Ground Penetrating Radar Survey of

Interstate 70 Across Missouri

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SUMMARY

Current geotechnical procedures for monitoring the condition of roadways are time consuming and can be disruptive to traffic, often requiring extensive invasive procedures (e.g., coring). Ground penetrating radar (GPR) technology offers a methodology to perform detailed condition assessment of existing roadways, with the added advantage over other techniques of being rapid and cost-effective. This study applies GPR techniques to a survey along Interstate 70 across the state of Missouri. Goals of this survey were threefold: 1) determine layer thicknesses every tenth mile (primarily asphalt and concrete, with base coarse information secondary); 2) update history information related to types of pavements that make up I70 across Missouri; and 3) note regions where the radar signal appears anomalous. Goals (1) and (2) are related and were the primary goals. Goal (3) required visually interpreting the full data set and was done as a guide for further investigation. The result is an extensive data set allowing the user to visualize the east and westbound pavement profiles in comparison to design history information, view a table of surface types and anomalous regions associated with those profiles, and cross-reference this information with the GPR-interpreted layer data at 0.1 mile marks in spreadsheet form.

BACKGROUND AND METHODOLOGY

Ground penetrating radar (Daniels, 1996; Cardimona, et al., 1998) uses a radio wave source to transmit a pulse of electromagnetic energy into a nonmagnetic body. The reflected energy, originating within the body at interfaces between materials of different dielectric properties or of differing conductivities, is received and recorded for analysis of internal structure of the body. GPR data consist of a) changes in reflection strength, b) changes in arrival time of specific reflections, c) source wavelet distortion, and d) signal attenuation. When applied to the analysis of roadways, these different GPR signatures can be used as discriminants for detecting poor quality pavements (e.g., insufficient asphalt overlay, variable concrete pavement or base coarse).

Ground penetrating radar techniques applied to roadway assessment are relatively new. Only recently has the instrumentation been improved so that interpretable high resolution data can be obtained regarding pavement condition. Various GPR tools and methodologies exist (e.g., ASTM D 4748-87), some with more potential than others. Modern antennae for roadway analysis are normally designed as air-launched horn antennae with nominal peak frequencies of around 1.0GHz, offering the ability to obtain high resolution images of pavement layers. Data can be collected by monostatic antennae, which means the same antennae acts both as transmitter and receiver, or with bistatic antennae where the transmitting and receiving antennae are separate. Bistatic horn antennae designed for high speed road pavement imaging are normally mounted behind a truck in a line parallel to vehicle motion, and they offer more rapid data collection and thus more samples per distance than does the monostatic tool. Multichannel recording instrumentation in either monostatic or bistatic modes allow us to collect more than one pass of data along the vehicle traverse. Collection of this data is fast and not disruptive to traffic patterns, with reasonable collection speeds up to 50mph.

The standard methodology for the automatic interpretation of GPR data over pavements (ASTM D 4748-87) measures reflection amplitudes. These reflection amplitudes, scaled with an initial amplitude calibration, allow for the determination of layer dielectric constants. The contrast in dielectric constant (relative dielectric) across an interface is what produces the reflection in the first place, so the reflection amplitudes can be related to the dielectric values with a layer-stripping technique; i.e., the relative dielectric of the first layer is determined, then it is used to determine the relative dielectric of the next layer, and so on. Once all layer dielectric constants are determined, the layer thicknesses can be calculated using the radar wave velocities (based also on the dielectric constants) and the measured travel time of each interface reflection. This automatic interpretation must include core samples for each different pavement along the GPR survey in order to best determine dielectric constants (ASTM D 4748-87).

This interpretation procedure implies that all layer interfaces are represented by distinct reflection peaks in the recorded GPR signal. That all layers are represented means that each reflection coefficient is large enough to produce a returned signal with an amplitude above the noise level. That all reflection peaks be distinct relates to the vertical resolution of the GPR tool. This resolution will be most related to the peak frequency of transmission, because the wave velocity divided by the wave frequency determines the wavelength of the radar in the pavement layers. For an antenna with nominal frequency of 1.0GHz, the wavelength would be on the order of a tenth of a meter for a medium with a dielectric constant of 9 (corresponding to a radar velocity of 0.1m/ns). The slower the medium (the larger the dielectric constant) or the larger the source frequency, the better the resolution (smaller the wavelength).

User guided interpretation uses similar concepts to the automated interpretation scheme, but the amplitude of reflection events is not formally used to measure dielectric constants. Instead, after interface reflections (and their associated travel times) are picked from the data, ground truth is used to calibrate the signal. Dielectric constants are determined from this ground truth, and layer thickness estimates along the whole survey are then produced.

FIELD ACQUISITION PROCEDURES

We have performed an extensive ground penetrating radar survey of road pavement along Interstate 70 across Missouri. The instruments and the software for analysis of the data are manufactured by Geophysical Survey Systems, Inc. In Summer 1998, the Department of Geology and Geophysics at UMR acquired GPR data along both east and westbound I70 from Mile marker 20 (Kansas City) to 210 (St. Louis) in Missouri. These data were acquired using 1.0GHz air-launched horn antennae (Geophysical Survey Systems, Incorporated antenna model #4208). All data were collected at 30mph yielding ~5 radar scans/m (1.5 scans/ft, or 1 scan per 8 inches) with a 20 ns time recording window. The scans-per-meter defines the horizontal sampling. The time recording length determines (with the radar velocity) the maximum depth imaging expected which was on the order of one meter for this survey. We mounted the bistatic antennae behind a pickup truck, acquiring two channels of data resulting in parallel survey passes separated by three feet.

For calibration, we collected radar data over core locations near to the start of the survey (on I70 near Columbia, MO). In addition, a calibration file was acquired each new day of the survey, consisting of data recorded in place over a metal (perfect) reflector.

The difficult logistics of acquisition required that data be collected in four mile sections to keep the file sizes manageable (just under 32MB). Starting and stopping every four miles introduced a horizontal error during acquisition of on average 19 feet over four miles, for about 4.75 ft/mile position error. From approximately mile 144-180 eastbound, acquisition was undersampled relative to the rest of the survey at 5scans/m. This was due to incorrect acquisition parameter settings for such a large file size, but could be compensated for during processing with only minimal extra position error. The total data collected amounted to just under 3GB of data, posing yet another logistical problem of storage of the entire data set. Data were stored directly onto 1GB removable media during acquisition and ultimately were stored on CD-ROM for archiving.

ANALYSIS AND INTERPRETATION PROCEDURES

Preliminary qualitative determination of anomalous roadway areas can be done during acquisition or during post-survey assessment of the data. Quantitative interpretation of the roadway data to help produce layer thickness estimates requires correlation with ground truth. Ideally, the ground truth consists of core information from every different roadway surface; however, in the absence of this, design plans were used to calibrate the radar data in this study, with an associated loss in confidence in the resulting interpretation. The design plans we used are from the history information supplied by MoDOT. This history information could only be used as a guide, as it is incomplete and inaccurate. Of course, one of our primary goals was to update and correct this information.

Neither of the calibration techniques were truly effective for analysis of the extensive data set we acquired. Although some of the calibration files were not collected under ideal circumstances and proved less than useful, the use of the calibration file technique for automated analysis of this extensive data was not appropriate. The automated technique requires that all layer interfaces be interpretable (above the noise level and resolvable), and also all layers and numbers of layers should ideally be consistent. Our data from I70 included patchy and discontinuous roadway for both asphalt and concrete pavements. In addition, the concrete pavements included both non-reinforced and reinforced concrete. The reinforcement essentially puts an additional layer into the pavement analysis. Use of the calibration file for automated analysis broke down and required constant interpreter input to keep it on track through these changes in pavement character. In addition, the base of the concrete (concrete to base coarse interface) was often difficult to interpret and the automated analysis technique using a calibration file requires each interface to be distinct and clear (above the noise level). With such variability across some 400 miles of roadway, the limited core control (one area of concrete and one area of asphalt) was basically useless. Further analysis and investigation would require core control from numerous points along the surveyed portion of I70.

Using the history information as a guide, we chose to use interpreter guided analysis throughout the study. Since we wanted to produce a listing of anomalous areas, this required interpreter involvement through analysis of the entire data set and thus our analysis technique was consistent with meeting our third goal. Our analysis procedure involved multiple steps:

1) **Stacking** 9 scans (to reduce file size and increase signal to noise ratio)
2) **Layer Picking** (Surface, asphalt, concrete) interfaces (using both channels of data as a guide for helping to see all layer interfaces).
3) **Distance Correction** (based on 4 mile) (cut/paste long files to files that ran short)(MS-Excel)
4) **Sorting** of 0.1 Mile data. (Microsoft query to subsample original layer files)
   a) Averaged GPR signal from 20 ft window around each 0.1 mile interval.
5) **Graphing** and interpretation of data (from query) using Microsoft Excel
   a) Distance converted to continuous mile marker (from linear feet to continuous mile)
   b) Dielectric constant determined from design data (thickness estimate) and acquired data (travel time measurement) to get average velocity estimate. We used dielectrics of 4.2 for the asphalt (based on 172-176 E, 3in design) and 10.5 for concrete (based on 110-114 E, 8in design). Calibration positions were chosen based on regions that had strong, laterally continuous GPR reflections.
   c) Thickness estimates based on 2 way travel time between layer events. [i.e. (t2-t1)*Vel/2]
   d) Design-history information converted to continuous mile and summarized in spreadsheet information.
   e) Data Filtered to throw out No data sections in GPR and design spreadsheet information.

f) Graphs of GPR and design showing calculated thickness for asphalt and concrete compared with design/history thickness information.

6) **Interpretation** of un-stacked data to locate anomalous features and classify surface material type (i.e. asphalt or concrete).

7) **Identify** and tabulate areas exhibiting anomalous radar signatures.

SUMMARY OF RESULTS

Figures 1 and 2 (multi-page) show profile plots for east and west bound driving lane. The radar layer thickness estimates are tabulated for every tenth mile mark in Appendix A. In figures 1 and 2, layer thicknesses are plotted as a function of distance (continuous mile) based on the GPR interpretation and are compared with the design history information. Where the two plots diverge, the design history may be in question. For example, the eastbound asphalt thickness from mile 20 to about 40 is much thicker than the history records indicate, and this extra thickness was confirmed by MoDOT personnel.

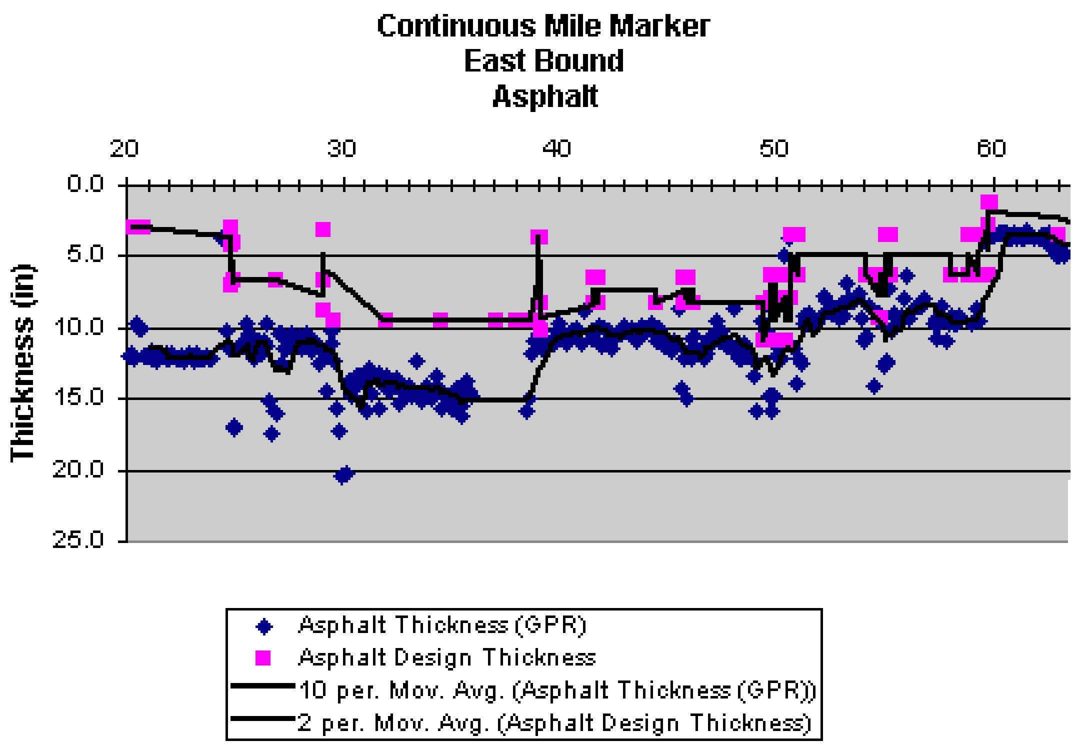
Table 1 summarizes surface pavement types along I70 as 1) asphalt, 2) reinforced concrete, 3) reinforced concrete patch, 4) non-reinforced concrete, 5) non-reinforced concrete patch, 6) bridge or 7) unknown. This table should be used in conjunction with Figures 1 and 2 when assessing the roadway. In particular, we note in Table 1 if we have lower confidence in the GPR interpretation based on the quality of the GPR data (“pd” or “vpd” for “poor data” and “very poor data”).

Table 2 delineates anomalous regions exhibited in the radar data, and Table 3 lists anomalies that correspond to tenth mile positions for correlation with ground truth (e.g., falling weight deflectometer). Radar anomalies are categorized into six different types:

1) increase amplitude --interface with stronger than surrounding reflectivity (presumably due to greater dielectric contrast)

2) decrease amplitude	--interface with weaker than surrounding reflectivity (presumably due to lower dielectric contrast)
3) thickening	--interface that drops down over a relatively broad region, (indicative of layer that increases in thickness or layer dielectric that increases)
4) thinning	--interface that raises up over a relatively broad region, (indicative of layer that decreases in thickness or layer dielectric that decreases)
5) discontinuous	--interface that is broken up or sharply (vertically) variable
6) washout	--very localized layer thickening presumed to be related to moisture content (slow velocity push-down)

Each of these anomalies can be associated with the base of asphalt, base of concrete (reinforced or non-reinforced), the reinforcement itself, or the base coarse layer. In addition, we note in some places where the surface of the roadway was especially rough and where we interpret pavement patches, since these might be indicative of roadway problems. Figures 3-12 display examples of radar anomalies, labeled at nearest tenth mile mark. Note that the "thickening" and "thinning" areas, and the more localized "washout" areas as well, should show up on the pavement profile data. These areas are designated "anomalous" because they are more localized than variations in layer thickness are expected to be if they are related to pavement layering put down by MoDOT, although that may prove to be the correct situation. These anomalous regions should be investigated for correlation of ground truth with the radar signatures.



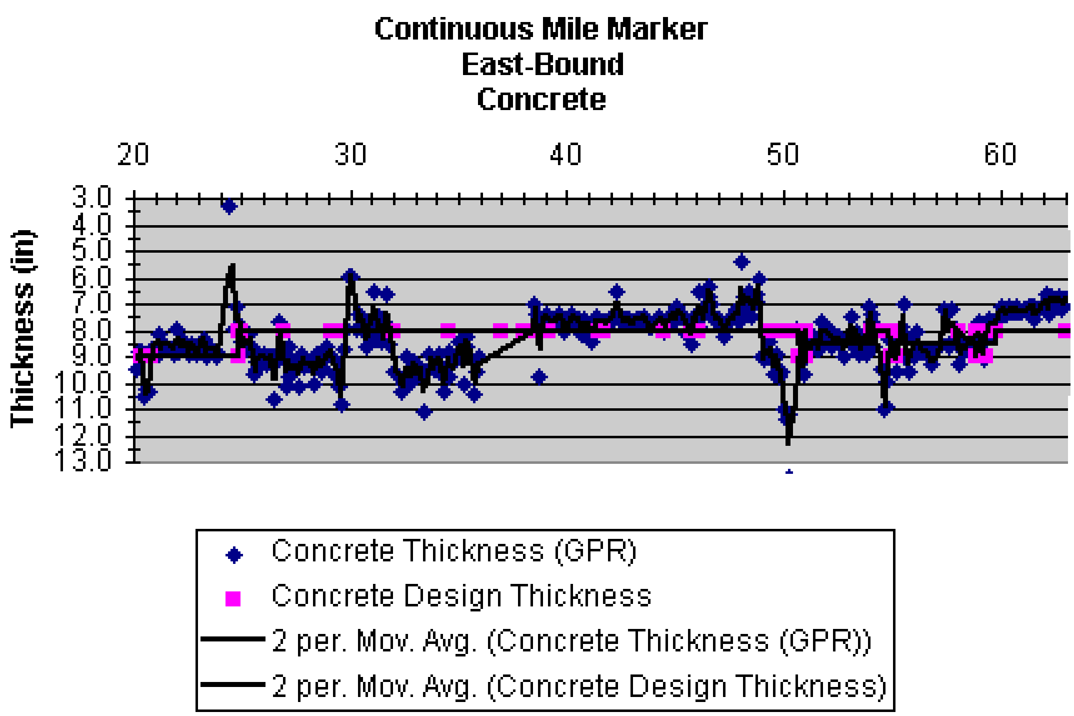
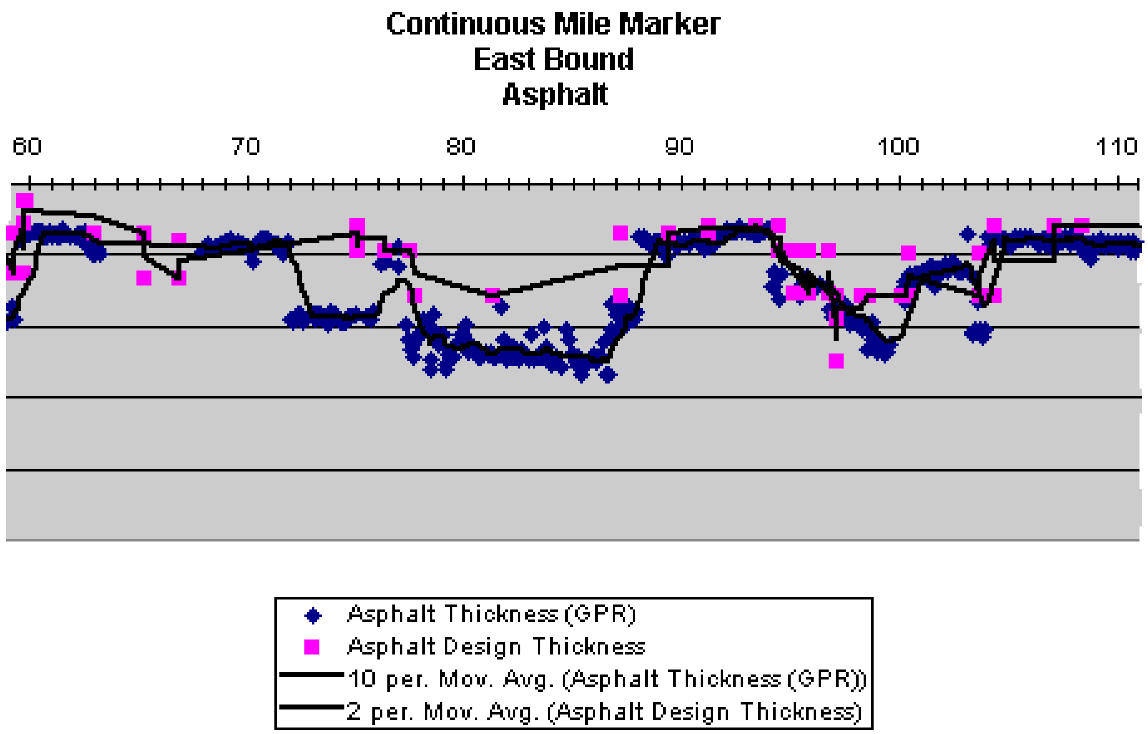


Figure 1. Eastbound pavement layer profiles.



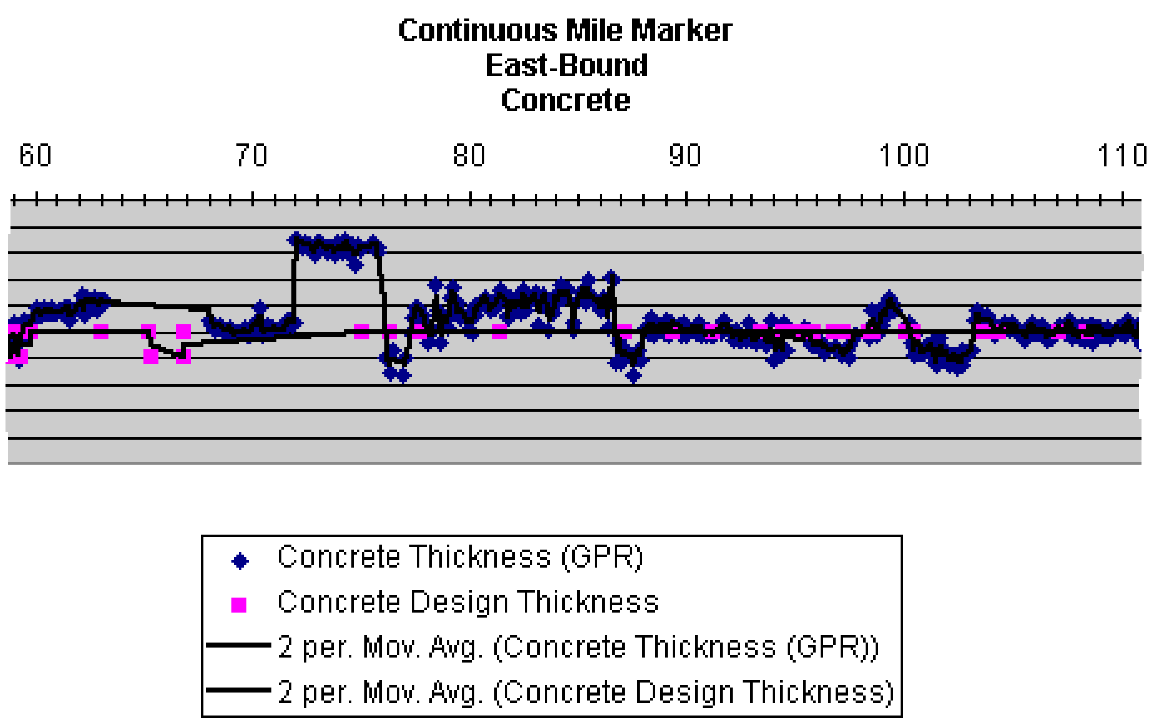
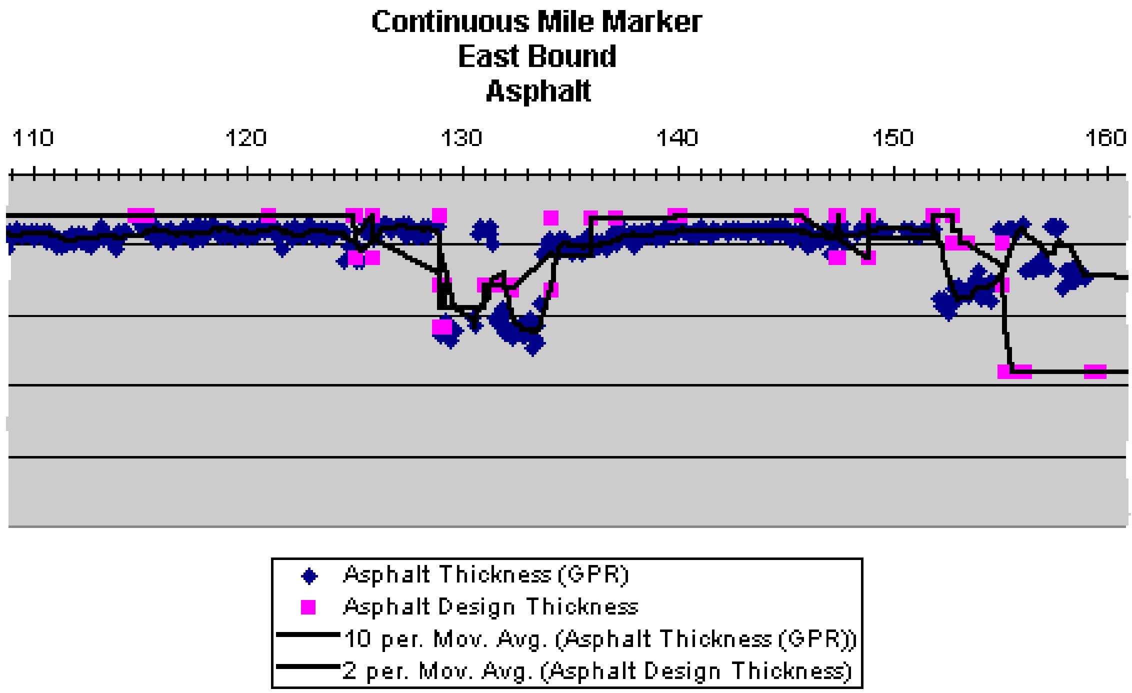


Figure 1 cont. Eastbound pavement layer profiles.



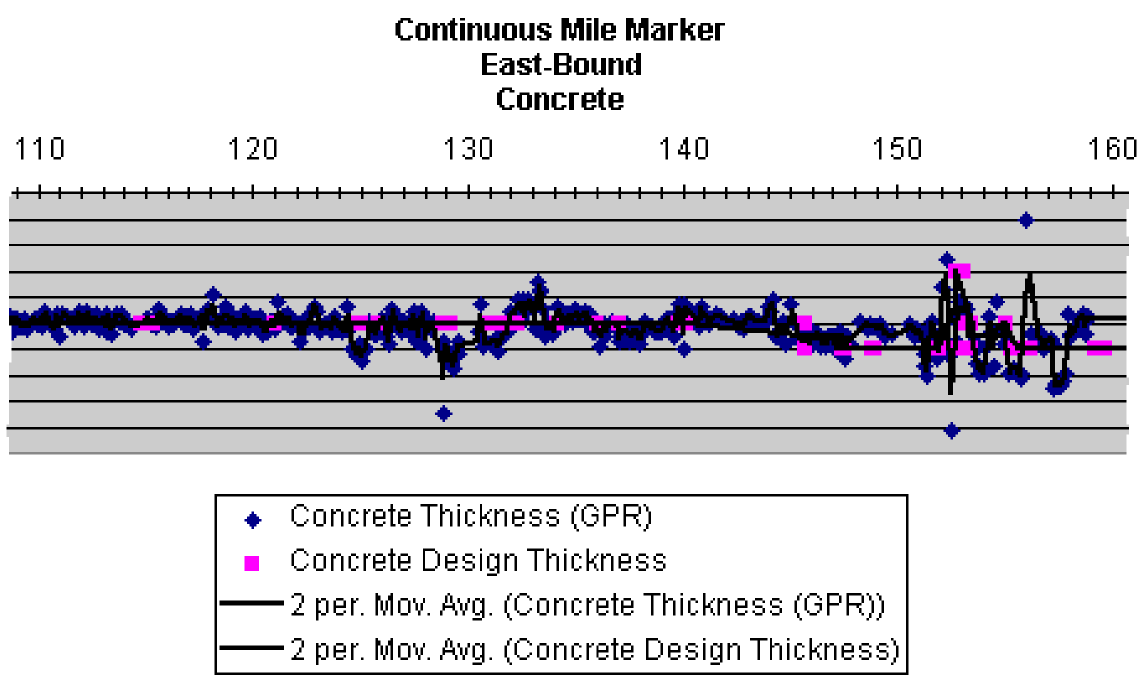
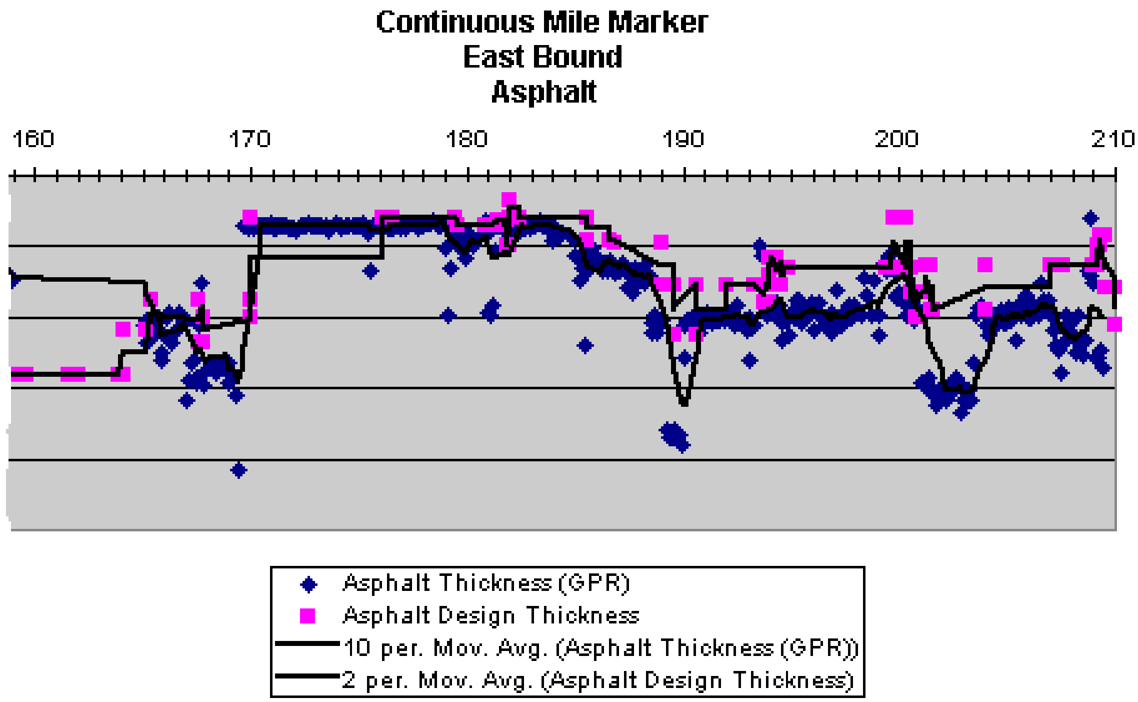


Figure 1 cont. Eastbound pavement layer profiles.



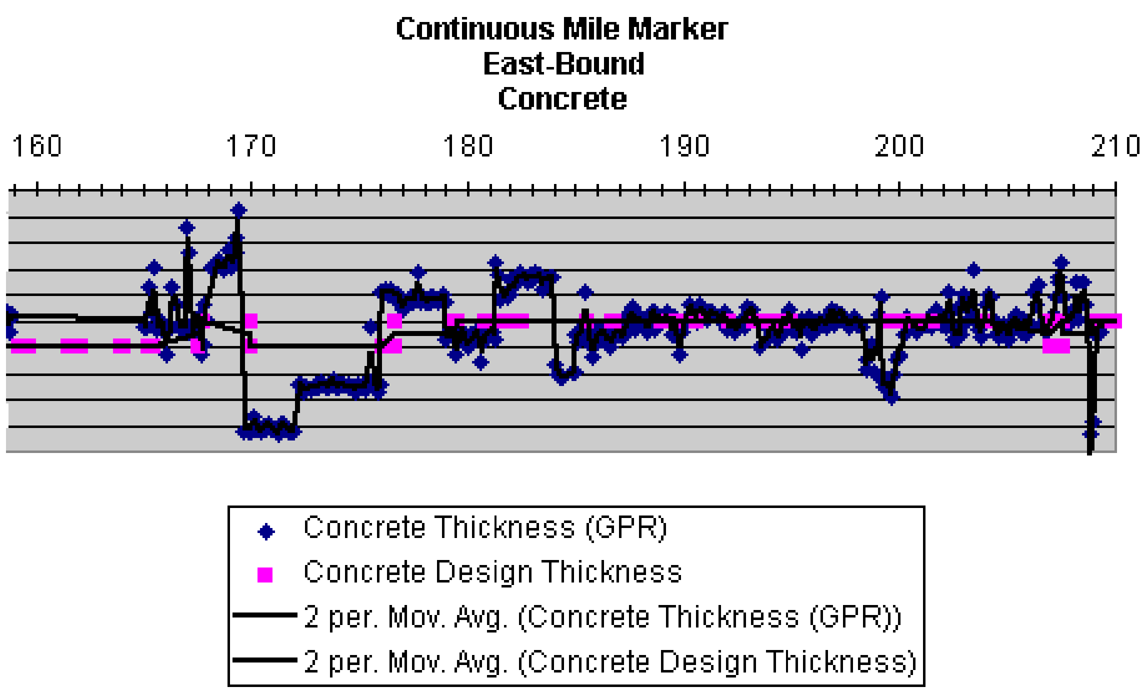
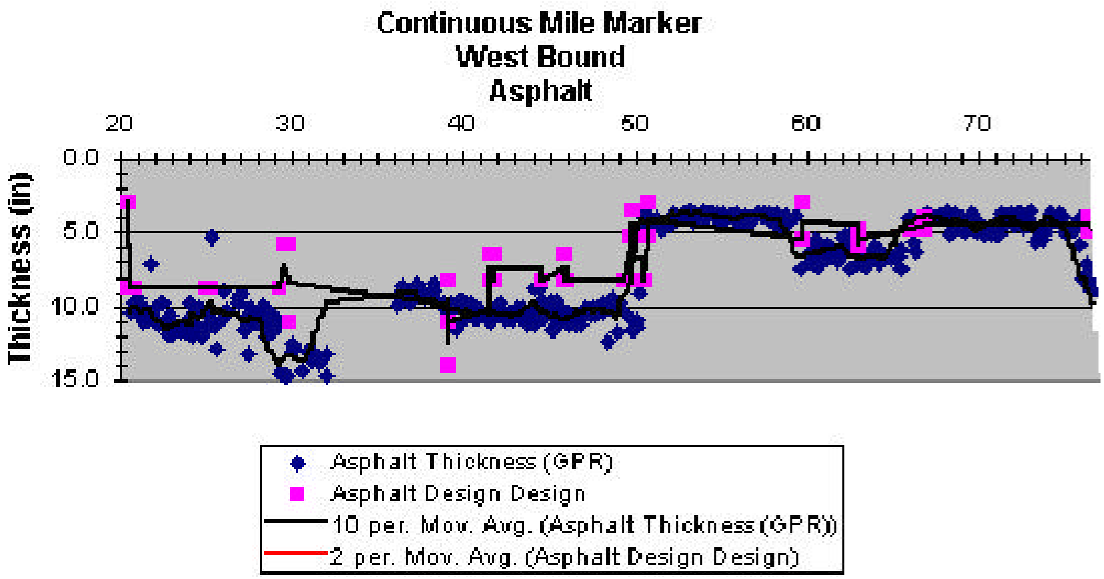


Figure 1 cont. Eastbound pavement layer profiles.



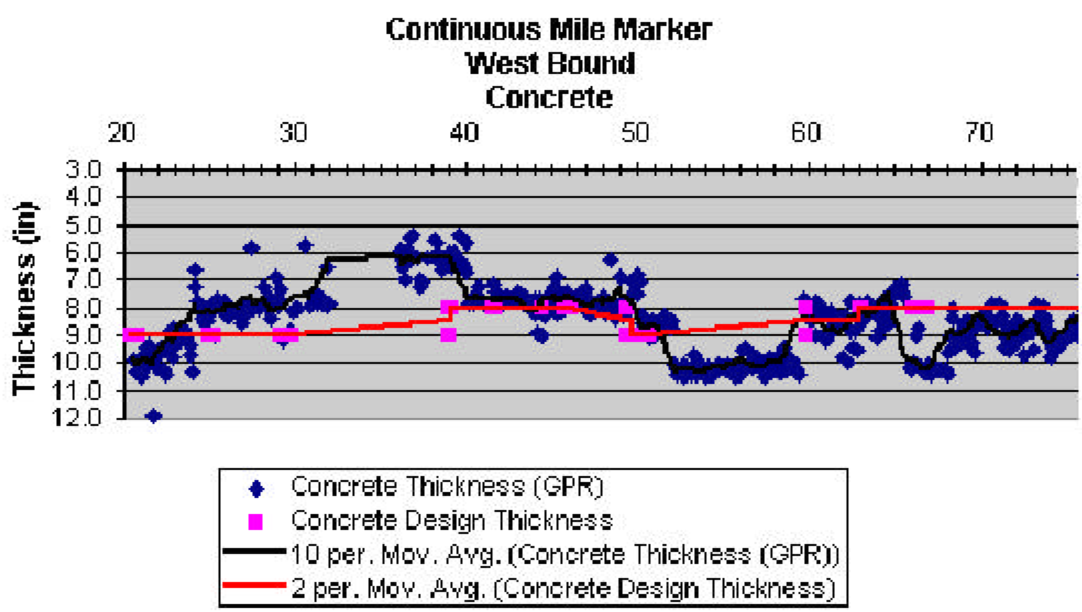
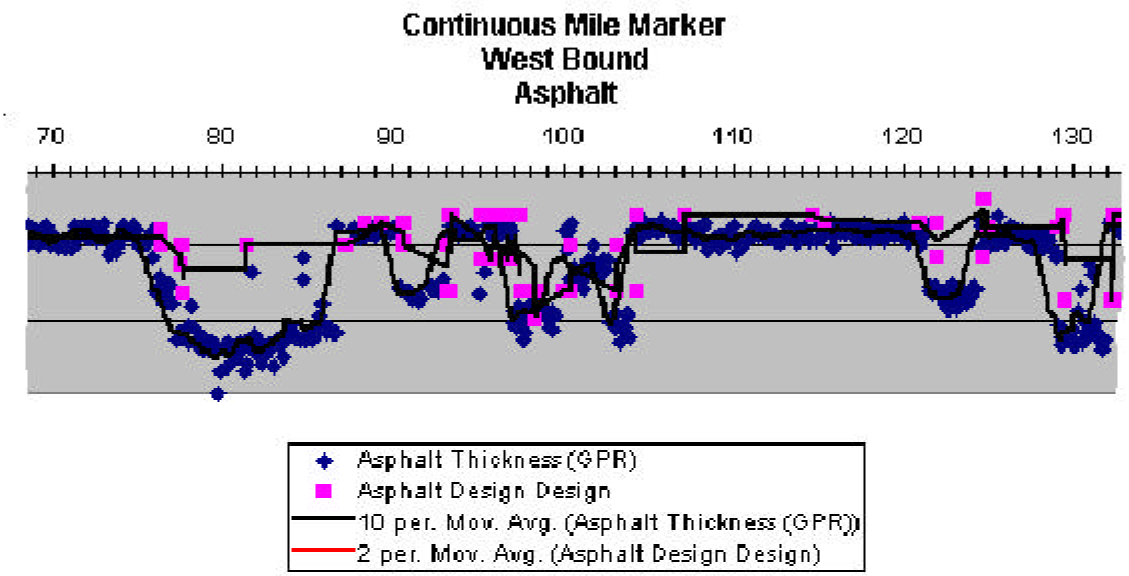


Figure 2. Westbound pavement layer profiles.



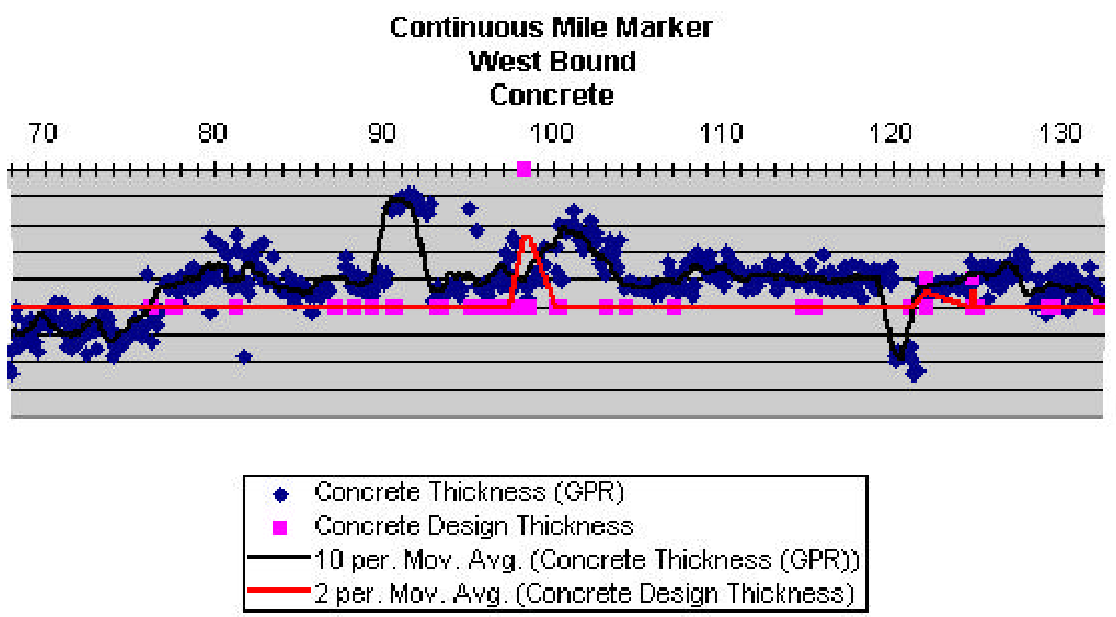
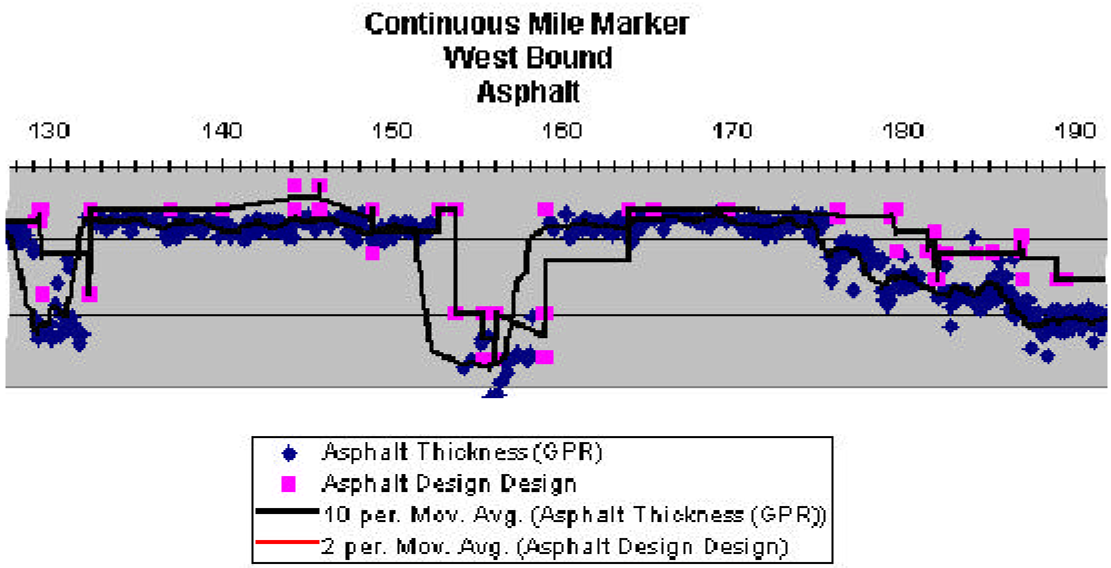


Figure 2 cont. Westbound pavement layer profiles.



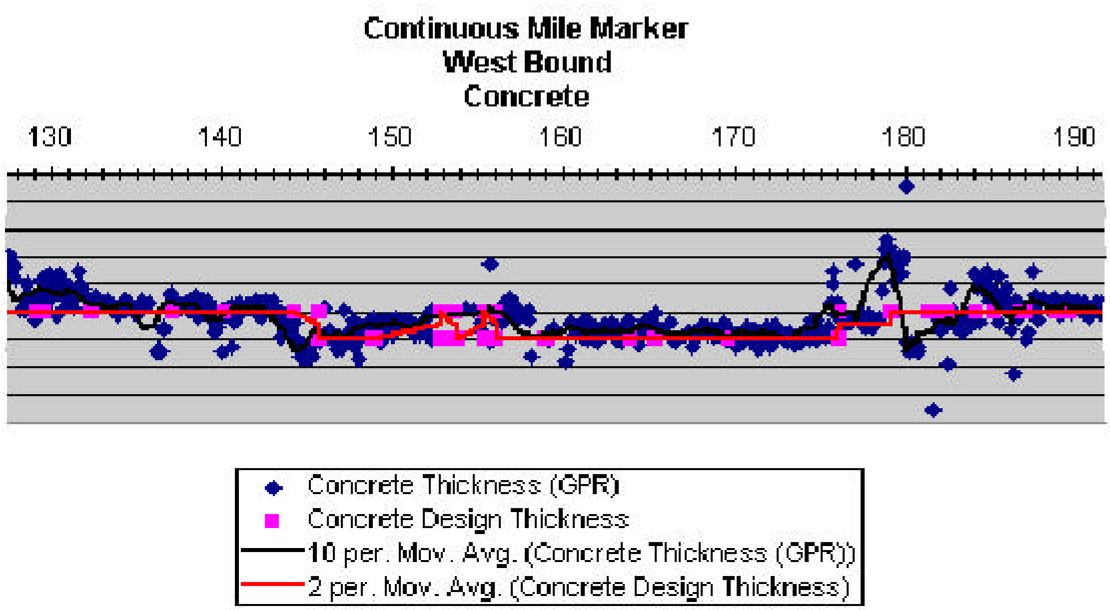
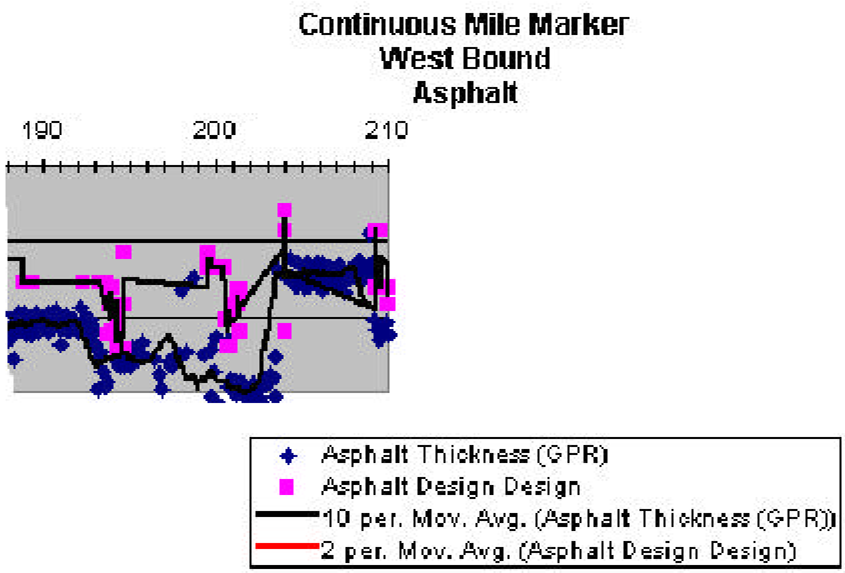


Figure 2 cont. Westbound pavement layer profiles.



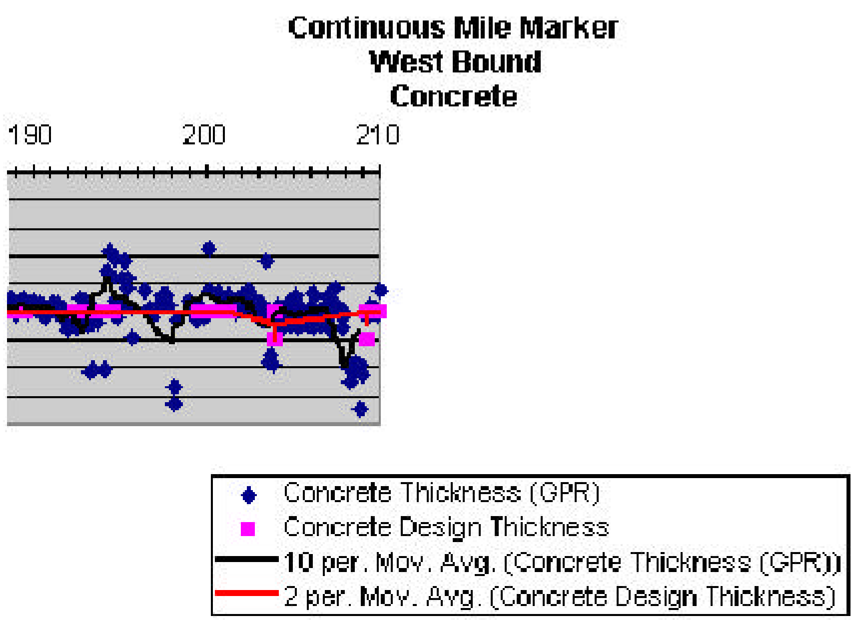


Figure 2 cont. Westbound pavement layer profiles.

TABLE1a

East Bound I-70

Surface Type

Eastbound

Cont. Mile Mark	Start	End	Surface type	Notes
20	20.000	20.453	pcr	
	20.453	21.606	ac	
	21.606	21.612	ppcn	
	21.612	21.646	br	
	21.646	21.655	ppcn	
	21.655	24.000	ac	
24	24.000	24.396	ac	
	24.396	24.405	pcn	
	24.405	24.432	br	
	24.432	24.437	pcn	
	24.437	25.181	ac	
	25.181	25.189	pcn	
	25.189	25.289	br	
	25.289	25.292	pcn	
	25.292	26.627	ac	
	26.627	26.633	un	PPCN?
	26.633	28.001	ac	
28	28.000	29.311	ac	
	29.311	29.322	pcn	
	29.322	29.355	br	
	29.355	29.361	pcn	
	29.361	29.493	ac	
	29.493	29.509	pcn	
	29.509	29.543	br	
	29.543	29.552	pcn	
	29.552	32.002	ac	
32	32.000	33.451	ac	
	33.451	33.493	br	
	33.493	33.519	un	ppcn? , vpd
	33.519	36.000	ac	vpd
36	36.000	37.984	ac	
	37.984	37.991	pcn	
	37.991	38.034	br	
	38.034	38.040	pcn	
	38.040	39.759	ac	
	39.759	39.859	ppcn	?
	39.859	40.033	ac	

40	40.000	41.101	ac	vpd
	41.101	41.107	ppcn	vpd
	41.107	41.148	ac	vpd
	41.148	41.159	pcn	vpd
	41.159	41.177	br	vpd
	41.177	41.187	pcn	vpd
	41.187	42.208	ac	vpd
	42.208	42.212	ppcn	vpd
	42.212	43.998	ac	vpd
44	44.000	44.008	ac	
	44.008	44.053	ppcn	
	44.053	44.544	ac	
	44.544	44.547	ppcn	
	44.547	45.327	ac	
	45.327	45.331	ppcn	
	45.331	45.339	ac	
	45.339	45.416	ppcn	
	45.416	46.380	ac	
	46.380	46.385	ppcn	
	46.385	47.459	ac	
	47.459	47.462	ppcn	
	47.462	47.632	ac	
	47.632	47.634	ppcn	
	47.634	48.000	ac	
48	48.000	48.011	ac	vpd
	48.011	48.015	ppcn	vpd
	48.015	50.403	ac	vpd
	50.403	50.408	ppcn	vpd
	50.408	50.455	br	vpd
	50.455	50.464	ppcn	vpd
	50.464	52.000	ac	vpd
52	52.000	52.938	ac	
	52.938	52.944	ppcn	
	52.944	54.252	ac	
	54.252	54.285	ppcn	
	54.285	54.323	ac	
	54.323	54.327	ppcn	
	54.327	54.348	br	
	54.348	54.352	ppcn	
	54.352	56.000	ac	
56	56.000	56.235	ac	
	56.235	56.268	ppcn	
	56.268	56.281	ac	
	56.281	56.318	ppcn	
	56.318	56.411	ac	

	56.411	56.418	ppcn	
	56.418	56.472	ac	
	56.472	56.512	ppcn	
	56.512	56.989	ac	
	56.989	56.994	ppcn	
	56.994	56.997	ac	
	56.997	57.012	ppcn	
	57.012	57.096	ac	
	57.096	57.108	ppcn	
	57.108	60.000	ac	
60	60.000	61.784	ac	pd
	61.784	61.788	ppcn	pd
	61.788	63.568	ac	pd
	63.568	63.584	ppcr	pd
	63.584	64.002	ac	pd
64	64.000	64.867	ac	pd
	64.867	64.871	ppcn	pd
	64.871	65.655	ac	pd
	65.655	65.662	ppcn	pd
	65.662	65.748	br	pd
	65.748	65.784	ppcn	pd
	65.784	67.999	ac	pd
68	68.000	89.299	ac	pd
	70.130	70.138	ppcr	pd
	70.138	70.192	ac	pd
	70.192	70.197	ppcn	pd
	70.197	70.907	ac	pd
	70.907	70.911	ppcn	pd
	70.911	72.000	ac	pd
72	72.000	76.000	ac	
76	76.000	77.062	ac	pd
	77.062	77.066	ppcn	pd
	77.066	77.198	br	pd
	77.198	77.204	ppcn	pd
	77.204	78.120	ac	pd
	78.120	78.122	ppcn	pd
	78.122	78.167	br	pd
	78.167	78.172	ppcn	pd
	78.172	80.000	ac	pd
80	80.000	84.000	ac	pd
84	84.000	86.746	ac	pd
	86.746	86.749	ppcn	pd
	86.749	87.757	ac	pd
	87.757	87.761	ppcn	pd
	87.761	88.000	ac	pd

88	88.000	92.000	ac
92	92.000	92.810	ac
	92.810	92.813	ppcn
	92.813	92.959	br
	92.959	92.965	ppcn
	92.965	94.746	ac
	94.746	95.097	pcr
	95.097	95.103	ppcn
	95.103	95.156	br
	95.156	95.161	ppcn
	95.161	95.380	pcr
	95.380	96.000	ac
96	96.000	96.338	ac
	96.338	96.698	pcr
	96.698	97.903	ac
	97.903	98.184	pcr
	98.184	99.367	ac
	99.367	99.364	ppcn
	99.364	99.487	ac
	99.487	99.492	ppcn
	99.492	99.665	ac
	99.665	99.945	pcr
	99.945	100.000	ac
100	100.000	103.999	ac
104	104.000	107.965	ac
	107.965	107.971	ppcn
	107.971	107.997	ac
108	108.000	111.999	ac
112	112.000	113.111	ac
	113.111	113.115	ppcn
	113.115	113.144	br
	113.144	113.153	ppcn
	113.153	114.350	ac
	114.350	114.361	ppcn
	114.361	114.934	br
	114.934	114.942	ppcn
	114.942	116.000	ac
116	116.000	117.726	ac
	117.726	117.732	ppcn
	117.732	117.754	br
	117.754	117.759	ppcn
	117.759	119.990	ac
120	120.000	122.227	ac
	122.227	122.234	ppcr
	122.234	122.369	br

	122.369	122.376	ppcn
	122.376	123.080	ac
	123.080	123.087	ppcn
	123.087	124.000	ac
124	124.000	124.325	ac
	124.325	124.329	ppcn
	124.329	128.000	ac
128	128.000	128.714	ac
	128.714	128.720	ppcn
	128.720	128.761	br
	128.761	128.767	ppcn
	128.767	130.897	ac
	130.897	131.170	pcr
	131.170	132.000	ac
132	132.000	134.771	ac
	134.771	134.796	br
	134.796	136.000	ac
136	136.000	136.610	ac
	136.610	136.623	pcn
	136.623	136.675	br
	136.675	136.687	ppcn
	136.687	140.000	ac
140	140.000	144.000	ac
144	144.000	148.000	ac
148	148.000	152.000	ac
152	152.000	153.354	ac
	153.354	153.366	ppcn
	153.366	153.437	br
	153.437	153.454	ppcn
	153.454	154.638	ac
	154.638	154.810	pcr
	154.810	156.000	ac
156	156.000	158.948	ac
	158.948	160.000	pcr
160	160.000	164.000	pcr
164	164.000	164.887	pcr
	164.887	167.665	ac
	167.665	167.682	br
	167.682	168.000	ac
168	168.000	172.000	ac
172	172.000	176.000	ac
176	176.000	177.049	ac
	177.049	177.061	ppcn
	177.061	178.578	ac
	178.578	178.600	ppcn

	178.600	180.000	ac
180	180.000	184.000	ac
184	184.000	188.000	ac
188	188.000	192.000	ac
192	192.000	192.874	ac
	192.874	192.881	ppcn
	192.881	196.000	ac
196	196.000	197.136	ac
	197.102	197.144	ppcr
	197.144	197.158	ac
	197.158	197.163	ppcn
	197.163	197.166	ac
	197.166	197.170	ppcn
	197.170	200.000	ac
200	200.000	204.000	ac
204	204.000	205.579	ac
	205.579	205.583	ppcn
	205.583	208.000	ac
208	208.000	208.897	ac
	208.897	208.902	ppcn
	208.902	208.904	ac
	208.904	208.908	ppcn
	208.908	208.910	ac
	208.910	208.913	ppcn
	208.913	209.470	ac
	209.470	209.517	ppcn
	209.517	209.546	br
	209.546	209.607	ppcr
210	209.607	210.000	ac

Pavement type codes

ac	asphalt
pcr	reinforced concrete
ppcr	reinforced concrete patch
pcn	non-reinforced concrete
ppcn	non-reinforced concrete patch
br	bridge
un	unknown

Note codes

pd	poor data
vpd	very poor data

TABLE1b

West Bound I-70

Surface Type

Westbound

Cont. Mile Mark	Start	End	Surface type	Notes
	24	21.652	ac	
	21.65221	21.643	ppcn	
	21.6433	21.608	br	
	21.60766	21.599	ppcn	
	21.59933	21.588	ac	
	21.5877	21.581	ppcn	
	21.58073	20.427	ac	
	20.42679	20.400	ppcn	
	20.40005	20.371	br	
	20.37138	20.340	ppcn	
	20.3402	20.000	ac	
	28	25.283	ac	pd
	25.28277	25.179	br	
	25.17869	25.158	ppcn	
	25.15779	24.427	ac	
	24.42668	24.422	ppcn	
	24.42204	24.395	br	
	24.39476	24.373	ppcn	
	24.37329	24.000	ac	
	32	29.571	ac	pd
	29.5714	29.567	ppcn	
	29.56724	29.545	br	
	29.54488	29.374	ac	
	29.3739	29.346	br	
	29.3456	29.334	ppcn	
	29.33372	28.000	ac	
	36	33.562	ac	vpd
	33.56204	33.552	ppcn	
	33.55177	33.511	br	
	33.51109	33.501	ppcn	
	33.50083	32.000	ac	
	40	38.061	ac	vpd
	38.06092	37.719	un	
	37.71941	36.000	ac	
	44	40.000	ac	pd

48	47.180	ac	pd
47.17977	47.176	ppcn	
47.17648	47.099	ac	
47.09867	47.096	ppcn	
47.09577	47.087	ac	
47.0865	47.083	ppcn	
47.08284	46.830	ac	
46.8297	46.816	ppcn	
46.81618	45.516	ac	
45.51632	45.512	ppcn	
45.51207	45.439	ac	
45.4387	45.432	ppcn	
45.43233	45.418	ac	
45.41804	45.410	ppcn	
45.40993	45.385	ac	
45.38463	45.367	ppcn	
45.36726	45.336	ac	
45.33598	45.332	ppcn	
45.33154	45.325	ac	
45.32458	45.320	ppcn	
45.31976	45.288	ac	
45.2879	45.276	ppcn	
45.27612	45.038	ac	
45.03804	45.035	ppcn	
45.03495	44.830	ac	
44.8297	44.826	ppcn	
44.82584	44.643	ac	
44.6426	44.640	ppcn	
44.6399	44.294	ac	
44.29369	44.290	ppcn	
44.28983	44.282	ac	
44.28191	44.278	ppcn	
44.27844	44.000	ac	
52	50.460	ac	
50.45993	50.413	br	
50.41315	49.502	ac	
49.50239	49.412	ppcr	
49.41155	49.372	br	
49.37195	49.262	ppcr	
49.26208	48.821	ac	
48.82087	48.818	ppcn	
48.81776	48.811	ac	
48.81058	48.807	ppcn	
48.80709	48.000	ac	
56	54.350	ac	

54.35035	54.346	ppcn	
54.34609	54.325	br	
54.32537	54.321	ppcn	
54.32131	52.801	ac	
52.80059	52.795	ppcn	
52.79498	52.000	ac	
60	59.470	ac	
59.46973	59.465	ppcn	
59.46451	55.998	ac	
64	62.589	ac	pd
62.58925	62.576	ppcn	
62.57589	62.295	ac	
62.29537	62.293	ppcn	
62.29265	60.800	ac	
60.79982	61.956	ppcn	
61.9556	61.725	ac	
61.72464	61.712	ppcn	
61.71167	60.003	ac	
68	65.730	ac	pd
65.72967	65.644	br	
65.64449	64.760	ac	
64.76032	64.757	ppcn	
64.75664	64.010	ac	
64.00994	64.005	ppcn	
64.0051	64.004	ac	
72	69.130	ac	
69.13043	69.125	ppcn	
69.12461	69.108	ac	
69.10753	69.101	ppcn	
69.10074	68.426	ac	
68.42628	68.422	ppcn	
68.42201	68.000	ac	
76	72.795	ac	
72.79457	72.780	ppcr	
72.78019	72.000	ac	
80	78.245	ac	
78.24474	79.994	ppcn	
79.99395	79.985	ac	
79.98465	79.980	ppcn	
79.98038	79.933	br	
79.9327	79.926	ppcn	
79.9263	78.990	ac	
78.98964	78.853	br	
78.85279	77.757	ac	
84	80.002	ac	

88	87.795	ac
87.79481	87.792	ppcn
87.79209	87.579	ac
87.57893	87.567	ppcn
87.5669	87.548	ac
87.54768	87.543	ppcn
87.54341	87.689	ac
87.68901	87.547	pcr
87.54749	87.543	ppcn
87.54321	86.746	pcr
86.74612	84.677	ac
84.67671	84.674	ppcn
84.6738	84.657	ac
84.6571	84.654	ppcn
84.6538	84.000	ac
92	88.000	ac
96	95.370	ac
95.36989	95.162	pcr
95.16196	95.144	ppcn
95.14422	95.091	br
95.091	95.070	ppcn
95.06952	94.737	pcr
94.73702	92.942	ac
92.94229	92.933	ppcr
92.93342	92.788	br
92.78777	92.000	ac
100	99.940	ac
99.94027	99.659	pcn
99.65925	99.534	ac
99.53358	99.528	ppcn
99.52834	99.418	ac
99.41818	99.415	ppcn
99.41488	98.637	ac
98.6368	98.634	ppcn
98.6337	98.381	ac
98.38138	98.377	ppcn
98.37673	98.354	ac
98.35384	98.347	ppcn
98.34744	98.176	ac
98.17639	97.895	pcn
97.89498	96.690	ac
96.69004	96.330	pcr
96.3297	96.000	ac
104	102.733	ac

102.7331	102.730	ppcn	
102.7298	100.000	ac	
108	104.000	ac	
112	108.299	ac	
108.2989	108.293	ppcn	
108.2931	108.000	ac	
116	114.841	ac	
114.8406	114.348	br	
114.348	113.129	ac	
113.1289	113.099	br	
113.0994	112.000	ac	
120	117.757	ac	
117.7575	117.736	br	
117.7358	116.000	ac	
124	122.700	ac	
122.6997	122.695	ppcn	
122.6953	122.569	ac	
122.5688	122.566	ppcn	
122.5655	122.368	ac	
122.3676	122.355	ppcn	
122.3554	122.224	br	
122.2241	122.213	ppcn	
122.2135	121.226	ac	
121.226	121.198	br	
121.1983	120.000	ac	
128	127.091	ac	vpd
127.0909	127.061	br	
127.0607	126.943	ac	
126.9425	126.338	br	
126.3376	125.618	ac	
125.6182	125.602	ppcn	
125.6019	125.562	br	
125.5616	125.551	ppcn	
125.5508	124.503	ac	
124.503	124.444	ppcn	
124.4445	124.025	ac	
124.0249	124.020	ppcn	
124.0197	124.000	ac	
132	130.343	ac	pd
130.343	130.297	br	
130.2971	128.769	ac	
128.7693	128.732	br	
128.7317	128.012	ac	
136	134.784	ac	pd
134.7844	134.760	br	

134.7598	132.000	ac
140	138.432	ac
138.432	138.428	ppcn
138.4281	138.420	ac
138.4201	138.414	ppcn
138.4145	138.257	ac
138.2572	138.253	ppcr
138.2533	136.685	ac
136.6853	136.632	br
136.6319	136.000	ac
144	140.000	ac
148	144.000	ac
152	150.354	ac
150.3539	150.347	ppcn
150.3475	149.806	ac
149.806	149.798	ppcn
149.7984	149.001	ac
149.0007	148.994	ppcn
148.9944	148.000	ac
156	153.480	ac
153.4796	153.410	br
153.4096	151.995	ac
151.995	156.000	ac
164	160.000	ac
168	164.000	ac
172	168.191	ac
168.1909	168.121	br
168.1209	168.000	ac
176	172.000	ac
180	179.237	ac
179.2369	179.233	ppcn
179.2328	179.153	ac
179.1529	179.148	ppcn
179.1478	176.000	ac
184	181.595	ac
181.5952	181.443	pcr
181.4428	180.000	ac
188	185.372	ac
185.3722	185.351	ppcn
185.3506	185.115	ac
185.115	185.107	ppcn
185.1075	184.906	ac
184.9057	184.899	ppcn
184.8991	184.000	ac
192	188.000	ac

196	193.104	ac	
193.1042	193.101	ppcn	
193.1007	192.869	ac	
192.8692	192.866	ppcn	
192.8662	192.000	ac	
191.9998	196.000	ac	pd
195.9999	200.000	ac	pd
199.9999	204.000	ac	
210	209.602	ac	
209.602	209.543	ppcr	
209.5429	209.516	br	
209.5156	209.465	ppcr	
209.4653	208.301	ac	
208.3014	208.297	ppcn	
208.2973	208.000	ac	

Pavement type codes

ac	asphalt
pcr	reinforced concrete
ppcr	reinforced concrete patch
pcn	non-reinforced concrete
ppcn	non-reinforced concrete patch
br	bridge
un	unknown

Note codes

pd	poor data
vpd	very poor data

TABLE 2a

East Bound I-70

Eastbound Anomalies

Radar Anomalies

Mile Marker from	to	type	Notes
23.230	23.240	wo	
26.627	26.633	daac	Patch?
27.310	27.359	rs	
29.500	29.509	iapcn,dcpcn	
30.668	30.686	tnac	
31.356	31.462	tnac	
37.170	37.176	iasb	
38.265	38.273	iaac	
42.651	42.654	dcac, iaac	
43.036	43.061	rsac	
43.443	43.494	dcac, iaac	
43.573	43.693	dcac, iaac	
43.983	43.994	rsac	
44.001	44.008	rsac	
46.078	46.100	thac,darn	
49.327	49.353	dcac	
49.537	49.548	dcsb	
50.118	50.135	rsac	
50.600	50.616	rsac	
52.429	52.541	daac, dcac,rsac	
52.580	52.588	iaac	
52.746	52.736	rsac	
52.887	52.939	rsac, dcac	
54.229	54.272	rsac,rsppcn,dcac	
54.376	54.420	dcac,rsac	
54.401	54.409	iasb	
55.324	55.492	dcas,rsac	
55.728	55.907	rsac	
56.096	56.137	daac	
56.235	56.270	iasb	
56.480	56.512	iasb	
56.989	56.994	iasb	
56.997	57.012	iasb	
57.096	57.108	rsppcn	
58.566	58.594	iarn	

59.069	59.081	dcac	
59.398	59.424	daac	ppca?
64.582	64.853	rsac	
64.878	65.148	ppcn	multiple small patches
66.827	66.832	thac	
69.967	69.981	rsac, daac	
72.578	72.583	wosb	
74.265	74.273	daac,rsac	
74.652	74.558	iaac	
74.625	74.655	rsac	
76.258	76.318	dcac	
81.524	81.783	tnac	
90.721	90.758	iasb	
92.509	92.554	dcrn, iarn	
95.919	93.964	wosb	
98.326	98.351	dcac	
98.649	98.654	iaac	
103.493	103.521	dcac	
103.684	103.698	dcac	
113.951	113.960	wosb	
115.214	115.232	iapcr	
117.674	117.693	thac, rsac	
120.546	120.464	wosb, iappcr	
123.271	123.285	wosb, iappcr	
123.757	123.765	wosb, iappcr	
124.164	124.184	wosb	
124.472	124.542	rsac	
125.599	125.630	iarn	
127.065	127.083	rsac	?
128.442	128.702	thac	
135.912	135.924	iasb, rsac	
136.168	136.212	iasb, wosb?	
137.249	137.266	iasb	
137.288	137.318	iasb	
139.872	139.893	wosb	
140.195	140.213	wosb	
140.390	140.425	wosb	
142.803	142.844	wosb	
147.761	147.773	wosb	
147.820	147.846	wosb	
169.366	169.426	thac	
176.648	176.672	wosb	
178.992	179.208	thac	
180.918	181.228	thac	

185.058	185.066	wosb
185.547	185.555	wosb, iasb
206.104	206.475	daac
208.854	208.965	tnac

Anomaly code		**Interface suffix code**	
wo	washout	sb	base coarse
ia	increase amplitude	ac	asphalt
da	decrease amplitude	pcn	nonreinforced concrete
th	thickening	pcr	reinforced concrete
tn	thinning	rn	reinforcement
dc	discontinuous		
rs	very rough surface		

TABLE2b

West Bound I-70

Radar Anomalies

Westbound Anomalies

Mile Marker From	to	type	Notes
29.55788	29.33312	thac	
38.35111	38.28608	tnac	
43.9594	43.92821	thac	
49.59029	49.58697	iarn	
49.60896	49.60434	iarn	
50.22413	50.21415	wosb	
58.64805	58.62173	iarn	
59.49225	59.48725	iasb	mult-diffractin
61.82464	61.81224	iasb	
62.05101	62.04545	iasb	
62.37029	62.3677	iasb	
62.64903	62.63811	iasb	
64.25323	64.23602	daac	
64.63951	64.51014	dcac	
66.47486	66.23184	dcac	
66.47912	66.46302	rsac	
70.23084	70.19849	iaac	
73.33718	73.32721	tnac	
76.95675	76.94713	wosb	
80.33408	80.3091	iaac	
81.05631	81.04928	daac (Rn)	
81.95378	81.7258	tnac	
85.93265	85.7403	tnac	
87.8023	87.79731	iarn	
88.09122	88.07919	rsac	
88.95336	88.94734	iasb	
94.32918	94.32135	iarn	
97.43517	97.32346	dcac	
97.88514	97.8402	dcac	
99.17385	98.94766	mult-patches	
100.6227	100.6003	iaac	
100.9732	100.9682	iasb	
101.0111	101.0033	wosb (iasb)	

102.9055	102.8835	dcac
103.2549	103.2066	dcac
105.9358	105.8515	iapcr base
108.9096	108.8997	iaac
111.1879	111.179	wosb
117.8282	117.8156	iarn
117.9288	117.9201	ia-pcn
120.7302	120.7216	wosb
122.0723	122.0544	wosb
122.5861	122.5798	wopcr base
123.017	123.0057	woac (pcr)
131.204	130.976	tnac
132.7331	132.7253	iapcr base
132.852	132.8219	thac
137.0673	137.0607	wosb
137.8254	137.8121	wosb
137.8528	137.8415	wosb
140.4037	140.3884	iasb
145.7696	145.7094	rsac (thac)
145.9867	145.9484	rsac
149.9547	149.9384	thac
155.6473	155.4827	tnac
161.7786	161.7732	thac
166.1633	166.1528	thac
167.7181	167.6989	iarn (rs at ends)
169.9395	169.9242	wosb
170.1219	170.1102	wosb (iapcr)
171.8365	171.8265	iapcr (wosb)
172.2815	172.2672	wosb
172.6534	172.6382	wosb
173.3262	173.2905	wosb
173.7897	173.7736	wosb
174.02	174.0002	wosb
174.2654	174.2526	wosb
176.7845	176.7671	wosb
179.8302	179.8206	wosb
180.7118	180.6974	wosb
180.7468	180.7355	wosb
181.9371	181.8785	thac
182.5097	182.3899	tnac
184.1968	184.186	iarcr
184.8411	184.8213	daac
185.0076	184.8655	mult-patches
185.5761	185.4858	mult-patches
186.8315	186.8267	iasb

196.4254	196.4169	iaac
196.8694	196.853	dcac
198.1918	198.1824	dcac
208.8515	208.7555	thac

Anomaly code		**Interface suffix code**	
wo	washout	sb	base coarse
ia	increase amplitude	ac	asphalt
da	decrease amplitude	pcn	nonreinforced concrete
th	thickening	pcr	reinforced concrete
tn	thinning	rn	reinforcement
dc	discontinuous		
rs	very rough surface		

TABLE 3a

Eastbound

Tenth Mile Anomalies

Mile Marker from	to	type	Notes
29.5		iapcn,dcpcn	
43.6		dcac, iaac	
44.0		rsac	
46.1		thac,darn	
50.6		rsac	
52.5		daac, dcac,rsac	
52.9		rsac, dcac	
54.4		dcac,rsac	
55.4		dcas,rsac	
55.8	55.9	rsac	
56.1		daac	
56.5		iasb	
57.0		iasb	
57.1		rsppcn	
59.4		daac	ppca?
64.6	64.8	rsac	
64.9	65.1	ppcn	multiple small patches
76.3		dcac	
81.5	81.7	tnac	
94.0	95.9	wosb	
103.5		dcac	
103.7		dcac	
120.5		wosb, iappcr	
124.5		rsac	
125.6		iarn	
128.5	128.7	thac	
137.3		iasb	
140.2		wosb	
140.4		wosb	
169.4		thac	
179.0	179.2	thac	
181.0	181.2	thac	
206.2	206.4	daac	
208.9		tnac	

Anomaly code		Interface suffix code	
wo	washout	sb	base coarse
ia	increase amplitude	ac	asphalt
da	decrease amplitude	pcn	nonreinforced concrete
th	thickening	pcr	reinforced concrete
tn	thinning	rn	reinforcement
dc	discontinuous		
rs	very rough surface		

TABLE 3b

Westbound

Tenth Mile Anomalies

Mile Marker from	to	type	Notes
29.4	29.5	thac	
38.3		tnac	
64.6		dcac	
66.3	66.4	dcac	
70.2		iaac	
81.8	81.9	tnac	
85.8	85.9	tnac	
87.8		iarn	
97.4		dcac	
99	99.1	nult-patches	
100.6		iaac	
102.9		dcac	
105.9		iapcr base	
108.9		iaac	
131	131.2	tnac	
155.6	155.6	tnac	
167.7		iarn (rs at ends)	
173.3		wosb	
174		wosb	
180.7		wosb	
181.9		thac	
182.4	182.5	tnac	
184.9	185	nult-patches	
185.5		mult-patches	
208.8		thac	

Anomaly code		Interface suffix code	
wo	washout	sb	base coarse
ia	increase amplitude	ac	asphalt
da	decrease amplitude	pcn	nonreinforced concrete
th	thickening	pcr	reinforced concrete
tn	thinning	rn	reinforcement
dc	discontinuous		
rs	very rough surface		

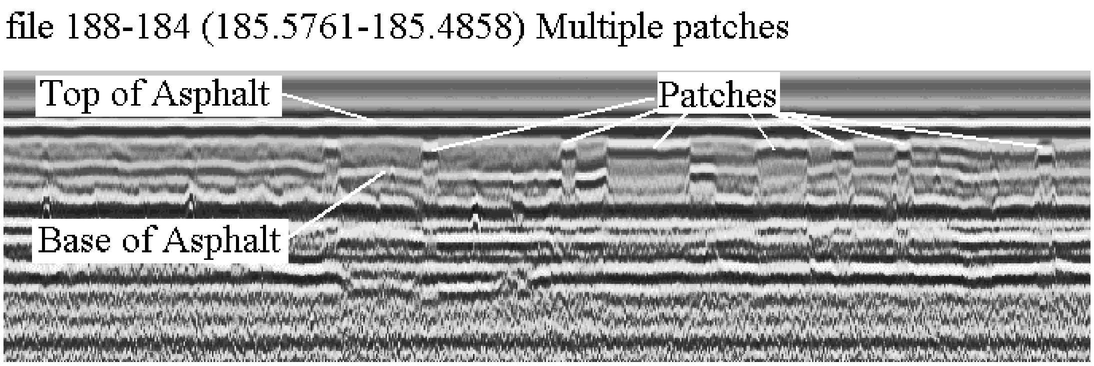


Figure 3. Example GPR profile at 185.5 mile westbound showing radar signature of multiple patches in the pavement.

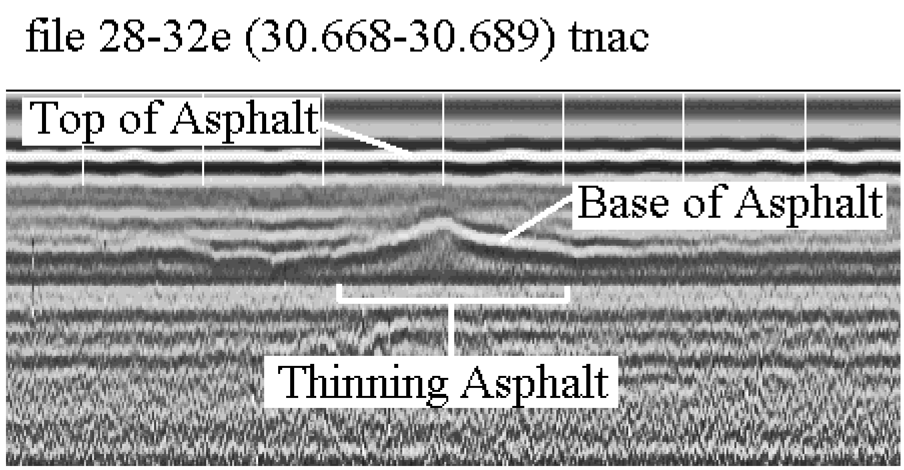


Figure 4. Example GPR profile at 30.7 mile eastbound showing radar signature of anomalously thin area in asphalt pavement.

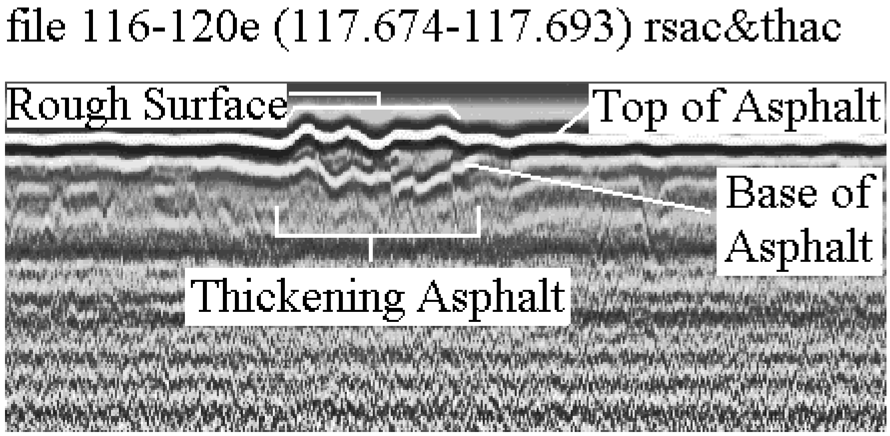


Figure 5. Example GPR profile at 117.7 mile eastbound showing radar signature of anomalously thick area in asphalt pavement, here associated with very rough pavement surface.

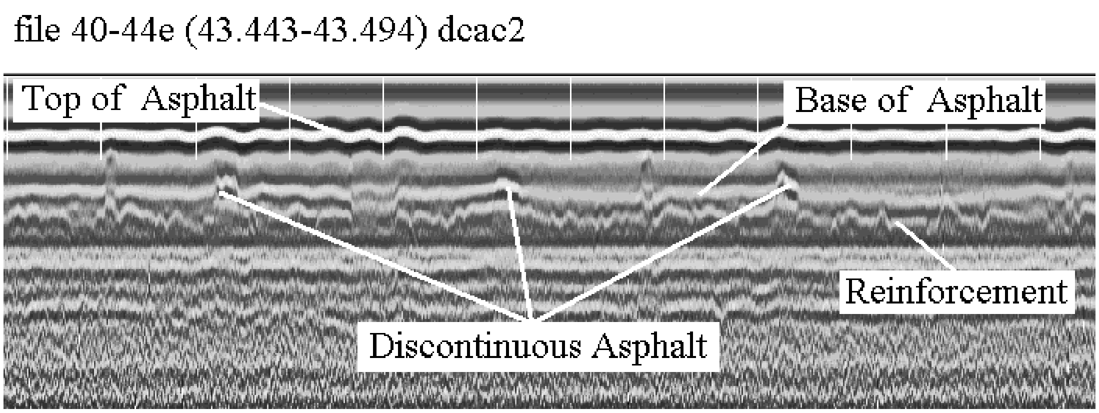


Figure 6. Example GPR profile at 43.5 mile eastbound showing radar signature of discontinuous area in asphalt pavement.

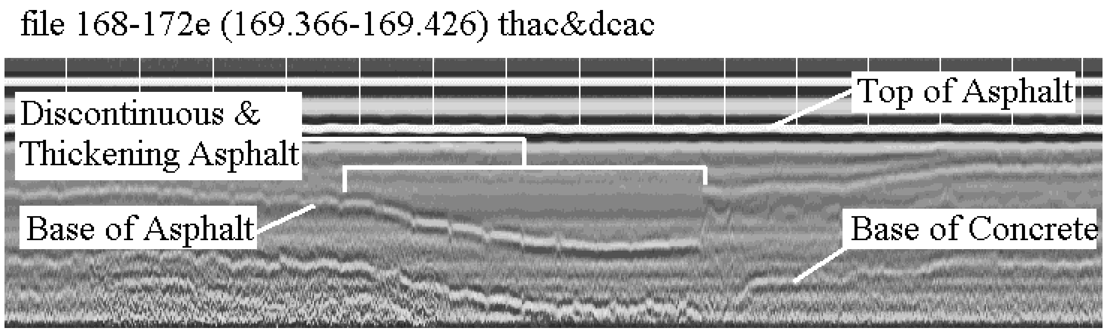


Figure 7. Example GPR profile at 169.4 mile eastbound showing radar signature of thickening asphalt pavement area associated here with a discontinuity in the asphalt layer.

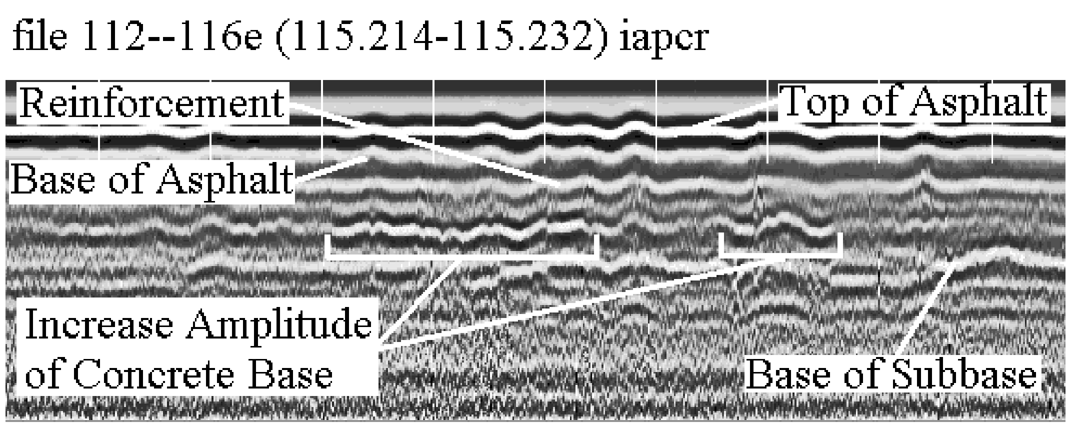


Figure 8. Example GPR profile at 115.2 mile eastbound showing increased amplitude radar signature at base of concrete interface.

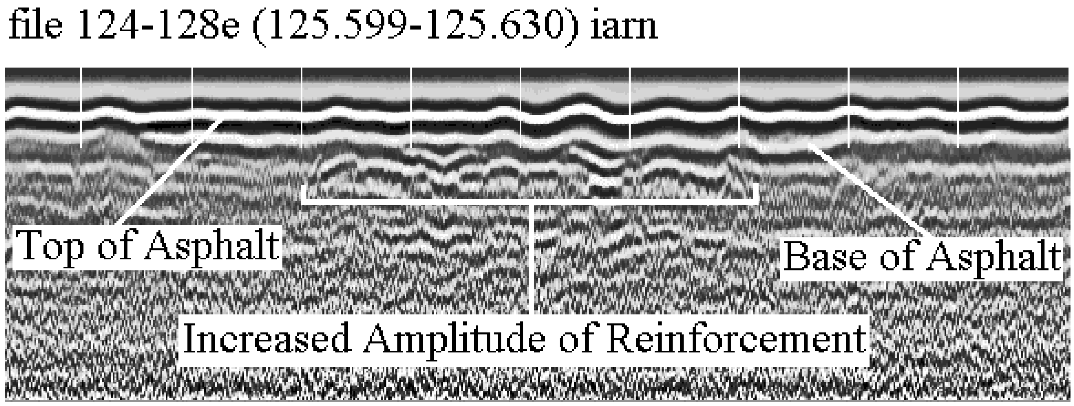


Figure 9. Example GPR profile at 125.6 mile eastbound showing increased amplitude radar signature of concrete reinforcement.

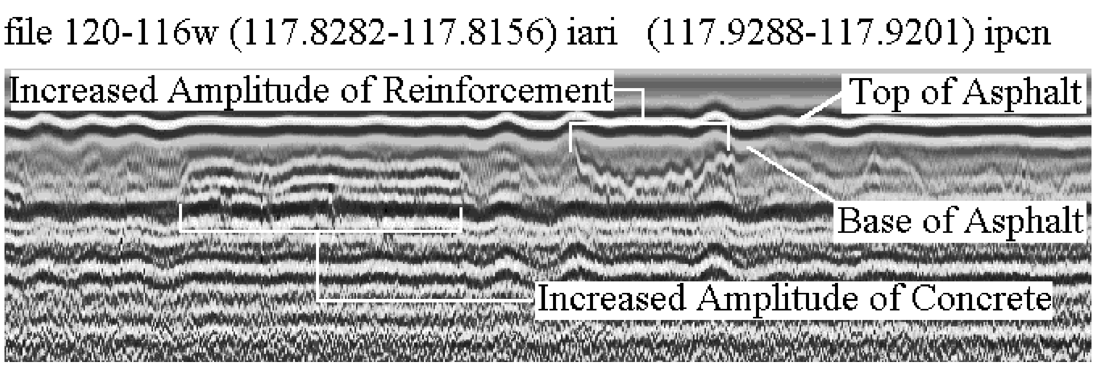


Figure 10. Example GPR profile at 117.8 mile westbound showing increased amplitude radar signature of both the concrete reinforcement and base of concrete interface.

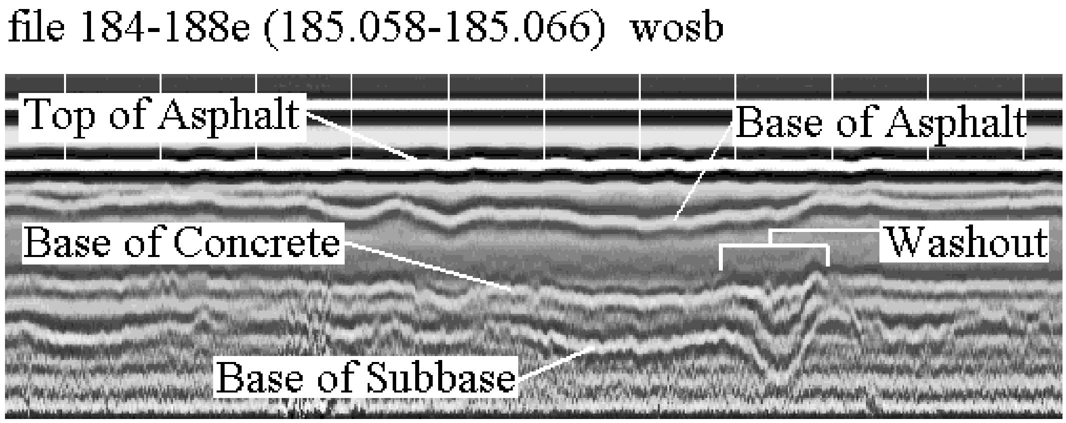


Figure 11. Example GPR profile at 185 mile eastbound showing radar signature of possible washout in basecoarse affecting also the base of concrete reflection.

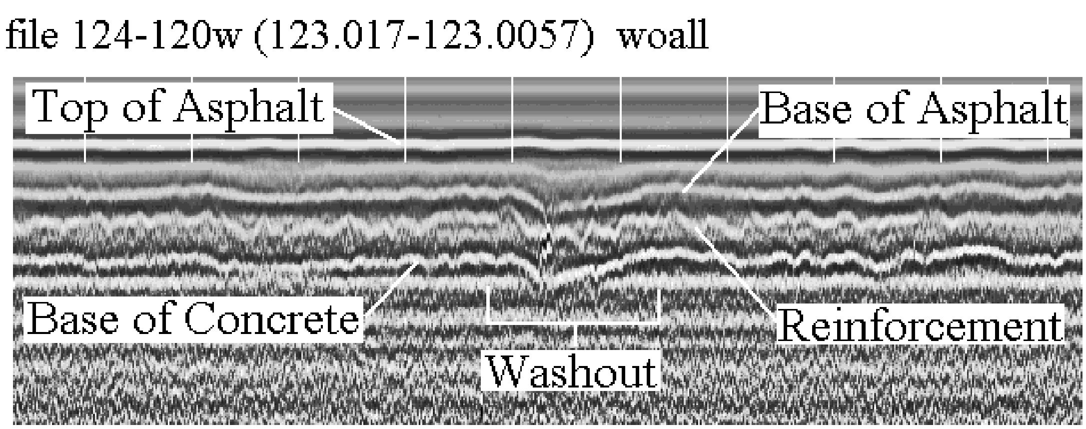


Figure 12. Example GPR profile at 123 mile westbound showing radar signature of possible washout affecting all pavement layers (base of concrete, concrete reinforcement and asphalt overlay).

SUGGESTIONS FOR FUTURE WORK

1) Get core information from various anomalous regions and correlate findings with radar signatures to aid in future automatic identification of problem areas. This core information could be obtained at areas where previous geotechnical ground truth were acquired (e.g., falling weight deflectometer) for further comparison.
2) Re-survey area of I70 currently being resurfaced for comparison with previous profile. In addition, get information on pavement layers that were stripped prior to resurfacing (during milling process or other) for correlation with radar profile in this report.
3) Get core information from various points along the I70 corridor in order to adjust dielectric constants along the length of the surveyed portion of I70.
4) Collect data over a small portion of the previously surveyed area (in area untouched by MoDOT maintenance) in which good and bad areas exist (areas easy to interpret and areas more difficult to interpret). With an associated calibration file carefully acquired, compare results of automated technique (desired) and interpreter-based technique (as used in this study) for more definitive investigation of when/where the automated technique breaks down.

CONCLUSIONS

In this report we have applied the ground penetrating radar technique to high resolution roadway pavement analysis along 380 miles of Interstate 70 across Missouri. Through a comparison with history information, we have demonstrated the utility of the tool for determining pavement layer thickness estimates in a rapid fashion and across a large portion of roadway. We have produced pavement layer profiles based on the GPR data which can be used to revise and update design history information. In addition, we have delineated areas of anomalous radar signals which may be indicative of roadway problems and can be further investigated. Because completely automated techniques need to be used carefully, in particular when reflections from specific layers (e.g., concrete to base coarse) are not clearly defined, interpreter input is necessary to help guide the analysis and keep it as accurate as possible when faced with such a large quantity of data covering such widely variable roadway surface.

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