Ground Penetrating Radar for the Land Surveyor

Joseph D. Fenicle, PS

12.12.08

Introduction

While driving home from a meeting for Michigan Remonumentation I began to day dream about Ground Penetrating Radar (GPR) and its application to land surveying. See, a few days prior I was watching a rerun of CSI: NY titled *Run Silent, Run Deep*, and the main detective was utilizing GPR to search for human remains under the turf at Giants Stadium in East Rutherford, New Jersey. This was an obvious work of fiction by Jerry Bruckheimer and the folks at CBS, but the application was real and human remains have been searched for and found with GPR in a real world forensic application. The CSI episode brought me back a few years when in early 2004 the guys at *Mythbusters* on the Discovery Channel actually ran an episode that included GPR and the search for human remains. They were trying to prove or disprove the urban legend about Jimmy Hoffa, ironically, being buried under the same Stadium in New Jersey. To test the equipment they buried two pig carcasses under a concrete sidewalk and consequently locating them with the GPR. Then they actually went to the football field and ran the GPR equipment along the end zone and other areas of the field, to see if they could find Hoffa's remains. The search proved inconclusive and the Myth was busted, but even back then it made my mind spin of GPR and its application to land surveying and its search for land corners that have been deemed lost or obliterated when they are truly existent. This technology will make any surveyor contemplate before ever setting another corner based on single or double proportionate measurement.

To prove GPR had a connection to land surveying, I contacted Ground Penetrating Radar Systems (GPRS) of Sylvania, Ohio. They agreed to meet with me and perform a demonstration of their equipment and its application to corner recovery and the various other functions of our County Engineers Office. John Kessinger, Regional Director of GPRS brought out some of his equipment and showed us its various applications to land surveying and beyond.

Real World Applications for GPR (Land Surveying and Beyond)

According to Gary Olhoeft, Professor of Geophysics, Colorado School of Mines "The first ground penetrating radar survey was performed in Austria in 1929 to sound the depth of a glacier". GPR was also used over forty years ago by the Atomic Energy Commission and has since evolved to a place never before imagined. Originally used by scientists, it is now used by technicians and land surveyors alike to identify and locate features under the earth's surface in a variety of applications. Mainly used for scanning concrete and locating underground utilities the applications of GPR are almost up to the imagination of the user. In additional to concrete and utilities, GPR is also used for road and bridge inspection, geology and archaeology, environmental assessment surveys, ice and snow depth surveys, forestry, mining, forensics, military and countless other applications. This includes searching for non ferrous or magnetic survey monuments as buried beneath the earth's surface.

Some of the more popular applications of GPR are when it was used to measure the thickness of the ice road used by the semi trucks on the History Channel show *Ice Road Truckers*. This again is a real world application as the thickness of the ice is critical to the delivery of supplies to the diamond mines. As previously stated, GPR is one of the most important tools in forensic, underground, investigation. Representatives from John's company, GPRS, volunteered their time to go to Aruba in 2004 and search for the remains of the highly publicized Natalie Holloway case. The search was futile.

According to John, 75% of their work, nationwide, is dealing with concrete and finding its associated properties like rebar spacing, buried conduit and post tensioning cables. John went on to say that about 15% of his work is dealing with environmental issues like buried tanks and dumpsites. The other 10% is split between 1% in forensics and 9% in miscellaneous like geological and archeological explorations. This deals with everything from finding the depth to bedrock to searching for hidden treasures.

While John was in our office he ran his equipment right in our conference room. He showed us with precision and accuracy where the heating ducts were, horizontally and vertically, and the thickness of the concrete slab itself. He could even tell us if the duct material was metallic or not. This was interesting to see, but I wanted to see if the GPR could locate a culvert pipe or most importantly, a lost survey stone from the mid 1800's.

Anomalies

I set up a mock scenario for John to test the GPR equipment on. I wanted to see if the equipment was really everything I have been reading about and seeing on TV. In June of 2008, due to road construction, I exposed a corner stone on one of our County Roads. I had solid reference ties and GPS coordinates to aid in its recovery, as shown in Figure 1. After excavation, I noted the top of the stone to be 18 inches below the existing pavement. Later in the construction season the road was reclaimed and resurfaced and I re-measured the elevation to the top of the pavement in which the stone was under, still being 18 inches deep. John set up his GPR equipment, a SIR-3000 with a 400 MHz antenna by Geophysical Survey Systems, Inc. (GSSI) of Salem, New Hampshire. Being unfamiliar with survey monuments, I explained the approximate dimensions of a typical stone and let him search. He ran a grid approximately one foot apart back and forth over the search area. Sure enough, as figure 2 shows, he had a hit on his screen that was unmistakably a large object under the road. He turned his search grid by 90 degrees and continued his search. He wanted to figure out it was a long object or an isolated object. It was indeed an isolated object and it was the stone I wanted him to find. He hit the horizontal location right on the head and his depth to my measured 18" was within an inch or so. John proved himself and his equipment seemed fairly simple to use and the results seemed fairly easy to analyze with some experience.

The equipment that was going to rip up the old asphalt and road base was going to a depth of 15 inches. We had to hand dig the stone to verify it would not get hit by the mill. The excavation took approximately half a day, not to include the sore muscles and associated blisters. What took us half a day, John and his GPR equipment performed in less than five minutes.

John went on to test the equipment on a new crossover with a 12" PVC pipe. We knew where the pipe was, but I wanted to see what the screen looked like when the radar found an anomaly. Any anomaly shows up on the screen with a horizontal and vertical position, just like the stone did. John was easily able to locate the pipe and even the location of the stone backfill where the crossover was installed. Once again the vertical distance from the road surface to the top of the pipe was measured within an inch or so. Figure 3 shows a screen shot of the 12" PVC pipe crossover at a depth of approximately thirty inches. You can also see the stone backfill in the trench. At our office we have to recovery many old drain tiles across fields and I wanted to test the GPR to see how well it worked in this application. It performed without a flaw.

GPR and how it Works

GPR was originally explained to me as a sophisticated and super expensive fish finder. Where a fish finder utilizes sonar (sound navigation and ranging), GPR utilizes radar. Sonar sends out acoustic waves whereas radar sends out electromagnetic waves. Then, not to confuse the issue, there are our laser scanners which use lidar (light detection and ranging). GPR sends radar into the ground at varying frequencies as limited by the United States Federal Communications Commission (FCC). Unlike sonar and lidar, the FCC states that "…GPRs operate only when in contact with or within close proximity of, the ground for the purpose of detecting or obtaining the images or buried objects". The FCC continues to states that "The energy from the GPR is intentionally directed down into the ground for this purpose. Operation is restricted to law enforcement, fire and rescue organizations, to scientific research institutions, to commercial mining companies, and to construction companies".

The benefit behind GPR is that it is completely harmless and environmentally friendly. A blogger back in 2006 wrote on RPLS.com that "I hear being around those high energy units for more than a few seconds makes you sterile, hard of hearing and your eyes cross". He may have been joking and in reality it is the farthest thing from the truth. There is no radiation involved and the only side effect is that you can't use your cell phone while operating the equipment. In fact GSSI states that "…it is extremely safe and emits roughly 1% of the power of a cellular phone signal". According to GSSI, "GPR works by sending a tiny pulse of energy into a material via an antenna. An integrated computer records the strength and time required for the return of any reflected signals. Subsurface variations will create reflections that are picked up by the system and stored on digital media. These reflections are produced by a variety of material such as geological structure differences and man-made objects like pipes and wire".

GPR Accuracy, Limitations and Associated Costs

The GPR unit from GSSI had a clicker on the wheel, much like a clicker on a typical survey measuring wheel. The unit maps the data by creating a series of baselines and plotting the location of the anomaly over the map. The dimensions along the baseline are kept track by the clicks on the wheel. The baselines are either located with GPS (which can be plugged right into the GPR unit), or with a total station. Objects can also be located directly with a GPS unit of total station if preferred. The horizontal locations are accurate to within the size of the antenna. The 400 MHz unit we tested was approximately a foot square, but smaller antennas can be used for greater detail. It all depends on the application in which results are desired. John showed me a much larger 200 MHz antenna used for mapping objects at greater depths and also a much smaller 2600 MHz antenna used for detailed concrete work.

The vertical aspect of GPR greatly depends on the soil type and density. In our experiment, he was about an inch off, but that is not to say it didn't pick up road base on top of the stone itself.

One of the biggest things I learned was that the GPR is very picky in various types of soil and sites with extreme backfill. We were working in an area of fine sandy loam soil, but not heavy clay like some spots across the country. The sandier the soil, the better the GPR works, the denser, more clay oriented soil, the worse it works. John stated from experience "…typically the ratio in which GPR will pick up objects is one inch diameter for every one foot of depth". Therefore the stone we located (being about six inch diameter) would have disappeared from the GPR screen at a depth of approximately six feet.

Due to the growing popularity of GPR equipment The United States Department of Agriculture (USDA) did a study and produced maps across the county of the soil suitability and the effects it has on GPR equipment. According to the USDA "A common concern of GPR service providers is whether or not GPR will be able to achieve the desired depth of penetration in the soils of an assignment area. In many soils, high rates of signal attenuation severely restrict penetration depths and limit the suitability of GPR for a large number of applications”. These maps were produced using data from the State Soil Geographic and the Soil Survey Geographic databases. Figure 4 shows the *Ground-Penetrating Radar Soil Suitability Map of the Conterminous United States* as published by the USDA and the Natural Resources Conservation Service. The study goes on to state that “The penetration depth of GPR is determined by antenna frequency and the electrical conductivity of the earthen materials being profiled. Soils having high electrical conductivity rapidly attenuate radar energy, restrict penetration depths, and severely limit the effectiveness of GPR. The electrical conductivity of soils increases with increases in water, clay and soluble salt contents”. Basically is you are working in an area of high, wet, clay the GPR equipment is going to be very limited in its effectiveness. If you are working in an area of high salt content, consider the equipment practically useless because of the high electrical conductivity. The perfect scenario for GPR is a dry sandy site; yielding the greatest depth, precision and accuracy.

At the end of our demonstration I inquired about the cost not only of the equipment, but of the fees associated with hiring out GPRS. John said their rates are $750 for four hours (minimum) and $200 thereafter. According to Peter Masters of GSSI the unit we tested costs around $17,900, $5000 for the antenna, and anywhere from $2000-$4500 for software to process the GPR data. Other units range from $19,000 to $24,000 including the antenna but not the software.

Conclusion

I see the future of GPR and land surveying growing exponentially in the next few years. It may not be in every private surveyor’s survey truck, but I see it showing up in the city, county, state and federal government levels. As the price of the equipment drops and the demand increases we will be seeing more and more GPR applications in the future. We will be able to find that missing corner stone, field tile, buried oil drum or abandoned pipeline. We will be able to measure the thickness of our roads and depth to bedrock. We can determine rebar spacing in concrete and identify the post tensioned cables. We can even go on forensic searches or simply search for that hidden treasure. GPR can really open up the market and diversify you survey company or make your office the go to place for those “lost” survey corners. This takes us back to the beginning and my earlier comments about thinking long and hard before setting a corner that you consider to be lost. Walt Robillard et al sums it up in *Brown’s Boundary Control and Legal Principles*. “When a corner is positioned in accordance with the lost corner theory of proportioning, the surveyor must be convinced that no future surveyor or court will be able to locate the original corner in a different place. Proportionate measurement is always a rule of last resort”. GPR is now one more tool that can now be used to hold this theory true and help us all sleep better at night.