ISSN : 0974 - 7435 Volume 10 Issue 2

BioTechnology
An Indian Journal

FULL PAPER

BTAIJ, 10(2), 2014 [275-280]

Application of BP neural network for the design of isolated structure

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ABSTRACT

The effects of local construction of isolation layer on the overall architecture are described in this thesis. Nowadays, the earthquake is a great problem in the world, for it can not be predicted. The only thing we can do is to enhance the ability to resist the earthquake. So, the first thing of all is to improve the seismic performance of buildings. Based on BP neural network, a preliminary design system for isolation is established with the seismic fortification type, seismic fortification intensity, site classification, seismic grouping, the depth-width ratio, the length-width ratio, ground floor stiffness, mass and area as the main influencing factors, and the largest layer shear force ratio of the structure after isolation and the largest displacement as output results. After the network training with 25 training samples, the network test is done by 15 test samples. By the comparison of the test results with the actual design results, it is acknowledged that the average accuracy rate of neural network reaches 96%, which shows the analysis on the damping effect that the system of preliminary isolation design based on BP neural network has on isolated structure has high efficiency and accuracy. © 2014 Trade Science Inc. - INDIA

KEYWORDS

Design of isolation structure;
BP neural network;
Network training;
Network test.

INTRODUCTION

In recent years, the researches and application of the isolation technology have made great progress. Especially after 5.12 Wenchuan earthquake, the isolation technology has received unprecedented attention. With the rapid development of isolation technology in recent years, there are a lot of base isolated buildings at home and abroad. The isolation layer is arranged on the lower position of structure, such as the first layer, the first layer of the capital, the chassis of the multi-tower building and so on and building isolation measures become more diverse. Base isolation, as an effective seismic design method, has been widely used. A structure needs to be established on the time-procedure analysis of isolated and non-isolated shear force model in the design of current base isolation. Therefore, during the seismic isolation design process, the arrangement on the isolation layer and the parameter selection of isolation rubber bearing requires several adjustments, calculation and optimization, in order to finally obtain the optimal damping effect of the structure. Artificial neural network is used in this thesis to build up causality network based on samples to study the influence of base isolated struc-

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ture on the whole building.

The 1st hypothesis: isolation bearings should have sufficient vertical stiffness to bear vertical load of superstructure

The 2nd hypothesis: the overall horizontal stiffness of isolated layers should be appropriate;

The 3rd hypothesis: isolated layers have larger equivalent viscous damping ratio.

The 4th hypothesis: the unreasonable selection of parameter should be ignored when the isolated structure design is considered.

ESTABLISHING AND SOLVING THE MODEL

Under frequent earthquakes, the largest layer shear force ratio $R_{v,\max}$ is used to measure the damping effect: $\max[v_{ib}/v_i]v_{ib}$ is for the shear force between layers on Layer i of isolated structure under frequent earthquakes; v_i is for the shear force between layers on Layer i of non-isolated structure under frequent earthquakes. The largest displacement of isolation bearings under rare occurrence earthquakes needs to meet: ①Δ≤0.55D; ②Δ≤3nt R. is for displacement of isolation bearings under rare occurrence earthquakes; D is for effective diameter of isolation bearings;n is for layers of rubber in isolation bearings; t_R is for thickness of rubber on each layer in isolation bearings. Mathematic description for BP neural network.

The topological structure of BP neural network is usually composed of input layer, hidden layer and output layer. It is supposed that the input vector is $X=(x_1,x_2,\cdots,x_i,\cdots x_n)^T$, the output of hidden layer is $H=(h_1,h_2,\cdots,h_j,\cdots h_l)^T$, the output of output layer is $Y=(y_1,y_2,\cdots,y_k,\cdots y_m)^T$, the expected output vector is $Q=(q_1,q_2,\cdots,q_k,\cdots q_m)$, the weight matrix from input layer to hidden layer is $V=(V_1,V_2,\cdots,V_j,\cdots V_l)^T$, the weight matrix from hidden layer to input layer is $W=(W_1,W_2,\cdots,W_k,\cdots W_m)^T$.

In positive signal propagation, the input signal is input to the hidden layer, and hidden layer output signal H is obtained by weight vector of hidden layer nodes v_j; then hidden layer output signal H inputs forward to the output layer, and the output signal of this layer Y is got by the weight vector of output layer nodes w_k.

In back propagation, for the output layer and hidden layer, there is

$$y_k = f(net_k)=\sum_{j=0}^{l} w_{jk}y_j \qquad k=1,2,\cdots,m \tag{1}$$

$$h_j = f(net_j)=\sum_{i=0}^{n} v_{ij}y_j \qquad j=1,2,\cdots,l \tag{2}$$

When the network output and the desired output differ, the output error E is

$$E=\frac{1}{2}\sum_{k=1}^{m}\{q_k - f[\sum_{j=0}^{l} w_{jk} f(\sum_{i=0}^{n} v_{ij}x_i)]\}^2 \tag{3}$$

From formula (3), it can be seen that the network output error is a function of the weights of each layer v_{ij}, w_{jk}, so the network error E can be changed by adjusting the weights. The error signal δ^y is obtained by comparing the desired output Q and the actual output Y, so the adjustment amount of the output layer weights is:

$$\Delta w_{jk}=\eta\delta_k^y h_j=\eta\left(q_k-y_k\right)y_k\left(1-y_k\right)h_j \tag{4}$$

The error signal vectoranti-transmits to each node of hidden layer through weight vector of each hidden layer node and gets the error signal of hidden layer, so the adjustment amount of hidden layer weights δ^y is

$$\Delta v_{ij}=\eta\delta_j^h x_i=\eta\left(\sum_{k=1}^{m}\delta_k^y w_{jk}\right)h_j\left(1-h_j\right)x_i \tag{5}$$

η is the proportional coefficient to reflect learning rate of the network in the training.

In the whole learning process, weights are adjusted until the error reaches the required precision. So the final network output is

$$y_k=\sum_j w_{kj} f\left(\sum_j v_{ij}x_i+b_1\right)+b_2 \tag{6}$$

b_1,b_2 are respectively the threshold values for the hidden layer and the output layer.

The selection of isolation design parameters

The 9 more important parameters in isolation design are as neural network input. They are respectively the seismic fortification type of the building, seismic fortification intensity, site classification, seismic grouping, the depth-width ratio, the length-width ratio, total mass, ground floor stiffness and ground floor area. And the quantization results of the seismic fortification type, seismic fortification intensity, site classification and earthquake group are respectively shown in TABLE 1, TABLE 2 and TABLE 3.

TABLE 1 : Quantized value of seismic fortification intensity

Seismic fortification intensity	quantized value
Degree 7(0.1g)	0.08
Degree 7 (0.15g)	0.12
Degree 8 (0.2g)	0.16
Degree 8 (0.3g)	0.24
Degree 9 (0.4g)	0.32

TABLE 2 : Quantized value of seismic fortification category

Seismic fortification category	quantized value
Category A	0.67
Category B	0.8
Category C	1

TABLE 3 : Quantized value of site classification and earthquake group

Earthquake group	Site classification		
	I	II	III
Group 1	0.25	0.35	0.45
Group 2	0.3	0.4	0.55
Group 3	0.35	0.45	0.65

The numerical range and units of depth-width ratio, the length-width ratio, total mass, ground floor stiffness and the ground floor area are different, so the data must be conducted in normalization processing before input, in oder to make the input component trained in dimensionless forms, and also to avoid the occurrence of neuron saturation phenomenon caused by the absolute value of the net input being too large. The formula of normalization processing is:

$$\overline{x_i} = \frac{2(x_i - x_{\min})}{x_{\max} - x_{\min}} - 1$$

$\overline{x_i}$ is the input value after normalization, x_i is for the output data, $x_{\max}$ represents the maximum value of the data set, and $x_{\min}$ represents the minimum value of the data set.

Quantization of output results

It is stipulated that the damping effect of structure is determined by the damping coefficient of structure in horizontal level. According to the evaluation and quantization of damping coefficient in horizontal direction on the isolation effect, TABLE 4 is quantized value of the shear force ratio. $\Delta \leq 0.55D$ as displacement control condition, the largest displacement constraints of isolation rubber bearing with the diameter of 300mm, 400mm, 500mm and 600mm are quantified. TABLE 5 is for the quantized value of the largest displacement of isolation bearings.

TABLE 4 : Quantized value of shear force ratio

largest layer shear force ratio	Damping coefficient in horizontal direction	Quantized value
0.53	0.75	(1,0,0,0)
0.35	0.50	(0,1,0,0)
0.26	0.38	(0,0,1,0)
0.18	0.25	(0,0,0,1)

TABLE 5 : Quantized value of the largest displacemen of isolation bearings

Diameter of isolation bearings(mm)	allowable maximum displacement(mm)	Quantized value
300	165	(1,0,0,0)
400	220	(0,1,0,0)
500	275	(0,0,1,0)
600	330	(0,0,0,1)

Neural network training

40 isolation design samples are divided into 2 groups. 25 samples in Group A is for neural network training, while 15 samples in Group B is for neural network test. Neural network isolat-networkl is used to test the largest layer shear force ratio of the structure under frequent earthquakes. The inputs of network are seismic fortification type of the building, seismic fortification intensity, site classification, seismic grouping, the ratio of height to width, the length-width ratio, total mass, the ground floor stiffness. The network is trained by back propagation algorithm based on the optimized theory of Levenberg-Marquardt. The target value of training error is 1×10^{-1}. In isolat-network1, when in Step 12 of the training, the requirement of error is achieved,

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so the training comes to an end. Neural network isolat-network2 is to test the largest displacement of isolation bearings of the structure under the rare occurrence earthquake. The inputs of network are seismic fortification type of the building, seismic fortification intensity, site classification, seismic grouping, the depth-width ratio, the length-width ratio, the ground floor stiffness. and the mass per ground floor area. The network is trained by back propagation algorithm based on the optimized theory of Levenberg-Marquardt. The target value of training error is 1×10^{-5}. In isolat-network 2, when in Step 23 of the training, the requirement of error is

TABLE 6 : Testing results of the largest layer shear force ratio by neural network isolate-network1

sample label	whether it is suitable for isolation	Test output	Expected output	Network test results	The actual design result	Right or Wrong
Sample 1	suitable	(0,1,0,0)	(0,1,0,0)	0.35	0.35	right
Sample 2	suitable	(0,0.999,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 3	suitable	(0,0,0,0.999)	(0,0,0,1)	0.18	0.18	right
Sample 4	suitable	(0,0.992,0,0)	(0,1,0,0)	0.35	0.35	right
Sample 5	suitable	(0,1,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 6	suitable	(0,0.999,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 7	suitable	(0,0,0.998,0)	(0,0,1,0)	0.26	0.26	right
Sample 8	suitable	(0,1,0,0)	(0,1,0,0)	0.35	0.35	right
Sample 9	suitable	(0,1,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 10	suitable	(0,1,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 11	suitable	(0,0.999,0,0)	(0,1,0,0)	0.35	0.35	right
Sample 12	suitable	(0,0.995,0,0.671)	(0,1,0,0)	0,35	0,35	right
Sample 13	suitable	(0,1,0,0)	(0,1,0,0)	0,35	0,35	right
Sample 14	suitable	(0,0.999,0,0)	(0,1,0,0)	0.35	0.35	right
Sample 15	suitable	(0,1,0,0)	(0,1,0,0)	0,35	0,35	right

TABLE 7 : Testing results of the largest displacement of isolation bearing by neural network isolate-network2

sample label	Test output	Expected output	Network test results	The actual design result	Right or Wrong
Sample 1	(0,0,0.901,0.998)	(0,0,0,1)	330	330	right
Sample 2	(0,0.006,0.942,0)	(0,0,1,0)	275	275	right
Sample 3	(0,0,0.999,0)	(0,0,1,0)	275	275	right
Sample 4	(0,0,0.999,0)	(0,0,1,0)	275	275	right
Sample 5	(0,0,0.999,0)	(0,1,0,0)	220	220	right
Sample 6	(0,0,0.999,0)	(0,0,1,0)	275	275	right
Sample 7	(0,0.162,0.985,0)	(0,0,1,0)	275	275	right
Sample 8	(0,0.035,0.986,0)	(0,0,1,0)	275	275	right
Sample 9	(0,0,1,0)	(0,0,1,0)	275	275	right
Sample 10	(0,0.994,0.068,0)	(0,1,0,0)	220	220	right
Sample 11	(0.179,0,0.980,0)	(0,0,1,0)	275	275	right
Sample 12	(0,0,0.999,0)	(0,0,1,0)	275	275	right
Sample 13	(0,0,1,0.322)	(0,0,0,1)	275	330	right
Sample 14	(0,0.999,0,0)	(0,0,1,0)	275	275	right
Sample 15	(0,0.999,0,0)	(0,1,0,0)	220	220	right

achieved, so the training comes to an end.

Before the system of preliminary isolation design is tested by using neural network, according to the provisions of the applicable conditions of isolation structure in seismic codes, the software of matlab6.5 is used in programming. By the input of upper structure information for each test sample, the judgement whether the structure is suitable for isolation is made. The structure should meet the requirements in seismic codes in order to enter into the neural network test. Otherwise, the output of the system is that the structure is not suitable for isolation, and system program terminates.

CONCLUSION

For the largest layer shear force ratio of structure test after isolation, there are 15 samples for testing. The test results show that the test result of the 15 samples are the same as the results of actual isolation design, and accuracy rate of network test reaches 100%. That shows the prediction of largest shear force ratio of isolated structure in buildings under frequent earthquakes has higher accuracy by BP neural network isolat-network1. TABLE 6 is the testing results of the largest layer shear force ratio by neural network isolat-network1.

For the largest displacement of isolation bearing test after isolation, there are 15 samples for testing. The test results show that the largest displacement of isolation bearing of the 14 samples are the same as the results of actual isolation design, and accuracy rate of network test reaches 93.3%. That shows the prediction of largest displacement of isolation bearing in buildings after isolation has higher accuracy by BP neural network isolat-network2. TABLE 7 is the testing results of the largest displacement of isolation bearing after isolation.

From the test results of neural network in TABLE 6 and TABLE 7, it can be seen that the average accuracy of network has reached 96%, which means the use of BP neural network to analyse effect of isolated structure is a feasible. Compared with the traditional isolation design, this method is simple, rapid and accurate and has high value of engineering application. It is shown in this model that the analysis on the damping effect that the system of preliminary isolation design based on BP neural network has on isolated structure has high efficiency and accuracy.

In isolation design, the application of the system of preliminary isolation design based on BP artificial neural network can achieve good effect of auxiliary design. Only by grasping the basic information of the upper structure, can the largest layer shear force ratio under frequent earthquakes and the range for the largest displacement of isolation bearing under rare occurrence earthquake after isolation be rapidly analysed by using the system in the early stages of isolation design, so as to better assist the design.

ACKNOWLEDGEMENTS

This paper is supported by the Natural Scientific Fund Project in Hebei Province (A2011209019) and the Instructional Project of Science and Technology from Coal Industry Association (MTKJ2013-415).

Students innovation project in Hebei United University Qinggong College.

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