USE OF GROUND PENETRATING RADAR DATA FOR REHABILITATION OF COMPOSITE PAVEMENTS ON HIGH VOLUME ROADS

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by

Kenneth R. Maser.
President, Infrasense, Inc.
14 Kensington Road, Arlington, MA 02476-8016, USA
781-648-0440 fax-781-648-1776
kmaser@infrasense.com

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ABSTRACT

The paper describes five applications of Ground Penetrating Radar (GPR) to composite pavements on sections of interstate highway: I-495 near New York City, I-95 in New Haven, I-90 and I-294 in Chicago, and the Grand Central Parkway in New York City. The sections, which ranged in length from 4 to 18 miles, were evaluated with GPR for asphalt thickness and, in some cases, for the condition of the underlying concrete. This information was used to plan and carry out rehabilitation and reconstruction programs. Given the high traffic volumes on these roads, lane closures to allow for direct pavement evaluation were unacceptable, and GPR was chosen as the data collection method. The GPR data was collected at normal driving speeds without interference to traffic, and was coordinated with mileposts and other structures to insure ground control for location referencing. The data was then analyzed to produce graphical plots and tabular spreadsheets of asphalt thickness. Contour plots were also produced showing locations of likely deterioration in the underlying concrete. The GPR thickness results were evaluated for reliability through correlation with data from core samples. The results of each survey were used as input in planning and scoping the subsequent rehabilitation work. The paper describes the project objectives, the equipment used, the data analysis methodology, the results obtained, the use of the GPR data, and correlations with available core data.

INTRODUCTION

The paper describes five applications of Ground Penetrating Radar (GPR) to composite pavements on sections of interstate highway: I-495 near New York City, I-95 in New Haven, I-90 and I-294 in Chicago, and the Grand Central Parkway in New York City. In each case the owner agency was seeking to determine depth of asphalt. In three of the cases the condition of the concrete base was evaluated. Both evaluations served as part of a planned reconstruction project in which the asphalt overlay was to be removed and replaced. The asphalt thickness information was used to determine bridge clearances above the original concrete surface after asphalt removal, and to estimate total asphalt removal quantities. Concrete condition assessment was used to estimate the location and extent of any repairs that would have to be made as part of the reconstruction project. The key features of each projects are summarized in Table 1.

The GPR data on these projects was collected using a 1 GHz horn antenna operating at normal driving speeds with the radar equipment mounted to a survey vehicle. The radar data was analyzed using automated software to determine layer thicknesses and concrete condition. The final analyzed data is presented in tabular form as Excel spreadsheets, and in graphical form as a series of longitudinal thickness plots and plan area condition maps. The I-495 and I-90 projects included correlation of the GPR data with core data taken on the pavement.

Ground penetrating radar equipment generates short pulses of electromagnetic energy, which penetrate into the pavement structure and reflect back from the material interfaces. The amplitude and arrival time of these return reflections are used to determine the thickness and properties of the pavement layers. The radar equipment used in this project is an air-coupled horn antenna suspended above the pavement surface. When mounted to a vehicle, this system can collect data at normal driving speed. The equipment was set up to generate approximately 1 scan per foot travel. These scans are continuously digitized and stored on the on-board computer. Markers placed in the data during the survey at mile markers and at other reference locations are used for ground control of the radar distance measurements.

DATA COLLECTION

GPR data was collected at normal driving speed, which ranged from 45 to 55 mph. The radar equipment used a 1 GHz short pulse horn antenna manufactured by Pulse Radar, Inc. of Houston, TX (for the I-495 project) and by Geophysical Survey Systems, Inc. (GSSI) of Salem, NH (for all other projects). In each application, the antenna was suspended from the survey vehicle with a nominal operating height of 18 inches above the pavement surface (see Figure 1). Each vehicle was equipped with a distance-measuring instrument (DMI), which electronically recorded longitudinal distance along with the GPR data. The GPR survey van was followed by a shadow vehicle. The shadow vehicle assisted the survey vehicle in maintaining lane alignment during the survey. No lane closures or traffic disruptions were required to conduct this work.

Prior to each the survey, reference locations were identified and, if necessary, marked along the side of the road. These reference locations included milepost markers, signs, and bridge decks. During the survey, manual markers were placed in the data when the survey vehicle crossed each of these locations. These control points were later used for DMI adjustments, are presented as reference locations in the output results. They are also used as reference points for verification coring. In order to provide condition data, multiple parallel survey lines were collected in each lane—one in each wheel path and one along the centerline.

DATA ANALYSIS

Principles of GPR Data Analysis

Upon completion of the survey, the data was copied to CD-ROM taken to the office for analysis. The pavement layer thickness analysis is carried out by computing the arrival times and amplitudes of the reflections from the different layers. Layer thickness is calculated from the arrival time of the reflection from the top and bottom of each layer as described in reference *(1)(2)*. Concrete deterioration can be inferred from changes in the dielectric properties of the concrete *(3)(4)(5)(6)*. This methodology was originally developed for overlaid decks, since access to the concrete surface via other traditional methods is limited. For overlaid concrete decks, the variation of the dielectric constant of the concrete is used to determine deterioration. Concrete with a high moisture and chloride content, as associated with corrosion damage and punky concrete, will produce highly variable reflections at the overlay/concrete boundary. These conditions can be quantified using the calculated dielectric constant of the concrete. The analysis principles previously applied to bridge decks were applied in this work to the overlaid concrete pavement.

Figure 2 shows samples of the raw GPR data. The I-495 data reveals the joints and the bottom of the concrete. The I-90 and I-95 data samples, however, do not reveal these features. Absence of the reflection from the bottom of the concrete is likely due to the similarity of dielectric constants between the concrete and the sub-base layers. This is frequently observed in concrete pavement on granular base. The absence of joint indications suggest that the dowel bar length may be too short or too widely spaced to be picked up by the GPR at the sampling rates used in this project. The analysis procedures discussed above have been applied to the raw data in order to calculate the layer thickness and concrete condition, as discussed in further detail below.

Layer Thickness Evaluation

For layer thickness evaluation raw data was analyzed at 2-foot intervals, and presented in both tabular and graphical formats. For the tabular format, the data was presented at 0.01 mile intervals, where each data value represented the average thickness over a 0.01 mile interval surrounding the reported location. The tabular data is provided as an Excel spreadsheet. For the plotted format, the data is presented at 2-foot intervals, where each data points represents the average thickness over a 10 foot interval surrounding the plotted point. In this way, the plots reveal some of the local irregularities that has been averaged out in the tabular results. A sample plot is shown in Figure 3. Both the tabular and graphical formats include the distance control points, which were marked during the conduct of the survey.

The graphical presentation in Figure 3 shows three lines representing the thickness in each of the three lanes surveyed. The gaps in the asphalt thickness data occur at bridge decks, where there is no asphalt present.

Asphalt/Concrete Interface Condition

To evaluate concrete condition, the data was analyzed to determine the concrete dielectric constant. The data analysis then identified those areas where the dielectric constant departed significantly from the mean. These are areas, which have either high or low moisture content, indicating either excessive moisture infiltration or high void content. Either of these conditions can be associated with deterioration at the bottom of the asphalt or within the upper 2 inches of the concrete. Areas showing these extremes in dielectric constant are highlighted in a plan view area map. The map was created from three survey lines per lane, or a total of nine survey lines in each direction. The map is generated from a contour plot of concrete dielectric constant, where the areas above and below the threshold are the only areas shown. A sample concrete condition map is shown in Figure 4. The shading on the map indicates the severity of the condition, ranging from low at the light end to high at the dark end.

DISCUSSION OF RESULTS

Comparison with Cores

Core data was collected on the I-495, I-90, and I-294 projects.

On I-495, a comparison between the analyzed GPR data and the core data was made to verify the accuracy of the calculations, and if necessary, to calibrate the analysis procedure. Asphalt thickness at four stations was measured along a calibration run behind an existing lane closure. Since there was no traffic, the GPR data was collected at low speed and the GPR data could be precisely identified at the core locations. Asphalt thickness was calculated from the GPR data for the calibration survey, and the calculated asphalt thickness was compared to the core data. The GPR thickness calculations were all within 5% of the core thickness. Based on this result, it was concluded that no calibrations would be necessary, and that the analytic procedure would meet the accuracy specifications of the project.

On I-90 and I-294, cores were taken and provided for comparison to the GPR data. Since all of the GPR data was collected at high speed, it was difficult to precisely locate the GPR data to coincide with the locations of the cores. Since most of the cores were taken at milepost markers, the manual marks placed in the GPR data were used as reference locations for the corresponding GPR data. It is estimated that the deviation between GPR and core locations might be between 5 to 10 feet using this method.

On I-90, data from 89 cores was collected and correlated with the GPR data at the core locations. In order to account for the possible location discrepancies, the average GPR thickness in the vicinity of the core was used for evaluation. A comparison of this data to the GPR data is shown in Figure 5(a). The solid line is the best linear fit to the data. The slope of the best-fit line is close to 1, but there is some scatter, and the R^2 value of the best fit line is 0.72. The average difference between GPR and core data is –0.1 inches, and the average absolute error is 0.4 inches.

A similar analysis with similar results was carried out for I-294. Data from 28 cores taken at mid-slab was collected and used for comparison with the GPR data. The comparison of this data to the GPR data showed an average deviation between core and GPR data of -0.01 inches, and an RMS error of 0.44 inches. The GPR data is plotted against the core data in Figure 5(b).

Thickness Distribution

The GPR layer thickness data was used to produce an overall picture of the thickness distribution for each of the roads tested. One presentation of this information is as a histogram of pavement thickness. Figure 6 shows thickness histograms for both the northbound and southbound lanes of I-95. The distribution shows the most frequently occurring thickness values, as well as the range of some of the outlier areas.

Concrete Condition

The plotted condition data for both I-90 and I-95 show localized areas where the dielectric contrast between the asphalt and the concrete is extreme (high or low). Figure 4 shows an example of one such plot. This can indicate moisture in the concrete or at the asphalt/concrete boundary, or it can indicate high air content in the concrete possibly due to cracking from freeze thaw or other damage mechanisms. Most of the areas shown in the plots are consistent across one or more lanes, indicating conditions that affect most of the roadway width. Such conditions might be related to drainage, subsurface support, profile, or other factors affecting the entire roadway at these locations. Ground truth data on concrete condition was not available for the reported projects.

CONCLUSIONS

Ground penetrating radar (GPR) has shown to be and effective and accurate means for characterizing asphalt overlay thickness on composite pavement structures. This thickness data is useful in determining bridge clearances, material removal quantities for rehabilitation purposes. The GPR capability is particularly valuable on high-density roads where lane closures for this purpose are prohibitive. GPR data can also be used to assess the condition of the concrete under the overlay for estimating repair requirements during rehabilitation.

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TABLE 1 Summary of Key Features of Each Survey

PROJECT	LOCATION	LENGTH (MI)	PROJECT LIMITS	# OF LANES	EVALUATION
I-495 Long Island Expy.	Nassau, NY	9	exits 32 to 40	3 in each direction	AC thickness
I-94 Connecticut Turnpike	New Haven, CT	4	exits 50 to 54	3 and 2 in each direction	AC thickness and concrete condition
I-90 Northwest Tollway	Chicago, IL	15	MP 0-15	3 in each direction	AC thickness and concrete condition
I-294 Tri-State Tollway	Chicago, IL	18	MP 0-15	3 in each direction plus shoulders and ramps	AC thickness
Grand Central Pky	New York City	9	Bell Blvd. to the Triborough Bridge	3 and 4 in each direction	AC thickness and concrete condition

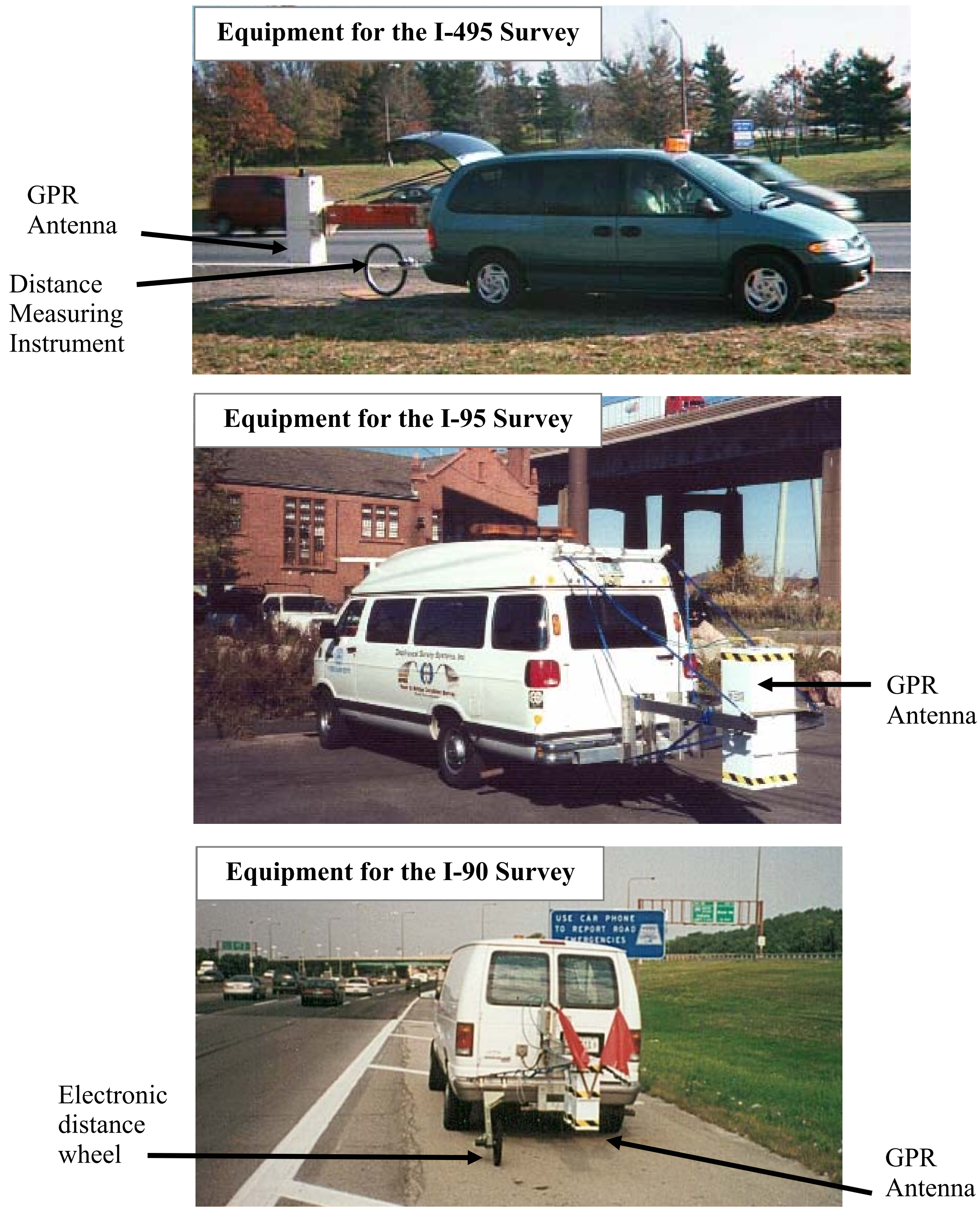
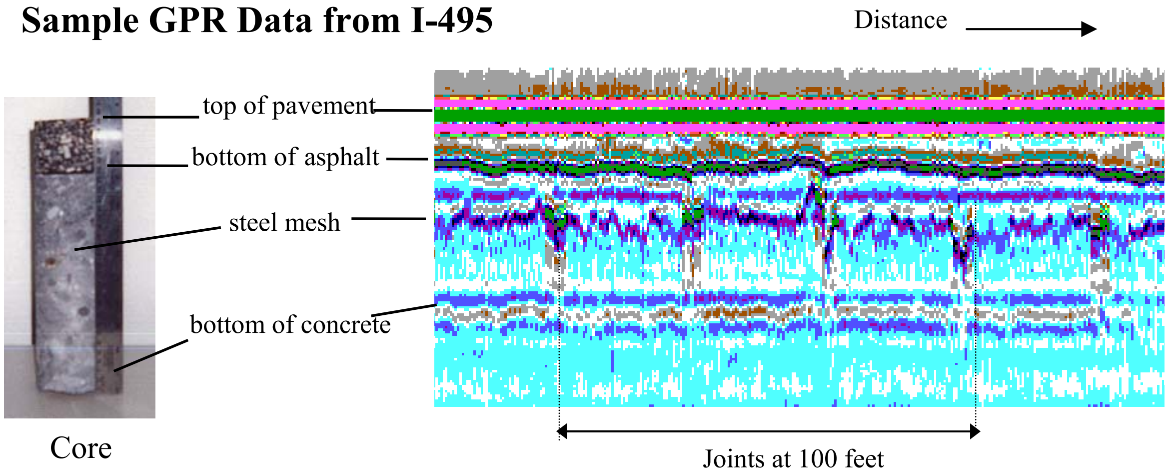
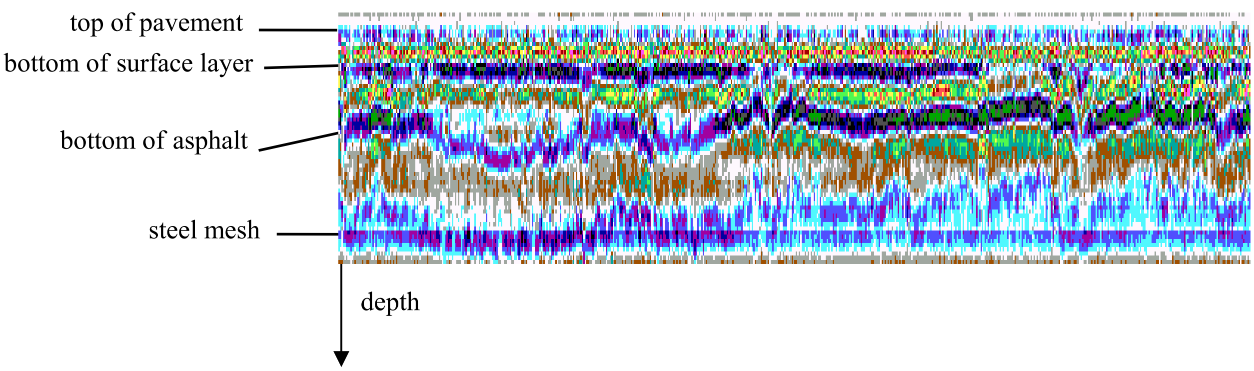


FIGURE 1 Examples of Equipment used for GPR Data Collection.

Sample GPR Data from I-495



Sample GPR Data from I-90



Sample GPR Data from I-95

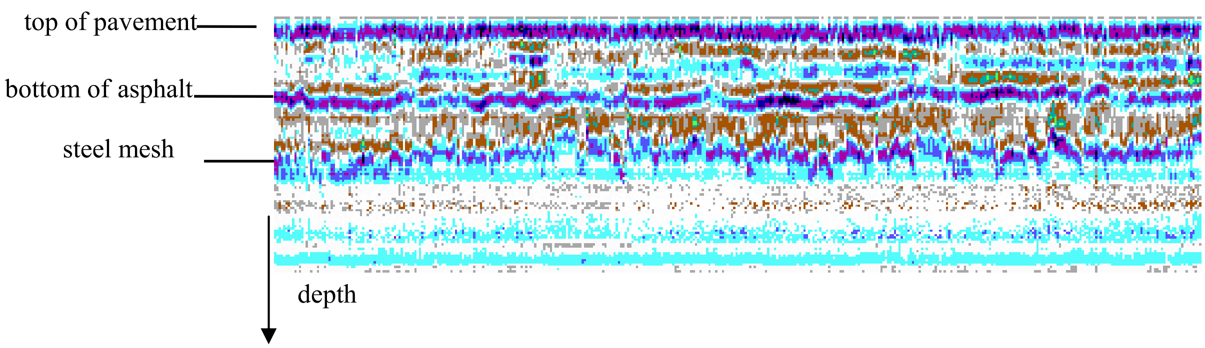


FIGURE 2 Samples of Raw GPR Data.

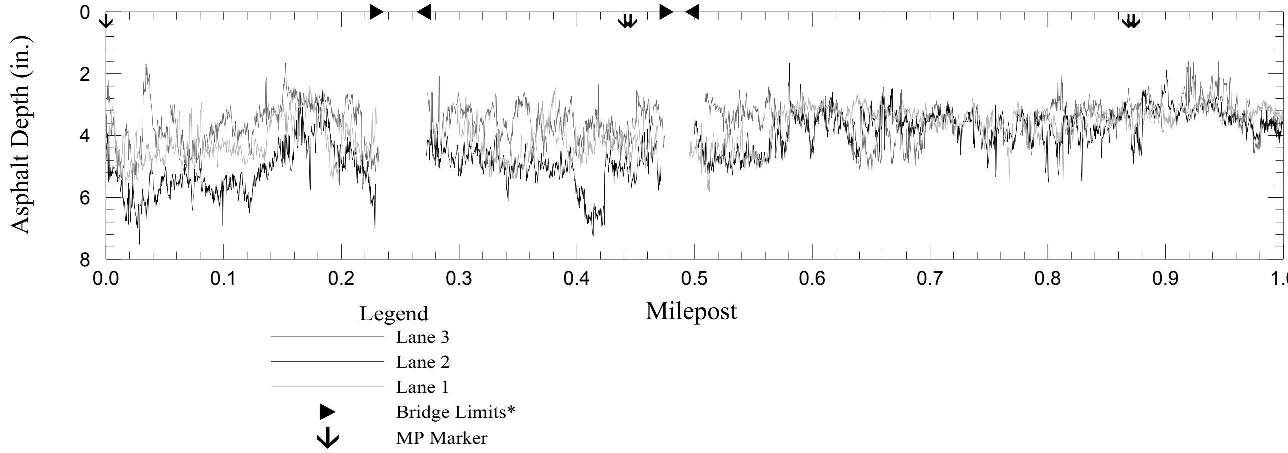


FIGURE 3 Sample of Graphical Thickness Survey Output (from I-90).

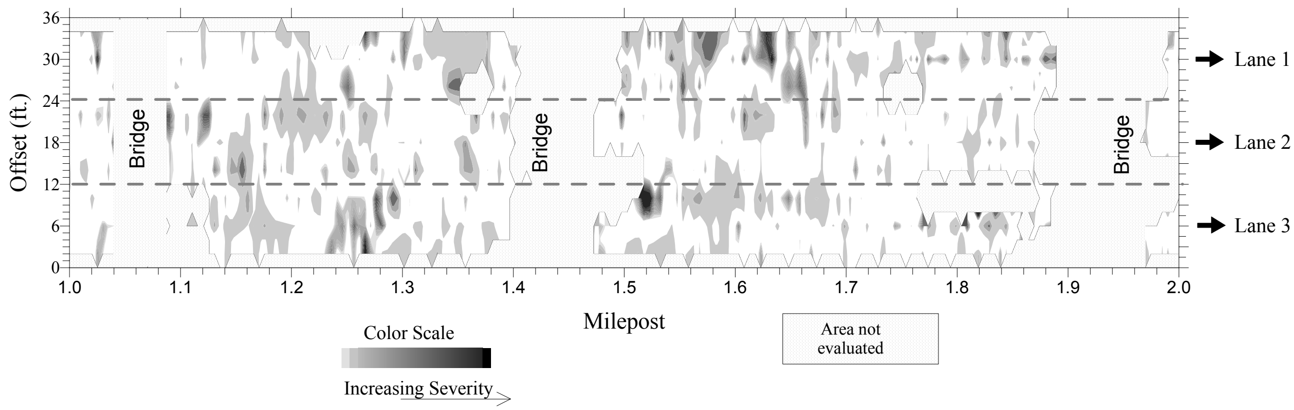
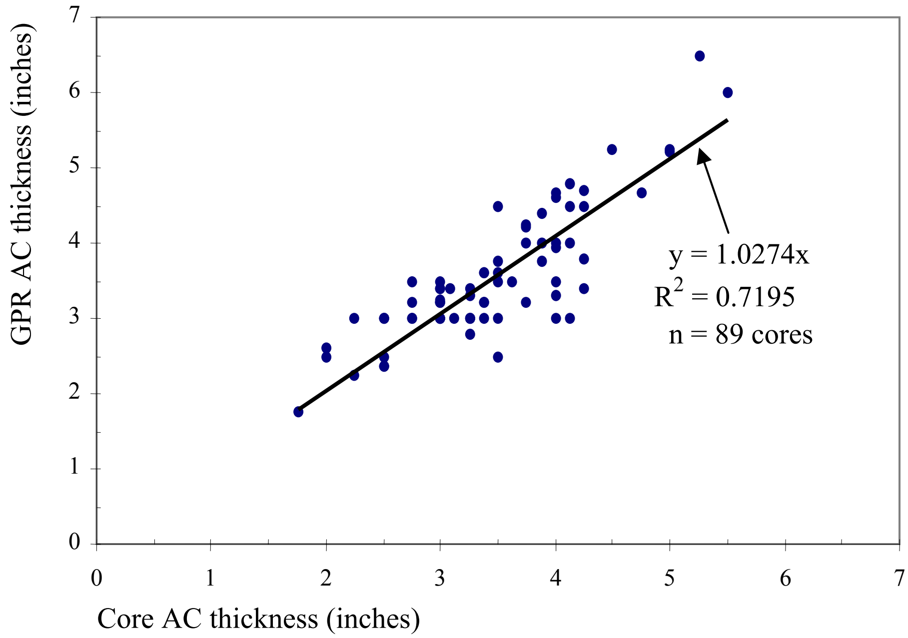
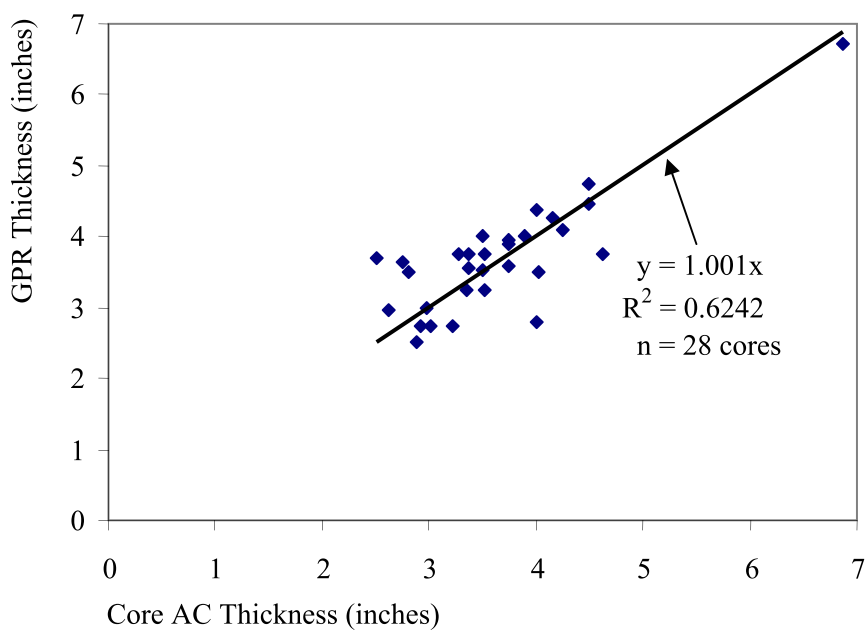


FIGURE 4 Example Concrete Condition Map for I-90.

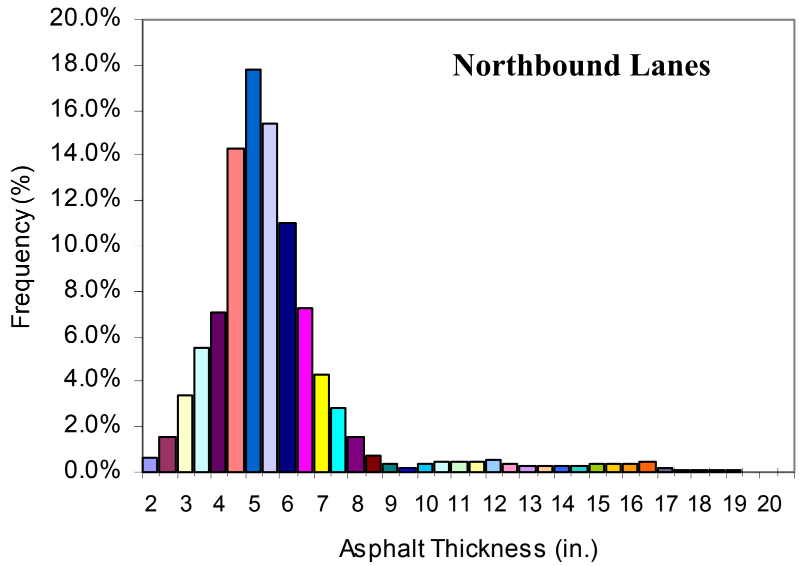


(a) I-90



(b) I-294

FIGURE 5 GPR vs. Core Thickness for Asphalt Overlay.



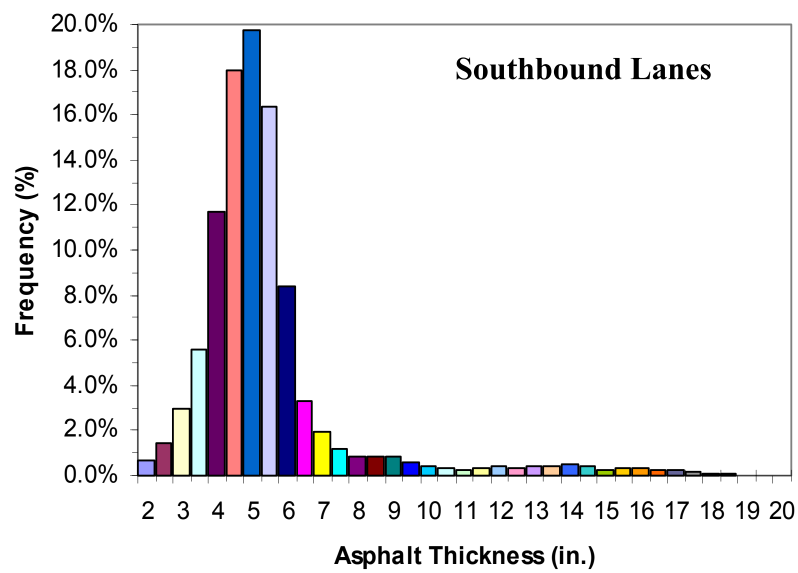


FIGURE 6 Frequency Distribution of Asphalt Thickness for I-95.