SUBSURFACE VIEWS

GPR INNOVATIONS HARDWARE AND SOFTWARE

October 2016 - Vol. 14, No. 48

Detecting voids under concrete foundations

Using GPR to ensure construction safety

Throughout the world, there are many geographic regions where soil properties can wreak havoc on engineered structures. When the underlying soil heaves (expands) or subsides (contracts), structural foundations can shift or be damaged. One such geographic area is the gulf coast region in the United States. The soil is subject to extensive subsidence. To reduce the impact of this, it is standard practice to use concrete piles as part of foundation construction. These piles are driven up to 80 feet into the ground to transfer the load from the soil directly under the foundation (which is more likely to subside) to the deeper soil or bedrock that provide sufficient bearing capacity for the structure.

When new construction projects on existing structures call for the use of heavy equipment, such as cranes, precautions must be taken to ensure the structure can support this machinery. For safety and to minimize structural damage, it is now becoming standard practice in Texas to check for voids and/or weak soil zones beneath the structure before installing heavy machinery.

Using GPR is an effective way to detect voids under concrete foundations. In this case study, the Port Arthur refinery in Texas was planning additional construction on their site.

Sensors & Software

They had a number of areas where they needed to place cranes to aid with the construction. Although there were no visible cracks or evidence of shifting in the foundations, they wanted assurance that they were operating on solid ground before proceeding and hired Tolunay-Wong Engineers, Inc. to perform GPR surveys on the foundations.

Tolunay-Wong used a Noggin 500 SmartCart to scan 9 separate areas. On one particular concrete slab, they found a surprising result. During the data collection, they noticed some anomalies in the line data, as shown in Figure 1. They recognized the regular rebar response from the concrete slab, at 0.6 foot depth. But just below the slab there were high amplitude reflectors appearing at intervals under the concrete slab. This is indicative of a sudden change in properties under the slab – but what did it mean? Was this the boundary of concrete to native soil or something else? Was it showing the piles that were part of the foundation? To gain a clearer picture, a 55 x 30 foot grid was collected on the slab.

After processing the grid, the rebar in the concrete slab were clearly visible in the 0.6 foot depth slice (Figure 2). Slicing deeper revealed again, more clearly, the regular pattern of high amplitude reflectors, as shown in the 1 foot depth slice (Figure 3). Upon initial analysis, it was thought that the high amplitude areas (red areas in Figure 3) may be the support piles and the concrete-to-soil boundaries were the lower amplitude areas. The only way to know for sure was to drill and gather ground-truth information. Upon drilling, voids were discovered under the concrete slab that coincided with the high amplitude
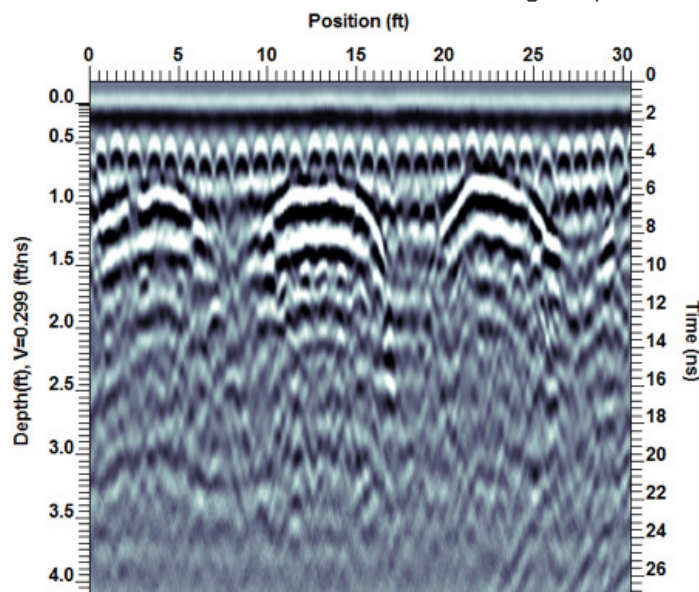

Figure 1: Cross-section showing the expected, regular rebar response in the concrete slab at a depth of 0.6 ft, as well as puzzling high amplitude reflectors at depth of 1 foot.
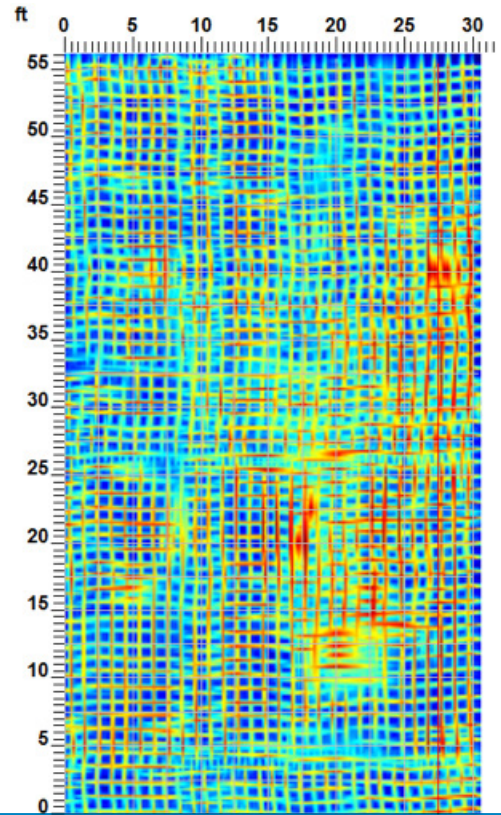

Figure 2: Depth slice at 0.6 ft showing the grid pattern of the rebar in the concrete slab.

GPR responses – the reflections were from the voids (a concrete to air boundary)! The lower amplitude responses were from the concrete slab to concrete pile boundary. The GPR grid survey showed that the entire structure was being supported solely by the piles, and that all of the underlying soil had subsided from underneath the slab. Drilling confirmed the voids had a vertical extent up to 1.5 feet.

Once the extent of the voids was known, the voids were filled to solidify the foundation. The site was then ready for the construction project and the heavy lifting equipment was safely installed.

This is one example of how looks can be deceiving – there was no physical evidence of any problems with the concrete foundation; however, had heavy equipment been installed without performing a due diligence GPR scan, major base stability problems could have ensued.

The strong change of properties between concrete and air (relative permittivity change from 9 to 1) means the voids appear as strong reflections in GPR data. The concrete piles and concrete floor have similar properties and thus produce weak or no reflection where the slab was in contact with the piles.

With a quick GPR scan to determine anomalous areas and one or more cores in those areas to ground-truth, you can create a picture of the subsurface. GPR provides a safe and cost-effective method to look beneath the surface for voids and confirm you have a solid foundation for many applications - from construction to runway inspections to road maintenance. **Data courtesy of Tolunay- Wong Engineers, Inc.**
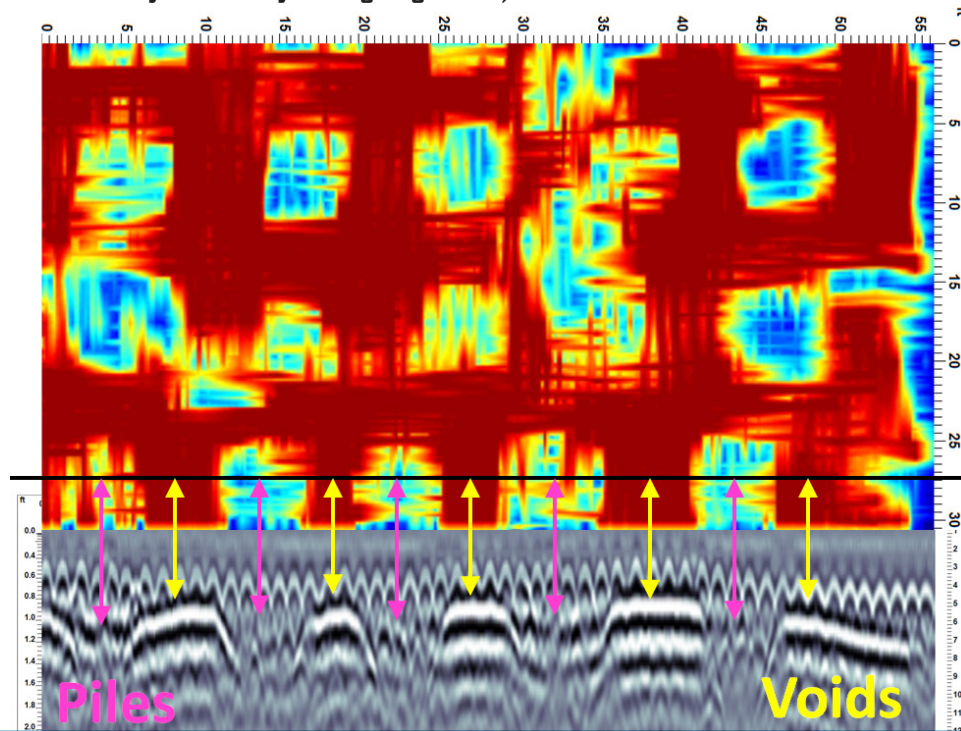

Figure 3: Depth slice at 1 foot and cross-section (Line Y11, at ~28 ft) with the piles and voids marked. The high amplitude responses in the cross-section correspond to the red areas in the depth slice.

Cemetery Data – "Grave" Interpretational Mistakes

Surveying cemeteries is a common application for GPR due to its ability to detect non-metallic objects like coffins. It is also possible to find burials, even without coffins, by detecting the disturbed soil associated with digging the grave. But, for cemetery surveys (and many other types of surveys for that matter) keeping an open mind when interpreting GPR data is important because what you expect to see in the data, and what you really do see in the data, may not match.

Noggin 500 GPR data was collected over an area of unmarked graves in the Rebecca Street Cemetery in Pretoria, South Africa.

Looking at one of the GPR cross-sections, a pattern of evenly-spaced hyperbolic responses at similar depths is observed (Figure 1).

It is not an unreasonable interpretation to suggest that each hyperbola indicates the position of a grave. However, once a grid of data lines was collected and processed into depth slices, an interesting, unexpected pattern emerged that caused the operators to change their initial interpretation of the data.

The 20 x 10 meter grid was collected in a few minutes by collecting 21 parallel lines, each 20 meters long and spaced 0.5 meters apart.

Looking closely, the hyperbolic responses seen in the GPR line do NOT correspond with the grave responses in the depth slice. In fact, the hyperbolas are actually strong responses *between* the graves, while the graves in the depth slice are caused by weaker (low amplitude) GPR responses.

Figure 2 shows the GPR line at 3.5 meters that runs over top of several graves. Examining the cross section reveals that there is a strong scattering layer at about 0.7 meters depth. The GPR reflections from this layer, visible between the graves, were initially thought to be the responses from the graves.

This layer is characterized by a hyperbolic "texture"; many overlapping hyperbolas caused by the geometry of the layer (yellow box in Figure 2). This boundary could be very rough, with a jagged interface with the material above. Or, this layer may consist of coarse grained materials and large rocks, each one producing a hyperbolic response in the GPR cross-section. Both situations would account for the hyperbolic texture observed in the GPR line data.

The graves are located at the places where this layer is absent because it was removed when the graves were dug. In this case, the graves were not detected directly by the GPR but correspond to where the layer was NOT detected by the GPR.

This layer was not exposed during the field work to ground truth the findings (for obvious reasons!) but we suspect that the grave diggers at this site are probably
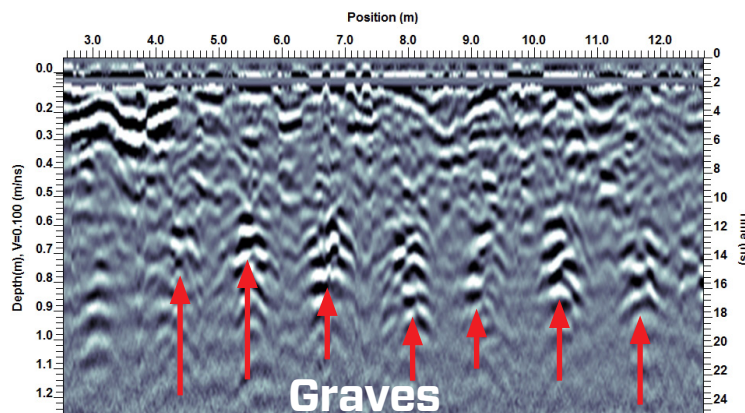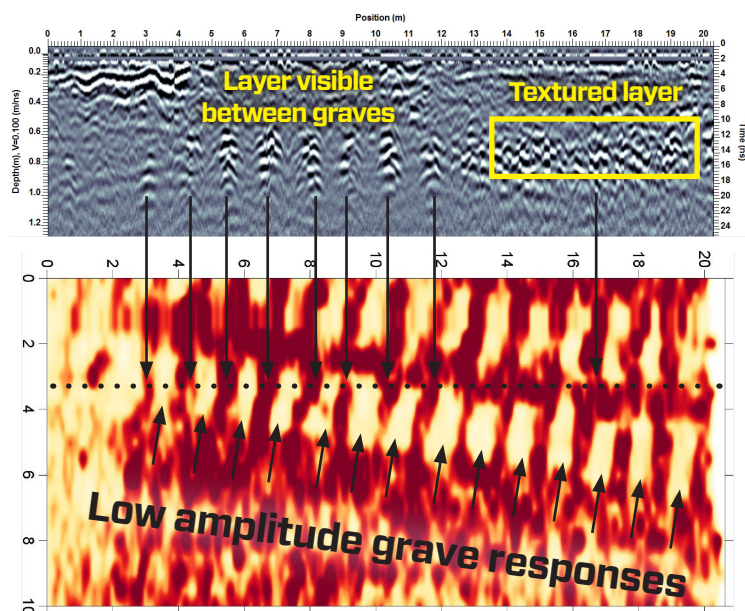

Figure 1

Figure 2

very familiar with this layer at 0.7 meters because it may be challenging to dig through. It is unfortunate that we were unable to confirm this notion.

This is an excellent example of the value of collecting GPR data in grids and generating depth slices to see the "big picture" before jumping to an interpretation of the data. It also shows how you need to be flexible with your thinking and be prepared to change your assumptions when faced with more evidence from the data – necessary skills to be an effective GPR interpreter.

Data courtesy of Dr. Jarrod Burks from Ohio Valley Archaeology

TIPS

Automatic Output Files

Having a GPS connected to an LMX200 or Noggin GPR system automatically generates simple, standard output files that clearly communicate the position of underground features – without the need of any GPR processing software.

During data acquisition, the GPS records the survey paths of all GPR lines and grids collected in a GPR project. When the GPR operator finds a target of interest in the data, they can add a field interpretation by simply touching the target response directly on the display screen to add a colored dot at that position.
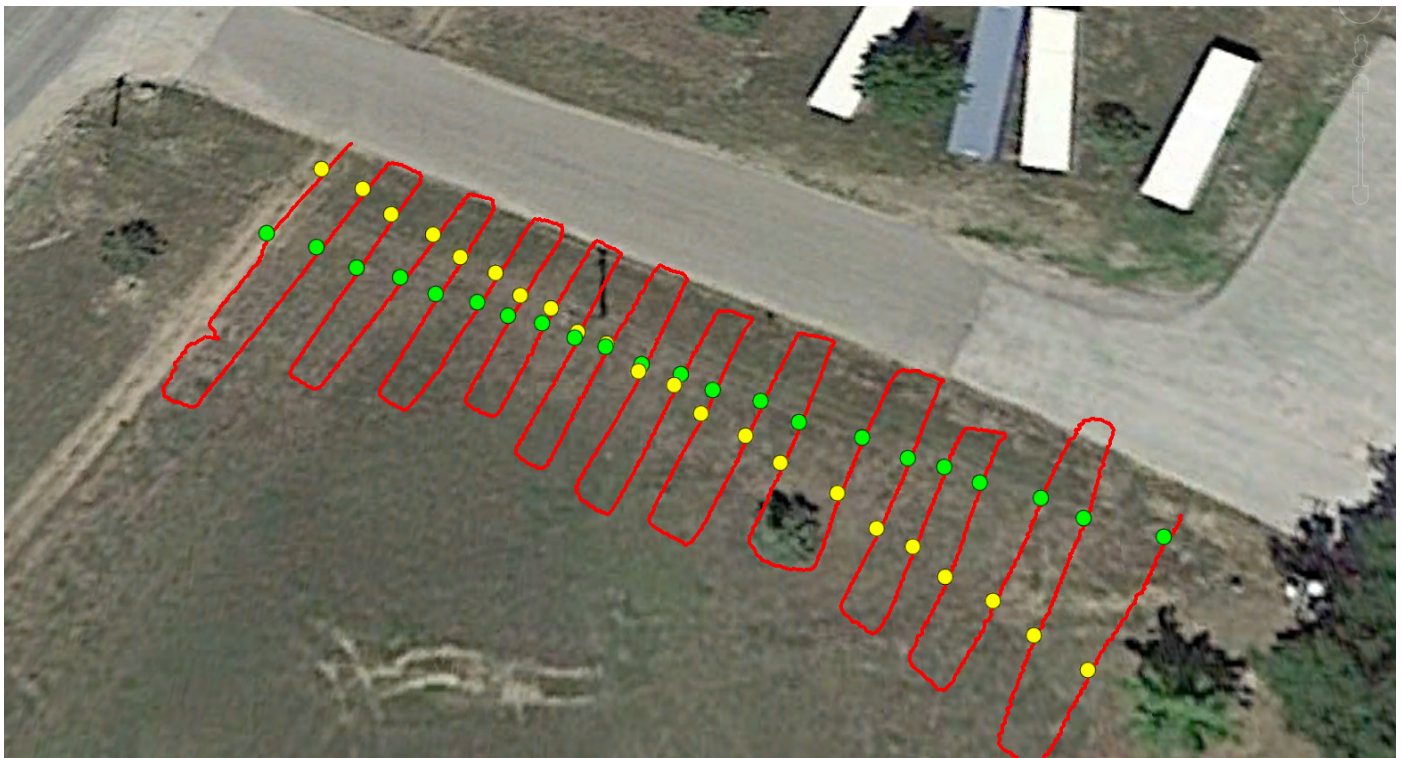

Figure A

Figure B

The operator can also add a marker flag to indicate objects on the surface that should be noted to assist with data interpretation – things like a change in surface materials, a large metal object nearby that might cause an air wave or a large rut where the GPR antennas were not coupled with the surface. All this data, the GPS survey paths, field interpretations and marker flags are displayed in the Map View window on the display unit to show the relative position of these observations. This allows the user to quickly see patterns in the data to help with interpretation; for example, if the field interpretations form a straight line, the object is linear. Figure A shows the Map View screen where the 6 field interpretations are actually two utilities.

When the field work is complete, data is transferred to a USB memory stick by simply connecting it to the display unit. Along with the raw GPR data saved in a GPZ file, there are two other files that are automatically copied to the memory stick:

1) A map view of the data in each project is saved in a KMZ format so it can be opened in free GIS software like Google Earth ™ (Figure B).

2) Spreadsheet (CSV) files listing the latitude, longitude, UTM Northing and Easting and depth of the field interpretations and flags are also output (Figure C). These files can be opened in Microsoft Excel, CAD or other design software.

When an LMX200 or Noggin system has a GPS, these file outputs are automatically generated. These files assist the GPR operator in understanding what was found and can be elegant, simple and fast deliverables to clients.

Tool	Interpretation	GPR Line	Position (m)	Depth (m)	Soil Cal	GPS-Easting (	GPS-Northing	Latitude	Longitude	GPS-Elevation
Point	Green	Lineset/line3	35.79	0.34	Moist Soil (91)	499691.35	4399054.26	39.7414	-105.004	1591.3
Point	Green	Lineset/line3	44.73	0.91	Moist Soil (91)	499696.1	4399046.49	39.7413	-105.004	1591.42
Point	Green	Lineset/line3	45.89	1.07	Moist Soil (91)	499696.71	4399045.48	39.7413	-105.004	1591.47
Point	Green	Lineset/line3	50.94	0.72	Moist Soil (91)	499699.03	4399040.98	39.7413	-105.004	1591.56
Point	Orange	Lineset/line3	56.92	0.68	Moist Soil (91)	499701.77	4399035.44	39.7412	-105.003	1591.61
Point	Orange	Lineset/line3	60.53	0.76	Moist Soil (91)	499703.41	4399032.22	39.7412	-105.003	1591.75
Point	Orange	Lineset/line3	69.72	0.81	Moist Soil (91)	499706.4	4399023.96	39.7411	-105.003	1592.08
Point	Orange	Lineset/line3	70.91	0.71	Moist Soil (91)	499705.3	4399024.81	39.7411	-105.003	1592.04
Point	Orange	Lineset/line3	76.79	0.6	Moist Soil (91)	499702.11	4399029.93	39.7412	-105.003	1591.88
Point	Orange	Lineset/line3	78.01	0.58	Moist Soil (91)	499701.52	4399030.97	39.7412	-105.003	1591.85

Figure C

Upcoming Courses

Subsurface Imaging with GPR course - November 7, 2016. Mississauga, ON, Canada

Concrete Scanning with GPR course - November 8, 2016. Mississauga, ON, Canada

3 day GPR course - May 31- June 2, 2017. Mississauga, ON, Canada

Upcoming Tradeshows

American Geophysical Union (AGU)
December 12-16, 2016, Moscone Center South, San Francisco, CA, USA

Transportation Research Board (TRB)
January 8-12, 2017, Washington, D.C., USA

World of Concrete (WOC)
January 17-20, 2017, Las Vegas, Nevada, USA

Sensors & Software Inc.   +1 905 624 8909

1040 Stacey Court   sales@sensoft.ca
Mississauga, ON   **www.sensoft.ca**
Canada L4W 2X8

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