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Possibility of Finding The Fundamental Frequency of Concrete Specimen by using Multi-Impact Loading

Rikki Vitria[1], Hilmi Sanusi[1], Roszilah Hamid[2]

[1] *Department of Electrical, Electronic and System Engineering, National University of Malaysia*
Bangi, Selangor 43600, Malaysia
E-mail:rikkvi@gmail.com, hilmisanusi@vlsi.eng.ukm.my

[2]*Department of Civil and Structure Engineering, National University of Malaysia*
Bangi, Selangor 43600, Malaysia
E-mail:roszilah@vlsi.eng.ukm.my

***Abstract*— Possibility of finding the fundamental frequency of concrete specimen by using multi-impact loading is presented in this paper. Solenoid acts as an impact generator to generate pulse trigger for the multi-impact loading. An accelerometer, ADXL330 from Analog Device detects the vibration signal resulted from the impact loading. Observation from the accelerometer output shows oscillatory signal once the concrete specimen receives a single impact. However, if the applied impact is repeated periodically or called multi-impact loading, the fundamental and harmonic will add up and constitute a pulse in the frequency domain. Duality property in Fourier theorem states that a pulse in frequency domain is a sine wave in time domain and vice versa. Each impact received by the concrete produces a vibration that comprises of fundamental and harmonic frequency The signals are analyzed using a Fast Fourier Transform (FFT) toolbox in Matlab®. The results from the study provide valuable information for a better understanding to indicate the defect in the concrete.**

***Keywords*— Fundamental frequency, Multi-impact loading, solenoid, accelerometer, Fast fourier transform**

I. INTRODUCTION

Most of infrastructural facilities such as road foundations, barriers, dams, and others are constructed with concrete materials. Some of these concrete structures are subjected to vibration forces such as impact loading or dynamic shock of moving vehicles and earthquake. Depending on structural type and dynamic load applied, the induced vibration in a given structure varies in amplitude and in frequencies with excitation source. These phenomenons may cause concrete structures to fail. There is no doubt that dynamic property of concrete material such as dynamic modulus elasticity and natural frequency are of importance to these structures analysis and design. Dynamic modulus is a characteristic of the dynamic response of the material, and natural frequency is a characteristic associated with the material and structure system [1].

A method to determine defect and anomaly in concrete, the impact-echo method, is used through generating a high-energy stress pulse. Surface displacements were measured near the impact point. The stress pulse undergoes multiple reflections between the test surface and the reflecting interface, and results in a periodic surface motion. This permits frequency analysis of the recorded surface displacement waveforms. The dominant frequency in the amplitude spectrum is used to determine the depth of the reflecting interface from the known wave speed [2]. Another method of detecting cracks in concrete pillars is by using an acceleration pickup a shock is given on the pillar with a hammer. Several types of stationary waves generated in the pillar are observed with the sensor on an edge of the pillar. The method identifies the location of the cracks by modeling the sensor output as an output of a linear dynamic system with unknown parameters and applying a Kalman filter and the maximum likelihood method [3].

Based on the previous studies, researchers have used a single pulse impact loading to excite the concrete. In this study however, a novel approach of applying multi-impact loading onto concrete specimen is investigated. Initial result shows that the output behaves differently compared to single impact. A Fourier theorem is used to analyze the output signal from the accelerometer to find fundamental frequency of concrete.

II. MATERIAL AND METHODS

In the study, the specimen are three kind of concrete cube, 15 cm × 15 cm × 15 cm. they are normal concrete (NC), cracked concrete (CC) and hollow concrete (HC). An impact loading mechanism is attached on one side and an accelerometer sensor to detect the vibration is on the other side. The specimen is hanged in order to let the specimen to vibrate freely. Three-axis accelerometer from Analog Devices, ADXL330, is able to detect static and dynamic acceleration. The ADXL330 is capable to detect vibration from 0.5Hz to 1600Hz in X and Y axis and 0.5Hz to 550Hz in Z axis. The ADXL330 which has a minimum full-scale range of ±3 g is fabricated in a small, thin, low power with signal conditioned voltage outputs, all on a single monolithic IC. Even though the highest sensitivity frequency is 1600Hz [4], the sensor is still beneficial if the impact loading frequency is low.

A solenoid connected to a power amplifier is used to generate multi-impact loading to the concrete. The mechanism is attached to the concrete so that it has the same reference. A frequency generator produces the pulse trigger needed to activate the solenoid with a known frequency. Due to high impact needed to produce impact loading, a huge solenoid is used, which in turn reduce the impact loading frequency. Further improvement will use a smaller solenoid with higher current capability and a Neodymium magnet attached to the hammer to increase the impact force

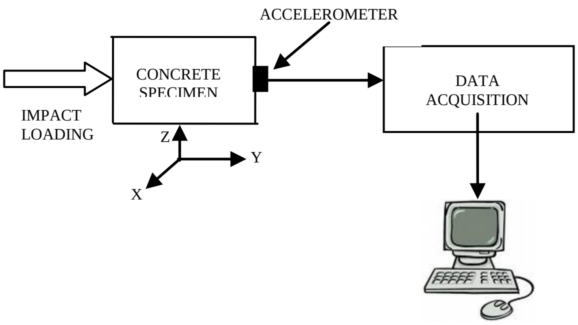

Fig. 1 Schematic set up of the multi-impact loading

The experiment set up is shown as in Fig. 1. The output signal from the accelerometer is connected to a data acquisition device. It is assumed that the vibration in Z axis is very low compared to X and Y axis, thus, only those axes are connected to the data acquisition device. The sensor data is sent to a personal computer through USB cable for analysis. Both single impact and multi-impact loading are analyzed. Comparing both effects from the loading indicates the possibility of using the multi-impact loading to determine defect in the concrete structure

III. RESULTS AND DISCUSSION

Fig. 2 shows oscillatory signal from the output signal from the X axis of the accelerometer due to a single impact loading. The axis is selected because of the vibration in X axis is the most dominant as it is in the same direction as the impact. The captured signal is actually an impulse response of the concrete specimen.

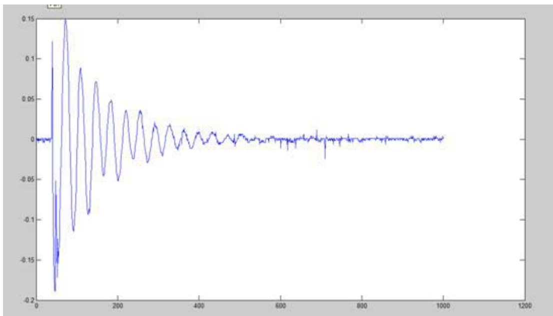

Fig. 2 Output signal of accelerometer in X axis when single impact is given

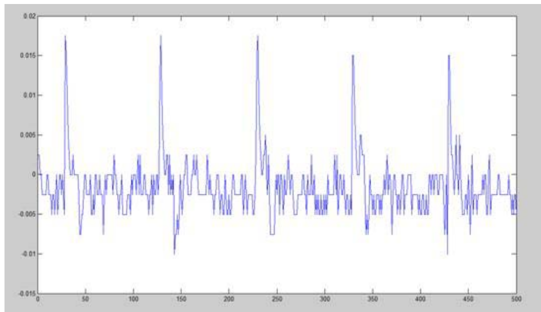

Fig. 3 Output signal of accelerometer in X axis when multi-impact is given on normal concrete

As the impact frequency increases, the effect adds up and creating a stream of impulses as seen in Figure 3. This stream of impulses is a cumulative of fundamental and harmonic frequencies produced by a single impact as the frequency from the impact increases. The transfer function of the concrete specimen can be obtained by taking a Fourier transform of the impulse response as:

$$\Im\{\delta(t)\} = 1 \tag{1}$$

And

$$H(j\omega) = \Im\{h(t)\} \tag{2}$$

$$y(t) = h(t) * u(t) \tag{3}$$

Where

$y(t)$ is the output response

$h(t)$ is the impulse response

$u(t)$ is the input

When the input applied to the system is an impulse, the response of the system is simply

$$y(t) = h(t) \tag{4}$$

Or similarly

$$y(j\omega) = h(jw) \tag{5}$$

Where $H(j\omega)$ is the transfer function of the concrete sample.

Since the fundamental frequency is unknown, the impulse response must be sampled at very high frequency in order to obtain the high definition of Fourier Transform. However, if the applied impact is repeated periodically, the fundamental and harmonic will add up and constitute a pulse in the frequency domain. Duality property in Fourier theorem states that a pulse in frequency domain is a sine wave in time domain and vice versa. Each impact received by the concrete produces a vibration that comprises of fundamental and harmonic frequency. The accumulation of fundamental and harmonic frequency from the response of the concrete produces a stream of pulse as described by the Fourier series [4].

$$a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t)\cos(nt)\,dt, n \geq 0 \tag{6}$$

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(t)\sin(nt)\,dt, n \geq 1 \tag{7}$$

$$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n\cos(\mathrm{nx}) + b_n\sin(\mathrm{nx})) \tag{8}$$

This result indicates the possibility of finding the fundamental frequency of the concrete specimen. The fundamental frequency of the concrete structure depends on the shape, size, material and reinforcement. If there is a crack in the structure, the fundamental frequency is definitely changed to a higher frequency, it is seen in fig. 4 and fig. 5.

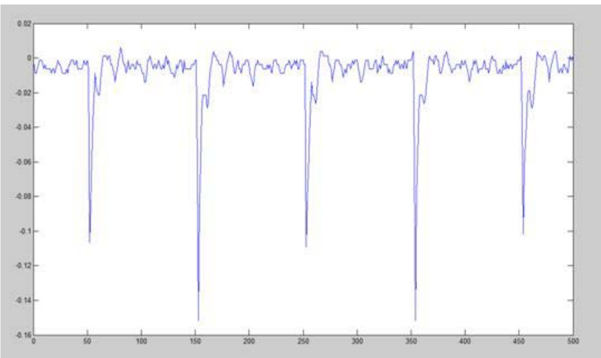

Fig. 4 Output signal of accelerometer in X axis when multi-impact is given on cracked concrete

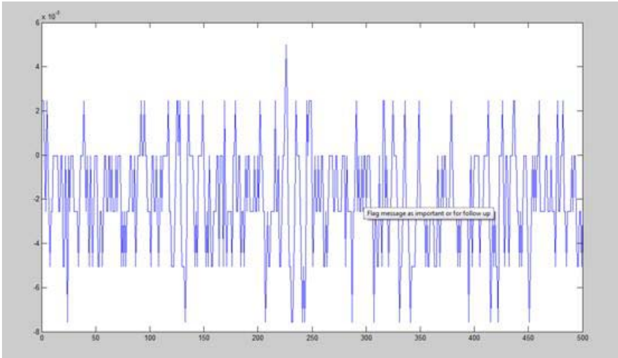

Fig. 5 Output signal of accelerometer in X axis when multi-impact is given on hollow concrete

IV. CONCLUSIONS

When concrete specimen receives a single impact, the accelerometer output shows oscillatory signal. Whereas as the impact frequency increases, when multi-impact is applied, the effect adds up and creating a stream of impulses as seen. This stream of impulses is a cumulative of fundamental and harmonic frequencies produced by a single impact as the frequency from the impact increases. This result indicates the possibility of finding the fundamental frequency of concrete specimen. The fundamental frequency of the concrete structure depends on the shape, material and reinforcement. If there is a crack in the structure, the fundamental frequency is definitely changed to a higher frequency

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