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A NEW METHOD FOR DAMAGE DETECTION IN SYMMETRIC BEAMS USING ARTIFICIAL NEURAL NETWORK AND FINITE ELEMENT METHOD

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Abstract

In this paper a new method for crack detection in symmetric beams is presented. Natural frequency is frequently used as a parameter to detect cracks in structures. In symmetric structures, it isn't possible to identify the location and the depth of a crack using only the natural frequencies. This is due to the fact that the natural frequencies for any symmetric position of a crack with respect to symmetry plane of the structure are the same. In this research it is assumed that the structure is a rectangular beam which is fixed at both ends. ***F****inite* ***E****lement* ***M****ethod (****FEM****) was used to obtain natural frequencies of beam in different conditions of cracks. Then assumed the crack is located at the right side of the structure. Based on data were obtained from FEM, two distinct* ***A****rtificial* ***N****eural* ***N****etworks (****ANN****s) were trained for crack location and depth detection in some different conditions and then were tested. As it was assumed that the crack is at the right side of the beam, two symmetric positions could exist for a crack. Finally using an algorithm based on first vibrational mode shape of structure, locations and depths of cracks have been identified with good approximations.*

Keywords: Crack Detection; Symmetric Beam; Mode Shape; Natural Frequency; Artificial Neural Network

1. Introduction

Crack is one of the common faults that if develops, may cause catastrophic damages in structures. A lot of studies have been done on non-destructive estimation methods. The non-destructive methods used so far can be divided in four groups. The first group includes methods that determine if there is a specific fault in the structure or not [1, 2]. The second group includes methods not only capable of identifying the fault but also locating it [3-5]. The third group includes methods capable of specifying more information about the fault, like the depth [6-9], and the fourth group contains methods that can even estimate the effect of the fault on the structure. In recent years investigators have shown great interest in vibration analysis method and so there are a lot of investigations in this area. Dimarogonas reviewed methods of investigating cracked structures in 1996 [10]. Crack causes a local flexibility in the structure which affects the dynamic behaviour. For example it reduces the natural frequencies and changes the mode shapes. Analyzing these effects can be used for crack detection [11]. Dimarogonas et al. modeled a crack using local flexibility and calculated the equivalent stiffness utilizing fracture mechanics [12, 13]. Adams et al. developed an experimental technique to estimate the location and the depth of a crack based on the changes of the natural frequencies [14]. In another investigation Dimarogonas presented methods which relate the depth of the crack to the changes of the natural frequencies when the crack location is known [15]. These methods can be used to identify cracks in different structures. Gudmunson presented a method to predict the changes of the natural frequencies caused by faults such as cracks, notches, etc [16]. Masoud et al. investigated vibrational characteristics of a fixed-fixed beam with a symmetric crack considering coupling effect of crack depth and axial load [17]. Shen et al. presented a method based on minimizing the difference between the measured data the data obtained from an analytical data to identify cracks in an Euler-Bernoulli beam [18]. In this paper the parameter used to identify the fault is natural frequency. This is because of the fact that measuring natural frequency is cost effective [20], and can be done accurately in most structures [11].

A new technique used frequently for damage identification in recent years is neural network. Wu et al. used back propagation neural network to identify the fault location in a simple frame [21]. Kao and Hung presented a two step method for identifying cracks based on neural network. First step was to identify damaged and undamaged system situations. Second step was fault detection in structures. In this step a trained neural network was used to produce free vibration response of the system and finally a comparison was made between the results to evaluate changes in amplitude and periods [22]. Chen et al. worked on using neural network for fault detection in engineering structures in case the excitation signal is not available [23].
In this paper back error propagation neural network is used to estimate natural frequencies in different crack locations and crack depths of symmetric beams.

2. Modal Analysis

The structure investigated in this paper is a beam fixed at both ends with an open crack (Fig. 1).

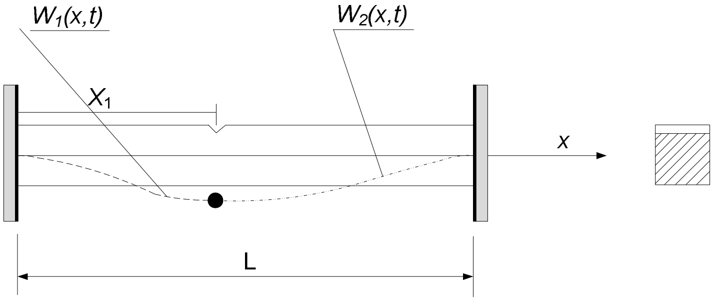

Fig. 1. Schematic of clamped-clamed beam with an open crack

Table 1 gives the beam's material and geometrical characteristics. Since the structure is symmetric with respect to a plane passing through the center and normal to the *x* direction, for a crack located at a distance of *x* from any of the two supports, there are two possible conditions with the same value of natural frequencies. In this section it is assumed that the crack is located at the right side of the beam. Three natural frequencies of the structure are calculated for different conditions of crack locations and depths using finite element method. The natural frequencies of the considered cracked beam were calculated by using modal analysis. In this article the 2D elements have been used for modal analysis. This element is defined by eight nodes which have two degrees of freedom at each node include translations in the perpendicular directions. A meshed view of the typical structure in crack region has been illustrated in Fig. 2.

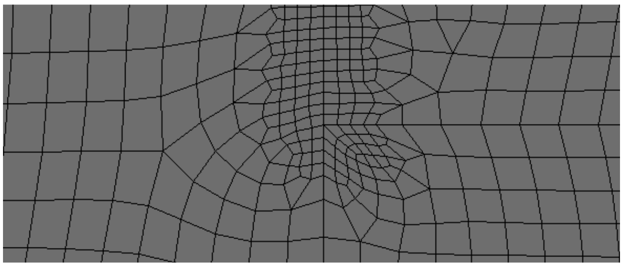

Fig. 2. Typical finite element discretisations.

Table 1. Beam Characteristics

Density (Kg/m3)	Poisson Ratio	Elasticity Modulus (GPa)	Length (mm)	Thickness (mm)	Depth (mm)
7860	0.3	210	175	12.5	25

3. Artificial Neural Network

Nowadays Artificial neural networks are used in many engineering applications. The most popular type of neural network is the **M**ulti-**L**ayer **F**eed **F**orward (**MLFF**). A schematic diagram of a typical MLFF neural network architecture is depicted in Fig. 3.

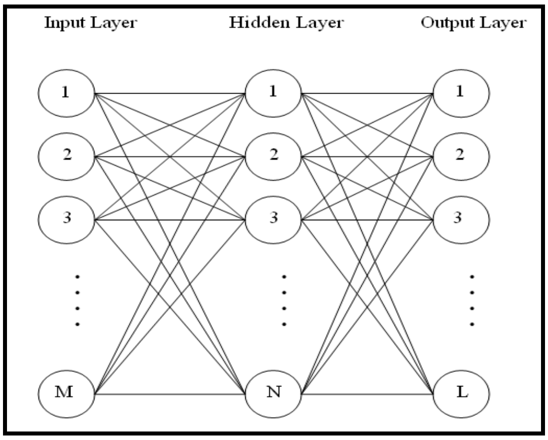

Fig. 3. Schematic diagram of typical MLFF neural network

The network usually consists of an input layer, some hidden layers and an output layer. Usually knowledge is stored as a set of connection weights. The process of modifying the connection weights, in some orderly fashion, uses a suitable learning method called training.

The back-error propagation is the most widely used learning algorithm. It is one of the most powerful learning algorithms in neural networks. The back-propagation neural network was proposed by McClelland and Rumelhart [25] in a ground-breaking study originally focused on cognitive computer science. In this paper the structure of neural network includes three layers: the input layer, hidden layer, and output layer. The variable M shows the total neuron number in the input layer, variable N shows the total neuron number in the hidden layer, and the variable L shows the total neuron number in the output layer. Values w_{MN} are the weights between the input and the hidden layer. Values w_{LN} are the weights between the hidden and the output layer. The operation of back error propagation is consisting of three steps:

1- Feed-forward step:

$$v_j = w_{LN}(n) u_{j+1}(n); \tag{1}$$

$$o_j(n) = \varphi(v_j(n)) = \frac{2}{1 + \exp(-v_j(2n))}; \tag{2}$$

Where, o_j is output, u_j is input, u_{j+1} is output of hidden layer and φ is a transfer function.
2- Back-propagation step:

$$\delta_j(n) = e_j(n).\varphi'(v_j(n)) = (d_j(n) - o_j(n))o_j(n)(1 - o_j(n)); \tag{3}$$

Where, δ_j represents the local gradient function, e_j shows the error function, o_j means the actual output and d_j is desired output.
3- Adjust weighted value:

$$w_{NM}(n+1) = w_{NM}(n) + \Delta w_{NM}(n) = w_{NM}(n) + \eta \delta_j(n).o_j(n); \tag{4}$$

where η is the learning rate. Repeating these three steps results to the value of the error function will be zero or a constant value.
In this paper two distinct neural networks are employed for prediction of locations and depths of cracks. Networks consist of an input layer, a hidden layer and an output layer with 4, 20 and 1 neurons, respectively. In each network, transfer functions for neurons of hidden and output layers are Tansig and Purline, and are defined as equation (5) and (6) respectively.

$$f(x) = \frac{2}{(1 + \exp(-2x)) - 1}. \tag{5}$$

$$f(x) = x. \tag{6}$$

4. Crack Detection Procedure

In this section three different natural frequencies from two different crack conditions are used to train the network as the input and the corresponding locations and depths are obtained as the output. These data are based on the assumption that the crack is located at the right side of the beam. It should be noted that a crack located at the left side of the beam gives the same output. In order to determine the original location of the crack, beam deflection is calculated at two arbitrary symmetrical points located at the right and the left side of the beam. The original crack location is at the side which has the bigger value of deflection. It happens because the crack lead to local flexibility in its surrounding [11], therefore in the same distances from two end of symmetric beam, the side that cracked is there, has more deflection rather than other side. This matter has been proved with FEM analysis of considered beam that is tabulated in Table 3.

5. Results

Table 2 compares first four natural frequencies of structure that obtained from modal analysis of present study and the analytical results that presented in reference [24]. In should be mentioned that, in Table 2, f_i represent the i^{th} natural frequency of cracked beam.

Table 2. Comparison of the natural frequencies obtained from present study and Ref. [24].

Crack Location (mm)		35	70
Crack Depth (mm)		12.5	12.5
Present Work (HZ)	f_1	3823.1	3483.4
	f_2	8776.6	8787.8
	f_3	15785	15700
	f_4	23203	21366
Reference [24] (HZ)	f_1	3819.1	3395.3
	f_2	8743.6	8679.5
	f_3	14691.1	15474.0
	f_4	22849.1	21518.7
Error (%)	f_1	0.1	2.6
	f_2	0.4	1.2
	f_3	7.4	1.4
	f_4	1.5	0.7

Table 3 shows the deflection values of structure in the considered point at first vibrational mode shape of beam that was obtained for two different crack locations. The corresponding predicted values of crack locations and depths are compared with the actual values in Table 4. As has been shown in this Table, the predicted crack characteristics are in good agreement with actual data, which the maximum errors were 1.3% and 1.2% for depth and location of crack, respectively. Therefore it can be concluded that the presented method of this paper is suitable for crack detection in symmetric beams. Also it should be mentioned that the presented method can be applied to many other symmetric cracked structures.

Table 3. Deflections of two symmetric points

Number	1	2
Depth (mm)	1.1607	1.5
Location (1) (mm)	122.5	122.5
Deflection (1) (mm)	1.8099	1.6284
Location (2) (mm)	52.5	52.5
Deflection (2) (mm)	1.6123	1.7878

Table 4. Comparison of predicted and actual depth and location of crack

Number	1		2	
Parameter	Depth	Location	Depth	location
Predicted Results (mm)	8.86	122.41	3.0	51.87
Actual Results (mm)	8.75	122.5	3	52.5
Errors (%)	1.3	0.7	0	1.2

6. Conclusion

This paper presented a new method for crack identification in symmetric beams. In this study, first of all, it was determined that identifying the crack location in a symmetric beam with an open crack is not possible knowing only the natural frequencies. Two distinct ANNs were employed for prediction of locations and depths of cracks in half of beam. Then an algorithm based on calculating the beam deflections at two arbitrary symmetric points on first vibration mode shape was presented to identify the original location of the crack. Then it was showed that the predicted crack characteristics were in good agreement with actual data, which the maximum errors were 1.3% and 1.2% for depth and location of crack, respectively. Finally it was concluded that the presented method of this study is suitable and useful for crack detection in symmetric beams.

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