Demonstration of using crossed dipole GPR antennae for site characterization

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Abstract. Crossed dipole (cross-pole) and parallel dipole (co-pole) GPR data were acquired at an industrial site that formerly operated as a creosote wood treating facility in order to locate buried pipes and tanks or other possible contaminant-filled subsurface structures. Cross-pole data are not typically considered during GPR field studies, but proved essential for accurate site characterization at this location, as images produced using co-pole data had a poor signal to noise ratio. Data interpretations were confirmed through exploratory trenching conducted subsequent to this study. The GPR data proved successful in locating back-filled trenches that contained creosote-filled drainage tile, as well as vaults and a pit filled with pure creosote product at the site.

Introduction

Ground Penetrating Radar (GPR) is a geophysical method that is commonly used to investigate the shallow subsurface for environmental and engineering applications (Ulriksen, 1982; Olhoeft, 1986; Daniels and Roberts, 1994; Zeng and McMechan, 1997; and Arman and Daniels, 1998). Site characterization with the aid of GPR is generally accomplished through interpretation of co-pole (parallel transmit and receive antennae) field data, as cross-pole (orthogonal transmit and receive antennae) data are typically not acquired. It is important however to consider polarization when planning a GPR field survey, as the sensitivity of cross-pole and co-pole antenna arrangements are different depending on the type of target and subsurface conditions.

Cross-pole and co-pole GPR surveys were conducted at an industrial site in Marion, Ohio, prior to its remediation by the Ohio EPA and the U.S. EPA. The site has been a major concern to both agencies for the past 10 years (Ohio EPA, 1991; U.S. EPA, 1998) due to high concentrations of creosote in surficial soils. Cross-pole data produced better images than co-pole data, and were more useful for locating subsurface targets in this study.

Polarization of GPR electromagnetic fields

Polarization, the direction and magnitude of the electromagnetic field as a function of time and space, can have a significant impact on the GPR response, and is therefore important to consider during data acquisition, processing and interpretation (Roberts et al., 1992; Roberts, 1994; Roberts and Daniels, 1996). Polarization of the transmitted signal impacts how waves are scattered (reflected and diffracted) from heterogeneities in the subsurface, and the subsequent orientation of the received scattered waves. Receiving antennae are sensitive to the polarization of scattered electromagnetic waves. The target symmetry (shape and orientation) also has an impact on the polarization of a scattered wave, as do the incident angle of the wave, antenna separation, and the impedance contrast of the materials. A scattered wave can have the same polarization as the incident wave, or it can be polarized differently, in which case it is said to be "depolarized" (Beckman, 1968).

Dipole antennae, which are typically used for GPR field surveys, radiate electromagnetic waves with the electric field vector components predominantly oriented parallel to the long axis of the antenna. These waves are considered to be linearly polarized, as the direction of the electric and magnetic fields remain fixed during propagation (Kraus, 1984). The most common antenna arrangement used for GPR field studies is a co-pole configuration, where the transmit and receive antennae (and thus the electric and magnetic fields) are aligned parallel with each other. A cross-pole configuration, which is not frequently used for GPR field surveys, consists of transmit and receive antenna oriented orthogonal to one another. Both co-pole and cross-pole data were acquired in this study using a 500 MHz multi-antenna system with triangular bow-tie dipole antennae. The transmit antenna was oriented or-

![Figure 1. Multi-antenna system showing bow-tie dipole antennae used to acquire co-pole and cross-pole data.](image-url)
thogonal to the direction of traverse for both configurations, and the separation between the center of the transmit and receive antennae was 23 cm (see Figure 1).

A co-pole antenna configuration receives reflected and scattered energy that has the same polarization as the incident energy. Co-pole field data are most commonly acquired with the transmit and receive antennae oriented perpendicular to the direction of traverse. Co-pole data are sometimes acquired with the transmit and receive antennae parallel to the direction of traverse, because the orientation of an antenna that produces linearly polarized waves relative to targets influences the orientation and the amount of energy that reflects from asymmetrical targets. Metallic pipes yield strong reflections when oriented parallel to the long axis of a dipole transmit antenna in a co-pole antenna configuration, but yield weak reflections when oriented orthogonal to the transmit antenna (Daniels and Roberts, 1994). A co-pole configuration is better for imaging smooth planar features such as soil horizons or stratigraphy, as the majority of the energy yielded from these targets contains the same polarization as the incident energy.

A cross-pole configuration receives energy with a polarization that is orthogonal to the transmit antenna. A cross-pole configuration is less sensitive to smooth planar targets, and is more sensitive to targets that yield more depolarized energy, such as those with rough surfaces or those oriented asymmetrical with respect to the transmit antenna (Roberts et al., 1992).

Field and interpretation parameters

The GPR survey was conducted on a 30 by 91 meter grid just northwest of the intersection of State Route 309 and Hopland road in Marion, Ohio, with a spacing of 0.9 meters between north-south traverse lines. Near-surface geology at the site consisted of clay-rich glacial and lacustrine heterogeneous materials. Traverse lines were run in the vicinity of existing concrete pads, where tanks containing creosote previously existed. Data were acquired using the 500 MHz multi-antenna system, with a fixed number of traces recorded per distance traveled. Co-pole data were recorded with a receive antenna oriented perpendicular to the traverse direction, while cross-pole data were recorded with a receive antenna oriented parallel to the direction of traverse (see Figure 1). Data processing consisted of bandpass filtering subsequent to data acquisition to improve the signal to noise ratio by reducing high and low frequency noise. Both two-dimensional (2D) profile sections and three-dimensional (3D) volume displays/block views of the data were produced for interpretation using user-defined amplitude threshold scales that optimized the images produced.

Figure 2 shows a co-pole 2D profile line series and 3D display of the same area containing an anomaly caused by a creosote-filled pit. This figure demonstrates how this 3D visualization approach is different than using a side-by side series of 2D profile lines. A cross-pole 2D profile and 3D display depicting the same creosote-filled pit anomaly shown in Figure 2 are presented in Figure 3. The boundaries of this anomaly are clearly evident in Figure 3, from 2.5 to 7.0 meters on the distance axis and from 4.0 to 11.0 nanoseconds on the time axis, whereas the boundaries of the pit are not easily distinguishable in Figure 2. It is clear from the data in Figures 2 and 3 that the cross-pole data contained much less clutter/undesirable signals and provided superior images for identification of this anomalous feature.
Figure 3. Creosote-filled pit anomaly: (a) cross-pole 2D profile, and (b) cross-pole 3D display.

Figure 4. 2D profiles and 3D displays of anomalies caused by creosote tank pads, adjacent trenched area containing creosote-filled drainage tile, and a creosote-filled vault for cross-pole and co-pole data: (a) 2D cross-pole, (b) 3D cross-pole, (c) 2D co-pole, and (d) 3D co-pole.
Figure 4 shows cross-pole and co-pole 2D profiles and 3D displays of anomalies caused by two creosote tank pads, an adjacent back-filled trench that contained creosote-filled drainage tile, and a creosote-filled vault beneath the northernmost tank pad. Anomalies resulting from the tank pads are evident in the cross-pole data from 13 to 20 and 24 to 30 meters, and from 0 to 14 nanoseconds, with an anomalous back-filled trench area between them. It is clear from this figure that the cross-pole data again produced better images for identifying the anomalous features of interest at this field site. The anomaly caused by the creosote-filled vault beneath the northern-most tank pad (from 15 to 18 nanoseconds) is clearly evident on the cross-pole data, whereas it is not on the co-pole data. Additionally, rebar within the southern-most tank pad (from 10 to 11 nanoseconds) was imaged using the cross-pole configuration while it was not shown using a co-pole arrangement.

Conclusions

Clutter present on GPR data can make interpretation difficult. Co-pole data acquired at the site contained a high amount of clutter due to layering in surficial materials and as a result of ringing caused by excessive near-surface water saturating these materials. Because the cross-pole antenna arrangement was less sensitive than the co-pole arrangement to these sources of clutter (which yielded little depolarized energy) and more sensitive to the targets of interest that were non-planar and rough objects (which yielded more depolarized energy), images with a better signal to noise ratio were produced using the cross-pole configuration. Comparing images produced from the two different antenna orientations illustrates the potential effectiveness of acquiring cross-pole data during GPR field surveys, as depending on the study objectives and subsurface conditions, cross-pole data may increase geophysical interpretation potential.

The importance of polarization and considering the use of cross-pole data in addition to traditionally acquired co-pole data when GPR is used for site characterization has clearly been demonstrated through this study. Interpretation using cross-pole data proved valuable for locating targets of interest at this site. The locations of features interpreted from the cross-pole data were confirmed during exploratory trenching. Pipes were present where suspected at the site, and back-filled trenches were identified adjacent to the creosote tank pads as shown on the cross-pole data. Other anomalies were found to represent vaults beneath the tank pads and a pit containing pure creosote product.

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