Research on Settlement Prediction of Building Foundation in Smart City Based on BP Network

Luyao Wei
Department of Architecture and Civil Engineering,
Shijiazhuang University of Applied Technology, Shijiazhuang 050000, China

***Abstract*—In the construction process of high-rise buildings, it is necessary to predict the settlement and deformation of the foundation, and the current prediction methods are mainly based on empirical theoretical calculations and methods and more accurate numerical analysis methods. In the face of the interference of complex and ever-changing terrain and parameter values on prediction methods, in order to accurately determine the settlement of building foundations, this study designed a smart city building foundation settlement prediction method based on BP neural network. Firstly, a real-time dynamic monitoring unit for building foundation settlement was constructed using Wireless Sensor Network (WSN) technology. Then, the monitoring data was used to calculate the relevant parameters of building foundation settlement through layer sum method. Finally, input the monitoring data into the BP network results, adjust the weights of the output layer and hidden layer using settlement related parameters, and output the settlement prediction results of the smart city building foundation through training. The study selected average error and prediction time as evaluation criteria to test the feasibility of the method proposed in this article. This method can effectively predict foundation settlement, with an average prediction error always less than 4% and a prediction process time always less than 49ms.**

Keyword*—Smart city; intelligent architecture; foundation settlement; settlement prediction; BP neural network; parameter

I. Introduction

Urban high-rise buildings are increasing recently. From the beginning of construction to the completion acceptance of high-rise buildings, regular monitoring of foundation settlement and prediction of deformation trend are of great significance to ensure the construction safety and normal use of the building [1]. Therefore, many models and methods are put forward to solve the prediction problem of foundation settlement and deformation. These methods can be roughly categorized as two kinds: theoretical calculation and measured data analysis method based on measured data. Among them, the theoretical calculation method can be subdivided into empirical method and numerical analysis method. The former is simple and practical, and is generally determined based on laboratory test results combined with relevant experience, and the calculated results generally have a large deviation from the measured values [2-3]. The latter is the product of modern mechanics research and develops gradually with the progress of computer technology. With the continuous development of computer technology, the methods for analyzing foundation settlement and deformation have gradually evolved from experience to empirical theory. However, due to the complexity and variability of factors that affect foundation settlement and deformation in practical engineering, it is difficult to determine the values of various geological parameters, which makes it difficult for analysts to establish numerical models that match the actual engineering situation, thus greatly limiting the application of this method in engineering practice [4].

Therefore, a prediction method of building foundation settlement based on the “S-index” mathematical model is designed in research [5]. This method firstly analyzes the settlement law of building foundation, then optimizes the Logistic curve (S curve) model and exponential curve model, and puts forward “S-exponential” mathematical model, and theoretically analyzes the model from the mathematical point of view. In study [6], a soft soil foundation settlement prediction method is designed based on the modified and optimized comprehensive prediction model. For predicting soft soil foundation settlement, a modified and optimized comprehensive prediction model is proposed to solve the problem that the choice of single prediction method is difficult to adapt to the actual engineering situation. The monitoring data of soft soil foundation settlement are independently mined from different angles to analyze the change law of soft soil foundation settlement, and the comprehensive prediction of soft soil foundation settlement is realized. Firstly, the hyperbolic method and GM (1,1) model are considered comprehensively, and a preliminary comprehensive prediction model is established based on the arithmetic weighted average combination idea. Then, the real-time correction weight coefficient is constructed, the real-time correction amount is calculated to modify the preliminary comprehensive prediction model, and the comprehensive prediction model of modification optimization is established. Finally, the modified and optimized comprehensive prediction model can be used to predict soft soil foundation settlement. In reference [7], the grey model with fractional order is studied and applied to the prediction of foundation settlement. This method takes the grey model as the research object and improves the prediction effect of the grey model by changing the integer order differentiation into fractional order differentiation. The biggest difference between this model and the traditional model lies in the addition of fractional order recognition. Firstly, the ordinary differential equation without input is obtained by combining grey theory. Then the input term is introduced and the ordinary differential equation is transformed to obtain the fractional differential equation. However, it is found in practical application that the method has the disadvantages of large average error and long time consuming. In [8], it was found that current clustering algorithms lack effective representation learning, and deep learning techniques can be utilized in document clustering to enhance the learning process. Firstly, by retaining important information in the initial data, the original samples and their extensions are pushed together to solve the problem of learning representation. In addition, the problem of cluster position preservation is also addressed by pushing adjacent data points together. To this end, a deep embedding clustering framework based on compressed autoencoders (DECCA) was proposed to learn document representation. In addition, in order to grasp relevant document or word features, the Frobenius norm was added as a penalty term to the traditional autoencoder framework, which helps the autoencoder perform better. The authors in [9] proposed a new grey wolf optimized Extreme learning machine model, namely GWO-ELM model. This model trains and predicts land subsidence by combining Extreme learning machine and grey wolf optimization algorithm, and establishes three GWO-ELM models considering the influence of time series, settlement factors and optimization to predict land subsidence near the foundation pit. The prediction results show that the average relative error and Mean absolute error values from large to small are: GWO-ELM model based on time series, GWO-ELM model based on sedimentation factor, and three GWO-E optimized GWO-ELM models. In reference [10], healthcare is also widely integrated with the Internet of Things to develop an upcoming industrial system. Utilizing this type of system can promote optimal patient monitoring, effective diagnosis, intensive care, and include appropriate surgery for existing critical illnesses. Due to massive data theft or privacy breaches, security, and privacy based on patient information data, it has become necessary to protect personal patient information data in digital communities. The article emphasizes excellent monitoring and perceptual extraction of keyframes, as well as lightweight cosine functions for further processing using hybrid chaotic mapping keyframe image encryption. This encryption combines keyframes, is very secure, and is not affected by external factors or any opponents. The proposed method verifies the effectiveness of the entire IIoT ecosystem.

Smart City is a term that originated in the field of media and has become popular in recent years. The concept refers to using a variety of information technologies to integrate urban systems and services to achieve greater efficiency in resource utilization, improved urban management and services, and ultimately a higher quality of life for citizens. This innovative approach to city building can help alleviate many of the problems cities face, such as overcrowding and poor resource management. Wisdom City, on the other hand, is a new generation of technology-based city management strategies that integrate knowledge and innovation from all walks of life. It combines the latest advances in information technology, industrialization, and urbanization to effectively meet the challenges posed by modern urban development. Through refinement and dynamic management, it aims to enhance the quality of urbanization and promote better urban management performance, ultimately improving the quality of life for urban residents [11-12].

Smart city is an innovative approach to city building that leverages next-generation information technologies to integrate urban systems and services. These technologies include the Internet of Things, cloud computing infrastructure, and geospatial infrastructure, as well as various tools and methods such as social networks, Wikis, and all-media integrated communication terminals. This approach to city building is characterized by comprehensive and thorough perception, broadband interconnection, intelligent integration, and sustainable innovation. It is driven by user innovation, open innovation, mass innovation, and collaborative innovation, and involves a range of integrated methods such as Living Lab and Fab Lab. The goal of smart city development is to improve resource utilization, optimize urban management and services, and enhance the overall quality of life for city dwellers through innovation and collaboration [13]. The idea of smart city has emerged as a response to the changing landscape of the networked world. In the knowledge society, this advanced form of information development is seen as the successor to the digital city. The construction of a smart city is a complex process that involves the integration of multiple technologies and the democratization of innovation. Key to this is the application of new generation technologies like cloud computing and the Internet of Things, which drive the development of comprehensive perception and ubiquitous interconnection. Using mobile technology, the concept of smart city also involves the democratization of innovation, aimed at enhancing the quality of life for citizens. The approach is characterized by converged application and ubiquitous computing and has the potential to revolutionize the way cities are managed and function.

Based on the above background, smart architecture came into being. Intelligent building first rise in foreign countries, through intelligent device for intelligent management for the whole building space and its internal facilities, according to the architectural space feature matching corresponding intelligent system, in order to achieve energy conservation and emissions reduction, comfortable living, convenient management, safety and environmental protection effect, such as the main service groups, using, and managing personnel to live [14-15]. Therefore, we can understand that, in construction of digital intelligent wisdom city is the city development direction, intelligent building is in the process of building construction,, unit for construction personnel and management personnel to provide digital intelligent management, the operation of the service system, the main service groups are construction workers, construction management and construction enterprises; Smart building is to provide intelligent services for residents, users and managers after the building is completed.

Therefore, when maintaining the stability and safety of intelligent buildings, it is very important to accurately predict the foundation settlement. Therefore, in view of the shortcomings of traditional methods, this study designed a prediction method for foundation settlement of smart city buildings based on BP neural network.Based on WSN, this study aims to establish a real-time dynamic monitoring system for building foundation settlement. Based on measured data, a hierarchical summation method is used to determine the parameters related to building foundation settlement. Finally, the monitoring data is input into the BP neural network, and the weights of the output layer and hidden layer are modified based on the parameters related to settlement, ultimately achieving the prediction of basic settlement in smart cities. The feasibility of the proposed algorithm was tested using average error rate and prediction time as evaluation indicators.

The prediction method of smart city building foundation settlement based on BP network is to analyze the structure of the BP network, input monitoring data into the BP network model results, adjust the weights of the hidden layer and output layer using settlement related parameters, and output the prediction results of smart city building foundation settlement through training. It can be well applied in more intelligent building construction in the future, and can accurately predict foundation settlement, Make timely response. Compared with other methods, the building foundation settlement prediction system based on WSN technology proposed in the study is innovative, and the experimental verification in the following text shows that the prediction has smaller errors and faster response speed.

II. Foundation Settlement Prediction of Smart City Buildings

A. *Real-time Dynamic Monitoring of Building Foundation Settlement*

In this study, WSN technology is firstly used to construct a real-time dynamic monitoring unit for building foundation settlement. The overall architecture of the monitoring unit is shown in Fig. 1.

The monitoring unit mainly includes the following four parts: building sensor node distribution module, sensor network module, communication module and upper computer monitoring module. Among them, the sensor network mainly collects the foundation settlement displacement data, and sends the data to the serial port of the coordinator, and then to the upper computer module. The middleware of serial communication can identify whether the information is valid or not, and analyze the valid and available information, and then transfer and store it in the database. The monitoring module of upper computer can realize remote node information management and control, historical information retrieval, data curve visualization and dynamic warning, etc.

As for real-time dynamic monitoring of building foundation settlement, it is defined that settlement measurement is effective when the monitoring error is controlled within 50mm [16]. Therefore, the unit adopts a displacement sensor with a precision of 0.1mm. Its operating principle is: when the sensor is compressed due to displacement, the resistance of the winding resistance wire changes a series of times, so that the voltage also changes, and the displacement can be estimated by the voltage change value. The measurement environment is shown in Fig. 2.

Use reinforced concrete design to make the base point of the column pillar, and dig down 3m at the base point. The triangular bracket is installed and fixed at the settlement monitoring position of the wall. One end of the displacement sensor is fixed on the base point, and the other end is in contact with the triangular baffle. Once the foundation settlement, the wall will also downward displacement, triangular baffle and sensor will produce extrusion, at this time the sensor is compressed, the voltage between point B and C will produce a certain change, so as to obtain the foundation settlement data.

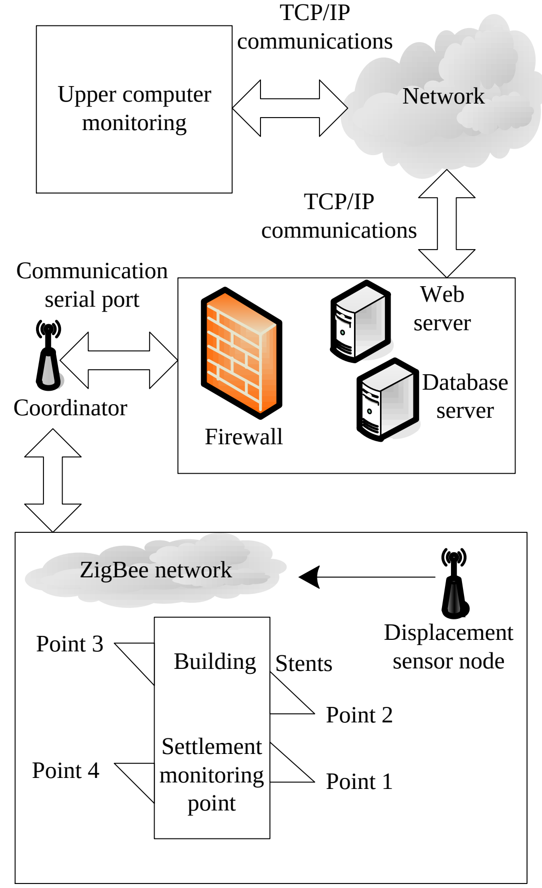

Fig. 1. The whole structure of real-time dynamic monitoring unit for foundation settlement.

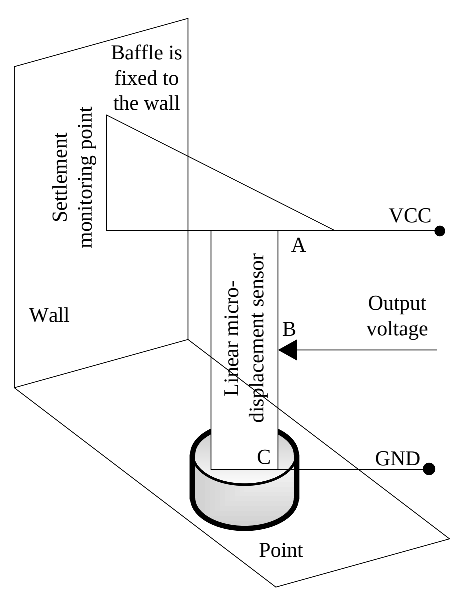

Fig. 2. Schematic diagram of measurement environment.

When displacement sensors are set at the corresponding positions of settlement monitoring points, multiple displacement sensor monitoring points are set around the building [17-18]. The plane distribution of monitoring points is shown in Fig. 3.

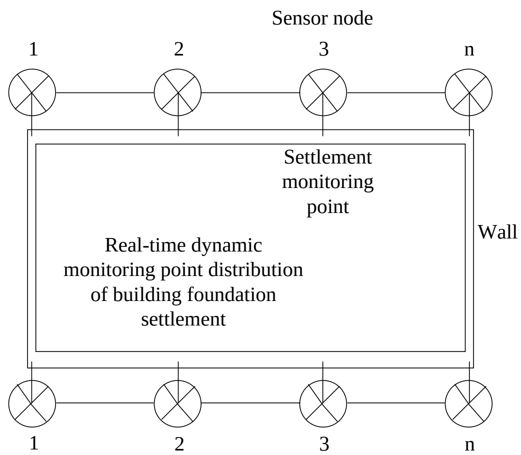

Fig. 3. Plane distribution of monitoring points

The building foundation settlement information data acquisition module is composed of highly accurate displacement sensor and ZigBee network equipment. Among them, the main function of each displacement sensor in ZigBee network is to communicate with superior nodes, and collect real-time displacement data of building foundation settlement and complete package transmission [19]. The routing node is mainly responsible for relaying the information data of monitoring points, so as to ensure that all monitoring points can efficiently send data to the coordinator position in the whole communication range. The coordinator is responsible for bringing together all the ZigBee network data and enabling the network to be turned on or off.

TABLE I. EXPLANATION OF FORMULA SYMBOLS

Formula symbols	Meaning
ψ	Axial stress
ψ'	Axial strain
E	Initial combined deformation modulus of soil mass
B	Poisson's ratio of soil mass
δ	The failure ratio of soil mass
c	Soil cohesion
f	The maximum principal in the vertical direction
f'	Minimum principal stress in the horizontal direction
∂	Pressure coefficient of static soil

The upper computer software adopts B/S mode, which has the biggest advantage of realizing data storage and real-time dynamic monitoring in the gateway of the coordinator, and at the same time, it can use the network to inquire the displacement information data and early warning situation remotely. The communication between the coordinator and the upper computer of the system is realized by gateway. The communication gateway detects the data flow, receives the data flow packet from the serial port in real time, parses the data, and saves it to the corresponding database. Once the sensor displacement exceeds the limit, the exceeding information data will be saved in the warning information Table I. The client can browse through the Internet to check the system measured data and graph as well as the construction warning situation.

B. *Calculation of Related Parameters*

The above monitoring data of building foundation settlement are introduced into the Duncan-Chang constitutive model and combined with the layer-summation method to calculate the relevant settlement parameters.

Duncan-chang model is a constitutive model constructed based on the correlation curve between Kondner's triaxial stress and strain [20-21], and its expression is as follows:

$$D = \frac{\psi \times v}{(m+n)\psi'} \tag{1}$$

Where, ψ and ψ' respectively represent axial stress and strain, v represents soil confining pressure, and m and n represent fitting parameters of the curve between stress and strain. The calculation process is as follows:

$$\begin{cases} m = \dfrac{1}{E} \\ n = \dfrac{1}{B\psi} \end{cases} \tag{2}$$

Where, E represents the initial joint deformation modulus of soil mass, and B represents poisson's ratio of soil mass.

Assume that δ represents the failure ratio of soil and the ratio between the failure partial stress ψ and the ultimate partial stress $B\psi$, which is generally 0.75-1. Thus, equation (3) can be obtained:

$$n = \frac{\delta}{\psi} = \frac{\delta(1-\sin\varphi)}{2c\cos\varphi + 2v\sin\varphi} \tag{3}$$

Where, c represents the cohesion of soil and φ represents the Angle of internal friction. Since the Duncan-Chang model only considers the settlement under the influence of deviational stress, the foundation deformation caused by hydrostatic pressure should also be taken into account.

$$s = s_i + s_i' \tag{4}$$

In the formula, s represents the vertical deformation of the i -th layer, s_i and s_i' represent the vertical deformation under the influence of water purification pressure and deviational stress, and these two parameters are calculated by Hooke's Law and Duncan-Chang respectively.

Because different compressible layers in the foundation will have different deformations under the influence of additional stress, it is necessary to obtain the initial deformation modulus value. Under the influence of dead weight stress, the maximum principal stress f in the vertical direction and the minimum principal stress f' in the horizontal direction are obtained, then the initial ground stress calculation process of the i -th compression layer is as follows:

$$F=\left(\gamma_k h_k+\frac{g}{2}\times p\right)\times\partial \tag{5}$$

Where, γ_k and h_k respectively describe the weight value and thickness value of soil at layer k, g represents the mean value of vertical dead weight stress, p represents the mean value of horizontal lateral pressure, and ∂ represents the pressure coefficient of static soil, which can be expressed as:

$$\partial=\frac{B}{1-B} \tag{6}$$

C. Settlement Prediction Based on BP Network

BP(Back Propagation) network is a multi-layer feed-forward neural network trained according to error reverse Propagation algorithm, and it is one of the most applied neural network models. BP network is a multi-layer feedforward network trained by error back propagation. Its algorithm is called BP algorithm. Its basic idea is gradient descent method, and gradient search technology is used to minimize the mean square error of the actual output value and the expected output value of the network.

The BP neural network is particularly effective when it comes to solving problems that a simpler perceptron cannot, such as the Exclusive OR (XOR). Structurally, the BP network consists of three layers: input, hidden, and output. In practice, the BP algorithm uses the square of the network error as the objective function and employs a gradient descent method to calculate the minimum value of this function. This allows it to effectively map complex, high-dimensional data sets onto a lower-dimensional space, providing a powerful and flexible tool for a range of applications. Ultimately, the BP neural network is a powerful tool that can help unlock the potential of big data [22].

The BP algorithm is a multi-step process that involves both forward and backward propagation. During forward propagation, the input signal is transformed through the hidden layer and generates an output signal through nonlinear transformation. If the actual output is different to the expected output, then the error backpropagation process begins. Backpropagation involves adjusting the weight and threshold in the direction from output to input, allowing the system to learn and adjust based on the errors identified. This process is iterative, with the network continually re-evaluating and refining its judgments based on new data [23]. Error backpropagation is the process of transmitting output error back through the hidden layer to the input layer. This involves apportioning the error to all of the elements in each layer and using these error signals to adjust the weights of the connections between nodes. Through the repeated adjustment of these connection strengths and threshold values, the error can be minimized along the gradient direction, allowing the network to learn and adapt to new data. Eventually, this process leads to the identification of network parameters, such as weights and thresholds that correspond to minimal error. Once these parameters are identified, the training process is complete, and the neural network is ready to process new inputs. By applying nonlinear transformations to these inputs, the network can effectively map them onto a lower-dimensional space and process them with minimal error.

With the BP neural network analysis, for the influence of mechanical parameters change due to the nonlinear soil, combined with BP network to achieve accurate prediction of building foundation settlement. Fig. 4 shows a three-layer BP model.

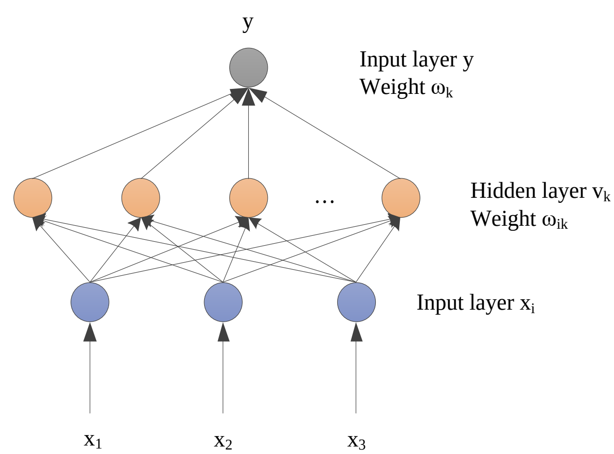

Fig. 4. BP model.

In general, the number of hidden layers in BP neural network ≧ 1. All mappings from m dimension to q dimension can be realized by using 3-layer BP neural network. Therefore, the number of hidden layers can be set as 1, and the number of existing neurons is k. The connection strength between this layer and other two layers needs to be described by using weights. The input vector is described by $X=\{x_1,x_2,x_3\}$; The output vector is described by y. The weights of hidden layer and output layer are ω_{ik} and ω_k respectively. In the hidden layer, vectors matching neurons are described by v_k.

The core idea of BP neural network is that signal and error are propagated forward and backward respectively. The neuron excitation function is described by $f(*)$. According to the forward propagation of the signal, expressions related to the hidden layer described in Formula (7) and (8) can be obtained:

$$y_k = f\left(net_k\right), k = 1, 2, \cdots, n \tag{7}$$

$$net_k = \sum_{i=1}^{n} \omega_{ik} x_i, k = 1, 2, \cdots, i, \cdots, n \tag{8}$$

Expressions about the output layer obtained are described by formulas (9) and (10) :

$$z_k = f\left(net_k\right) \tag{9}$$

$$net_k = \sum_{i=1}^{n} \omega_{ik} y \tag{10}$$

On this basis, the expected and actual output is subtracted. Suppose e represents the error function, and its calculation process is as follows:

$$e == \sum_{k=1}^{n} \left(t_k - z_k\right)^2 \tag{11}$$

The application process of error function to input layer is as follows:

$$E = \sum_{k=1}^{n} \{t_k - f[\sum_{j=1}^{n} \omega_{ik} f(\sum_{i=1}^{m} \omega_{ik} y)]\}^2 \tag{12}$$

With the above formula, the weight can be adjusted to make the error change. The error is continuously reduced to ensure that the weight adjustment amount and its negative gradient change trend are the same, namely, the basic criterion of weight adjustment, which is described by the following formula:

$$\Delta\omega_{ik} = -\eta \frac{\partial e}{\partial \omega_{ik}} \tag{13}$$

Where, η represents the learning rate, and its value range is (0,1). Gradient descent is described by a negative sign.

The weight of each layer is updated in a circular way. The learning process of BP neural network, namely the process of repeatedly updating the weight, and the increase of new data can gradually reduce the error.

Based on the above analysis, the concrete prediction steps of foundation settlement of smart city building based on BP network are designed. Before the prediction, it is difficult to establish the specific relationship between the influencing factors and the settlement because the mechanism of foundation settlement deformation is relatively vague and the influencing factors are highly complex, which is also the fundamental reason why the application of conventional analysis methods is limited and the effect is not ideal.

Considering that the measured settlement data already contains the information of influencing factors, the settlement data in a certain time period is taken as the input of the neural network, and the predicted data in an unknown time period is taken as the output data. Therefore, in this study, the first three monitoring data are used to predict the next data, and the BP network structure is determined as follows: the number of nodes in the input layer is 3, the number of nodes in the hidden layer is 5, and the number of nodes in the output layer is 1.

According to the measured foundation settlement value of the project, 27 samples were established. The first 17 samples were used as training samples for BP neural network training and learning, and the last 10 samples were used as prediction samples to test the prediction and generalization ability of the established BP neural network model. The steps are as follows:

Step 1: Assume that the input information of BP neural network is x, the target input is d, and the actual output is y, and randomly generate the initial value and threshold value as the connection weight between nodes.

Step 2: According to the real-time dynamic monitoring of settlement of building foundation obtained in Part 2.1, calculate the actual output y of BP neural network, and the process is as follows:

1) For input layer node, its output a_i is equal to the input x_i data, that is, $a_i = x_i$;

2) For the hidden layer node, its input is $net_k^H = \sum_{i=1}^{3} \omega_{ik}^H$, its output is $a_k = f\left(net_k^H - \phi_k\right)$, ϕ_k is the threshold of the hidden layer node, f is generally Sigmoid function;

3) For the output layer node, its input is $net^0 = \sum_{k=1}^{n} \omega_k^{aH} a_k$ and its output is $a_k = f\left(net^0 - \phi^0\right)$, ϕ^0 is the threshold of nodes in the output layer;

Step 3: Calculate the energy function $E = \left(d - y\right)^2$. If the energy function is less than the specified value, go to Step 5; otherwise, go to Step 4;

Step 4: Adjust the weights of hidden layer and output layer in combination with relevant parameters of settlement of building foundation calculated in Part 2.2.

Step 5: Train the next sample until each training sample in the training sample set meets the target output, then BP network learning is completed. The actual output result is the prediction result of foundation settlement of smart city buildings.

III. Simulation and Analysis

A. Preparing

For verifying the actual use of the prediction of foundation settlement of smart city buildings based on the designed BP network, the following simulation experiment is designed to verify it.

Windows 10 (64-bit, Anaconda3+TensorFlow 1.4.0) is the operation system, and the simulation platform is MATLAB.

Select a high-rise building in a smart city as the experimental object. The building covers an area of 45m×23m. The overall structure is scissor wall. Bored piles are used in the foundation treatment process. The east and south sides of the building are adjacent to the street, the north side is more multi-storey buildings, and the west side is adjacent to a high-rise building to be built.

The site was rebuilt after the original low building was demolished, so the site is relatively flat. The relative height difference of the ground is roughly 1.4m. The overlying strata of the building construction mainly include loess and paleosol, while the underlying strata are mainly silty clay and sandy soil.

Fig. 5 shows the contour line of settlement of the experimental building. Among them, K1-K6 are the 6 detection points respectively. In the form of settlement isoline distribution, the middle part of the experimental building gradually expands to both sides, forming a curve in the form of equal settlement closure. This isoline reflects that the settlement amount generated by iteration of the stress of the building foundation is the largest, while the two sides are relatively small.

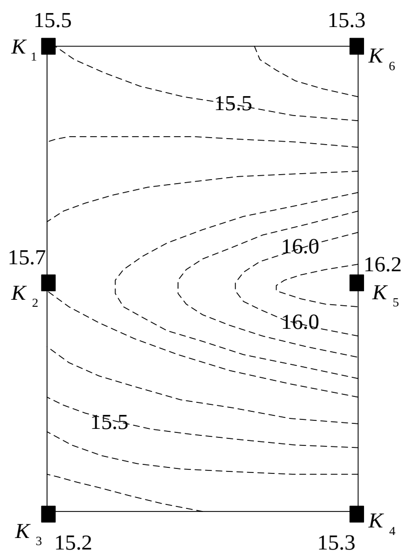

Fig. 5. Contour diagram of settlement of experimental building.

Fig. 6 shows the change of foundation settlement rate of the building over time. The settlement rate reaches the maximum value in the process of capping the main structure of the building, and becomes more and more stable after the completion of load loading. If the settlement rate of different monitoring positions is roughly the same, it indicates that the building has entered the stable period of foundation settlement.

B. Based on Inspection

The method in this paper was loaded on the Matlab platform to monitor the K1-K6 monitoring points and obtain the relevant data of building foundation settlement. The accuracy of the measurement results in this paper was judged by comparing with the actual values.

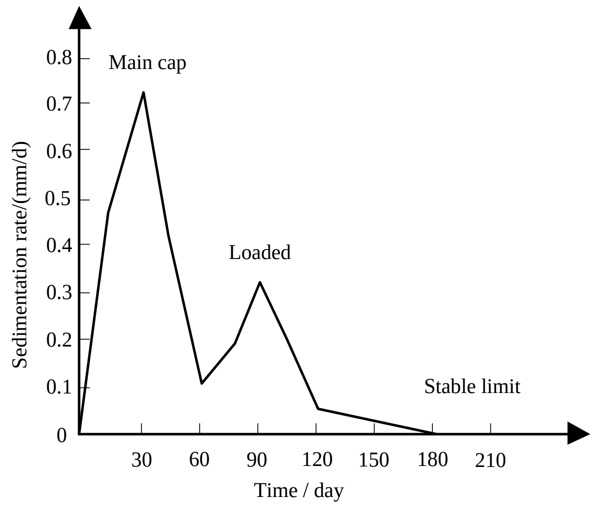

Fig. 6. Schematic diagram of sedimentation rate over time.

By comparing the difference between the predicted settlement value and the actual settlement value, the fitting degree between the two values is calculated. The fitting degree is calculated by the sum of the remaining squares. The closer the value is to 1, the smaller the gap between the predicted value and the true value is. The calculation process of fitting degree is as follows:

$$R = 1 - \frac{|q - x|}{x} \quad (14)$$

Where, R represents the fit degree, q is the predicted settlement value. x is the actual value. The fitting curve is shown in Fig. 7.

From Fig. 7, in different time periods, the fitting degree between the predicted results and the actual settlement value is always close to 1, which proves that the fitting degree between the two is high. Therefore, this method can effectively predict foundation settlement.

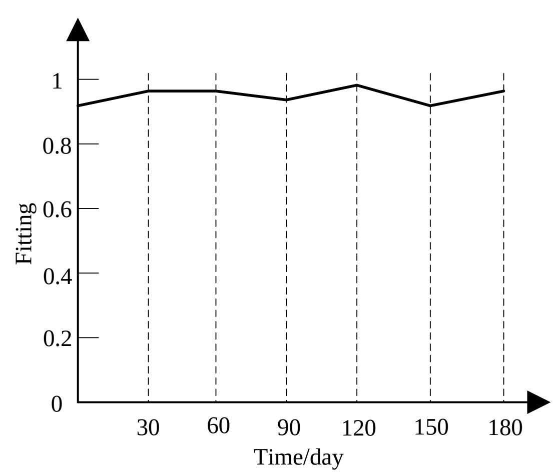

Fig. 7. Accuracy curve of calculated results.

C. *Contrast Test*

In order to avoid unconvincing results, method of researches [5] and [6] were compared to for performance verification together with the proposed method. The comparison indicators are as follows:

1) Average error (AE). The reliability of a foundation settlement prediction method can be evaluated based on the AE of its prediction results. A lower AE indicates higher prediction performance, greater reliability, and a stronger application advantage. By minimizing the AE, practitioners can ensure that their predictions are as accurate and reliable as possible. This can be achieved through careful selection of prediction models, validation of prediction results, and ongoing refinement of prediction methods based on new data. The calculating is followed:

$$A = \frac{sum\frac{|y'-y|}{y}}{N} \times 100\% \tag{15}$$

A represents the foundation settlement prediction AE. N is sample size. y and y' represents real and predicted settlement value.

2) Time consuming. The time consumed in the forecasting reflects the timeliness. Higher timeliness needs shorter time consuming. The shorter the forecasting process, the higher the timeliness of the forecasting method, that is, the higher the forecasting efficiency.

First, the AE was tested, as shown in Fig. 8.

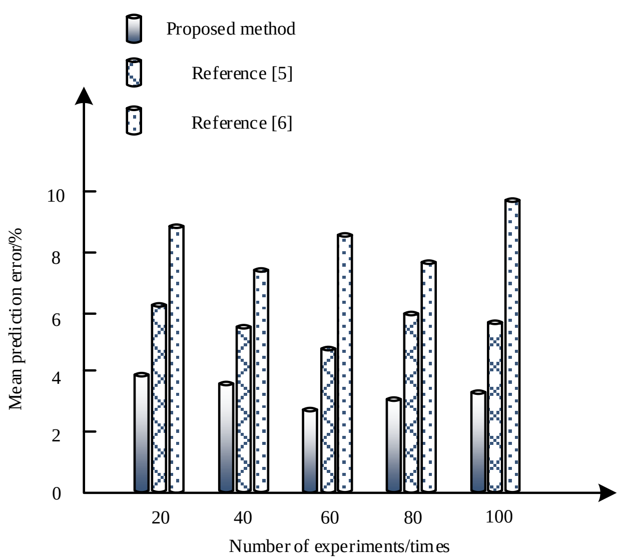

Fig. 8. Comparison of mean error of different prediction methods

The results shown in Fig. 8 indicate the prediction methods AE changes. However, in comparison, the AE of method of study [5] take the highest, and the highest AE is near 10%. The AE of this paper's method is the lowest, always below 4%, indicating it has higher reliability in predicting foundation settlement of smart city buildings.

Then we test the time-consuming process of foundation settlement prediction with different methods as shown in Table II.

The results in Table II show that the prediction time of different foundation settlement prediction methods also changes constantly with the experiments number. The prediction process of the method of reference [5] takes 50.13-ms68.03ms, and that of the method of reference [6] takes 61.02ms-71.81ms. However, the prediction time of method of this paper is always lower than 49ms. In contrast, the prediction process of method of this paper takes less time, which indicates that method of this paper has higher timeliness.

TABLE II. COMPARISON OF THE PREDICTION PROCESS TIME OF DIFFERENT METHODS

Number of experiments/times	Predict the duration of the process/ms		
	Method of this paper	Method of reference [5]	Method of reference [6]
1	38.41	50.13	61.02
2	41.26	52.59	62.32
3	42.37	54.62	64.14
4	42.54	56.42	64.74
5	43.54	57.26	66.25
6	44.86	61.53	67.11
7	43.60	62.45	67.82
8	47.02	64.86	68.74
9	48.22	67.64	70.85
10	48.53	68.03	71.81

IV. CONCLUSION

In order to maintain the stability and safety of smart city buildings, this study designed a prediction method for foundation settlement of smart city buildings based on BP network.

Firstly, WSN technology is used to construct the real-time dynamic monitoring unit of building foundation settlement, which mainly includes four parts: building sensor node distribution module, sensor network module, communication module and upper computer monitoring module. Then, the above monitoring data are introduced into the Duncan-Chang constitutive model and combined with the layer-summation method to calculate the relevant parameters of building foundation settlement. Finally, on the basis of analyzing the structure of BP network, the monitoring data is input into the BP network model results, and the weights of hidden layer and output layer are adjusted by using subsidence related parameters, and the settlement prediction results of smart city building foundation are output through training.

In the experiment part, two parts of basic test and contrast test are designed. The results of basic test show that: in different time periods, the fitting degree between the predicted results of Method of this paper and the actual settlement value is always close to 1, which indicates that proposed method can effectively predict foundation settlement. The comparative test results tell that the average prediction error of Method of this paper is always below 4%, and the prediction process takes less than 49ms, indicating that method of this paper has high reliability and timeliness of prediction. However, there are still some shortcomings in this study. For example, when selecting experimental sites and buildings, due to limited conditions and fewer buildings that meet the requirements, the type of building selected for the experiment is relatively single, and the universality of the proposed method in various experimental buildings has not been further tested.

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