Overview of GPR Applications in Civil Engineering

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Abstract

Ground Penetrating Radar (GPR) is an imaging technique that uses wide-band non sinusoidal electromagnetic waves to produce high-resolution images of the subsurface typically from 0-–10 m depth. GPR is an effective tool for subsurface inspection and quality control on engineering construction projects. The survey method is rapid, nondestructive and noninvasive. GPR has been successfully applied to a very wide range of tasks ranging from mapping geological structures, to identifying defects in concrete.

***Keywords**: Ground penetrating radar (GPR), Nondestructive, Subsurface*

INTRODUCTION

Ground penetrating radar (GPR) is similar in its working principle to the radar used in air traffic control. It is a valuable device in locating defects and voids in concrete structures, and in determining embedded reinforcement and other sub-surface details. Masonry and earth structures can also be scanned to assess the condition of inner layers. The principles of the system and its applications are discussed briefly in this paper along with typical images. Images of reinforcement details in a column and a bridge pier are presented along with a three-dimensional view of slab reinforcement. The quality of soil compaction can also be estimated by the sub-surface images.

Ground penetrating radar (GPR) is widely adopted for sub-surface imaging to assess the structural condition and to locate buried objects. The system comprises an antenna emitting electromagnetic energy, and receiving the reflected energy from the

MANTECH Publications

Journal of Transportation Engineering and Its Applications
Volume 5, Issue 1, January-April, 2020

surfaces as well as that from the inner layers, besides a processor

GPR emits electromagnetic energy that is projected in the form of radio frequency pulses into the structural element. The energy reflected depends upon the type and nature of the antenna, and the materials involved. The energy reflected is transformed into visual images, which provide extensive data on the sub-surface (inner) materials, when interpreted properly.

In principle, the working of GPR is similar to that of the radar used by air traffic controllers and vehicle speed surveillance systems used by traffic police. In the case of air traffic control systems, the signal emitted by the antenna is reflected by the objects in the air, and is received by the same antenna and processed to locate the objects. GPR uses the same principle by processing the signal reflected from various depths of a structural element the system is helpful in locating the bars embedded in structural elements, sub-surface voids and delamination due to the changes in the electromagnetic properties of the medium of energy penetration. The system is useful not only in assessing structural concrete elements, but also in soils and masonry buildings, ancient monuments as well as locating buried pipes and ducts. Some of the applications of the GPR along with a brief discussion on the principles and image processing are presented in this paper.

GPR SYSTEMS

Ground penetrating radar (GPR) is a technique of obtaining sub-surface images using electromagnetic radiation. The energy radiated by the antenna of the system penetrates the surface, and is either absorbed or reflected back at any discontinuities.

GPR is valuable in locating defects and voids in concrete structures, determining embedded reinforcement and other subsurface details. Masonry and earth structures can also be scanned to assess the condition of inner layers. The antenna housing comprises a transmitter and a receiver. The signal transmitted by the antenna is reflected at the interfaces of different materials (dielectric properties) and sensed by the receiver to create an image of reflections as the antenna is moved over the surface. The antenna dipoles create images of the reflected energy, which gives an indication of the sub-surface objects depending upon their electrical conductivity and dielectric constant. The antenna comprises basically a transmitter and a receiver, and utilises electromagnetic energy to procure data on sub-surface conditions of a body. The technique relies on the transit time measurement of transmitted and reflected energy impulses to estimate the distance of penetration. Figure 1 shows a typical GPR system with antenna and processor. The person to the right is holding the 1.5 GHz antenna mounted on a cart for scanning.

ANTENNA

Antenna is the most crucial element of the GPR system. The quality of data, range resolution and depth of Penetration primarily depend upon the antenna characteristics. Antennae of various specifications are available for various applications. The most significant parameter for an antenna is the depth of penetration, which depends upon the conductivity of the material.

It may be noted from Table 1 that higher the frequency of the antenna, the lower is the depth of penetration and smaller is the size and pulse duration. An antenna with 1,500 MHz frequency can penetrate only upto about half a metre generally, while a 15 MHz antenna can penetrate upto 200 m. However, deeper penetration of about twice the values indicated in Table 1 is possible depending upon the materials.

The antennae may be mounted on a wheeled cart to monitor the distance moved or may be dragged at a uniform rate over the required surfaces. The rugged antennae can be moved over vertical surfaces and even ceilings, if necessary. The antennae can also be mounted on a motor vehicle, and driven over the surfaces to be monitored, especially road and bridge surfaces.

Table1 Typical characteristics of Antennae

No.	Frequency, MHz	Pulse duration, ns	Penetration depth, m	Size, mm	Weight, kg
1	1500	0.6	~ 0.5	40×100×165	2.0
2	1000	1.0	0.75	40 × 100×165	2.0
3	900	1.1	2.0	80×200×330	3.4
4	400	2.5	5.0	170×300×300	6.4
5	200	5.0	9.0	300×600×600	17.7
6	80	12.0	20.0	1200	
7	40	25.0	40.0	2400	
8	20	50.0	150.0	4800	
9	15	60.0	200.0	6000	

MATERIAL PROPERTIES

The depth of penetration depends upon several factors such as electrical conductivity of the medium and dielectric constant. The electro-magnetic energy penetrates deeper in resistive materials (dry sand, ice and dry concrete) than in conductive materials (wet concrete, salt water and wet soil). The energy is absorbed by the conductive materials and hence does not penetrate deep. The technique is eminently suitable to investigate materials with low electrical conductive materials such as concrete, sand, wood and asphalt.

Table 2 indicates the properties of a few common materials the di electric constant of the material governs the velocity of the energy propagation, being inversely proportional to the square root of the dielectric constant. The velocity of radiation is 300 mm / ns in air with dielectric constant as unity and the velocity in water with a dielectric constant of 81 is one-ninth of the velocity in air. The values of penetration depth for various antenna frequencies listed in Table 1 are for a dielectric constant of 9. The depth of penetration will be more than that indicated in the table for materials of lower dielectric constant.

Further, antennae of the same frequencies for deeper penetration are also available. The depth of penetration for high frequencies (> 100 MHz) could be nearly double the values indicated in Table 1 for specific configurations.

Table 2 Typical material properties and velocity of propagation

No.	Material	Dielectric constant	Velocity, mm/ns
1	Air	1	300
2	Water	81	33
3	Granite	5 – 8	134 - 106
4	Dry sand	3 – 6	173 – 122
5	Wet sand	25 – 30	60 – 55
6	Dry soil	3 – 5	173 – 134
7	Fresh concrete	11	90
8	Dry concrete	6 – 8	122 – 106
9	Asphalt	4	150

IMAGE PROCESSING

Sub-surface features can be identified by the reflections at various depths of the scanned surface. The dielectric constant of the material and the estimated depth of penetration are selected for scanning. The material scanned may include layers of various di electric constants, including air between the contact surfaces of the antenna and the structural element. However, all the layers are scanned for the dielectric constant selected. Since the velocity of propagation in air is much more than that in the material, the depth of air layer appears large for the high dielectric constant selected (usually 4 – 6).

The images indicate the sub-surface details of the scanned objects, when interpreted by comparison with the data available. The penetration depth and resolution also depend upon the type and nature of the antenna adopted.

The amount of energy reflected at an interface of dissimilar materials depends upon the dielectric properties of the materials and on the conductivity. Metal objects show a very bright reflection due to high conductivity. Consequently, reinforcement in a concrete element provides a strong reflection at the interface due to high contrast in dielectric properties, while concrete and soil provide only a weak reflection.

APPROPRIATE APPLICATION TARGETS

The applications GPR are very varied and include the location of buried services, the detection voids or cavities, mapping bedrock depth or faults and fracture zones in rock. Other applications include locating steel reinforcing in concrete, geotechnical foundation investigations, archaeological, environmental and hydrogeological surveys. GPR is an effective tool for subsurface inspection and quality control on engineering construction projects. The numerous applications of GPR include the following:

1) Mapping pipes (including PVC pipes), cables and other buried objects.

2) Continuous inspection of layers in road pavements and airport runways. Due to the rapid data acquisition rates, it can be used at highway speeds to monitor changes in subgrade and asphalt pavement layers.

3) Mapping cavities or voids beneath road pavements, runways or behind tunnel linings.

4) To monitor the condition of railway ballast, and detect zones of clay fouling leading to track instability.

5) Detailed inspection of concrete structures, location of steel reinforcing bars and pre- and post-tensioned stressing ducts. GPR can be used in 3-D mode to map multiple layers of steel in buildings, in order to avoid damage when drilling through such structures.

6) Detection of zones of honeycombing, voiding and chloride attack in concrete.

7) Mapping zones of deterioration and delamination on bridge decks.

8) Mapping zones of termite attack or fungal decay in trees or timber structures, such as wooden bridge beams.

9) Mapping soil, rock or fill layers in geological and geotechnical investigations, or for foundation design.

10) Mapping bedrock and excavation conditions along proposed cable or pipeline excavations.

11) Detection of unmarked graves in forensic studies and the location of bodies buried in snow avalanches.

12) Hydrogeological and glaciological investigations, and monitoring the spread of hydrocarbon contamination in the ground.

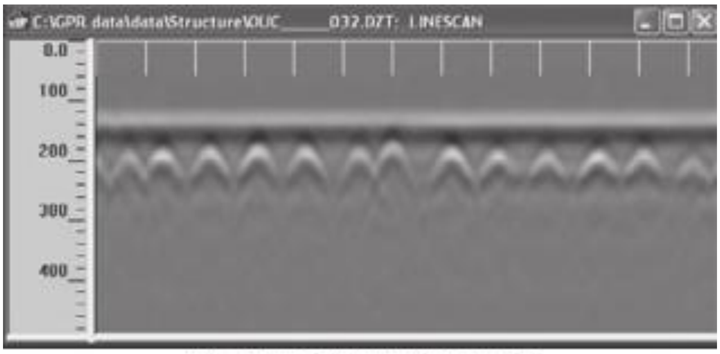
CASE STUDY OF A BRIDGE PIER

The pier of a bridge shown in Figure 1 was scanned to locate the reinforcement details using a 1.5 GHz antenna.

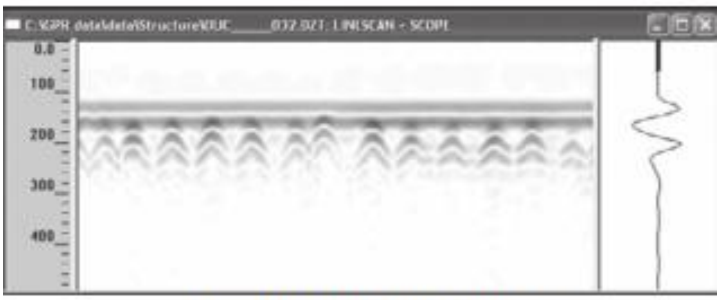
Figure 1 – A Bridge Pier

Figure 2 (a) indicates the images obtained when the antenna was moved horizontally along the pier width.

The location of the longitudinal bars is discernible in the figure. The image can be also viewed in different colour modes (Figure 2 (b)) to note the details. A line scan is also indicated in Figure 2 (b) to locate the concrete surface. The first kink (peak) in the line scan indicates the interface between concrete surface and air. The peak of the hyperbola locates the bars. The clear cover to the longitudinal bars of the pier can be estimated as 75 mm from the figure. **Figure 3** shows the image of the pier when scanned along its height over the narrow side (parallel to bridge axis) on a different colour palette. The reflections of the transverse bars with a concrete cover of about 190 mm can be noticed in the figure along with a second layer of ties at a depth of about 290 mm from the concrete surface. The horizontal lines above the hyperbolas indicate different layers of concrete. The spacing of the ties at about 160 mm can also be noted from the horizontal distances marked in the figure.



(a) Normal (grey) colour mode



(b) Colour mode with a line scan

Figure 2 Longitudinal reinforcement in the bridge pier (1.5 GHz antenna)

GPR is useful to locate bars at different levels below the surface.

GPR is supported by powerful software for image processing. Figure 4 shows a three dimensional subsurface image of a slab. The slab was scanned over a grid of 12 lines spaced at 50 mm (an area of 600 mm x 600 mm). The images scanned in orthogonal directions are stored as grid data, and processed to form a three dimensional image. The 100 mm thick slab was reinforced with 8 mm bars spaced at 100 mm in orthogonal directions. The three dimensional image can be sliced where required to view the details.

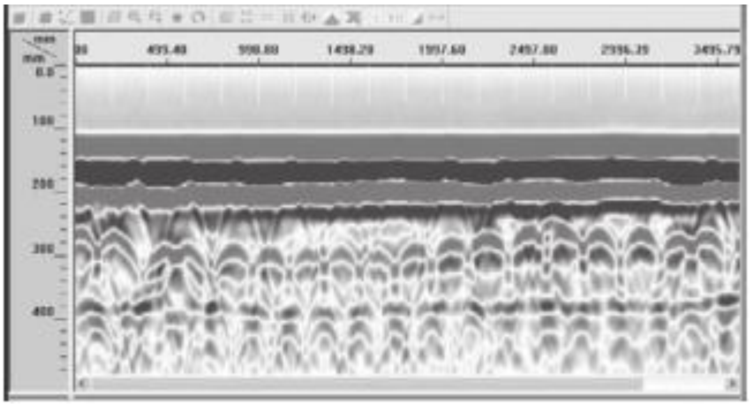


Figure 3 Transverse reinforcement of the bridge pier (1.5 GHz antenna)

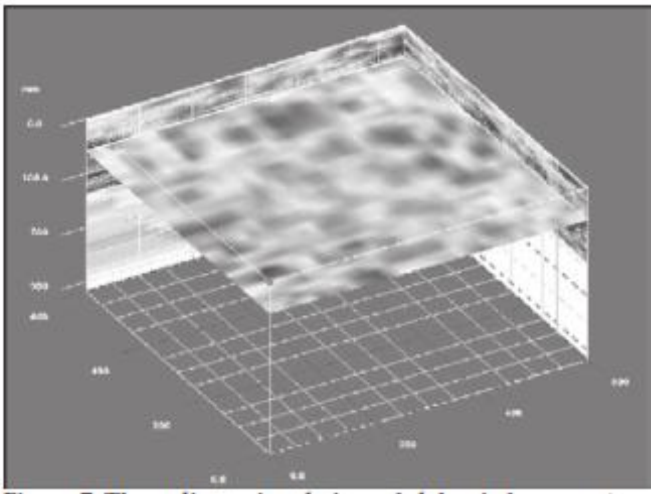


Figure 4. Three dimensional view of slab reinforcement (1.5 GHz antenna)

CONCLUSION

GPR, while very useful, has its shortcoming just as all things do. Very populated regions tend to pose problems to proper GPR data collection. Populous areas contain things like power lines, buildings and highways that can have high amounts of EM 'noise', which is any EM signature that the receiver unit of the GPR may pick up during data collection, can interfere and influence data collection.GPR failing to operate at a high level of efficiency in cities can be a detriment, in that cities can often benefit the most from its use where there are many buried utilities such as power lines and sewage piping. This paper has shown that GPR can be a valuable asset to aid in the research of faulted areas. The basics of GPR methodology and application were discussed to give a better understanding of the way in which it works and the some of the ways it can be used. The significance of GPR and the possibilities that come with its use was touched upon as well. GPR is a convenient, nondestructive, and cost-effective tool that researchers can benefit from in many areas of study.

SUMMARY

Ground penetrating radar (GPR) is widely adopted for sub-surface imaging to assess structural condition and also to locate buried objects. The system is backed by powerful software to obtain an insight into the subsurface layers. A GPR system comprises of an antenna emitting electromagnetic energy, and receiving the reflected energy from the surfaces as well as that from the inner layers besides a processor. The energy reflected is transformed into visual images, which provide extensive data on the subsurface (inner) materials, when interpreted correctly.

To obtain the best results it must be applied correctly by properly trained personnel, who are familiar both with the physical principles of the method and also of its limitations. The resultant data should be interpreted carefully, combining the relevant information of above ground and subsurface features. Calibration of the results using boreholes or test pits is recommended.

FUTURE DEVELOPMENTS

The penetration depth of GPR systems in use today is limited by the transmitted power. They use high voltages (up to 1,000 volt impulses) and low frequency (25–50 MHz antennae), which can reach up to 40 m depth in low conductivity ground conditions. Future GPR systems will deploy a new generation of UWB current-driven antenna, rather than voltage-driven antenna. These have the advantage of being able to transmit much higher mean power into the ground, and also use a smaller footprint, enabling them to be mounted inside robotic mining machines.

ACKNOWLEDGEMENT

Thanks to the Chancellor, Vice Chancellor, Registrar, Director and my colleagues of Reva University for encouragement and support .

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