The Use Of Ground Penetrating Radar To Determine An In-Situ HMAC Surface Course Lift Thickness Profile: A Case Study – Highway 401, Trenton Ontario

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Abstract

The Ontario Ministry of Transportation (MTO) retained Stantec Consulting to complete a Ground Penetrating Radar (GPR) survey with the intent of identifying the thickness of the surface course on Highway 401, from 500 m west of the Trent River Bridge, in Trenton Ontario, westerly 11.7 km. The GPR survey was completed in the eastbound and westbound travel lanes to determine the pavement layer surface course profiles. The surface course on this section of Highway 401 consisted of a Dense Friction Course (DFC) which was delaminating at a number of locations.

Conventional GPR surveys identify the entire thickness of a bituminous material over a granular base or concrete pavement. The application of GPR technology used on this project was considered non-conventional since the survey equipment was used to isolate the surface layer from the rest of the bituminous pavement layer. Additionally, core data was used to calibrate and validate the GPR thickness data.

The GPR data was checked for quality and processed using RADAN 6.5, an advanced GPR data reduction software developed by GSSI. GPR data processing involves identifying reflections caused by changes in the electrical properties (dielectric, electrical conductivity, etc.) of a material. The data technician digitized the measured reflection and the software was used to convert the digitized reflection into layer thicknesses. Once the layers were identified with RADAN 6.5, the layer and thickness data was exported as an ASCI or Excel file. The exported GPR data was summarized and formatted as per the specifications outlined by MTO. The GPR layer statistics including the minimum, maximum, average, and standard deviation were reported and are presented in this paper.

The GPR data was calibrated using ground truth information obtained by cores that were extracted along Highway 401 within the project limits. This process involved inputting a known layer thickness (core information) at a given point along the GPR survey, into the RADAN software which allowed it to calculate the electrical properties for the specific asphalt material that was present on site. In total, 28 cores were used to calibrate the GPR data.

By default, the RADAN software will use an assumed average value for the electrical properties of the pavement materials if no ground truth information is available. The RADAN software will typically select the nearest core to calculate the electrical properties at each GPR scan.

This paper will discuss the specialized GPR equipment setup and survey/analysis methods used for this case study project. Ultimately, a near continuous depth profile on the surface course asphalt was determined. Considering deficient lift thickness as the primary causation, this data was used to determine the extent of pressing repair needs which in turn was used to structure a preventative pavement intervention.

1. Introduction

Presently, a significant portion of the cost of maintaining a pavement network goes towards determining the remaining service life of our pavements and various other assets. “One of the greatest challenges in rehabilitating pavements is determining what is causing them to deteriorate and selecting the most appropriate rehabilitation measures” [FHWA 2011].

Traditionally, provincial and municipal agencies have used destructive methods such as coring and boring to obtain layer thicknesses and to determine subsurface conditions. In some cases, and depending on the pavement section, hundreds of cores and boreholes are required in order to obtain these parameters. Not only is this destructive process time-consuming it is also expensive and requires lane closures and traffic control. This can create potential safety hazards to both the workers on site as well as the traveling public.

Ground Penetrating Radar (GPR) is a technology that is able to collect layer thickness data at a rate of more than 300 km per day. The GPR field survey combined with data reduction software, trained engineers can create continuous sectional images of the pavement subsurface by measuring the reflected high frequency waves’ intensity and arrival times emitted from the GPR antenna. As shown below, in Figure 1, the technology is based on one of the fundamental laws of physics; energy will be reflected at interfaces having significant differences in dielectric constants. The data reduction software is then used to calculate the conductivity of the material. By comparing the results to known dielectric constants, the software can isolate each individual layer of material and determine a thickness of that material.

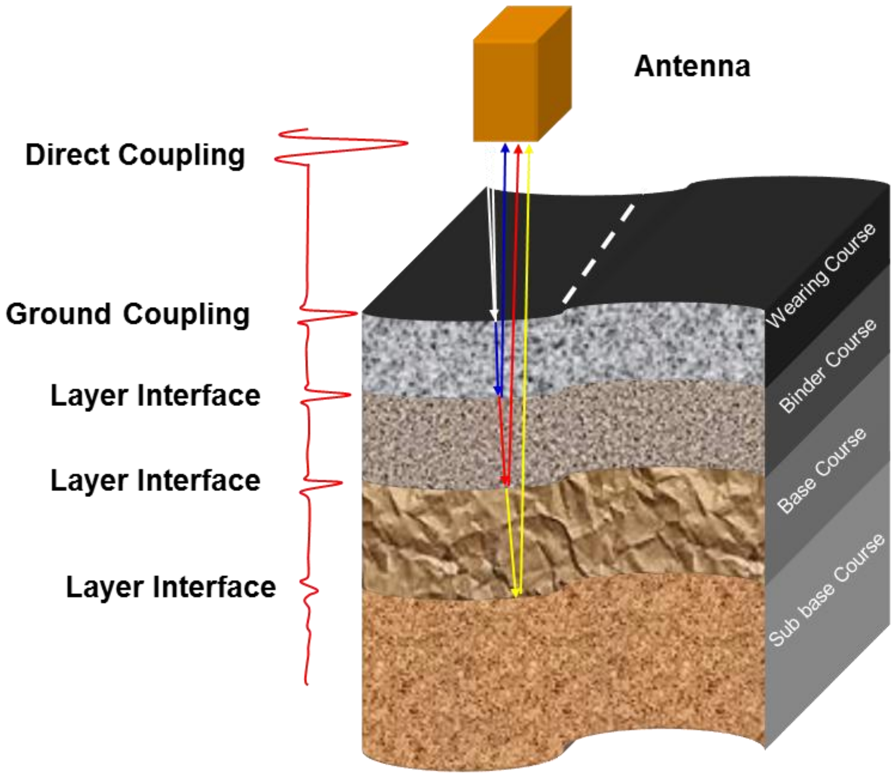

Figure 1: Principle of GPR Data Collection

The main advantage of using GPR is that it is non-destructive and it is relatively easy to conduct the surveys. The equipment can be mounted on a vehicle and can travel at regular highway speeds, therefore eliminating the need for lane closures. As a result, GPR surveys will not interrupt traffic and are inherently safer than traditional destructive methods.

1.1.Objective

The objective of this paper is to present the results of this non-conventional GPR survey conducted on Highway 401, near Trenton, Ontario. Additionally, the paper will identify the specialized equipment settings that were utilized in order to identify the thin delaminating surface course as well as discuss how this project aided the MTO in maximizing their pavement preservation budget.

Background

In 2009, the Ontario Ministry of Transportation (MTO) retained Stantec Consulting to complete a GPR survey with the intent of identifying the thickness of the surface course on Highway 401, from 500 m west of the Trent River Bridge westerly 11.7 km, in Trenton, Ontario. The GPR survey was completed in the eastbound and westbound travel lanes to determine the pavement layer surface course profiles. The surface course on this section of Highway 401 consists of a Dense Friction Course (DFC) which is delaminating at a number of locations. Core data was used to calibrate and validate the GPR thickness data.

Highway 401, within the study limits, is a rural divided four lane freeway facility. The average annual daily traffic (AADT) is in the range of 40,000 with 35% heavy commercial vehicles. The pavement structure is a deep strength flexible design with an average of 280 mm of asphalt over base and subbase granular material over a prepared silty sand subgrade. Testing was carried out on Monday July 6th, 2009. The MTO had observed that the surface course, which consists of a Dense Friction Course (DFC), was delaminating at a number of locations. Prior to the GPR survey, the MTO had recently repaired some of the severely delaminated sections with a mill and Superpave 12.5 FC2 overlay.

1.1.Pavement Section History

The sections analyzed were located on Highway 401 just outside of Trenton, Ontario. Figure 2, shown below presents the project limits.

Figure 2: Project Limits

The last major rehabilitation performed on this pavement section was in 1994, and consisted of a 40 mm mill and overlay using the following:

- 50 mm Heavy Duty Binder Course (HDB)
- 40 mm Dense Friction Course (DFC)

The DFC placed under the 1994 contract used a specification that allowed lower asphalt cement to stone content. The resulting mixes, as in this case, often displayed a dry, open-textured appearance. This specification was amended in the years following this project and has now been superseded by the adoption of Superpave Mix Design methodologies by the Ministry. Overall, the pavement was considered to be performing well 16 years after the rehabilitation with a Pavement Condition Rating (PCR) of approximately 80 on a scale of 100.

The dry open textured appearance of the pavement can be seen in a photograph of the pavement surface shown in Figure 3.

Figure 3: Dense Friction Course (DFC)

During the winter months of 2007 and 2008, the DFC layer was observed to be delaminating in large sections requiring unplanned repairs by maintenance crews. Field reviews identified that in areas where delamination occurred, the surface course was atypically thin.

A review of the construction records from 1994 indicated issues with low percentages of asphalt cement content in the mix as well as the absence of a tack coat during paving of the surface course as contributing factors to the premature deterioration of the pavement.

A photo depicting the typical delamination of the surface is shown below in Figure 4.

Figure 4: Delamination of DFC

1.2.Selection of GPR Technology

The MTO needed to determine the extent and distribution of the thin areas in order to request additional funds for either localized repairs, or if needed, rehabilitation.

A conventional coring program was considered to identify any remaining thin areas. However, this type of investigation would be costly considering the section of Highway 401 had a length of 11.7 cl-km with two lanes in either direction. Additionally, conventional coring would provide thickness data at discrete points rather than continuously. Also, it was speculated that additional potholing or delaminating of the pavement could be triggered at the core locations.

A visual survey was completed by the ministry subsequent to initial delamination repairs. However, this proved challenging, as the appearance of the surface while dry and open textured was observed to be consistent throughout giving little indication as to the location of future failures. Remaining delaminations existed mostly on paved shoulders and were not necessarily representative of the condition in the travelled lanes.

Pavement management records indicated a different mineralogy for the surface course as compared to the underlying binder course asphalt. It was postulated that this difference in mineralogy combined with differences in porosity might be discernible with the use of GPR technology. The mix designs for the two different pavement courses are presented in Figures A.1 and A.2 in Appendix A. The HDB course used a limestone aggregate while the DFC mix used a trap rock, or basalt, aggregate.

2. Project Specifications

The MTO retained Stantec to use a GPR survey in order to determine the surface course asphalt layer thickness profile. Any areas with an identified thickness of less than 30 mm would be highlighted and recommended for rehabilitation. The 30 mm threshold was selected since it corresponded with the Superpave Guidelines for a Dense Fine Graded Mix type with a maximum nominal aggregate size of 12.5 mm.

Typically when performing a GPR survey, the equipment is setup to scan the underlying materials to a depth of 600 mm. In this case, the equipment needed customized settings in order to isolate the thin surface lift of the asphalt pavement.

Initially, the MTO requested that a pilot project be conducted to first determine if the surface layer could be isolated from the rest of the pavement structure with a high degree of confidence. This initial phase of the project was done without correlation coring. Once the MTO reviewed the data and was satisfied with the results, a full scale testing program with correlation coring was completed.

2.1. Data Collection

GPR data was collected continuously along each lane and direction of Highway 401 within the project limits. GPR testing was conducted using a GPR system manufactured by Geophysical Survey Systems Inc (GSSI). It consisted of a SIR-20 data acquisition system with a Panasonic Toughbook Computer, a model 4105 2.0-GHz air coupled horn antenna, wheel-mounted distance measuring instrument (DMI) and a Horn antenna vehicle mounting unit. The operator also recorded a detailed log describing the locations or occurrences of any objects or intersections that may be in the test path while testing. The GPR vehicle was equipped with a Trimble GPS system that simultaneously collected GPS coordinates along the road sections.

In order to collect high resolution GPR data for the surface course, the antenna was set to collect at 8 ns. The transmission rate for the GPR data collection was set to 100 kHz. Data was collected at a scan rate of 153 scans/sec and 6 scans/m.

At the beginning of testing, the GPR antenna and DMI were calibrated. During data collection, the operator "flagged" the start and end of all sections within the data file. It is important to note that several factors can influence signal penetration and the quality of collected data. Pavements or base/subbase materials with high moisture contents adversely affect GPR signal penetration. To limit or eliminate this problem, data was not collected during or immediately after a rain event.

High frequency radio interference caused by overhead wires, cell phone towers, transmission lines, etc. can cause significant "noise" within a data file making it difficult to interpret. This problem is hard to avoid or prevent as these items are "fixed" and cannot be "removed" from the vicinity of the test section.

2.2. Data Calibration and Analysis

Correlation coring was used for this project in order to increase the accuracy of the layer profile by calibrating the measured waves to a known thickness and reference location. Pavement cores were extracted from all lanes along Highway 401 and from the acceleration and deceleration lanes at the

Service Station and Wooler Road. In addition, a continuous GPR survey was performed along all lanes of Highway 401 and within the project limits including the acceleration and deceleration lanes at the Service Station and Wooler Road to determine the pavement layer surface course profiles.

The GPR data was checked for quality and processed using RADAN 6.5, an advanced GPR data reduction software developed by GSSI. GPR data processing involves identifying reflections caused by changes in the electrical properties (dielectric, electrical conductivity, etc.) of a material. The data technician digitized the measured reflection and the software was used to convert the digitized reflection into layer thicknesses. Once the layers were identified with RADAN 6.5, the layer and thickness data was exported as an ASCI or Excel file. The exported GPR data was summarized and formatted as per the specifications outlined by MTO. The GPR layer statistics including the minimum, maximum, average, and standard deviation were reported and are presented in this paper.

It is worth noting that at a few locations, additional lifts of asphalt concrete were observed in the GPR profile beneath the surface course. These intermediate lifts were not observed continuously throughout the GPR profiles and were not included in layer processing as the scope of work was to identify the surface course thickness.

Stationing for the Highway 401 eastbound and westbound lanes were established using the provided MTO chainages. The west limits of the project is at station 16+732 in the Township of Brighton easterly to the east project limits at station 17+800 in the Township of Murray, 500 m west of the west end of the Trent River Bridge. The speed change lanes at the Service Station are located at station 12+450 in the Township of Murray, and the Wooler Road overpass is located at station 15+183 in the Township of Murray. The township line is at Station 20+632 Twp of Brighton which also equates to Station 10+000 Twp of Murray.

The GPR data was calibrated using ground truth information obtained by cores that were extracted along Highway 401 within the project limits and also from the acceleration and deceleration lanes at the Service Station and Wooler Road. This process involved inputting a known layer thickness (core information) at a given point along the GPR survey, into the RADAN software which allowed it to calculate the electrical properties for the specific asphalt material that was present on site. In total, 28 cores were used to calibrate the GPR data.

By default, the RADAN software will use an assumed average value for the electrical properties of the pavement materials if no ground truth information is available. The RADAN software will typically select the nearest core to calculate the electrical properties at each GPR scan.

3. Results

The GPR data was exported at an interval of 5 m. Each GPR thickness measurement represents the average layer thickness over the 5 m interval.

A number of pavement sections were identified to have significant sections of continuous thin asphalt surface course with an average thickness of approximately 30 mm or less. These sections are provided below in Tables 4.1 to 4.5 including approximate station-to-station limits and summary statistics.

Table 4.1: Highway 401 – Eastbound Lane 1 Thin Surface Course Sections

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	EB 1	12+795 to 12+820	Murray	29.57	32.18	30.33	1.20

Table 4.2: Highway 401 – Eastbound Lane 2 Thin Surface Course Sections

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	EB 2	16+815 to 16+920	Murray	27.64	34.79	30.00	2.45
Hwy 401	EB 2	17+115 to 17+270	Murray	27.05	38.36	30.95	2.93

Table 4.3: Highway 401 – Westbound Lane 1 Thin Surface Course Sections

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	WB 1	16+260 to 16+065	Murray	20.95	37.27	30.90	3.04
Hwy 401	WB 1	18+452 to 17+537	Brighton	20.52	34.01	27.24	3.31
Hwy 401	WB 1	17+242 to 16+742	Brighton	26.52	36.25	30.83	2.13

Table 4.4: Highway 401 – Westbound Lane 2 Thin Surface Course Sections

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	WB 2	15+330 to 15+110	Murray	26.86	33.17	29.47	1.76
Hwy 401	WB 2	15+000 to 14+650	Murray	26.86	35.54	30.46	1.79
Hwy 401	WB 2	14+555 to 14+390	Murray	26.86	35.54	30.33	1.69
Hwy 401	WB 2	14+060 to 13+725	Murray	26.07	33.96	30.86	1.76
Hwy 401	WB 2	13+150 to 12+530	Murray	23.70	41.82	32.77	3.44

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	WB 2	12+125 to 11+835	Murray	25.29	34.41	31.15	2.60
Hwy 401	WB 2	20+102 to 19+142	Brighton	26.26	34.04	28.25	1.42
Hwy 401	WB 2	18+532 to 18+132	Brighton	27.23	34.04	30.13	1.75

Table 4.5: Wooler Road – Eastbound Acc. Lane Thin Surface Course Sections

Section	Lane	Stations	Twp	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Wooler Road	EB Acceleration	14+990 to 15+075	Murray	26.32	30.22	29.25	1.10

Table 4.6, shown below, presents the overall summary of the measured surface course for the entire 11.7 km length of Highway 401 by lane number.

Table 4.6: Highway 401 – GPR Layer Statistics by Lane Number

Section	Length (km)	Direction	Lane	GPR AC Surface Coarse (mm)			
				Min.	Max.	Avg.	Stdev
Hwy 401	11.7	Eastbound	1	27.1	59.6	42.1	4.9
			2	27.0	59.0	40.8	4.7
		Westbound	1	20.5	62.3	40.4	7.3
			2	23.1	56.0	34.8	5.9

As shown in the above tables, all lanes were observed to contain areas of thin DFC surface course. Table 4.6 identifies westbound lane 2 as having the lowest average thickness of DFC surface course. A sample screenshot from the RADAN software illustrating the quality of the wave reflection is presented in Figure A.3 in Appendix A.

4. Conclusion

Following the GPR survey by Stantec, the MTO plotted flagged areas of Highway 401 from surface distress surveys against the limits of the identified thin surface course areas from the GPR survey using GIS. All pavement sections identified, by the GPR survey, as having a surface course of less than or equal to 30 mm was selected for a mill and overlay rehabilitation treatment. The MTO then rationalized the areas of proposed improvements and selected the most cost-effective and technically sound alternative.

Since continuous lift thickness data was made available through the GPR survey, the MTO was able to avoid using variable milling depths by selecting a larger milling depth to account for the variation in the surface lift thickness.

Overall, the project was deemed to be a success. Using a GPR survey to quantify the extent of the thin DFC areas was found to be quicker, safer and more cost-effective than using typical destructive methods. The MTO was able to accurately determine a thickness profile of the dense friction surface course over a heavy duty binder course with a high degree of confidence and use the continuous lift thickness data over all lanes of Highway 401 to facilitate quantification of immediate resurfacing needs and selection of a single milling depth with a high level of confidence.

This project as a case study presents several challenges and opportunities. There are many potential uses of knowing a continuous in-situ layer depth profile on a lift of HMAC pavement. For pre-engineering on a facility that has a premium surface course over binder course asphalt with differing mineralogy the information could be used to plan a milling operation to "mine" premium RAP for use in production of premium mixes. There is some potential for use in metre squared specifications to use GPR technology for acceptance purposes. From a forensic perspective, as demonstrated on this project, knowledge of station-to-station limits of potential future delaminations permits targeted preventive treatments.

References

[FHWA 2011] Murphy, Mike, “Priority, Market-Ready Technologies and Innovations: Ground Penetrating Radar”. Federal Highway Administration, McLean, Virginia, 2011.

Appendix A

JUN-11-1995 13:56 FROM J EMERY GEOTECHNICAL TO 16135454786 P.02

PAVEMIX - MARSHALL MIX DESIGN REPORT 1/9

Prepared for: Armbro Construction JOB NO: 95513D

CONTRACT NO: 94-27 HOT MIX TYPE: HDBC (50/50 By Volume) ITEM NO: 6
HWY: 401 LOCATION: Hwy 30 Easterly to Hwy 16
DATE SAMPLES RECEIVED: May, 1995 DATE COMPLETED: June 11, 1995
TEST RESULTS SUPPLIED BY: P.Eng JEGEL

JOB MIX FORMULA - GRADATION PERCENT PASSING *

% AC	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	600	300	150	75
4.7	100.0	98.9	91.9	86.2	70.8	49.9	40.2	32.2	27.3	8.8	5.5	4.1

MARSHALL PROPERT.	REQUIRED	SELECTED
% VOIDS,SSD (min)	3.5	
(max)	4.5	3.7
FLOW (min)	8.0	13.2
STABILITY, N(min)	8000	13493
% VMA (min)	13.5	13.5

% CA#1	34.1
% CA#2	14.6
% FA#1	30.8
% FA#2	20.5
Gb	2.692

% RAP	–
% AC RAP	–
RAP PEN	
BRIQ. BRD	2.443
MRD	2.537
MRD (SSD)	**

ASPHALT CEMENT	
SUPPLIER	PENETRATION
Petro-Canada	85/100

ADDITIVE		
SUPPLIER	TYPE	% of AC
-	-	-

AGG. TYPE	DESCRIPTION - SOURCE	INVENTORY NO	BRD	ABS %
CA#1	HL 8 Stone (Long's)	B08-015-0	2.695	0.532
CA#2	HL 3 Stone (Long's)	B08-015-0	2.701	0.456
FA#1	Screenings (Long's)	B08-015-0	2.675	0.691
FA#2	Blend Sand (IKO)	C01-148	2.705	0.855

AGGREGATE GRADATION - PERCENT PASSING

AGG. TYPE	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	600	300	150	75
CA#1	100.0	96.7	76.2	59.8	33.7	2.9	1.4	1.2	1.1	1.1	1.0	0.8
CA#2			100.0	99.2	54.8	3.2	1.7	1.6	1.5	1.5	1.4	1.2
FA#1					100.0	90.9	61.1	35.5	23.5	17.1	12.0	8.0
FA#2							100.0	99.1	92.4	11.2	2.1	0.9

* Fines Returned to the Mix (1.0%).
Minus 4.75 mm Aggregate Component of JMF Adjusted.
** No Air Voids 'Correction' Necessary, No Visible Aggregate Absorption for MRD Mix at 4.7 - 5.2% AC.

REMARKS: Gradations from Samples (Checked Against Process Control).
Briquettes Compacted at 140°C, 55 Blows Mechanical (≈75 Blows Manual).
AI MS-2 Procedures Followed. This Mix Design is Subject to Marshall Compliance Checks that May Require JMF Adjustment.

Figure A.1: HDBC Mix Design

94-3524

ARMBRO CONSTRUCTION LTD.

25 VAN KIRK DRIVE, UNIT 8, BRAMPTON, ONTARIO L7A1A6
FAX(416)451 –5791. TEL(416)451 –0690.

QUALITY ASSURANCE LABORATORY.

CONT.NO.	94 – 27.	ITEM NO.7.
MIX DESIGN.	D F C.	DATE FEB. 16 1995.

JOB MIX FORMULA – GRADATION PERCENT PASSING.												
A.C.	26.0	19.0	16.0	13.2	9.5	4.75	2.36	1.18	600	300	150	75
4.6%	100.0	100.0	100.0	99.8	82.9	47.0	32.5	22.1	16.0	11.2	8.2	6.0

MARSHALL	REQUIREMENT	SELECTED
AIR VOIDS	3.0% 0.5%	2.7%
FLOW (MIN)	MIN 8	15.0
STAB.(MIN).	8900 N.	15807 N
VMA.(MIN)	N/A	

		BRD.	ABSORP.
C/A#1	57.0%	2.956	0.647
C/A#2			
F/A#1	35.0%	2.861	0.626
F/A#2	7.0%	2.823	0.644
DUST	1.0%	2.662	
TOTAL AGG	100.0%	0.000	

Gsb.	2.910
Gse.	3.065
Gmb.	2.727
Gmm.	2.803

ASPHALT TYPE.	
SUPPLIER.	PENETRATION
PETRO–CANADA.	85–100

ANTI – STRIPPING ADDITIVE	
LEVEL	TYPE.
0.0	0.0

AGG. TYPE.	SOURCE / INVENTORY NO.
COARSE AGG # 1	H L 1 STONE.
	COI – 58
	MARMORA.
	100% CRUSHED AGG.
FINE AGG # 1	SCREENINGS.
	C O I – 5 8
	MARMORA.
	100% CRUSHED AGG.

AGG. TYPE.	SOURCE / INVENTORY NO.
FINE AGG # 2	BLENDING SAND.
	C O I – 5 8
	MARMORA.
	100% CRUSHED AGG.

AGG.	AGGREGATE GRADATION – PERCENTAGE PASSING.											
TYPE	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	600	300	150	75
C/A #1	100.0	100.0	100.0	99.6	70.0	7.2	1.5	1.3	1.3	1.3	1.3	0.7
C/A #2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
F/A #1	100.0	100.0	100.0	100.0	100.0	99.7	67.6	44.6	33.4	23.0	16.8	12.1
F/A #2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	67.2	37.3	19.9	8.8	5.0
F/A #3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure A.2: DFC Mix Design

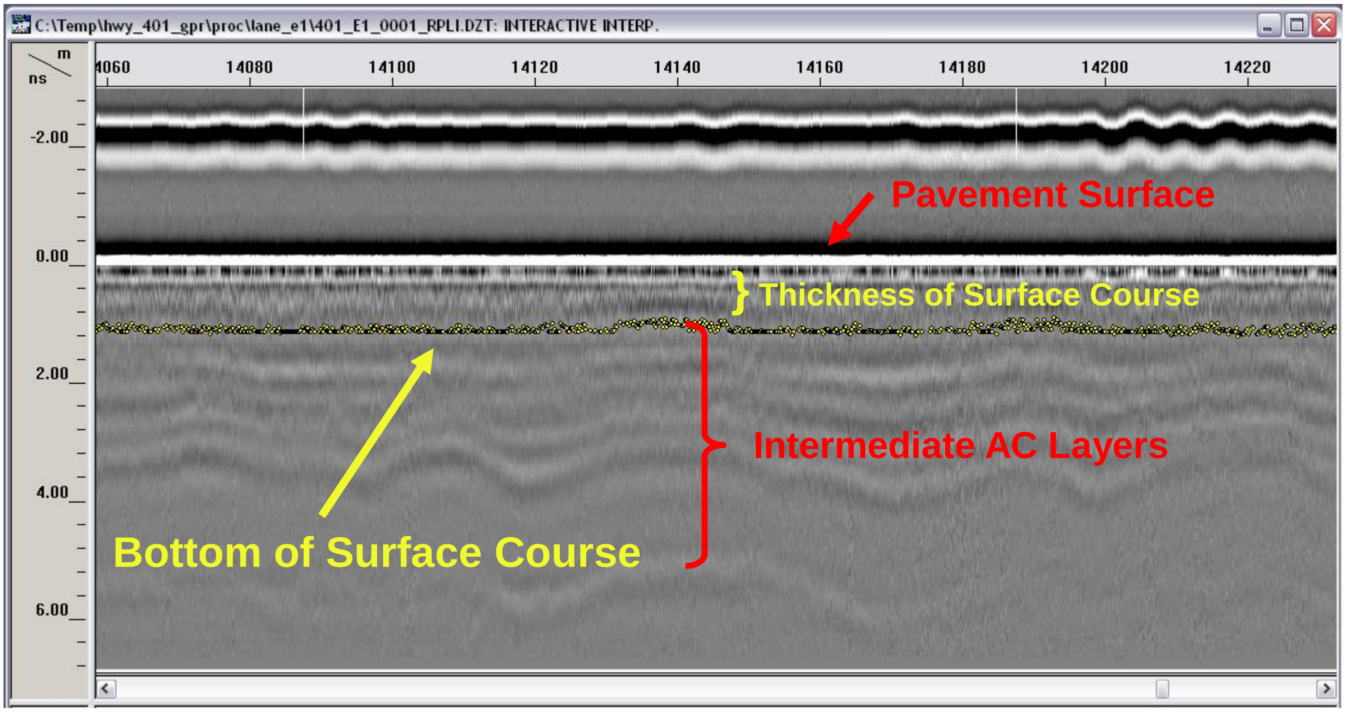

Figure A.3: Sample GPR Profile from RADAN