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Rutgers/NJDOT Pavement Resource Program (NJDOT Statewide GPR Project Network GPR Data Collection and Analysis Update of HPMA GPR Database)

FINAL REPORT
May 2008

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16. Abstract

Center for Advanced Transportation Infrastructure (CAIT) of Rutgers University is mandated to conduct Ground Penetrating Radar (GPR) surveys to update the NJDOT's pavement management system with GPR measured pavement layer thicknesses. Based on the review of the GPR data currently in the pavement management system, it has been identified that 2328 miles of pavement have "No GPR Data," and 1550 miles of pavement have data with "Gaps". Gaps generally refer to missing portions of data of about 50 to 100 ft in length. The number and distribution of Gaps vary. In some cases, the sections with gaps contain adequate GPR information to interpolate thicknesses between the gaps. For the purpose of this work plan, the section with "No GPR Data" are considered to be of the highest priority.

As a part of the Pavement Management Systems (PMS) project, ground-penetrating radar (GPR) surveys were conducted at locations throughout New Jersey. Interpretations of the survey information were conducted for network-level pavement management purposes. The objective of the work was to provide NJDOT with information obtained by the GPR survey regarding pavement structure and layer properties (thickness, dielectric, etc…) to aid at decision-making, improvement of FWD back-calculation or characterization of pavement thickness variability over potential project sections.

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INTRODUCTION

Center for Advanced Transportation Infrastructure (CAIT) of Rutgers University is mandated to conduct Ground Penetrating Radar (GPR) surveys to update the NJDOT's pavement management system with GPR measured pavement layer thicknesses. Based on the review of the GPR data currently in the pavement management system, it has been identified that 2328 miles of pavement have "No GPR Data," and 1550 miles of pavement have data with "Gaps". Gaps generally refer to missing portions of data of about 50 to 100 ft in length. The number and distribution of Gaps vary. In some cases, the sections with gaps contain adequate GPR information to interpolate thicknesses between the gaps. For the purpose of this work plan, the section with "No GPR Data" are considered to be of the highest priority. Detailed information of these sections is presented in Table 1. The geographical distribution of these sections is also depicted on the New Jersey State map as presented below. Red lines on the figure indicate the sections with no GPR data.

As a part of the Pavement Management Systems (PMS) project, ground-penetrating radar (GPR) surveys were conducted at locations throughout New Jersey. Interpretations of the survey information were conducted for network-level pavement management purposes. The objective of the work was to provide NJDOT with information obtained by the GPR survey regarding pavement structure and layer properties (thickness, dielectric, etc…) to aid at decision-making, improvement of FWD back-calculation or characterization of pavement thickness variability over potential project sections.

The project included field surveys, associated data analysis, and reporting on approximately 1254 directional miles (roughly one quarter the State's network) of pavements designated as network-level investigations. Pavements consisted of all pavement types (flexible, rigid and composite) and were located throughout New Jersey. Surveyed sections are listed in Table 1.

SCOPE OF THE WORK

The envisioned work consists of surveying and analysis of 2328 miles of pavement having "No GPR Data," during the 2007 and 2008 analysis periods. This report addressed the data collection and analysis of 1232 miles of pavement sections with "No GPR Data". These sections are marked and highlighted in Table 1. The data on the remainder of the 2328 miles of pavement sections will be completed in the 2008 analysis periods.

Table 1. US and State highway sections surveyed.

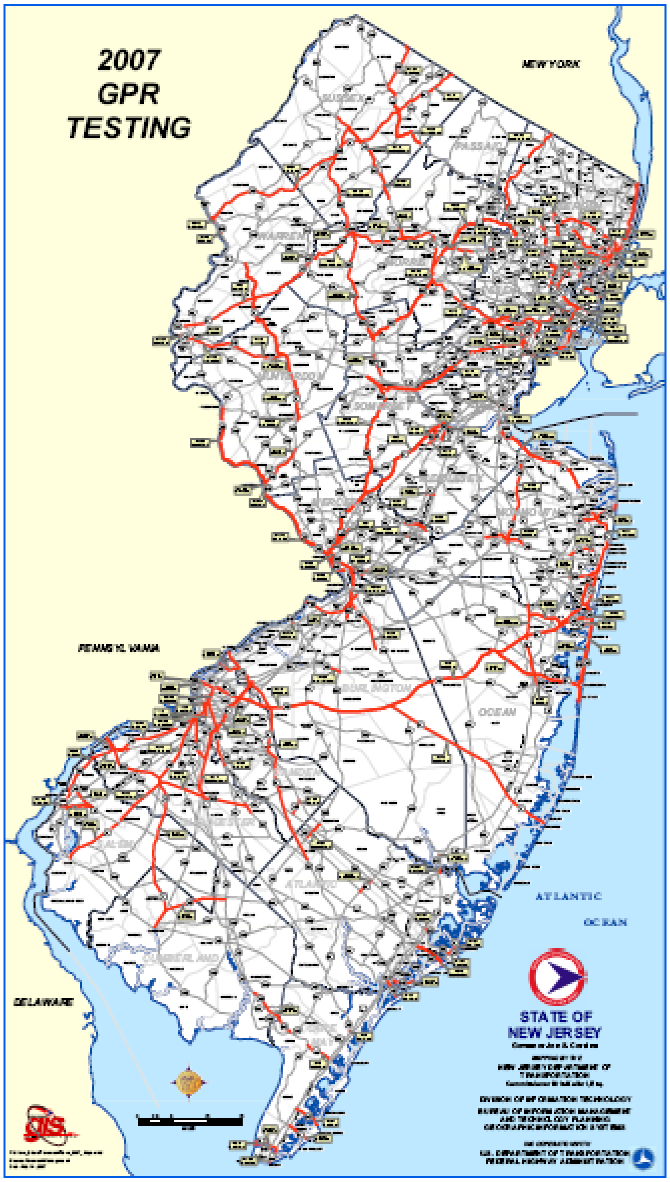
Rt. Type	*Rt. No.*	*Rt. Aux.*	*Dir*	*MP From*	*MP To*	*Section Length*
US	*1*	*B*	S	2.73	0	2.73
US	*1*	*B*	N	0	2.73	2.73
NJ	*26*		W	1.92	0	1.92
NJ	*26*		E	0	1.92	1.92
NJ	*27*		S	33.5	38.35	4.85
NJ	*27*		S	22	33.5	11.5
NJ	*27*		S	22	10	12
NJ	*27*		S	10	0	10
NJ	*27*		N	0	9.67	9.67
NJ	*27*		N	9.67	17	7.33
NJ	*27*		N	17	29	12
NJ	*27*		N	29	38.35	9.35
NJ	*28*		W	26.22	20	6.22
NJ	*28*		W	20	14.66	5.34
NJ	*28*		W	14.66	9	5.66
NJ	*28*		W	9	0	9
NJ	*28*		E	0	7	7
NJ	*28*		E	7	12	5
NJ	*28*		E	12	21.9	9.9
NJ	*28*		E	21.9	26.22	4.32
NJ	*29*		N	0	8	8
NJ	*29*		N	8	18.9	10.9
NJ	*29*		N	18.9	20	1.1
NJ	*29*		N	20	34.76	14.76
NJ	*29*		S	34.76	20	14.76
NJ	*29*		S	20	10	10
NJ	*29*		S	10	0	10
NJ	*31*		N	21.95	37	15.05
NJ	*31*		N	37	48.93	11.93
NJ	*31*		S	48.93	34	14.93
NJ	*31*		S	34	22	12
NJ	*33*	*B*	S	6.98	0	6.98
NJ	*33*	*B*	W	0	6.98	6.98
NJ	*35*		E	22.25	13	9.25
NJ	*35*		S	13	0	13
NJ	*35*		S	0	15	15
NJ	*35*		N	15	22.25	7.25
NJ	*35*		N	49.3	34.5	14.8
NJ	*35*		S	34.5	49.3	14.8
US	*40*		N	5.64	1.7	3.94
US	*40*		W	1.7	5.64	3.94

Rt. Type	*Rt. No.*	*Rt. Aux.*	*Dir*	*MP From*	*MP To*	*Section Length*
NJ	*41*		E	0	14.22	14.22
NJ	*41*		N	14.22	0	14.22
NJ	*44*		S	9.59	0	9.59
NJ	*44*		S	0	9.59	9.59
NJ	*45*		N	28.51	13	15.51
NJ	*45*		S	13	0	13
NJ	*45*		S	0	13	13
NJ	*45*		N	13	28.51	15.51
NJ	*47*		N	62.83	75.19	12.36
NJ	*47*		S	75.19	62.83	12.36
NJ	*48*		E	0	4.25	4.25
NJ	*48*		W	4.25	0	4.25
NJ	*56*		E	0	6.7	6.7
NJ	*56*		E	7.5	9.19	1.69
NJ	*56*		W	9.19	7.5	1.69
NJ	*56*		W	7.5	5	2.5
NJ	*56*		E	6.7	7.5	0.8
NJ	*56*		W	5	0.15	4.85
NJ	*56*		W	0.15	0	0.15
NJ	*57*		E	0	10	10
NJ	*57*		E	10	21.1	11.1
NJ	*57*		W	21.1	8	13.1
NJ	*57*		W	8	0	8
NJ	*70*		E	26	36	10
NJ	*70*		E	36	51	15
NJ	*70*		E	51	59.84	8.84
NJ	*70*		W	59.84	51.3	8.54
NJ	*70*		W	51.3	44	7.3
NJ	*70*		W	44	30	14
NJ	*70*		W	30	10	20
NJ	*70*		W	10	0	10
NJ	*70*		E	0	11	11
NJ	*70*		E	11	26	15
NJ	*72*		E	0	17	17
NJ	*72*		E	17	28.74	11.74
NJ	*72*		W	28.74	13	15.74
NJ	*72*		W	13	0	13
NJ	*73*		N	22	34.6	12.6
NJ	*73*		S	34.6	14	20.6
NJ	*73*		S	14	0	14
NJ	*73*		N	0	12	12
NJ	*73*		N	12	22	10
NJ	*77*		S	22.55	10	12.55
NJ	*77*		S	10	0	10

Rt. Type	*Rt. No.*	*Rt. Aux.*	*Dir*	*MP From*	*MP To*	*Section Length*
NJ	*77*		N	0	10	10
NJ	*77*		N	10	22.55	12.55
NJ	*79*		S	12.13	0	12.13
NJ	*79*		N	0	12.13	12.13
NJ	*91*		W	2.26	0	2.26
NJ	*91*		E	0	2.26	2.26
NJ	*122*		W	2.42	0	2.42
NJ	*122*		E	0	2.42	2.42
US	*130*		S	9	0	9
US	*130*		N	0	9	9
US	*130*		N	9	14.5	5.5
US	*130*		N	23.5	30	6.5
NJ	*140*		E	0	0.96	0.96
NJ	*140*		W	0.96	0	0.96
NJ	*171*		S	2.81	0	2.81
NJ	*171*		N	0	2.81	2.81
NJ	*172*		E	0	0.81	0.81
NJ	*172*		W	0.81	0	0.81
NJ	*173*		W	14.62	12.81	1.81
NJ	*173*		W	11.7	0	11.7
NJ	*173*	*W*	E	0	11.7	11.7
NJ	*173*	*W*	E	12.81	14.62	1.81
US	*202*		N	31	40	9
US	*202*		N	40	44.6	4.6
US	*202*		N	44.6	51	6.4
US	*202*		N	51	62	11
US	*202*		N	62	62.8	0.8
US	*202*		N	65.52	68.5	2.98
US	*202*		N	68.5	80.31	11.81
US	*202*		S	80.31	67.1	13.21
US	*202*		S	67.1	65.4	1.7
US	*202*		S	63	56.4	6.6
US	*202*		S	56.4	42	14.4
US	*202*		S	42	31.51	10.49
US	*206*		N	78.32	95.6	17.28
US	*206*		N	97.1	110	12.9
US	*206*		N	110	116.54	6.54
US	*206*		S	116.54	107	9.54
US	*206*		S	107	97.1	9.9
US	*206*		S	95.61	78.32	17.29
US	*206*		S	71.64	54	17.64
US	*206*		S	54	36	18
US	*206*		S	35.4	31.3	4.1
US	*206*		N	31.3	46	14.7

Rt. Type	***Rt. No.***	***Rt. Aux.***	***Dir***	***MP From***	***MP To***	***Section Length***
US	*206*		N	46	60	14
US	*206*		N	60	71.62	11.62
US	*206*	*Z*	S	45.36	42.57	2.79
I-	*287*	*L*	N	17.84	21	3.16
US	*322*		E	0	11.1	11.1
US	*322*		E	11.2	25.88	14.68
US	*322*		W	25.88	11.2	14.68
US	*322*		W	11.1	0	11.1
NJ	324		E	0	1.51	1.51
NJ	324		W	1.51	0	1.51

The purpose of the project was to collect GPR data in both directions of State-maintained roads to assess pavement layer thickness. The layer thickness will be used as input to the HPMA database.



BACKGROUND

A GPR antenna transmits high-frequency EM (Electro-Magnetic) waves into the ground. A portion of the energy is reflected back to the surface from the interface of two adjacent (usually layered) materials with different electrical properties and it is received at the antenna. Schematic of a single GPR measurement and its idealized record for flexible and rigid pavement profiles are shown in Figure 1. To construct a GPR profile, several measurements are made along the survey line and the reflected wave amplitudes for each scan are plotted with different colors to construct a GPR profile. A typical GPR profile is shown in Figure 2. In most ground-coupled antenna surveys, high-amplitude, hyperbolic reflections (arch-shaped features) are generally observed in GPR records over buried metallic objects such as pipes and tanks, but these “hyperbolas” are commonly seen when the antenna passes over point targets such as rounded boulders or even PVC (usually water-filled, but sometimes gas) utilities.

When horn (air-coupled) antennas are used for high-speed pavement or bridge deck surveys, however, the most likely high-amplitude reflections existing in the data occur from man-made interfaces such as pavement layers, pavement overlays on concrete bridge decks, steel mesh or reinforcing mats, and bridge deck bottoms. Other common interfaces seen in the data include reflections from asphalt or concrete pavement and the base material beneath it, the base/subbase interfaces, and subbase/subgrade contacts within a pavement system. The measured time of arrival of each of these signals and its amplitude are used to measure and estimate (by way of calculation using a calibrated data collection technique) subsurface “target” depths, GPR propagation speed, and often, subsurface structural condition.

GPR has been used with varying degrees of success to solve a variety of subsurface investigation problems. Its use in pavement and transportation infrastructure assessments or quality assurance (QA) inspections has recently grown, and it is rapidly becoming an accepted (and recommended) non-destructive evaluation (NDE) technology in this field. In recent years, improvements in systems, sensors (antennas) and computing capability have allowed experienced GPR service-providers to both (a) collect and process data in a rapid fashion, and (b) accurately assess the condition of both existing structures (in-service inspections) and new construction (Quality Assurance—QA).

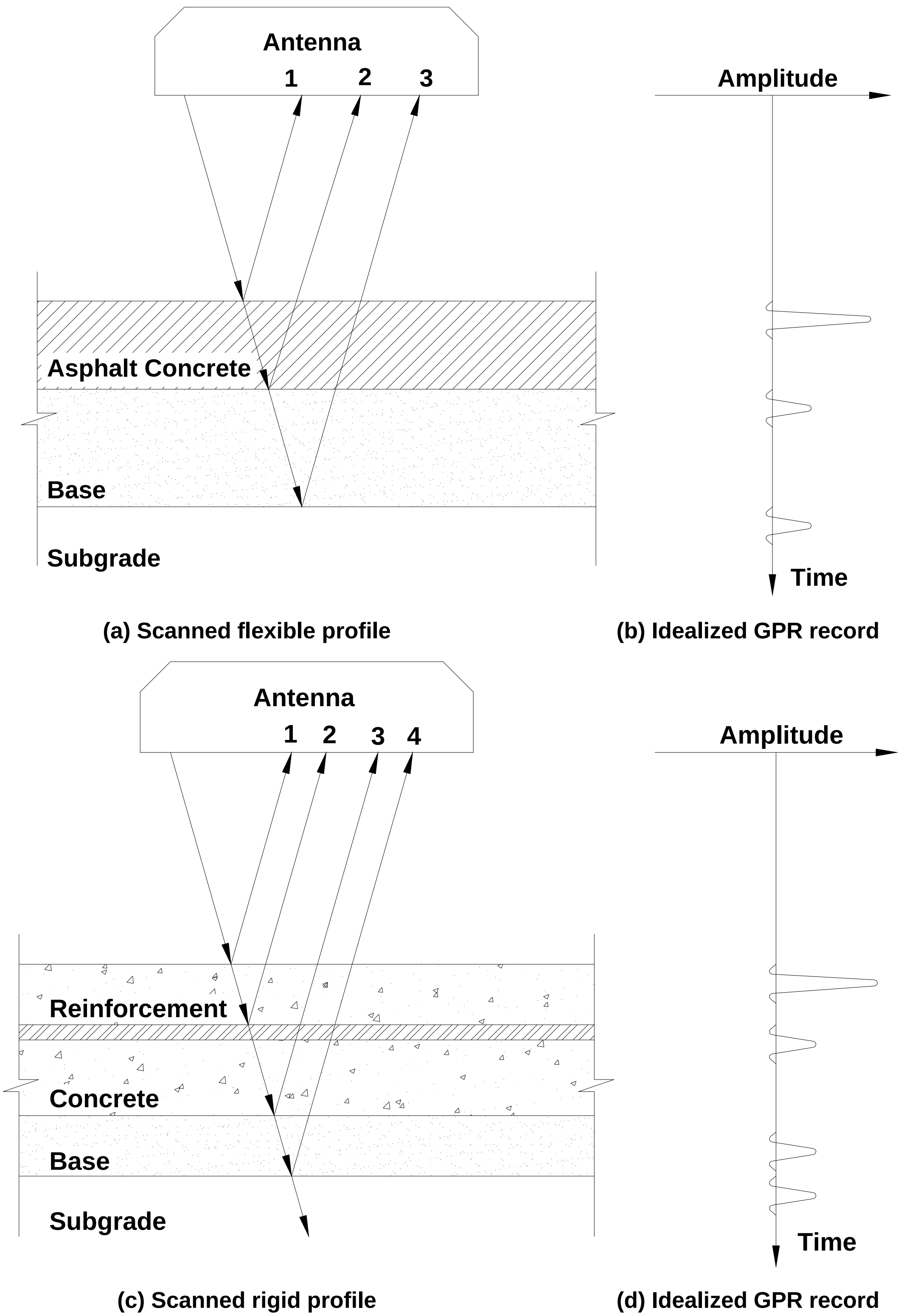


Figure 1. Schematics of a GPR measurement and its idealized record for flexible and rigid pavement profiles.

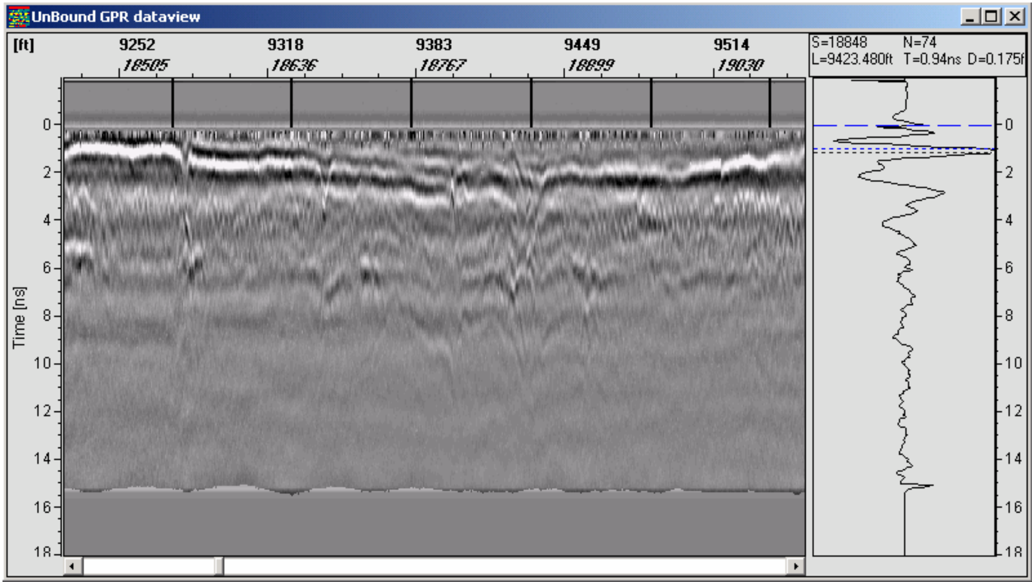


Figure 2. A typical GPR profile.

SURVEY EQUIPMENT

Equipment setup for surveys is shown in Figure 3 and 4. As shown in these Figures, GPR equipment consisted of a Geophysical Survey Systems Inc. (GSSI) SIR-20 two-channel data acquisition unit controlled by a rugged-ized portable laptop; a 1000 MHz (1 GHz) air-coupled (horn) antenna designed for high-speed, non-contact surveys over pavements and bridge decks; a portable (shippable) antenna deployment frame with an attached survey wheel; vehicle mounted Nu-metrics® distance-measuring instruments (DMI); digital video camera mounted on the vehicle; additional laptop computer for image capturing, and Trimble AgGPS-132® Differential GPS receiver and antenna.

(a) Vehicle setup for surveys

(b) SIR-20 data acquisition unit and GPS Receiver

Figure 3. (a) Equipment setup for surveys and (b) SIR-20 data acquisition unit and GPS receiver.

(a) Survey wheel, GPS antenna and GPR antenna

(b) Laptop computers for GPR and video data collection

Figure 4. (a) Another view of equipment setup and (b) laptop computers for data collection.

All the GPR equipment used in the survey are manufactured by Geophysical Survey Systems, Inc. (GSSI), and represents the latest in highway GPR systems. All the network level data were collected using SIR-20 (SIRveyor model) two-channel, high-speed data acquisition unit and Model 4108 transceiver TEM horn antennas (1 GHz), at speeds requiring no traffic control. GSSI Model SIR-20 Data Acquisition System is the only GPR unit capable of data collection at rates at, or in excess of, 300 scans/second. Precision and bias of the GPR system conforms to ASTM D 4748-98; the antenna was shielded from interference due to other sources of electromagnetic radiation such as mobile phones and radio during data collection; and the system was capable of collecting data at scan intervals of 1 to 10 ft at the appropriate vehicle speed. GSSI provides a certificate of calibration which verifies that the system has undergone the required tests for (1) reflection tests (metal plate and end reflection), (2) noise to signal ratio (SNR) test, (3) long-term signal stability test, (4) signal stability test, and (5) concrete penetration test.

The GPR vehicle was equipped with two distance-measuring instruments (DMI), each of a precision higher than 1 ft per mile (0.0189% of measured distance) at an operating speed of 65 mph. The Nu-Metrics® DMI was capable of automatically displaying the distance and vehicle speed. The higher-resolution, encoder-based DMI provided higher quality GPR data, yet does not have a capability for displaying vehicle speed. Due to higher resolution of encoder-based DMI all surveys was conducted using survey wheel as data acquisition trigger.

During all surveys, there was digital camera recording of the pavement with live audio feed from operator marking special pavement features and indicating milepost. A separate laptop computer controlled the camera and images were streamed to computer simultaneously during surveys.

A Trimble AgGPS-132 ® differential GPS (DGPS) antenna and receiver was also mounted on GPR vehicle. GPS coordinates of survey line were recorded with a frequency of 1 Hz simultaneous with collection of GPR and digital video images.

Video and GPS coordinates were collected and synchronized simultaneously using RoadCamGui Software produced by Road Scanners ®. This software enables synchronization of GPS and video images collected during surveys. These data were later on synchronized with GPR scans based on distance measured separately with survey wheel from start of survey line.

METHODOLOGY & DATA QUALITY

Data from the antenna were collected while surveying at posted speeds averaging between 50 and 60 mph on highways and expressways, and 30-50 mph on local roads on the network level. All surveys were performed without any traffic control.

Due to higher resolution and better results of encoder-based survey wheel, the wheel was set to record data to the hard drive at a distance-based rate of 2 scans/foot for all surveys (while the system generated scans at a time-based rate was increased to 250 scans/second). The encoder-based survey wheel was calibrated over a distance of 300 feet prior to any survey.

The SIR-20 data acquisition unit can collect data at rates of up to 800 scans/second. If transmit frequency is set above 500 KHz the unit provides optimum data quality as a result of more sample-averaging (to improve signal-noise ratio) which occurs at the higher transmit rates. However at excessively high transmit rates slightly degraded signal is also generated. The slight gain in signal quality from more sample averaging (at the >500 kHz rate) does not compensate for the decrease in quality that also occurs at that rate. Since at all surveys, high survey speeds was critical and there was not a need to sample in a spatially dense (many scans/foot) fashion, the balance of moderately high transmit rate of 450 KHz and moderate scan rate of 250 scans/second with 2 scan/foot data output produced extremely high signal quality.

This is essential for a GPR pavement thickness survey, where material dielectric properties (and GPR propagation speeds through the pavement) are calculated from the measured data at each scan location, and dielectric properties are used to convert measured travel time to depth (and thickness) values for the layers in the pavement system. Additionally, increased signal-noise ratio (GSSI SIR-20 provides the cleanest signal among all GSSI systems) allows for slightly greater penetration—all other things equal (antennas)—in situations where GPR penetration is difficult, i.e. many concrete pavements.

Data collection setting and parameters, including scans/second, scans/ft, and ft/mark are user-specified inputs that affect respectively how many scans of GPR data are collected in any given second, how many scans are written to the data file based on distance traveled, and how often a visual mark will be placed in the data at a user-specified distance interval. Other user defined parameters such as time Range (ns), samples/scan and bits/sample all affect the "depth sample" and resolution of the data, and can affect whether a high-quality signal is recorded as such. The values for these parameters and other settings for surveys are shown in Figure 5.

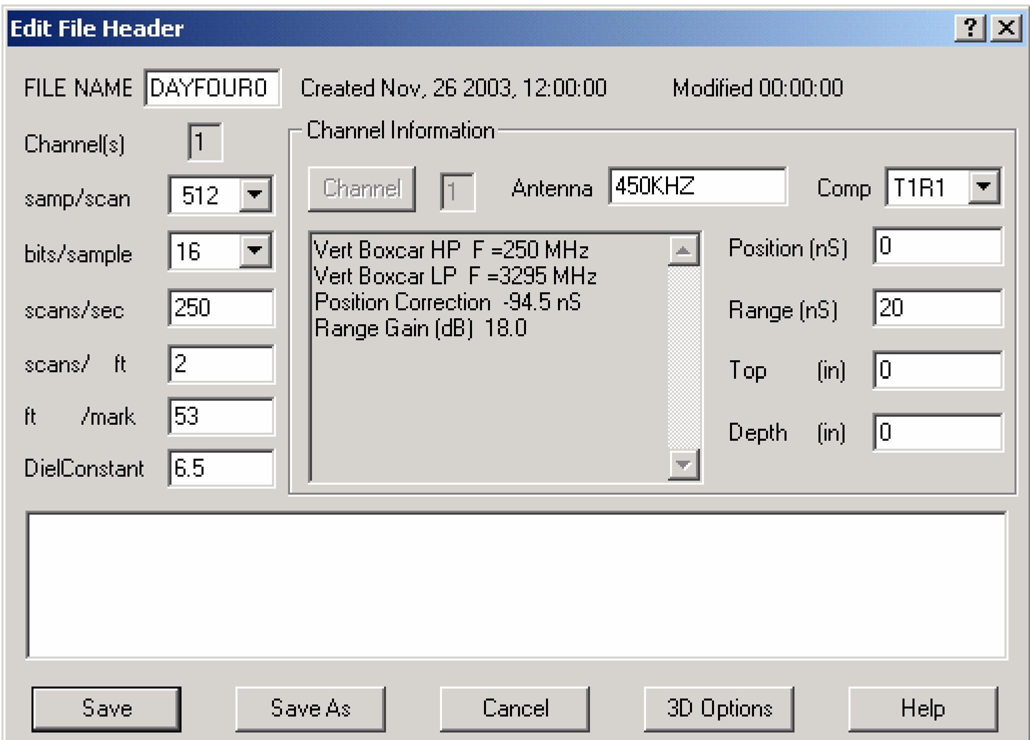


Figure 5. Data collection setting and parameters for surveys.

In all of the pavement surveys, required scan density (for reporting and/or data collection) was maximized—more scans/foot were collected than required by specification—so that better interpretations could be made. Very often, increased spatial density makes all the difference between an accurate and an inaccurate pavement layer interpretation. Often, horizontal stacking or "smoothing" the data from a sample with greater spatial sampling can minimize local aberrations (electronic artifacts) in the measured signal that are not representative of true subsurface properties. The end result is that there is greater flexibility, when required, to post-process the data and accurately interpret it when signal response is less than desirable. After interpretation is completed, it is routine practice to reduce the data output to the client's specified reporting interval (i.e. 0.01 Mile).

Each GPR scan produces information about the layer interfaces. These scans, interpreted for layer properties such as thickness or layer dielectric constant, provide a “depth sample”. A “depth sample” simply refers to the fact that the GPR signal, at every scan location, provides information about all the pavement layers in a vertical sequence. When evaluating pavement variation along its length, including layer structure variation and thickness of the various pavement components, GPR’s high spatial scan density can be thought of as being equivalent to a like number of core samples. If 2 scans/foot of data are collected, this profile information is quite comparable (though not as exact) to extracting cores every six inches along the pavement’s length—or slicing a continuous vertical section, 2 to 3 feet in depth, along the entire GPR survey path

There was simultaneous acquisition of digital video data. The captured images were used during interpretation, and reporting to determine details such as survey lane ID and its changes during survey or help to interpret special visually visible pavement features. The video images were also used to verify interpreted pavement structure to the extent possible from visual inspection (i.e. first paving layer type, and possibly verification of composite pavements).

Coordinates of the survey line are also recorded using Trimble *Ag*GPS® 132, a high-performance GPS receiver that uses either free public or subscription-based differential correction services to calculate sub-meter positions in real-time with a frequency of 1 Hz.

GPR scans, Video images, GPS coordinates along with New Jersey DOT official transportation map, as shown in Figure 6, are synchronized and linked together using Road Doctor™. Road Doctor™ is software, which can read, link, and output various survey datasets (including GPR, FWD, Video, and data already stored in PMS databases). The software can both processes GPR data and link it to any other distance- or coordinate-based pavement data, including a PMS. A typical Road Doctor™ view of linked GPR, video, and roadway map is shown in Figure 7. All surveyed data are linked before any post processing and all the processed data are submitted along with created Road Doctor™ files.

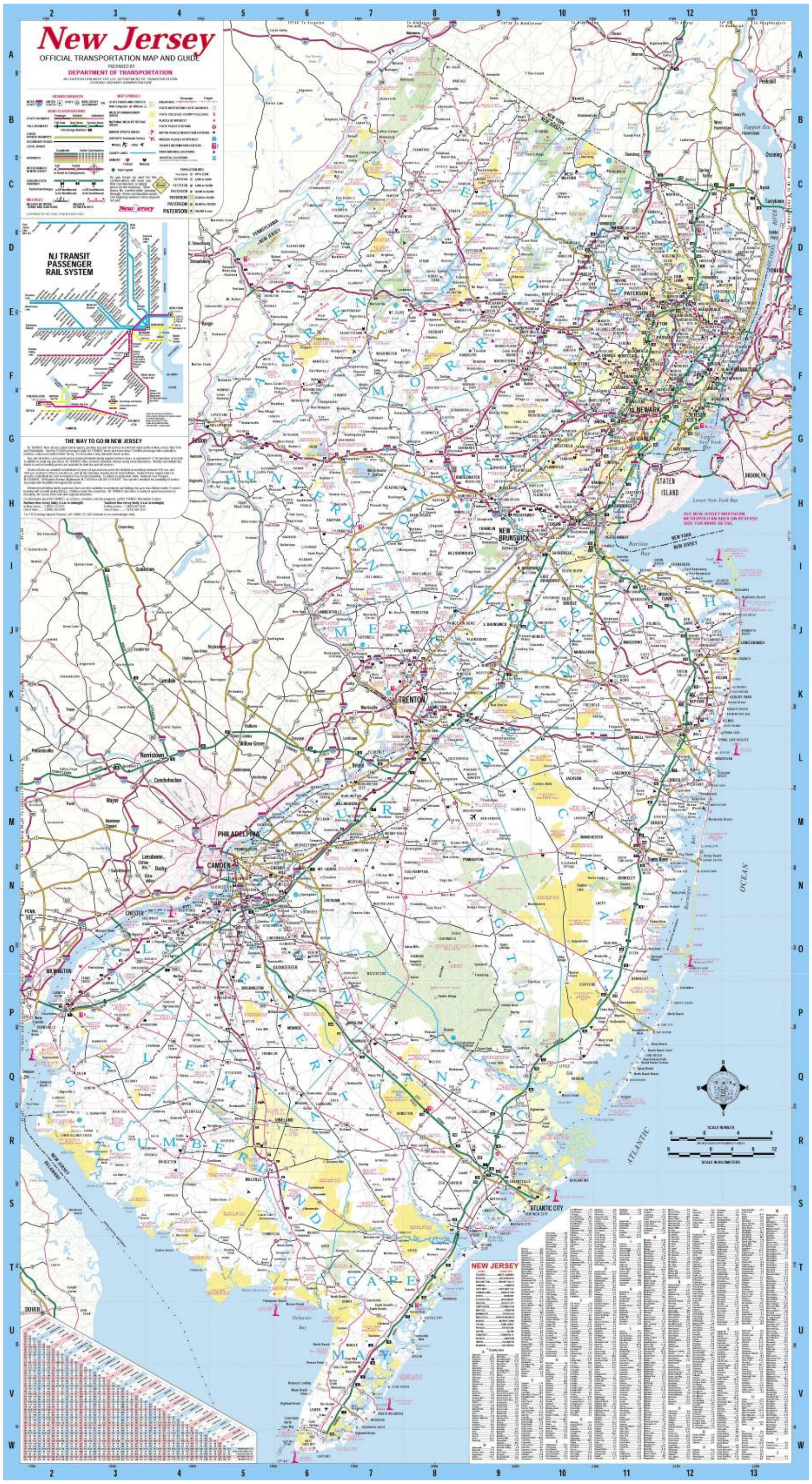


Figure 6. New Jersey DOT Official Transportation Map.

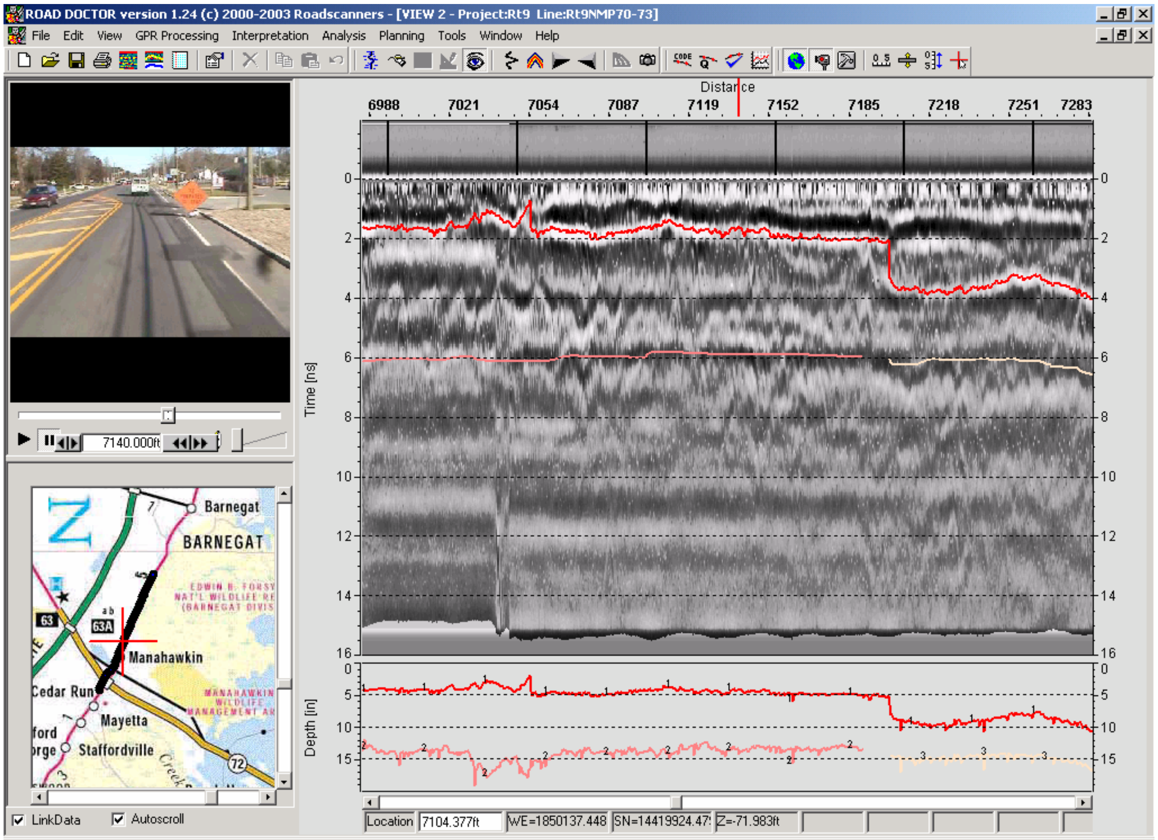


Figure 7.Typical Road Doctor™ view of linked GPR, video, and roadway map (US-9 NB near milepost 71)

DATA COLLECTION (FIELD) PROCEDURES

GPR Data Collection was collected with carefully designed and consistent procedures to ensure the quality of the data. These quality control/quality assurance (QA/QC) procedures are:

- At least 25 to 30 minutes of system/antenna warm-up, prior to collecting either calibration data or field data was assigned to ensure that antenna electronics have stabilized so that a consistent signal is generated throughout the duration of survey.

- Both DMI and survey wheel were calibrated carefully over a 300 feet interval prior to any surveys.
-
- Prior to any survey, presence of differential beacon is verified and necessary changed were applied to GPS receiver settings to ensure highest quality GPS coordinate readings.

- Horn antenna mounted on fiberglass rails, extended at least 3 feet distance from the back of the survey vehicle. Cross section of any nearby metallic objects was minimized to minimize unwanted reflections in data. Ratchet straps are used to stabilize the antenna and minimize vibration as well as to fine tune antenna deployment height to about 20 inches (the optimal deployment height for peak performance). Finally, antenna cable is secured to minimize unwanted signals and prevent any damage to antenna connections.

- Metal plate calibration scans with the same survey setting were collected at each day of testing. During long testing (more than app. 6 hours), two metal plate calibration scans were collected.

- All surveys where conducted at 50-60 mph on highways and expressways and at 30-50 on local roads. Lane closures were not necessary for these surveys. Due to safety precautions, all surveys were performed with yellow strobes and work lights.

- The vehicle was driven in a constant position with respect to the lane's width, i.e. it was driven to "center" the vehicle midway between the lane stripes while driving. Extreme care was taken (including surveying as close to mentioned speeds as traffic would allow) to remain in that lateral position throughout the length of each GPR profile line during testing. When lanes merged, or divided (as often occurs when the travel lane becomes the exit lane for a ramp near an exit) or lanes had to be changed, a quick lane change was made to possibly maintain the "lane ID". The recorded survey video is used to verify any locations where this may have occurred and the changes are reported in final Excel sheet results.

- As the data profiles were collected, the continuously streaming GPR record was viewed by the GPR operator on the laptop's monitor to ensure recording of good quality data.

- The location (milepost) of the test data are marked manually on GPR data with markers and clearly marked on video through audio input of operator at interval ranging between 0.1 ~2 mile based on the availability of mile markers on the road. These marks were used later during processing and reporting to correct any possible errors in distance measurements with DMI or survey wheel.

- Upon completion of each day of testing all gathered data were backed up immediately for future processing.

DATA PROCESSING

Data were collected using GSSI's **RADAN®** (**RA**dar **D**ata **AN**alyzer) software with Road Structure Assessment (RSA) Module. However, Data were processed using Road Scanners® Road Doctor™ software. Following processing steps applied to the GPR data during both data collection (gain & filters) and post-processing:

(a) During Data Collection

- Vertical filter IIR HP N=2 F=0 MHz (vertical filtering of samples in a single scan, in time domain)
- Vertical Boxcar HP F =250 MHz (vertical filtering of samples in a single scan, in time domain)
- Vertical Boxcar LP F =3295 MHz (vertical filtering of samples in a single scan, in time domain)
- Static Stacking N=1 (horizontal filtering of scans in spatial (distance) domain)
- Range Gain (dB) 15.0 (constant signal amplification throughout)

Figure 8 shows typical data collection and processing settings for typical GPR survey.

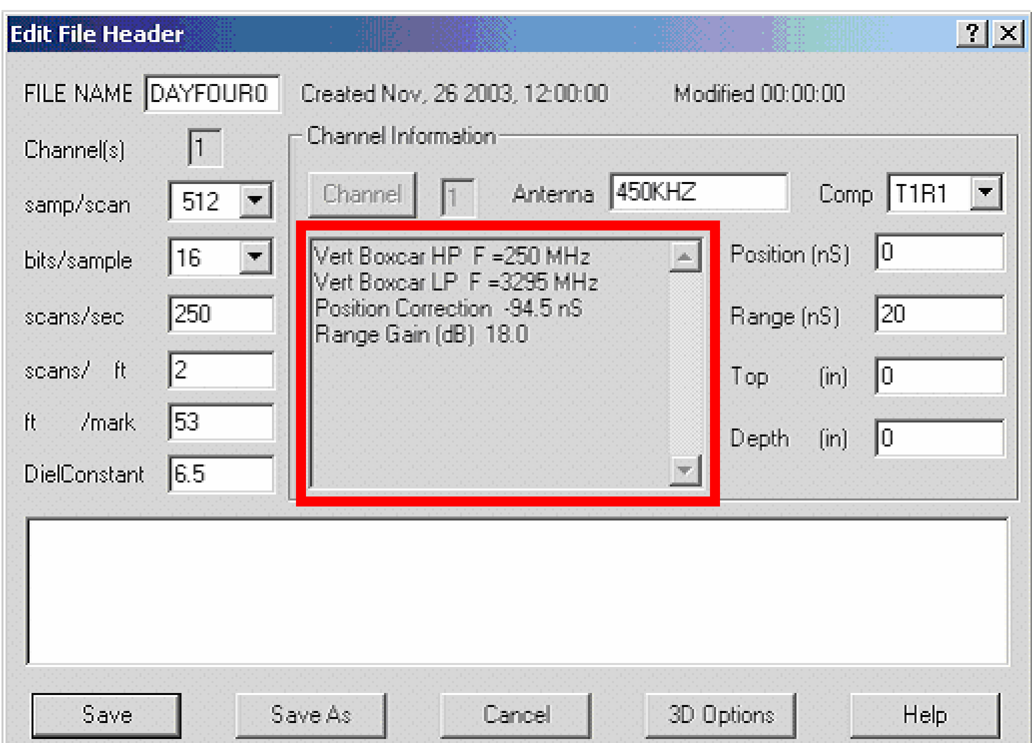


Figure 8. Data collection and processing setting and parameters for typical network level data.

(b) During Post-Processing of Data

Using RADAN's RSA Module, a metal plate calibration file (collected in the field with the raw data, using the same data collection parameters, filters, etc…but no distance-based scanning, and the sampe gain) was processed so that the following could be achieved:

- Amplitude normalization of the data, relative to antenna deployment height during collection of each scan as the survey progressed.

- Removal of clutter (reflections between the pavement surface, the antenna transmitter and receiver, the deployment frame and the back end of the survey vehicle—all constant (or nearly so) at each specific calibration file height) from each scan, again depending on deployment height of the antenna during each scan.

- Calculation of velocity (GPR propagation speed) through pavement, based on relative reflection equation which compares the metal plate reflection amplitude at any given deployment height to the normalized surface reflection amplitude for each scan collected during the entire survey at that same deployment height. Each scan, then, is assigned a velocity, computed from these amplitude values and the measured travel time to the layer in question within that scan.

- Calculation of a pavement depth (asphalt thickness), based on the velocity and the travel time (calculated using the one-way, not two-way travel time from time "zero"—the pavement surface—to the arrival of the "picked", or identified, Layer 1 reflection).

- As the pavement bottom is identified, and the distance, travel time, amplitude (measured values), and related (calculated) variables such as velocity and depth are determined, the information can be stored to ASCII files as master files, or as output files with specified parameters selected by the user.

(c) During Layer Identification

Several interpretation tools are used to efficiently process the data, accurately identify and mark layers, and record the data in an ASCII file. Interactive interpretation of the data resulted in identification of several pavement layers along surveyed roadways, which is reported in Excel spreadsheets and ASCII files.

(d) During formatting for HPMA upload

It was necessary to reformat the output of the RoadDoctor spreadsheets to a format that could be uploaded to the HPMA database. The sample format was received and the unit reformatted the spreadsheets to be compatible with HPMA. The results were forwarded to the Pavement Resource Program.

RESULTS

Interpretation of the data resulted in identification of several pavement layers and pavement types (rigid, flexible and composite) along surveyed roadways. The collected GPR survey data are processed and interpreted and results are provided in form of RADAN data files (*.dzt), and Road Doctor project files. (about 50 Gigabyte of data). To further facilitate the integration of survey results with PMS applications, survey data for each independent GPR scan path are also provided in specified Excel spreadsheet formats, which can be opened in database, or PMS applications

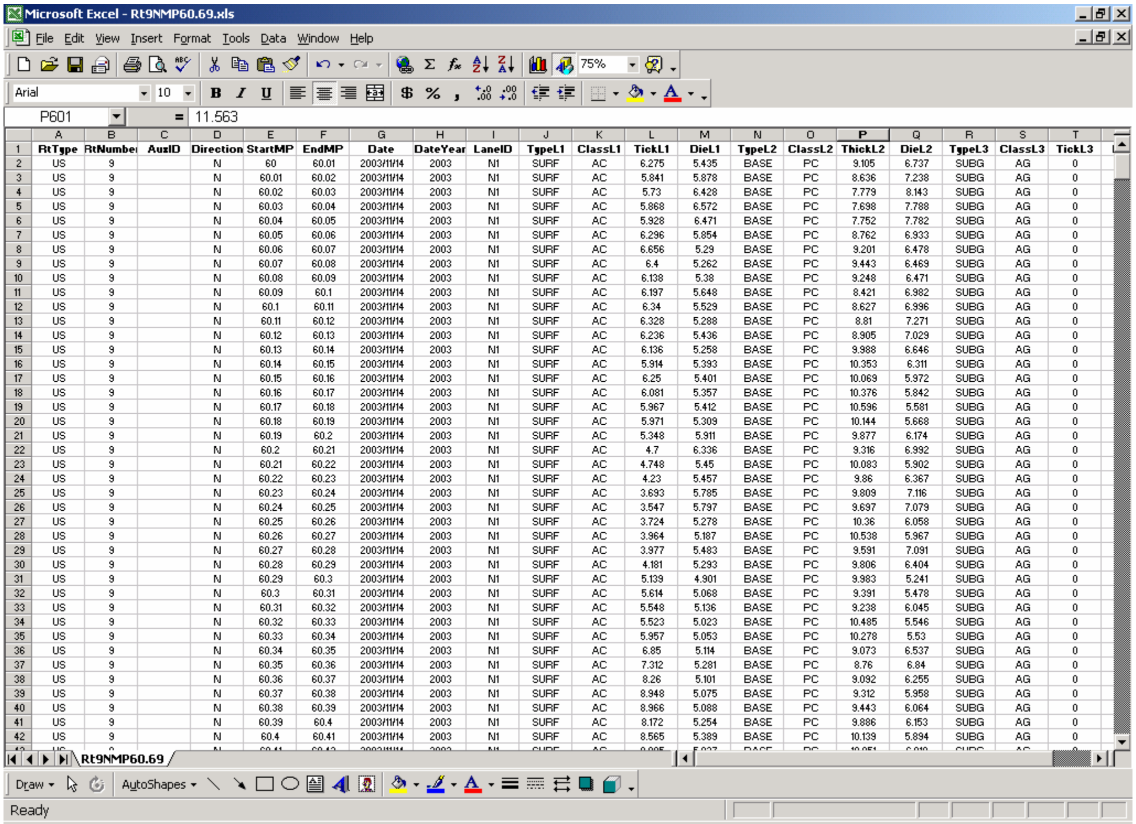
The parameters calculated for each layer are stored along with position of the scan with respect to its distance along the test road (indicated in 1/100 mile increments) Figures 9 illustrates the specified file format for data reporting. The columns represent from left to right route number, auxiliary route ID, direction, lane ID, x the distance along survey in project level surveys, milepost, layer ID, average thickness, and average dielectric for all picked layers. This data is reformatted into HPMA Input file format as illustrated in Figure 10.

There have been some calibration core taken on some roads independent of survey results and used during the interpretation and layer picking to help to verify and/or calibrate the GPR measured thickness and dielectrics.

For all sections a pavement surface layer is reported. For most sections, the thickness of the base and subbase (if any) is reported. Occasionally the interface between the surface and base or base and subbase is not identifiable. The can be the result of two circumstances:

1. The material in the layer pair is electrically similar, for example, a silty sand base and a HMA surface layer.
2. The thickness is and number of HMA layers is large or the moisture content of a layer is high and the radar wavefront cannot penetrate to the base or subbase layer.

The GPR data inserted into the HPMA database provides the ability to compare the GPR layer thickness results with those of the Asbuilt records for a given section of pavement as shown in Figure 11 below.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	RtType	RtNumber	AuxID	Direction	StartMP	EndMP	Date	DateYear	LaneID	TypeL1	ClassL1	TickL1	DieL1	TypeL2	ClassL2	ThickL2	DieL2	TypeL3	ClassL3	TickL3
2	US	9		N	60	60.01	2003/11/14	2003	N1	SURF	AC	6.275	5.435	BASE	PC	9.105	6.737	SUBG	AG	0
3	US	9		N	60.01	60.02	2003/11/14	2003	N1	SURF	AC	5.841	5.878	BASE	PC	8.636	7.238	SUBG	AG	0
4	US	9		N	60.02	60.03	2003/11/14	2003	N1	SURF	AC	5.73	6.428	BASE	PC	7.779	8.143	SUBG	AG	0
5	US	9		N	60.03	60.04	2003/11/14	2003	N1	SURF	AC	5.868	6.572	BASE	PC	7.698	7.788	SUBG	AG	0
6	US	9		N	60.04	60.05	2003/11/14	2003	N1	SURF	AC	5.928	6.471	BASE	PC	7.752	7.782	SUBG	AG	0
7	US	9		N	60.05	60.06	2003/11/14	2003	N1	SURF	AC	6.296	5.854	BASE	PC	8.762	6.933	SUBG	AG	0
8	US	9		N	60.06	60.07	2003/11/14	2003	N1	SURF	AC	6.656	5.29	BASE	PC	9.201	6.478	SUBG	AG	0
9	US	9		N	60.07	60.08	2003/11/14	2003	N1	SURF	AC	6.4	5.262	BASE	PC	9.443	6.469	SUBG	AG	0
10	US	9		N	60.08	60.09	2003/11/14	2003	N1	SURF	AC	6.138	5.38	BASE	PC	9.248	6.471	SUBG	AG	0
11	US	9		N	60.09	60.1	2003/11/14	2003	N1	SURF	AC	6.197	5.648	BASE	PC	8.421	6.982	SUBG	AG	0
12	US	9		N	60.1	60.11	2003/11/14	2003	N1	SURF	AC	6.34	5.529	BASE	PC	8.627	6.996	SUBG	AG	0
13	US	9		N	60.11	60.12	2003/11/14	2003	N1	SURF	AC	6.328	5.288	BASE	PC	8.81	7.271	SUBG	AG	0
14	US	9		N	60.12	60.13	2003/11/14	2003	N1	SURF	AC	6.236	5.436	BASE	PC	8.905	7.029	SUBG	AG	0
15	US	9		N	60.13	60.14	2003/11/14	2003	N1	SURF	AC	6.136	5.258	BASE	PC	9.988	6.646	SUBG	AG	0
16	US	9		N	60.14	60.15	2003/11/14	2003	N1	SURF	AC	5.914	5.393	BASE	PC	10.353	6.311	SUBG	AG	0
17	US	9		N	60.15	60.16	2003/11/14	2003	N1	SURF	AC	6.25	5.401	BASE	PC	10.069	5.972	SUBG	AG	0
18	US	9		N	60.16	60.17	2003/11/14	2003	N1	SURF	AC	6.081	5.357	BASE	PC	10.376	5.842	SUBG	AG	0
19	US	9		N	60.17	60.18	2003/11/14	2003	N1	SURF	AC	5.967	5.412	BASE	PC	10.596	5.581	SUBG	AG	0
20	US	9		N	60.18	60.19	2003/11/14	2003	N1	SURF	AC	5.971	5.309	BASE	PC	10.144	5.668	SUBG	AG	0
21	US	9		N	60.19	60.2	2003/11/14	2003	N1	SURF	AC	5.348	5.911	BASE	PC	9.877	6.174	SUBG	AG	0
22	US	9		N	60.2	60.21	2003/11/14	2003	N1	SURF	AC	4.7	6.336	BASE	PC	9.316	6.992	SUBG	AG	0
23	US	9		N	60.21	60.22	2003/11/14	2003	N1	SURF	AC	4.748	5.45	BASE	PC	10.083	5.902	SUBG	AG	0
24	US	9		N	60.22	60.23	2003/11/14	2003	N1	SURF	AC	4.23	5.457	BASE	PC	9.86	6.367	SUBG	AG	0
25	US	9		N	60.23	60.24	2003/11/14	2003	N1	SURF	AC	3.693	5.785	BASE	PC	9.809	7.116	SUBG	AG	0
26	US	9		N	60.24	60.25	2003/11/14	2003	N1	SURF	AC	3.547	5.797	BASE	PC	9.697	7.079	SUBG	AG	0
27	US	9		N	60.25	60.26	2003/11/14	2003	N1	SURF	AC	3.724	5.278	BASE	PC	10.36	6.058	SUBG	AG	0
28	US	9		N	60.26	60.27	2003/11/14	2003	N1	SURF	AC	3.964	5.187	BASE	PC	10.538	5.967	SUBG	AG	0
29	US	9		N	60.27	60.28	2003/11/14	2003	N1	SURF	AC	3.977	5.483	BASE	PC	9.591	7.091	SUBG	AG	0
30	US	9		N	60.28	60.29	2003/11/14	2003	N1	SURF	AC	4.181	5.293	BASE	PC	9.806	6.404	SUBG	AG	0
31	US	9		N	60.29	60.3	2003/11/14	2003	N1	SURF	AC	5.139	4.901	BASE	PC	9.983	5.241	SUBG	AG	0
32	US	9		N	60.3	60.31	2003/11/14	2003	N1	SURF	AC	5.614	5.068	BASE	PC	9.391	5.478	SUBG	AG	0
33	US	9		N	60.31	60.32	2003/11/14	2003	N1	SURF	AC	5.548	5.136	BASE	PC	9.238	6.045	SUBG	AG	0
34	US	9		N	60.32	60.33	2003/11/14	2003	N1	SURF	AC	5.523	5.023	BASE	PC	10.485	5.546	SUBG	AG	0
35	US	9		N	60.33	60.34	2003/11/14	2003	N1	SURF	AC	5.957	5.053	BASE	PC	10.278	5.53	SUBG	AG	0
36	US	9		N	60.34	60.35	2003/11/14	2003	N1	SURF	AC	6.85	5.114	BASE	PC	9.073	6.537	SUBG	AG	0
37	US	9		N	60.35	60.36	2003/11/14	2003	N1	SURF	AC	7.312	5.281	BASE	PC	8.76	6.84	SUBG	AG	0
38	US	9		N	60.36	60.37	2003/11/14	2003	N1	SURF	AC	8.26	5.101	BASE	PC	9.092	6.255	SUBG	AG	0
39	US	9		N	60.37	60.38	2003/11/14	2003	N1	SURF	AC	8.948	5.075	BASE	PC	9.312	5.958	SUBG	AG	0
40	US	9		N	60.38	60.39	2003/11/14	2003	N1	SURF	AC	8.966	5.088	BASE	PC	9.443	6.064	SUBG	AG	0
41	US	9		N	60.39	60.4	2003/11/14	2003	N1	SURF	AC	8.172	5.254	BASE	PC	9.886	6.153	SUBG	AG	0
42	US	9		N	60.4	60.41	2003/11/14	2003	N1	SURF	AC	8.565	5.389	BASE	PC	10.139	5.894	SUBG	AG	0

Figure 9. Typical spreadsheet format of reported results.

RTTYPE	RTNUMBE	AUXID	DIRECTIO	STARTMP	ENDMP	DATE	DATEYEAR	LANEID	NOTES	TYPEL1	CLASSL1	TICKL1	DIEL1	TYPEL2	CLASSL2	THICKL2	DIEL2
NJ	26		SB	1.92	1.91	8/15	2007	1		Surf	AC	5.19	7.2	Base	AG	11.88	
NJ	26		SB	1.91	1.90	8/15	2007	1		Surf	AC	4.52	6.8	Base	AG	11.59	
NJ	26		SB	1.90	1.89	8/15	2007	1		Surf	AC	5.03	6.8	Base	AG	10.94	
NJ	26		SB	1.89	1.88	8/15	2007	1		Surf	AC	5.43	6.7	Base	AG	10.76	
NJ	26		SB	1.88	1.87	8/15	2007	1		Surf	AC	5.19	6.8	Base	AG	11.13	
NJ	26		SB	1.87	1.86	8/15	2007	1		Surf	AC	4.67	6.9	Base	AG	11.45	
NJ	26		SB	1.86	1.85	8/15	2007	1		Surf	AC	4.57	6.8	Base	AG	10.95	
NJ	26		SB	1.85	1.84	8/15	2007	1		Surf	AC	4.86	6.9	Base	AG	11.33	
NJ	26		SB	1.84	1.83	8/15	2007	1		Surf	AC	4.38	6.8	Base	AG	11.21	
NJ	26		SB	1.83	1.82	8/15	2007	1		Surf	AC	4.24	6.7	Base	AG	11.22	
NJ	26		SB	1.82	1.81	8/15	2007	1		Surf	AC	4.13	6.6	Base	AG	11.11	
NJ	26		SB	1.81	1.80	8/15	2007	1		Surf	AC	4.05	6.8	Base	AG	11.19	
NJ	26		SB	1.80	1.79	8/15	2007	1		Surf	AC	4.17	7	Base	AG	11.33	
NJ	26		SB	1.79	1.78	8/15	2007	1		Surf	AC	4.31	7	Base	AG	11.69	
NJ	26		SB	1.78	1.77	8/15	2007	1		Surf	AC	4.56	6.8	Base	AG	12.03	
NJ	26		SB	1.77	1.76	8/15	2007	1		Surf	AC	4.62	6.9	Base	AG	12.26	
NJ	26		SB	1.76	1.75	8/15	2007	1		Surf	AC	4.7	6.7	Base	AG	12.32	
NJ	26		SB	1.75	1.74	8/15	2007	1		Surf	AC	5.07	6.8	Base	AG	11.56	
NJ	26		SB	1.74	1.73	8/15	2007	1		Surf	AC	4.66	6.8	Base	AG	12.95	
NJ	26		SB	1.73	1.72	8/15	2007	1		Surf	AC	4.48	6.6	Base	AG		
NJ	26		SB	1.72	1.71	8/15	2007	1		Surf	AC	3.9	6.9	Base	AG	11.43	

Figure 10. Spreadsheet for upload to HPMA

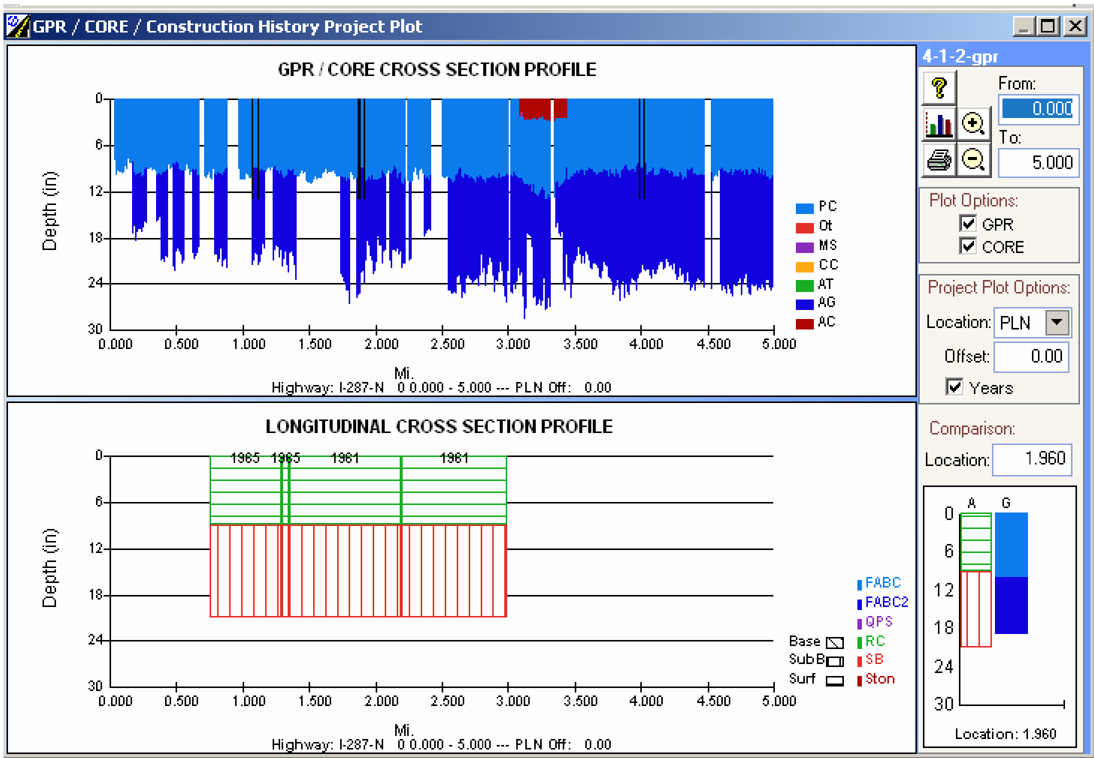


Figure 12. HPMA and Asbuilt Data in HPMA

DISCUSSION

In general, pavements surveyed demonstrate a wide range of variation with respect to pavement type and thickness of AC and PCC layers along a survey line and between different routes. This variation can be an indication of different construction history of pavement, different design of pavement, maintenance history (such as repair of sinking slabs by resurfacing as shown in Figure 12 or complete removal of one or more slab and resurfacing), change of pavement alignment, intrusion in pavement to install utility pipes, and many other factors.

It is highly unlikely that these variations can be fully quantified with a coring program. It is one of the advantages of GPR technology that can detect these variations and provide a good estimate of layer thicknesses to be used in pavement management system for design and maintenance purposes.

During the quality control analysis of the GPR data imputed into the HPMA, several file were identified to contain anomalies. These pavement sections will be reanalyzed or retested.

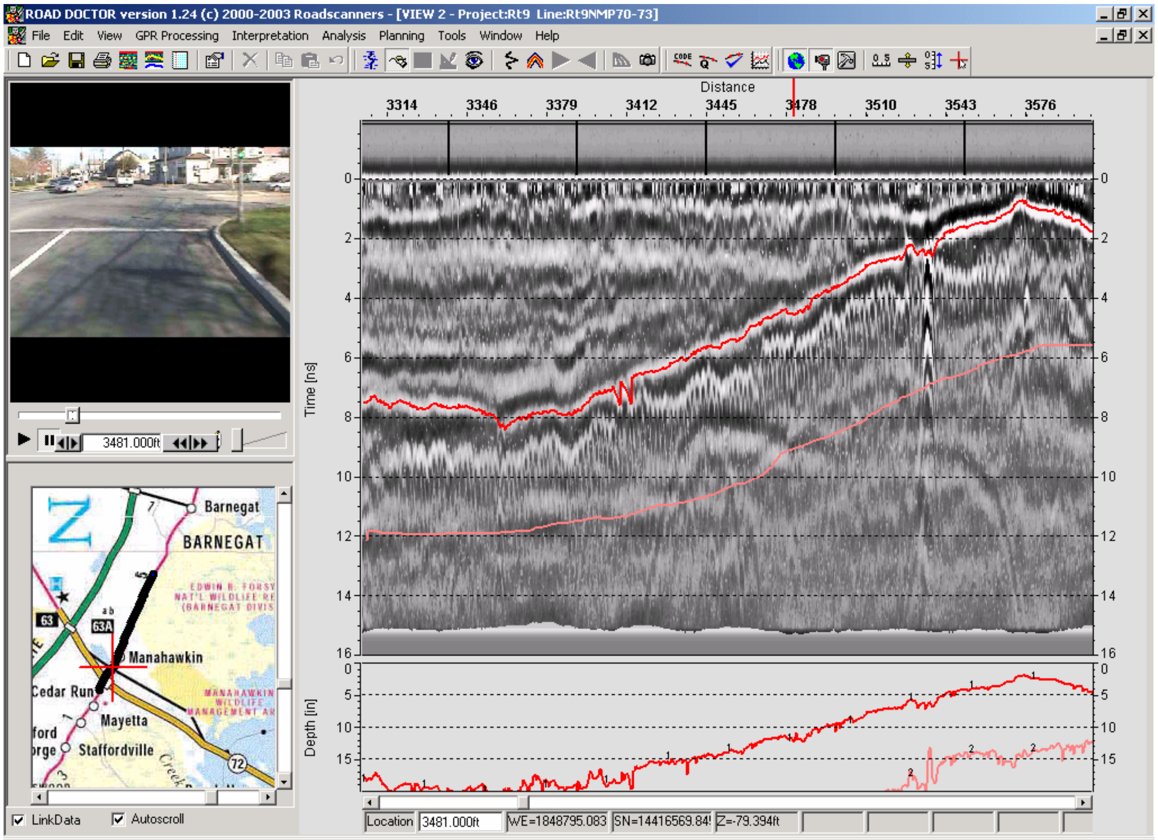


Figure 12. Sinking concrete slab (US-9 NB near MP70)

SUMMARY

GPR's continuous profiling capability, and ability to estimate pavement layer thickness and type without the use of cores, is a valuable precursor to ground-truth, FWD and other evaluation. This capability is clearly demonstrated throughout this work, which included network level survey of 1254 miles State highways. The final results of the work are provided in terms of Excel files, summarizing GPR survey results in specified formats and intervals.

REFRENCES

1. Geophysical Survey Systems Inc., “RADAN for Windows NT – User’s Manual”, Version 4.0.1.0, 2002.
2. Roadscanners Inc., “Road Doctor™ Software – User’s guide”, Version 1.1, 2001.
3. Transportation Infrastructure Systems, “NJDOT Statewide GPR Pilot Project Report”, March 2003.