ABSTRACT

Assessing internal damage levels in concrete roadways is an excellent opportunity for the application of nondestructive evaluation techniques, such as ground penetrating radar (GPR). Concrete roadways, particularly those on bridges, are high-performance structural elements that are subjected to severe environmental and mechanical stresses. These stresses cause corrosion of reinforcing bars, the promotion of internal cracking, eventually large-scale spalling, and the formation of deep potholes. This damage usually initiates internally and does not appear on the surface until it is at an advanced state. The use of asphalt overlays further exacerbates this problem. One of the most important, yet difficult to identify, defects is a delamination, which can be due to expansion associated with reinforcing bar corrosion. The GPR reflections from a delamination can be relatively weak, whereas the reflection from a reinforcing bar can be fairly strong. This paper presents the results of a laboratory and field study that focused on GPR methods of detecting delaminations in concrete roadways. The measurement technique used 0.5 to 6.0 GHz air-coupled waves to probe the roadways. Delaminations as small as 0.5 mm were simulated and detected in the laboratory. Field measurements are suggestive that this technique can be effective for field use.

Key words: concrete, corrosion, damage, delamination, detection

INTRODUCTION

This study is focused on assessing the ability of GPR to detect damage inside of concrete roadways. The main damage item of interest is the air-filled delamination that runs from rebar to rebar. These are usually caused by chloride ion penetration, which promotes corrosion of the rebars. The products of the corrosion exert a swelling force on the surrounding concrete, which causes cracks and delaminations to form. Other items of interest are the overall degradation of concrete that occurs when roadways are subjected to repeated environmental stresses, such as freeze-thaw action and the penetration of chloride ions. The study consisted of a series of laboratory and field tests. The laboratory tests were designed to simulate damage in concrete slabs. Healthy and severely damaged bridges were scanned in the field tests.

GPR SYSTEM

The GPR system used in this study is a custom built step-frequency system. The heart of the system is an HP8753D Network Analyzer, which provides both the source signals and the return signal acquisition. The bandwidth of the analyzer is 0.05 to 6.0 GHz. This results in a center band frequency that is somewhat higher than most GPR roadway inspection systems. The analyzer is mounted on a moveable cart. A measuring wheel with an optical encoder provides position data. The system was controlled by a PC running custom software that stored the data and produced real time B-scans for the operator to examine. The antenna was a horn that used an impedance matching asymmetric apex, Figure 1 (Aurand, 1998). After several iterations with tapered and flared ends that provided excellent impedance matching at the launch point, but were troubled with secondary reflections, a compromise antenna design that has a tapered end, but no flare was used (Huston et al., 1999 and 2000; and Hu, 1999). This horn antenna is similar to one described by Smith (1995), Figure 2.
Figure 1: Detail of impedance-matching low-loss antenna apex connection.

Figure 2: Photo of horn antenna before mounting and encasement.

Figure 3: Schematic of the cart with antenna and the layout of the three thin test slabs.

Figure 4: B-scan image resulting from a scan across the center of the three-slab stack.

Figure 5: Sample waveform from the B-scan of the three-slab stack.

Figure 6: B-scan of the slab with a metal plate placed in between the second and third slabs.

Figure 7: Schematic of the cart with antenna and the layout of the three thin test slabs.

Next, a series of tests were conducted in which air-filled delaminations were artificially created in concrete slabs through the use of thin Styrofoam inserts, Figure 7.

The first slab to be tested (Slab 1) was subjected to accelerated corrosion by an electrolytic process and saltwater soaking. The slab was heavily corroded. Slab 1 was scanned with the radar system in the same way that the three stacked slabs were scanned. The features can be seen in the B-scan images in Figure 8. A corresponding filled delamination after passing through 120 mm of concrete and a delamination.
waveform appears in Figure 9. The rebars are not visible in the B-scan, but the thin delamination is visible.

Figure 6: Sample waveform from three-slab stack with metal plate inserted between second and third slab.

![Waveform](image)

Figure 7: Schematic of Test Slab 1 with embedded foam defects.

![Schematic](image)

Figure 8: B-scan of Slab 1.

Test Slab 2 was poured around the same time that Slab 1 was poured. It also contains embedded foam defects. However, it did not undergo any environmental stressing. Instead, Slab 2 was coated with 38 mm of Quick Patch™ asphalt. This was done to represent an overlay of asphalt on a bridge deck surface. A B-scan of Slab 2 appears in Figure 10. The system is able to identify the thin delamination through the asphalt overlay. The rebars are also apparent.

Figure 9: Sample waveform for Slab 1.

![Waveform](image)

Slab 3 also contained thin Styrofoam™ delaminations. A B-scan appears in Figure 11. The defect and the rebars are clearly visible.

Figure 10: B-scan of Slab 2.

![B-scan](image)

Figure 11: B-scan of Slab 3.

**FIELD TESTS**

A series of field tests were conducted on bridges that were both damaged and undamaged. Figure 12 is picture of the Bostwick Bridge in Vermont (USA). The deck is severely damaged. Figure 13 is a B-scan of the Bostwick bridge deck. Note that the only features that are visible on the scan are the asphalt patches. Figure 14 is a picture of the Turkey Lane bridge in Vermont (USA). The deck on this bridge is in excellent shape. Figure 15 is a B-scan of the Turkey Lane bridge deck. The rebars are visible, as well as the transition to the adjacent dirt roadway.
AKNOWLEDGEMENT AND DISCLAIMER

This article, prepared in cooperation with the New England Transportation Consortium, does not constitute a standard, specification or regulation. The contents of this article reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views of the New England Transportation Consortium or the Federal Highway Administration. Access to the bridges was provided by the Vermont Agency of Transportation.

REFERENCES

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CONCLUSIONS

A step frequency GPR system using a horn antenna and operating in the frequency band of 0.05 to 6.0 GHz can detect defects as small as 1 mm in the laboratory, without any sophisticated signal processing.