Crack Detection of Fixed-Simply Supported Euler Bernoulli Beam Using Elman Networks

Siamak Ghadimi[1], Seyed Sina Kourehli[2]
Department of Civil Engineering, Ahar branch, Islamic azad university, Ahar, Iran
[2]Email:s-kourehli@iau-ahar.ac.ir (Corresponding author)

Abstract

In this paper, the crack detection and depth ratio estimation method are presented in beam-like structures using Elman Networks. For this purpose, by using the frequencies of modes as input, crack depth ratio of each element was detected as output. Performance of the proposed method was evaluated by using three numerical scenarios of crack for fixed-simply supported beam consisting of a single cracked, two cracked and three cracked beams have been investigated. The results indicate that the proposed method is effective in the crack detection and estimation of crack depth ratio in beam-like structures.

Keywords: Crack detection; Beam-like structures; Elman Networks; Frequency

1- Introduction

Crack detection and estimation in different engineering fields have attracted many researches in the last decades. To detect crack in structures, is one of the most important vibration-based methods. Because the modal parameters of structures like frequencies, dynamic flexibility, modal strain energy, frequency response function and mode shape curvature are so sensitive to structural properties like stiffness, it can therefore be used for detecting crack in structures [1]. Khaji et al. [2] developed a closed-form solution for crack detection in Timoshenko beams with various boundary conditions. In this study, an analytical approach was proposed for crack identification in uniform beams based on bending vibration measurements. Hu et al. [3] presented nondestructively detection of matrix cracks in composite laminates by using the modal strain energy method. The damage in the form of a matrix crack in the laminates was created by using a tensile load. Kisa et al. [4] proposes a numerical model that combines the finite element and component mode synthesis methods for the modal analysis of beams with circular cross section. Obtained results show the effects of location and depth of cracks on the natural frequencies and mode shapes of the studied beams. In another work, Owolabi et al. [5] proposed a method for crack detection in beams using changes in frequencies and amplitudes of frequency response functions.

Soft computing methods using dynamic parameters of structures have been utilized increasingly for structural damage detection due to their excellent pattern recognition capability. Saeed et al. [6, 7] used ANN and adaptive neuro-fuzzy interface system

(ANFIS) in order to predict the location and size of cracks in curvilinear beam elements. In this study, natural frequencies and frequency response functions (FRFs) were applied as input .According to these studies, cracks longer than 5 mm can be located with acceptable accuracy, even if there are different levels of noise in the input data. Ramadas et al. [8] presented a method to combine damage detection features of ultrasonic lamb wave with first and second natural frequencies for detection of transverse cracks in a composite beam. Also, Kourehli [9-10] used artificial neural network and incomplete noisy modal data and incomplete static responses to structural damage detection and estimation. In another work, Kourehli [11] used least square support vector machine and the iterated improved reduction system to do structural damage diagnosis. Coupled Simulated Annealing (CSA) and standard simplex method using 10-fold cross-validation techniques were adopted to determine the optimal tuning parameters in the LS-SVM model. The obtained results indicated that this method can provide a reliable method to accurately identify the structural damage. Suresh et al [12] presented a method to identify crack location and depth in a cantilever beam using a modular neural network approach. In this study, modal frequencies are used to train a neural network to identify both the crack location and depth. In this paper, the frequencies of modes were applied as the inputs of the ELMAN back propagation in order to predict the size of cracks in beam elements. The performance of the proposed method was evaluated by using three scenarios for fixed simply supported beam consisting of single and multi-cracked Euler–Bernoulli beams. The obtained results show the capability of the proposed method for crack detection using ELMAN.

2. The Proposed method

In this section, the proposed method for structural crack detection and estimation are illustrated. First, the model reduction method is formulated. Then, the ELMAN back propagation neural network is presented.

2.1- Crack detection in beam like structure using modal data such as frequencies

In the finite element method, the global stiffness and mass matrices are formed by assemblage of element matrices. So, the global stiffness matrix of a cracked structure can be made using the cracked element stiffness matrices as followed:

$$[K^c] = \sum_{j=1}^{Ne} [K_j^c] \qquad (1)$$

Where, K^c and K_j^c are the cracked global stiffness matrices and the cracked element stiffness matrices of the jth element, respectively; and N_e is the total number of finite elements. Thus, the eigenvalue equations for a cracked structure become:

$$([K^c] - \lambda_i^c[M])\{\phi_i^c\} = 0 \quad i = 1,2,\dots,n \qquad (2)$$

Where, λ_i^c and ϕ_i^c are the square of the ith natural frequency and the ith mode shape of the cracked structure, respectively. The closed-form of cracked element stiffness matrix can be given as follows [13].

$$[K_j^c] = \frac{-1}{BL^2}\begin{bmatrix} (2A+CA+1) & (A+1)L & -(2A+CA+1) & (A+AC)L \\ & L^2 & -(A+1)L & AL^2 \\ & & (2A+CA+1) & -(A+AC)L \\ \text{Symmetric} & & & CAL^2 \end{bmatrix} \tag{3}$$

In which:

$$A = \frac{L(K) + 6EI\alpha(1-\alpha)}{2L(K) + 6EI(\alpha^2)} \tag{4}$$

$$B = (A-1)\frac{L}{2EI} + (A+1)\frac{\alpha}{K} - \frac{1}{K} \tag{5}$$

$$C = \frac{2L(K) + 6EI(1-\alpha)^2}{L(K) + 6EI\alpha(1-\alpha)} \tag{6}$$

$$K = \frac{Ew(h^2)}{72\pi f(\eta)} \tag{7}$$

$$\eta = \frac{d}{h} \tag{8}$$

$$f(\eta) = 0.638\eta^2 - 1.035\eta^3 + 3.7201\eta^4 - 5.1773\eta^5 + 7.553\eta^6 - 7.332\eta^7 + 2.4909\eta^8 \tag{9}$$

Where ,d is the crack depth, w represents the beam width, E is the modulus of elasticity, h denotes the beam depth, η represents a non-dimensional crack depth ratio and L is the length of beam element. Also ,K is the equivalent spring stiffness for a single-sided open crack based on the theory of fracture mechanics [14]. Also, mass matrix of Euler-Bernoulli beam is given by [15]:

$$M = \frac{\rho Al}{420}\begin{bmatrix} 156 & 22l & 54 & -13l \\ 22l & 4l^2 & 13l & -3l^2 \\ 54 & 13l & 156 & -22l \\ -13l & -3l^2 & -22l & 4l^2 \end{bmatrix} \tag{10}$$

Where, ρ is the material mass density$A$ is cross section of beam and l is the length of beam elements. Moreover, it is assumed that no change would occur after damage in the mass matrix.

2.2- ELMAN back propagation

Elman Networks are a form of recurrent Neural Networks which have connections from their hidden layer back to a special copy layer. This means that the function learnt by the network can be based on the current inputs plus a record of the previous state(s) and outputs of the network. In other words, the Elman net is a finite state machine that learns what state to remember (i.e., what is relevant). The special copy layer is treated as just another set of inputs and so standard back-propagation learning techniques can be used (something which isn't generally possible with recurrent networks) [16].

3. - Numerical examples

In this section, the efficiency and effectiveness of the proposed methods are evaluated through some numerically simulated damage identification tests.Fixed-simply supported beamsare chosen with three different scenarios of crack for each of them for the purpose.

3.1- Fixed simply supported beam

A fixed-simply supported beam, as shown in Fig. 1 with a finite-element model consisting of 10 beam elements, is considered. The material properties of the beam are Young's modulus E=200GPa, the Poisson ratioμ= 0.3 and density= $7800\,{}^{kg}/_{m^3}$. Also, the beam is divided into 10 equal elements. The numerical studies are carried out within the MATLAB (2015) [17] environment, which is used for the solution of finite element problems.

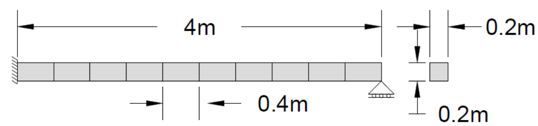

Fig.1. Fixed-Simply supported beam with 10 elements

Table .1. Three different crack scenarios for cantilever beam

Scenario 1	Scenario 2		Scenario 3		
Number element / Crack depth ratio	Number element/Crack depth ratio		Number element/Crack depth ratio		
Element 4 / 0.3	Element 2 / 0.3	Element 9 / 0.2	Element 1 / 0.2	Element 4 / 0.3	Element 8 / 0.3

In this paper a new method has been introduced to generate the training patterns. So, a number of structures with different modal properties, using random damage severity between 0 and 0.3 for all elementswere considered, and their responses to the dynamic excitation were computed using the numerical analyses. As seen in Fig.2, nine different intervals have been used and 1000random scenarios from each interval were used for ELMAN training. The crack location of each element is supposed in the middle. Figures 3 and 4 show the capability of proposed method for crack detection and estimation in the beam-like structures for cantilever beam. It can be seen that the crack depth can be obtained, for three different scenarios using the frequencies by using ELMAN. For this example the properties of ELMAN network have been assumed in Table 2.

Table .2. Properties of ELMAN network

Type of network	
Learning function	TRAINLM
Adaption learning function	LEARNGDM
Performance function (error)	MSE
Number of layers	2
Number of neurons	10
Transition function	TANSIG

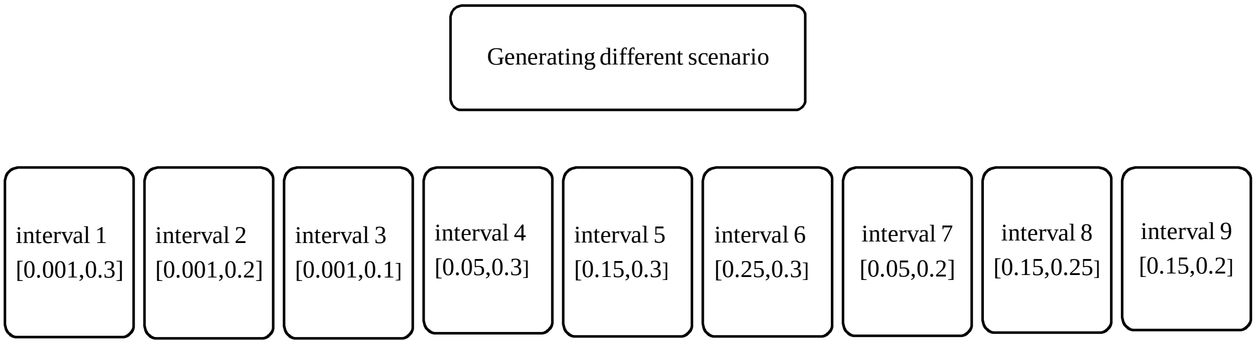

Fig. 2.The procedure to generate different scenarios for training and testing

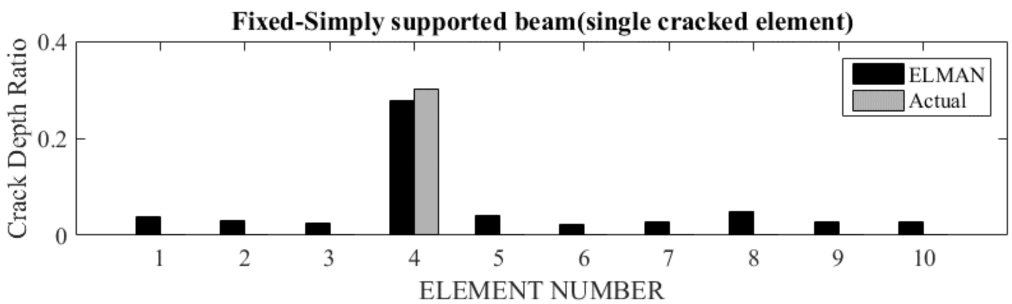

Fig .3. Result for scenario 1 of fixed-simply supported beam using Elman

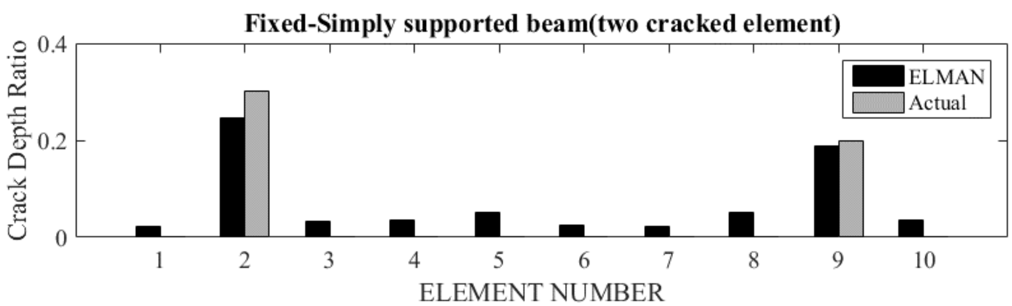

Fig .4. Result for scenario 2 of fixed-simply supported beam using Elman

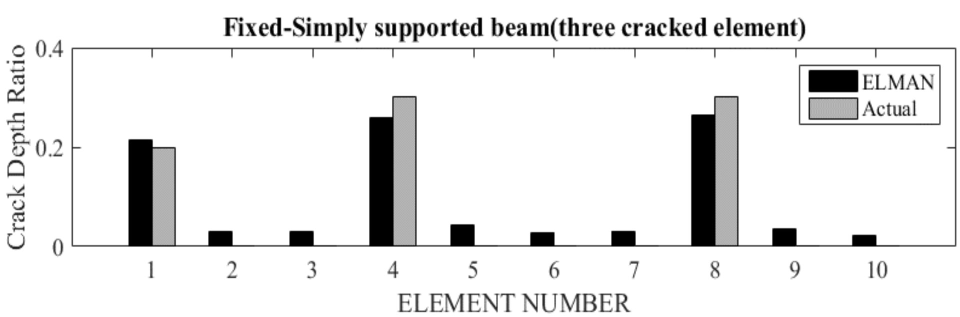

Fig .5. Result for scenario 3 of fixed-simply supported beam using Elman

4. Conclusion

In this paper, a new method was proposed for crack detection and estimation in beam elements using artificial neural networks. The natural frequencies were applied as the inputs of the ELMAN network in order to predict the size of cracks in beam elements. The performance of the proposed method was evaluated by using three scenarios for fixed-simply supported beam consisting of single cracked element of beam and multi cracked beam element. The obtained results indicate that ELMAN works well in prediction of crack in elements.

References

[1] Doebling et al. (1998).A summary review of vibration-based damage identification methods. The Shock and Vibration Digest 30: 91-105.

[2] Khaji N, Shafiei M, Jalalpour M. (2009). Closed-form solutions for crack detection problem of Timoshenko beams with various boundary conditions. Int. J. Mech. Sci.;51:667–681.

[3] Hu, H., Lee, C. H., Wu, C. B., & Lu, W. J. (2010). Detection of matrix cracks in composite laminates by using the modal strain energy method. Mechanics of Composite Materials, 46(2), 117-132.

[4] Kisa, M., &Gurel, M. A. (2006). Modal analysis of multi-cracked beams with circular cross section. Engineering Fracture Mechanics, 73(8), 963-977.

[5] Owolabi GM, Swanidas ASJ, Seshadri R. (2003). Crack detection in beams using changes in frequencies and amplitudes of frequency response function. J. Sound Vib.;265:1–22.

[6] Saeed, R.A., Galybin, A.N. and Popov, V. (2012). “Crack identification in curvilinear beams by using ANN and ANFIS based on natural frequencies and frequency response functions”, Neural Comput. Appl., 21, 1629-1645.

[7] Saeed R.A. and George, L.E. (2011). “The use of ANN for cracks predictions in curvilinear beams based on their natural frequencies and frequency response functions”, J. Comput., 3(12), 113-125.

[8] Ramadas, C., Balasubramaniam, K., Joshi, M. and Krishnamurthy, C.V. (2008).“Detection of transverse cracks in a composite beam using combined features of lamb wave and vibration techniques in ANN environment”, Int. J. Smart Sens. Intel. Syst., 1(10), 970-984.

[9] Kourehli S S (2015). Damage assessment in structures using incomplete modal data and artificial neural network, International Journal of Structural Stability and Dynamics, 15(6), 1450087. DOI: 10.1142/S0219455414500874.

[10] Kourehli, S S (2015). Damage Quantification method using artificial neural network and static response with Limited Sensors, Journal of Vibroengineering, 17 (3): 1317-1325.

[11]Kourehli, S S (2015). LS-SVM regression for structural damage diagnosis using the iterated improved reduction system, International Journal of Structural Stability and Dynamics, 16 (6), DOI: 10.1142/S0219455415500182.

[12] Suresh S, Omkar SN, Ganguli R, Mani V. (2004). Identification of crack location and depth in a cantilever beam using a modular neural network approach. Smart Mater. Struct.;13:907–915.

[13] Mehrjoo M, Khaji N, Ghafory-Ashtiany M (2013). Application of genetic algorithm in crack detection of beam-like structures using a new cracked Euler-Bernoulli beam element,Applied Soft Computing, 13: 867–880.

[14] Ostachowicz W M, and Krawczuk M (1991). Analysis of the effect of cracks on the natural frequencies of a cantilever beam, Journal of sound and vibration 150: 191-201.

[15] Qian GL, Gu SN, Jiang JS (1990). The dynamic behavior and crack detection of beam with a crack, Journal of sound and vibration 138 (2): 233-243.

[16] http://wiki.tcl.tk/15206.

[17] MATLAB (2013).Matlab User Manual, Mathwork Inc. Lowell, MA, U.S.A.