Subsurface Imaging Using Non-Intrusive Ground Penetrating Radar

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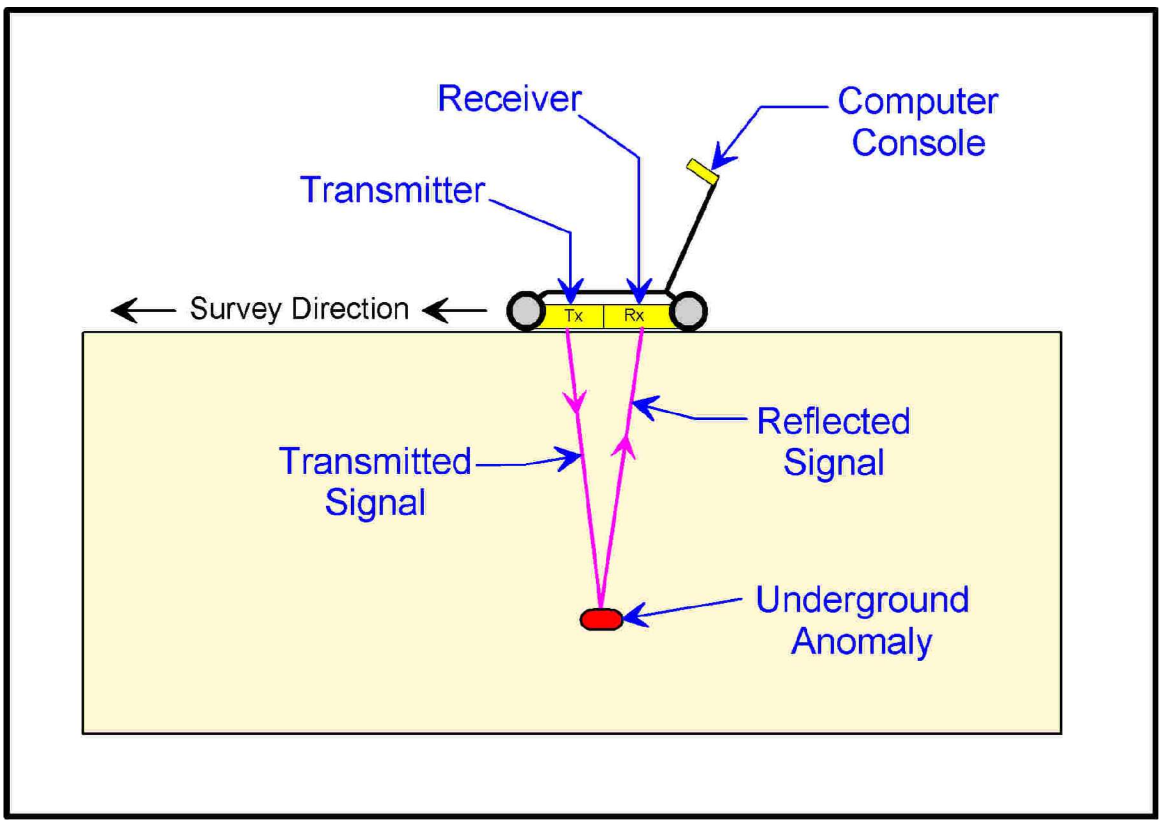
Many Cemetery operators are faced with limited space and a growing demand for burial plots. Some have chosen to install mausoleums as a mechanism to address this need. Unfortunately, documentation of plot locations can be limited on older portions of cemeteries, thus limiting development of the property. Few methods other than digging or probing can identify gravesites, except for imaging the subsurface through non-intrusive ground penetrating radar (GPR). Further, GPR is also quick and inexpensive, since approximately an acre per day can be imaged.

Ground penetrating radar is a geophysical tool that uses shallow-focus radio waves to image the shallow subsurface. GPR employs radio waves from 1 to 1,000 MHZ frequency to map structures and features buried in the ground. Radio waves were first used as a method to measure thickness of ice sheets in the Arctic and Antarctic (i.e., late 1960's). Later (i.e., late 1970's), radio waves were used in various solid earth applications. GPR consists of the radiation of radar waves downward from a transmitting antenna (Figure 1). Variations in the return signal are continuously recorded; creating a profile of the subsurface. Responses are caused by radar wave reflections from interfaces of material's different dielectric properties. Consequently, radar responds to the changes in electrical properties between soil and, for example, a drum, air pocket, or tank.



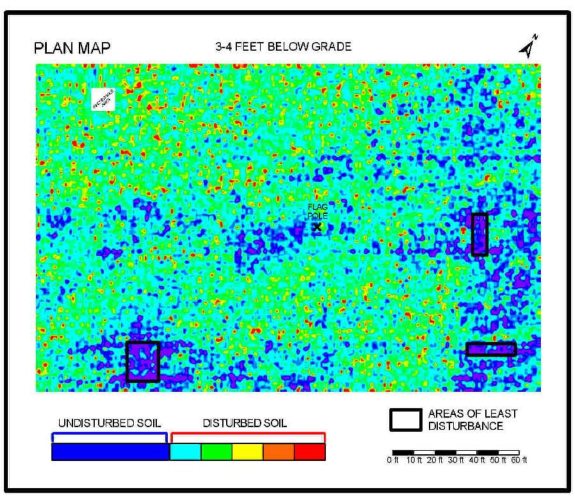
The time the radar pulse takes to travel from the transmitting antenna to the buried object is the two-way travel time and is dependent upon the dielectric properties of the media. The dielectric properties are a complex function o f the composition and moisture content of the subsurface soil and rock materials. Water and clay have higher dielectric values than common soils and rock, and thus create longer travel times. The greater the water saturations, the lower the radar velocity:

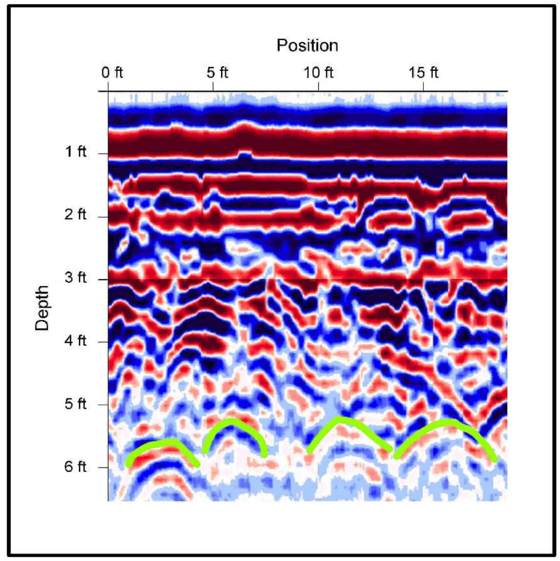
$$V_m = \frac{c}{\sqrt{\varepsilon_r}} \qquad (1)$$

Depth is calculated from the velocity, thus:

$$D = \frac{cT}{2\sqrt{\varepsilon_r}} = \frac{V_m T}{2} \qquad (1)$$

Where, $\boldsymbol{V}_m$ is the velocity of the material; ***c*** is the velocity of light, $\boldsymbol{E}_r$ is the relative dielectric constant; and T is the two-way travel time in nanoseconds (ns; 1 ns = 1 x 10^{-9} seconds). Thus, the depth of penetration is a function of the radar signal attenuation within the subsurface media. This attenuation consists of electrical, scattering and spreading losses. Consequently, the primary factor controlling electrical attenuation of the radar signal is the electrical conductivity of the soil/rock system and the



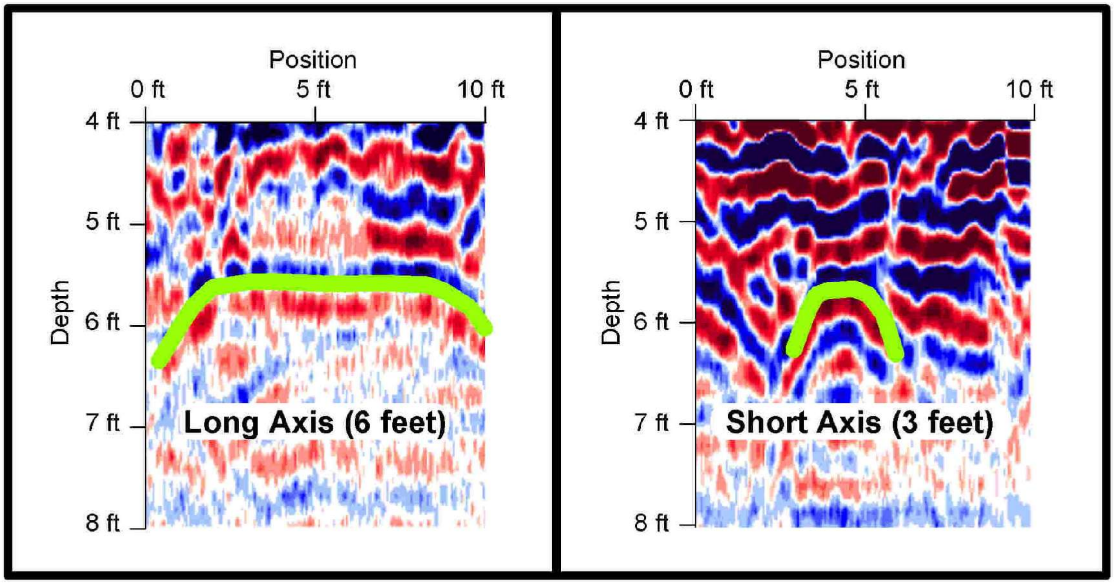


radar frequency. An increase in either the subsurface conductivity or the radar frequency will result in greater attenuation of the radar signal. High conductivities due to dissolved salts from road salt, for example, will cause strong attenuation of the radar signal.

The Allegany County Public Works Department, Cumberland, Maryland operates Allegany County Cemetery for the indigent (i.e., a Potter's Field). Records over the past one hundred years failed to show where additional space in this unmarked cemetery existed. Allegany County elected to image 2 acres of the Allegany County Cemetery using GPR to determine the location of available space.

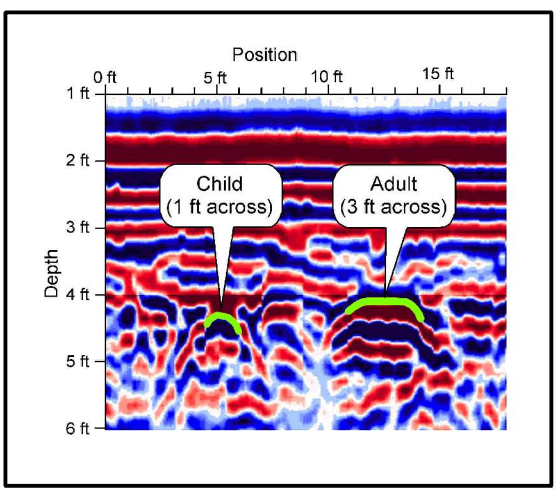
The GPR system deployed during this investigation consisted of a 250-MHZ frequency transmitter and receiver that are spatially positioned to collect reflected energy through a Pentium microprocessor computer (i.e., laptop). Data collection occurred every 0.08 feet and included a 4-stack process (i.e., increasing the signal-to-noise ratio) and a velocity of 0.1 m/s (i.e., fine grained sand and shale).

Data processing consisted of applying a gain function to increase the weak reflectors



and dampen the strong reflectors. A high pass filter (i.e., DEWOW function) was applied to eliminate the residual slow decay of the transmitter signal.

The GPR records were collected every 0.08 feet along transit lines spaced every 3 fee. The lines were collected orthogonally, roughly east-west and then north-south. This high density coverage affords the use of an average-amplitude mapping. Average amplitude mapping consists of bracketing a time (or depth) window and contouring the amplitudes (at a specific depth) to show coffins or disturbed heterogeneous soil.



An average amplitude (depth map) at 3-4 feet below grade shows that most of the area investigated has been disturbed (Figure 2). The warmer colors (red, orange, yellow, and green) show more soil disturbance, whereas the deep blue colors show little or no soil disturbance.

In addition to determining soil disturbance, GPR profiles can be used to directly image a vault, a coffin or an individual (Figure 3). Under ideal circumstances, the condition and composition of the buried object can be inferred, (i.e. Determine if it is a vault or coffin, and if it is comprised of wood, cement, or metal). GPR profiling is also useful in determining the orientation of the buried individual (Figure 4). Additionally, the depth and size of the individual can be determined and adults can be differentiated from children or babies (Figure 5).

Development of limited space on older cemeteries can pose significant technical issues since disturbing the subsurface through intrusive digging is not always a viable option. Non-intrusive ground penetrating radar can quickly and inexpensively image the subsurface to determine the location of burial plots. Ground penetrating radar is a tool that can help cemetery operators properly manage their facilities.