Subsurface Utility Engineering

Home
Search
Our Mission
News / Events
The SUE Process
  Sample 'Scope of Work'
SUE Services
  3D Underground Imaging
  Utility Coordination
  Utility Design
  Ground Penetrating Radar
  Surveying & Mapping
  Global Positioning Systems
  Geo. Information Systems
  CADD
SUE Projects
SUE FAQ
Media / Press
World Markets
  USA
  Canada
  China
  Puerto Rico
  United Kingdom
Idea Submission
About TBE
Offices
Contact Us
Site Map
Career Opportunities
Bookmark This Site

Thank you for visiting the TBE Article Archives.

Achieving a More Complete View of the Subsurface with 3D Underground Imaging

ABSTRACT

Over the past several years, ground penetrating radar (GPR) systems have been developed and improved upon to enable the accurate mapping of underground utilities and other structures. Many companies now consider the use of GPR a standard process in their Subsurface Utility Engineering (SUE) investigations. Now systems have been introduced that deploy multiple GPR antennas on one platform to allow creation of 3D images of the subsurface for even more complete mapping. In addition, these 3D Radar systems have been augmented by multi-sensor electromagnetic geophysical systems to help image metallic targets. These 3D Underground Imaging systems help engineers do a better job of mapping whatever is in the subsurface by producing high data density images of the target zone. Having such data available benefits State Departments of Transportation, utility owners, and others by aiding in project design and decreasing project delays due to unknown underground structures that may otherwise be discovered only during construction. This paper describes such a 3D Underground Imaging system and then provides relevant case histories.

INTRODUCTION

Thanks to 3D Underground Imaging technology, locating and identifying underground facilities, especially in large or highly congested areas, has gotten easier recently. This technology lets the user see what lies beneath the ground in three dimensions for mapping targets such as buried utility lines, trenches, storage tanks, debris, rock formations and even voids.

When applied to utility investigations, 3D Underground Imaging adds another dimension to the locating and mapping capabilities of Subsurface Utility Engineering (SUE). In some situations, especially in areas with few anticipated underground facilities, the more conventional subsurface utility designating, locating and mapping services are all that is necessary. However, in areas with a known high volume of underground facilities, such as highly urbanized areas with multiple buried utility lines, the heavy congestion may cause conventional SUE technologies to miss some features. 3D Underground Imaging excels in these types of situations because it "sees" in three dimensions, rather than two, and provides a full view of what lies beneath.

Unlike conventional ground penetrating radar (GPR), 3D Underground Imaging incorporates a multi-sensor radar system that includes 14 GPR channels instead of just one. It collects underground data in 5.12-ft-wide swaths that are merged together to create full 3D images of the underground.

In addition to 3D Radar, 3D Underground Imaging also includes electromagnetic technology in the form of a multi-sensor Electromagnetic Induction (EMI) system, which allows for the rapid and accurate detection of conductive facilities and objects. EMI complements the 3D Radar data to enhance the overall result of a 3D Underground Imaging investigation. 3D Underground Imaging has proven to be an attractive option for characterizing the subsurface in large or complex areas.

MEASUREMENT SYSTEMS

3D Underground Imaging technology consists of a multiple sensor 3D Radar system, a multiple sensor Electromagnetic Induction (EMI) system, and state-of-the-art geophysical 3D data processing, interpretation and management software.

Multiple Sensor 3D Radar System

The 3D Underground Imaging 3D Radar system is a 14-channel, cart-based ground penetrating radar unit that is typically towed behind a vehicle during survey operations as shown in Figure 1.

The system consists of two banks of seven antennas each with a fixed spacing between each antenna module of 4.8 in (12.2 cm). Data are acquired by each of the 14 channels at a spacing of 1.0 in (2.54 cm) in the direction of travel. The complete 14- channel system is capable of imaging a 5.12 ft (1.56 m) wide data swath in a single pass and multiple survey passes are typically performed to create a three dimensional (3D) data set covering the entire project area.
The central frequency of each GPR Christopher Proulx, Gary Young 2 antenna element is 400

MHz.

The GPR system can acquire data at speeds up to 5 miles per hour (8 km per hour) across the ground surface with acquisition timing controlled by a wheel encoder. Positioning information is logged with a global positioning system (GPS) receiver or robotic tracking theodolite.

FIGURE 1 3D Radar system with dedicated tow vehicle

3D Radar data are post-processed using standard GPR algorithms such as deconvolution, frequency filtering, background removal and 3D Kirchhoff migration. Processed data are then merged with the appropriate survey data files. The multiple survey swaths, geo-referenced to the desired coordinate system, are assembled into a composite 3D data block of the project area from which buried utilities and other subsurface features are interpreted.

It should be noted, however, that although differences between conventional singlechannel GPR and Multi-channel 3D GPR are numerous, the underlying physical laws governing the propagation of electromagnetic energy pertain to both methods equally. Namely, investigation depths of 3D GPR are limited, in the same manner as conventional GPR depths are, by electrical properties of soils. Highly electrically-resistive soils (dry sands) allow for the investigation of the subsurface to depths exceeding 20 ft (6.1 m), while highly conductive soils (wet clays) may prohibit penetration to depths greater than 3-4 ft (0.91-1.22 m).

Multiple Sensor EMI System

The 3D Underground Imaging multiple sensor EMI system is a Time Domain Electromagnetic (TDEM) system consisting of three pairs of transmitter and receiver coils configured and synchronized to operate simultaneously as a single array along a survey swath. The TDEM coils are mounted on an electrically nonconductive deployment cart that is towed behind a vehicle as shown in Figure 2. The complete system is able to cover a five foot wide swath in a single pass at survey speeds up to 5 miles per hour (8 km per hour).

The coil systems are time domain-based metal detectors which detect both ferrous and non-ferrous metallic objects and other changes in electrical conductivity.

FIGURE 2 Multi-sensor EMI system with positioning hardware

The EMI system is rated to detect metals to depths of 12-14 ft (3.65-4.27 m). Each system consists of a transmitter coil which generates a pulsed primary electromagnetic field using a unipolar, rectangular current. This primary field induces secondary currents in any buried metallic objects or other subsurface, electrically conductive targets. When the primary field is shut off it begins to decay and shape of this decay curve contains information about the metal utilities and other conductors that lie within the range of the system. Two receiver coils measure the decay of the secondary EM field response using four time gates along the decay curve. Data from the four channels are contoured and placed into the 3D interpretation program for analysis.

Data Interpretation and Development of Final Product

Interpretation of the 3D GPR and EMI data sets is controlled by an operator who interfaces with leading edge 3D geophysical software that facilitates imaging of both measurement data sets and other information including as-built drawings, and provides tools for viewing and picking targets from the data set. The software also provides mathematical inversion tools for determining depths from EMI data, which are 2D data sets when collected. The operator and software record the detected target locations, depths, and orientations for merging into the final electronic maps, which are converted into standard CADD formats for compatibility with clients' internal systems. For utility applications, the most accurate and complete results are obtained by combining 3D Underground Imaging results with standard Subsurface Utility Engineering results into a finalcomprehensive utility CADD map.

3D UNDERGROUND IMAGING CASE STUDIES

Case Study #1 – 3D Radar, Power Plant Expansion, North Carolina

Introduction

A North Carolina fossil plant was faced with enacting a flue gas desulphurization retrofit program in order to comply with the latest environmental regulations. The environmental retrofit program for the 70 year-old plant was to include significant construction and excavation at the existing plant site to include the installation of several 36 in (91 cm) diameter concrete caissons to support new structures. During the early design stages of the project, the design engineers wanted to account for all known and unknown subsurface utilities as well as potential unknown underground obstacles that would negatively impact the costs and timetable of design and construction activities. Due to the age and complexity of the facility, the designers assigned high probability to the potential presence of subsurface utilities that may have been represented incorrectly on existing maps, or omitted entirely. The designers also decided that the advanced age of the plant would increase the probability that construction activities occurring on the site since the 1930's, resulting in buried underground obstacles (structures, debris), may have gone unrecorded.

Geophysical Investigation

Due to suspicions of the presence of buried underground obstacles, in addition to an array of known and unknown subsurface utilities, the designers opted to employ 3D Underground Imaging on their project, in addition to a complete SUE investigation. Considering the unknown nature of materials composing potential subsurface features, the 3D Radar technology was chosen for its ability to image all materials, regardless of electrical conductivity characteristics. The project designers selected areas for investigation totaling approximately two acres where construction activities had the potential to come into conflict with subsurface features. The study area was then subdivided into three subsections based on site logistics and data file manageability considerations. Over a three day period, virtually every accessible square foot of the study area was covered with the 3D Radar system, resulting in 81 3D Radar data swaths. In comparison, in order to achieve similar data densities through a conventional single-channel GPR investigation, more than 1100 GPR transects would have been required.

Real-time positioning of the 3D Radar antenna arrays during data collection, as well as the accurate positioning of corresponding subsurface features interpreted through data postprocessingand analysis, was acquired through the use of a differentially-corrected GPS (DGPS) system, achieving sub-decimeter (3.93 in) horizontal accuracy. Following field data collection activities, the GPR data were processed with RADAN Version 6.0 from Geophysical Survey Systems, Inc. (GSSI) using standard algorithms. The processing filters applied to all data were background removal, range gain adjustment, deconvolution to remove multiple reflections, stacking, and band-pass filtering. Through this digital filtering process, near surface features and deeper targets become more readily apparent in the data set. Velocity analysis was also performed on several of the GPR data sets to better determine the dielectric constant of the subsurface soils and ultimately a more accurate estimate of the target depths. After processing the individual data files, the GPR swaths were assembled into several 3D Radar data blocks representing the surveyed areas. Interpretation of the 3D data set allows slices to be made down through the data block with respect to time (depth). In this manner, the linear trends representing buried utilities and other features may be illuminated to gain an understanding of their shape, amplitude, depth, location and orientation. Interpreted target locations and depths were determined directly from the 3D data set, recorded, and transferred to project drawing files.

Results

Analysis of 3D Radar data blocks yielded the identification of approximately 120 distinct subsurface features. The majority of these features coincided with utility location information garnered through the SUE investigation and/or plant utility plans. However, several additional previously unknown targets were identified as well. Figure 3 illustrates the phenomenon through which features are illuminated and interpreted at varying depths within each 3D Radar data block.

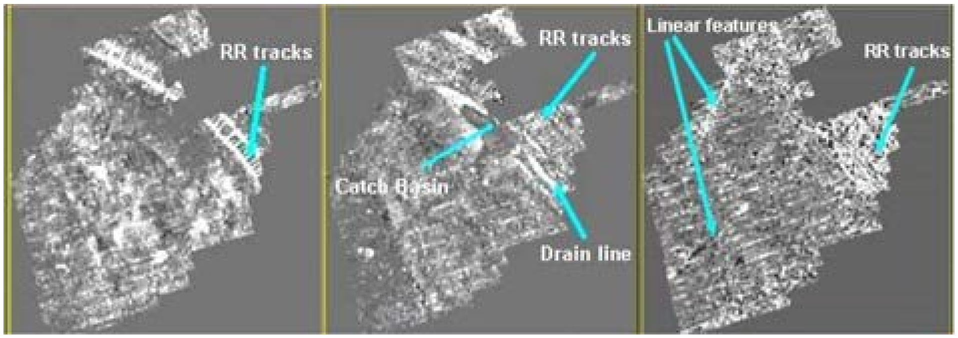

FIGURE 3 Series of depth slices from a 3D Radar data block to illustrate how targets appear and disappear as slices of varying depth are viewed. (A) Plan view section of GPR data taken at a slice 8 inches below ground surface in. At this shallow depth, the only features that can be identified are the surface railroad tracks and ties. (B) Depth slice taken at 15 inches depth. The

railroad tracks are less distinct, but a feature interpreted as a drain and catch basin are now visible. (C) Depth slice at a depth of 33 inches. In this view, deeper linear features that may correspond to buried utilities can be seen.

Of significant importance to the designers of the plant expansion was the identification of several unknown utilities and areas of buried reinforced concrete, buried rebar, and buried railroad ties that coincided with the preliminary design locations of several of the 36 in (91 cm) concrete caissons. After receiving CADD drawings with accurately positioned subsurface features interpreted from the 3D Radar data, the designers were able to decide in which areas they would amend their initial design based on the new subsurface information, and in which areas they would maintain their initial design and remove the subsurface debris at select conflict points. In either scenario, the 3D Radar information aided the designers in a decision-making process that would ultimately increase the probability of avoiding unexpected redesigns and/or significant construction delays.

Case Study #2 – 3D Radar, Sewer Line Elevation Profiling, Florida

Introduction

A local engineer consulting with a Florida city was tasked with the rehabilitation of a 16-inch diameter ductile iron sanitary force main that was experiencing significant corrosion and subsequent failure at certain locations throughout a 1000 ft (305 m) length of pipeline. The engineer and city officials had reason to believe that localized high points in the pipe caused by sudden changes in the pipe elevation (slope) were trapping sewer gases against the pipe wall in small pockets. Over time, the gases within these pockets were interacting with the pipe wall and causing accelerated corrosion, which when left unchecked, was contributing to localized failure of the pipeline. In order to prevent future pipe failures related to this phenomenon, the “high points” needed to be identified and these sections of pipe replaced with straight sections.

Geophysical Investigation

3D Underground Imaging was chosen to be employed on this project due to the ability of the 3D Radar system to cover a 5.12 ft (1.56 m) wide swath in one pass, as well as its capability of tracking the position of the radar system (and subsequent GPR data) to survey-grade tolerances in both the horizontal and vertical dimensions.

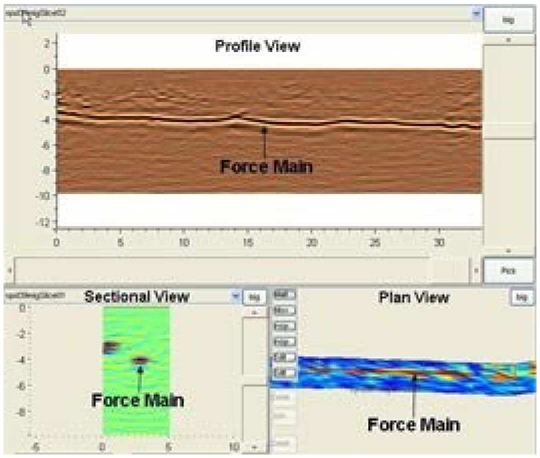

FIGURE 4 3D data screen that was analyzed as part of the utility elevation profiling.

Prior to the field data collection phase, the horizontal location of the force main was approximated on the ground surface throughout the length of the proposed project. In addition, survey control was established in the study area to enable survey-grade positioning of the 3D Radar system during data collection.

Field data collection consisted of a single 3D Radar data swath centered over the approximate horizontal position of the force main, requiring less than one day to complete. The real-time position of the 3D Radar system was tracked and recorded automatically during data collection using a robotic survey total station. This enabled each of the 168,000 GPR data points along this 1,000 ft (305 m) data swath to be positioned to surveygrade accuracy on the local survey datum provided by the city.

Results

By tracking a survey prism mounted at a fixed point on the 3D Radar system, the robotic total station was able to produce an accurate survey (elevation profile) of the ground surface over the entire length of the 3D Radar data swath. In order to calculate the depth to the force main, a radar velocity analysis was performed and a representative dielectric constant was assigned to the subsurface soils.

Depth values (below ground surface) of the force main were then converted to elevations by comparing them to the elevation profile of the ground surface. A profile plot of elevations of the force main was then produced, allowing the client to analyze the actual profile of the force main for sudden slope changes.

Following analysis of the force main elevation profile, those sections of pipe experiencing sudden slope changes were selected for further ground-truthing and eventual rehabilitation.

Case Study #3 – 3D Radar/EMI, Airport Expansion, New Jersey

Introduction

In order to extend runways as part of a minor airport expansion, project designers required utilities beneath an adjacent roadway to be accurately mapped for their eventual removal or replacement during construction efforts. The locations of at least four utilities were known to exist in the affected area.

Geophysical Investigation

In addition to a standard Subsurface Utility Engineering investigation, the designers opted to employ 3D Underground Imaging to supply them with the most comprehensive and accurate subsurface information available.

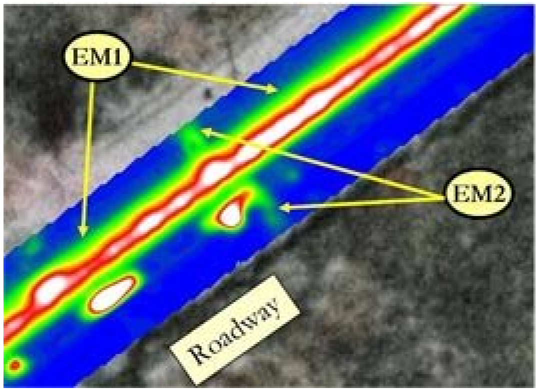

FIGURE 5 EMI contour map overlaying site aerial imagery that illustrates a strongly conductive linear feature (EM1) interpreted to be a gas main and a weakly conductive unknown crossing feature (EM2). The two white ovals represent passing automobiles.

3D Radar and EMI survey swaths were conducted along the approximately 1,000 ft (305 m) section along the road to be moved as well as along a walking path adjacent to the roadway. In the roadway, the ability to collect data at significant speeds allowed for data swaths to be acquired with the flow of traffic in the appropriate travel lanes. This resulted in minor disruption of normal traffic patterns as travel lanes were not required to be shut during data collection. The 3D Underground Imaging survey resulted in approximately one acre of coverage within the study area. It is noted that the amount of data acquired with the 3D Radar system during the four hours required to perform the study is equivalent to 336 individual GPR transects with a conventional singlechannel GPR system

Following data collection, both sets of 3D Underground Imaging data were interfaced with DGPS data and adjusted to appropriate state plane coordinates.

Results

Results of the 3D Underground Imaging investigation generally agreed with available published utility information and SUE results. The lone feature discovered solely through the 3D Underground Imaging investigation was a small diameter utility crossing the roadway, as evident in the EMI contour map shown in Figure 5. Interestingly, this feature was not accounted for in the 3D Radar dataset, indicating that the feature was either too small to be imaged or was located at a depth greater than the maximum radar penetration depth. Project designers were able to use the utility information in the resulting CADD utility plans to proceed confidently in their overall project design.

CONCLUSION

3D Underground Imaging represents a major evolution in the application of geophysical technologies for the underground mapping of utilities and structures.

3D Underground Imaging employs a 14-channel 3D Radar system, a multi-sensor Electromagnetic Induction system, accurate real-time positioning systems, and leading edge geophysical data management software to collect high density geophysical data and create three dimensional depictions of subsurface environments which are more accurate and comprehensive than those created with traditional two dimensional technologies.

Whether employed as a complement to a comprehensive Subsurface Utility Engineering investigation, or utilized as a stand-alone method to image other subsurface objects or features in large or complex areas, 3D Underground Imaging is proving to be a valuable tool in the quest for subsurface characterization.

The application of 3D Underground Imaging to the pre-design phase of a project can enhance the accuracy of project designs and cost estimates and help to streamline construction by using all three dimensions to capture as much of the total underground picture as possible.

Credits

Author(s)
Christopher R. Proulx
Gary N. Young, P.G.

Submitted To:
Transportation Research Board
Utilities Committee

Read Another Article

Proactive Utilities Management: Conflict Analysis and Subsurface Utility Engineering

Plaguing the overwhelming number of projects dedicated to servicing and updating the nation’s aging and increasingly congested infrastructure, the seemingly unavoidable delays due to utility complications continue to retard progress and emaciate already tight budgets.
Read Full Article

More Articles
- Following GDOT’s SUE Subconsultant Process
- Subsurface Utility Engineering: A common language we can all understand and use.
- Full price costing is vital to restore and maintain our infrastructure