SEEING THE UNKNOWN - The Use of GPR in Civil Engineering

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ABSTRACT: Civil Engineers are always confronted by the uncertainties in the subsurface that lie beneath their proposed or existing structures. While most often, soil borings would be adequate, in some applications this is not necessarily so as borings give detailed information but only at discrete locations and anything in between is "interpolated".

GPR on the other hand, gives a continuous information stream of the subsurface along its scan lines. 3D visualization is also possible by using *orthogonal* mesh of scan lines and the mesh sizes can be varied to suit the requirements.

While it is not a replacement for the use of borings to determine *soil design parameters* at discrete locations, GPR is a very useful adjunct to the borings in gathering reliable information particularly in-between borehole positions.

In problematic areas such as in *Karst* terrains or in areas with suspected *Geotechnical or Geologic anomalies or even man made buried objects such as Ordinance or buried pipes,* a continuous visualization of the subsurface is necessary in order to identify problem areas and thus enable an adequate plan of action when designing the substructure or determining what lies underneath.

Particularly in large projects, surprises in the subsurface have cost significant increases in the construction budget and/or resulted in large time delays.

Ground Penetrating Radar (GPR) has been used successfully worldwide for the location of buried objects and mapping the subsurface stratification more clearly.

In this paper, we wish to share the underlying principles on the use of GPR and also highlight various successful applications of the technology in solving day to day Civil Engineering problems.

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1. INTRODUCTION

Often we are confronted with the need to determine that what lies underneath a project. Sometimes, borings may not be adequate to give a detailed picture of the subsurface. This is critically important in the case of suspected presence of Geologic or Geotechnical anomalies such as faulting, cavities or manmade objects and even explosives.

Particularly where the exact location of the anomaly is unknown, the use of non invasive methods would avoid the large disturbances and disruption that excavation or borings would bring.

Thus, *Geophysical Methods* such as *Seismic Refraction SR* and *Ground Penetrating Radar GPR* come into the fore in providing a clear visualization of the subsurface. Of these, GPR comes as a good candidate for this purpose.

2. BACKGROUND

This Paper presents our local practical experience in the deployment of Geophysical methods, most specifically GPR to address and provide solutions to various practical problems where conventional approaches may not give adequate information or may not provide it in a faster or more accurate way.

Although Geophysical methods address the need for more information compared to conventional borings, these are not substitute to actual soil borings when soil design parameters (strength and compressibility) are needed.

However, borings may provide only limited discrete information points or are limited because of budgetary restrictions while Geophysical methods may provide a continuous data stream or even three dimensional images of the desired target of interest. Thus these two methods are complementary and would provide a more meaningful information record when done together or when augmented by each other.

One of these valuable geophysical methods is *Ground Penetrating Radar* or *GPR.*

3. ORIGIN

Ground Penetrating Radar Technology was an offshoot of the military use of radar and was spurred by the need to do research in the thick ice of the Polar Ice Cap. The developed technology has now also reverted to military use again in the detection of buried mines (IED's) and arms caches.

3.1 Uses

- Used for detection of Cavities, caves and other Geologic Anomalies such as buried faults.

- Used for detection of Buried objects such as pipes, IED's and Archeological artifacts
- Used for environmental scanning to determine waste landfills and pipeline leaks.
- Used For determination of structural thickness of Roadways and pavements
- Used for detection of Rebars and other embedded Objects in Concrete.

4. BASIC EQUIPMENT DESCRIPTION AND OPERATION

4.1 Equipment

The basic field equipment consist of the Control Computer, the *Electro Magnetic Pulse(EMP)* Antenna and the Cart with the associated power supply and distance measuring device which is synchronized with the computer to give accurate distance readings with the scanned images. There is also an option to connect this with a Global positioning system or GPS.

Figure 1. The Basic GPR Field Equipment

1. MALA PROEx Control Unit with power supply with internal calibration routines built in.

2. MALA Optical Module – connects to all antennas through high speed fiber optic cables.

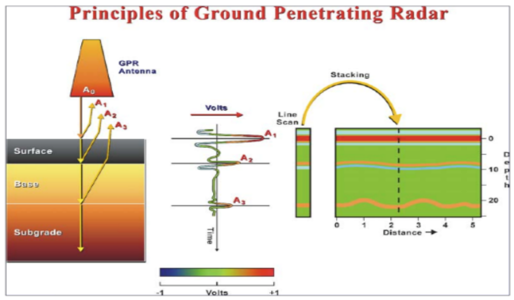
3. MALA measuring wheel used for automatic distance measurement and control of the survey line.

4. MALA XV Monitor – the dedicated monitor includes all bult in software (*Groundvision Software)* to view the survey and process the profiles without the need for a laptop.

5. MALA Rough Terrain Cart – contains all the GPR equipment and accessories including the distance measuring pulse encoder.

4.2 Operation

More simplistically, radar impulses are transmitted at a frequency of 100 to 500 kHz from the equipment and are bounced back or absorbed by objects depending A receiving antenna receives the bounced signals or pulses and are processed by computer in Real Time to provide a computer image of the subsurface. on the material stiffness and saturation and other interferences. See Figure Below: [3]



GPR transmits and receives up to 50 pulses per second. Transmitted wave is reflected at each layer interface, the amount of the energy reflected is primarily a function of moisture content and density. The captured data is an X-Y plot of amplitude against arrival time. To conveniently display many of these traces a color coding scheme is used to convert this into a color display. This is analogous to looking at an X-Ray of the pavement section.

The choice of Ultra magnetic Impulse Frequency to use determines the effective depth for exploration. The Frequency is *inversely* proportional to the effective depth of exploration. Very high Frequencies are used for shallow depths such as for roadway pavement structure investigation where a continuous record of the pavement structural thickness to the nearest millimeter is desired for dispute resolution or for QA and audit purposes.

5. IMAGE POST PROCESSING AND INTERPRETATION

After the initial field scanning and data gathering, the image is post processed in the office using proprietary data interpretation software such as *OBJECT Mapper, EASY 3D and GROUND Vision.*[4]

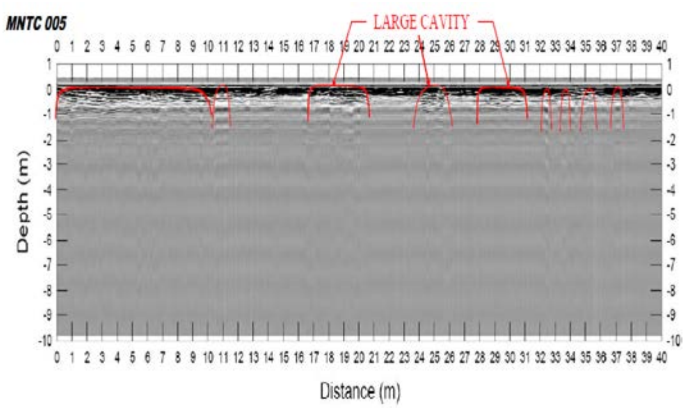


Figure 2. The figure above shows the GPR SCAN IMAGE showing the locations of detected cavities

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[3] REF 1.0 From Internet Download TEXAS DOT Presentation of GPR in Civil Engineering

[4] Mala Geosciences SOFTWARES

The image is post processed in a high Resolution large screen TV Monitor and desktop computer using the applicable software.

Figure 3. Image Processing using High Resolution TV Monitor

Cavities or anomalies show as distinct features in the post processed scan with characteristic signatures or shapes.

Cavities are displayed as hyperbolic shapes and solid obstructions such as buried concrete as very dark parallel lines.

Soil stratification or layering are also discernible due to the different contrasting layers with various shading and strengths. The darker the shade the stiffer or harder the layer encountered.

In some cases, pipe leaks can also be discerned due to the disaggregated stratification and large disturbed lines in the vicinity of the pipe leak breaking the layering or stratification.

With the additional software tools, visualization in ***2D & 3D*** are easily made because of the large contrasts in the image as well as the characteristic signatures of anomalies and obstructions in the subsurface.

Thus, as an example, the location of abandoned piles or the presence of buried structures and even unexploded ordnance such as bombs or shells can be detected provided these are within the scanning path of the equipment.

6. LIMITATIONS OF TECHNOLOGY

The presence of highly saturated plastic clays would tend to mask the radar signals and may produce no radar image at all or very hazy ones leading to some inaccuracies in the procedure. In addition, the presence of surface obstructions such as concrete pavements, the presence of subsurface boulders and other objects would tend to affect the accuracy of the signals and the images generated.

In highly conductive zones, such as saturated montmorillonite clays or saline marshes, it is almost impossible to obtain useful results below 1-2 wave lengths of the antenna. [5]

7. PRACTICAL APPLICATIONS

7.1 General

The following applications are discussed to illustrate the versatility of the GPR equipment in seeing the unknown.

Most of these applications were done with basic scanning procedures using a 250 MHz antenna.

7.2 Detection of Fortune Hunting Tunnel

We conducted the soils exploration program for this facility consisting of several buildings in Lahug, Cebu. Several borings indicated cavities at approximately 20.0 meters depth. Originally these were suspected as cavities in the Karstic limestone environment of the area. However, because of the consistent depth of occurrence and the size of the cavity as detected in the borings, we tried to trace the occurrences. Through enough, the trace started from outside and continued towards the main building. We recommended the conduct of additional borings and GPR scanning of the area. The owner did not approve this as the depth and size of cavities were very small.

However, towards the completion of the main building and during the excavation of storm drainage, the tunnel entrance, daylighted near the edge. Further probing indicated that it was indeed a manmade tunnel. The pictures and the illustration [6]clearly show what has been initially suspected as solution channels was in fact a fortune hunting tunnel.

The results of the GPR scanning revealed and confirmed the general Tunnel alignments earlier revealed by the Subsurface Soil Exploration Program conducted for the Temple facility.

In addition, a separate Tunnel alignment was indicated along the Housing area and possibly continuing towards the parking area at the NW corner of the Main Parking.

Generally, the GPR scans as stated agreed with the general Tunnel alignment for the main tunnel detected during the site soil exploration.

✖ 5] **SEGJ. "Application of Geophysical Methods to Engineering and Environmental Problems". Advisory Committee on Standardization, The Society for Exploration Geophysicists of Japan, 2004.**

6] **Illustration and photo courtesy of *Engr. Rommel Fajardo.***

The main tunneling effort was directed towards the Main Hill as the old villa in the hilltop was used by the Senior Japanese staff for *Lahug Airfield*. It has always been common knowledge that where the Japanese Generals are billeted, buried treasure can be found.

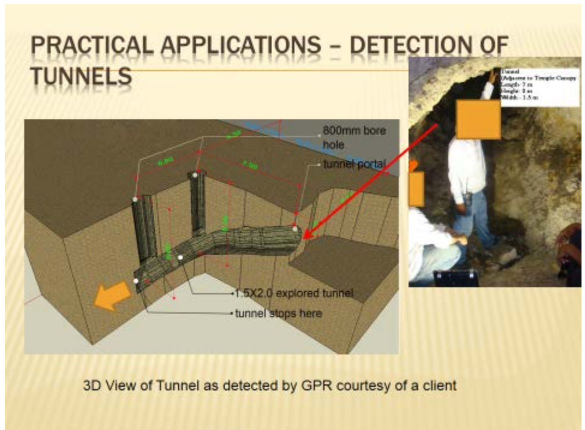


Figure 4. A 3D sketch of the Tunnel System as discovered by GPR and verified by subsequent investigation at the portals

Thus, it is possible that the tunnel would have continued towards the old house footprint where the Tunnel is approximately situated although this cannot be ascertained as the building mat foundation has already been constructed.

As a result, the main tunnel and the branch tunnels were ordered sealed with concrete grout with the former taking in 7 Transit mixer Loads of concrete and the latter another 5 Transit mixer loads.

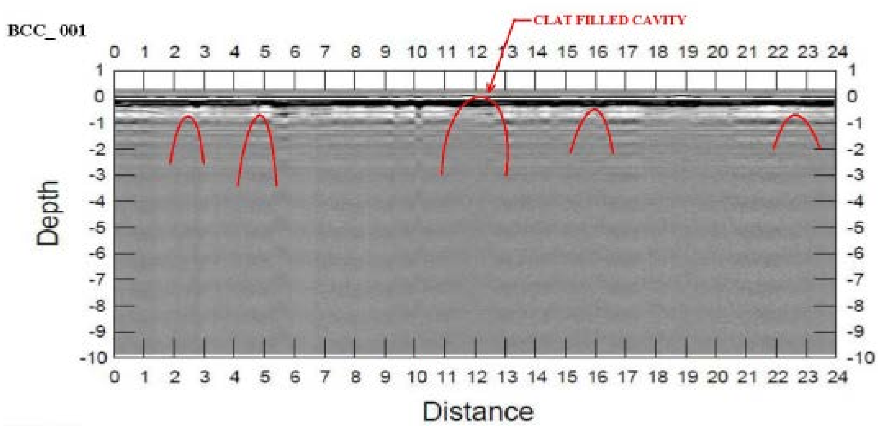
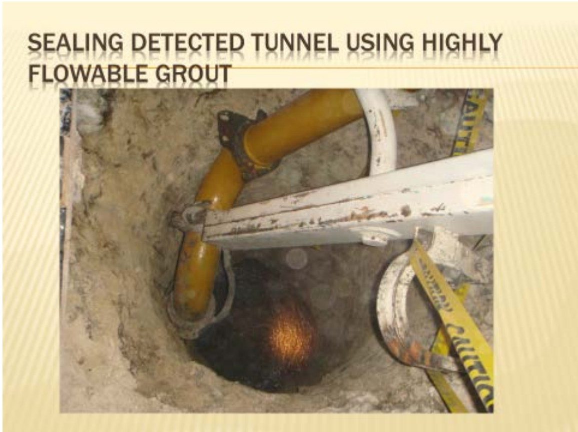


Figure 5. The Hyperbolic Symbols indicate the presence of small shallow cavities exposed during excavation



7.3 Detection of Cavities under Buildings

7.3.1.Basement Excavation

An excavation for multi-level basement uncovered initially large cavities that were daylighted by the excavation. We were requested to undertake GPR scanning to verify if there are any more hidden cavities underneath the level of the mat foundation.

However, suspected voids filled cavities, which are not of significant size have been inferred from our scanning profiles as well as several manmade structures such as footing tie beams.

Visual manifestations of some exposed tunnels were evident at the footprint of the building within the basement excavation. These were photographed and also marked in our plans. These discovered large sized tunnels prompted the conduct of GPR scanning in order to locate any further occurrences.

Some of these tunnels that have daylighted are relatively large and are either hollow or filled partially with soil or decayed *organic* materials.

The GPR survey at the basement has not detected any hollow tunnels or cavities comparable in size to the cavities earlier excavated and daylighted by the contractor for the basement excavation.

Figure 6. The picture shows the occurrence of cavities (arrows) which are filled with Organic Materials

The cavities as detected were relatively very small and possibly the locations for fossilized tree roots or vegetation.

Thus construction proceeded for the mat foundation without any concern on the presence of cavities.

7.3.2.Cavities and Solution Channels in karstic Limestone

The site of a proposed airport is underlain by Karstic limestone which is known to have major cavities and solution channels in a Southern Visayas Island.

We were asked to undertake borings and GPR scanning in order to map or delineate the extent of the cavities.

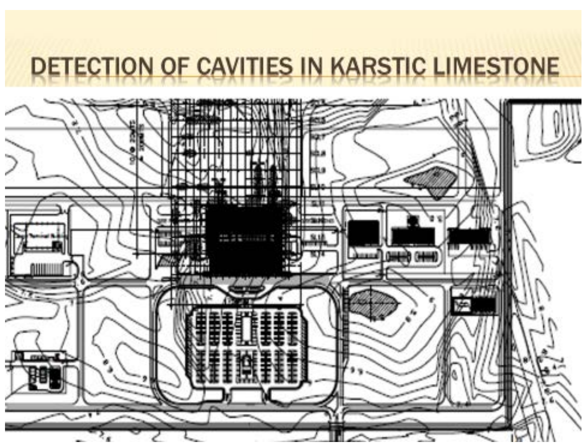


Figure 7. Partial view of Apron area with identified cavities

7.4 Detection of Buried Waste Dumpsite

We were asked by a client to survey and delineate suspected waste dumpsites within their factory which was buried a long time ago.

We conducted a grid survey with orthogonal scan lines spaced 10.0 meters apart in both directions.

The GPR scanning identified the location and extent of the dumpsites which we then mapped and referenced against the plant grid coordinate system. The detected landfill were earmarked for disposal outside the plant battery limit to an approved *Sanitary Landfill.*

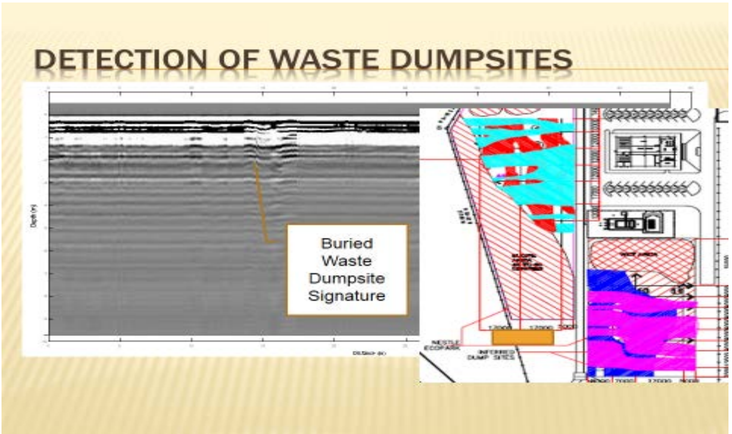
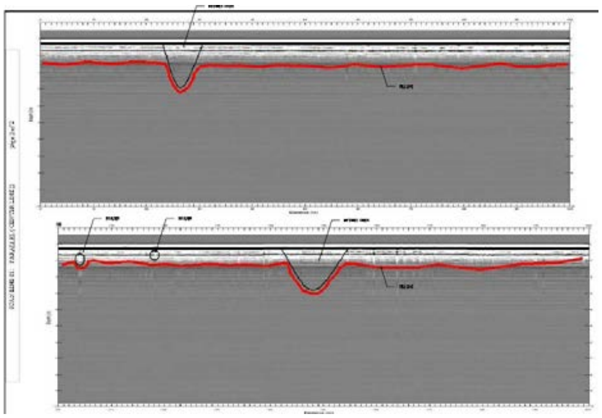


Figure 8. The Differences and Contrast of the layers are evident. The waste is identified by dark and light layers. The Light blue color in the map indicates the horizontal extent of the waste Landfill.

7.5 Detection of Buried Creeks and Depressions

Sometimes, in the haste to make land saleable, land development was done haphazardly, and creeks and depressions were hurriedly filled with pushed over materials that are uncompacted. These have often caused problems when structures are built over these areas, as settlements and deformations may result when the pushed over material is loaded.

The figure below shows a creek which was filled with loose fill and covered by compacted material above the creek.



The creek shown by the depression is shown as well as the NGL portrayed by the bold line. The two images were taken at 20 meter offsets and when represented in plan , show an inclined creek crossed by the perpendicular scan lines.

7.6 Detection of Leaks Under Tanks and Pipelines

In one occasion, we were engaged to undertake detailed scanning inside a food factory where old sewer lines and storm drains were buried under the factory floor. The objective was to locate the decommissioned utilities, but more importantly, to locate the source of the leak in a sewer line that is mixing with the storm drain and thus causing a concern due to cross contamination.

Numerous unsuccessful attempts were tried before in locating the suspected leaking pipes causing disruptions in the operations as these have to be excavated at the suspect locations.

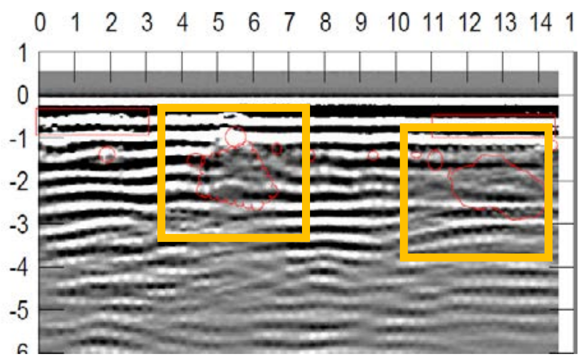


Figure 9. Shows the image of two pipes in parallel both causing upheavals in the subsurface immediately below indicative of a leak

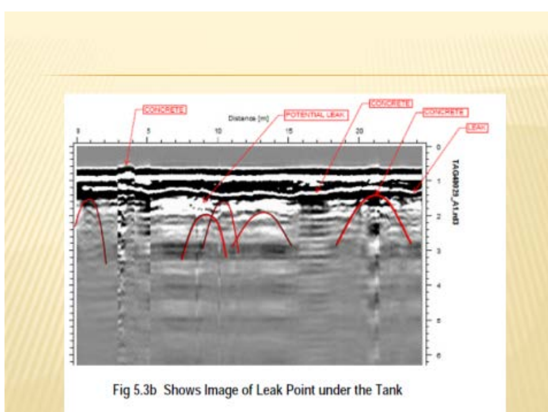


Fig 5.3b Shows Image of Leak Point under the Tank

In another engagement to detect cavities and solution channels, we were able to detect a leak point underneath a water tank as shown by disruptions in the soil layers underlain by cavities in karstic limestone. Dissolution of the limestone can create a sinkhole which can collapse the tank.

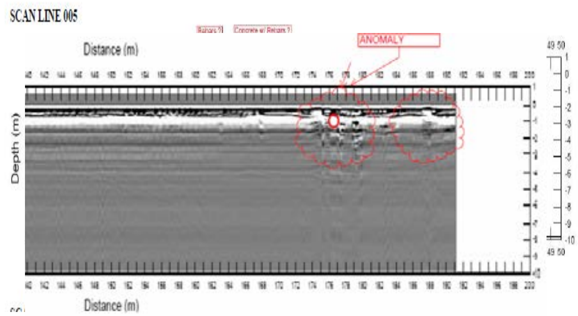


Figure 10. The figure above shows a buried pipe with tell tale signs of upheaval in the layering possibly caused by leaks.

7.7 Detection of Buried Utilities

Buried utilities are a concern particularly during excavations or even during borings at a site. For utilities, where as-built plans have not been prepared accurately, it would be difficult and sometimes even dangerous to undertake invasive methods or excavations without scanning the subsurface. This is particularly true in the case of pipelines for Petroleum or LNG or other lines such as water mains. Provided that the scan lines are Orthogonal to the pipe alignment and the scans are done at regular intervals, a 3D visual image can be generated using software post processing.

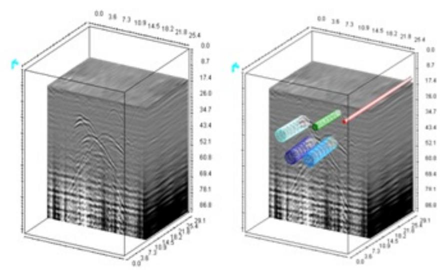


Figure 11. 2D and 3D Visualization of a Pipeline using Software Postprocessing

7.8 Very Shallow Non-Invasive Scans

Where shallow non-invasive scans are needed particularly in large area scans or relatively very long alignment investigations, there is no substitute to the use of GPR for mapping the subsurface. However, a higher frequency antenna is required as the depth of penetration varies in an Inverse proportion to the Antenna frequency. The Lower the frequency, the deeper the depth scanned.

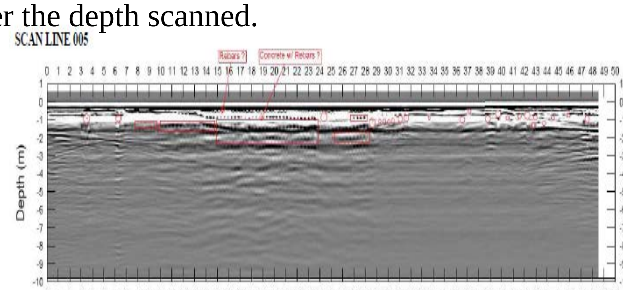


Figure 12. The figure above shows the presence of pipes as well as buried concrete with the rebars showing as closely spaced block dots

7.8.1. Roadway Pavement Structural Investigation and Audit

The pavement structural thicknesses of roadways can be determined either at discrete locations or as a continuous stream when connected to a GPR and a vehicle pushed or drawn GPR system. The alignment locations are automatically linked by GPS to the GPR records and even to a real time video.

This is particularly useful when making pavement condition surveys or when doing QA verification of the as constructed pavement structural thicknesses.

Figure 13. A vehicle system with the GPR and GPS is used for continuous Roadway surveys [7]

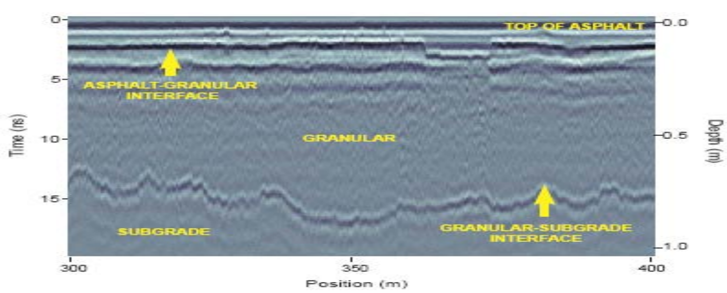


Figure 14. A section of an AC pavement along the alignment showing the layer thicknesses to within a millimeter accuracy (by scaling the depth)[7]

7.8.2. Detection of Embedded Rebars and Conduits in Concrete

Another practical use for a GPR system is the determination of Rebar layouts or embedded conduits in concrete structures.

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[7] **TEXAS DOT Presentation**

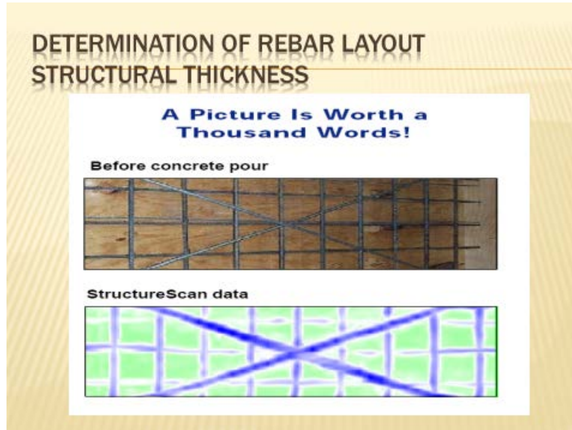

Figure 15. The scanning and actual layout vs the scanned layout is shown in the above pictures from Mala Geosciences

8. SUMMARY AND CONCLUSIONS

GPR as shown in the examples can be truly versatile equipment in helping the engineer see the unknown and in the process make more informed decisions about his project or solutions to problems confronting him.

GPR allows a clear visualization of the subsurface in 2D or 3D. Intelligent deployment of the technology requires a keen eye to detect the anomalies and their differing signatures. However, with more advance software for post processing, the GPR becomes a very powerful tool indeed in the hands of the Engineer.