Damage Detection in Cantilever Beam

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Abstract: ***Cracks in vibrating component can initiate catastrophic failures. Therefore there is need to understand dynamics of cracked structures. In the present study, vibration analysis is carried out on a cantilever beam with two open transverse cracks, to study the response characteristics. A neural network for the cracked structure is trained to approximate the response of the structure by the data set prepared for various crack sizes and locations. It is verified from both computational and simulation analysis that the presence of crack decreases the natural frequency of vibration.***

Keywords: cracks, cantilever beam, neural networks, FEM

1. Introduction

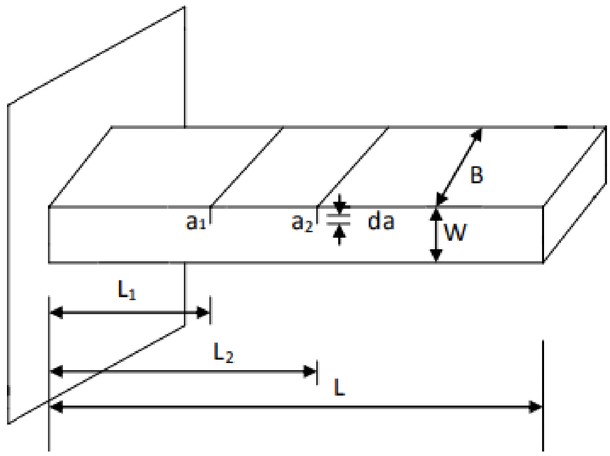
Cracks in a structure may be hazardous due to static or dynamic loadings, so that crack detection plays an important role for structural health monitoring applications. If cracks remain undetected and reach their critical size, then a sudden structural failure may occur. The objective is to carry out vibration analysis on a cantilever beam with and without crack. The results obtained analytically are validated with the simulation results. In first phase of the work two transverse surface cracks are included in developing the analytical expressions in dynamic characteristics of structures. The use of neural networks in detecting the damage has been developed for several years, because of their ability to cope with the analysis of the structural damage without the necessity for intensive computation. In this study feed-forward multi-layer neural networks trained by back-propagation are used to learn the input (the location and depth of a crack)-output (the structural eigen frequencies) relation of the structural system. A neural network for the cracked structure is trained to approximate the response of the structure by the data set prepared for various crack sizes and locations.

2. Literature Review

Orhan Sadettin [2] has studied the free and forced vibration analysis of a cracked beam was performed in order to identify the crack in a cantilever beam. Single- and two-edge cracks were evaluated. Dynamic response of the forced vibration better describes changes in crack depth and location than the free vibration in which the difference between natural frequencies corresponding to a change in crack depth and location only is a minor effect.

3. Theoretical Analysis

The beam with a two transverse edge cracks is clamped at left end, free at right end and it has a uniform structure with a constant rectangular cross-section. The Euler–Bernoulli beam model was assumed. The damping has not been considered in this study. A cantilever beam of length L, of uniform rectangular cross-section B×W with cracks located at positions L1 and L2 is considered in fig.(4.1). The cracks are assumed to be an open crack and have uniform depths a_1 and a_2 respectively. In the present analysis the axial and bending vibration are considered.



4. Neural Network

Studies on neural networks have been motivated to imitate the way that the brain operates. A network is described in terms of the individual neurons, the network connectivity, the weights associated with various interconnections between neurons, and the activation function for each neuron. The network maps an input vector from one space to another. The mapping is not specified, but is learned. The network is presented with a given set of inputs and their associated outputs. The learning process is used to determine proper interconnection weights and the network is trained to make proper associations between the inputs and their corresponding outputs. Once trained, the network provides rapid mapping of a given input into the desired output quantities. This, in turn, can be used to enhance the efficiency of the design process.

In this study, we use the back-propagation network, that is, a multi-layer feed-forward neural network topology with one hidden-layer as shown in Figure 5.4. The feed forward back propagation (BP) network is a very popular model in neural networks. In multilayer feed forward networks, the processing elements are arranged in layers and only the elements in adjacent layers are connected. It has minimum three layers of elements (i) the input layer (ii) the middle or hidden layer and (iii) the output layer. The name back propagation derives from the fact that computations are passed forward from the input to output layer, following which calculated errors are propagated back in the other direction to change the weights to obtain better performance.

Back-propagation networks can be learned when presented with input-target output pairs.

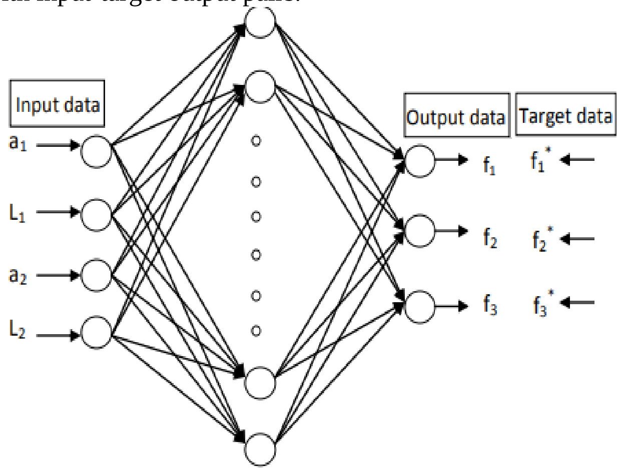


Figure: Three-layer neural network utilized in this study.

Matlab program

Creation

Feed-Forward Networks

newff(mm, sizeArray, transferFunctionCellArray, trainingAlgorithm);

LVQ Networks

newlvq(mm, hiddenLayerSize, percentages);

Elman Networks

newelm(mm, sizeArray, transferFunctionCellArray);

mm: Matrix of size number_of_inputs x 2. Each row contains the minimum and maximum value that a particular input node can have.

sizeArray: array that contains size for each layer (not including input)

transferFunctionCellArray: Cell Array that contains strings representing the transfer functions for each layer (not including input layer).

Transfer function	MATLAB® String
logarithmic-sigmoidal	logsig
tangential-sigmoidal	tansig
hard limit	hardlim
linear	purelin
competitive	(automatic for appropriate layer)

trainingAlgorithm: A string representing the training algorithm for the network

Training algorithm	MATLAB® String
Batch Gradient Descent with Momentum	traingdm
Resilient Backpropagation	trainrp
BFGS	trainbfg
Levenberg-Marquardt	trainlm
Random	trainr

hiddenLayerSize: The size of the hidden layer

percentages: matrix of expected percentages of inputs.

Training

[net, tr] = train(net, trainData, T, [], [], VV);

net: neural network to be trained

trainData: training data set

T: desired output for each input

VV: struct array of with validation inputs and targets

Testing

output = sim(net, testData);

net: neural network to be tested

testData: testing data set

Finite Element Modeling

The ANSYS 15.0 finite element program was used for free vibration of the cracked beams. For this purpose, the key points were first created and then line segments were formed. The lines were combined to create an area. Finally, this area was extruded and a three-dimensional V-shaped edge cracked beam model was obtained. We modeled the crack with a 0.5mm width on the top surface of the beam and a crack going through the depth of the beam. A 20-node three-dimensional structural solid element under SOLID 185 was selected to model the beam. The beam was discretised into 1045 elements with 2318 nodes. Cantilever boundary conditions are modeled by constraining all degrees of freedoms of the nodes located on the left end of the beam. The subspace mode extraction method was used to calculate the natural frequencies of the beam.

Neural Network Training

The clamped-free beam of Figure 4.1 has a length of L=0.8 m, width of the beam = 0.05 m, depth of the beam = 0.006 m, the material properties are E = 0.724x10 11 N/m2 , Poisson's ratio = 0.334, ρ= 2713 kg/m3 . For the preparation of the learning data, 10 sets of a crack depths a1=a2=0.0003,...., 0.003m (step size=0.0003m) are introduced at the 17 different crack locations L1=0.04,...., 0.68m (step size=0.04m) and L2=0.08,...,0.72m (step size=0.04m). Totally 170 cases or patterns (10 different crack depths and 17different crack locations) are solved for the first three frequencies. The patterns which consist of 170 sets of data are used to train the neural network.

5. Results

The problem involves calculation of natural frequencies and mode shapes for cantilever beam without a crack and with two cracks of different crack depths. The results calculated analytically are validated with the results obtained by simulation analysis. The method described has been applied to a cracked Bernoulli-Euler beam. Aluminum has taken the beam. Properties: Width of the beam = 0.05 m Depth of the beam = 0.006 m Length of the beam = 0.8 m Elastic modulus of the beam = 0.724x10 11 N/m 2 Poisson's Ratio = 0.334 Density = 2713 kg/m 3 End condition of the beam = One end fixed and other end free (Cantilever beam).

6. Conclusion

The frequency of the cracked cantilever beam decreases with increase in the crack depth for the all modes of vibration. For moderate cracks (a1/w=a2/w=0.1667) appreciable changes in mode shapes are noticed and for deep cracks (a1/w=a2/w=0.5) the change in mode shapes are quite substantial. A neural network for the cracked structure is trained to approximate the response of the structure by the data set prepared for various crack sizes and locations.

References

[1] C.Ramachandran*, Dr.R.Ponnudurai** Finite element analysis of beam having crack at various locations International Journal of Scientific and Research

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[2] Orhan Sadettin, Analysis of free and forced vibration of a cracked cantilever beam, NDT and E International 40, (2007), pp.43-450.

Appendex-A

Nueral network Program in MATLAB

```
%crack size
a1=0.0003:0.0003:0.003;
a2=0.0003:0.0003:0.003;
%crack location
L1=0.04:0.04:0.68;
L2=0.08:0.04:0.72;
%input
x=[a1 a2 L1 L2];
%target (transpose of f1)
f1=[138.04  138.06  138.06  138.05  138.02  138.05  138.03
138.06  138.05  138.06  138.05  138.04  138.04  138.02
138.03  138.03  138.04  138.01  138.04  138.02  138.01
137.97  137.95  137.99  138.03  138.05  138.04  138.01
137.96  137.92  137.91  137.95  137.98  138.02  137.92
137.01  137.99  137.93  137.86  137.83  137.89  137.97
137.03  138 137.97  137.84  137.78  137.77  137.82  137.89
137.97  137.85  138.01  137.99
];
%initiation
net=newff(minmax(a1),[13 1],{'logsig','purelin','trainln'});
%specifications
net.trainparam.epochs=100;
net.trainparam.goal=1e-25;
net.trainparam.lr=0.01;
%training
net=train(net,x,f1);
%testing
x=sim(net,a1(6))
%answer is 138.0400
```

Appendix-B

Test data

Sno	a1	a2	L1	L2	f1	f2	f3
1	0.0003	0.0003	0.04	0.08	7.8668	49.293	138.04
2	0.0003	0.0003	0.08	0.12	7.8678	49.302	138.06
3	0.0003	0.0003	0.12	0.16	7.8683	49.306	138.06
4	0.0003	0.0003	0.16	0.2	7.8682	49.305	138.05
5	0.0003	0.0003	0.2	0.24	7.8671	49.296	138.02
6	0.0003	0.0003	0.24	0.28	7.8694	49.306	138.05
7	0.0003	0.0003	0.28	0.32	7.8686	49.297	138.03
8	0.0003	0.0003	0.32	0.36	7.8697	49.3	138.06
9	0.0003	0.0003	0.36	0.4	7.8889	49.292	138.05
10	0.0003	0.0003	0.4	0.44	7.8702	49.298	138.06
11	0.0003	0.0003	0.44	0.48	7.8699	49.296	138.05
12	0.0003	0.0003	0.48	0.52	7.8702	49.298	138.04
13	0.0003	0.0003	0.52	0.56	7.8706	49.301	138.04
14	0.0003	0.0003	0.56	0.6	7.8699	49.299	138.02
15	0.0003	0.0003	0.6	0.64	7.8701	49.301	138.03
16	0.0003	0.0003	0.64	0.68	7.8697	49.3	138.03
17	0.0003	0.0003	0.68	0.72	7.8697	49.301	138.04
1	0.0006	0.0006	0.04	0.08	7.8591	49.269	138.01
2	0.0006	0.0006	0.08	0.12	7.8594	49.284	138.04
3	0.0006	0.0006	0.12	0.16	7.8602	49.292	138.02
4	0.0006	0.0006	0.16	0.2	7.8635	49.306	138.01
5	0.0006	0.0006	0.2	0.24	7.8644	49.303	137.97
6	0.0006	0.0006	0.24	0.28	7.8646	49.287	137.95
7	0.0006	0.0006	0.28	0.32	7.8665	49.282	137.99
8	0.0006	0.0006	0.32	0.36	7.8679	49.276	138.03
9	0.0006	0.0006	0.36	0.4	7.8683	49.266	138.05
10	0.0006	0.0006	0.4	0.44	7.8683	49.259	138.04
11	0.0006	0.0006	0.44	0.48	7.869	49.261	138.01
12	0.0006	0.0006	0.48	0.52	7.8689	49.265	137.96
13	0.0006	0.0006	0.52	0.56	7.869	49.272	137.92
14	0.0006	0.0006	0.56	0.6	7.8692	49.278	137.91
15	0.0006	0.0006	0.6	0.64	7.8706	49.295	137.95
16	0.0006	0.0006	0.64	0.68	7.8703	49.298	137.98
17	0.0006	0.0006	0.68	0.72	7.8702	49.301	138.02
1	0.0009	0.0009	0.04	0.08	7.8443	49.215	137.92
2	0.0009	0.0009	0.08	0.12	7.8458	49.256	137.01
3	0.0009	0.0009	0.12	0.16	7.8497	49.287	137.99
4	0.0009	0.0009	0.16	0.2	7.8545	49.302	137.93
5	0.0009	0.0009	0.2	0.24	7.8577	49.296	137.86
6	0.0009	0.0009	0.24	0.28	7.8595	49.274	137.83
7	0.0009	0.0009	0.28	0.32	7.8617	49.25	137.89
8	0.0009	0.0009	0.32	0.36	7.8636	49.228	137.97
9	0.0009	0.0009	0.36	0.4	7.8656	49.215	137.03
10	0.0009	0.0009	0.4	0.44	7.8651	49.196	138
11	0.0009	0.0009	0.44	0.48	7.8685	49.214	137.97
12	0.0009	0.0009	0.48	0.52	7.8678	49.218	137.84
13	0.0009	0.0009	0.52	0.56	7.8701	49.242	137.78
14	0.0009	0.0009	0.56	0.6	7.8704	49.262	137.77
15	0.0009	0.0009	0.6	0.64	7.8706	49.279	137.82
16	0.0009	0.0009	0.64	0.68	7.8697	49.286	137.89
17	0.0009	0.0009	0.68	0.72	7.8697	49.294	137.97
1	0.0012	0.0012	0.04	0.08	7.8268	49.159	137.85
2	0.0012	0.0012	0.08	0.12	7.8307	49.233	138.01
3	0.0012	0.0012	0.12	0.16	7.8383	49.291	137.99
4	0.0012	0.0012	0.16	0.2	7.8431	49.303	137.84
5	0.0012	0.0012	0.2	0.24	7.8499	49.293	137.74
6	0.0012	0.0012	0.24	0.28	7.852	49.251	137.67
7	0.0012	0.0012	0.28	0.32	7.8546	49.202	137.74
8	0.0012	0.0012	0.32	0.36	7.8593	49.176	137.91
9	0.0012	0.0012	0.36	0.4	7.8618	49.145	137.01
10	0.0012	0.0012	0.4	0.44	7.8655	49.139	137.03
11	0.0012	0.0012	0.44	0.48	7.8667	49.144	137.9
12	0.0012	0.0012	0.48	0.52	7.8681	49.165	137.72
13	0.0012	0.0012	0.52	0.56	7.8699	49.194	137.57
14	0.0012	0.0012	0.56	0.6	7.8702	49.229	137.55
15	0.0012	0.0012	0.6	0.64	7.8702	49.257	137.63
16	0.0012	0.0012	0.64	0.68	7.8693	49.273	137.76
17	0.0012	0.0012	0.68	0.72	7.87	49.291	137.92
1	0.0015	0.0015	0.04	0.08	7.7981	49.062	137.71
2	0.0015	0.0015	0.08	0.12	7.8079	49.201	138.01
3	0.0015	0.0015	0.12	0.16	7.8181	49.272	137.92
4	0.0015	0.0015	0.16	0.2	7.8276	49.296	137.7
5	0.0015	0.0015	0.2	0.24	7.8351	49.278	137.49
6	0.0015	0.0015	0.24	0.28	7.8425	49.223	137.46
7	0.0015	0.0015	0.28	0.32	7.8497	49.166	137.63
8	0.0015	0.0015	0.32	0.36	7.8536	49.094	137.84
9	0.0015	0.0015	0.36	0.4	7.8587	49.058	138.02
10	0.0015	0.0015	0.4	0.44	7.862	49.036	138
11	0.0015	0.0015	0.44	0.48	7.8652	49.054	137.81
12	0.0015	0.0015	0.48	0.52	7.8667	49.08	137.52
13	0.0015	0.0015	0.52	0.56	7.869	49.132	137.3
14	0.0015	0.0015	0.56	0.6	7.8701	49.183	137.24
15	0.0015	0.0015	0.6	0.64	7.8699	49.227	137.37
16	0.0015	0.0015	0.64	0.68	7.8718	49.275	137.66
17	0.0015	0.0015	0.68	0.72	7.8721	49.299	137.89
1	0.0018	0.0018	0.04	0.08	7.7674	48.959	137.56
2	0.0018	0.0018	0.08	0.12	7.7809	49.155	137.99
3	0.0018	0.0018	0.12	0.16	7.7944	49.268	137.9
4	0.0018	0.0018	0.16	0.2	7.8087	49.296	137.55
5	0.0018	0.0018	0.2	0.24	7.8205	49.264	137.25

6	0.0018	0.0018	0.24	0.28	7.8306	49.188	137.2
7	0.0018	0.0018	0.28	0.32	7.8388	49.093	137.4
8	0.0018	0.0018	0.32	0.36	7.8469	49.01	137.75
9	0.0018	0.0018	0.36	0.4	7.8528	48.943	137.99
10	0.0018	0.0018	0.4	0.44	7.8574	48.9	137.96
11	0.0018	0.0018	0.44	0.48	7.861	48.924	137.67
12	0.0018	0.0018	0.48	0.52	7.8653	48.969	137.25
13	0.0018	0.0018	0.52	0.56	7.88681	49.049	137.95
14	0.0018	0.0018	0.56	0.6	7.87	49.132	137.9
15	0.0018	0.0018	0.6	0.64	7.8704	49.2	137.1
16	0.0018	0.0018	0.64	0.68	7.8718	49.257	137.45
17	0.0018	0.0018	0.68	0.72	7.871	49.284	137.78
1	0.0021	0.0021	0.04	0.08	7.7269	48.826	137.37
2	0.0021	0.0021	0.08	0.12	7.75	49.103	137.96
3	0.0021	0.0021	0.12	0.16	7.7668	49.257	137.83
4	0.0021	0.0021	0.16	0.2	7.7844	49.293	137.9
5	0.0021	0.0021	0.2	0.24	7.7997	49.247	136.92
6	0.0021	0.0021	0.24	0.28	7.8138	49.138	136.84
7	0.0021	0.0021	0.28	0.32	7.8254	49	137.13
8	0.0021	0.0021	0.32	0.36	7.8375	48.886	137.63
9	0.0021	0.0021	0.36	0.4	7.8463	48.806	137.96
10	0.0021	0.0021	0.4	0.44	7.8524	48.752	137.93
11	0.0021	0.0021	0.44	0.48	7.8604	48.768	137.53
12	0.0021	0.0021	0.48	0.52	7.8613	48.82	136.89
13	0.0021	0.0021	0.52	0.56	7.8667	48.939	136.49
14	0.0021	0.0021	0.56	0.6	7.8691	49.059	136.43
15	0.0021	0.0021	0.6	0.64	7.8696	49.15	136.67
16	0.0021	0.0021	0.64	0.68	7.8717	49.235	137.2
17	0.0021	0.0021	0.68	0.72	7.8725	49.285	137.69
1	0.0024	0.0024	0.04	0.08	7.673	48.65	137.12
2	0.0024	0.0024	0.08	0.12	7.7055	49.03	137.92
3	0.0024	0.0024	0.12	0.16	7.7321	49.231	137.73
4	0.0024	0.0024	0.16	0.2	7.7564	49.293	137.11
5	0.0024	0.0024	0.2	0.24	7.7777	49.232	136.57
6	0.0024	0.0024	0.24	0.28	7.7932	49.076	136.4
7	0.0024	0.0024	0.28	0.32	7.8102	48.897	136.81
8	0.0024	0.0024	0.32	0.36	7.8251	48.736	137.46
9	0.0024	0.0024	0.36	0.4	7.8361	48.596	137.92
10	0.0024	0.0024	0.4	0.44	7.8468	48.554	137.9
11	0.0024	0.0024	0.44	0.48	7.8554	48.605	137.36
12	0.0024	0.0024	0.48	0.52	7.86	48.686	136.58
13	0.0024	0.0024	0.52	0.56	7.8644	48.802	135.92
14	0.0024	0.0024	0.56	0.6	7.8683	48.959	135.78
15	0.0024	0.0024	0.6	0.64	7.8702	49.104	136.21
16	0.0024	0.0024	0.64	0.68	7.8712	49.206	136.89
17	0.0024	0.0024	0.68	0.72	7.872	49.272	137.55
1	0.0027	0.0027	0.04	0.08	7.62	48.479	136.891
2	0.0027	0.0027	0.08	0.12	7.6534	48.943	137.86
3	0.0027	0.0027	0.12	0.16	7.6849	48.202	137.62
4	0.0027	0.0027	0.16	0.2	7.7176	48.283	136.76
5	0.0027	0.0027	0.2	0.24	7.7454	48.206	136.05
6	0.0027	0.0027	0.24	0.28	7.7688	49	135.89
7	0.0027	0.0027	0.28	0.32	7.7907	48.762	136.42
8	0.0027	0.0027	0.32	0.36	7.8112	48.562	137.28
9	0.0027	0.0027	0.36	0.4	7.8246	48.372	137.86
10	0.0027	0.0027	0.4	0.44	7.8365	48.294	137.79
11	0.0027	0.0027	0.44	0.48	7.8501	48.367	137.12
12	0.0027	0.0027	0.48	0.52	7.8564	48.477	136.11
13	0.0027	0.0027	0.52	0.56	7.8634	48.652	135.3
14	0.0027	0.0027	0.56	0.6	7.8666	48.827	134.9
15	0.0027	0.0027	0.6	0.64	7.8687	48.029	135.6
16	0.0027	0.0027	0.64	0.68	7.8723	48.182	136.54
17	0.0027	0.0027	0.68	0.72	7.8724	48.262	137.39
1	0.003	0.003	0.04	0.08	7.5523	48.27	136.59
2	0.003	0.003	0.08	0.12	7.5899	48.844	137.8
3	0.003	0.003	0.12	0.16	7.6353	49.189	137.51
4	0.003	0.003	0.16	0.2	7.6737	49.273	136.39
5	0.003	0.003	0.2	0.24	7.7025	49.156	135.35
6	0.003	0.003	0.24	0.28	7.7414	48.916	135.32
7	0.003	0.003	0.28	0.32	7.768	48.607	135.97
8	0.003	0.003	0.32	0.36	7.7928	49.323	137.06
9	0.003	0.003	0.36	0.4	7.8129	48.118	137.83
10	0.003	0.003	0.4	0.44	7.8288	48.031	137.75
11	0.003	0.003	0.44	0.48	7.8418	48.042	136.8
12	0.003	0.003	0.48	0.52	7.863	48.737	136.3
13	0.003	0.003	0.52	0.56	7.861	48.46	134.56
14	0.003	0.003	0.56	0.6	7.8658	48.717	134.29
15	0.003	0.003	0.6	0.64	7.8697	48.955	134.88
16	0.003	0.003	0.64	0.68	7.8724	49.14	136.03
17	0.003	0.003	0.68	0.72	7.8715	49.242	137.16