious. In a certain range, with the increase of grouting pressure, the surface settlement decreases gradually. When the grouting pressure exceeds a certain value, the influence of grouting pressure on the land surface settlement becomes larger. This is because with the increase of grouting pressure, more pore fluid pressure is generated in the soil body, which makes the pore water volume in the soil gradually decrease. At the same time, the amount of grouting has great influence on the land surface settlement. When the grouting amount is small, the influence of the grouting amount on the land surface settlement is small. When the amount of grouting increases, the influence of the amount of grouting on the land surface settlement becomes larger. When the grouting pressure reaches a certain value, the pore fluid pressure in the soil does not increase.

5.2.4 Influence of Pipe Jacking Construction Environment on Ground Settlement.

In the process of pipe jacking construction, the surface settlement is a dynamic change process. When the environmental conditions of pipe jacking construction change, the surface settlement will also change. Because there are many factors affecting the surface settlement and they are independent of each other, many factors should be considered when predicting the surface settlement under pipe jacking.

When the environmental conditions of pipe jacking construction (distance of surrounding buildings, burial depth and pipe burial depth) change, the surface settlement will also change. When the environmental condition of pipe jacking construction is that the distance of the building is less than 20m, the surface settlement is small; When the environmental conditions of pipe jacking construction are between 20m and 40m, the surface settlement increases with the change of environmental conditions of pipe jacking construction. When the pipe jacking construction environment condition is that the buried depth of pipe is between 8 and 14m, the surface settlement decreases with the increase of buried depth of pipe. When the pipe jacking construction environment condition is that the buried depth of the pipe is between 14m and 28m, the surface settlement decreases with the increase of the buried depth.

6 Analysis of Prediction Results

In the process of pipe jacking construction, it is inevitable to produce a large surface settlement. Therefore, in order to make the surface settlement prediction result more accurate, the improved BP neural network model is used to predict the surface settlement under pipe jacking, considering the influence of construction parameters and construction environment on the surface settlement. Genetic algorithm is used to predict the ground settlement under pipe jacking construction: first, input the original data; Second, model training; Third, the algorithm cycles 10 times to calculate the relative error; Fourthly, the output results are shown in Table 4.

Table 4. Algorithm test results

Mean relative error	4. 75% (average)
frequency	10 times

As can be seen from Table 4, the average relative error of genetic algorithm for predicting surface settlement under pipe top penetration is 4. 75% on average, so the prediction accuracy of genetic algorithm is up to standard. Therefore, adopting genetic algorithm to improve BP neural network model can predict surface settlement under pipe top penetration more accurately.

In order to verify the applicability of the proposed model, three different formation parameter combinations (namely, sandy silt and silty clay) are selected to predict the surface settlement under pipe jacking construction. The results show that the surface settlement of sandy silt is smaller than that of silty clay, but still larger than that of silty clay. Therefore, the sandy silt can be used as the main prediction formation for the prediction of surface settlement under pipe jacking construction.

At the same time, when the above intelligent algorithm is used to predict the surface settlement under the top pipe, it is found that the prediction results using the improved BP neural network model are more consistent with the actual monitoring results. This is because the influencing factors of ground settlement under pipe jacking are more complicated. Therefore, many factors such as influencing factors, pipe jacking construction parameters and pipe jacking construction environment should be considered comprehensively when predicting the surface settlement under pipe jacking.

7 Conclusion

To sum up, pipe jacking construction has become an indispensable and important part in the field of underground engineering, and the safety and stability of underground engineering has always been the focus of attention of construction personnel. Due to the particularity of pipe jacking engineering, it is necessary to monitor and manage in strict accordance with relevant norms during construction. However, due to the limitation of monitoring technology and the influence of human factors, the problems that may occur in the construction process are not accurately, timely and effectively controlled. However, on the basis of existing studies, the method proposed in this paper

adds a new detection dimension and constructs a new detection route, which solves the problems of previous problems and avoids related defects, so that detection results can be obtained more comprehensively and accurately.

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