Application of artificial neural networks in predicting frequencies of cantilever beam when stiffness reduction

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Abstract. The paper presents the results of solving the problem of predicting cantilever beam frequencies when stiffness reduction. The problem is solved by artificial neural networks with the finite element method in 2-dimensional frame. The numerical calculation shows that the application of ANN in predicting the frequency of structure (cantilever beam) is reliable and feasible. The results presented in this paper are very promising, we can use this method to study more complex structural problems.

1 Introduction

In recent years, understanding a structure's condition is considered more important. The state of the structure and its safety strongly depend on the degradation of the structural elements (beams, supports, etc.). During the using process, the stiffness of the section in the structure can be reduced, leading to a reduction of structural stiffness, change of state parameters (frequencies, etc.), and bearing capacity of the structure. Predicting the frequency of structures to determine the technical state of the structure is very important.

In the field of technology (in general) and construction (in particular), artificial neural networks (ANNs) have been researched and applied by many scientists to model non-linear relationships between parameters of the object, modeling the behavior relationships of the structure, in which the vibration parameters of the structure can be predicted based on the available input and output data set. Applying ANNs in predicting the parameters of the structure (displacement, strain, frequency, ...) due to changing geometrical parameters or causing damage to the structure (reduction stiffness section, reduction link, ...) is of great interest [1-13]. M. Xu used a Horseshoe and Bayesian lasso to identify the damaged structure [12]. Borowiec applied ANNs to identify beam stiffness reduction [13].

In this paper, the author studies the method of applying ANNs, evaluates the accuracy of the model, and serves as a basis for research to solve the next specific problems.

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2 Methods

2.1. The equations of motion of the frame structural in 2-dimensional frame

Considering of frame structural in the form of a 2-dimensional frame in the coordinates Oxz, with the assumptions: The strain of the frame structural is linear and small. The analysis model of the structure is shown in Figure 1.

The finite element method (FEM) will be used to build the equation of the motion of the frame structural. The equations of motion of the frame structural according to FEM after applying boundary conditions can be shown as follows [14, 15, 17]:

$$\mathbf{M}\ddot{\mathbf{U}}(t)+\mathbf{C}\dot{\mathbf{U}}(t)+\mathbf{K}\mathbf{U}(t)=\mathbf{P}(t) \tag{1}$$

Where $\mathbf{U}(t),\dot{\mathbf{U}}(t),\ddot{\mathbf{U}}(t)$ are the displacement, velocity, and node acceleration vectors of the structure.

$\mathbf{M},\mathbf{K},\mathbf{C}$ are mass, stiffness, and damping matrices of the structure

$\mathbf{P}(t)$ is the nodal load vector of the structure.

The damping matrix of the structure can be calculated as:

$$\mathbf{C}=\alpha\mathbf{M}+\beta\mathbf{K} \tag{2}$$

Where α,β are Rayleigh damping coefficient, determined by the two lowest frequencies of the structure ω_1,ω_2; and the corresponding damping ratios ζ_1,ζ_2 according to the formula:

$$\begin{Bmatrix}\alpha\\\beta\end{Bmatrix}=\begin{Bmatrix}\dfrac{2\left(\zeta_1\omega_2-\zeta_2\omega_1\right)\omega_1\omega_2}{\omega_2^2-\omega_1^2}\\[2ex]\dfrac{2\left(\zeta_2\omega_2-\zeta_1\omega_1\right)}{\omega_2^2-\omega_1^2}\end{Bmatrix} \tag{3}$$

Equation of free vibration of the structure:

$$\mathbf{K}\mathbf{U}(t)+\mathbf{M}\ddot{\mathbf{U}}(t)=\mathbf{0} \tag{4}$$

To solve (4), using the Power- Sweeping method [17].

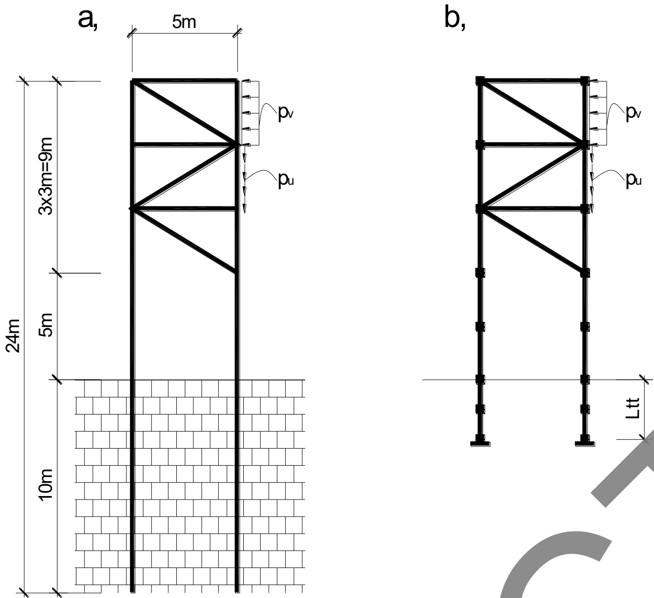


Fig. 1. The structure and model.

The matrices of the structure in equation (3) are built by the "direct stiffness" method [14, 15, 17]. The global matrix of structural $\mathbf{M}$, $\mathbf{K}$ and nodal load vector $\mathbf{P}$ are established from mass matrices, stiffness matrices, and nodal load vectors of elements in the local coordinate system [17].

Based on the above algorithms, the author has built the SYM program to solve the problem of the frame structure in a two-dimensional model in MATLAB language [16] and has been tested for reliability [17].

2.2. Artificial neural networks (ANN) and using in predicting frequencies

The structure of an artificial neuron in a neural network is inspired by the concept of a biological neuron. Artificial neural networks are computing systems that can be trained to learn a complex relationship between two or many variables or data sets. There are many algorithms for determining the network parameters. The most well-known algorithms are backpropagation and Levenberg-Marquardt algorithms. Backpropagation is a gradient-based algorithm, which has many variants. Levenberg-Marquardt is usually more efficient but needs more capable computer memory.

In this paper, applications of Artificial Neural Networks (ANN) using the Levenberg-Marquardt algorithm for the prediction of cantilever beam frequencies when stiffness reduction.

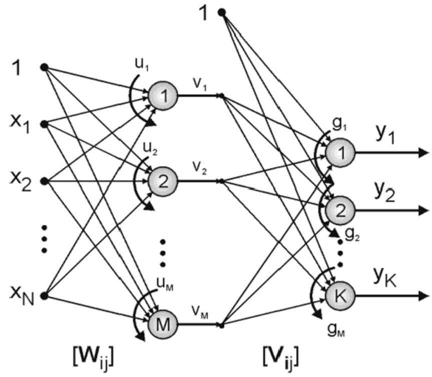


Fig. 2. The structure of the ANNs.

To study the method of applying ANNs in predicting structure frequencies when stiffness reduction, instead of using the input data set from measured parameters, we can use the available calculation programs (SAP, ADINA, ... or self-build programs) to create the input data set. In this study, the author uses the SYM program to create the input data set, SYM has been tested for reliability [17].

3 Results and Discussion

In this example, we consider a cantilever beam with length l = 0.7m (Fig. 3). cross section beam is 0.06m x 0.008m, the material has parameters: Young's modulus E=2.03x10^5 MPa, mass density = 7800 kg/m^3. In the FE model, we divide the beam into 10 finite elements.

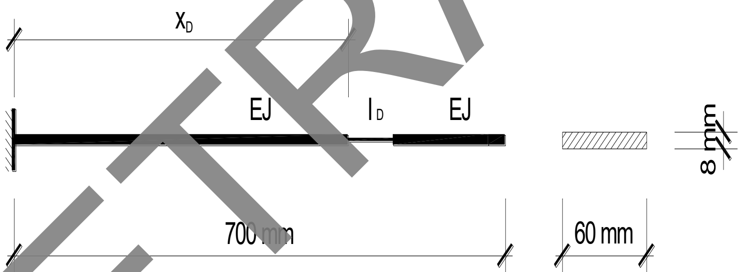


Fig. 3. Cantilever beam

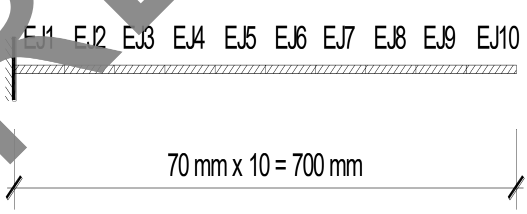


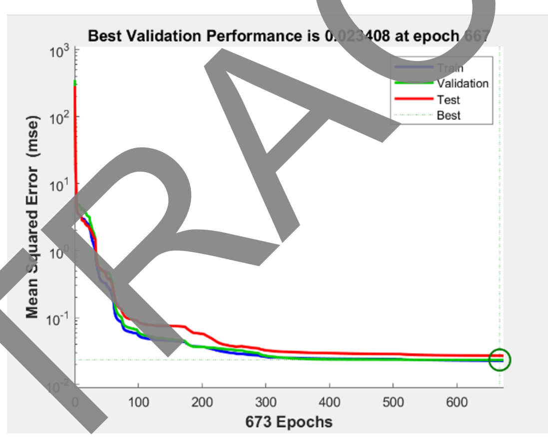
Fig. 4. Model of cantilever beam

The problem is solved using SYM software, with the beams modeled using beam elements. In this example, only one damage at a time was considered. During the study, the damage was in each element of the FE model in turn. The damage of the beam was simulated by the progressive reduction of the stiffness in one finite elemen, the reduced stiffness EJ equalled 40%EJ then 42%EJ, 44%EJ, ... to 98%EJ, with 2%EJ adding, where EJ is the initial stiffness of an undamaged element. An ANNs was applied to predict the frequency of the structure when changes position and reduces the stiffness of the section. In each example, some patterns used to train and test the ANNs were obtained by changing the damage location and its extent. In each case, 15% of patterns were selected as testing ones, and the remaining 70% of patterns were considered as training ones. All neural networks computation were performed using Neural Network Toolbox for Matlab [16].

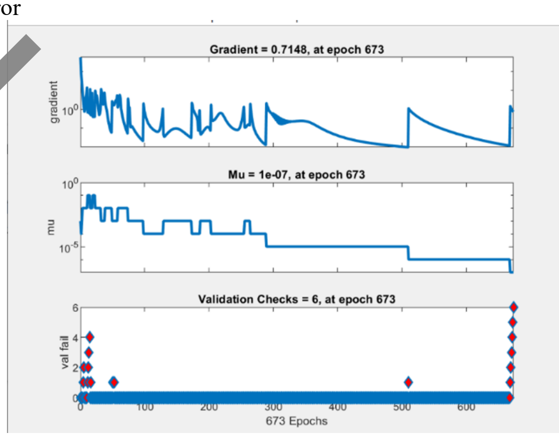
Ten different locations of damage and 29 value of stiffness after reduction (42% - 98%) were considered, with 2%EJ adding, and in total 290 simples were obtained; some of them created the training set (202 simples), the others created the testing set (44 simples). The input vector (x = {xD, ID}) had two elements, which described the location and percent reduction of damage. Several network architectures were tried out, the best results being obtained from one hidden ANN layer with ten neurons. The output vector consisted of three eigenfrequencies ($y = \{\omega_1 \quad \omega_2 \quad \omega_3\}$), where ω_i is the ith eigenvalues.

The results of prediction of the frequency of the structure ($y = \{\omega_1 \quad \omega_2 \quad \omega_3\}$) are presented in Table

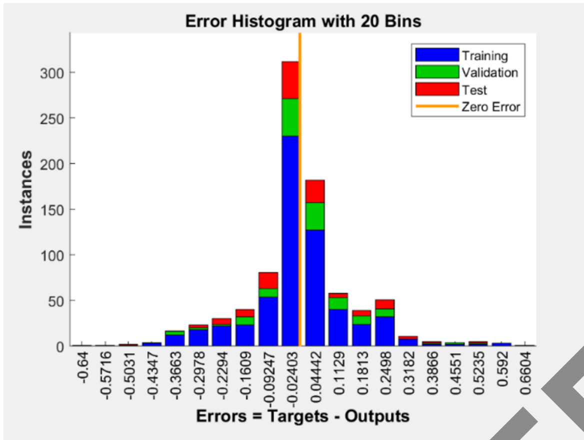
Table 1. and Fig. 5 The ANNs was able to predict the frequency of the structure.



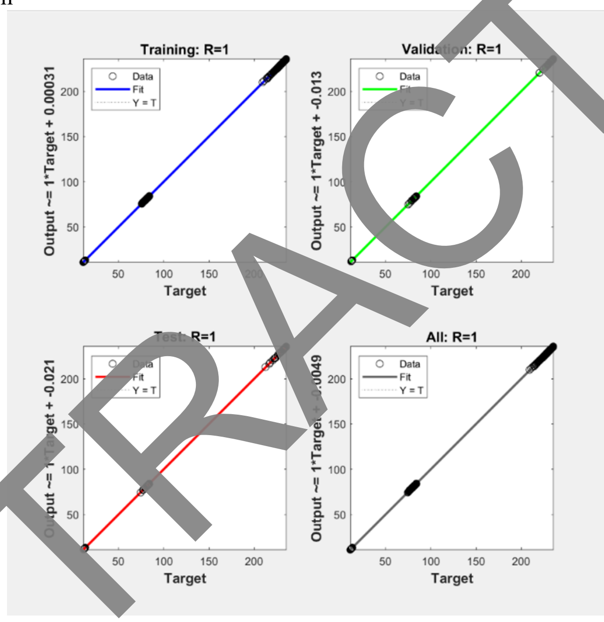
a. Mean squared error



b. Training state



c. Error Histogram



d. Regression

Fig.5. The results of prediction of the frequency of Cantilever beam

Table 1. The results of prediction of the frequency of Cantilever beam

X_D (m)	I_D (%)	Assumption value			Prediction value		
		f_1 (Hz)	f_2 (Hz)	f_3 (Hz)	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)
0.00	60	11.9835	78.7097	225.5948	12.0353	78.9919	226.0907
0.07	82	13.0546	83.6919	234.9543	12.9331	83.5191	234.6749
0.63	78	13.4118	84.0447	235.2504	13.4221	83.9472	235.1289

With the results presented in Fig.5, mean squared error (MSE)=0.023, $R^2 = 1$, the prediction results are correct, the error is less than 0.2 %. This result ensures reliability and accurate prediction of the three natural frequencies of the structure.

4 Conclusions

The article presents the results of research on predicting 03 cantilever beam frequencies when reducing the stiffness (the location and percent reduction of damage) of the structure. The problem is solved using ANNs and the finite element method. The results of the problem are almost absolutely correct. Therefore, it can be concluded that ANNs can predict the frequency of a structure, in this case a cantilever beam, reliably and feasible. The results presented in this paper are very promising, we can use this method to study more complex structural problems.

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