IMPROVING IMPACT-ECHO METHOD BY WAVELET TRANSFORM FOR INFRASTRUCTURE INSPECTION

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ABSTRACT

Impact-echo, either in time domain or frequency domain, is one of the methods commonly used to measure thickness or strength of concrete structures. However, due to the anisotropic characteristics of concrete, the back-wall echoes are often very difficult to identify from received noisy time domain signals, and it is also frequently difficult to select a dominant frequency peak on an impact-echo spectrum for thickness calculation. wavelet transform was explored to solve this problem. With assistance of this tool, received noisy time domain impact-echo signals can be transformed directly. Periodic patterns corresponding to the back-wall echoes of measured structure will emerge from a two dimensional scalogram which is the result obtained from a continuous wavelet transform (CWT). Consequently, thickness measurements for concrete structures become more confident and reliable. The effectiveness of wavelet transform for concrete structure measurements of some research nuclear reactors is discussed in this paper.

INTRODUCTION

In Taiwan many new and aging infrastructures are required to evaluate their quality. Impact-echo, either in time domain or frequency domain, is one of the methods commonly used to measure the thickness or strength of concrete structures (Lin & Jhu, 1992, Pai et al., 1995, Sansalone & Carino, 1988). However, due to the anisotropic characteristics of concrete, the back-wall echoes are often very difficult to identify from noisy time domain signals received and the thickness of the concrete structure is not easy to measure. Therefore the frequency domain analysis is often used to substitute for the time domain analysis. In the frequency domain analysis, the received time signal is transformed by fast Fourier transform (FFT) and a dominant frequency peak is selected from an impact-echo spectrum. From the frequency corresponding to this peak and the known acoustic velocity of the tested concrete, the thickness of the concrete structure can be calculated. However, it is also frequently difficult to select a dominant frequency peak on an impact-echo spectrum for the structure thickness calculation.

In order to overcome the above problem, a research project was conducted to seek suitable signal processing methods for it. Wavelet transform was found to be helpful in solving this problem.

In this paper the theory of wavelet transform is introduced briefly. A scalogram, which is the result of continuous wavelet transform (CWT), obtained from a research nuclear reactor is displayed to show the effectiveness of CWT. Finally the limitation of CWT for concrete structure thickness measurements is discussed.

IMPACT-ECHO METHOD AND ITS LIMITATION

In impact-echo measurement, a transient stress pulse is introduced into an investigated concrete structure by mechanical impact on its surface, and this pulse undergoes multiple reflections between the opposite surfaces, as shown in the system diagram in Figure 1. The received time domain impact-echo signals are usually too noisy; a typical example is shown in Figure 2. This signal was acquired from a 90cm thick concrete block, which was cut from the concrete shielding of a research reactor being decommissioned. No information, such as back-wall echoes, can be drawn from it without any support of powerful signal processing tools. Therefore, fast Fourier transformation (FFT) is considered to transform the time domain signals into frequency domain for thickness measurements.

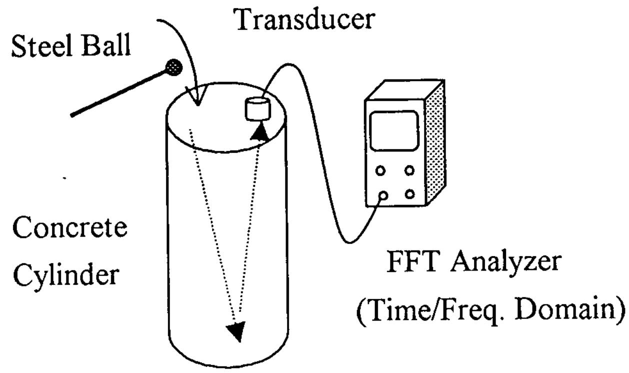


Figure 1. System Diagram of Impact-Echo Method

Time (512 pts. for 7.797μSec)

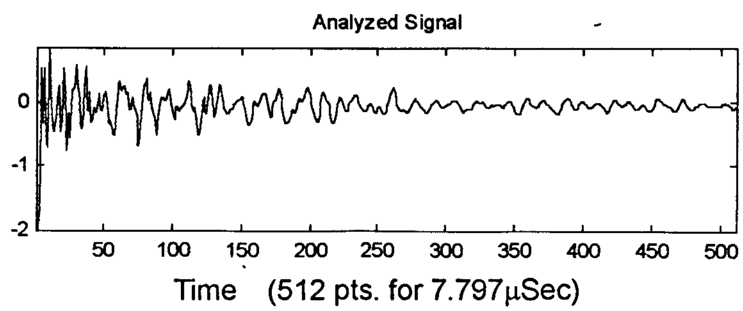


Figure 2. Noisy Time Domain Signal of a Concrete Block

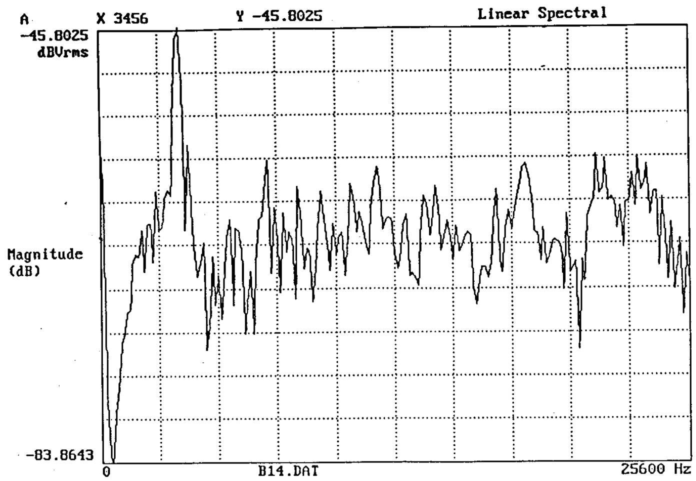
The FFT analyzer used is a portable, compact unit with a large video display and a micro floppy disc. A steel ball, of diameter from 5 to 50mm, was selected to make an impact near the transducer. Thicker concrete structures use a larger steel ball. An accelerometer, with a frequency range from 1 Hz to 10 kHz, was attached to the surface of the concrete structure as a transducer. A thin layer of grease was applied between the transducer and the concrete structure surface for coupling. By monitoring displacements caused by the propagation of P-wave (longitudinal wave), the frequency of successive arrivals is determined. With the known propagation velocity, the thickness of a concrete structure, d , can be calculated simply by:

$$d = \frac{v}{2f}$$

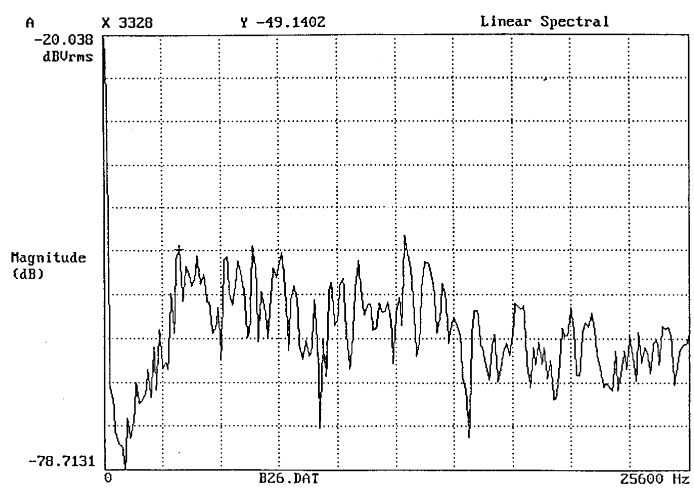
where v is the propagation velocity, and f is the frequency.

In recent years, many concrete structures have been tested with the impact-echo method by this project. Most received signals were noisy in the time domain, and have to be analyzed in the frequency domain.

The propagation velocity in a specific concrete structure was determined by testing a known thickness concrete beam that was made from the same materials and process as the structure to be tested. For example, an average velocity of 3500 m/s was determined for a concrete box girder. Figure 3 represents two typical frequency spectra obtained at various locations of a box girder of a constructing bridge. On Figure 3(a), the dominant frequency peak at 3456 Hz represents the thickness, 50 cm, of the measured girder. However, in Figure 3(b) it is not easy to identify a dominant peak. Only experienced engineers can achieve more reliable measurements. This is a drawback of the impact-echo method.



(a)



(b)

Figure 3 Two Impact-Echo Spectra of a Box Girder

WAVELET TRANSFORM AND ITS APPLICATIONS

Wavelet transform is a relatively new signal processing method (Chui, 1992, Olmo & Presti, 1994). It is implemented as a bank of filters that decompose a signal into multiple signal bands. Wavelet transform separates and retains the signal features in one or a few of these sub-bands. Thus, one of the biggest advantages of using the wavelet transform is that signal features can be easily extracted. In many cases, a wavelet transform outperforms the conventional FFT when it comes to feature extraction and noise reduction. Wavelet transform is capable of revealing aspects of data that other signal analysis techniques miss, aspects like trends, breakdown points, discontinuities in higher derivatives, and self-similarity. Among these, self-similarity was the aspect revealed from our impact-echo signals for concrete structure thickness measurements.

For many signals, Fourier analysis is extremely useful, because the signal's frequency content is of great importance. However, it has a serious drawback. In transforming to the frequency domain, time information is lost. In an effort to correct this deficiency, Fourier transform was adapted to analyze only a small section of the signal at a time by windowing the signal. This technique, called the short-time Fourier transform (STFT), maps a signal into a two-dimensional function of time and frequency. While the STFTs compromise between time and frequency information can be useful, the drawback is that once a particular size time window is chosen, that window is the same for all frequencies. Many signals require a more flexible approach that can vary the window size to determine more accurately either time or frequency.

A wavelet is a waveform of effectively limited duration that has an average value of zero. Several families of wavelets (e.g. Harr, Daubechies, Biorthogonal, Coiflets, Symlets, Morlet, Mexican hat, and Meyer) have been proven to be useful (Misiti et al., 1996). While Fourier analysis consists of breaking up a signal into sine waves of various frequencies, wavelet transform is the breaking up of a signal into shifted and scaled versions of the original wavelets. Hence, it can be thought of as the cross-correlation of a signal with a set of wavelets of various 'width'. Wavelet transform inherently defines various sized windows in the transform and the computation does not need to be done window by window.

Wavelet theory covers quite a large area and treats both continuous and discrete-time cases. There are several types of wavelet transforms, and, depending on the application, one may be preferred to the others. For a continuous input signal, the time and scale parameters can be continuous, leading to the CWT. The way employed successfully in this project for the impact-echo signal transform was CWT.

The CWT of a continuous time signal $x(t)$ with respect to a basic wavelet $h(t)$ is the two-dimensional function of time t and scale a

$$CWT_x(t,a) = \frac{1}{\sqrt{|a|}} \int x(t) h^*\left(\frac{t-t}{a}\right) dt$$

Since the same basic wavelet *h(t)* is used for all the filter impulse responses, the wavelet analysis is self-similar at all scales. It means that CWT measures the 'similarity' between the signal and the basic functions.

The result of a CWT is usually displayed on a scalogram, which is defined as a squared modulus of the CWT. It is a distribution of the energy of the signal in the time-scale plane. The x-axis represents position along the signal (time), the y-axis represents scale, and the color or gray scale at each x-y point on the scalogram represents the magnitude of the wavelet coefficient. It produces an easily interpretable visual two-dimensional representation of signals.

Figure 4 is a typical example of a scalogram. It is a CWT result of the noisy time domain signal mentioned in Figure 2. The wavelet used for this transform was the db1 of the Daubechies family wavelets (Misiti et al., 1996). The impact-echo frequency spectrum of this concrete block is shown in Figure 5. It is difficult to select the dominant peak on it, because there are several peaks and the marked one that corresponds to the thickness is not the highest among them. However, on the CWT scalogram the periodic patterns, which appear at 27, 60, 92, 125 et al. of the x-axis, correspond to the back-wall echoes obviously. With the known wave velocity, the thickness of the tested girder can be calculated from the time axis directly or by averaging several periodic patterns.

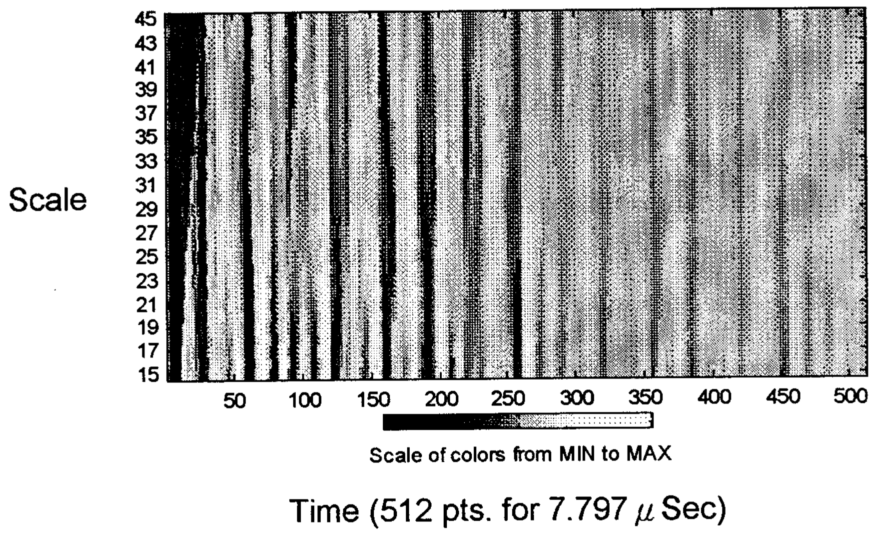


Figure 4 CWT Scalogram of Concrete Block

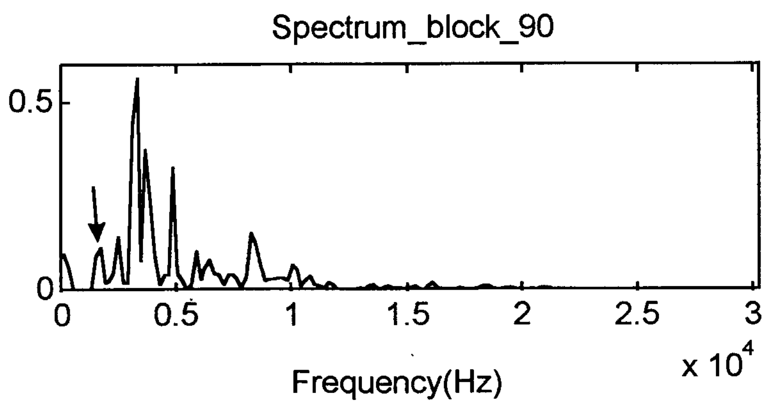


Figure 5 Frequency Spectrum of Concrete Block

Although the effectiveness of the CWT for thickness measurement is obvious in the mentioned example, CWT is not effective for all measurements. It also has a limitation. As with our experience, it is good for structures with a narrower surface area and smaller cross-section, e.g. concrete piles and concrete cylinders. However the CWT is not helpful for thickness measurements of thicker structures with wider surface areas, e.g. concrete shielding and continuous walls. Our experience from the testing of three research reactors reveals that CWT is difficult to get periodic patterns from concrete shielding thicker than 50 cm. It is because the waves, which undergo multiple reflections between the opposite surfaces, might diverge in a wider structure and the energy received by the transducer should be smaller.

CONCLUSION

The continuous wavelet transform provides two-dimensional visualizations of one-dimensional signal and allows the important features at various scales to be viewed. The noisy impact-echo signal received from specific concrete structures, e.g. concrete shielding thinner than 50 cm and concrete cylinders, for thickness measurement could be processed by CWT in the time domain directly to obtain periodic patterns, which corresponded to the back-wall echoes, on a two dimensional scalogram. With these periodic patterns and known velocity, the thickness can be calculated easily. Moreover, the wavelet transform procedure has been proved to be computationally efficient, so that this tool can be profitably employed in site measurements. Consequently, thickness measurements for concrete structures become more accurate and reliable.

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KEY WORDS

Concrete inspection, impact-echo method, scalogram, wavelet transform, infrastructure, thickness measurement.