A GPR SENSITIVITY ANALYSIS FOR LOCATING VARIOUS UTILITIES

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ABSTRACT

In terms of interpretability, pseudo-three dimensional (herein referred to as 3D) ground penetrating radar (GPR) data are superior to conventional two dimensional (2D) GPR data, mostly because they provide a more accurate visual image of the subsurface. Additionally, features that are too subtle to be interpreted with confidence on individual 2D profiles may appear more anomalous, and therefore more interpretable, within a 3D data volume.

In an effort to evaluate and demonstrate the relative advantages and disadvantages of 2D and 3D GPR technologies, a suite of GPR profiles were acquired across a specially constructed simulated utility test site in St. Louis Missouri. These data were processed and analyzed as conventional 2D profiles. They were also used to generate multiple 3D data volumes, with variable simulated acquisition parameters.

The 2D and 3D data were evaluated in terms of interpretability and utility. The conclusion reached is that 3D GPR imaging technologies provide for more accurate and user-friendly interpretations, and that the advantages of greater reliability and improved visualization often outweigh the increased costs associated with acquisition, processing and interpretation.

INTRODUCTION

Ground penetrating radar (GPR) technology is used regularly for locating buried utilities and Subsurface Utility Engineering (SUE). Typically, a grid of 2D GPR profiles are acquired across a study site, and processed and interpreted thereafter using conventional and well-established 2D procedures. The interpretations of each 2D profile are generally transferred onto a base map of the study site. These plan view maps are very useful inasmuch as they depict the relative spatial (lateral only) locations of the utilities, but are somewhat limited because they are only two dimensional.

Figure 1. GPR test area, pit excavation prior to placement of pipes.

Although the advantages of 3D GPR imaging technologies are well known, this approach has not been commonly used for utility detection because it has not been cost-effective. 3D GPR data are slightly more time-consuming to acquire, and until recently have been much more expensive to process and interpret, mostly because economical 3D imaging software has not been available.

Recently released versions of GPR processing software, incorporating pseudo-3D processing and interpretation capabilities, have made 3D GPR imaging much more efficient and cost-effective. In an effort to demonstrate the utility of the developing technology, a 3D GPR dataset was acquired at a test site in St. Louis. The acquisition, processing and interpretation of these data are discussed herein.

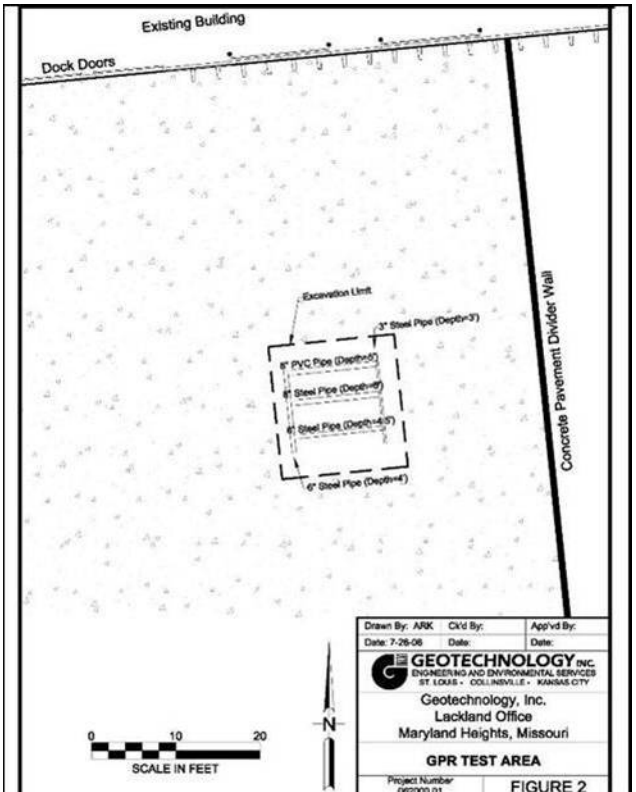

Figure 2. GPR test area layout.

The 3D GPR test area, located in western St. Louis, Missouri, is also Geotechnology Inc.'s new headquarters. During construction, simulated utilities were buried in a test area in the parking lot prior to paving. The test area was essentially a rectangular pit excavated in native soils (mainly silty clay) with dimensions of approximately 4.5 meters (15 feet) on each side, as shown in Figure 1. Five steel and one PVC pipe segments were buried at different depths (ranging from approximately 1 to 1.8 meters, or 3 to 6 feet) and orientations. A site plan showing the GPR test pit location and pipe layout is presented as Figure 2. The test area was designed to simulate real world conditions where geophysical tools may be required for utility detection. The pipe diameters were between approximately 7.6 and 20.3 centimeters (3 and 8 inches); pipes were placed at depths typically for water, gas, and drain lines. The depths were measured and the pit and pipe locations were surveyed using differential GPS. The pit was backfilled with crushed limestone gravel and the area was paved with reinforced concrete. GPR data were collected in a typical two-dimensional (2D) survey configuration (lines in both directions) such that (3D) processing could be performed using approximately 0.3, 0.6 and 1.2 meter (1, 2, and 4 foot) inter-profile spacings. Data collection parameters, including range and gains, were set in the field and remained constant throughout the entirety of the field work.

METHODOLOGY / DATA PROCESSING

GPR is a geophysical technique in which a broadband pulse of electromagnetic (EM) signal is transmitted into the ground. The signal travels through underlying materials and is partially reflected by subsurface features. The magnitudes of the reflected signals are a function of contrasts in the dielectric permittivity and conductivity of the subsurface features. Metal pipes are often characterized by visually distinguishable reflections because of the large dielectric contrast between the subgrade materials and the steel (or other material) of the pipe. The reflected signal is recorded as a function of the time required for the signal to travel down to and back from the reflecting surface (two-way travel time in nanoseconds). GPR data are generally collected along near-linear survey lines and the results are presented as 2D profiles representing a 2D time-depth (or depth) image of the subsurface beneath the survey line. Pseudo-three dimensional (3D) GPR data are generated from parallel and perpendicular 2D profiles. Typically, 2D GPR data are collected using an approximately 1.5 to 3 meter (5 to 10 foot) spacing for a utility location survey. Frequently, the data are interpreted in the field and suspect utilities are marked at this time. Alternatively, the recorded GPR files can be brought back to the office for more detailed processing and interpretation, and a map showing the locations of utilities can be generated.

The test area GPR data were collected using a Geophysical Survey Systems, Inc. SIR-3000 system and an antenna with a center frequency of 400 megahertz (MHz). Data were collected by pulling the antenna along parallel and perpendicular survey lines at a slow walking pace. Survey lines were spaced approximately 0.3 meters (1 foot) apart, and a survey wheel was used to place digital distance marks on the data for horizontal reference. The GPR survey limits extended approximately .3 meters (1 foot) to the east, 1 meter (3 feet) to the south, 2 meters (7 feet) to the north, and 1.2 meters (4 feet) to the west beyond the limits of the excavation, as shown in Figure 2.

The GPR data were processed as part of the 3D interpretation using GSSI RADAN software. Background removal, bandpass filtering, surface normalization, deconvolution, and migration were applied to the GPR data to enhance reflections and reduce background noise. The GPR profiles were coalesced to generate 3D data volumes. 3D data volumes allowed for the more accurate interpretation of laterally-continuous subsurface features.

ANALYSIS

2D Versus 3D Data. The GPR interpretations were based on the analyses of the processed 2D data profiles and 3D data volumes. Figure 3 shows representative 2D GPR profiles over anomalous features consistent with the presence of subsurface piping in both the north-south and east-west directions. The 2D data in Figure 3 are displayed in a raw format with only a surface normalization applied, which resembles the data presentation normally used for interpreting utility locations onsite. A dielectric constant value of 8 was used to convert the vertical scale from two-way traveltime in nanoseconds to depth in feet. The horizontal scale on the 2D profile represents distance along the survey line in feet, as recorded by the survey wheel. The depth to the bottom of the 2D profile is approximately 1.8 meters (6 feet). The red arrows represent interpreted pipes that would typically be marked in the field. The green dashed line represents the location of a surface joint in the pavement. As noted in Figure 3 two pipes were interpreted in the east-west profile. The north-south profile actually crosses three pipes but one was not imaged, see the bottom profile in Figure 3. The pipe not imaged was an eight inch PVC pipe at approximately 1.5 meters (5 foot) depth, and is located near 5 meters (17.5 feet) on the south to north profile.

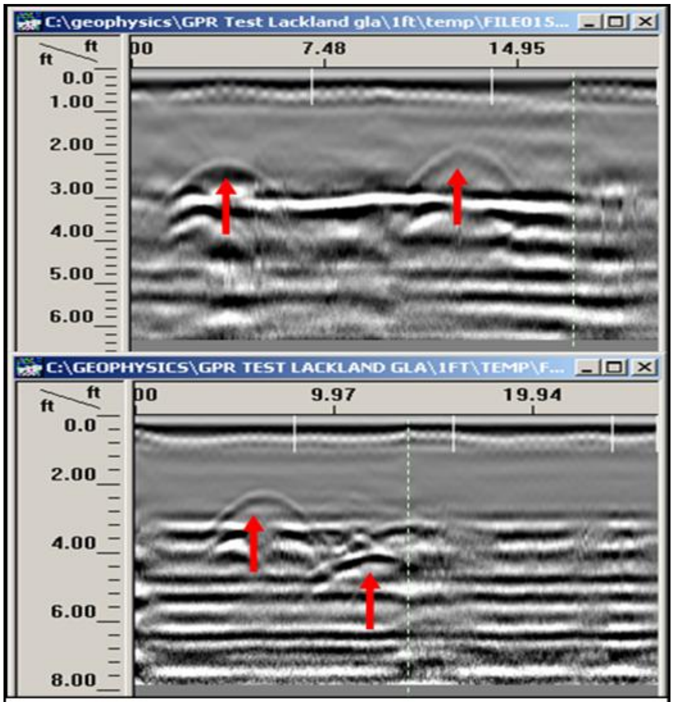

Figure 3. East to west profile crossing at 4.5 meter (15 feet) northing, Top. South to north profile crossing at 4.5 meter (15 feet) easting, Bottom.

Interpretation of 3D GPR data for identification of buried pipes involves processing the 2D profiles to enhance and collapse the hyperbolic pipe signatures into point features. The data can then be converted to a 3D data volume in depth/time slices, and linear features can be interpreted. The 3D depth slice represents a relatively thin data slice situated at a given depth. An alternate method of interpreting 3D data is to show the entire 3D cube in a transparent mode allowing only GPR reflections within a specified range of amplitudes to be viewed. The data example shown in figure 4 is a plan view (depth slice) of the 3D data. The data shown in this example were collected on an approximate 0.6 meter (2 foot) line spacing. The transparency view that best allows the pipes to be imaged differs with depth; therefore the data is presented in two parts, shallower and deeper data. The left image on Figure 4 represents the shallow depths and the right image represents the greater depths of the GPR profiles. The light colored linear objects are interpreted as pipes and are represented by red dashed lines; the green dashed lines represent the approximate location of concrete joints.

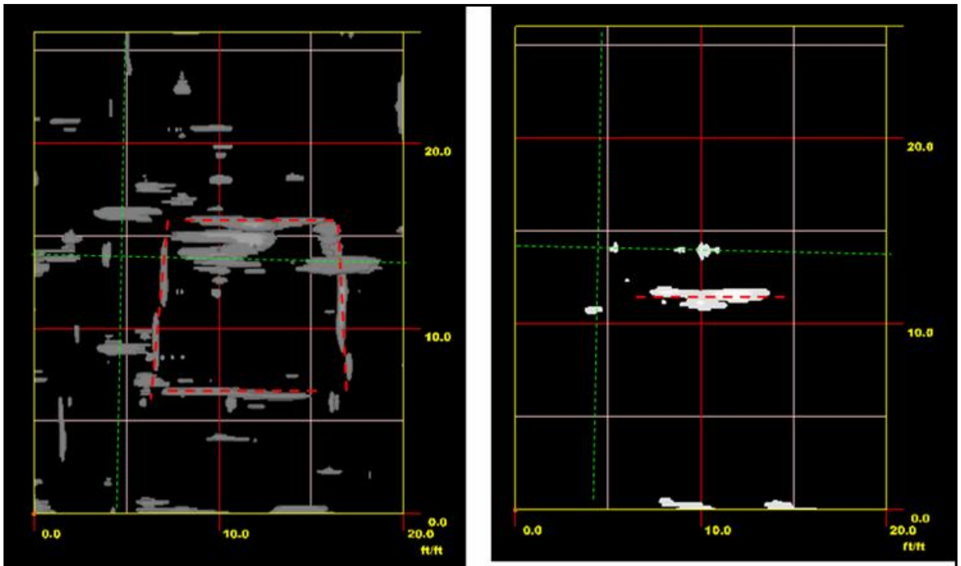

Figure 4. Left – Shallow 3D GPR interpretation. Right – Deeper 3D GPR interpretation.

3D Line Spacing Variations. One of the main advantages to using a 3D interpretation program is the benefit of viewing the dataset in its entirety. Subtle images that may have been "missed" on individual 2D profiles are often more readily identified on 3D GPR data. A main consideration in terms of the utility of 3D data is the survey line spacing. Figures 5, 6 and 7 represent 3D GPR data generated using approximately 0.3, 0.6, and 1.2 meter (1, 2 and 4 foot) survey line intervals, respectively. All three data volumes were processed using the same basic parameters, and are displayed at the same depth slice interval.

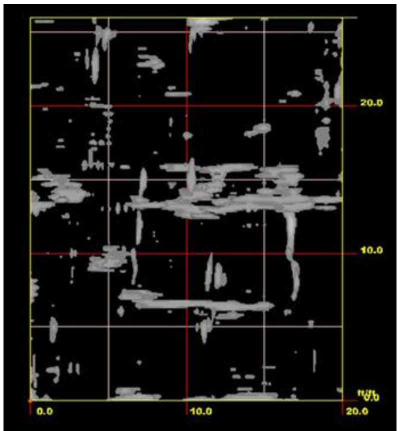

Figure 5. 3D GPR (0.3 meter or 1 foot line spacing)

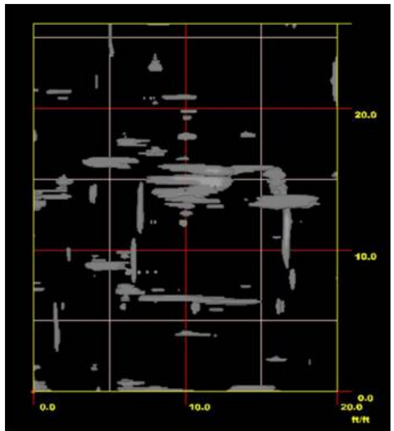

Figure 6. 3D GPR (0.6 meter or 2 foot line spacing)

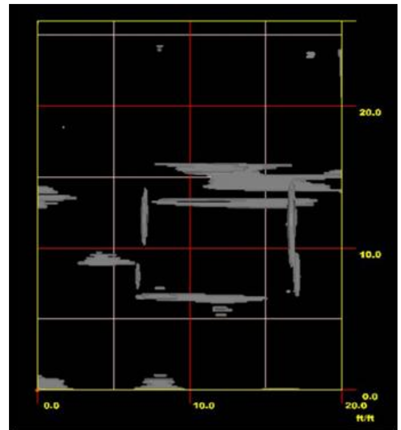

Figure 7. 3D GPR (1.2 meter or 4 foot line spacing)

The 0.3 meter (1 foot) line spacing display images more subtle features within each depth slice. Additionally, the images of the metal pipes are more continuous and the subtle image of the PVC pipe (trending east-west near 5 meter or 17 foot northing) is more easily interpreted on this data set than on the displays of Figures 6 and 7. The 0.6 meter (4 foot) spacing data display appears to be less noisy, but the known PVC pipe is not as apparent in the data. The 0.6 meter (4 foot) spacing data appear "smoother" due to the lateral summing of the higher amplitude features over larger grid nodes. These data examples only represent the shallower anomalies. It appears moisture or a change in backfill in the area between the surface joint and PVC line (approximate 4 to 5 meter or 13 to 17 foot northing) makes the interpretation of pipes more difficult, and could lead to false interpretations.

CONCLUSIONS

The primary objective of this study was to evaluate the relative utilities of 2D and 3D GPR surveying. The conclusion reached is that although the metal pipes are imaged on both the conventional 2D GPR profiles and the 3D GPR volumes, the 3D display is superior because it is more visually interpretable, accurate and user-friendly. In our opinion, the benefits of 3D GPR imaging technologies generally outweigh the additional expense associated with data acquisition and processing.

However, for increased accuracy, we encourage users to analyze both the acquired 2D profiles and the out 3D data volumes, as duplicity in interpretation provides for greater reliability.

REFERENCES

Geophysical Survey Systems, Inc., 2003, RADAN for Windows User's Manual: GSSI, North Salem, New Hampshire.