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DETECTION OF DEFECTS IN A CANTILEVER BEAM USING MODAL TEST DATA

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ABSTRACT

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

Key Words : Cracked Beams, Impact shock test, Crack detection, Vibration

DOĞAL FREKANS VERİLERİ KULLANILARAK ANKASTRE BİR KİRİŞTE HASARLARIN BELİRLENMESİ

ÖZET

Bu çalışmanın amacı çatlaklı kirişlerde hasar yeri ve derinliği hakkında bilgi edinmektir. Bu amaçla kirişte darbe vuruşu sonucu oluşan titreşimler incelenmiştir. Hasarlı ve hasarsız kirişlerden elde edilen sinyal hem zaman hem de frekans ortamında karşılaştırılmıştır. Bu sonuçlar kullanılarak bir hasarın yeri ve derinliği titreşim sinyallerinden belirlenebilir.

Anahtar Kelimeler : Çatlaklı kirişler, Darbe vuruş testi, Çatlak tespiti, Titreşim

1. INTRODUCTION

Beams are very important construction element because of its widespread usage in steel construction and other machines. Cracks form due to cycling loads leading to fatigue of the structure and discontinuity in interior configuration. Cracks present in vibrating components could lead to catastrophic failure. For this reason there is a need to understand the dynamics of cracked structures (Chati et al., 1997). When a structure suffers damage, its dynamic properties can change. Specially, crack damage can cause a stiffness reduction, with an inherent reduction in natural frequencies, an increase in modal damping, and a change to the mode shapes (Ratcliffe, 1997). From these changes the crack position and magnitude can be identified. Since the reduction in natural frequencies can be easily observed, most of the researchers use this feature. In the work by (Kam and Lee, 1992), 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 experimentally. For the two ends pinned beam with one crack, mathematical expressions were derived by (Chondros et al., 2001) to examine the effect of the crack to the natural frequency of beam. This study was proved by experimentally. (Chondros and Dimarogonas, 1998) 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 (Matveev and Bovsunovsky, 2002). 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 investigated the variation of the natural frequency of the beam. (Rizos et al., 1990) developed a method based on the amplitudes at two points in a structure vibrating at one of its natural frequencies and an analytical solution of the dynamic response. (Springer et al.) used variations in natural frequency to identify damage in members that can be modelled as longitudinally vibrating beams. (Shen and Chu, 1992) investigated the existence of fatigue cracks by exciting the structures at different frequencies and using a numerical study for the response analysis. (Chondros et al., 1998) developed a continuous cracked beam vibration theory for the lateral vibration of cracked Euler-Bernoulli beams with single or double edge cracks. This continious cracked beam vibration theory is used for the prediction of the dynamic response of a simply supported beam with open surface cracks. In this study, dynamical behaviour of the an edge cracked cantilever beam is analysed. Effect of crack location and depth on the modal properties of the beam experimentally investigated to identify the location and depth of the crack. The impact-echo method was used to excite natural frequencies of the beam

2. METHOD

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 (Steinbach and Vey, 1975). The technique became known as the *sonic-echo* or *seismic echo* 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, 1986), 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. Figure 1 (Sansalone, 1997), 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 (Sansalone and Carino, 1986). The right hand side of Figure 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 and are free from important methods that are widely used for the non-destructive examination of materials defects. Ultrasonic and impact echo test methods are two important methods that are widely used for the non destructive examination of materials (Kumar et al., 1999; 2000).

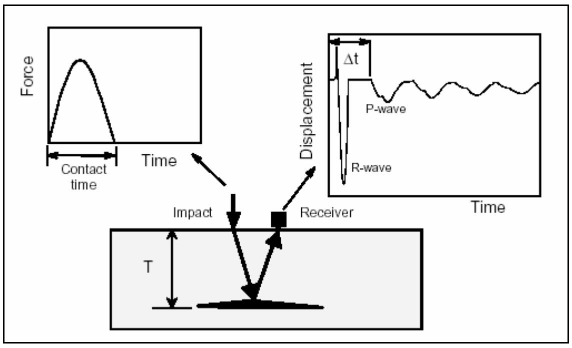

Figure 1. The impact-echo method

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

(Sansalone, 1997). 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.

3. 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 are inspected. In this study, a metal beam with a cross-sectional area of 29 x 4 mm^2 and a length of 500 mm is used. A metal ball is dropped onto 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.

As is known that transverse vawes' vibrations are relatively more than from the longitudinal waves' (Sansalone et al., 1987). Therefore, in this study, transverse waves' vibrations are examined. Test mechanism is shown in Figure 2. The beam is clamped with left end (X = 0) and the right end is free. The vibration sensor (by Wilcoxon Research) is attached to X = 250 mm from the left end, Its voltage sensitivity is 104 mV/g and its resonance frequency is 34 kHz. The 20.4 g metal ball is dropped onto the free end of the beam. 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.

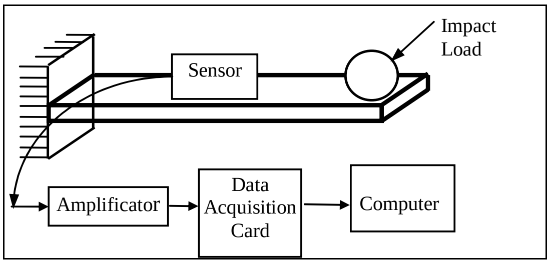

Figure 2. Block diagram of the test system

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. Experimental setup is shown in Figure 3, 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. The location of notches are varied and the stiffness of the beam is calculated. Their values are given in Table 1.

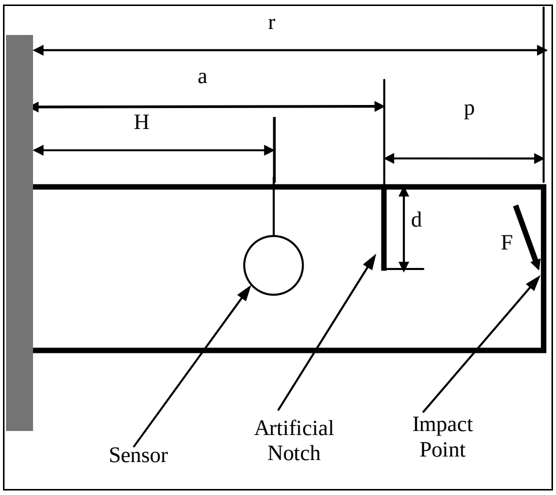

Figure 3. The beam with artificial notch

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 (Kam and Lee, 1992, Chondros and Dimarogonas, 1998, Chondros et al., 1998; 2001), stiffnesses obtained by static analysis were decreased about defect points. Also, an impact onto these points influenced magnitude of the dynamic force and its frequency. In fact, it was 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 were determined numerically by the measurement systems with microprocessors. Thus, we can learn if the structures were suitable for the standard or not.

Firstly, the defect depth is varied from 4mm to 12 mm by step 4 to estimate effect of the defect depth on modal properties of the beam, when location of the sensor, the defect, impact point are 250 mm, 375mm and 500 mm respectively. 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 depth of the defect increases, the amplitude of vibration also increases as shown in Table 2, Table 3 and Figure 4.

Table 2. The First and Second Natural Frequencies and Corresponding Amplitudes of Healthy and Defected Beams for Defect Depth 4 mm, 8 mm, and 12 mm When a=375 mm, r=500mm and H=250 mm

	f_1 (Hz)	Ampl. (dB)	f_2 (Hz)	Ampl. (dB)
The healthy beam	94	1550	500	3619
Defect depth of (4 mm)	108	897	537	2990
(8 mm)	107	913	537	3147
(12 mm)	106	1300	532	4592

Table 3. The Third Natural Frequency and Corresponding Amplitude of Healthy and Defected Beams for Defect Depth 4 mm, 8 mm, and 12 mm When a = 375 mm, r = 500 mm and H = 250 mm

	f_3 (Hz)	Ampl. (dB)
The healthy beam	1250	575
Defect depth of (4 mm)	1338	1085
(8 mm)	1325	1478
(12 mm)	1331	1884

In Figure 4 and 5, red colour represents the defected beam signals and the black colour represents the healthy beam signals.

In same manner, the different defect locations (165 mm, 335 mm 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, 375 mm respectively. 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 4 and Figure 5.

Table 4. The first and Second Natural Frequencies and Corresponding Amplitudes of Healthy and Defected Beams for Defect Locations 165 mm, 335 mm and 415 mm when d = 4 mm, r = 375 mm and H = 250 mm.

a (mm)	f_1 (Hz)	Ampl. (dB)	f_2 (Hz)	Ampl. (dB)
The healthy beam	518	1750	1288	1800
165	508	3060	1256	1600
335	525	1520	1306	2940
415	568	1230	1413	2950

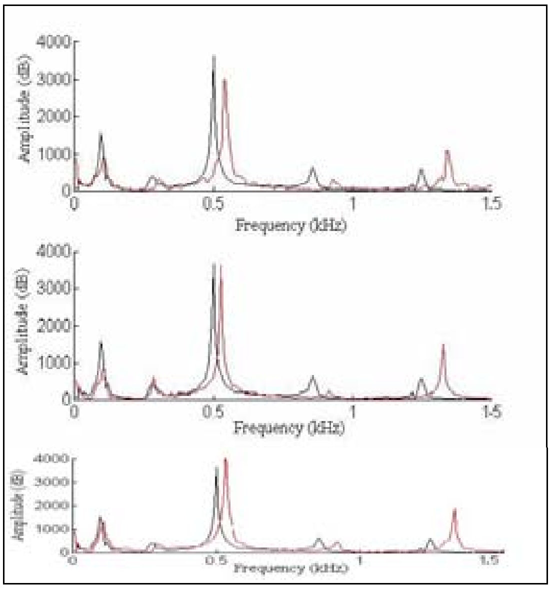

Figure 4. Fast Fourier Transform of the vibration signals for d = 4 mm, 8 mm, 12 mm and H = 250 mm, r = 500 mm, a = 375mm.

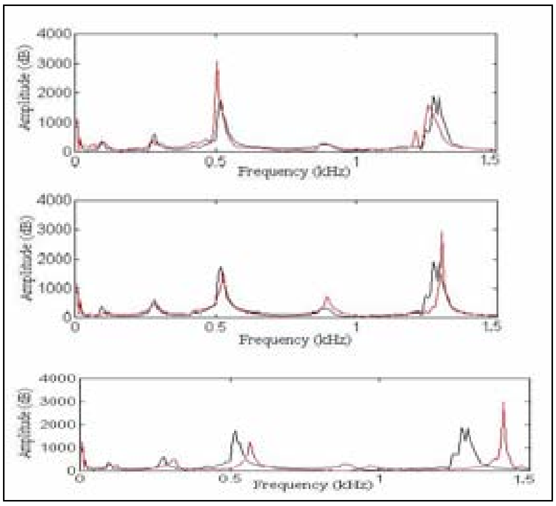

Figure 5. Fast Fourier Transform of the vibration signals for a = 165 mm, 335 mm, 415 mm and H = 250 mm, r = 375 mm, d = 4mm

4. CONCLUSION

Test procedure was repeated for different beams made of same material and geometry, but with notch of varied position and depth. The signal obtained from the defective and non-defective beams were 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 position of the notch result in changes in natural frequencies and amplitude of vibration. It is shown that the depth of the defect increases, the amplitude of vibration also increases. When 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 and depth of a defect can be determined from vibration signals.

If the defects were large and located about the impact point, they were easy to identify. If the defect locations were 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 was realised by impact echo method experimentally. 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 was applied to the computerized measurement systems, even complex structures were modelled by CAD software programme. Their suitable impact points were selected by computer. Thus, defect detection was made easily and economically.

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