Discrimination of the Background Media of Concrete Using Electromagnetic Impact Driving Method

PACS REFERENCE: 43.60.Qv

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ABSTRACT: The discrimination of the background media of concrete by spectral analysis of multi-reflected elastic waves brought forth by electromagnetic impact driving method was studied. In order to receive the elastic wave with high signal to noise ratio, reinforcing bar steel buried inside the concrete is utilized as sound source with vibration induced by impact electromagnetic field radiated by a spiral coil put on the surface of concrete. The quality factor of the resonant peak of multi-reflected waves in the spectrum derived by linear prediction coefficient is employed for discrimination. Differences are shown in the experiment of air, sand and water background.

INTRODUCTION

Concrete slab buried with reinforcing bar steel is a popular material for construction. A usual structure of the embankment for flood prevention is soil and sand filling covered by concrete slab. The strength of the embankment will lower down if there is soaked water or hollow cavity inside, which is caused by the fall down of the inner soil and sand. Therefore, an effective method to detect the inside condition of embankment is necessary for the prediction of flood.

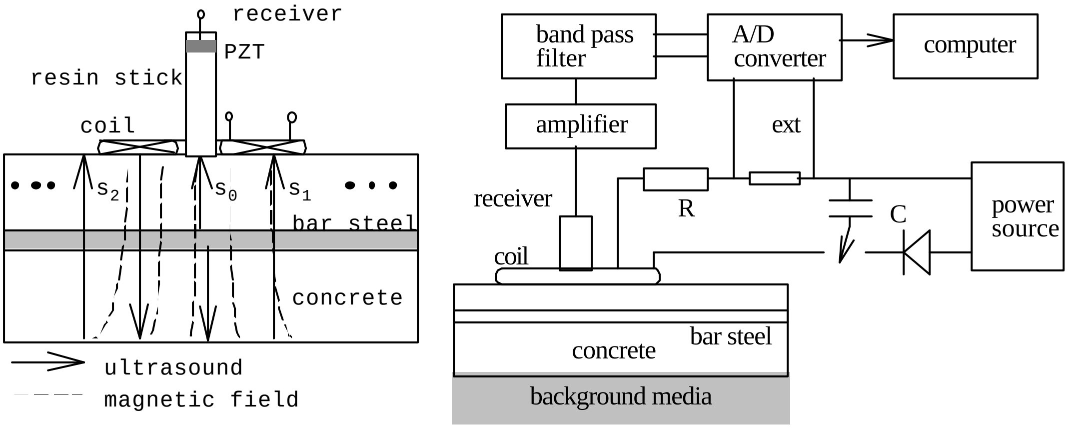
This paper studies a non-destructive approach of distinguishing the background media of concrete using elastic waves received from the exposed surface. The electromagnetic impact driving (EMID) method[1,2] proposed in our previous work is employed. The reinforcing bar steel is utilized as sound source with vibration induced by impact electromagnetic field radiated by a coil put on the surface of concrete. By an ultrasonic receiver putting on the surface of the concrete, the elastic wave radiated from the bar steel propagating to the surface is received as direct wave, and those reflected between the surface and the interface is received as multi-reflected waves. Reflected waves with comparatively satisfactory SN ratio can be received because of the higher energy of elastic wave than that transmitted by conventional PZT transducer.

Though different background medium takes different reflectivity of elastic wave at the interface with concrete, it is hard to be discriminated by its reflectivity drawn from the time domain amplitudes of reflect wave and direct wave. Because the time delay between direct wave and reflect wave is very short comparing with the pulse width, and thus the direct wave overlaps severely with the multi-reflected waves. In this paper, the quality factor of the resonant peak of multi-reflected waves is employed to distinguish the background media. Moreover, because the normal Fourier transform brings forth many uneven details in the spectrum, which makes the quality factor be unstable, the linear prediction coefficient (LPC) method is employed for spectrum derivation.

The mechanism of the EMID sound source as well as the principle of the LPC method is introduced. Experimental results of air, sand and water background show that the quality factor varies with the same tendency as the reflectivity.

EXPERIMENT SYSTEM

Fig.1 illustrates the diagram of experiment system. A flat spiral coil is placed on the surface of the concrete slab just above the buried in bar steel. During the condenser discharge process, the coil transfers an electric alternating current pulse to an electromagnetic field. The bar steel horizontally buried in the concrete vibrates with the impact driving of this field, as a powerful sound source. The elastic wave radiated from the bar steel is reflected on both the surface and the interface of concrete with its background medium. The direct wave (s_0) as well as the multi-reflected waves (s_1, s_2, …) is received by an ultrasonic transducer placed at the center of the coil on the surface. The concrete specimen used in the experiment is a 15cm thick slab, inside that a bar steel with 13mm diameter is buried 5cm deep. A urethane resin stick with 0.12ms elastic wave delay time is installed in front of the PZT receiver to separate the elastic wave from electromagnetic induction wave.



(a) Sound source and receiver (b) Experiment system

Fig.1 Diagram of experiment system

Fig.2 shows an example of the received signal while the background medium is air. It is shown that the elastic wave (about 0.12ms~0.4ms) and the electromagnetic induction wave (about 0~0.12ms) are separated.

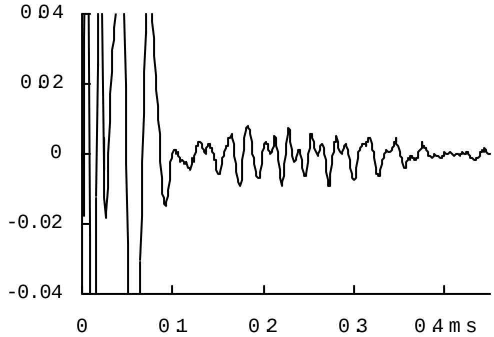


Fig.2 Example of received signal (background medium is air)

In a simple plane wave perpendicular incident condition, the reflectivity of elastic wave at the interface formed by media 1 and 2 is written by

$$R = \frac{\rho_2 c_2 - \rho_1 c_1}{\rho_2 c_2 + \rho_1 c_1},$$

where ρ is the density and c is the sound velocity. Here the 1st medium should be the concrete and the 2nd is the background medium (air, sand or water). These parameters of the materials employed in the experiment are listed as following,

ρ_c = 2.41 g/cm^3; ρ_a = 0.0013 g/cm^3; ρ_s = 1.6 g/cm^3; ρ_w = 1.0 g/cm^3

c_c = 4100 m/s; c_a = 331 m/s; c_s = 240 m/s; c_w = 1500 m/s

where the subscript c, a, s and w denote concrete, air, sand and water respectively. Accordingly, the reflectivity of the interface of concrete with air, sand and water are calculated to be –1.0, -0.92, and -0.74 respectively.

It is easy to be thought that the reflectivity can be calculated directly by the amplitudes of direct wave and reflected wave, but the time domain signals of different background media show little differences because the time delay between direct wave and reflect wave is very short comparing with the pulse width, and thus the direct wave overlaps severely with the multi-reflected waves, just as shown in Fig.2.

On the other hand, it is considered that the quality factor of the resonant peak of the multi-reflected elastic waves in the spectrum should be different according to different reflectivity. The quality factor is defined as

$$Q = \frac{f_0}{f_2 - f_1}, \tag{1}$$

where f_0 is the frequency of the resonant peak, and f_1, f_2 are the quadrant frequencies ($f_2 > f_0 > f_1$).

SIGNAL PROCESSING

In order to eliminate the influence of the electromagnetic wave and the direct wave, signals begin from the time of first reflect wave (s_1) is employed for processing. The propagating time of s_1 from the bar steel to the surface of concrete is calculated to be about 0.06ms. Therefore, in the following signal processing section, only signal during 0.18ms~0.4ms is taken into consideration.

Fig.3 shows an example of the normalized power spectrum of the multi-reflected waves derived by Fourier transform. The 0.18ms~0.4ms part of signal shown in Fig.2 is employed. The spectrum shows a resonant peak of multi-reflected waves at about 40kHz, as well as a comparatively lower resonant peak of the sensitivity of the PZT receiver at about 76kHz. However many uneven details are shown together with them. These uneven details around the main resonant peak will cause unstable noise to the quality factor.

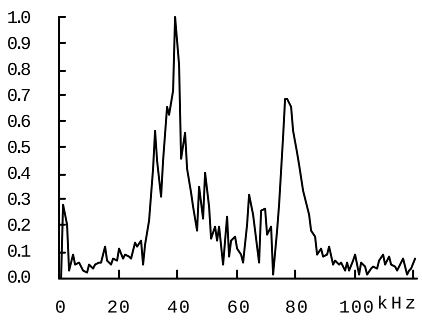


Fig.3 Power spectrum derived by Fourier transform

In order to obtain a spectrum with no uneven details at resonant peak, the LPC method is employed. The linear prediction can be described simply as that the current datum x_n can be predicted by the linear synthesis of former data x_{n-i}(i=1,2,…,p)

$$x'_n = x_n - e_n = -\sum_{i=1}^{p} a_i x_{n-i} \quad (n = p+1, p+2, \cdots, N)\,, \tag{2}$$

where x'_n and x_n denote the prediction and the real value respectively, e_n is the prediction error, a_i is the LPC, p is the order of prediction, and N is the data length of the whole signal. As to a known signal x_m (m=1,2,…,N), its LPC a_i can be derived by least square condition of the prediction error e_n. The result is

$$\begin{vmatrix} R_0 & R_1 & \cdots & R_{p-1} \\ R_1 & R_0 & \cdots & R_{p-2} \\ \vdots & \vdots & \ddots & \vdots \\ R_{p-1} & R_{p-2} & \cdots & R_0 \end{vmatrix} \begin{vmatrix} a_1 \\ a_2 \\ \vdots \\ a_p \end{vmatrix} = \begin{vmatrix} R_1 \\ R_2 \\ \vdots \\ R_p \end{vmatrix}, \tag{3}$$

where

$$R_i = \frac{1}{N-p} \sum_{n=p+1}^{N} x_n x_{n-i} \qquad (i = 1,2,\cdots,\ p) \tag{4}$$

is the self-correlation of the signal x_m. Then, the spectrum of the signal shown by its LPC is

$$X(w) = \frac{1}{1 + \sum_{k=1}^{p} a_k e^{jktw}}\,, \tag{5}$$

where t is the sampling interval.

Fig.4 shows the normalized power spectrum derived by LPC, of the signal same as that used in Fig.3. Comparing to Fig.3, it is shown significantly that the curve around the main resonant frequency is very clear.

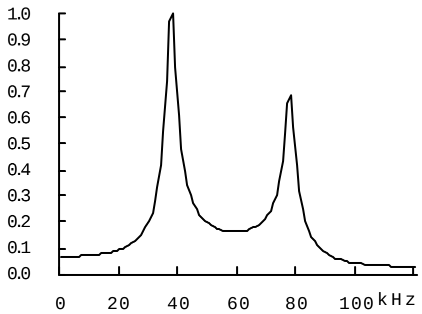


Fig.4 Power spectrum derived by LPC

EXPERIMENT RESULTS

The multi-reflected waves are measured for all the three kinds of background media (air, sand and water). Similar as that shown in Fig.2, the direct wave and the multi-reflected waves overlap together, and it is hard to discriminate the background media by the signals in time domain. Nevertheless, in their spectral derived by LPC, the difference of the sharpness of the resonant peak of multi-reflected waves are shown with the same tendency of their reflectivity. The quality factors are listed in Tab.1 together with the reflectivity of corresponding background media.

Table 1. Reflectivity and quality factor of different background media

Background medium	Air	Sand	Water
Reflectivity	-1.0	-0.92	-0.74
Quality factor	15.43	13.70	11.35

CONCLUSION

Powerful elastic wave is provided by the electromagnetic impact driving method in concrete slab with reinforcing bar steel, and the signal to noise ratio of received multi-reflected signal is satisfactory. Though the background media (air, sand and water) take different reflectivity, it can hardly be distinguished by the time domain signal owing to the overlap of direct wave and multi-reflected waves. The discrimination method using the quality factor of the resonant peak of the multi-reflected waves is proposed. The experiment result show that the spectrum with clear resonant peak of the multi-reflected waves is derived by linear prediction coefficients, and the quality factor of the resonant peak of the multi-reflected waves varies with same tendency as the reflectivity corresponding to different background media. Further research on the optimization of experimental condition and the quantitative relation of the quality factor with he reflectivity are expected.

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