DEFECT DETECTION IN A CANTILEVER BEAM FROM VIBRATION DATA

[1]Ertuğrul ÇAM, [2]Murat LÜY, [3]İlhan KOCAARSLAN, [4]Cengiz TAPLAMACIOĞLU

[1,2,3]Kırıkkale University, Faculty of Engineering, Department of Electrical&Electronics, Kırıkkale
[4]Gazi University, Faculty of Engineering, Department of Electrical&Electronics, Ankara
E-mail: cam@kku.edu.tr, mluy@kku.edu.tr, ilhan@kku.edu.tr, taplam@mmf.gazi.edu.tr
Phone: +90-318-357 35 71, Fax: +90-318-357 24 59

ABSTRACT

The aim of this study is to obtain information about the damage on the flexible beams. For this purpose, the vibrations due to impact shock is analysed. The signal obtained from the defective and non-defective beams are compared both in time and frequency domain. By using these results, the position of a defect can be determined from vibration signals.

Keywords: Flexible Beams, Non-destructive Impact shock test, Vibration.

I. INTRODUCTION

Beams are very important construction element because of its widespread usage in steel construction and other machines. Also, it is important to know dynamic behaviour of defected beams. Therefore, this subject is studied by researchers since it is useful to identify defect locations and magnitudes.

In the work by Kam and Lee [1], the finite elements method has been used to determine the crack locations and magnitudes for a cantilever beam which has one crack. Natural frequency of the beam has been also determined and verified experimentaly.

For the two ends pinned beam with one crack, mathematical expressions were derived by [2] to examine the effect of the crack to the natural frequency of beam. This study was proved by experimentally. Chondros and Dimarogonas[3] made some experiments with an aluminium which is a cantilever beam with a crack. They proved that the experiments agree with the mathematical formulas.

Expressions for bending vibrations of an Euler-Bernoulli beam were determined by [4]. They studied the effects of the ratio of crack location to the length of the beam and also the ratio of the depth of the crack to the height of the beam. They examined the variation of the natural frequency of the beam.
There are several methods to determine the defects of the structures. The greatest success in the practical application of stress wave methods for flaw detection in material has been to use mechanical impact to generate the stress pulse. Impact produces a high energy pulse that can penetrate deep into material. The first successful applications of impact methods occurred in geotechnical engineering to evaluate the integrity of concrete piles and caissons [5]. The technique became known as the *sonic-echo* or *seismicecho* method. The impact response of thin concrete members, such as beam, composite, slabs and walls, is more complicated than that of long slender members. Work by Sansalone and Carino [6], however, led to the development of the *impact-echo method*, which has proven to be a powerful technique for flaw detection in relatively thin materials.

II. METHOD

Figure 1 [7], is a schematic of an impact-echo test on a plate with a large air void below the surface. The pulse consists of compression (P), shear (S) and Rayleigh (R) waves. P and S waves propagate into the object along spherical wavefronts. R wave propagates along the surface. These waves are reflected by internal defects and the boundaries and the reflected waves propagate back to the surface. At the top of surface, the waves are reflected again and they propagate into the test object. Thus, a transient resonance condition is set up by multiple reflections of waves between the top surface and internal flaws or external boundaries. A transducer which is located close to the impact point is used to monitor the surface displacements caused by arrival of these reflected waves. If the transducer is placed close to the impact point, the response is dominated by P-wave echoes [6]. The right hand side of Fig. 1 shows the pattern of surface displacements that would occur. The large downward displacement at the beginning of the waveform is caused by the R-wave, and the series of repeating downward displacements of lower amplitude are due to the arrival of the P-wave as it undergoes multiple reflections between the surface and the internal void. Critical material structures need to be evaluated during their service to ensure that they have not deteriorated. Ultrasonic and impact echo test methods are two important methods that are widely used for the non destructive examination of materials

[8,9].

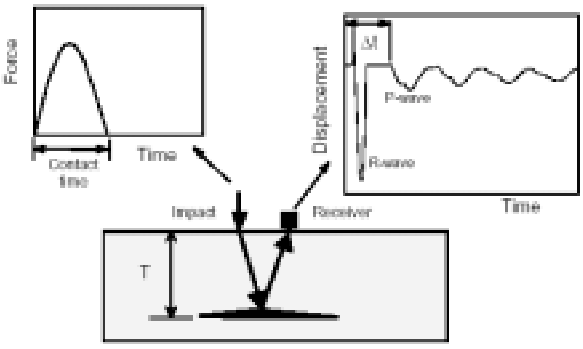

Figure 1. The impact-echo method

Testing of thick concrete structures using ultrasonic technique is often difficult due to heavy scattering and attenuaiton of the sound energy in the medium and the resultant poor signal–to–noise ratio of the reflected signal amplitudes. In addition, in thick structures, ultrasonic through transmission technique in suggested. This needs accesibility of both surfaces as well as proper alignment of both transducers, which is difficult, if not impossible. To overcome these limitations and to reliably examine the material structures, impact echo test was developed in the mid 1980s as a non-destructive test method [7]. Impact-echo tecnique involves introducing a transient stress pulse into a test object by mechanical impact and monitoring the surface displacements caused by the arrival of reflections of the pulse from internal defects and external boundaries. The proposed method has been tested for beams with cracks of varying sizes at different locations.

III. EXPERIMENTS

The aim of this study is to obtain information about the damage on the beams. For this purpose, the vibrations due to impact shock is inspected. In this study, a metal beam with a cross-sectional area of 29x4 mm^2 and a length of 500 mm is used. A metal ball is dropped on to the beam from a constant height in order to excite vibrations. When the metal ball dropped, some longitudinal and transverse vibrations are created in the beam.

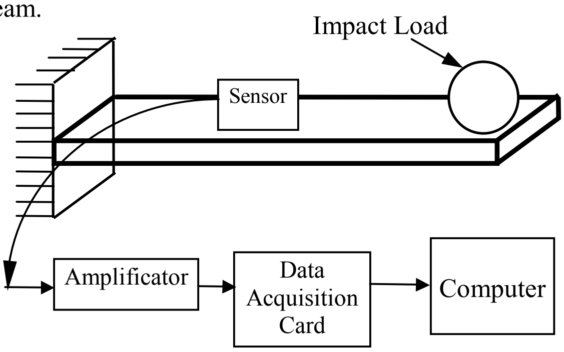

Figure 2. Bolck diagram of the test system

As is known that vertical vawes' vibrations are relatively more than from the horizontal waves' [10]. Therefore, in this study, vertical waves' vibrations are examined. Test mechanism is shown in Figure 2. The beam is clamped with left end (X=0) and right end is free. The vibration sensor (by Wilcoxon Research) is located at X=250 mm from the left end, Its voltage sensitivity is 104 mV/g and its rezonance frequency is 34 kHz. The 20.4 g metal ball is dropped to the beam at X=500 mm point from left end. The force applied to the system is determined from the Equation 1.

$$F(t)= \sqrt{km}\ V_0 \sin\left(\sqrt{k/m}\ t\right) \qquad (1)$$

When the metal ball hit the beam, vibration signals are amplified with an amplificator (by Wilcoxon Research). Its gain is constant and 10. The vibration signals are sampled with fs=100 KHz in a data acquisition card (by PC-LAB). They are transferred and recorded to the computer. All this operations take 165 miliseconds and 16384 data are recorded.

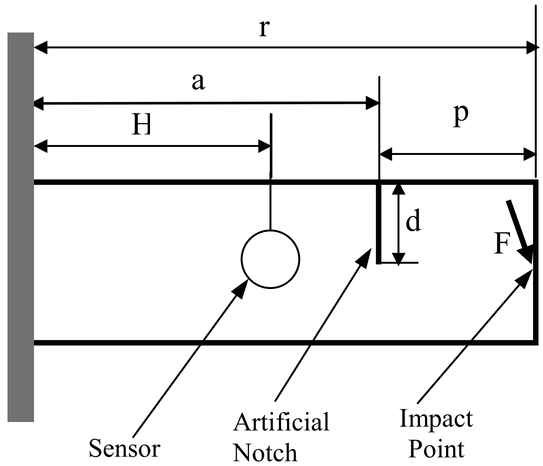

Figure 3. The beam with artificial notch

After these, a program is written in MATLAB to calculate fast fourier transform of the vibration signals. Test procedure is repeated for different beam made of same material and geometry, but with notch of varied position and size. The notches on the beam can be considered as the artificial defects.

In Figure 3, experimental setup is shown where H is location of the sensor, a is notch location, d is notch depth (same for all the beams), r is impact point from left end, r+p is the length of the beam. The location of notches are changed and the stiffness of the beam is calculated. Their values are given in Table 1.

Table 1. Stiffness of the beam for variable 'a'

a (mm)	**k (KN/m)**
400	111.25
300	104.91
200	96.08
100	85.01

As mentioned in [1,2, 3, 11, 12, 13], stiffnesses obtained by static analysis are decreased about defect regions. Also, an impact into these regions influences magnitude of the dynamic force and its frequency. In fact, it is more suitable to inspect the acceleration spectrum than the stiffnesses of the impact points for the measurement technique. Currently, the needed frequencies and magnitudes of systems are determined numerically by the measurement systems with microprocessors. Thus, we can learn if the structures are suitable for the standard or not.

For the experiments, the different defect locations (a is taken 165 mm, 335 mm, 375 and 415 mm from left end of the beam) are chosen to investigate effect of the defect location on modal properties of the beam when location of the sensor and impact point are 250 mm. The experiment is conducted under above conditions for healthy and defected beams, then natural frequencies and corresponding amplitudes are obtained for these beams. It can conclude that the location of the defect increases, the amplitude of high frequency vibration also increases but the amplitude of low frequency vibration decreases as shown in Table 2 and Figure 4.

Table 2. Measured frequencies and amplitudes
(d=400 mm, r=500 mm, H=250 mm)

a (mm)	f_1(Hz)	G_{max1}	f_2(Hz)	G_{max2}	f_3(Hz)	G_{max3}
Healthy Beam	94	1550	500	3619	1250	575
165	94	1273	506	4402	1250	175
335	100	1055	525	1803	1300	1750
375	108	897	537	2990	1338	1085
415	113	535	568	2188	1413	1090

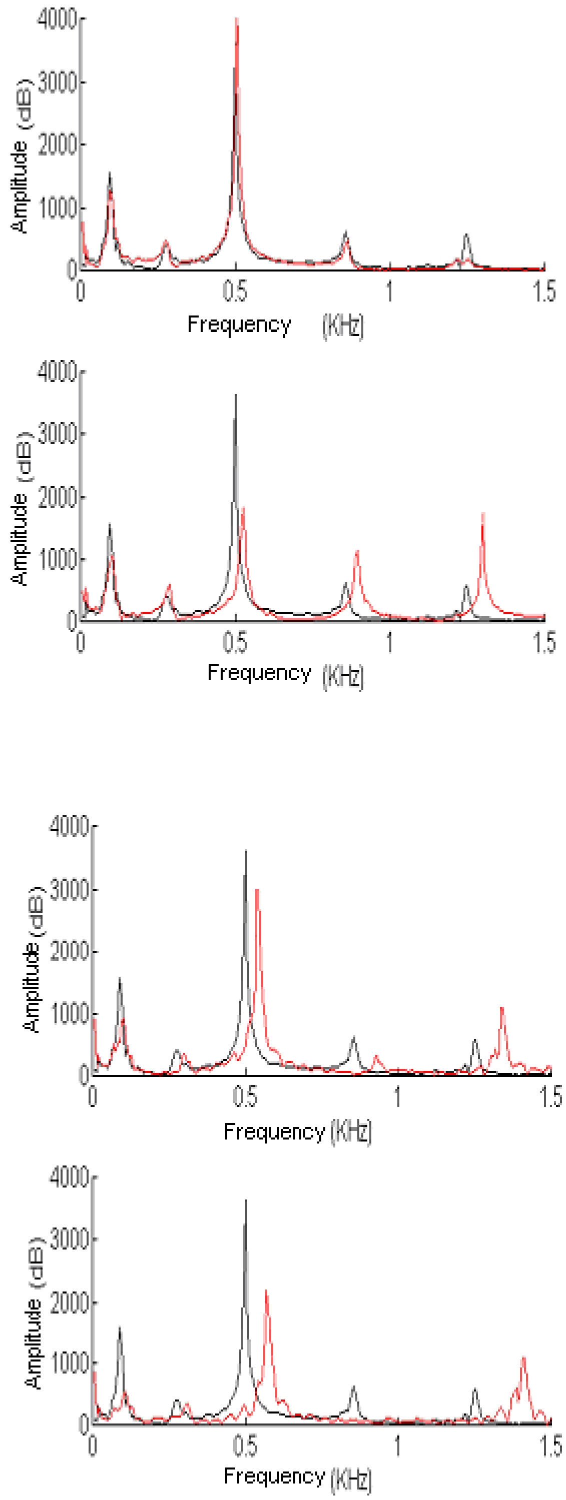

Figure 4. Fast Fourier Transform of the vibration signals for d=4mm, H=250mm, r=500mm a=165mm, 335mm, 375mm, 415mm, respectively.

In Figure 4, red colour represents the defected beam signals and the black colour represents the healthy beam.

IV. CONCLUSIONS

Test procedure is repeated for different beams made of same material and geometry, but with notch of varied location The signal obtained from the defective and non-defective beams are compared both in time and frequency domain. In the time domain, differences between defective and non-defective beams cannot be distinguished. However, in the frequency domain, the differences have some useful information about the defect.

Varying the location of the defect result in changes in natural frequencies and amplitude of vibration, namely, the location of the defect increases, the amplitude of high frequency vibration also increases but the amplitude of low frequency vibration decreases. By using these results, the location of a defect can be determined from vibration signals.

If the defects are large and located about the impact point, they are easy to identify. If the defect locations are far from the impact point, the structure must be searched with variable impact points.

Results of the beam examined in this study confirmed the theorical outcomes related to the stiffnesses coefficient. Defect detection tecnique is realised by impact echo method experimentaly. For the complex structures, the finite element method can be used to find suitable impact points. Impact echo method can be developed using artificial neural network algorithm. Since the impact echo method is applied to the computerized measurement systems, even complex structures are modelled by CAD software programme. Their suitable impact points are selected by computer. Thus, defect detection is made easily and economically.

REFERENCES

1. Kam, T. Y. and Lee, T. Y. "Detection of Cracks in Structures Using Modal Test Data", *Engineering Fracture Mechanics*, Vol.42, No.2, pp. 381-387, 1992

2. Chondros, T. G., Dimarogonas, A. D., Yao, T. "Vibration of a Beam with a Breathing Crack", *Journal of Sound and Vibration*, (2001), 239(1), 57-67

3. Chondros, T. G., Dimarogonas, A. D. "Vibration of a Cracked Cantilever Beam", *Journal of Vibration and Acoustics*, Vol.120, pp. 742-746, July 1998

4. Matveev, V.V. and Bovsunovsky, A. P. "Vibration-Based Diagnostics of Fatigue Damage of Beam-Like Structures", *Journal of Sound and Vibration*, (2002), 249(1), 23-40

5. Steinbach, J. and Vey, E., 1975, "Caisson Evaluation by Stress Wave Propagation Method", *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 101, GT4, April, pp. 361-378.

6. Sansalone, M., and Carino, N.J., 1986, "Impact-Echo: A Method for Flaw Detection in Concrete Using Transient Stress Waves", *NBSIR 86-3452*, National Bureau of Standards, Sept., 222 p.

7. Sansalone, M., Impact Echo: The Complete Story, ACI Struct J., 94(6), pp:777-786, 1997.

8. Kumar, A., Thavasimuthu , P., Kalyanasundaram, P., Raj, B., Structural Integrity Assesment of Ring Beam of a Pressurized Heavy Water Nuclear Reactorusing Impact Echo Technique, CD-ROM, Proceedings of 15th World Conference on NDT, Roma, 2000.

9. Kumar, A., Jayakumar T., Subramanian, C.V., Thavasimuthu, M., Testing of Concrete Structures for Determination of Strength and Detection of Flaws Using Low Frequency Ultrasonic and Impact Echo Techniques, J. Non-Dest. Eval., 19(2), pp:43-46, 1999.

10. Sansalone M., Nicholas J.C.,Nelson N.H., A Finite Element Study Of Transient Wave Propagation in Plates, National Bureau Standarts Gaithersburg, 92, 267- 287, 1987.

11. Chati M., Rand R ve Mukherjee, S. "Modal Analysis of a Cracked Beam", *Journal of Sound and Vibration*, (1997), 207(2), 249-270

12. Rizos, P. F., Aspragathos and Dimarogonas A. D. "Identification of Crack Location and Magnitude in a Cantilever Beam From the Vibration Modes", *Journal of Sound and Vibration*, (1990), 138(3), 381-388

13. Ratcliffe C. P. "Damage Detection Using a Modified Laplacian Operator on Mode Shape Data", *Journal of Sound and Vibration*, (1997), 204(3), 505-517