Ground Penetrating Radar Quality Assurance Characterization of Asphaltic Concrete Surfacing

Prepared by:

Curtis Berthelot, Ph.D., P. Eng., PSI Technologies Inc.
221 Jessop Avenue, Saskatoon, SK, Canada, S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190
cberthelot@pavesci.com

Brian Taylor, P.Eng., PSI Technologies Inc.
221 Jessop Avenue, Saskatoon, SK, Canada, S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190
btaylor@pavesci.com

Erin Stuber, E.I.T., PSI Technologies Inc.
221 Jessop Avenue, Saskatoon, SK, Canada, S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190
estuber@pavesci.com

Diana Podborochynski, E.I.T., PSI Technologies Inc.
221 Jessop Avenue, Saskatoon, SK, Canada, S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190
dpodborochynski@pavesci.com

Rielle Haichert, E.I.T., PSI Technologies Inc.
221 Jessop Avenue, Saskatoon, SK, Canada, S7N 1Y3
Phone: (306) 477-4090, Fax: (306) 477-4190
rhaichert@pavesci.com

Brent Marjerison, M.Sc., P.Eng., Saskatchewan Ministry of Highways and Infrastructure
350 3rd Avenue North, Saskatoon, SK, Canada S7K 2H6
Phone: (306) 933-7088, Fax: (306) 933-6161
brent.marjerison@gov.sk.ca

Rob Bushman, M.Sc., P.Eng., Saskatchewan Ministry of Highways and Infrastructure
2174 Airport Drive, Saskatoon, SK, Canada S7L 6M6
Phone: (306) 933-5636, Fax: (306) 933-8313
rob.bushman@gov.sk.ca

Paper prepared for the
Pavement Evaluation, Performance, and Management Poster Session
of the 2009 Annual Conference of the
Transportation Association of Canada
Vancouver, British Columbia

ABSTRACT
Saskatchewan Ministry of Highways and Infrastructure commissioned a ground penetrating radar (GPR) survey to develop a non-destructive methodology for performing post construction quality assurance characterization of a newly upgraded flexible pavement structure. The survey employed multiple passes of GPR to determine conventional hot mix asphalt concrete (HMAC) surfacing quality assurance measures including layer variability thickness and density. The GPR survey found that 21 percent of the southbound lane and 14 percent of the northbound lane showed low, moderate, or high severity surfacing variability. It was also determined that more asphalt mat variability was present towards the outside of both lanes.

Based on the results of this study, GPR was found to provide a measure of HMAC surface irregularity, as well as the severity of the surface variability. The pilot GPR analysis correlated well with the visual condition survey of the surface. As well, the GPR measured HMAC layer thicknesses were validated as they correlated well with retrieved HMAC core thicknesses. However, the GPR did not provide an adequate correlation to surface density.

In summary, this research demonstrates that GPR may be a valuable non-destructive measurement tool to provide quality assurance measures of mat thickness and variability of HMAC surfaces in Saskatchewan.

INTRODUCTION

It has been well documented that hot mix asphalt concrete (HMAC) layer variability such as segregation causes accelerated deterioration of HMAC surfaces over their performance life, particularly in high moisture and/or freeze thaw conditions (1, 2, 3). Segregation often occurs in localized areas of the HMAC surface and is caused by an inconsistent gradation within the HMAC mix during placement. Severe segregation is typically exhibited by areas of excessive coarse aggregate resulting in an open surface texture.

The primary mechanism of segregation is when the coarse aggregate fraction of the HMAC mix separates from the fine aggregate fraction during hauling and placement. Segregation results in pavement performance problems, poor durability, shorter pavement structure life, and higher maintenance costs (2). In addition, segregation of the HMAC surface may lead to increased roughness, raveling, or increased water penetration into the pavement sub-structure (1). Presently, in Saskatchewan, segregation is quantified primarily by visual condition survey techniques and tends to focus only on very severe segregation.

The primary method used to measure asphalt concrete surfacing density in the field is by nuclear density gauge (2). The thickness of HMAC surfacing has traditionally been evaluated based on random core thickness measurements and/or estimated based on the amount of HMAC placed. HMAC surface thickness and uniformity can have a significant impact on the structural performance of flexible pavement both in the short and long term. As such, the thickness and uniformity of the HMAC surface layer are also critical quality assurance measures of HMAC paving end product value.

This study attempted to develop a less subjective, sensitive, and more spatially continuous and non-destructive survey methodology for performing post construction quality assurance characterization of HMAC surfacing. Non-destructive testing, such as ground penetrating radar (GPR) surveying, for project-level asset management surveys has been used in Saskatchewan on a pilot basis for over eight years (3, 4, 5, 6). GPR technology at the project-level has successfully been used to identify the cause of existing problems in pavement structures and to determine optimal rehabilitation strategies (3, 4, 5, 6, 7, 8). GPR surveys have also been used to help determine pavement layer thickness, to detect the presence of moisture within a pavement structure to estimate the frost susceptibility of the pavement sub-structure, and to evaluate the HMAC surface and pavement sub-structure quality in terms of uniformity, segregation, or stripping (2, 3, 7, 8).

OBJECTIVE

The objective of this study was to employ GPR to evaluate the presence of HMAC layer variability, to quantify the HMAC surface thickness, and to quantify HMAC density on a typical pavement rehabilitation project for quality assurance purposes.

STUDY SCOPE

A secondary highway that had recently undergone typical pavement rehabilitation was selected as the test section for the pilot non-destructive survey. The total asphaltic surface area of each lane of the candidate highway was approximately 67,400 m^2.

A GPR survey was performed employing a one GHz central frequency air coupled pulse radar system as shown in Figure 1. GPR profiles were collected in both directions (northbound and southbound) along each wheelpath, between the wheelpaths, along the fog line, and along the centerline at one meter intervals spatially referenced by electronic distance measurement. To compare the surface variability evaluation results obtained from GPR, a visual condition survey was performed.

The scope of this project compared the GPR results to the targeted ground truth cores in an attempt to develop a non-destructive methodology for performing post construction quality assurance characterization of a newly upgraded flexible pavement structure on a spatially continuous basis. As a result, the GPR survey results were compared to the HMAC surface layer thicknesses and densities determined from 15 targeted ground truth cores, as provided by SMHI. Ground truth cores were targeted based on the spatially continuous GPR profiles to obtain samples of HMAC representative of the spectrum of GPR properties found along the test section.

VISUAL CONDITION UNIFORMITY SURVEY

Figure 2 and Figure 3 show digital photos taken during the visual condition quality assurance survey of the test section. Figure 2 shows an area of good HMAC surfacing and Figure 3 shows a poor section. Based on the visual condition survey performed by the authors, low, moderate, and severe segregation cumulatively appeared to be present across approximately 15 percent of the surface area of the surveyed test section. As well, the majority of the HMAC surface variability exhibited a regular spacing interval of approximately 30 to 40 meters.

GPR HMAC SURFACE UNIFORMITY EVALUATION

A surface layer quality index was calculated to assess the relative variability of the HMAC surface based on the GPR surface dielectric profiles. Given more surface variability was observed towards the outside of the lane, a sensitivity analysis was performed on a single GPR profile collected along the outside southbound wheelpath/fogline over the entire segment length to validate the segregation sampling model developed in this research.

As a first step in the validation of GPR to characterize HMAC surface variability, varying sub-segment statistical sample lengths of 5 m, 10 m, 20 m, 30 m, 40 m, and 50 m were examined to evaluate the ability to isolate and identify HMAC. HMAC surface layer quality index was defined at three levels.

- A good section had low severity variability (surface layer quality index greater than 90).
- A fair section had moderate severity variability (surface layer quality index between 80 and 90).
- A poor section had high severity variability (surface layer quality index less than 80).

Based on the sub-segment sample lengths used in the evaluation, Figure 4 illustrates the surface layer quality index with respect to the selected sample intervals. As seen in Figure 4, a sub-segment length of 20 meters was determined as the apex of sensitivity for the GPR surface layer quality index. Note that the 20 meter interval results concur with approximately half the visually identified relative spacing of surface segregation recorded at between 30 and 40 meters. Also, note that a spacing of 40 meters is likely indicative of end-of-load segregation or poor construction practices. As a result, 20 meters was selected as the sub-segment length to calculate surface layer quality index. Figure 5 illustrates the surface layer quality index evaluation using 20 m sub-segment sample lengths within a good section, fair section, and poor section.

A limitation to performing conventional visual condition surveys to determine the presence and extent of HMAC quality is its dependence on subjective visual interpretation and difficulty to identify low to moderate levels of segregation. Based on the GPR surface layer quality index evaluation, Figure 6 illustrates the percentage of surface area with respect to each longitudinal pass collected. As seen in Figure 6, there is an evident trend of increased variability towards the outside of the travelled lanes of the test section in both directions, which concurred with the visual condition survey. These results also concur with research by Saarenketo that found dielectric values measured in the outer wheel paths to be almost invariably higher than those in the inner wheelpath (8).

Figure 7 illustrates the average percentage of surface layer quality index ratings with respect to each lane. As seen in Figure 7, the southbound lane and the northbound lane showed approximately 21 percent and 14 percent surfacing variability ranging from fair to poor surface layer quality index, respectively. Based on a paving surface width of 4.0 meters per lane, this corresponds to 14,154 m^2 of the southbound lane and 9,436 m^2 of the northbound lane showing surfacing variability. These results generally concur with the initial visual condition survey performed by the authors. However, the GPR did identify a slightly higher amount HMAC surface layer variability due to the ability to identify more low to moderate HMAC variability.

GPR HMAC SURFACE THICKNESS EVALUATION

The HMAC surface thickness is an essential component to the overall structural design of typical Saskatchewan flexible pavement structures. Therefore, uniform placement of the HMAC surfacing is critical to assure the specified structural quality is met, particularly in the case of relatively thinner asphalt surfaces commonly used in Saskatchewan. Ground truth cores are a conventional quality assurance measure used to evaluate HMAC surface thickness.

Core locations were targeted based on the range of spatially obtained GPR values. Table 1 summarizes and Figure 8 illustrates the HMAC surface core thickness relative to the GPR thickness measured and calculated at specific core locations. As seen in Table 1, Figure 8, and Figure 9, the HMAC surface thickness determined with GPR generally correlated well to the core thicknesses retrieved from the field. As seen from the survey data, there was a near unity correspondence between the HMAC core thickness and GPR thickness across measurements taken in this study. The difference in HMAC surface thickness between cores and GPR was found to range from –14 mm to +11 mm. On average across all 15 cores retrieved, the GPR measurements found the HMAC thicknesses to be 2 mm thinner than the core sample thicknesses. As a result, the HMAC surface thickness was found to be well within acceptable tolerance of surface thickness for paving quality assurance purposes, with an R^2 of 0.98.

Also seen in Table 1, Figure 8, and Figure 9, two of the 15 core samples were found to be considerably thicker than the rest of the core samples (core number 5 and 15 measured HMAC core thicknesses of 218 mm and 195 mm, respectively). This indicates areas of significant increased thickness in the HMAC structural layer profiles and/or areas where all of the old HMAC surface had not been removed prior to overlay. The GPR profiles positively identified these two locations where the core thickness was significantly thicker than the specified design.

GPR HMAC DENSITY EVALUATION

The GPR dielectric values and core densities are summarized in Table 2 and Figure 10. Although the correlation between the GPR dielectric permittivity and the core densities showed a general increasing trend with respect to one another, the coefficient of linear regression showed a moderate correlation of only 0.64, as seen in Figure 10. Overall, the GPR did not provide an adequate correlation to HMAC core density.

SUMMARY AND CONCLUSIONS

This study set out to perform a HMAC surface quality assurance measures using GPR. This study evaluated HMAC variability, thickness, and density of targeted cores and compared these ground truth results to those obtained from the GPR quality assurance survey. This survey employed multiple passes of GPR to identify conventional HMAC surfacing quality assurance measures and compared them to conventional visual surveying. The pavement segment employed in this study was a typical secondary Saskatchewan highway.

Based on the conventional visual condition survey performed by the authors, low, moderate, or high severity HMAC variability appeared to be present in approximately 15 percent of the surveyed surface area of the test section. In addition, segregated sections generally appeared to be present at regular spacing intervals of approximately 30 to 40 meters which is an indication of end-of-load segregation during paving. Also, it was also observed that more HMAC variability occurred along the outside edge of each lane.

The GPR determined the HMAC surface thickness measures to be 2 mm thinner on average than the ground truth core sample thicknesses. There was a near unity correspondence between the HMAC layer core thickness and GPR measured thickness with an R^2 of 0.98. The GPR did not provide an adequate correlation to HMAC core density.

A significant advantage to using GPR as a HMAC surfacing quality assurance measurement device is that it provides a non-destructive and more spatially continuous methods of assessing pavement quality as compared to traditional coring methods and visual inspection. GPR surveys are conducted from within a moving vehicle at highway speeds, thus allowing for continuous data collection, improved worker safety, and no interruption in the flow of traffic. In addition, GPR surveys provide information on the thickness of the pavement layers as well as the quality of the road sub-structure. Incorporating GPR to detect surface variability and to verify HMAC surface layer thickness for quality assurance purposes provides the opportunity to improve spatial uniformity of new HMAC surfaces.

In summary, GPR appears to provide a good correlation to traditional surface uniformity and HMAC surface layer thickness measures that are well within acceptable thickness tolerance for engineering quality assurance purposes.

REFERENCES

(1) Roberts, F., Kandhal, P., Lee, D., Kennedy, T. 1996. Hot mix asphalt materials, moisture design, and construction. Second Edition, National Asphalt Pavement Association Research and Education Foundation, Lanham, Maryland.
(2) Sebasta, S. and Scullion, T. 2003. Application of infrared imaging and ground-penetrating radar to detect segregation in hot-mix asphalt overlays. Transportation Research Record 1861: 37-43.
(3) Berthelot, C., Stuber, E., Podborochynski, D., Fair, J., and Marjerison, B. 2008. Use of Non-Destructive Testing to Establish Seasonal Load Carrying Capacity of Saskatchewan Thin Paved Highways. Canadian Journal of Civil Engineering. Ottawa, Canada. Volume 35, Number 7, 1 July 2008, pp. 708-715.
(4) Berthelot, C., Taylor, B. T., Prang, C., Marjerison, B., Campbell, M., and Jing, C. Jan 10-15, 2009. Use of Structural Asset Management Measurements to Engineer Substructure Drainage Systems and Mitigate Climatic Effects on Roads. Transportation Research Board of the National Academies Annual Meeting, Washington, D.C. CDROM Proceedings Paper #09-1650.
(5) Berthelot, C., Stuber, E., Marjerison, B. and Warrener, S. Jan 10-15, 2009. Structural Evaluation of Seasonal Effects on Alternative Road Strengthening Systems in Saskatchewan. Transportation Research Board of the National Academies Annual Meeting, Washington, D.C. CDROM Proceedings Paper#09-2667.
(6) Prang, C. and Berthelot, C. Jan 10-15, 2009. Performance Valuation Model for Urban Pavements. Transportation Research Board of the National Academies Annual Meeting, Washington, D.C. CDROM Proceedings Paper#09-3637.
(7) Saarenketo, T. and Scullion, T. 2000. Road evaluation with ground penetrating radar. Journal of Applied Geophysics 43: 119-138.
(8) Saarenketo, T. 1997. Using ground-penetrating radar and dielectric probe measurements in pavement density quality control. Transportation Research Record 1575: 34-41.

LIST OF TABLES

Table 1 HMAC Core and GPR Thickness 8
Table 2 GPR Dielectric Value and Core Density 8

Table 1 HMAC Core and GPR Thickness

Core Number	HMAC Core Thickness (mm)	HMAC GPR Thickness (mm)	Thickness Difference (mm)
1	35	44	+9
2	40	44	+4
3	38	43	+5
4	38	44	+6
5	218	206	-12
6	65	52	-12
7	50	49	-1
8	45	48	+3
9	60	51	-9
10	65	51	-14
11	50	46	-4
12	60	50	-10
13	55	48	-7
14	45	46	+1
15	195	206	+11
Average	71	69	-2

Maximum Difference

Table 2 GPR Dielectric Value and Core Density

Core Number	Core Density		GPR Results	
	Core Density (kg/m^3)	Core Density from Mean (%)	GPR Dielectric Value	GPR Dielectric Value from Mean (%)
1	2352	-0.47	6.63	4.97
2	2330	0.47	6.75	3.15
3	2306	1.49	6.43	7.77
4	2352	-0.49	6.50	6.86
5	2378	-1.59	7.43	-6.50
6	2374	-1.41	7.33	-5.07
7	2354	-0.58	7.08	-1.58
8	2288	2.27	6.80	2.54
9	2375	-1.45	7.46	-6.98
10	2377	-1.54	7.54	-8.17
11	2318	0.98	6.96	0.25
12	2328	0.54	7.07	-1.36
13	2348	-0.32	7.19	-3.12
14	2246	4.05	6.11	12.32
15	2387	-1.95	7.33	-5.07

LIST OF FIGURES

Figure 1 Air-Coupled Ground Penetrating Radar 10
Figure 2 Good Hot Mix Asphalt Concrete Surface of Test Section........ 10
Figure 3 Localized segregated Asphalt Surface of Test Section........ 11
Figure 4 Percentage of Surface Layer Quality Index Value by Sub-Segment Sample Length........ 11
Figure 5 Surface Layer Quality Index Rating at 20m Sub-Segment Intervals........ 12
Figure 6 Percent of Surface Area Rated With Surface Layer Quality Index Ratings Across Longitudinal Pass 13
Figure 7 Average Percentage of Surface Layer Quality Index Ratings per Lane 13
Figure 8 Comparison of GPR and Core Thickness........ 14
Figure 9 Correlation of GPR and Core Thickness 14
Figure 10 Correlation of GPR and Core Density 15

Figure 1 Air-Coupled Ground Penetrating Radar

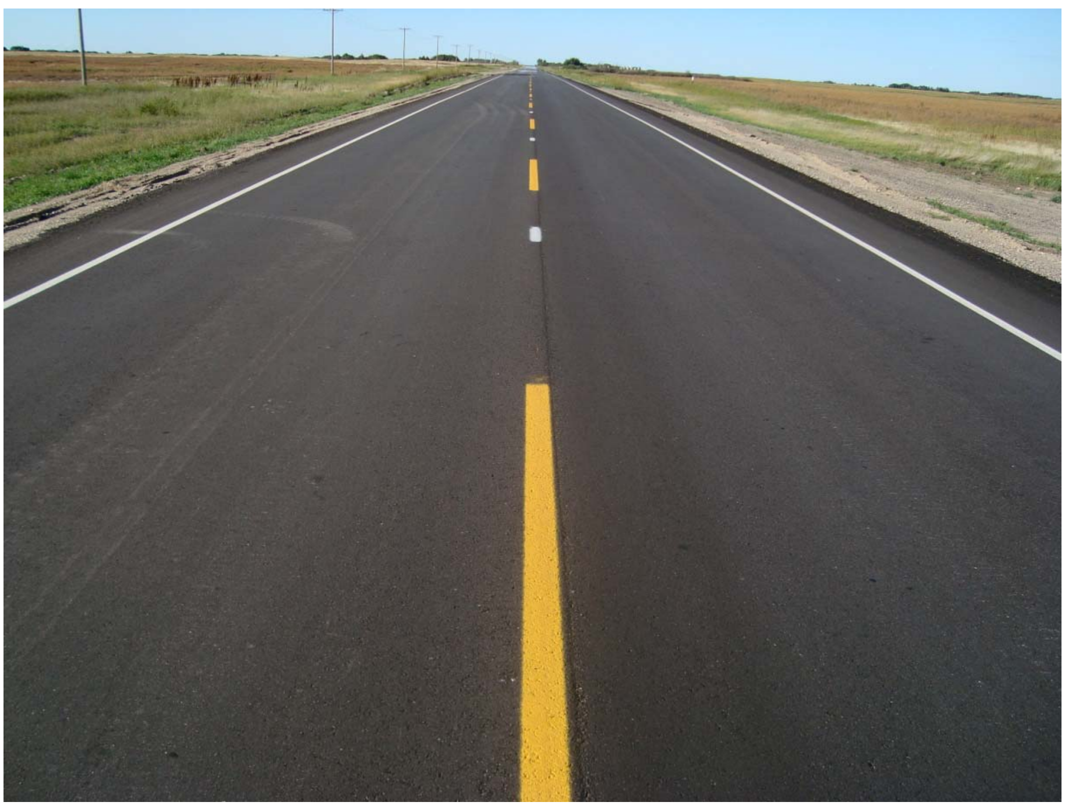


Figure 2 Good Hot Mix Asphalt Concrete Surface of Test Section

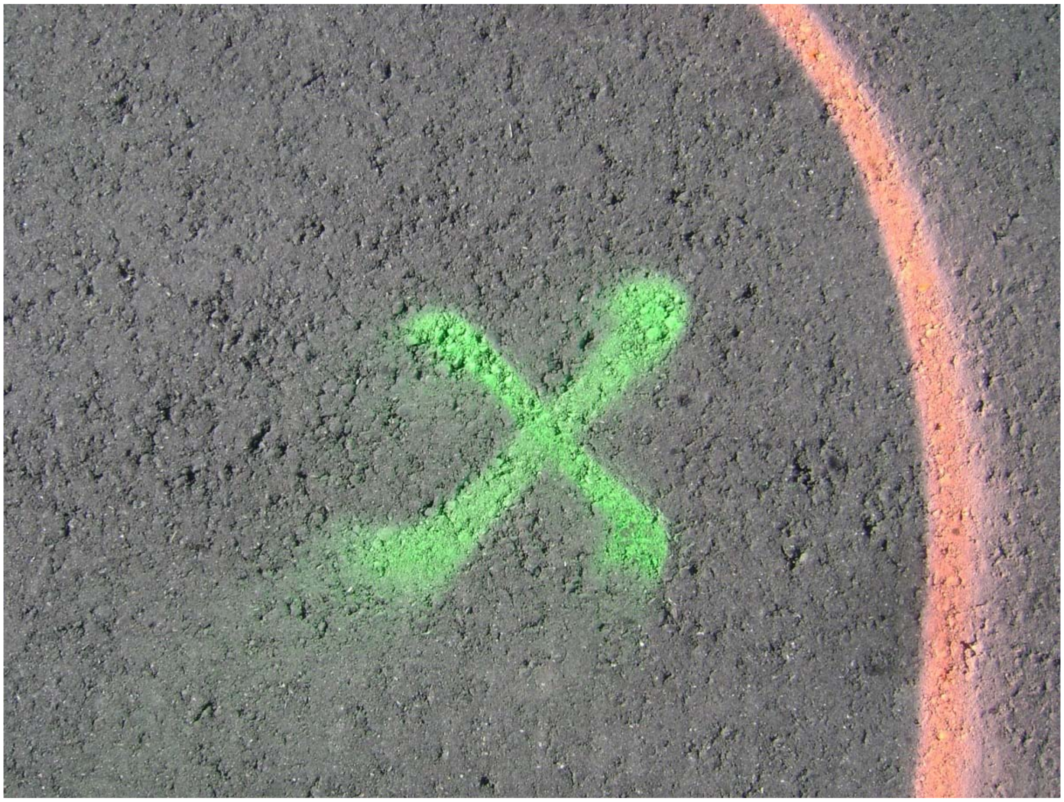


Figure 3 Localized segregated Asphalt Surface of Test Section

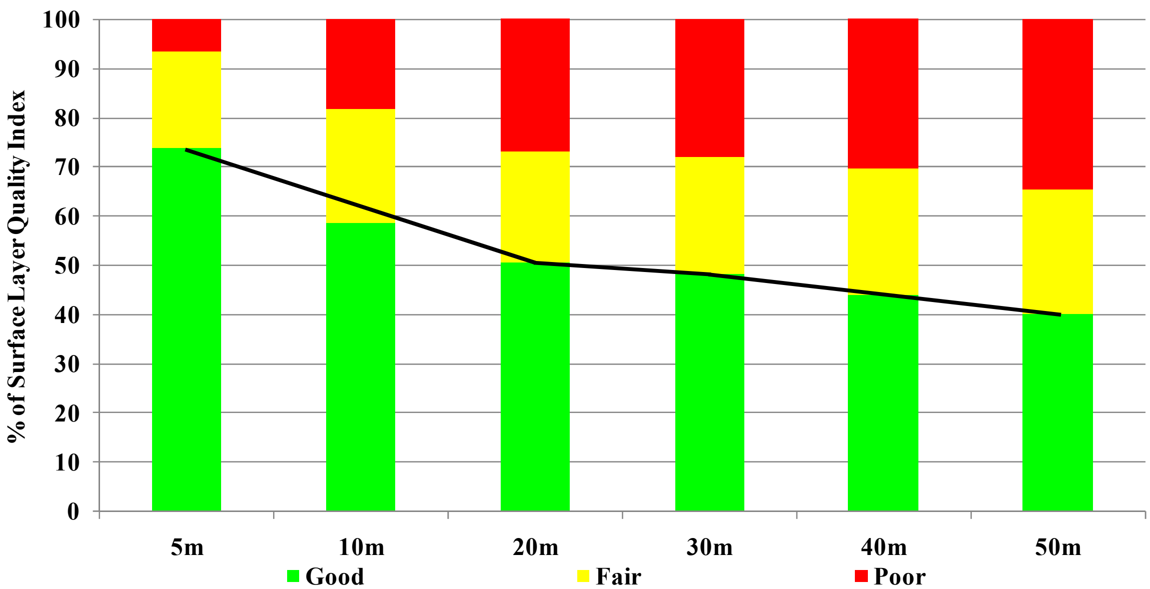
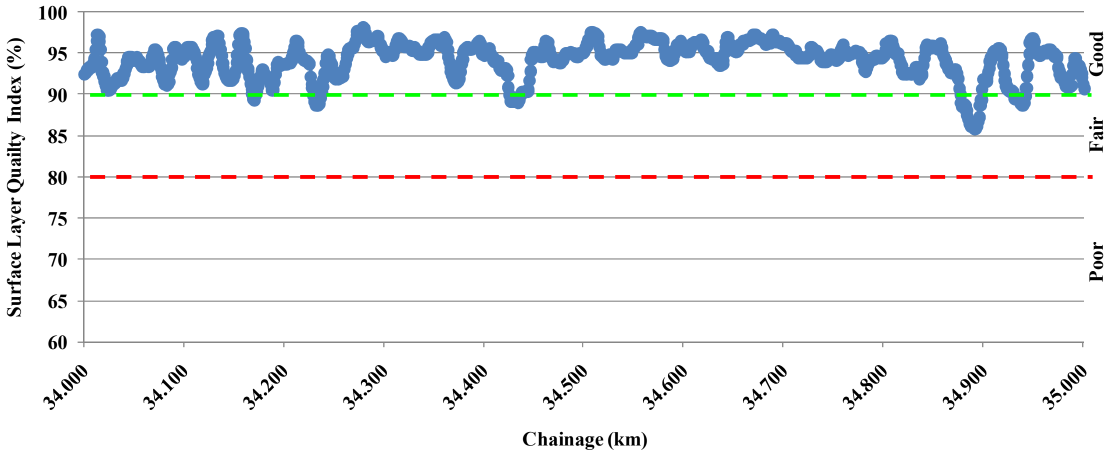
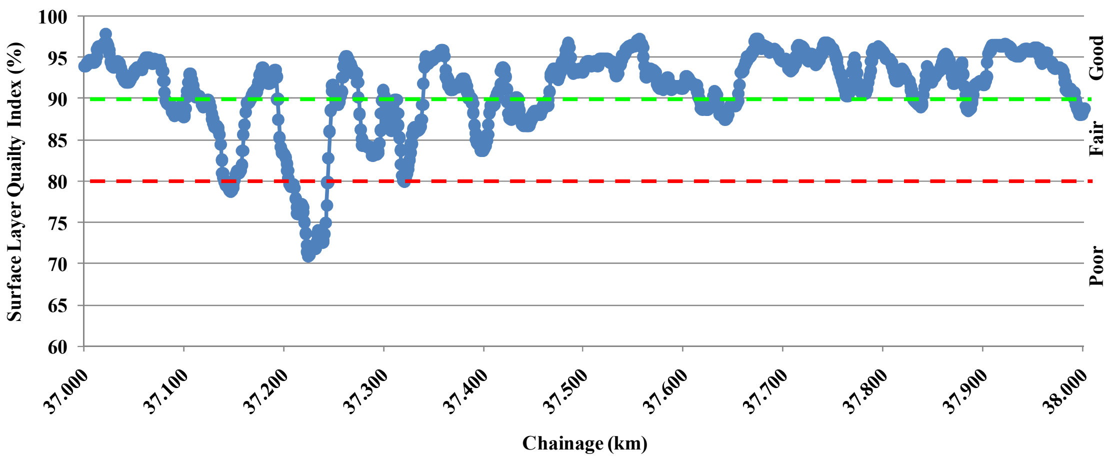


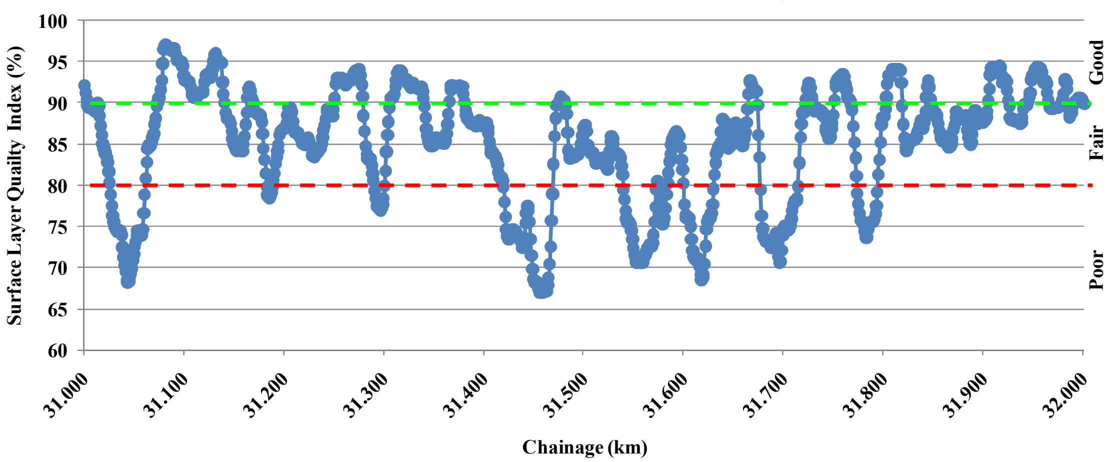
Figure 4 Percentage of Surface Layer Quality Index Value by Sub-Segment Sample Length



(a) Good Section (low severity variability)



(b) Fair Section (fair severity variability)



(c) Poor Section (high severity variability)

Figure 5 Surface Layer Quality Index Rating at 20m Sub-Segment Intervals

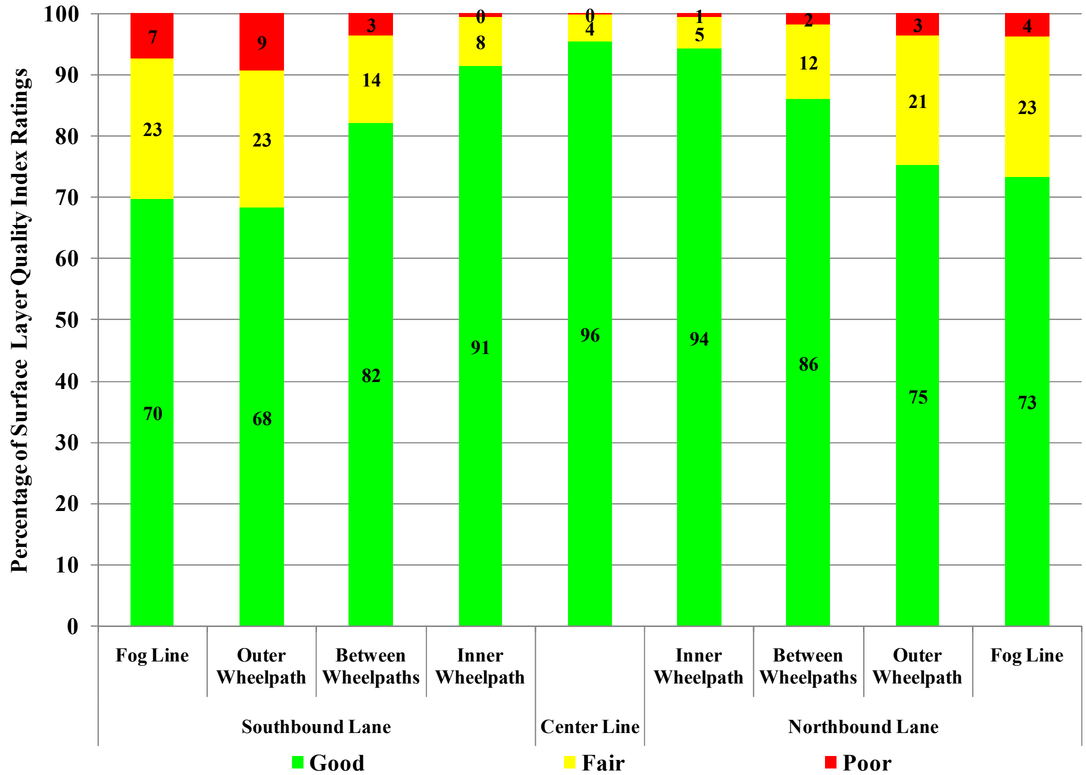


Figure 6 Percent of Surface Area Rated With Surface Layer Quality Index Ratings Across Longitudinal Pass

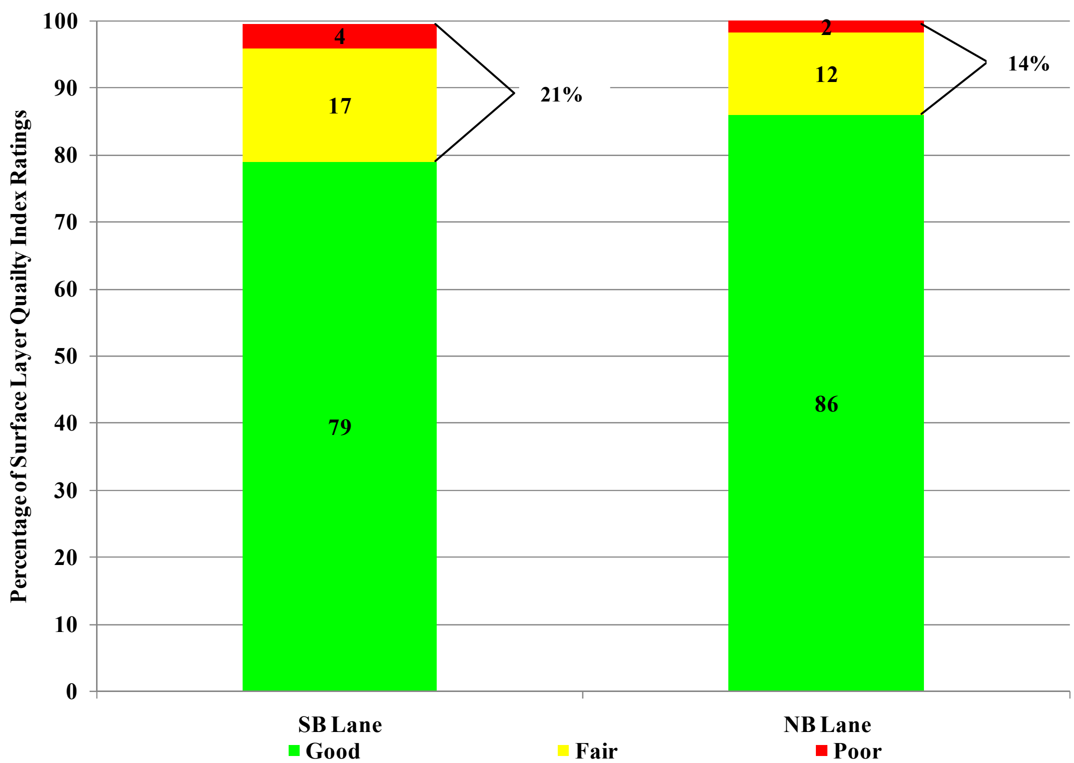


Figure 7 Average Percentage of Surface Layer Quality Index Ratings per Lane

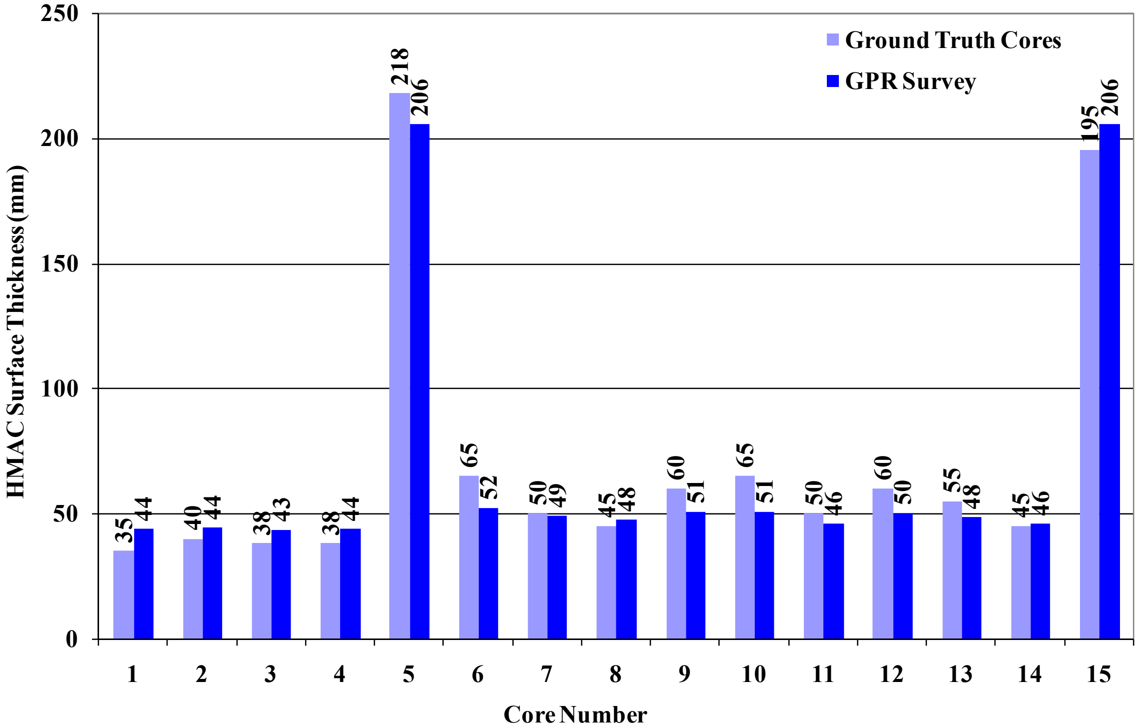


Figure 8 Comparison of GPR and Core Thickness

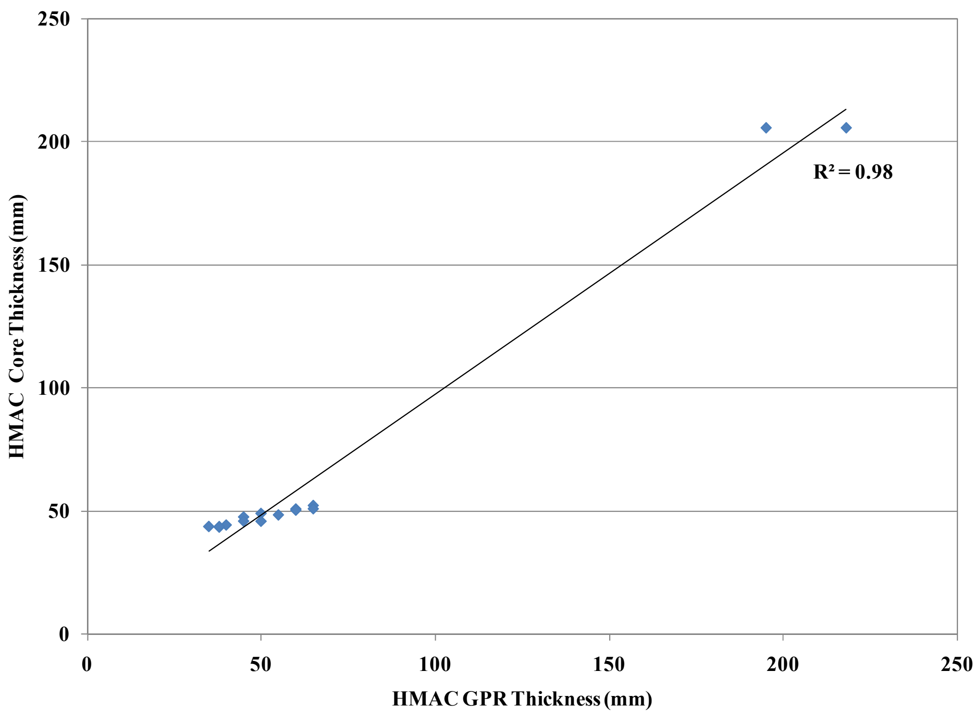


Figure 9 Correlation of GPR and Core Thickness

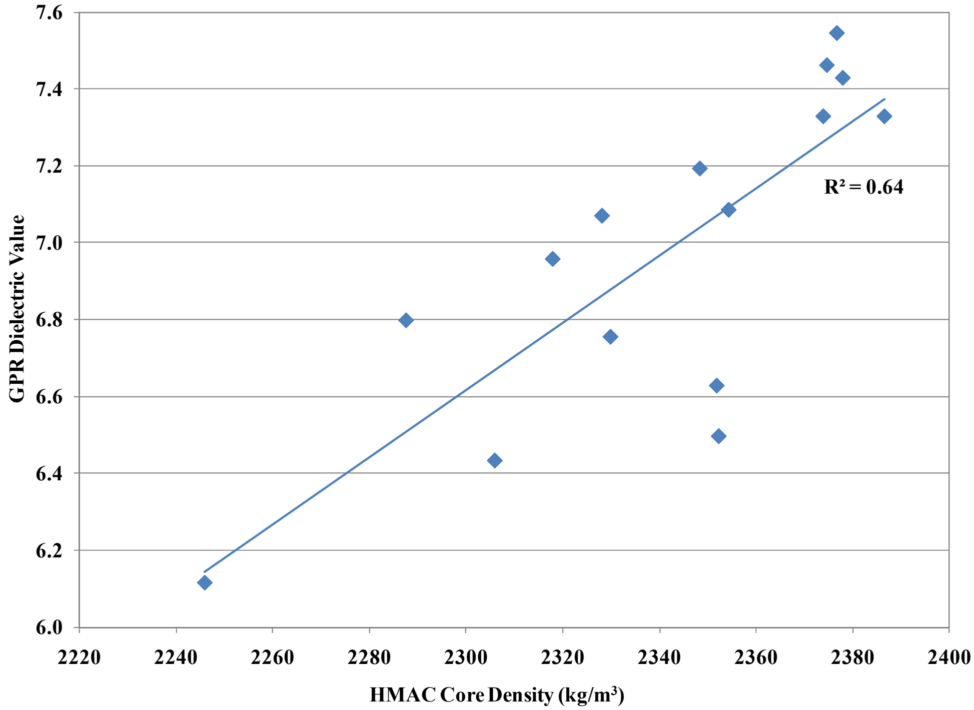


Figure 10 Correlation of GPR and Core Density