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Application of ultrasonic shear-wave tomography to identify horizontal crack or delamination in concrete pavement and bridge

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HIGHLIGHTS

- Delamination in concrete columns can be evaluated by the MIRA system.
- The MIRA detects concrete cover depth over reinforcing steel in concrete piers.
- The MIRA is able to estimate of slab thickness and delamination depth.

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ABSTRACT

As more concrete structures and pavements in the US are approaching or have already exceeded their design lives, the number of distresses and needed repairs have increased, along with the amount of funding needed. In this study, various concrete distresses in structures and pavements were evaluated with MIRA testing, which is based on the ultrasonic pulse-echo method. The distresses evaluated included horizontal cracking or delamination at the mid-depth of concrete pavement slabs, spalling and map cracking in concrete pavement slabs, mudballs in concrete runway, concrete cracks and delamination in bridge columns, and shallow concrete cover in bridge piers. MIRA was able to detect discontinuities in concrete, whether they are cracks, delamination at an interface of two concrete slabs, mudballs, or reinforcing steel.

1. Introduction

Distresses in concrete structures and pavements are caused by various mechanisms and determining optimum repair methods and boundaries is not an easy task, primarily because of the difficulty in estimating the condition of the concrete inside. Concrete coring is a method often used to evaluate the condition of concrete inside; however, coring is time-consuming and costly, and has limited value in determining the boundaries of needed repairs. A non-destructive testing (NDT) method capable of accurately evaluating concrete condition in a timely manner, which could provide accurate information needed for decision-making on repair methods and boundaries, is badly needed. As more concrete structures and pavements in the US are approaching or have already exceeded their design lives, the number of distresses and needed repairs has increased, along with the amount of funding needed. Accordingly, improving the performance of concrete repairs by selecting optimum repair methods and adequate repair boundaries has become quite important. Fig. 1(a and b) shows the examples of repeated distresses at previously repaired areas in continuously reinforced concrete pavement (CRCP). It is believed that these distresses occurred due to the selection of inadequate repair boundaries when the distresses were originally repaired. In general, repair boundaries are determined by field maintenance crew, who normally rely on visual evaluations only. Visual inspections normally cannot detect damages inside the concrete, and often result in misdiagnoses of the required repair boundaries and the distresses that reoccurred as shown in Fig. 1(a and b).

One of the most important requirements for any testing methods for identifying and selecting an optimum repair method and proper repair boundaries is the ability to accurately evaluate the condition of the concrete in the distressed areas. NDT methods could provide ideal candidates for this type of applications [1,2]. For an NDT method to be effective for this purpose, in addition to the capabilities described above, it should be easy to operate

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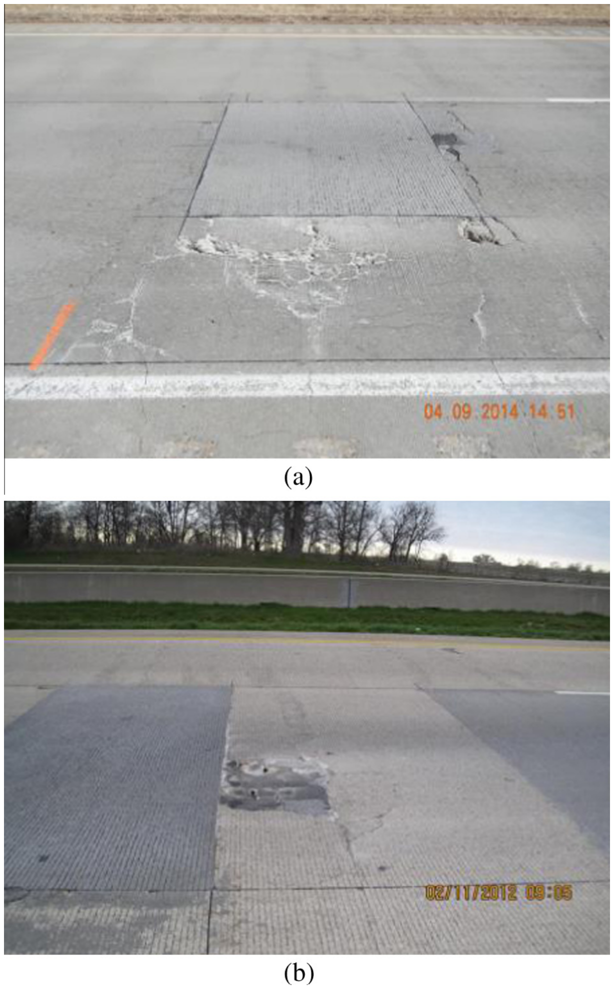

Fig. 1. Distresses at originally repaired area: (a) IH 27 in Lubbock, Texas and (b) IH30 in Pairs, Texas.

in the field and should also provide accurate information in a timely manner without in-depth analysis and interpretations [3,4]. Conventional ultrasonic testing such as ultrasonic surface waves and the method using impact echo, impulse response, and ground penetrating radar may satisfy most of the requirements for the NDT described above. However, this testing method usually leads to high scattering and attenuation of the transmitted pulses due to the very heterogeneous nature of concrete. In addition, the transducers (ultrasonic probes) have to be coupled to the surface of concrete pavement using a coupling gel, which makes the field testing take longer in some testing methods [5].

Ultrasonic shear-wave tomography with multiple arrays of probes in one head (commonly known as MIRA) overcomes the limitations of conventional ultrasonic testing [2–4,6,7] and could be an ideal NDT method for the evaluation of concrete integrity and the determination of proper repair boundaries. MIRA was applied to evaluate its effectiveness in determining concrete integrity as well as the repair boundaries in concrete pavement, bridge columns, and concrete runway.

2. Ultrasonic shear-wave tomography (MIRA)

MIRA is a low frequency (20–100 kHz) multifunctional phased array ultrasonic system to detect objects, interfaces, and anomalies in concrete structure. Shear-wave ultrasonic testing represents one of the most advanced techniques available in nondestructive testing of concrete [6]. The shear-waves are generated by exciting a piezoelectric material with a short-burst, high-amplitude pulse that has high voltage and current. The principle of the MIRA testing is based on the ultrasonic pulse-echo method using transmitting and receiving transducers in a "pitch-catch" configuration as shown in Fig. 2. One transducer sends out a stress-wave pulse and a second transducer receives the reflected pulse [4,7].

The time from the start of the pulse to the arrival of the echo is measured. The wave speed is computed and the depth of the reflecting interface is estimated. If the wave speed Cs is known, the depth of the reflecting interface can be calculated by Eq. (1) [8].

$$d = Cs\frac{\Delta t}{2} \tag{1}$$

where, Cs: shear wave speed,

Δt: travel time.

If there are distresses at the depth of the longitudinal steel in the form of horizontal cracking, which is usually the case in partial-depth punchouts in CRCP, the MIRA will detect the existence of the distress, as graphically shown in Fig. 2. From the pulse arrival times and the known positions of the transmitter-receiver pairs, the depth of the reflecting interface can be created.

Since the ultrasonic probes in the MIRA do not require a coupling gel to ensure the transmission of waves into the concrete, the probe can be moved from a position to the next position with almost no surface preparation. Accordingly, testing time can be reduced substantially compared to conventional ultrasonic testing. The antenna is also composed of a 4 by 10 array of point transducers. The transducers act as transmitters and receivers in a sequential mode. The transducers are heavily damped so that a short duration pulse is created.

One of the most powerful features of MIRA is its ability to reconstruct the condition of concrete in a three dimensional format [3,6], which allows engineers to evaluate the integrity of the concrete inside. To conduct a three dimensional analysis

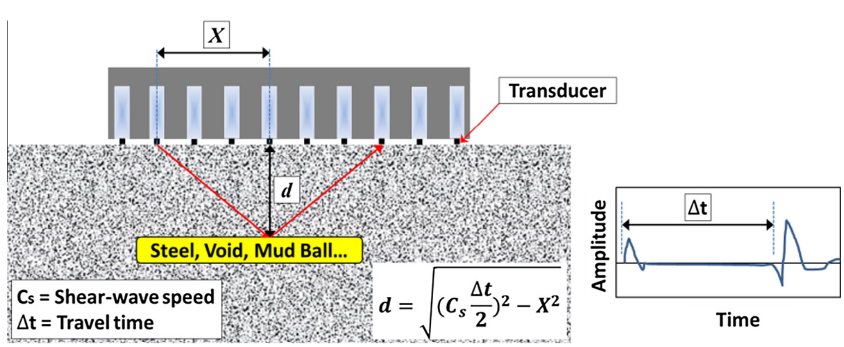

Fig. 2. Principle of the MIRA system [8].