2014 International Conference on Geological and Civil Engineering
IPCBEE vol.62 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V62. 3

Experimental Test for the Detection of Damage to a Concrete Beam

Saidi abdelkrim [1 +], Hamouine abdelmadjid [1] and Abdellatif megnounif [2]

[1]FIMAS Laboratory, University of Bechar, Po. Box 417 Bechar, Algeria

[2] Department of Civil Engineering, University of Abu Bakr Belkaid , Tlemcen, Algeria

Abstract. The using vibration analysis for early detection of cracks has gained popularity over the years and in the last decade substantial progress has been made in that direction. Dynamic characteristics of damaged and undamaged materials are very different. For this reason, material faults can be detected. The objective of this study is to analyze the vibration behavior of concrete beams both experimentally and using FEM software ANSYS subjected to the crack under free vibration cases. Besides this, information about the location and depth of cracks in cracked concrete beams can be obtained using this technique.

Keywords: Vibration, concrete beam, crack detection.

1. Introduction

The dynamic properties of a structure can be determined by FEM modal-simulations (Finite Element Method), or by experimental modal analysis. Dynamic characteristics of damaged and undamaged materials are very different. For this reason, material faults can be detected, especially in beams. Crack formation due to cycling loads leads to fatigue of the structure and to discontinuities in the interior configuration. Cracks in vibrating components can initiate catastrophic failures. Therefore, there is a need to understand the dynamics of cracked structures [1]. When a structure suffers from damage, its dynamic properties can change. Specifically, crack damage can cause a stiffness reduction, with an inherent reduction in natural frequencies, an increase in modal damping, and a change in the mode shapes [2]. From these changes the crack position and magnitude can be identified. Since the reduction in natural frequencies can be easily observed, most researchers use this feature. In the work by Kam and Lee [3], the finite elements method has been used to determine the crack locations and magnitudes for a cantilever beam with only one crack. Natural frequency of the beam has also been determined and verified experimentally. For the beam with one crack and pinned at the two ends, mathematical expressions were derived by [4] to examine the effect of the crack to the natural frequency of beams. Chondros and Dimarogonas [5] conducted a number of experiments with an aluminum cantilever beam with a crack. They proved that the experiments agree with the mathematical formulae. Expressions for bending vibrations of an Euler Bernoulli beam were derived by [6]. 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. [7] 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. [8] used variations in natural frequency to identify damage in members that can be modeled as longitudinally vibrating beams. Shen and Chu [9] 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. [10] developed a continuous cracked beam vibration theory for the lateral vibration of cracked Euler–Bernoulli beams with single or double edge cracks.

[+] Corresponding author. Tel.: + 213661152313; fax: +21349810157.
E-mail address: saidikarim2008@yahoo.fr.

This continuous 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 behavior of an edge cracked concrete beam was analyzed. Effects of crack location and depth on the modal properties of the beam were experimentally investigated to identify the location and depth of the crack. The method was used to excite natural frequencies of the beam. Additionally, in order to verify the experiments, a beam was modeled using ANSYS software.

2. Experimental Work

The occurrence of damage modifies the vibration characteristics of undamaged structures, such as natural frequencies, mode shape, and modal damping ratios. The characteristics of the undamaged structures are often referred to as baselines in damage detection, which can be identified with modal tests. In comparison with the baselines, any deviation of the structural parameters measured during the service life reflects possible damage and may be used to identify the severity and location of damage. Among various parameters, the natural frequency has been widely used as an indicator of damage occurring in a structure since it can be simply identified from modal tests with sufficient accuracy. If damage occurs in a structure, stiffness degradation takes place and the natural frequencies of the structure reduce accordingly.

The Frequency Analysis Based on the Fast Former Transform (FFT) Algorithm is the tool of choice for measurement and diagnostic of vibration. The FFT Analyzer is recently developed pc based virtual instrument. It uses impulse execution & either frequency domain analysis or time domain analysis to entrant the model Parameter from the response measurement in real time. Following impulse are execution of the specimen , the measured analog response signal maybe digitalized & analyzed using the domain techniques or transformed for analysis in the frequency domain using FFT Analyzer. The peaks in the frequency response spectrum are the location of natural frequency. The determination of frequency with the help of PULSE software requires the determination of following six identical concrete beams were cast and tested in laboratory. They are 50 cm long, and have a cross section of 10cm wide and 10cm deep. The concrete material used has a compressive strength of 26.4 MPa. The concrete beams are respectively cracked with crack 2, 4 cm and in the different crack locations 10, 20, 25 cm. The modulus of elasticity is 33.8 Gpa. We made The connections accelerometer.2, modal hammer Fig. 3, and Bruel and kjaer pulse analyzer system type – 3560 Fig. 4. The surface of the concrete beam was cleaned for proper contact with the accelerometer. Readings were taken for free-free boundary conditions for different concrete beams. The modal analysis results are compared with FEM package ANSYS and analytical values.

2.1. Accelerometer

Deltatron accelerometer combines high sensitivity Fig. 2, low and small physical dimensions making them ideally suited for model analysis. Easily fitted to different test objects using a selection of mounting clips.

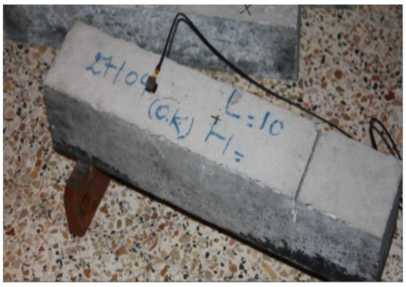

Fig. 1: Concrete beam

Fig. 2: Accelerometer

2.2. Model hammer

The model hammer exits the structure with a constant force over a frequency range of interest. Three interchange tips are provided which determine the width of the input pulse and thus the band width the hammer structure is acceleration compensated to avoid glitches in the spectrum due to hammer structure resonance.

Fig. 3: The modal hammer.

Fig. 4: Analyzer system type 3560

2.3. FFT Analyser-type(3560C)

Bruel and kjaer pulse analyzer system type – 3560. The software analysis was used to measure the frequency ranges to which the foundation various machines are subjected to when the machine is running with no load and full load. This will help us in designing the foundations of various machines on such a way that they are able to resist the vibration caused in them.

We made the connections accelerometer, modal hammer, and Bruel and kjaer pulse analyzer system type – 3560 Fig. 4. The surface of the concrete beam was cleaned for proper contact with the accelerometer. Readings were taken for free-free and fixed-free boundary conditions for different concrete beams. The modal analysis results are compared with FEM package ANSYS and analytical values.

3. Experimental Results and Analysis

In the experiment, firstly, the crack depth was varied from 20 to 40 mm to estimate effects of the crack depth on modal properties of the beam, when locations of the sensor, the crack is at 100, 200 and 250 mm, respectively. The experiment was conducted under above conditions for intact and cracked beams, and then natural frequencies and corresponding amplitudes were obtained for these beams. When we hit the beam with the model hammer, vibration signals were recorded by the computer. Then, a program PULSE used to calculate Fast Fourier Transform of the vibration signals. Test procedure was repeated for different beams made of same material and geometry, but with crack of varied locations and depths. The cracks on the beam can be considered as the artificial defects. The experimental setup is shown like Fig. 1.

From the experimental results, it was shown that as the depth of the crack increases, the natural frequencies decreases as illustrated in Fig. 5, and Fig. 6 and tabulated in Table 1.

In Fig. 7, dashed lines represent the cracked beam signals, while the solid lines represent the intact beam signals. In the same manner, the different crack locations (100, 200 and 250 mm from left end of the beam) were chosen to investigate effects of the crack location on modal properties of the beam when location of the sensor and point of the excitation using the modal hammer. From the experimental results, it can be concluded that while the location of the crack increases, the natural frequencies decreases tabulated in Table 2.

Table 1: The natural frequencies of the cracked beam with the depth of 20 mm

Frequency	intact	100 mm	200 mm	250 mm
(1)experiment ANSYS	2.888 2.539	2.752 2.513	2.048 1.901	2.048 1.987
(2)experiment ANSYS	3.328 3.302	3.200 3.135	3.136 3.150	3.108 3.143
(3)experiment ANSYS	4.672 4.724	4.688 4.084	4.544 4.313	4.325 4.295
(4)experiment ANSYS	5.568 5.676	5.056 5.140	5.184 5.337	5.092 5.252

Table 2: The natural frequencies of the cracked beam location of 200 mm

Frequency	intact	20 mm	40 mm
(1)experiment ANSYS	2.888 2.539	2.176 1.988	2.048 1.901
(2)experiment ANSYS	3.328 3.302	3.264 3.179	3.136 3.150
(3)experiment ANSYS	4.672 4.724	4.608 4.345	4.544 4.313
(4)experiment ANSYS	5.568 5.676	5.504 5.409	5.184 5.337

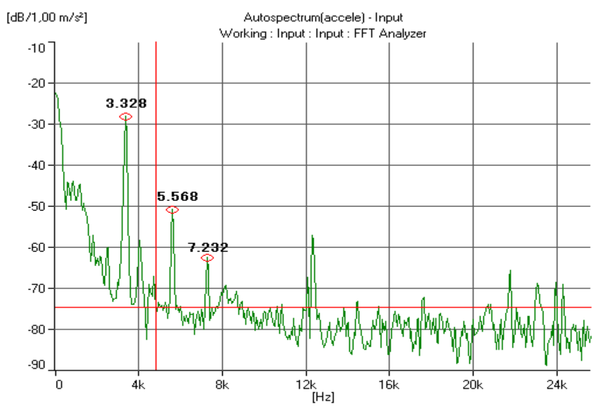

Fig. 5: Frequency of the no cracked beam.

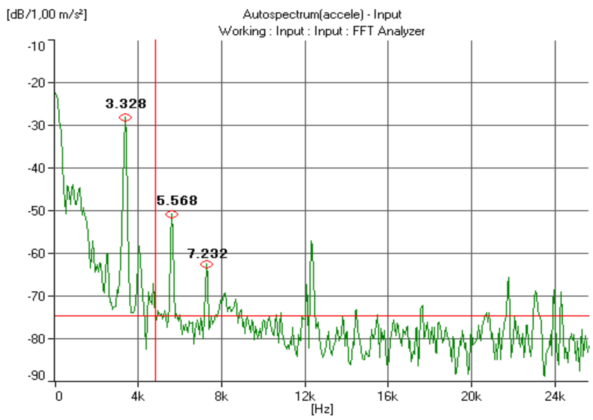

Fig. 6: Frequency of the cracked beam with 20mm depth at 200mm.

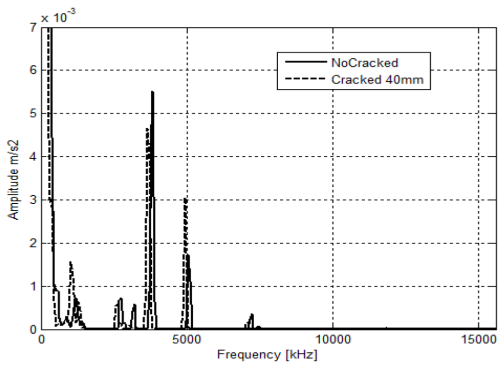

Fig. 7: Comparison of natural frequencies between the cracked and intact concrete beam.

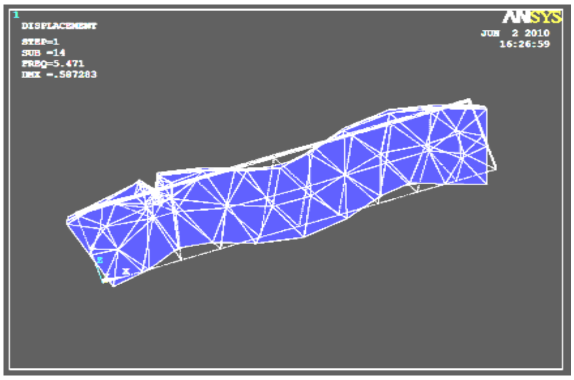

Fig. 8: Finite element modelling of the cracked beam.

ANSYS finite element program was used to generate natural frequencies of the intact and 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, in the end, this area was extruded and three-dimensional V shaped edge cracked beam model was obtained as shown in Fig. 8. The crack width is 20 mm on the top surface of the beam and crack goes through the depth of the beam. Fig. 8 shows the finite element mesh model of the beam. Subspace mode extraction method was used to calculate the natural frequencies of the beam. Ten modes were selected to extract and first ten natural frequencies were calculated for intact and cracked beams. One natural frequency was obtained by averaging of the ten frequencies so as to get more sensitive results. Table 1 and Table 2 show natural frequencies of the cracked beam obtained from experimental and finite element analyses.

4. Conclusion

In this study, dynamic analyses based on analysis of the cracked concrete beam were experimentally evaluated and a finite element model of the cracked beams was constructed to verify the experimental results. Our finite element model was only capable of calculating the natural frequencies of the cracked beams, not amplitudes, since the analysis focuses on free vibration (modal) analysis. In the experimental part of this study, the effect of crack depth and location on modal properties of the beam was investigated. For this purpose, the natural frequencies excited by a model hammer and the response of the beam were measured by an accelerometer. In order to investigate effects of varying crack depths, the cracks were taken 200 mm away from the left end of the beam and the depth of the cracks was taken 20, 40 mm, respectively. Therefore, three damage scenarios were considered for the analyses. Also, for examining the effect of varying crack locations, the cracks were located at 100, 200, and 250 mm, respectively from left end with 4 mm constant depth. Hence, three more damage scenarios were added. For both cases, it holds true that varying the location and depth of the cracks results in changes in natural frequencies and amplitudes of vibration. Additionally, the following conclusions can be from the analyses: When the location of the crack increases starting from the clamped end of the beam, natural frequencies of the beam and the amplitude of high frequency vibration also increase, but the amplitude of low frequency vibration decreases. It was shown that as the depth of the crack increases, the amplitude of vibration also increases at high frequencies but the natural frequencies decrease as expected. This is true because of the stiffness reducing is inversely proportional to the depth of a crack.

5. References

[1] Chati M, Rand R, Mukherjee S. Modal analysis of a cracked beam. *Sound Vib* 1997; 207(2):249–70.

[2] Ratcliffe CP. Damage detection using a modified laplacian operator on mode shape data. *J Sound Vib* 1997; 204(3): 505–17.

[3] Ratcliffe CP. Damage detection using a modified laplacian operator on shape data. *J Sound Vib* 1997;204(3): 505–17

[4] Kam TY, Lee TY. Detection of cracks in structures using modal test data. *Eng Fract Mech* 1992; 42(2):381–7.

[5] Chondros TG, Dimarogonas AD, Yao T. Vibration of a beam with a breathing crack. *J Sound Vib* 2001; 239(1): 57–67.

[6] Chondros TG, Dimarogonas AD. Vibration of a cracked cantilever beam. *J Vib Acoust* 1998; 120:742–6.

[7] Matveev VV, Bovsunovsky AP. Vibration-based diagnostics of fatigue damage of beam-like structures. *J Sound Vib* 2002; 249(1): 23–40.

[8] Rizos PF, Aspragathos AD, Dimarogonas AD. Identification of crack location and magnitude in a cantilever beam from the vibration modes. *J Sound Vib* 1990; 138(3):381–8.

[9] Springer WT, Lawrence KL, Lawley TJ, Damage assesment based on the structural frequency-response function, *Exp Mech* 1988; 28: 34–7.

[10] Shen MH, Chu YC. Vibrations of beams with a fatigue crack. *Comput Struct* 1992; 45: 79–93.