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GPR: Past, Present and Future

The continued evolution of ground penetrating radar as a tool for the detection of subsurface infrastructure.

The continuous increase in American consumers' demand for additional utility services, coupled with the depletion of available subsurface space in the United States' rights of way due to the constant addition of new subsurface infrastructure, demands that methods and technologies capable of mapping and assessing this infrastructure become more and more commonplace in the trenchless technology industry.

Ground penetrating radar (GPR) is a technology gaining greater popularity in the trenchless industry due to its ability to quickly, accurately and non-invasively "peer" into the subsurface and detect utilities and other facilities, composed of any material.

GPR is most often applied to the trenchless technology industry through the application of Subsurface Utility Engineering (SUE), the process of accurately locating and mapping the three-dimensional positions of subsurface utilities. A common application of GPR as part of this process is the identification of conflicting, non-metallic utilities unable to be identified with other electromagnetic methods.

This technology, however, can also be applied to a variety of additional applications related to the trenchless industry such as the identification of unconsolidated soils or void space along an HDD path, the assessment of large diameter facilities and the identification of underground storage tanks (USTs), to name a few.

GPR History

The first published use of GPR technology was recorded in the late 1920s when an Austrian geoscientist attempted to determine the thickness of an Arctic ice sheet. But it was not until nearly five decades later, in the 1970s, that a commercially produced GRP system was made available for non-government use. Early systems were bulky, cumbersome, non-portable units consisting of large antennas and computer processors connected to each other through an array of long cables.

Raw analog GPR data, in the form of wiggle traces were either stored on a hard drive or printer directly onto paper printouts. In either scenario, real-time data interpretation was not a possibility and decisions could not be formulated at the time of data collection. Accurate interpretation of the data required extensive post-processing of the data files.

Due to limitations imposed by the design of these early commercial GPR systems, GPR technology was used almost exclusively by geoscientists for applications such as ice thickness measurements, water table mapping, fracture detection in bedrock outcrops, bedrock fault zone detection, sinkhole detection and other applications that focused on determining shallow soil or rock characteristics.

The onset of the 1990s saw rapid technological advancement in the design of both GPR hardware and software. Developments like greater processing power, smaller size, simpler and more functional software and the use of fiber-optic cables al contributed to the application of the GPR method to other near surface functions in the engineering and environmental realms.

A significant development in the design of the GPR antenna was a major contributor to the acceptance of GPR technology. The development of the shielded antenna, through which most of the emitted energy is focused into the medium being studied, has made possible the use of GPR in areas possessing high levels of surface interference, such as trees, buildings, automobiles, people, etc. Unshielded antennas, the prevalent antenna available until the last decade or so, emit and receive radar energy to/from all directions, rendering data acquired in high interference areas difficult to interpret due to the presence of reflection from both surface and subsurface objects. Thus, past GPR investigations took place in fields or open areas and centered on the collection of geologic data. The development of the shielded antenna enabled the collection of data in all areas regardless of surface clutter, including locations such as rights of way, forests, parking lots, and even building interiors.

With current real-time digital GPR systems, processed digital data are collected and immediately displayed on digital video displays (such as laptop computers), rendering real-time field decisions commonplace. Additionally, while allowing for on-the-spot decision-making capabilities, current GPR systems still allow for advanced post-processing techniques, including 3-D rendering in some cases.

Current state-of-the-art GPR systems have evolved into compact, reliable, user-friendly instruments able to operate from start to finish by a well trained, technically experienced individual. Depending on the specific model and manufacturer, most current systems allow a user to acquire and interpret large amounts of subsurface data in a relatively short amount of time, as well as the ability to transfer corresponding findings to the ground in real time with a high degree of confidence.

The most recent developments from the GPR manufacturers center around specifically meeting the needs of utility locate professionals. These latest offerings are cart-based systems with easy-to-follow software flows and automated settings requiring minimal input to collect data. They include integrated weather-resistant monitors and antennas and enable the user to scan areas rapidly and mark utilities without data storage or further data processing.

How Does it Work?

The prospect of an array of limitations presented at project sites requires that a GPR operator possess the maximum amount of information about that site prior to proceeding with a GPR investigation.

Ground penetrating radar is a wave-based, electromagnetic, geophysical method and fundamentally detects interfaces between subsurface materials possessing varying electrical (dielectric) characteristics. A typical digital GPR system consists of transmitting and receiving antenna elements, a central control unit, and a field-ruggedized video display.

A GPR system operates by emitting electromagnetic radar impulses into the ground or other media at a high repetition rate, from an antenna array towed or pushed along the ground surface. Subsurface reflections occur at interfaces of materials with differing electrical characteristics (dielectric permittivities). Reflections of various amplitudes are produced at these subsurface interfaces and are detected by the receiving antenna element, depending on the incoming signal frequency and the magnitude of the difference in dielectric constants of the two materials. This information is fed back to the control unit where it is processed and transferred to a hard drive and a video display that produces a graphical representation of the acquired data as a continuous, two-dimension depth profile.

Common subsurface reflectors detected by GPR are: 1) natural conditions such as soil horizons, geologic bedding or foliation, void space, sink holes and water saturation level (freshwater and saltwater); 2) anthropomorphic conditions such as grave sites, disturbed (low density) soil, soil backfilled areas, buried facilities (utilities and tanks), as well as other buried objects that differ electrically from surrounding materials.

Suitability

A typical digital GPR system consists of transmitting and receiving antenna elements, a central control unit and a field-ruggedized video display.

Ground penetrating radar is a powerful remote-sensing tool when favor surface conditions are present. However, as with any non-invasive geophysical instrument that attempts to "see" beneath the surface, GRP is subject to specific limitations due to soil conditions, weather conditions and subsurface target characteristics.

The primary limiting factor of a GPR study is the maximum attainable depth of investigation. The phenomenon of signal attenuation (absorption) is the most pervasive factor affecting the depths to which radar energy will penetrate and is determined by the electrical properties of subsurface materials. Highly conductive/low resistive materials, such as saturated clays and saline soils, possess the highest attenuation characteristics and are not favorable for significant radar energy penetration. Soil conductivities, and thus the ineffectiveness of GPR, increase with elevated soil saturation levels, clay content and salt concentration. Signal attenuation however, is minimal in low conductive/highly resistive materials, such as dry quartz sand, bedrock and ice. These highly resistive materials allow the passage of radar energy and result in the study of subsurface phenomena at significant depths.

Transmitting frequencies also have an impact on the depth to which radar energy will penetrate. Generally, the depth of investigation increases as the transmitting frequency decreases. Consequently, the resolution of subsurface reflectors also decreases as the transmitting frequency decreases. Furthermore, due to the phenomenon of geometric spreading of transmitted energy, as depth increases, the minimum size necessary for a feature to be detected must also increase.

In essence, low frequency antennas, such as those emitting a central frequency 100 MHz or 250 MHz, have the ability to penetrate to significant depths in favorable soils. These low-frequency antennas, however, are not able to image subsurface reflectors with very high resolution, thus complicating data interpretation. Higher frequency antennas, such as those emitting a central frequency of 500 MHz or 800 MHz, will penetrate to much shallower depths, but will image subsurface reflectors with much higher resolution than their lower frequency counterparts.

GPR Users

The prospect of the array of limitations present at all project sites requires that a GPR operator possess the maximum amount of information about that project site before proceeding with a GPR investigation. By synthesizing geologic, climatic and target-specific information prior to the performance of a GPR investigation, a qualified individual will increase his/her chances of making effective decisions regarding survey design, frequency selection, realistic depth penetration expectations and data interpretation.

For those reasons, an experienced geologist or geophysicist with a working knowledge of the targeted subsurface area is the most qualified individual to perform an effective GPR investigation at most sites. This person will best minimize ambiguities associated with GPR data acquisition and interpretation, as well as more full understand results of an investigation within the bounds of the site limitations.

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