Application of neural networks in normal frequency computing of gauged arch shape

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Abstract

The general goal of this research is to determine natural regular frequency of an arch by artificial neural network with various supporting conditions. For the subject of neural network, training or learning algorithms are applied .The most famous of which is back propagation algorithm. In this research, the real frequency of plate is calculated first using ANSYS program and is defined as a goal function for neural network, so that all outputs of the network can be compared to this function and the error can be calculated. Then, a set of inputs including dimensions or specifications of arches are made using MATLAB program. After the determination of algorithm and quantification of the network, the phases of training and testing of the results are carried out and the output of the network is created. It is concluded that the performance of the neural network is optimum, and the errors are less than 7%, so the network trains in different manner. Furthermore the time of frequency calculations in neural network is less than real analysis time that calculated by ANSYS software, and it's precision is acceptable(less than 10%).

Key words: frequency, artificial intelligence, arch, training function, learning function.

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1. Introduction

Providing a program to answer to multivariate problem as input and output is hard or impossible because we can not consider all of variables and their effects on each other. Therefore, getting to know the artificial neural network and use of software can help to answer this problem. Also modern programming methods are the methods which are sensitive to error in input data but in artificial neural network, the training is on the base of experience and it can tolerate against errors. Artificial neural networks are used in different researching fields and professions, and are made by cooperation of scientists in different fields such as computer engineering, electronic, structure and biology. Talylor and Mannion (1992) have explained that neural networks are used in classification of data, recognition of letters and figures, estimation of functions and etc. Szewczyk and Hajela (1993) believe that neural network is developing in the structure engineering and will develop more and more. In the structure engineering, Fausset (1994) has neural network in optimization, analysis and designing, anticipates of results for soil and concrete, graphs theory and etc.

Arch modeling has been performed by ANSYS 11 software. According to optimization of design variables, such as base thickness (t0) and top thickness (t1) as parameters, all of key points are defined as follow:

Point 1: (0, 0) Point (2): (R, 0) Point3: (-R, 0) Pint4: (0, R)

Point 5(R+t0, 0) Point6: (-R-t0, 0) Point 7: (0, R+t1)

In order to study of this material, semicircular arch is defined by key points as parameters (fig.1).

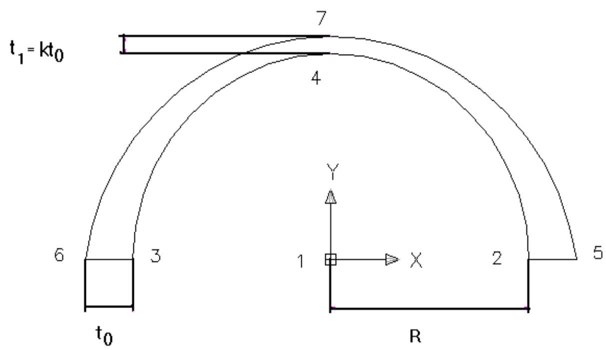

Figure 1: semicircular arch

In arch modeling, the tolerance increases because the thickness decreases from base to top. We should remember that in modeled arch, the thickness decrease from base (t0) to top (t1) linearly. Also, arch thickness in direction of length axis is 20 cm. Moore and Vanderplaats (1999) believed that motion of support nodes is zero, and dynamic force has no effect on them

2. Making an artificial neural network for approximation of plate's frequency

For network training, 200 arches with different dimensions have been chosen. They have been classified to 17 groups: semicircular, equilateral, four centered, catenary, lancet, ogee, tudor, obtuse anyee and four centered arches. The ogee, tudor, obtuse anyee and four centered pointed have been analyzed in 3 groups: diminished, normal and steep. Each of them has six parameters: base thickness, top thickness, radius, Young's modulus, Poisson's ratio and density. The base thickness, top thickness and radius are based on arch dimensions and Young's modulus, Poisson's ratio and density are on the based of arch quality. The alteration of base and top thickness is 0.5 to 1.8 m and 0.15 to 0.45m respectively .This alteration for radius is 2 to 8 m Changes of unit are according to decrease of input parameters dispersion. Also, the alteration for thickness is 0.002 to 0.22.Because arches are made by masonry, their quality coefficients are fixed. So, Young's modulus is 5×10^8 kg.cm^2, Poisson's ratio is 0.7 and density is 1460 kg.m^3. Because mapping range for input parameters should be 0 and 1, the units should changed for decrease of input parameters dispersion, so we consider micrometer, nanometer, kg.cm^2, µg .hectometer^3 for length, width, thickness, elastomer and density , respectively. Poisson's ratio is multiplied in 10^6.All of input parameters are divided to square of sum of square separately to network input mapping estimates between 0 to 1.All of results

which obtained by plate analysis in ANSYS11 software have been chosen as an objective function, to compare obtained output network with objective function and all errors has been calculated.
In this formula:

$$Net= newff(PR,[S_1S_2\ldots S_i] ,\{TF_1TF_2\ldots TF_n\},BTF) \quad (1)$$

Where:
PR: matrix of R×2 with minimum and maximum input elements
si: the size of ith layer
TFi : excitation of i layer(obtained by transfer function) with "tansgin" presupposition
BTF: network conversion function with "trainlm" presupposition

Grandhi (1993) has explained that network specifications are defined by network structures, number of layers, number of neuron in each layer, transfer function in layers, learning function and performance evaluation .Regarding to back propagation neural networks for plate frequency calculation, at first we should study newff, newcf, newelm structure then choose the best of them. In this paper, each of them is made separately, and they have different layer (2-5 layers), so the structure with less error is used for optimum network. For each structure 6 plates have been tested, and their specifications have been shown in table 1. One of the test samples is part of training input and others are new inputs.

arch sample	Base thickness	Top thickness	radius	Natural frequency (hertz)
Semicircular	0.82	0.22	5	19.62
Obtus angle	0.71	0.36	6	24.26
lancet	1.16	0.28	6	28.2
catenary	1.41	0.25	7	14.1
Ogee	1.32	0.38	4	24.26
Tudor	0.99	0.28	7	21.1

Table 1. Dimensions of arches for network test

3. The study of newff, newcf, newelm neural network

Here, the neural network with 2-5 layers is studied in newff structure. For each arch 20 networks (with different neurons) analyzed. Modulus network had 6 fixed neurons in input layer (plate variable parameters) and one neuron in output layer (arch frequency). The neural network with newelm and newef structure is studied and results are provided in table 2.

network	Two layer network	Three layer network	Four layer network	Five layer network

	Error percent average	Test time average	Error percent average	Test time average	Error percent average	Test time average	Error percent average	Test time average
Newff	8.1	0.062	8.19	0.076	7.17	0.094	7.19	0.054
Newcf	13.4	0.026	3.49	0.031	5.77	0.054	8.4	0.055
newelm	11.29	0.038	3.58	0.012	7.25	0.042	6.85	0.034

Table 2. Results of neural network with 2 to 5 layers

Considering to newelm, newcf and newff neural network output with 2 to 5 layers , it can be seen that under mathematical complex relations for regulation of interplay weight, we can not anticipated that by increase of layers, the network precision increases but we should get optimum network by trail and error test .After tests, it is determined that newelm neural network with 3 layers and error of 4.74 % has the best performance, so another stages will continue by this network.

3.1. Effect on neuron number (neural cell) in newelm neural network layers

Neuron number is important in each layer, so if the number of layer is low, neural network can not reflect nonlinear mapping between input and output . Because neurons number are determined by trial and error test, so newelm three layer neural network has been studied, separately.

It’s clear that three layer newelm neural network and 8 neurons in input layer and 8 neurons in the middle layer has less error. Figure 2 shows the error percent and neuron number in inner layer.

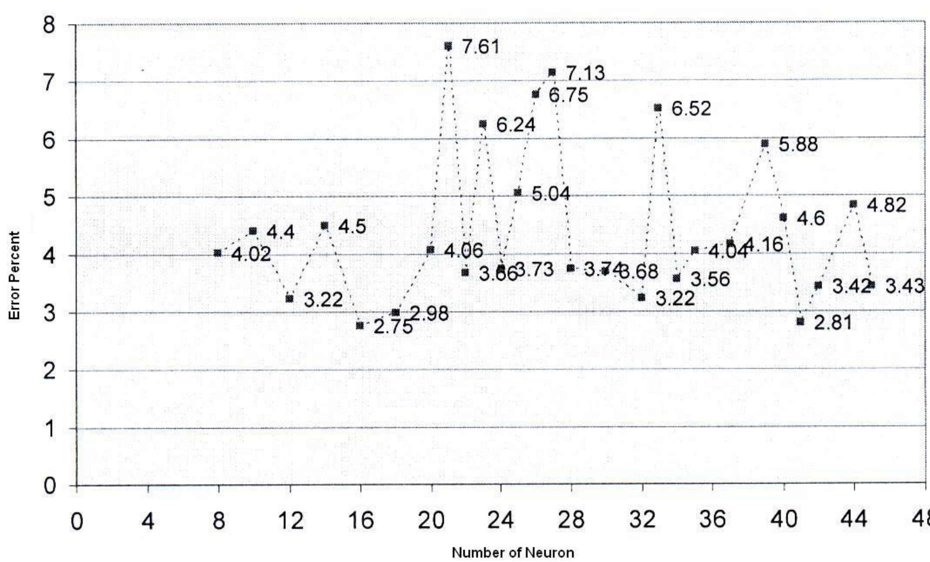

Figure 2. The effect of neuron number in inner layer on amount of error

3.2. The effect of excitement functions in newelm three layer neural networks

In neural networks, inputs processes by excitement function and produces output. According to the results, the best function for the first , second and third hidden layer are tansig, logsig and purelin, respectively. The error is 2.62.

3.3. The effect of training function on newlem three layer neural network

In network training, input and output vector couple with each other. In table 3, the results of comparison between different training function in newelm network are shown.

So, we found that Train cgf had less error (2.32%) and its performance was better than other functions.

Kind of training function	Average error percent	Average testing time(s)
Train lm	6.47	0.057
Train bfg	4.84	0.035
Train cgb	4.23	0.068
Train cgf	3.14	0.052
Train cgp	6.64	0.039
Train oss	3.66	0.033
Train rp	12.87	0.034
Train scg	14.45	0.053

Table 3. Effect of training function

3.4. The effect of learning function on newlem three layer neural network

In the neural network, calculations are layer by layer, so we can estimate outputs. At first, output of neural cells in a layer calculated and the result used as input for another layer. After that, according to input, the second layer output is calculated. This process continues to output make output vector. Learning functions are important, so the effect of learning function on newelm neural network is studied (table 4).

Kind of training function	Average error percent	Average testing time(s)
Learn gdm	11.1	0.032
Learn gd	9.36	0.043
Learn som	6.2	0.033
Learn p	11.26	0.037
Learn os	8.1	0.027
Learn lv_1	9.4	0.023
Learnlv_2	6.2	0.029
Learn con	18.5	0.027
Learn k	3.26	0.026
Learn I_s	8.35	0.075
Learn h	5.1	0.057
Learn hd	3.81	0.061
Learn wh	8.3	0.036

Table4 . Eeffect of learning function

According table 4, learn P function (error=2.32%) has better performance. In this function, training input functions are binary. After training, the network gets continuous input and produces output.

3.5. The effect of performance evaluation (error) on newelm three layer neural network
In performance evaluation, we want to study how a network performs by trained and new (untrained) input. Amount of training and network performance has been calculated by different parameters and methods .Each of them has been studied separately and the best functions have been chosen.(table 5)

Kind of training function	Average error percent	Average testing time(s)
mae	24.42	0.016
mse	16.25	0.017
Msereg	17.11	0.012
sse	6.22	0.015

Table 5. Effect of error function

According the results, sse function has the best performance.

4. Proposed neural network

By analysis, this neural network is suggested for calculation of arch frequency:

net= newelm (maxmin(p),[8 8 1],{′tansig' ′logsig' 'purelin'};'traincgb','learn p', 'sse') (2)

5. Network testing for arches by different radius

Different shapes of arches have been analyzed by ANSYS11 software, and their real frequency has been determined. They tested by proposed network and their efficiency were determined by errors (tables 6,7 ,8,and 9)

arch	Real frequency	Analysis time(s)	Network frequency	Training time(s)	Testing time(s)	Error percent
Semicircular	23.14	0.57	20.36	17.46	0.056	9.1
Obtus angle	20.18	2.1	23.41	21.12	0.052	3.2
lancet	21.62	3.33	26.13	17.1	0.081	1.26
catenary	28.7	4.36	17.36	9.46	0.023	6.1
Ogee	26.4	8.12	25.66	32.3	0.041	5.2
Tudor	21.11	14.1	25.2	15.4	0.017	4.38

Table 6. Arch analysis by radius of 4m

arch	Real frequency	Analysis time(s)	Network frequency	Training time(s)	Testing time(s)	Error percent
Semicircular	11.21	0.35	10.6	14.1	0.055	8.06
Obtus angle	12.8	1.11	13.2	24.2	0.031	3.52
lancet	11.4	4.26	11.6	35.41	0.012	9.1
catenary	12.3	3.46	14.7	18.5	0.012	2.1
Ogee	11.56	7.65	16.1	25.4	0.025	4.2
Tudor	13.1	18.1	14.2	17.1	0.011	2.56

Table 7:. Arch analysis by radius of 5m

arch	Real frequency	Analysis time(s)	Network frequency	Training time(s)	Testing time(s)	Error percent
Semicircular	9.4	1.22	7.5	13.35	0.051	8.2
Obtus angle	1.4	1.21	4.1	11.1	0.071	2.46
lancet	5.1	2.45	5.82	38.1	0.021	0.31
catenary	5.45	4.61	4.14	17.2	0.045	12.2
Ogee	6.61	7.12	7.1	12.4	0.031	0.21
Tudor	8.02	21.12	5.32	16.1	0.016	4.15

Table 8. Arch analysis by radius of 6m

arch	Real frequency	Analysis time(s)	Network frequency	Training time(s)	Testing time(s)	Error percent
Semicircular	14.1	0.48	13.26	16.1	0.021	6.95
Obtus angle	18.26	1.2	13.52	20.2	0.013	4.26
lancet	16.26	3.5	14.86	15.3	0.017	4.12
catenary	17.32	4.1	12.8	12.9	0.017	5.11
Ogee	21.1	8.12	25.6	24.2	0.018	3.2
Tudor	19.2	14.02	21.7	17.2	0.018	1.12

Table 9. Arch analysis by radius of 7m

Hitherto, according to different supports for plate, the first frequency output in neural network has been studied. Now, we study the first and second frequency output for plates with support in the corners, and the first to fifth frequency output for plates with supports in the opposite side to calculated proposed network power for higher frequencies (table 10).

arch	Real frequency	Analysis time(s)	Network frequency	Training time(s)	Testing time(s)	Error percent
Semicircular	6. 43	0.55	8.12	56.05	0.065	4.56

	11.34		13.07			5.83
Obtus angle	9.61	1.124	6.64	43.43	0.012	2.23
	12.11		14.43			3.46
lancet	7.61	2.42	8.18	49.65	0.023	5.19
	7.48		8.78			4.84
catenary	6.85	3.5	3.16	61.34	0.054	4.34
	4.91		4.12			5.15
Ogee	8.51	8.68	8.83	41.12	0.032	8.44
	18.89		132.23			5.16
Tudor	7.08	16.44	8.6	43.92	0.076	5.65
	11.28		10.76			8.16

Table 10. First and second frequency output for arches with radius of 6m

Conclusion

1-With regard to complex mathematical relations for regulation of weights in neural network, we can not anticipated that increase of layers improve the network output. So, after the study of 2 to 5 layer network, three layer network with newlem function has the best answer.

2- Usually, network data processes by excitement function to neural output signal produce. According to change of structure functions the network output changes. With regard to effect of excitement functions combination in neural network, tansig, logsig and porelin are suitable for the first, second and third hidden layer, respectively.

3- During network training, network weights converge, so with regard to input vector, the out put vector produced and network output convergence with goal function (real frequency) obtained by traincgb training function.

4- Powerful network can answer to trained and new (untrained) input. It calculated by learning function and performance evaluation function, the training function (learn p) and performance evaluation function (sse), are the best output for neural network.

5- The research shows that kind of plate and its condition can not influence on final results of network. With change of support conditions, the natural frequency obtains.

6- According to analysis, estimation of frequency with neural network is unlimited and outputs are accessible, but because structure elementary frequencies have more effects on dynamical analysis, they have been studied.

7- With artificial neural network, structure neural frequencies are estimated rapidly and exactly (less than 10%). So, after network training, we don't need plate analysis.

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