**Preparation and Recommendations for CC9 Baseline GPR Survey**

Objectives of the preparation of CC9 Ground Penetrating Radar (GPR) survey are:

* Determine the functionality of the GPR system, including antenna, distance measuring instrument (DMI), and controller (i.e., data acquisition system)
* Determine the antenna(s) with appropriate frequencies to identify layers (such as surface, base, and subbase) and their thicknesses at varying depths
* Propose GPR survey plan

Functionality of GPR System

Figure 1(a) and (b) show the Federal Aviation Administration’s (FAA) cart- and van-mounted GSSI GPR systems. The cart-mounted GPR system comprises 900 MHz ground-coupled antenna, DMI, and 1-channel SIR 3000 controller, while the van-mounted GPR system comprises 2 GHz air-coupled and 400 MHz ground-coupled antenna, DMI, and 4-channel SIR 30 controller. During on-site preparation work, all the components on both cart- and van-mounted GPR systems were connected and activated. After activation, the antennas, DMI, and controller communicated with each other and the system started collecting sub-surface image. Trial surveys were conducted using both of these antennas at locations of CC9 test pavement. GPR data from the trial survey were then post-processed by RADAN 7 (a GSSI GPR post-processing software) to reconstruct the images and check the data quality. Example GPR images from both cart- and van-mounted GPR systems are shown in Figure 2. The ‘red-line’ indicates the interface between two media with dissimilar dielectric constants (for instance, between air and asphalt layer or asphalt and aggregate layer). Pavement surface and layer interfaces can be tracked using the ‘red-line’. Locus of the ‘Parabola’ indicates the locations of buried/embedded objects such as instrumentation, conduit etc. Both cart- and van-mounted GPR systems, along with the GPR post-processing software were functional.

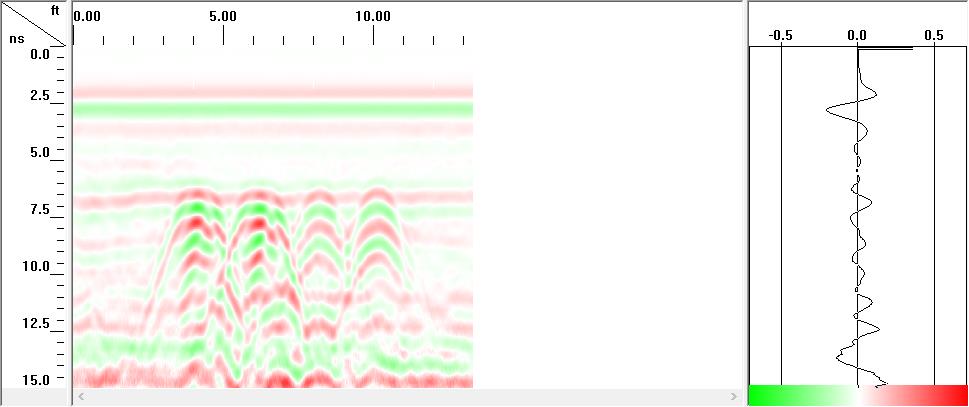
400 MHz antenna

2 GHz antenna

900 MHz antenna

(a) (b)

Figure 1. GPR system: (a) cart-mounted, and (b) van-mounted

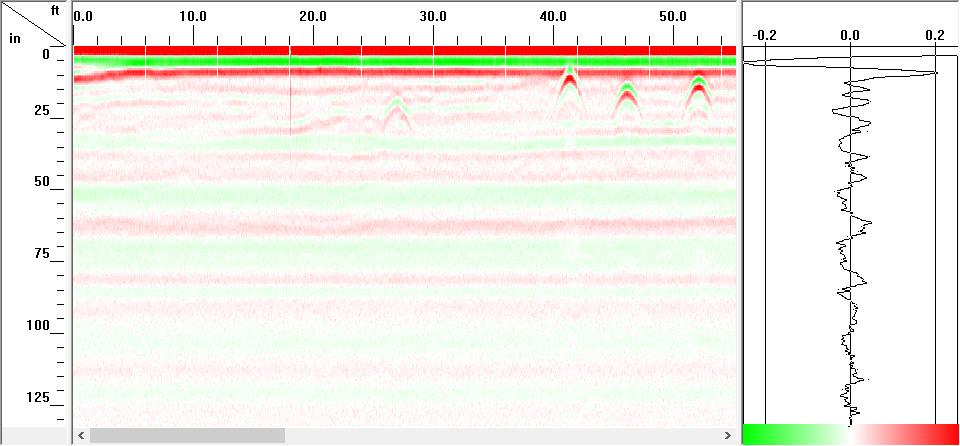


ASG locations

Layer interfaces

Pavement surface

(a)

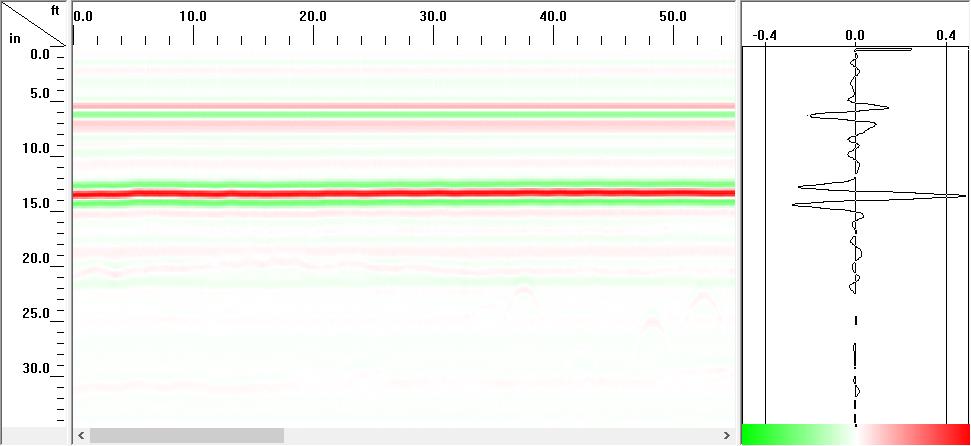


Instrumentation/Conduit

Pavement surface

Layer interface

(b)



Layer interface

Pavement surface

Transmitter-Receiver direct coupling

Instrumentation/Conduit

(c)

Figure 2. GPR images: (a) 900 MHz, (b) 400 MHz, and (c) 2 GHz

Determination of Required Antenna

A past study by Tarefder and Ahmed (2016) reported the applicability of different antenna frequency to identify the layer at varying depths, (a) 2 GHz air-coupled antenna: identification of asphalt layer and layers at shallow depth; (b) 900 MHz ground-coupled antenna: asphalt layer and unbound layers at intermediate depths; and (c) 400 MHz ground-coupled antenna: unbound layers at deeper depths. Our GPR survey with 400 MHz (van-mounted) and 900 MHz (cart-mounted) can identify asphalt and unbound layers, which was also reflected in GPR images from the trial survey (Figure 2). However, it was difficult to distinguish asphalt layer thicknesses between multiple test items such as 5.1-inch P-401MR in LFC-5N vs. 3.3-inch P-401MR in LFC-5N on CC9 (Figure 3). A preliminary post-processing of GPR images captured by 900 MHz on these two test items was not able identify this thicknesses difference, as shown in Figure 4(a). In Figure 4(b), P-401MR thickness dissimilarity between LFC-4N and LFC-5N was evident on the GPR image captured by 2 GHz antenna.

Dielectric constant (*ε*) of a pavement layer should be known to determine the velocity of GPR signal in that layer as follows (Tarefder and Ahmed 2016):

(1)

where velocity of GPR signal in a pavement layer, and velocity of GPR signal in air (= 11.8 in/ns). The signal velocity is then used to determine the layer thickness (*h*) using the following relationship:

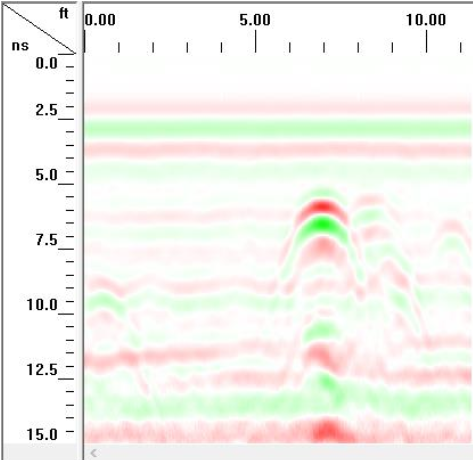
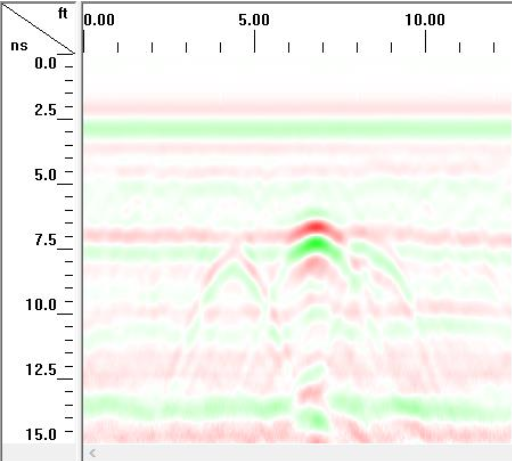
(1)

where 2-way travel time of GPR signal in a pavement layer. There is no direct methodology to determine the dielectric constant from the ground-coupled antenna data (i.e., 400 and 900 MHz). Dielectric constant can be determined from the 2 GHz air-coupled antenna data by conducting a metal plate calibration testing, so-called ‘Bumper-Jump’ test (Tarefder and Ahmed 2016). An illustration of a trial metal plate calibration test in the facility is shown in Figure 5. GPR data from this test is typically integrated to the 2 GHz air-coupled antenna data to determine the dielectric constant and thereby, interpret pavement layer thickness.

We recommend both 400 MHz ground-coupled and 2 GHz air-coupled antennas in addition to 900 MHz ground-coupled for CC9 baseline GPR survey to: (a) identify unbound layers at the deeper depth, (b) capture P-401MR thickness variation, and (c) determine the dielectric constant of pavement layers.



Figure 3. As-built Layer Thicknesses of CC9 Pavement Section



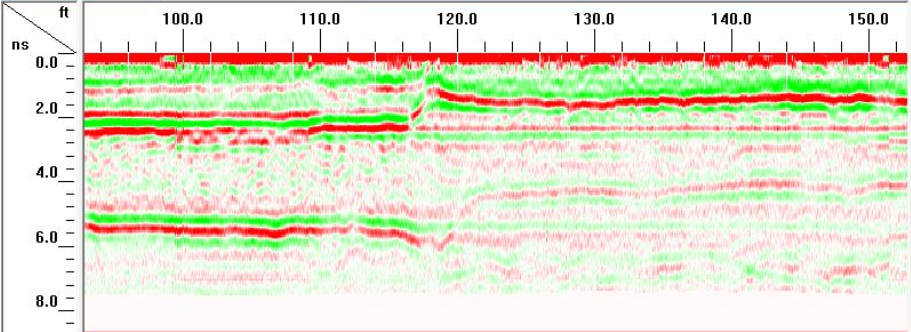
**LFC-4N**

**LFC-5N**

Pavement surface

Bottom of P-401MR

(a)



3.3-inch P-401MR in LFC-5N

5.1-inch P-401MR in LFC-4N

(b)

Figure 4. GPR image to distinguish thickness of P401MR: (a) 900 MHz, and (b) 2 GHz



Figure 5. Metal plate calibration test

Proposed Baseline Plan

The idea is to monitor the change in layer thickness due to traffic-induced permanent deformation and construct layer profiles. Cart-mounted 900 MHz ground-coupled antenna was initially proposed to conduct the full-width GPR survey along transverse direction. Since the GPR survey in the similar fashion is not feasible using the van-mounted GPR system, it is proposed to conduct full-length survey at multiple offsets with both 2 GHz air-coupled and 400 MHz ground-coupled antennas. Proposed CC9 baseline survey is summarized in Table 1.

Table 1. Proposed Baseline GPR Survey

| **Equipment** | **Antenna** | **Location** | | **Purpose** |
| --- | --- | --- | --- | --- |
| **Transverse** | **Longitudinal** |
| Cart-Mounted GPR | 900MHz ground-coupled | Full width | STA 0+15, 0+30,  STA 0+75, 0+90,  STA 1+35, 1+50,  STA 1+95, 2+10,  STA 2+55, 2+70 | Asphalt and Unbound Layer Thickness (at intermediate depth), Instrumentation Locations (if any, (for ground-truthing)) |
| Van-Mounted GPR | 400MHz ground-coupled | OFF -17.25 feet,  OFF -15.00 feet,  OFF -12.75 feet,  OFF +12.75 feet,  OFF +15.00 feet,  OFF +17.25 feet | Full length | Unbound Layer Thickness (at deeper depth), Instrumentation Locations (for ground-truthing) |
| Van-Mounted GPR | 2GHz air-coupled | OFF -17.25 feet,  OFF -15.00 feet,  OFF -12.75 feet,  OFF +12.75 feet,  OFF +15.00 feet,  OFF +17.25 feet | Full length | Asphalt and Unbound Layer Thickness Variation (at shallow depth), Instrumentation Locations (for ground-truthing) |

**Reference**

Tarefder, R. A., and Ahmed, M. U. (2016). Optimal Use of Falling Weight Deflectometer and Ground Penetrating Radar. Report No. NM12SP-01, University of New Mexico, Albuquerque, NM, USA. <https://dot.state.nm.us/content/dam/nmdot/Research/Final\_report-GPR.pdf>