# Using Ground Penetrating Radar as an Assessment Methodology in Roadway Rehabilitation

Mark Popik, M.Eng., P.Eng.

Applied Research Associates, Inc.,
5401 Eglinton Avenue West, Suite 204
Toronto, ON, Canada, M9C 5K6, tel. 416-621-9555, fax. 416-621-4719
email: mpopik@ara.com

Dave Redman, M.Sc.

Sensors & Software Inc.
1040 Stacey Court
Mississauga, ON, Canada, L4W 2X8, tel.905-624-8909, fax.905-624-9365,
email: dr@sensoft.ca

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## ABSTRACT

In assessing the existing condition of a pavement structure, locations of past maintenance activities are often overlooked, or concealed by rehabilitation activities such as mill and overlays. Potential problem areas may not be evident at the time of evaluation, and if ignored could increase the rate of deterioration of the pavement structure. Proper identification of potential problem areas could provide a more accurate assessment of the existing pavement condition and better understanding of the performance of a pavement structure. Understanding the deterioration of a pavement structure, will in turn allow owner agencies to calibrate forecasting tools in their pavement/asset management systems.

Ground penetrating radar (GPR) can be used as a tool for assessing the condition of the pavement structure at locations of surface distress, as well as identifying locations of previous subsurface maintenance activities that are not visible at the surface of the pavement.

This paper presents and discusses the subsurface imagery obtained from a GPR survey, identifies several potential subsurface problem areas, and describes the benefits of applying this technology as an assessment tool for the rehabilitation of roadways.

## BACKGROUND

In the spring of 2003, a detailed pavement investigation for the proposed pavement rehabilitation of Highway 401 from the Credit River to the Highway 410/403 Interchange, in the Region of Peel was completed. This work project (W.O. 00-23019) was located in the Ministry of Transportation (MTO) Central Region and extends a distance of approximately 6.0 km.

A typical pavement investigation was complete to develop appropriate rehabilitation recommendations for the Highway 401 main lanes. The pavement evaluation consisted of:

- Detailed pavement surface condition survey to determine the type, severity and extent of any observable pavement surface distresses.
- Geotechnical investigation including pavement coring and boreholes in the existing pavements.
- Laboratory testing of recovered samples of the pavement layers and subgrade for classification and determination of pavement design parameters.
- Pavement load/deflection testing of representative joints/cracks using Dynatest 8000 Falling Weight Deflectometer (FWD).

As a supplement to the normal investigation procedures, a GPR survey was conducted on a 1 km length of the Eastbound Lane 3 (Station 11+800 to 12+800). The survey section began at the western project limit (at the bridge structure over the Credit River) and continued for 1 km travelling eastbound.  A map and photograph of the GPR survey location is given Figure1.  The photograph is taken looking in the eastbound direction and clearly illustrates the western study limit at the east expansion joint for the bridge over the Credit River (pavement change).

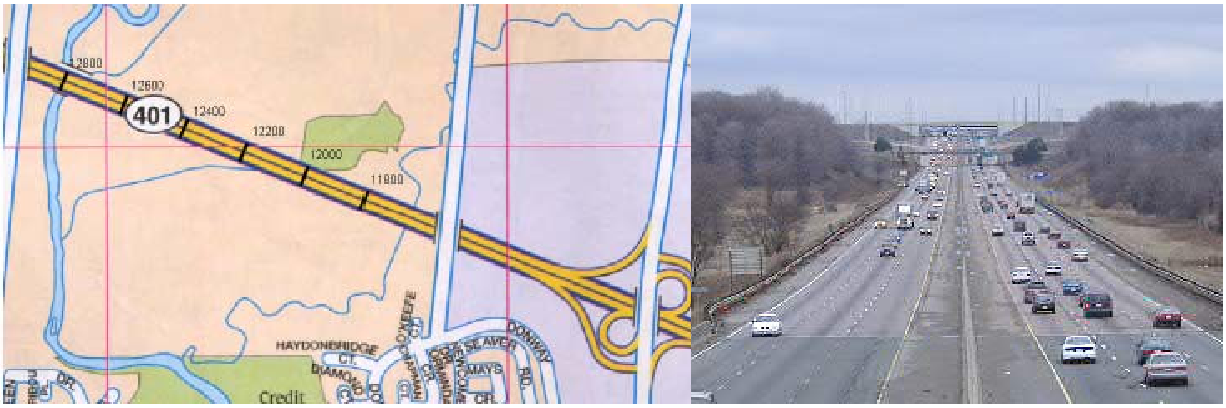


**Figure 1.  Map and Photograph of the GPR Survey Locations.**

The main objectives of the GPR survey included:

- Investigation of the subsurface pavement structure with GPR.
- Testing effectiveness of GPR on a composite pavement, with steel reinforcement in the Portland Cement Concrete (PCC) base.
- Determine if it is possible to identify joints and cracks in underlying concrete.
- Estimate asphalt and concrete thickness along 1 km length from the GPR survey using coring data for calibration and comparison.

This location was considered to be ideally suited for the GPR survey, as the existing highway pavement is of composite construction, with steel reinforcing in the PCC base. Throughout the test area core samples were extracted at 50 m intervals providing high frequency coring information for comparison of pavement layer thickness with the GPR survey data.

## SCOPE AND OBJECTIVES

The scope of the supplementary investigation was two-fold.  Firstly, combining the GPR survey with typical pavement condition investigations on major highways provides for test sections with some of the thickest pavement structures used in Ontario.  Secondly, the findings of the pavement condition investigation can be used to compare/calibrate the results of the GPR survey. The average pavement layer thickness, from the coring operation, was used to calibrate the GPR survey results, while the core locations were used to ensure accurate positioning throughout the study limits.  This paper presents the findings of the GPR survey and discusses the effectiveness of using GPR equipment as a rehabilitation technique on composite pavements.

## HISTORICAL INFORMATION

Highway 401 within the Highway 10 (Hurontario Street) to Highway 25 corridor was originally constructed in the mid to late 1950's as a dowelled joint exposed concrete pavement with wire mesh reinforcing and 33 metre slab lengths. The Highway was originally built as a four lane divided facility with the following rigid pavement structure:

225 mm of concrete pavement
300 mm of granular base

Hot Mix resurfacing was completed between 1969 and 1974, and adding a lane, in each direction, on the median side, with hot-mix, from four to six lanes took place between 1975 and 1981. In 1999, the study area was completely resurfaced with a partial depth milling of 40 mm and replacing it with 40 mm Heavy Duty Binder Course (HDBC) and 40 mm Dense Friction Course (DFC). Since this time, only regular maintenance (crack sealing) has been completed.

## PAVEMENT CONDITION EVALUATION

A detailed pavement condition survey for Highway 401 was completed in accordance with the procedures outlined in the MTO *Manual for Condition Rating of Rigid Pavements*, SP-026, September 1995. The typical distresses observed within the survey limits of the Highway 401 Lane 3, Eastbound, consisted of low severity transverse and longitudinal cracking. The density of the transverse cracking within the study area varied in extent from few to extensive.

In general, the ride comfort of the pavement section was found to be in good to fair condition. The Pavement Condition Ratings (PCR) as assessed by the MTO Central Region Geotechnical Section in 2002 assigned this section of highway a PCR rating of 72.

The field investigation indicated that the existing pavement on Highway 401 comprised a composite pavement structure, with an asphalt thickness varying from a low of 230 mm to a high of 310 mm. At these locations, a PCC base underlay the asphalt surface, with thickness ranging from 210 mm to 230 mm, for an average thickness of 215 mm. The asphalt thickness was measured to be 365 mm and was underlain by a granular base. For ease of reference, the pavement layer thickness, as determined from the boreholes is presented in Table 1.

Granular base/sub-base layers were encountered beneath the asphalt/ PCC base layer(s) at all borehole locations. The granular material consisted of brown crushed gravel, with thickness ranging from 245 to 1,020 mm. The subgrade soil predominately comprised silty clay till; however, several borehole locations encountered fine sandy silt within the survey site.

**Table 1. Summary of Boreholes Advanced in Test Area**

| Station | Asphalt Thickness (mm) | PCC Thickness (mm) | Granular Thickness (mm) | Subgrade Soil | Comments |
|---|---|---|---|---|---|
| 11+800 | 240 | 220 | 460 | Silty Clay Till | Steel Depth @ 320 mm |
| 11+850 | 265 | 215 | 330 | Silty Clay Till | Steel Depth @ 350 mm |
| 11+900 | 240 | 220 | 290 | Fine Sandy Silt | Steel Depth @ 320 mm |
| 11+950 | 240 | 215 | 245 | Fine Sandy Silt | Steel Depth @ 300 mm |
| 12+000 | 260 | 220 | 1,020 | - | Steel Depth @ 350 mm |
| 12+050 | 365 | - | 535 | Silty Clay Till | |
| 12+100 | 240 | 220 | 400 | Fine Sandy Silt | Steel Depth @ 310 mm |
| 12+150 | 270 | 220 | 500 | Fine Sandy Silt | Steel Depth @ 410 mm |
| 12+200 | 275 | 215 | 450 | Fine Sandy Silt | Steel Depth @ 345 mm |
| 12+250 | 310 | 215 | 625 | Silty Clay Till | Steel Depth @ 385 mm |
| 12+300 | 255 | 215 | 500 | Silty Clay Till | Steel Depth @ 400 mm |
| 12+350 | 240 | 215 | 445 | Silty Clay Till | Steel Depth @ 325 mm |
| 12+400 | 250 | 210 | 640 | Silty Clay Till | Steel Depth @ 365 mm |
| 12+450 | 250 | 215 | 445 | - | Steel Depth @ 350 mm |
| 12+500 | 230 | 230 | 420 | Silty Clay Till | Steel Depth @ 320 mm |
| 12+550 | 240 | 215 | 445 | Fine Sandy Silt over Silty Clay Till | Steel Depth @ 315 mm |
| 12+600 | 245 | 210 | 405 | Silty Clay Till | Steel Depth @ 340 mm |
| 12+650 | 260 | 215 | 365 | Gravely Silty Sand | Steel Depth @ 410 mm |
| 12+700 | 250 | 210 | 350 | Gravely Silty Sand | Steel Depth @ 305 mm |
| **Average** | **245** | **205** | **445** | | |

The falling weight deflectometer (FWD) is an impulse-loading device that is used to simulate moving wheel loads and measure the corresponding pavement response. The FWD applies a dynamic load by dropping a weight onto a spring connected to a circular loading plate. By varying the height, and in turn the weight, from which the weight is dropped, the magnitude of the load can be changed. For this project, a single drop at typical highway target load levels of 40, 55 and 70 kN was made. The resulting pavement deflections were measured by seven seismic deflection transducers, one located at the centre of the loading plate and six additional sensors typically spaced at intervals of -300, 300, 450, 600, 900 and 1500 mm. For purposes of joint and crack load transfer determination, the sensor typically located at 200 mm is placed 300 mm to the rear of the loading plate.

Testing was conducted within the survey limits to determine the joint/crack load transfer characteristics at random crack locations. At each joint/crack tested, two FWD tests were completed. The first was completed with the FWD loading plate positioned on the ‘approach’ side of the joint/crack and the second was completed with the FWD loading plate positioned on the ‘leave’ side of the joint. The test locations were selected to test predominately low severity cracks/joints. A summary of the FWD test results is presented in Table 2.

**Table 2. Summary of FWD Test Results on Low Severity Cracks**

| Station (km) | Load Transfer (%) | | Quality of Load Transfer |
|---|---|---|---|
| | Approach | Leave | |
| 11+817 | 88 | 77 | Good |
| 11+885 | 54 | 59 | Marginal |
| 11+909 | 83 | 54 | Marginal |
| 11+955 | 66 | 68 | Marginal |
| 12+059 | 75 | 72 | Good |
| 12+096 | 80 | 84 | Good |
| 12+105 | 68 | 69 | Marginal |
| 12+147 | 50 | 62 | Poor |
| 12+202 | 80 | 84 | Good |
| 12+261 | 53 | 41 | Poor |
| 12+324 | 80 | 84 | Good |
| 12+362 | 83 | 72 | Good |
| 12+406 | 70 | 71 | Good |
| 12+469 | 83 | 79 | Good |
| 12+531 | 64 | 69 | Marginal |
| 12+567 | 55 | 57 | Marginal |
| 12+614 | 60 | 63 | Marginal |
| 12+725 | 76 | 60 | Marginal |
| 12+746 | 69 | 90 | Marginal |
| **Average** | **67** | **66** | |

Deflection load transfer (DLT) is calculated as the ratio of the unloaded to loaded slab, multiplied by 100. A joint or crack with deflection load transfer of 100 percent corresponds to perfect load transfer, while a value of 0 percent corresponds to no load transfer. Over 70 percent load transfer is considered good, 50 to 70 percent marginal and less than 50 percent poor. Overall, 11 of 19 (58 percent) of all crack locations resulted in marginal or poor load transfer.

## GROUND PENETRATING RADAR INVESTIGATION

The GPR data sets were acquired with a Noggin 1000 SmartCart system, which incorporates and integrated field computer for data logging. This GPR, being both a ground-coupled system and operating at a high center frequency of 1000 MHz, provided the high spatial resolution and excellent penetration depth required for pavement imaging in this application (Annan 2006). A photograph of the GPR system used in the investigation has been provided in Figure 2.

The GPR data were acquired in the passenger wheel-path of Lane 3, from Station 11+800 to 12+700 at 0.01 m station spacings. During the GPR survey, fiducial markers were saved in the GPR files to indicate the position of cracks, core holes and other features observed on the pavement surface. These fiducial markers were then used to correlate specific pavement features with features observed in the GPR images during the data analysis. As well they provided exact positioning of core locations relative to the GPR data.

**Figure 2. Photograph of the Noggin 1000 SmartCart System.**

## Subsurface Pavement Investigation

The GPR cross section images showed many features described below including concrete joints, evidence of concrete slab movement, disruption in asphalt pavement above joints in concrete, subsurface patches and steel reinforcement. The images were also analyzed to determine the thickness and depth of the asphalt and concrete pavement.

The determination of depth using GPR requires a measurement of the propagation velocity of the electromagnetic (EM) pulse within the pavement. Velocity can be determined by fitting hyperbolas to scattering targets in the subsurface (e.g. steel rebar in pavement) or by measuring the travel time to a subsurface horizon of known depth. Typically for pavement applications calibration with a few cores provides the most accurate method for determining velocity. In this application the average velocities were determined from 15 cores over the survey area. The computed velocities were 0.108 m/ns to the bottom of asphalt and 0.100 m/ns to the bottom of concrete.

The GPR cross-section images (Figure 3) show three main horizons corresponding to the top of asphalt and, the top and bottom of the PCC layer. As well the steel reinforcing within the PCC layer that run perpendicular to the road direction create characteristic scattering hyperbolas within the images. The apex of the hyperbola is at the actual depth and position of the rebar.

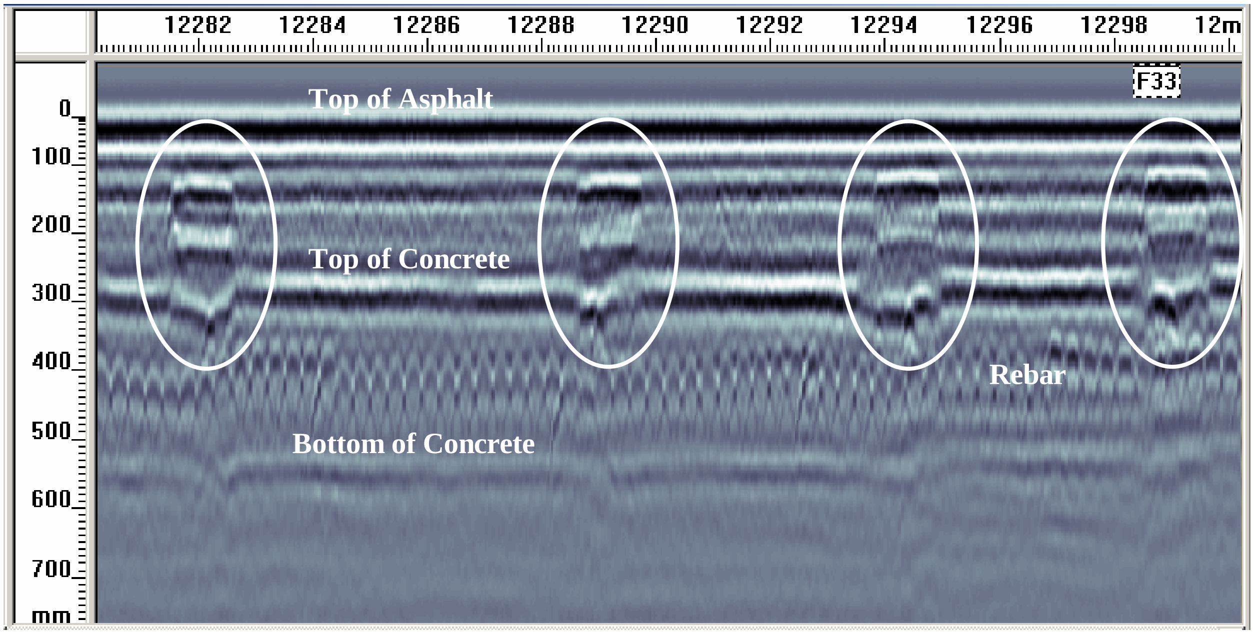
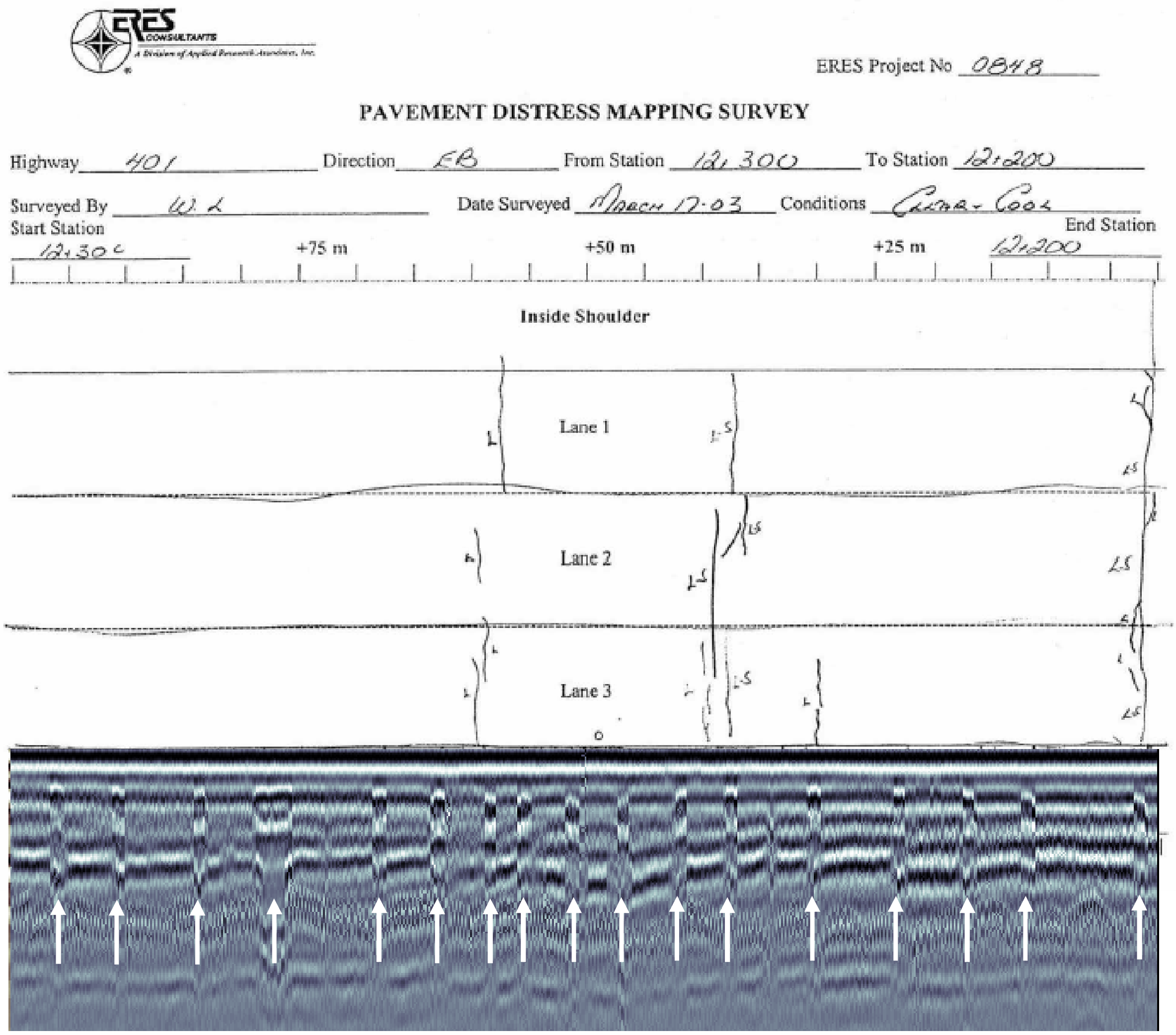


**Figure 3. GPR cross-section image showing repaired patches (circled) concealed beneath subsequent resurfacing.**

## Concealed Repair Patches

The GPR located numerous subsurface repair patches concealed by subsequent resurfacing. Typical asphalt crack repairs are shown in Figure 3 at the circled locations. Although these repairs did not extend through the PCC base, it does appear that partial depth repairs may have been completed on the PCC base before patching with asphalt concrete. These repair locations were not observed during the detailed condition survey, as this area had been resurfaced after the repairs had been completed.

A comparison of the GPR interpretation and the pavement distress mapping survey has been provided in Figure 4. The observed surface cracks correlate with the indicated location of some of the repair patches. The 100 m section displayed had 17 repair zones, typically 1 m in length and not visible on the pavement surface.



ERES CONSULTANTS
A Division of Applied Research Associates, Inc.

ERES Project No 0848

PAVEMENT DISTRESS MAPPING SURVEY

Highway 401 Direction EB From Station 12,300 To Station 12+200

Surveyed By W. L Date Surveyed March 17-03 Conditions Clear - Cool

Start Station 12+300

End Station 12+200

**Figure 4. A comparison of GPR interpretation with the detailed pavement distress mapping.** (Note:The arrows indicate the location of the repair patches that can also be seen in the GPR cross-section image. Note that the GPR data is shown in the outside shoulder location, but applies to Lane 3.)

From the information provided by the core/borehole advanced at Station 12+050, no PCC base was found to underlay the asphalt surface. The missing PCC base observed in the core was confirmed by the GPR (Figure 5) survey that showed a full-depth patch, with PCC base removal over a 3 m interval from 12+049 to 12+052. The core/borehole location is identified by the fiducial marker F20, marked during GPR data collection, and the empty core hole can also be seen in the GPR image directly below the fiducial marker.

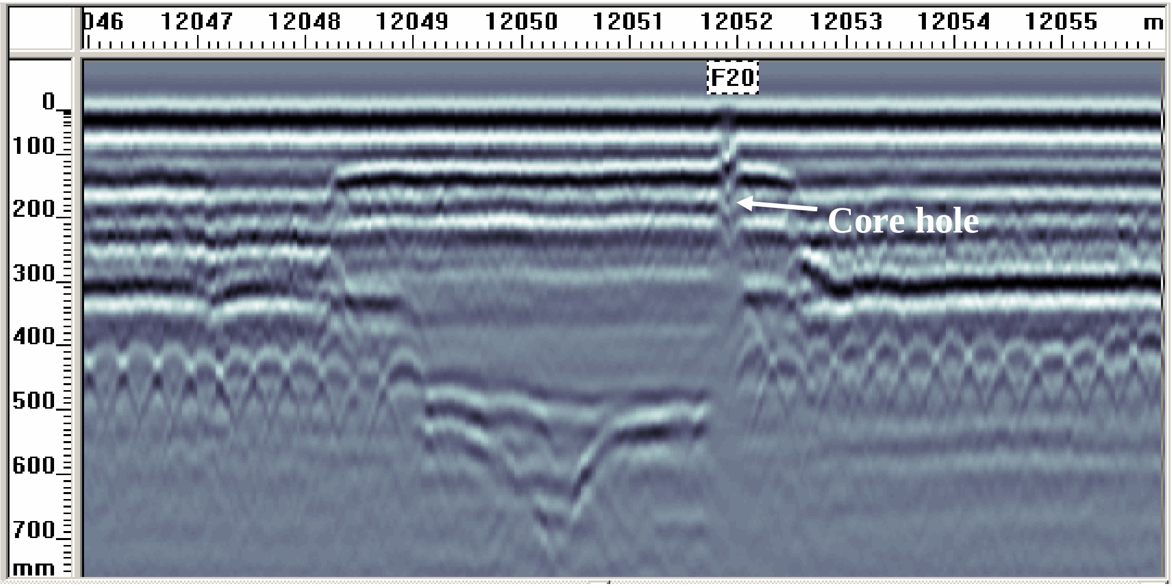


**Figure 5. A core/borehole located in a full-depth repair.**

## Steel Reinforcement

The characteristic diffraction hyperbolas from the reinforcing steel are ubiquitous in all the GPR data from this survey. An example of the typical rebar depth variation is shown in Figure 6 where the symbols at the apex of each scattering hyperbola mark the location of the reinforcing steel. The reinforcing steel was not present in some of the full depth patch repairs as is the case of the repair shown in Figure 5.

The average reinforcement depth from the GPR analysis was determined to be at 0.37 m compared to 0.35 m for the core data. Variability in reinforcing steel depths were found to fairly comparable as the reinforcing steel depths from the GPR survey varied from 0.32 to 0.45 m, and the reinforcing steel depths from the core samples varied from 0.30 to 0.41 m. The average root-mean square (RMS) deviation of the GPR depths from the core depths was found to be 10 mm. The GPR only responds to reinforcing steel transverse to the road while the core samples either direction of the wire mesh reinforcement. The transverse and longitudinal reinforcing steel will be at depths different by at least the diameter of the reinforcing steel. This may explain some of the differences observed between the GPR and core data.

## Crack/Joint Locations

The location of cracks and joints through the PCC can be identified in the GPR images by breaks in the horizons at the top and bottom of the PCC layer, sharp offsets in the depth to the top of the PCC layer, abrupt changes in slope of the top of the PCC layer and the presence of scattering hyperbolas at the top of the PCC base near the center of the repair zones. Some of these effects are visible in Figure 6 where the cracks have been identified. In some cases there is a disruption in the normal horizontal layering within the asphalt layer that is attributed to a crack penetrating through the asphalt indicating that there is potential movement at the crack in the PCC layer. A number of these crack manifestations are seen below in the GPR cross-section image. It is clear from the GPR cross sections that many of the cracks in the PCC layer also occur at the location of the concealed repair patches.

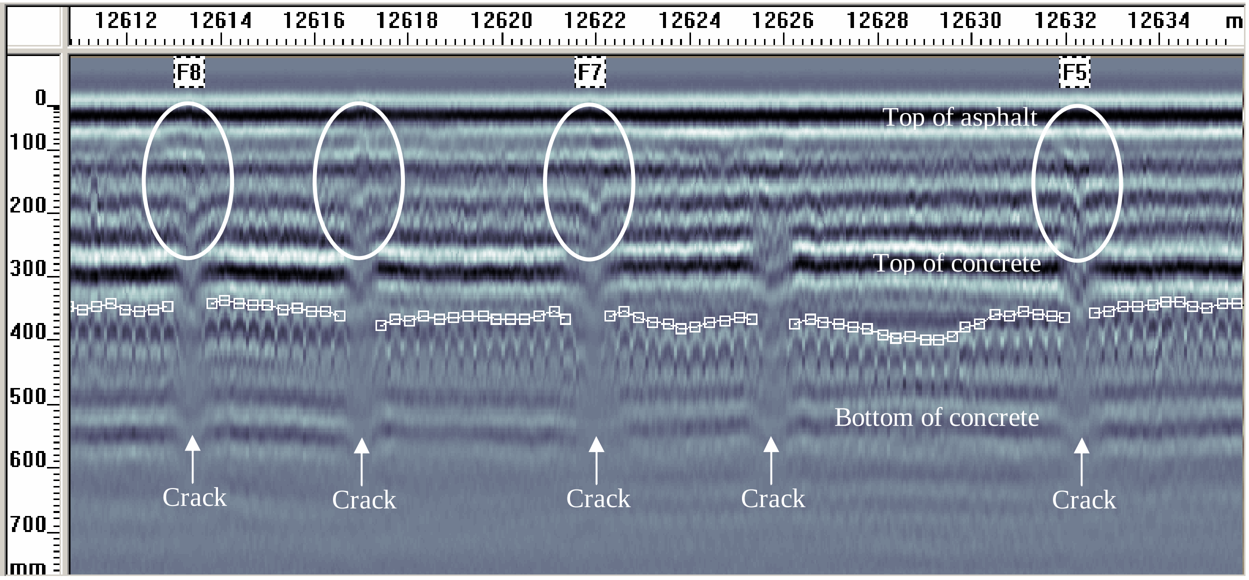
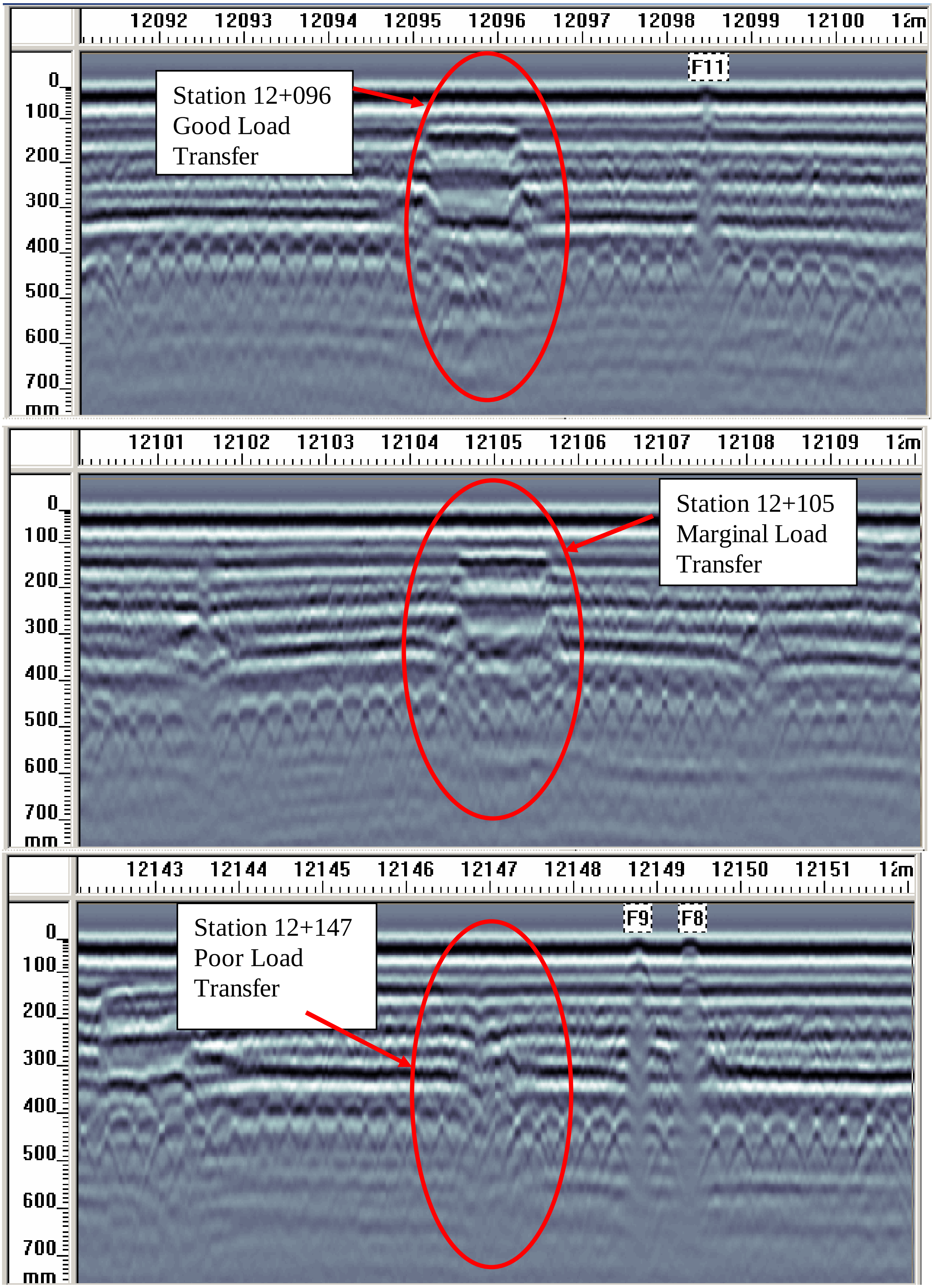


**Figure 6. GPR cross-section image showing joints/cracks and rebar.** (Note disruption in asphalt above PCC indicating active crack at circled locations. The fiducials F5, F7 and F8 at locations of surface cracking observed during GPR data collection. The symbols at the apex of each scattering hyperbola mark the locations of each individual rebar.)

Since GPR was clearly able to identify the joint/crack locations, GPR cross-section images were produced at three crack locations with load/deflection testing. The three crack locations of varying load transfer quality were located at Station 12+096 (good load transfer), Station 12+105 (marginal load transfer), and Station 12+147 (Poor Load transfer). The GPR cross section at these locations (Figure 7) illustrates the subsurface condition at each of the identified cracks/joints.

From the GPR survey, there is a noticeable difference between each of the three-load/deflection test locations. Disruptions at the bottom of the concrete reflectors are visible at all three crack locations, which indicate the likelihood of a possible joint/crack location in the underlying PCC base.

At Station 12+096, the GPR image identifies a subsurface full-depth repair area, which would explain the low severity crack reflecting through the surface course. The FWD testing at this location measured load transfers of 80 percent at the approach-side, and 84 percent at the leave-side to indicate a good quality of load transfer. Although the area had been previously repaired (prior to overlay), the image appears to be relatively consistent throughout the repair area, with no major disruptions.


Station 12+096 Good Load Transfer

Station 12+105 Marginal Load Transfer

Station 12+147 Poor Load Transfer

**Figure 7. GPR cross-section images at three load/deflection test locations.** (Note: Fiducial markers F8, F9, and F11 are core locations.)

A partial depth repair area was identified at Station 12+105, and at this location the FWD testing measured a marginal load transfer. At this crack location, movement of the PCC base is noticeable on either side of this repair area. The additional movement of the tilted PCC slabs would increase the rate of deterioration at this crack location, and would explain the reduction of load transfer at this crack location.

Poor load transfer was measured on the low severity crack at Station 12+147. Unlike the previous two crack locations, no previous repair areas can be seen at this location, however disruptions are noticeable within the asphalt and PCC layers. Prior to the recent resurfacing, this distressed area had been overlooked for repair. As a result, cracking had reflected through the overlay to deteriorate the surface course.

## Pavement Layer Thickness

The depth of the horizons in the GPR image corresponding to the asphalt and PCC layer was determined over the surveyed pavement section using specialized horizon picking software. In some locations, the interface between the bottom of asphalt and the top of the PCC layer and between the bottom of the PCC and the granular horizon can not be clearly seen in the GPR image due to poor contrast in electrical properties across the interface.

The results of the horizon picking process (Figure 8) show substantial variation in the depth of the asphalt and concrete. The core data results are quite comparable to the GPR determined depths. The average RMS deviations of the GPR depths compared to the core depths were found to be 3.1 mm for the asphalt layer and 3.5 mm for the concrete layer.

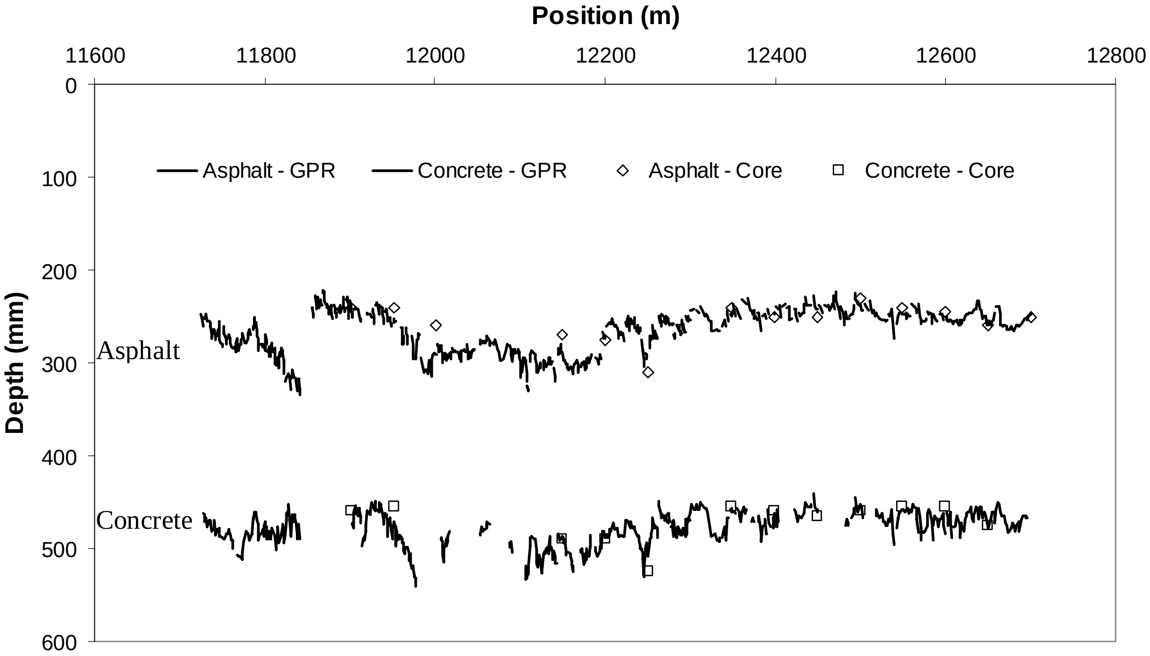


**Figure 8. Depths of asphalt and concrete layers determined from GPR compared with core data.** (Note: Cores collected at repair zones are not included.)

## CONCLUSIONS

Combining the GPR survey with traditional pavement condition investigations techniques proved to be beneficial for the pavement evaluation of this portion of Highway 401. The results of the GPR survey provided valuable information by identifying subsurface problem areas, areas of previous full-depth and partial-depth repairs, as well as helping to explain anomalies encountered during the field investigation.

In reviewing the information obtained from the GPR survey, several important conclusions can be drawn from this study. These conclusions are listed below.

- The GPR survey clearly identifies the location of cores/boreholes relative to buried pavement structures, especially when advanced through previously repaired areas. These repair areas are not typically evident from visual inspection of the pavement surface. Furthermore, GPR could also be used in advance of coring to select optimum coring locations.
- Subsurface pavement repairs are clearly visible in the GPR sections. The GPR survey was also found to differentiate between full-depth asphalt repairs, or partial depth asphalt repairs.
- The presence, and depth, of the reinforcing steel is easily determined from the results of the GPR survey. The reinforcing steel was also found to serve as an indicator of concrete, if it not otherwise evident.
- Joints and cracks in the underlying pavement slab are indicated in the GPR data by vertical offsets at the ends of the slab, scattering hyperbolas at either the top or the bottom of the crack in the concrete, and/or by disruption in the bottom of concrete reflector.
- The GPR survey clearly distinguished between the boundaries of the bottom of asphalt and the top of concrete.
- Concrete thickness can often be determined, but less accurately than the asphalt. In some cases the absence of a reflection event from the bottom of concrete does not allow a determination of its thickness.
- Cracks visible on the surface are clearly indicative of many possible pavement conditions as evident by the GPR data. The severity of the surface crack may not be a good indication of the pavement condition. Cracks observed within the asphalt with the GPR that are not visible at the surface from conditions surveys may indicate future problem areas.
- The pavement layer thickness are quite comparable to the core results after computing an average EM wave velocity from the core data.

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