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Assessing sensitivity of impact echo and ultrasonic surface waves methods for nondestructive evaluation of concrete structures

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HIGHLIGHTS

- Ultrasonic Surface Waves (USW) and Impact Echo (IE) NDT methods are thoroughly described.
- The sensitivity of the IE and USW methods to several parameters is demonstrated.
- The sensitivity is evaluated in both quality control and performance monitoring stages.
- The advantages of combining the IE and USW results are pointed out.

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ABSTRACT

Two nondestructive testing methods for performance monitoring of concrete structures are Impact Echo (IE) and Ultrasonic Surface Waves (USW). To fully investigate the sensitivity of these methods to different parameters, several concrete slabs were tested with the Portable Seismic Property Analyzer (PSPA). The concrete slabs included a number of intact slabs with varying thicknesses and a number of slabs containing artificial defects. This research study shows how the effectiveness of the IE and USW methods is limited by their sensitivity to the dimension and thickness of the slab, and depth and size of the defect within the slab.

1. Introduction

The United States transportation infrastructure is aging. Among the transportation infrastructure, bridges and tunnels are the most critical nodes in the highway system with many challenging and unresolved maintenance issues. Concrete bridge decks and tunnel linings are more susceptible to rapid deterioration as a result of environmental factors, traffic loads, and also due to the routine application of deicing salts and repeated freeze–thaw cycles. To allocate enough funds and to determine the appropriate timing and the extent of maintenance activities, it is essential to monitor the condition of bridge decks and tunnel linings. In addition to evaluation of deterioration stage, there is also a need for quality management of strength and thickness of new constructions. The common practices for condition assessment of transportation infrastructure have been visual inspection and destructive methods. Visual inspection does not capture hidden deterioration or damage and the results are widely variable and unreliable [1]. While destructive testing usually provides reliable assessment of the structure, the time and effort needed make this type of test impractical. As a result, the need for Non-Destructive Testing (NDT) is emerging.

Different NDT methods are being used for evaluation of concrete infrastructure. Based on overall value, accuracy, precision, ease of use, and cost, two of the widely used and promising methods, are Impact Echo (IE) and Ultrasonic Surface Waves (USW) [2,3]. The IE and USW methods are based on generation of stress waves and measurement of their velocities of propagation and other propagation characteristics such as reflection, vibration mode and dispersion. The USW method is used to measure the velocity of propagation of surface waves and to estimate elastic modulus of the material [4,5]. The IE method, on the other hand, can be used to estimate the thickness of the tested object and identify the position of body wave reflectors in the object [6,7]. These

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methods, in combination, have been successfully applied to quality control of strength and thickness and also to detect and characterize defects in concrete structures [8,9]. Based on numerical studies [10], the reliability of the IE and USW methods are affected by their sensitivity to several parameters, such as source to first receiver distance, receivers' spacing, geometry of the tested object (including the overall dimensions and thickness), boundary conditions, and size, location and type of discontinuities within the object.

This paper experimentally demonstrates the sensitivity of the IE and USW methods to the thickness of intact slabs, and depth and type of the defect within the defective slabs. The work was undertaken in two parts. In the initial stage, the sensitivity of the IE and USW methods to slab thickness was investigated in terms of quality control for thickness and strength. In the second stage of this study, the sensitivity of the IE and USW methods to the location and type of defects was evaluated.

2. Description of testing methods

2.1. Impact Echo (IE) method

The IE method is one of the most commonly used NDT methods in detecting delamination in concrete [6]. The basic principle of this method involves striking the surface of the tested object with an impactor, generating and transmitting stress waves at frequencies of up to 20–30 kHz, and measuring the response by a nearby receiver. By using fast Fourier transform (FFT) analysis, the recorded time-domain signal is converted into a frequency-domain function (amplitude spectrum), and the frequency of reflection, called thickness frequency, is monitored. In the case of a sound slab, the main reflection will be from bottom of the slab. In this case, the thickness (h) of the slab can be determined from the measured or estimated compression wave velocity (V_p) and the thickness frequency (f):

$$h = \frac{V_p}{2f} \tag{1}$$

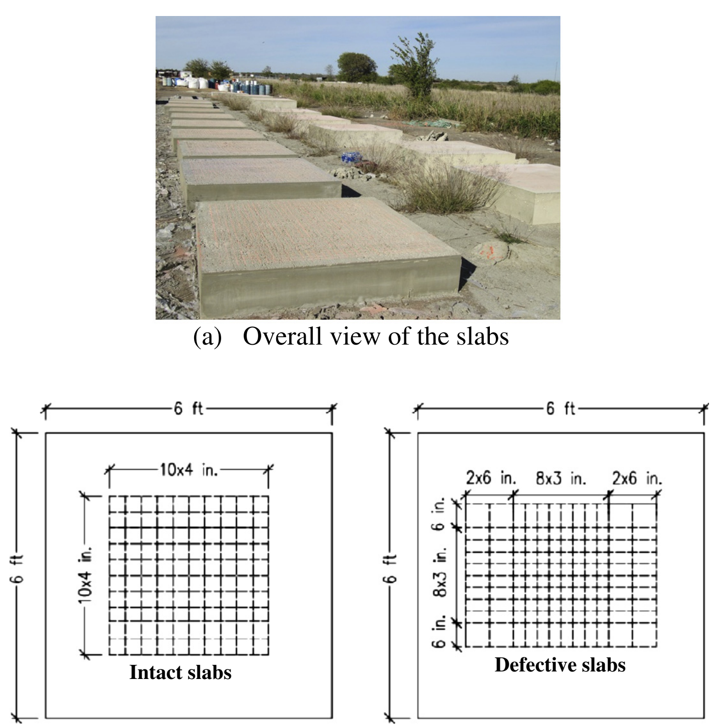
Eq. (1), developed in the early research leading to the development of the IE method, assumes that the wave speed across the thickness of the plate was the same as the compression wave velocity in a large solid [11]. More rigorous studies, however, have shown that the apparent wave velocity relating the thickness frequency and actual plate thickness is approximately 96% of the compression wave velocity [12]. Therefore, Eq. (1) is modified by multiplying it to a factor of, which β is 0.96 for concrete plates:

$$h = \beta\frac{V_p}{2f} \tag{2}$$

Other reflectors inside a concrete slab would be void, crack, delamination or various types of defects with different acoustic impedances than that of concrete. In the presence of a deep delaminated area, the frequency peak, called return frequency, shifts toward higher values than thickness frequency. The return frequency corresponds to the depth of the delamination. A shallow delaminated area is usually manifested by a low peak frequency (flexural frequency), indicating that little or no energy propagates toward the bottom of the slab and a flexural-mode response dominates the frequency response [13]. In this case, Eq. (2) is not applicable to measure depth of the delamination.

2.2. Ultrasonic Surface Waves (USW) method

The USW method is used to evaluate material properties (velocity of propagation of surface waves or elastic modulus) in the near surface zone of a medium [4]. The frequency range of interest is limited to a high-frequency range in which the surface wave's penetration depth is less than the thickness of the tested object. The USW method is based on impacting the surface of the object and recording the response of the object at two receivers. The velocity



(a) Overall view of the slabs

(b) Testing schemes of different slabs

Fig. 1. Experiments and testing schemes, 1 in. = 25.4 mm; 1 ft = 0.3048 m. (a) Overall view of the slabs and (b) testing schemes of different slabs.