GPR AS A TOOL FOR DETECTING PROBLEMS IN HIGHWAY-RELATED CONSTRUCTION AND MAINTENANCE

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Abstract

Three case studies utilizing GPR in highway related projects are presented. The first case involves the use of GPR for void detection and delineation caused by washout from an old brick-lined sewer beneath pavement showing varying signs of subsidence. A secondary purpose of this study was also the delineation of the sewer itself. Used in conjunction with three punch cores taken through the pavement for control, the GPR was able to delineate the void/washout/ loose soil zone and the location of the sewer.

The second case involves GPR evaluation of possible construction deficiencies related to cracking observed of a newly constructed soundwall. Efforts at void location within the soundwall and adjacent to rebar were mostly unsuccessful due to antennae resolution, although two potential voids were imaged. Although rebar posed difficulties in allowing the GPR signal to penetrate the wall, the rebar imaging itself gave indications of construction weaknesses. Correct antenna orientation allowed the location of soundwall bond beams and vertical rebar. Zones of excess concrete, missing bond beams, and vertical rebar were detected.

The third case involves GPR evaluation of possible construction deficiencies in a concrete bridge approach slab. Variations in the concrete and rebar mat (relative to baseline data collected nearby), and other radar anomalies indicate poor construction.

Introduction

Ground penetrating radar (GPR) is a very useful tool for many different kinds of highway investigations; a finding reached by numerous researchers, including Black and Kopac (1992), Davis et al. (1994), Mesher et al. (1995), and Saarenketo and Scullion (1994). The California Department of Transportation (Caltrans) has applied GPR in geological, geotechnical, and non-geotechnical construction investigations. Caltrans has utilized GPR to investigate highway-related, geologic issues such as faults, landslide slip-planes, stratigraphy and soil structure, geologic structure, water table location, depth-to-bedrock and bedrock topography. GPR has also been utilized to examine the actual structures, roadways, and foundations of the highway system to determine construction quality, location of voids within and beneath pavement and concrete, location and spacing of rebar, location and type of buried foundations, and location of pipes and utilities. GPR has been implemented in pre-construction highway-related archaeological investigations. Many of these investigations have been quite successful in achieving their objectives, and the efficacy of GPR selection and implementation continues to improve.

Three typical GPR case studies examining aspects of actual highway structures and roadways are presented here. The first case involves GPR detection and delineation of voids beneath pavement and concrete, and the location and condition of an old sewer line constructed prior to the state's archive of as-built plans. The second case is an investigation of a soundwall to confirm construction deficiencies. The third case examines the construction quality of a concrete bridge approach slab with suspected delamination and cold-jointing.

Data Acquisition

Although GPR surveys can be conducted in three modes- reflection, common-mid-point/ wide-angle reflection, and transillumination- the three case histories presented here all utilized the most common survey mode, reflection, with the transmitter-receiver antenna distances fixed. These investigations all

involved a Sensors and Software PulseEKKO 1000 acquisition system with different frequency antennas. A software package accompanying the acquisition system was used in collecting, processing, analyzing and displaying the radar data. Though fairly capable, this software does not allow for depth/time sections to be determined based on cross-sections with more than one velocity, basically due to the complexity of the reflection processing algorithms. The consequence of this inability to vary the velocity with depth often results in depth sections that are not entirely accurate, particularly when the material varies from clay (100 MHz EM velocity ~ 0.06 m/ns) to concrete (100 MHz EM velocity ~ 10 m/ns). Therefore, depths must be determined based on an interpretation of the subsurface materials, which is one of several reasons for obtaining direct corroborating evidence of subsurface conditions to correlate with the GPR data (such as roadcuts, cores, borings, pits, etc.).

Case Histories

Subgrade Void and Brick-Lined Sewer Delineation

A GPR survey was performed in the city of Burlingame, along California State Route 82 (running roughly north-south) to determine the extent of a sub-surface void space (with some loose soil) and an old (>70 years), brick-lined sewer thought to be responsible for creating the void. Prior maintenance work on a pothole next to the metal grate first revealed the presence of the void and the sewer, the location, extent and size of which was unknown due to lack of as-built plans dating back that far. The sewer was suspected of running parallel with the road near the juncture of the asphalt gutter and the sidewalk, due to the presence of a manhole to the south and the actual observation of the sewer next to the grate during the pothole repair. The asphalt gutter appears sunken, as does the sloping sidewalk, leading maintenance personnel to suspect other voids. The juxtaposition of the void/loose soil and the old sewer, which was obviously not watertight, led to the sewer being suspected as the cause of the void/washout, and hence, the interest in its location.

The GPR survey was conducted along the existing sidewalk and the right lane, beginning at a steel grate and extending south for about 40 meters. GPR data were collected along North-to-South and shorter West-to-East transects (Figure 1). Both the 900 MHz (greater depth of penetration; less resolution) and 1200 MHz (less penetration depth; more resolution) antennas employed were shielded, so the radar signal was not significantly impacted by the power lines situated overhead, nor the cars passing nearby. Three quick 4” diameter cores of the pavement and subgrade were taken with a portable coring machine in select locations to give control to the radar records.

Figure 2 shows the first 7.5 meters of the 900 MHz North-South profiles 1, 2, and 3, which were obtained parallel to the curbing, on the asphalt, and centered approximately 0.25, 0.45, and 0.65 meters from the curbing. Washout is evident from the steel grate to about 2.2 meters on profile 1, with profiles 2 and 3 showing a decreasing extent (1.8 and 1.4 meters) of void/washout/loose soil. This is the disturbed area noticed by maintenance the previous year while working with the steel grate. Based on these radar profiles, the disturbance does not appear to continue further than about 2.2 meters south of the steel grate. It also appears to be more significant closer to the curbing, with profile 4 (1 meter from curbing) not showing any significant disturbance.

Figure 3 shows the first 22.5 meters of the 900 MHz North-South profile 1, split into three sections: section A, from 0 to 7.5 meters, section B from 7.5 to 15 meters, and section C from 15 to 22.5 meters. This profile shows several features, including the disturbed area already demonstrated in figure 2. It does not show a brick-lined sewer, however, even though the line would later be discerned with GPR precisely in the location of this profile. Its absence, of course, is due to its orientation being parallel with the traverse, rather than perpendicular (which is the best orientation for observing linear objects like pipes and conduits). A subsurface, non-metallic (not seen by a metal detector) drainpipe leading from the church (to the west) into the street, however, is evident on this profile at 11.5 to 12.0 meters because its orientation is perpendicular to the GPR traverse. Its complete absence on profile 3 and 4 indicates that it terminates. Its termination is presumed to be in the north-south brick-lined sewer running parallel to the curbing.

The noticeable change in radar stratigraphy at about 18.5 to 19.0 meters on profile 1 corresponds precisely with recent pavement and concrete work associated with the driveway there.

The 1200 MHz north-south profiles do not penetrate quite as deeply as the 900 MHz profiles (higher frequency results in greater attenuation) but show slightly more feature resolution, corroborating profiles 1 to 4 and reinforcing the interpretations given for them.

Semi-hyperbolic anomalies in the West-East profiles delineate the location of the north-south sewer beneath the pavement. These anomalies indicate the sewer is located beneath the gutter about 0.6 meters from the curbing. These profiles indicate that the top of the sewer conduit lies at a depth of about 0.3 meters below the pavement surface. Washout of subgrade material or the existence of voids is not evident in these profiles.

Figure 4 shows three of these West-East profiles and the parabolic anomalies indicative of the sewer conduit. The left limbs of these parabolas are very flat or absent, which indicates that the conduit here may be rectangular or box-shaped in cross-section, not circular. In addition, this lack of a left limb is probably related to the extra cement of the sidewalk and the transition from sidewalk to asphalt over a 4 inch curbing that is situated just about where the left limb should be on the radar profile.

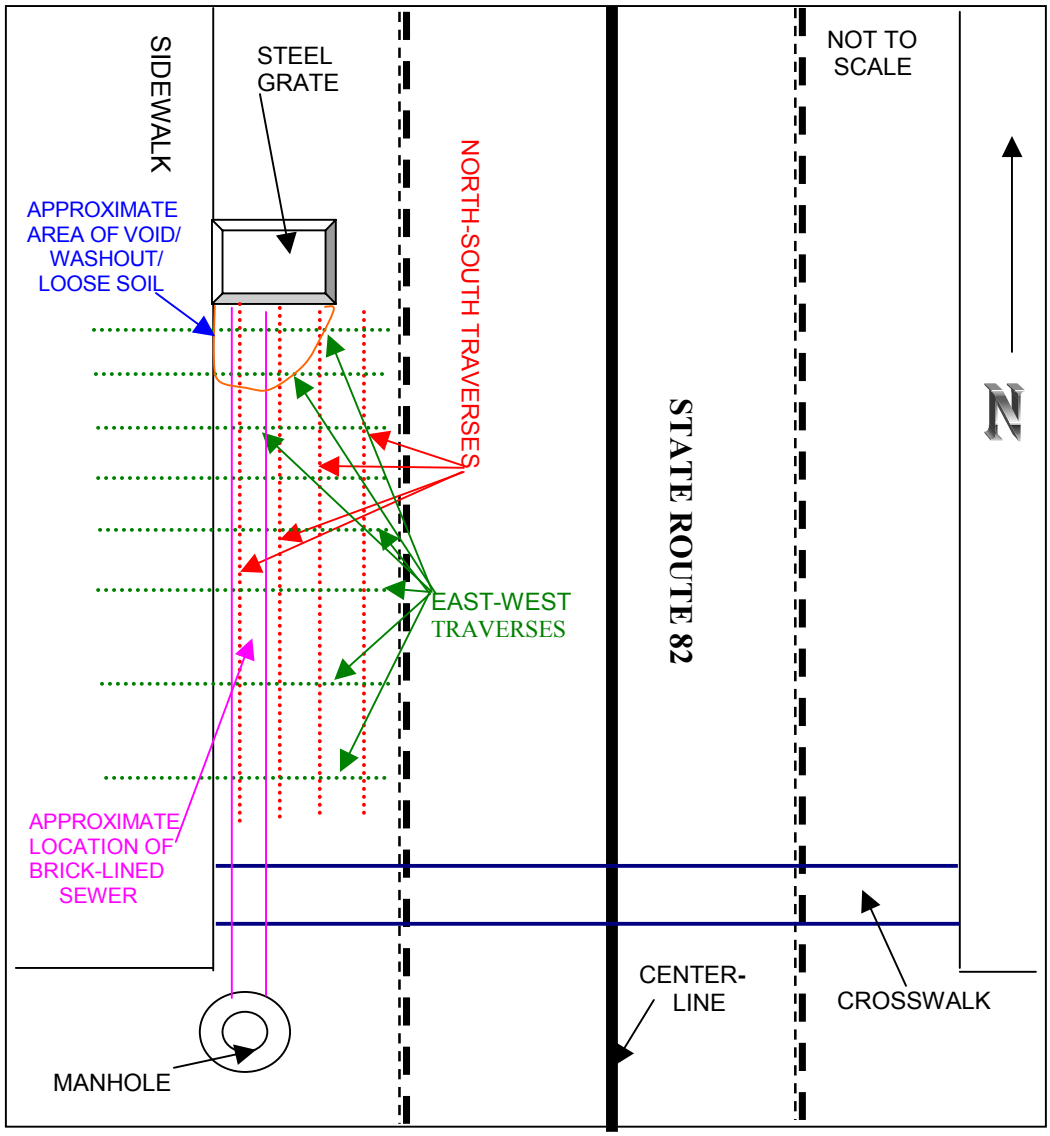

Figure 1. Location map for void/washout & brick-lined sewer investigation on State Route 82 in Burlingame. Map shows approximate location of GPR traverses, steel grate, imaged brick-lined sewer, and void/washout/loose soil area.

The presence of void space beneath the pavement, apparently produced by leakage from an old north-south sewage conduit, is confined to an area from 0.0 to 2.5 meters south of the steel grate that extends from just below the lip of the curb to almost 1 meter from the curb. No evidence of leakage-

produced void space exists anywhere else in the radar records. It is quite possible that leakage has occurred over time along the sewer and caused a gradual subsidence of the gutter and sidewalk edge, but no evidence of voids or loose material is found along it now, except near the steel grate. The sewer is located about 0.6 meters from the curb.

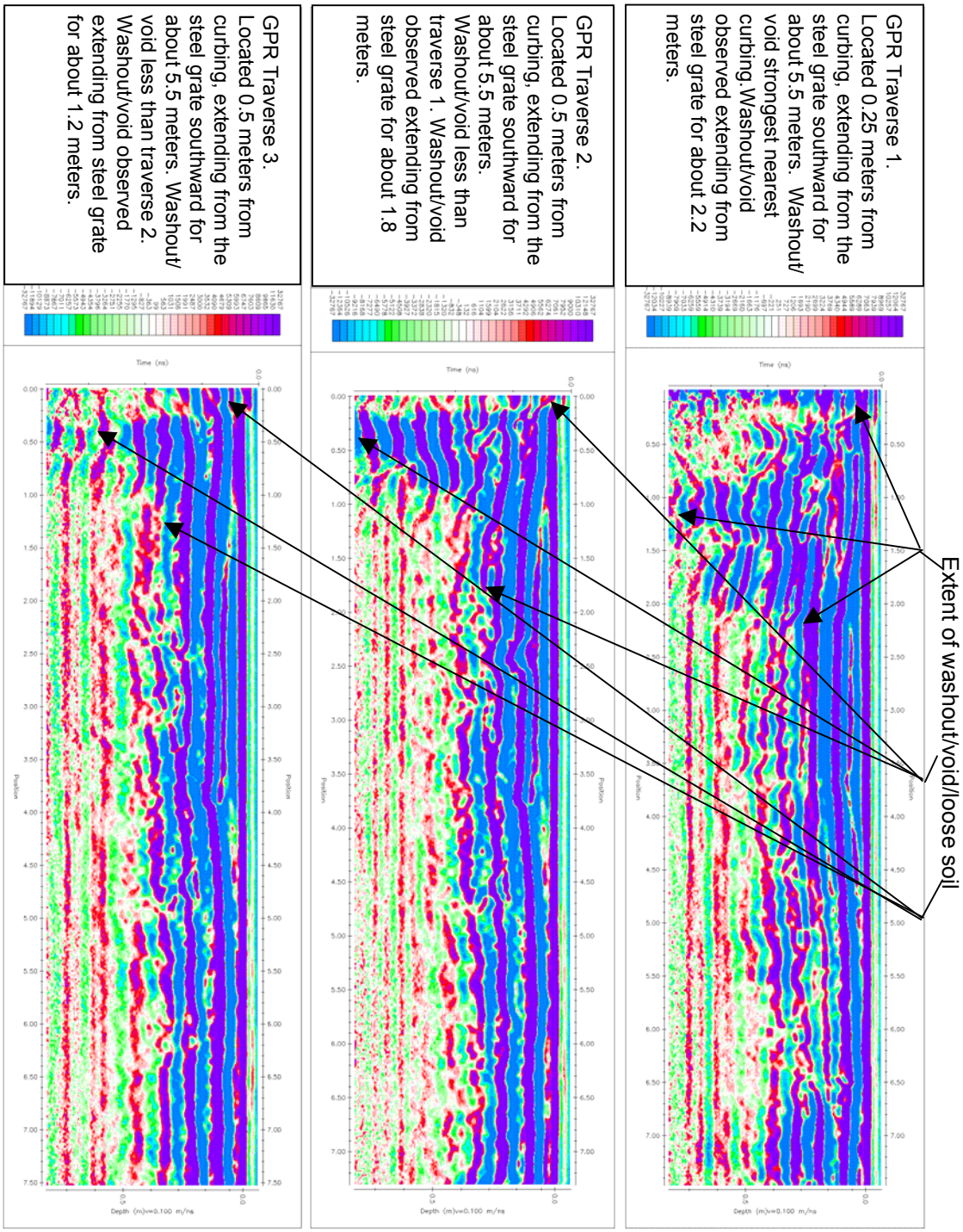

Figure 2. Initial portions of GPR traverses 1,2, and 3, each extending southward from the steel grate for about 7.5 meters. Traverse 1, 2, and 3 are located about 0.25, 0.45 and 0.65 meters from the curbing, respectively.

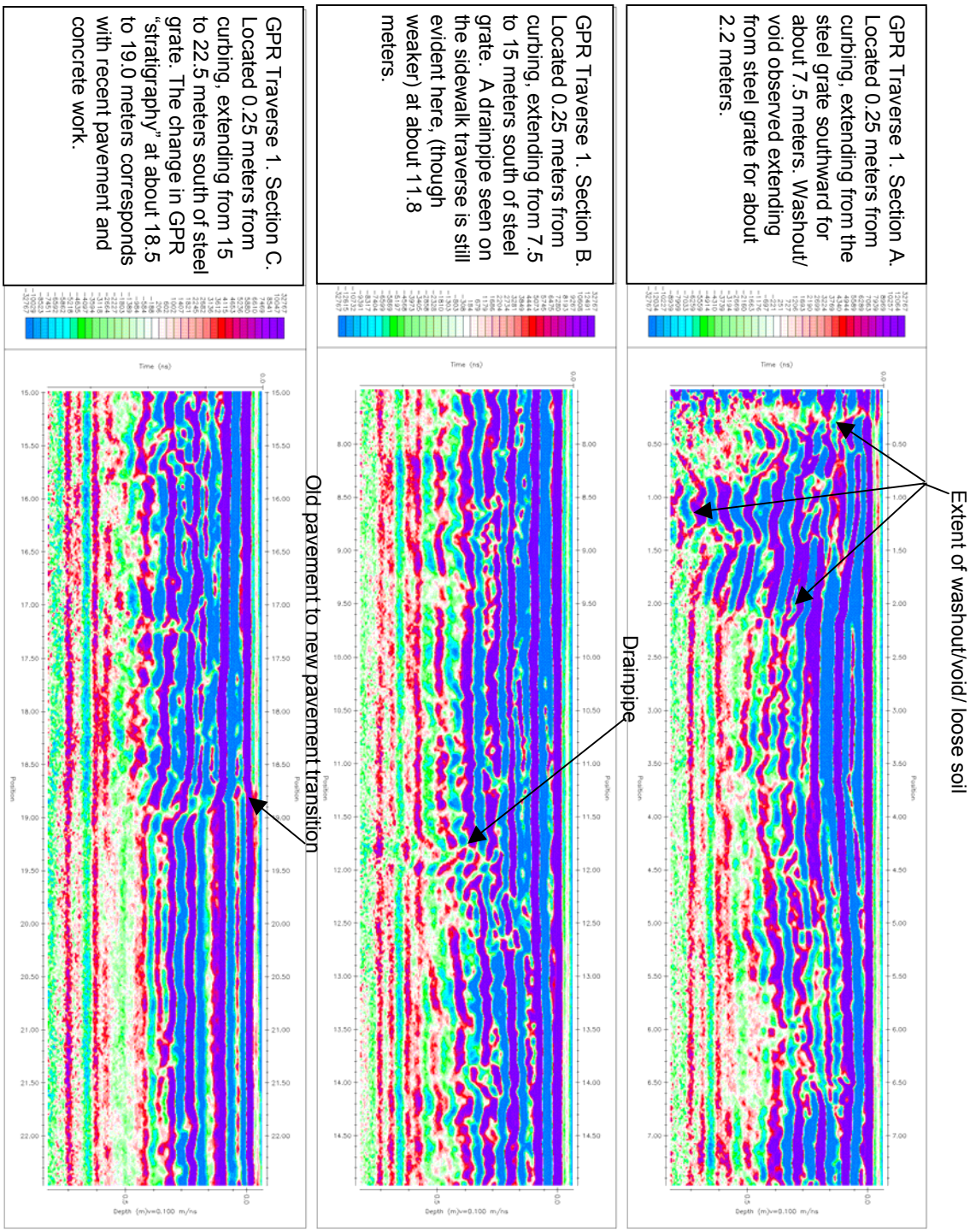

Figure 3. GPR traverse 1 from the steel grate (0.0) to 22.5 meters, in three sections: section A from 0.0 to 7.5 meters, Section B from 7.5 to 15 meters, and section C from 15 to 22.5 meters.

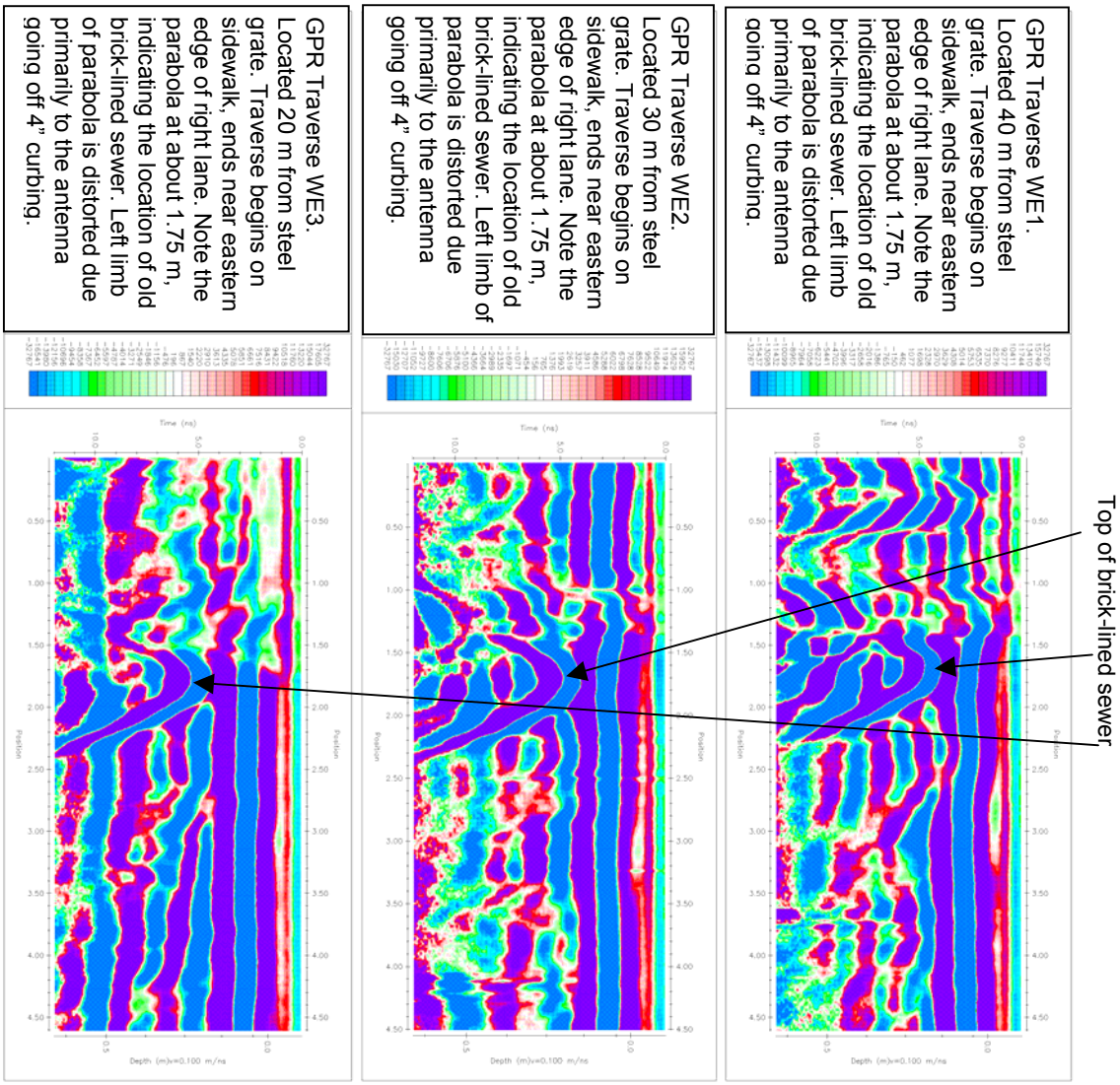

Figure 4. West to east GPR traverses 1, 2, & 3 running from atop the sidewalk to the eastern side of the right lane. Traverse 1, 2, & 3 are located 40, 30, & 20 meters from the steel grate. Arrows indicate the location of the top of the old brick-lined sewer. Depth of sewer on these cross-sections is not precise due to the inability of the software to utilize more than one velocity for the subsurface.

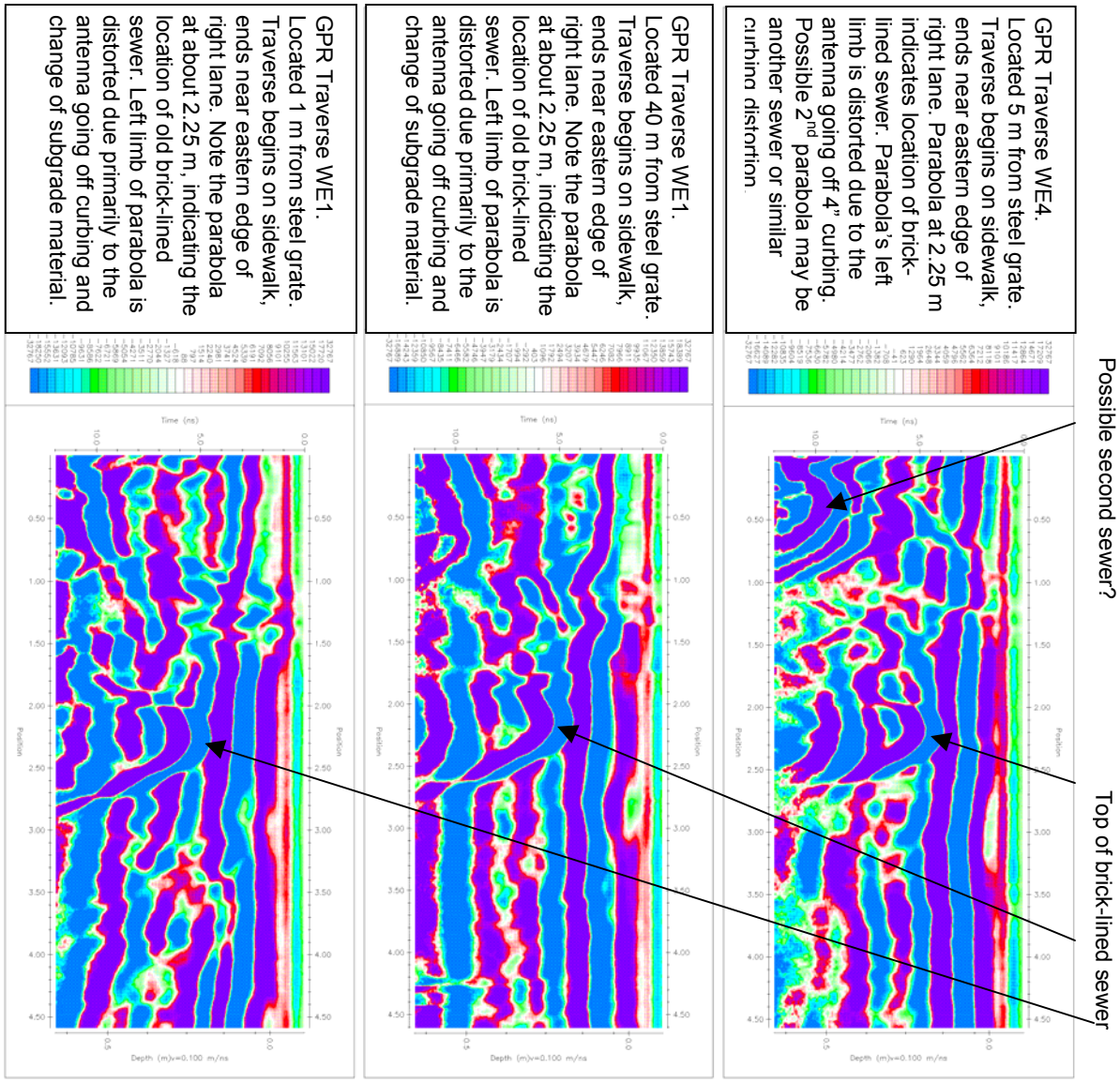

Figure 5. West to east GPR traverses 4, 5, & 6 running from atop the sidewalk to the eastern side of the right lane. Traverse 4, 5, & 6 are located 5, 2, & 1 meters from the steel grate. Arrows indicate the location of the top of the old brick-lined sewer and a possible additional sewer observed on traverse 4. Depth of sewer on these cross-sections is not precise due to the inability of the software to utilize more than one velocity for the subsurface.

Rocklin Sound Wall

GPR testing was performed on a newly constructed, cinder-block soundwall on Interstate 80 near the town of Rocklin, in an effort to evaluate possible construction deficiencies related to post-construction cracking of the wall. Construction specifications called for alternating empty cells vertically with grouted rebar strands, and placement of a horizontal, grouted bond beam through the entire wall length. The survey was done utilizing a 1200 MHz antenna.

Efforts to locate voids in grout where rebar was present were unsuccessful. Experiments performed after the survey on a test wall containing 38 mm (1.5 inch) cylindrical voids next to rebar confirmed that the strong GPR response to steel rebar masks most, if not all, of the response from possible voids. Use of predictive deconvolution to collapse to a single point the GPR "tails" that dip away from both sides of each

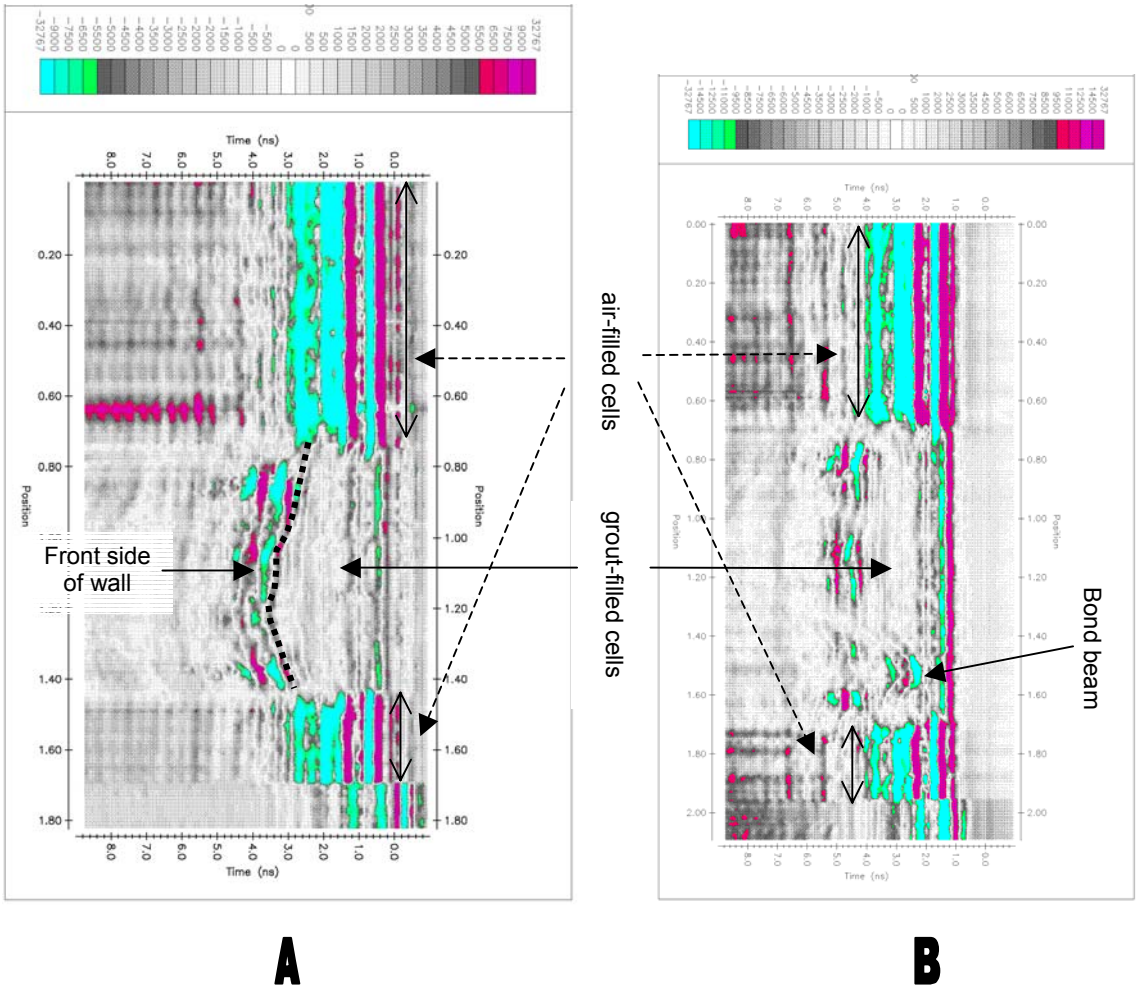

Figure 6. (A) Grout-filled cells adjacent to empty (air-filled) cells, no bond beam present. (B) Adjacent profile showing presence of bond beam within the grouted area. Reflection noted at later time in the grout-filled area is from the block/air interface at the front (freeway side) of the wall. Irregularity in that reflection is caused by architectural facing. "Ringing" in the record at late time is an artifact of the deconvolution filter applied to the data.

rebar, combined with other signal processing techniques, can assist in overcoming this problem. However, the results are still limited by geometrical constraints and the high conductivity of rebar, which greatly absorbs radar energy. In situations where the grout is thicker or the rebar is not so tightly spaced, the voids may not be entirely masked to the 1200 MHz antenna, allowing them to be at least partially discerned.

Resolution is another issue. For an air-filled void in concrete, theoretical resolution of the 1200 MHz antenna is approximately 6.25 cm (2.5 in.), which implies that while small voids may be detectable in a concrete-filled cell, voids separated by less than 6.25 cm cannot be distinguished as separate cavities.

A similar resolution and masking problem occurred behind the #19 - #22-sized vertical reinforcing bars, where the #16-rebar bond beam and grout-filled cells could not be easily recognized. This became apparent during the first day's survey; consequently, subsequent efforts to locate the bond beam focused on the empty (free of vertical rebar) cells. Bond beam detection was critically dependent on antenna orientation, with an antenna orientation perpendicular to the rebar axis maximizing detection. For the vertical reinforcement bars, orientation was less critical, although an orientation parallel to the rebar axis was found to produce the best lateral resolution. Figure 6-A shows grout-filled cells without rebar next to empty, air-filled cells on either side. No bond beam signature was apparent. Figure 6-B, recorded in the

same direction and approximately 1.5 meters away from 6A, shows grout-filled cells, again adjacent to air-filled cells. Here, however, a bond beam can be clearly seen running through the grouted cells. The results showed the amount of emplaced grout for the bond beam exceed specifications, as well as a missing bond beam in one location (figure 6A).

GPR also successfully located the vertical reinforcement bars and determined which cells were empty (air-filled).). This was achieved through careful observation of polarity reversals between reinforced cells (very high conductivity) and air-filled cells (very low conductivity). The location of rebar was independently confirmed with a metal detector, though the metal detector is not capable of the detailed resolution of GPR, nor can it distinguish between air-filled and grout-filled cells absent rebar. Zones of excess concrete were located and missing bond beam segments were detected. In addition, two potential voids in the concrete (figure 7) and an anomalous rebar signature were found.

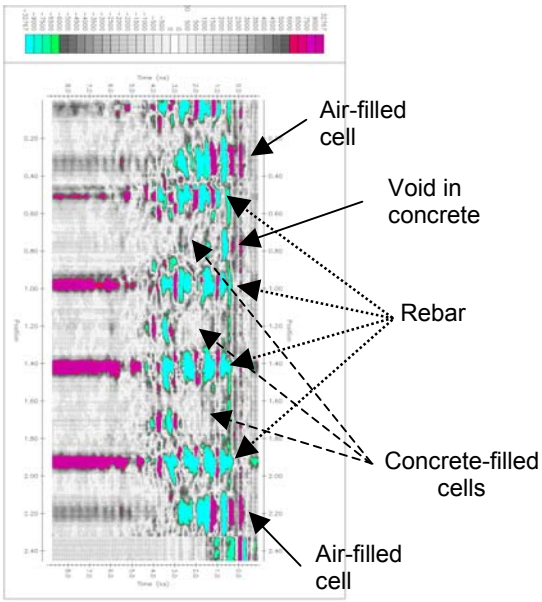

Figure 7. Grout-filled cells next to rebar. A possible void (indicated) is seen as a bleb in the otherwise reflection-free grout. Reflections visible at later time in the grouted cells are from the block/air interface at the front (freeway side) of the wall. "Ringing" in the record is an artifact of the deconvolution filter applied to the data.

Penryn Slab Investigation

A GPR survey was conducted to evaluate possible construction deficiencies of an abutment slab on Interstate Highway 80 near the town of Penryn. The survey was done with a 1200 MHz antenna. The survey lines were 3.0 meters in length, oriented east to west, perpendicular to the transverse (relative to the road) rebar and parallel to the longitudinal rebar of the upper steel reinforcing mat. The 1200 MHz survey lines were spaced about 0.12 meters apart. In order to establish a baseline, five survey lines, approximately 0.15 meters apart, were run east of the investigation site in an area believed to have been constructed correctly. A lower reinforcing mat was beyond the range of the 1200 MHz antenna. Therefore, a 450 MHz antenna was used in an attempt to image the lower reinforcing mat. Its resolution, however, was not fine enough to clearly image the deeper rebar and allow any conclusions to be made concerning the condition of the lower mat.

The survey lines obtained with the 1200 MHz antenna have an investigation depth of about 0.35 meters and provide good resolution of the transverse rebar of the upper mat. Transverse rebar of the upper mat appear as hyperbolic diffractions in the records (figure 8A). Some of the survey lines straddled the longitudinal rebar of the upper mat. Where this occurs, a high-amplitude continuous reflector from the longitudinal bar appears across the profile, with a dampened reflection from the transverse rebar. This is suspected to be responsible for the difference in the amplitude of the reflections observed between adjacent survey lines (compare figure 8A vs. figure 8B from the baseline survey).

Comparison of baseline 1200 MHz reflection records to the 1200 MHz survey reflection records indicates incorrectly positioned rebar and anomalies in the vicinity of a cold joint. The depth to the top of rebar in figure 8A (baseline profile) is approximately 0.1 m and the distance between rebar is fairly consistent. The depth to the top of rebar in the actual survey records generally varies between 0.20 and 0.25 meters, and the distance between rebar is highly variable. Numerous anomalies exist in the vicinity of the cold joint and are highlighted on some of the survey records presented in figure 9. The anomalies are areas of different electrical conductivity and may represent voids or delaminations in the structure approach slab.

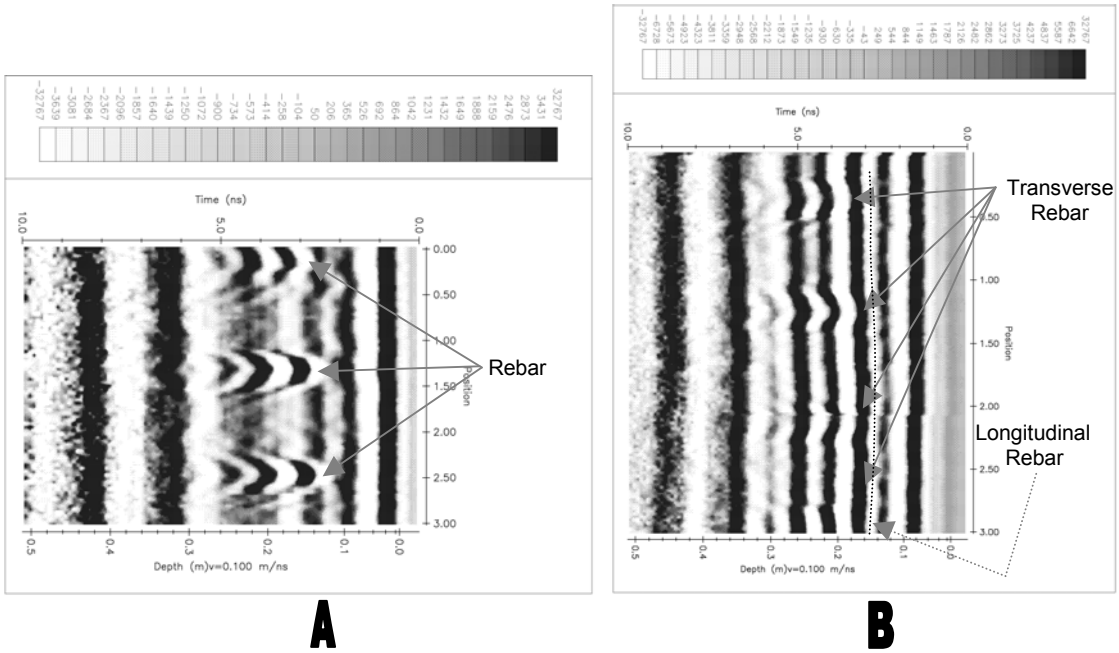

Figure 8. (A) Baseline GPR record showing transverse rebar (hyperbolas). (B) Baseline GPR record showing transverse rebar as subdued hyperbolas due to the effect of longitudinal rebar.

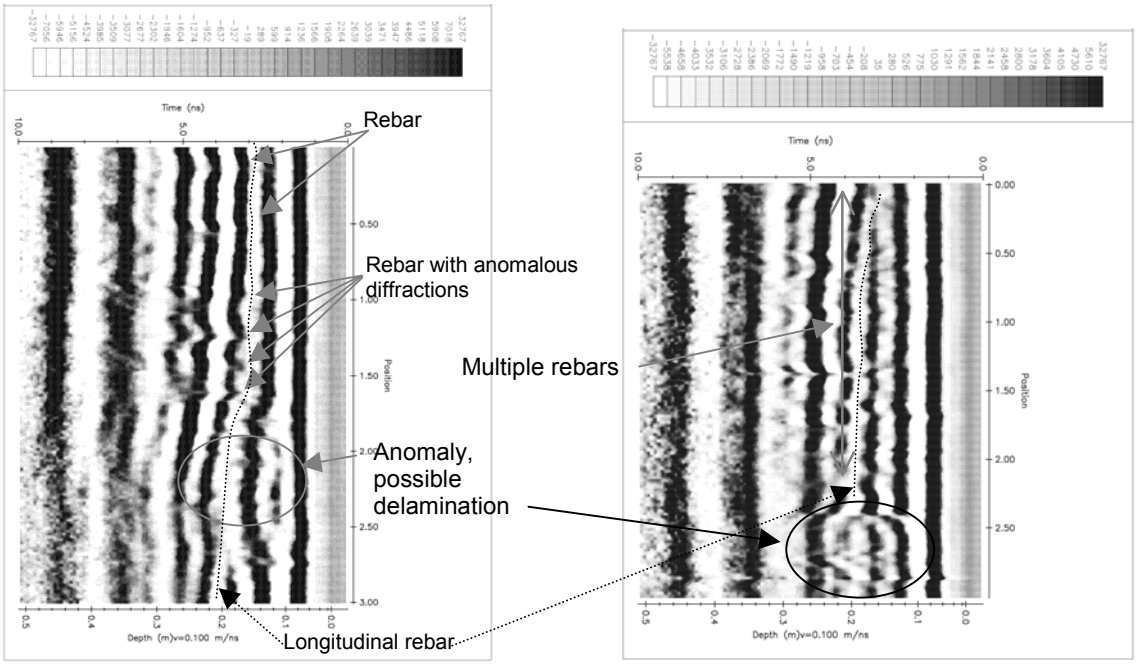

Figure 9. 1200 MHz GPR records showing transverse rebar (subdued by the longitudinal rebar) of the upper mat and possible construction deficiencies, including sloping uneven longitudinal rebar, anomalies, and possible delamination.

Summary

GPR can be highly useful in finding and delineating construction and maintenance problems related to highway structures, foundations and roadways. Like all non-destructive testing methods, GPR has its strengths and limitations. The strong GPR signature of rebar in structures, for example, can either interfere with an investigation or facilitate it (when the non-uniformity of the rebar positioning indicates construction failures, for example). Much success has been had in locating voids in various situations where the rebar is either absent or not tightly spaced. GPR is very capable of locating and delineating linear features such as rebar, pipes, culverts, sewers, and other similar objects (metallic and non-metallic) often encountered in highway investigations. GPR can often image subgrade, base, and soil stratigraphy quite efficiently, which is helpful in many roadway-related investigations.

Several things are important in the successful implementation of GPR in highway related projects. The operator/processor should have knowledge of the underlying principles of GPR and EM theory, and how they relate to earth and construction materials. A knowledge of the strengths and limitations of GPR is also essential to avoid making gross errors and to prevent the needless wasting of funds on surveys in situations where GPR is known not to work. Besides an adequate acquisition system, a fairly wide and complete suite of antennas ranging from about 50 MHz to 1200 MHz is recommended. Whenever possible, obtain sample signatures of the site conditions and correlate them to actual physical materials from the site (i.e., concrete, clay, sand, PCC, AC, etc.). Pavement corings, soil borings, trenches, roadcuts, etc., are all good sources of such correlative material.

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