Ground Penetrating Radar as a Sentinel Device

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INTRODUCTION

Geophysical methods provide a non-destructive non-intrusive method of subsurface investigation. Oftentimes, however, the target is difficult to "see" due to lack of contrast between the target and background. This lack of contrast can be rectified through the use of a sentinel device. A series of sentinel devices were used in downtown Pittsburgh, Pennsylvania to determine potential subsidence beneath a building sidewalk. This sentinel strategy was performed to predict future deformation of the sidewalk and to prevent foot-traffic hazards.

The building was installed in the early 1970s and the building footprint was over-excavated to provide for the construction of the basement. Soldier piles were installed to keep the loose sand, clay and gravel deposits from collapsing into the construction area. Prior to the installation of the perimeter sidewalk, 6-inch compacted lifts of fine- to medium-grained sand were placed in the annular space between the soldier piles and the native soil. A 1-foot thick grout and 1-foot thick concrete pad were placed on the fine- to medium-grained sand and overlain with a 4-inch sand sub-base prior to the installation of the decorative granite pavers (Figure 1).

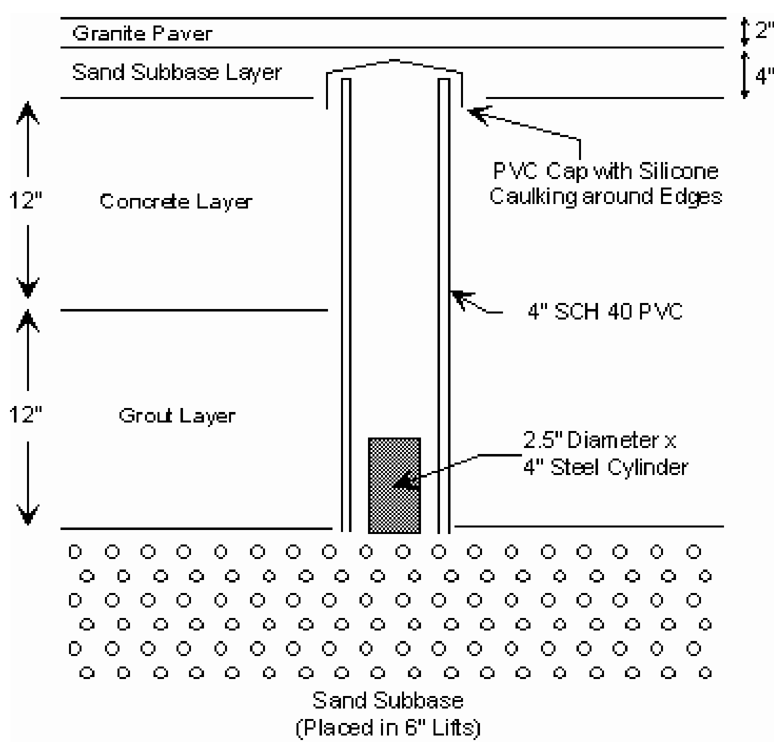

Figure 1: Profile of the sidewalk and underlying materials, showing the sentinel device for GPR detection.

Unfortunately, 15 years later the sand, cement/grout layer and pavers have subsided in many areas (Figure 2). The cost of the removal of the pavers and/or replacement of the pavers coupled with the cost of rehabilitating the subsurface was costing over $100,000 each event. Building management was keen to find a solution that would fit into a manageable budget since broken 4-ft by 5-foot granite pavers cost $4,000 to replace and the risk of injuries to pedestrian traffic was unacceptable.

Figure 2: Deformation of the expensive granite pavers due to subsidence of the fill materials (plastic scale is 1 foot).

The solution to the subsidence of the granite pavers also had to be non-destructive and not detract from the ambiance of the building and landscape. Geophysical solutions were addressed since they are non-destructive and non-intrusive investigative methods (Reynolds, 1997). Ground penetrating radar (GPR) was selected due to its ease of deployment, high-resolution subsurface imaging capabilities and ability to image through reinforced concrete (Daniels, 1996).

GROUND PENETRATING RADAR

Ground penetrating radar is used to image shallow regions of the subsurface primarily for geology, engineering, environmental science, and archeological exploration (Daniels, 1996). This survey utilized a 250 mHz GPR antenna array to image to a depth of approximately 4.5 feet below grade by transmitting radar waves (microwave band) downward from a transmitting antenna and collects the reflected energy at the receiving antenna (Figure 3). Variations in the dielectric properties of the subsurface materials are used to identify the presence of structures, voids, and changes in composition.

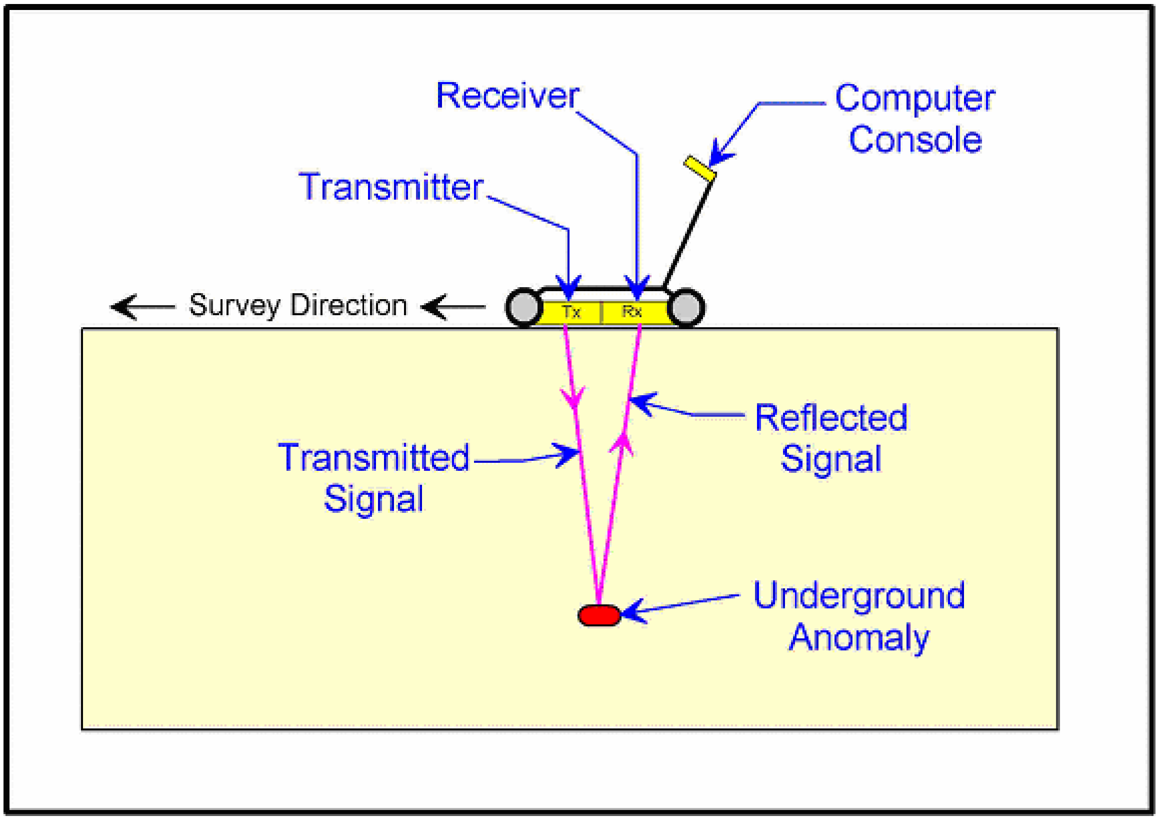

Figure 3: Schematic diagram of the ground penetrating radar system.

The dielectric properties of the subsurface determine the radar wave travel time. Materials with greater amounts of moisture increase the radar wave travel times. Consequently, dry soils and rock produce lower travel times:

$$V_m = \frac{c}{\sqrt{\mathcal{E}_r}}$$

Depth of the buried object or change in composition can be obtained from the velocity:

$$D = \frac{cT}{2\sqrt{\mathcal{E}_r}} = \frac{V_m T}{2}$$

Where, V_m is the velocity of the material; **c** is the velocity of light, $\mathcal{E}_r$ is the relative dielectric constant; and **T** is the two-way travel time in nanoseconds (ns; 1 ns = 1×10^{-9}) (Hutchinson, 2002). Attenuation of the radio waves occurs as survey depth increases and also depends on the dielectric properties of the subsurface material. Therefore, signal attenuation will occur as the conductivity of the media increases.

Velocity and time were used in order to accurately monitor the depth to the steel cylinder between measurement dates.

SENTINEL INSTALLATION

An investigation was conducted using a three-dimensional time-depth GPR mapping strategy to determine areas of potential subsidence. Fifteen areas were identified as having voids at depths associated with the loss of sand subgrade and collapse of the grout/concrete layer into the void (Figure 2). The loss of the sand subgrade may be related to poor placement of the sand or flushing of the sand from between the soldier piles and the outer wall of the former excavation. Nevertheless, these 15 areas in question were rehabilitated at great expense and building management required a sentinel strategy to minimize future cost and prevent injuries related to subsidence.

A 4-inch hole was cored through the cement/grout beds and a 4” Sch. 40 PVC pipe was grouted in place. The open-ended PVC pipe rests on the sand sub-grade and a 2.5” diameter by 4” long stainless steel bar was placed in the pipe. The depth to the top of the stainless steel bar resting on the on the sand subbase was measured. The bar then acts as a sentinel device; when the sand shifts the stainless steel bar will settle with it and GPR will be able to determine depth to the top of the bar. The pipe was capped and covered with 4 inches of the sand sub-base layer and the pavers were laid on top of the sand sub-base (Figure 1).

After completion of the installation of 44 sentinel devices in the 15 rehabilitated areas and 29 other areas along 1,000 feet of sidewalk, ground penetrating radar images were collected over the sentinels (Figure 4). The time-depth to the top of each bar was noted on the 2-way time profile from the GPR image. The velocity was determined using the measured placement depth to the top of bar and the 2-way time to the top of the bar. The velocity was recorded and will be used for each sentinel event to determine the depth to the top of each bar. An increase in the depth to the top of the bar is considered to be evidence of continued subsidence.

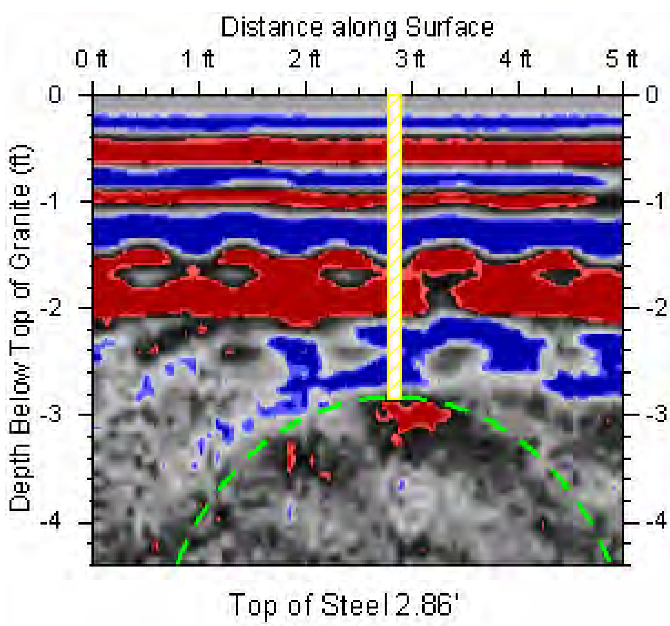

Figure 4: Ground penetrating profile image showing the diffraction pattern from the top of the solid steel cylinder.

SENTINEL MONITORING

Two years of biannual monitoring show that there have been only slight increases in the depth to the top of the bars in a few of the sentinel devices. These slight increases are assumed to be minor adjustments and not the development of a subsidence event. Nevertheless, these areas will be closely monitored in future monitoring events.

REFERENCES

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