Thickness Estimation and Crack detection in Concrete using Impact-echo Technique

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Abstract - *This paper discusses the applicability of using impact echo technique for estimation of thickness and detection of flaws in concrete blocks. In the laboratory, impact echo tests were performed to study the transient response of intact concrete cubes and cylinders. Similarly, impact response of concrete cubes and cylinders with flaws were also obtained. The output response of the defect-free specimen contains a single large amplitude peak of frequency corresponding to its full depth which is known as the thickness frequency. When a flaw is presented, the thickness frequency will be shifted to a lower value. This is the key information to identify the cracks and its depth from the output response. The actual crack depths were compared with impact echo results. The experimental results show a significant difference between the intact and the defected specimens.*

Key Words: Impact-Echo, Stress waves, Transient response, Thickness frequency, crack depth.

1. INTRODUCTION

In the recent days, more reliable and quantifiable Non-Destructive Testing (NDT) methods are available for concrete infrastructure worldwide. Condition assessment of concrete includes many parameters that affect the quality of the structure. Among that special care and preventive measure should be taken against internal cracks. Though cracking is not a serious problem in particular situations, small hairline cracks lead to major failure in some cases. Cracks can be identified from many NDT methods. Impact echo is one of the best methods for crack detection based on stress wave propagation. It can figure out the presence of flaws and discontinuities in a structure. The impact generated stress waves are propagated through the concrete surface and reflected by internal cracks and voids [1, 2]. The surface displacements caused by the reflected stress waves will be monitored by a transducer placed near the impact point. Using the Fast Fourier Transformation time domain waveforms are transferred to the frequency domain. The integrity of the structure can be identified from the frequency spectrum. This method has been successfully employed for thickness measurement of plate-like structures, detection of cracks in slabs, square, circular and rectangular columns, and detection of honeycombs [3].
Presence of single large amplitude frequency peak in the output spectrum gives the thickness of the concrete floor [4]. When a flaw is present the fundamental frequency will be shifted to a lower value. This is the key response to know the presence of a flaw. The reflections from the flaw surface will produce single large amplitude peak of frequency corresponding to the depth of flaw. Shorter duration impacts will provide better information about shallow cracks and honeycombs [5, 6]. When the depth of the crack increases the amplitude of high-frequency vibration will increase [7]. Impact echo responses gave better results in determining the thickness of carbon layer inside a blast furnace, determining the bonding and voids in the stone masonry structures, and detecting voids around the tendon ducts in post-tensioned concrete bridges [8-10].

This paper describes the impact responses of concrete cubes and cylinders with and without defects. The different sizes of cracks were simulated in concrete specimens at various depths. The thickness of defect-free cube and cylindrical specimens and depth of the simulated cracks were found out. The impact-echo responses show better results for the crack detection.

2. BACKGROUND

2.1 Working Principle

In the impact-echo method, transient stress waves are generated by tapping a small steel sphere against the test surface. The resulting low-frequency stress waves (frequency up to 80 kHz) then propagate through the surface as P-wave (dilatational) and R-wave (distortional) and along the surface as R-waves. The P and S waves are reflected by internal defects and external boundaries. A transducer placed near to the impact point monitors the surface displacements caused by the arrival of reflected waves. Generally, a P wave produces much larger displacements than the S wave at points near to the impact point. The transducer produces voltage time signal proportional to the displacement. This analog signal is digitized and then transformed to amplitude frequency spectrum by FFT technique. The large amplitude peak frequencies in the output spectrum provide information about the thickness, integrity of the structure and location of flaws. If C_P is the P wave speed in the test object, f is the frequency associated with the P wave reflection from the internal flaw or at the bottom surface then the depth of the flaw Dan be determined from the following formula.

$$D = \frac{C_p}{2f} \quad (1)$$

In a solid plate, the reflections between the top and bottom boundaries have a significant effect on impact echo response than the reflection from outside boundaries. The output spectrum contains single large amplitude peak of frequency f_T corresponding to the thickness of the plate, which is 96% of the frequency due to multiple arrival of P wave reflection.

$$f_T = \frac{0.96C_p}{2T} \quad (2)$$

where T is the thickness of the plate-like structure.

If the plate contains a flaw the thickness frequency can be shifted to a lower value. Because the waves travel around the flaw and corresponding wavelength will be increased. This will result in a lower frequency value. The presence of flaw can be identified from the frequency change. The location of the flaw can be determined from the large amplitude, higher frequency peak associated with the depth of the flaw.

2.2 Impact echo system

The test system of three major components: impactors, a hand-held transducer unit, a notebook computer connected with a high-speed analog-to-digital data acquisition system. Impactors are the small, hardened steel spheres (3-19mm in diameter) used to produce the elastic impact. The impact duration affects the response from the impact echo test. A Shorter duration impact results in the broader range of frequencies. The transducer produces analog signals proportional to the surface displacement. The computer-based data acquisition system can receive the signals from transducer, store, digitize and perform the signal processing and analysis.

3. EXPERIMENTAL PROGRAMME:

In this paper impact response of defected concrete specimens and defect free specimens are verified through the experimental investigation. The standard size of two cubes and five cylinders were casted with conventional concrete in the laboratory.

(a)

(b)

Fig-1: (a) Placing of Styrofoam sheet in the concrete cube; (b) Placing of plywood in the concrete cylinder.

Size of the cubes and cylinders are 150mm×150mm and 150mm×300mm.one cube and one cylinder were casted without defect. One cube and four cylinders were cast with cracks. Cracks were simulated using thick rigid Styrofoam sheets and thin plywood sheets and placed at known depths within the specimen as shown in the Fig. 1.

Impact response of defect-free specimens

The hardened concrete had a wave speed of about 3700m/s. During testing, the specimens were placed on thermo coal sheets. The impact was given at the centre of the specimen surface. A receiving handheld transducer was placed near the impact point. The impact-echo test conducted on a cylinder was illustrated in the following Fig. 2

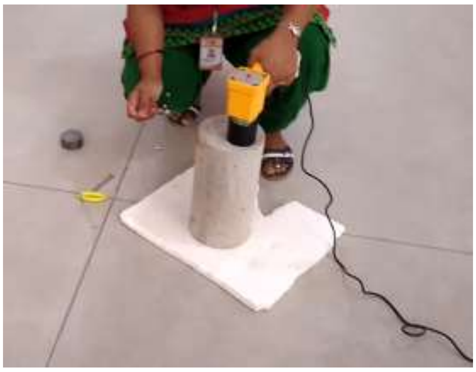

Fig-2: Impact-echo testing on the cylinder

The impact generated stress waves propagates through the concrete cube and cylinder surface and reflected from the opposite side. The surface displacements caused by the reflected p-waves were collected by the transducer. The amplitude-frequency spectrum in the output response helps to find the thickness of the defect-free cube and cylinder. The frequency of the single higher amplitude peak in the impact response gives the thickness of the specimens. The amplitude peak of frequency 12.2 kHz in the Fig. 3(a) gave the depth as 150mm for the cube and Fig. 3(b) gave the depth as 299mm for the cube.

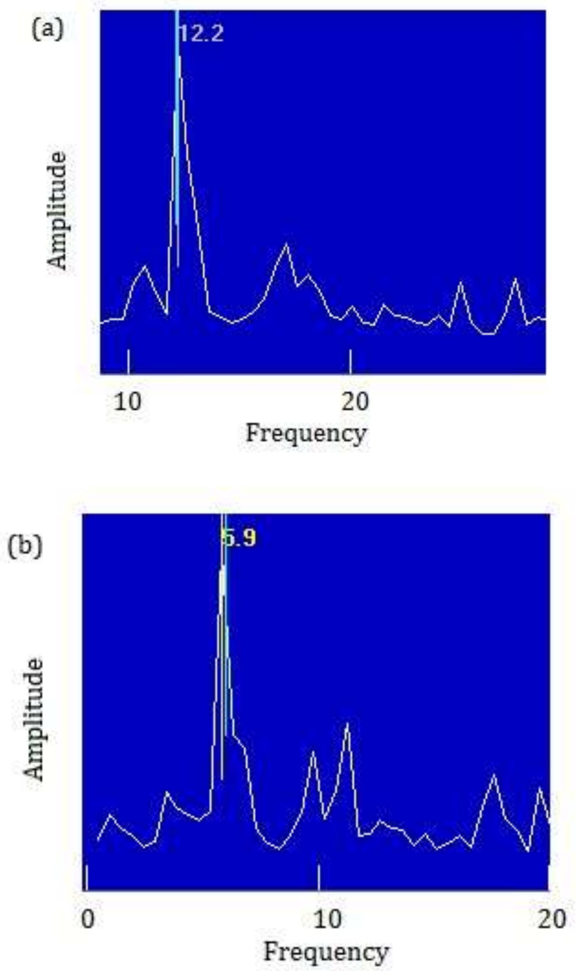

Fig-3: Impact response for (a) defect-free cube; (b) defect-free cylinder.

Table -1: Frequency values and thickness of defect-free specimen obtained from the impact-echo test

Type	Description	Test Result		Actual Thick. (mm)
		f_T (kHz)	Thick. (mm)	
Cube	C1	12.2	150	150
Cylinder	P1	5.9	307	300

The spectrum contains a number of small peaks due to the multiple p-wave reflections across the impact response. The comparison of output results with the actual values was given in Table 1. It shows a good agreement between actual values and the test results.

Impact response of defected specimens

To know how the presence of flaws in concrete specimens can affect the impact response, impact echo tests were conducted on defected concrete specimens. Results obtained from the impact response of defected cube and cylinders were given in this section.

The frequency spectrum obtained from the test conducted on the concrete cylinder P2 (150mm×300mm) containing a simulated crack of dimension 80mm×60mm at a distance of 150mm from the impact surface was shown in the figure Fig. 4(a) as a first example. Similarly, frequency spectrum obtained from the test on the defected cylinder P5 containing a simulated crack of dimension 120mm×40mm at a distance of 80mm from the impact surface was shown in the following figure Fig. 4(b) as a second example.

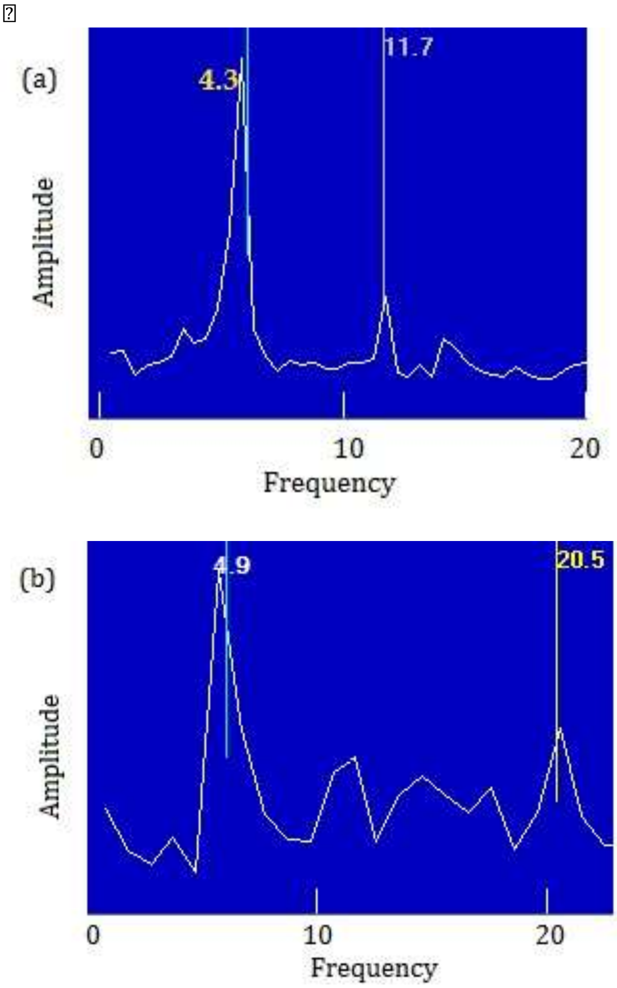

Fig-4: Impact response of (a) defected specimen P2 with 80mm×60mm crack at 150 mm depth; (b) defected specimen P5 with 120mm×40mm crack at 80 mm depth.

Comparing with the response spectrum of defect-free concrete cylinder P1 shown in the Fig. 3(b), the response of the defected cylinder in the Fig. 4(a) is quite different. The first amplitude peak in the Fig. 4(a) is at 4.3 kHz. This is lower than the thickness frequency of 5.9 kHz in the spectrum of defect-free specimen (Fig. 3(b)). This is due to the presence of crack at the particular depth. The reduction of thickness frequency to a lower value indicates the presence of a flaw. The output response in the Fig. 4(a) exhibits a second amplitude peak of frequency 11.7kHz caused by the reflection of P-wave from the crack surface. Using the wave speed as 3700m/s in Eq. (2) the depth of the crack obtained as 156mm which is closer to the actual value 150mm.

In the second example, considering the response of the concrete cylinder P5 having the crack of dimension 120mm×40mm at a distance of 80mm from the impact surface as shown in Fig. 4(b). This response is compared with the response shown in the Fig. 3(b). The thickness frequency of the cylinder 5.9 kHz is shifted to 4.9 kHz in the response obtained from the defected cylinder P5 (Fig. 4(b)). This is due to the presence of a crack. The shift of this thickness frequency to a lower value indicates the presence of a crack. Second peak of frequency 20.5 kHz in the spectrum (Fig. 4(b)) is caused by the P-wave reflection from the crack surface. Using the wave speed as 3700m/s in Eq. (2) the depth of the crack obtained as 90mm which is closer to the actual value 80mm. The results obtained from the all the defected specimens were given in the following Table 2. Comparing the Fig. 4(a) and Fig. 4(b) it is understood that the size and location of the crack influence the frequency peaks in the spectrum. When the size of the crack increases and depth of the crack decreases the amplitude of the frequency peak associated with the crack depth will increase.

Table-2: Frequency and crack depth obtained from the test conducted on defected specimens

Type	Details	Crack Size (mm)	Test Result		Actual Crack depth (mm)
			f_D (kHz)	Crack Depth(mm)	
Cube	C2	80×60	22.7	78	80
Cylinde	P2	80×60	11.7	156	150
	P3	50×45	9.2	197	200
	P4	50×45	7.1	253	250
	P5	120×40	20.5	90	80

The test results illustrated in this section shows that the impact response of defect-free specimens exhibits single large amplitude peak of frequency associated with the total thickness of the object. The patterns of wave propagation and deflection that occur within a solid structure due to impact are altered by the presence of flaw and these changes are evident in the waveform and spectra obtained from the impact echo test. The thickness frequency will be shifted to a lower value which is the key response to identify the crack and its location. The multiple P-wave reflections across the impact surface will produce a second large amplitude peak of frequency corresponding to the depth of the flaw in the spectrum and thus the depth can be determined easily.

Conclusions

The objective of this paper is to investigate the impact echo response of standard size of the concrete cube and cylindrical specimens with and without defects. The effect of size and location of crack depth on the frequency spectrum also studied. The thickness of the concrete specimens can be identified from the single higher amplitude frequency peak in the impact echo response spectrum. When a specimen contains flaw this thickness frequency will be reduced to a lower value. This shift indicates the presence of a flaw. From the frequency of second higher amplitude peak, the depth of the flaw can be determined. Increasing the size of the crack and reducing the depth of the flaw will result in the increase in the amplitude of the frequency corresponding to the crack depth. From the above results, it was concluded that the mean difference of impact echo test results with the actual values for thickness estimation will be 1.5% and crack detection will be 0.3%.

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