

JOINT TRANSPORTATION RESEARCH PROGRAM

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Nondestructive Evaluation of the Condition of Subsurface Drainage in Pavements Using Ground Penetrating Radar (GPR)

Introduction

Subsurface drainage features are routinely incorporated in the design of pavement systems as they are believed to increase pavement service life provided that they are installed correctly and maintained. Maintenance, however, is challenging in that location and subsequent inspection of outlet pipes, drainage conduits, and edge drains can be time-consuming and laborious.

Consequently, locating and evaluating the condition of existing subsurface drainage systems has now become a key factor to enable proper maintenance and increase the service life of pavement. There are several different methods that can be used to detect objects in subsurface settings, such as metal detectors, electronic marker systems, acoustic emission sensing, resistivity measurements, micro-gravitational techniques, and seismic reflection/refraction methods. However, ground penetrating radar (GPR)—a nondestructive geophysical technique that makes use of radio waves to examine low loss dielectric materials—appears to offer the greatest potential to facilitate drainage feature detection in subsurface settings.

In this context, the objective of this study was to determine whether GPR technology can be used to rapidly locate subsurface drainage features in pavements and thus alleviate some of the cost and complexity of maintaining these systems.

Findings

The work carried out in this program involved a two-pronged approach to improve GPR-based sub-pavement drainage system evaluation while maximizing the value of the Indiana Department of Transportation's (INDOT's) pre-existing investment in GPR hardware and remaining within project budget limitations. Two major avenues were explored to achieve improvements in GPR detection success: (1) software-based signal processing and (2) modifications of hardware test configurations.

From a signal processing perspective, two complementary sets of approaches were developed in this work, referred

to herein as Methods 1 and 2. Method 1 involves two signal processing algorithms that are designed to reduce GPR signal background clutter and noise by taking advantage of the somewhat uniform nature of the strata underlying constructed pavements and to systematically remove anomalous signals. The output of this method is a 1-D plot of potential target locations as a function of distance on the survey line along the roadway. This method proved to be very effective at identifying both X- (shallow depth, PVC) and K-drains (moderate depth, metal/clay) even when a hyperbolic signal return could not be observed in the 2-D data. Generally, all X-drains are routinely identified (with only occasional exceptions), with three to four false alarms per successful detection. Similarly, all known K-drains in the studied field test regions were successfully identified, although each successful K-drain detection was accompanied by a significant number of potential false alarms. While these false alarms all require field investigation, the effort associated with these investigations is likely substantially less than the effort required to manage the consequences of undetected, and thus unmaintained, K-drains. The reliability of Method 1 was shown to improve when scans obtained with two antennae are compared and when routine drain spacing is employed as a filter. These additional screens help to reduce false alarms to roughly two to three per successful detection.

Method 2 focuses on enhancing 2-D image quality to facilitate recognition of hyperbolic signal returns indicative of drain detection. When this method reveals a hyperbola, there is a clear "detect" outcome and thus the approach can clarify interpretation of potential targets identified via Method 1. It is important to note, however, that lack of a hyperbolic return in the 2-D image is not conclusive in declaring a "false alarm" as the statistical algorithms of Method 1 routinely detected pipes when no hyperbolic return was visible. Thus, in practice, it is likely important to investigate all potential target zones identified by Method 1. Overall, Method 2 would likely be most valuable if incorporated in an automated data processing system to help rapidly identify clear "detects" and thus limit the focus of in-field investigative study to only truly uncertain target zones.

From a hardware perspective, field experiments were also carried out in this work to assess the potential for alternative antenna configurations to enhance the detection success. Five different antenna configurations were tested. These tests reveal several conclusions that can be generalized as follows:

1. Survey line selection has a significant influence on the quality of obtained GPR images. In all cases, images obtained on the gravel side slope of roads provided clearer, higher SNR (signal to noise ratio) images of buried drains relative to images obtained in the middle of the shoulder of the roadway or at the pavement shoulder—gravel slope interface, and more frequently displayed, the characteristic hyperbolic returns expected from a buried conduit. It is worth noting that while operating on the gravel slope has some challenges in terms of maintaining the stability of the antennae, a survey line well off the roadway adds to the safety of the overall scanning operation. With this in mind, there is likely value in developing a robust outrigger setup that can facilitate antenna coupling with the ground on the gravel slopes beside roadways.
2. Test configurations involving two antennae facilitate more reliable detection strategies than single antennae configurations. The potential to compare results from two antennae along a shared survey line helps to distinguish background clutter and anomalies from actual pipe detections and facilitates signal averaging that can be employed to reduce the net background interference in post-processing. The benefits of this logic likely increase to a limit as additional antennae are added to the test setup.
3. In tests conducted with a transmitter and dual receivers operating at different frequencies, higher input frequencies yielded higher SNRdB results than lower input frequencies. However, at any given input frequency results obtained with the lower frequency receiver of the studied pair tended to provide higher SNRdB returns, indicating some loss in energy of the returned signal combined with a beneficial reduction in sensitivity to noise.
4. Cross-polarized configurations generally provided good results but did not yield a benefit that justified the added complexity of operating the cross-polarized system. It is important to note that only configurations involving a cross-polarized receiver oriented perpendicular to the transmitter and direction of travel and vice versa were pursued in this work. Other orientations of the entire cross-polarized setup may warrant future investigation.

Implementation

Based on the tests and data analyses performed herein, the following recommendations are provided to guide future deployments of GPR for subsurface drainage detection under pavements:

1. Implement the background reduction and anomaly detection algorithms developed in this work (Method 1) in a user-friendly software application that can be employed to process GPR data.
2. Implement the shape enhancement algorithms developed in this work (Method 2) to facilitate evaluation of potential target zones via an automated shape recognition routine.
3. Enhance on-board computing power employed in the field vehicle used to pull the GPR antennae so that data can be processed in real time, thereby enabling target zone marking during the GPR scanning operation (vs. post-data processing).
4. Develop a robust GPR unit outrigger capable of negotiating the gravel slopes alongside roadways to maximize energy coupling into the subsurface and enhance detection sensitivity.
5. Deploy (at least) two antennae in any survey operation to improve background management and facilitate results comparison that can increase the probability of successful detection and false alarm rejection.
6. Utilize configurations involving one transmitter and dual-frequency high-low receiver pairs to optimize energy input into the subsurface and minimize received noise.

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