The Prediction Method of Long-Span Cable-Stayed Bridge Construction Control Based on BP Neural Network

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Abstract: Based on a critical examination of the present methods for the prediction of construction control of long-span cable-stayed bridge, an improved method, the BP neural network model method, was introduced which has been applied to predict the bending defection of deck and the cable force in construction monitor of a cable-stayed bridge of the Yangtse River. The results indicate that the BP network model has a better forecast precision, which can fully satisfy the need of the engineering.

Key-word: BP neural network, long-span, cable-stayed bridge, construction control, prediction method

1 Introduction

With its good structure function, large cross over ability and the architectural attractiveness, the cable-stayed wins an important position in modern bridge structures. With its high-order super static characteristic, the main beam line shape and inside stress of structure has a close relation to the construction method and erection order adopted. In construction process, influenced by various factors, the errors between actual bridge state and designed state are hard to avoid. If the errors are not adjusted and controlled, they will cause a bigger difference between the ultimate bridge state and the theory state, and even endanger the structure safety. Therefore, more attentions should be paid to the construction control problem of a long-span cable-stayed bridge.

Currently there are many theories about bridge construction control, all have themselves successful cases. LIN Yuanpei creatively introduced Kalman's theory based on the random process control, and successfully applied it to the construction control of Liugang Bridge in Shanghai[1]. Fang Zhi, Liu Guangdong et al applied grey theory to cabled-stayed bridge construction control, and also got good prediction effect [2]. Han Dajian, Guan Wanyi[3], Zhang Yonshui[4] et al applied grey theory to predict the arch degree of bridge. Qi Yan, Lu Detang[5], Sun Quansheng[6],et al used BP nerve network in healthy detect of bridge structure. Zhou Jiagang, Ran Zhihong[7], Li Qiao et al [8] tried to use the BP nerve network to cable-stayed bridge construction control. However, so far, there is no a set of control method which is suitable to various conditions perfectly. They all have, more or less, blemish or limit conditions that are hard to overcome. If these methods are not proper used, very big error will be caused, even false conclusion. This paper applied the improvement BP nerve network to predict the elevation of deck and initial cable tension in steel bridge construction process. Ideal results were obtained when this model was applied to a Yangtze River bridge construction control.

2 BP network predicting method

2.1 Principle of BP network

The artificial nerve network theory is a branch of artificial intelligence research. It has strong ability to set up the model in complicated no-linear system circumstance and good ability to match in data process. The nerve network have the characteristic of self-organize, self-study, no-linear dynamic processing and strong tolerating wrong etc., have association of thought and logical reasoning and self-adaptability ability. It is good suitable for processing no-linear problems. Among nerves network models, the BP (Back Propagation) model is a most extensively used one. Accounting to the structure, the BP network is a typical multilayer

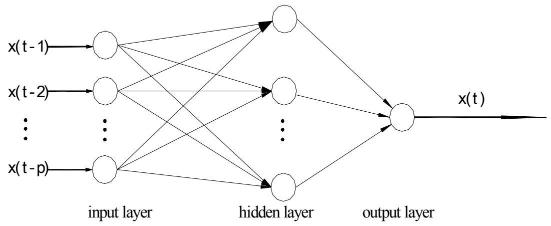

Fig.1. Diagrammatic sketch of BP networks

For each hidden layer, the import value of node is

$$net_j=\sum W_{ji}O_i \quad (1)$$

In equation (1), O_i is output of previous layer i node, W_{ji} is the weight connect previous layer node i and current layer node j.

The output of node j is

$$O_j = f(net_j) \quad (2)$$

In equation (2), f is the activation function. For BP network, f must be the function that satisfy monotony ascend relation from input layer to output layer, usually choosing Sigmoid function, its formula is

$$f(x) = \frac{1}{1+e^{-(x-\theta)}} \quad (3)$$

In equation (3), θ is the threshold of nerve center.

BP network training steps as follow [9]:

(1) Initialing the weight and the threshold, giving random number to all weights and all thresholds.

(2) Given input x and target output $\bar{y}$.

(3) Calculating actual output y.

(4) Modification weight w_{ji}

$$w_{ji} = w_{ji} + \Delta w_{ji} = w_{ji} + \eta\delta_{qj}\gamma_{qj} \quad (4)$$

In equation (4), η is learning factor, subscript q denoting sample q, j is node code, δ_{qj} is error modification coefficient, its value has two case:

When j is output layer node

$$\delta_{qj} = (y'_{qj} - y_{qj})f'(net_{qj}) \quad (5)$$

networks. It is divided into input layer, hidden layer and output layer, unit connect unit mutually between the layers. The same layer unit was not linked, the weight values of connect layers can be regulated by training (see figure 1).

When j is hidden layer node

$$\delta_{qj} = f'_j(net_{qj})\sum_k \delta_{qk}w_{kj} \quad (6)$$

If adding to inertia item α, then

$$\Delta w_{ji}(n+1) = \eta\delta_j y_j + \alpha\Delta w_{ji}(n) \quad (7)$$

(5) When iterative error achieves the tolerated precision, stop training, or else return to (2).

Via modified the weight and threshold time after time, causing error between the network output and target output is within scope of allow. Thus the stabile weight, threshold and the network structure is obtained. When the input vector of sample being predicted is substituted in the trained network, the network output value is namely the predicting value.

2.2 BP network design

2.2.1 Input and output

Various reasons may cause the deviation between actually measurement value of elevation of main beam and cable force and their theoretical value. If all these factors are taken into account, they not only increase the difficulty of the network analysis, but also make network carried on the training to some subordinate factors, resulting in network slow responding to key factors, thus affect the function of network, and make its adaptive ability worsened. Therefore, the problem must be studied in detail so that the main factors resulting in the deviation could be founds out, then these variable as importation parameter of BP network.

According to the structure characteristics of long-span steel cable-stayed bridge, the following 7 parameters are taken as the importation variables of the nerve network: temperature T(^{0} C), obliquity angle θ (degree) of cable, the distance L(m) from construction segment to main tower, the construction load P(KN), the stress of upper bowstring bar of control section, the theories calculation displacement δ_0(cm) of beam-end and theories initial cable force N_0(KN). Among these parameters theories displacement δ_0 reflects the compound influence of elasticity Yong mold, geometry characteristic of cross section, self-weight of components etc. Output parameters of network are actual δ_1(cm) and cable forceF_1(KN) . Thus the input layer unit number is 7, output layer unit numbers are 2.

2.2.2 Hidden layer design

The node numbers of the hidden layer has large influence on convergence speed of network. It is proven that[10]: when the node number of hidden layer are 2m+1 (m is node number of input layer), three layers BP network can arbitrarily accuracy approach arbitrarily a differentiable function, and can obtain good effect between the network capacity and the training time, so the node of the hidden layer is of 2 X7+1=15.

2.2.3 Model Choice

For the general energy system, along with change of time, future some interferences enter the system one after another and influence the system, constantly, for consider the interference, the lastly gotten data must be input into the model, rebuild up the model, predicting again , this is called as information evolvement model.

If the source data lists is X:

$$X=\{X(1), X(2), \dots , X(n)\}$$

When N+1 number X(n+1) is obtained, the new data lists is X:

$$X=\{X(1), X(2), \dots , X(n), X(n+1)\}$$

This is the information number row. The rest may be deduced by analogy.

However, along with change of time, the more and more information gain, requesting more computer memory capacity, thus the calculating work quantity will increase continuously. Obviously, this is not reasonable from the technique viewpoint. In addition, along with change of time, the old data will not adapt the new circumstance, or to say that the meaning of the old data will lower with change of time, so adding an new information, throwing away the most old data , then keeping the number of data not change , this is reasonable obviously. This kind of new data complement, old data throw away, be called the metabolism number list, the corresponding model is called the metabolism model. For example original list is X

$$X=\{X(1), X(2), \dots , X(n)\}$$

After the new data X(n+1) of complement, throw away the X(1) to get the X

$$X=\{ X(2), \dots , X(n), X(n+1)\}$$

This would be the metabolism model.

3 Project examples

3.1 Project brief

The main bridge of some cable-stayed bridge is make up of 3 spans(180+320+180) continuous steel truss, two towers, 2 x32 pair of cables , and the highway bridge panel adopted combining the technique on the top of the steel truss. Main span is make up of 26 x12m segments, two sides span is make up of 15x12m segments .The high of steel truss is l4 m, the high of tower above the highway bridge face about is 30m, and the angle between the cable plane and bridge surface is 15^0-33^0, this angle is far small the angle of cable of which cable-stayed bridge would be in usually meaning (see figure 2). In the sight of the high of tower and the cable angle, the design of main bridge is particular. To guarantee the bridge be constructed strictly according to the design, implementing monitor on the whole process of that bridge construction become the necessary and important link, and predicting the elevation of main beam of construction segment and initial cable tension are the main contents of the construction control. The purpose of this paper is to supply a real demonstration for Tianxinzhou Bridge which is being constructed.

Fig.2 The construction photo of some cable-stayed bridge

3.2 BP network prediction

3.2.1 Monitor data

Many data were measured in this bridge construction process. Such as the bending deflection, stresses and strain of main truss beam, deformations and stresses of tower, cable force, temperature, construction loads and geometric parameters of cross section, physical parameters, etc. For applying the BP network to predict the elevation of cantilever installation of cable-stayed bridge and initial cable force, according to analysis previously, parts of parameters are selected as show in table 1.

Table 1 The monitor data of actual bridge

	T (℃)	L (m)	θ (degree)	P (KN)	σ (MPa)	δ_0 (mm)	δ_1 (mm)	F_0 (KN)	F_1 (KN)
1	18	36	33.0	800	50	20	18	14000	13810
2	20	48	26.6	700	60	40	34	12000	11830
3	22	60	22.8	650	70	68	60	11000	10800
4	21	72	20.1	660	80	100	88	11000	10700
5	24	84	18.1	680	100	140	120	11000	10500
6	25	96	16.6	700	120	200	180	11000	10500
7	25	108	15.5	680	140	300	279	11000	10200
8	26	120	15.0	680	150	400	350	13200	13000

* In table 1, F_1, δ_1 are separately measurement cable force and measurement bending deflection

T– Average temperature of month during construction, L – Distance from the construction segment to tower axes, θ- Obliquity angle of cable, P - Construction load ,σ – Stress of control section, F_0, δ_0 theoretic cable force and theoretic bending deflection from the results of FEM calculated

3.2.2 The results of BP network prediction

A three layer BP network which structure is 7(input layer node number)-15(hidden layer node number) -2 (output layer node number) is used to train and predict for the data of list in table 1. The step is as follow:

(1) Choosing data of front 5 segments in table 1 as the input of network, given the control error (ε=0.01), via about 12000 times training, a stabile structure is obtained.

(2) By means of the trained network in step 1, predicting the bending defection and initial cable force of segment 6.

(3) Inputting the data of segment 2-6 into network, retaining the network, then predicting the bending defection and initial cable force of segment 7.

(4) Similarly step (3), a group of new data series are obtained.

The predicting results of 6-8 three segments are listed in table 2

The data in table 2 show that the BP network has good ability to fitting data, the maximum relative error is 5.5%, and it can control the error produced by other various factors, and can truly reveal the change law of main beam of cable-stayed.

3.3 Compared the results with that of other methods

For validating the reliability of neural network simulation, the results with BP network simulation on cable-stayed bridge bending deflection and cable force were compared with these by means of others methods（see table 2）.

Table 2 The comparison table of predicting results of some methods

segment	Grey prediction		Kalman's filter method		BP network		measurement	
	δ_0 (mm)	N_0 (KN)	δ_0 (mm)	N_0 (KN)	δ_0 (mm)	N_0 (KN)	δ (mm)	N (KN)
6	195	10800	200	11200	190	10550	180	10500
7	295	10500	300	10600	285	10180	279	10200
8	360	13100	358	13200	370	12800	350	13000

The results indicate that the error of grey prediction is bigger, and the results of Kalman's filter prediction and BP network prediction are close. Comparatively, BP network predicting results fit the measurement value better. Therefore, BP neural network method will be a more practical method.

4 Conclusions

The internal relations between monitor data and the artificial neural network were discussed, and the artificial neural network prediction model was set up, which is applied to predict the bending defection of deck and the cable force in construction monitor of a cable-stayed bridge of the Yangtse River. The conclusions are:

(1)The artificial nerve network can consider not only the quantitative factors, qualitative factors and indeterminate factors, useful information from yawp data, but also can overcome the shortages of grey method and Kalman method which demand a great deal of measurement data. Study indicate that The BP network predicting value can fit the measured value much better, the precision completely satisfy the request of the engineering and control. Therefore, the BP network is adopted to predict and forecast for cable-stayed bridge construction is completely viable and effective, this is a new complement to the traditional prediction methods.

(2) The key technique of neural network applied to engineering is the choice of network model, sometimes, for suiting the need of especial engineering, the arithmetic of network or structure of network will be improved. What problem can a specific model solve is still needed to study thoroughly.

(3) In practice engineering application, this method must be compared with other methods, namely for increasing the reliability and veracity manifold methods should be used.

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