ReBuild

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NON-DESTRUCTIVE TESTING (NDT)

PART - 5

GROUND PENETRATING RADAR AND ITS APPLICATIONS IN CIVIL ENGINEERING

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A Not-for-Profit Knowledge Centre

From the Editor's Desk

In a continuation of our efforts towards creating awareness on non-destructive testing for condition assessment of buildings and infrastructures, we have brought focus to this issue with ReBuild, one the most advanced equipment of Ground Penetrating Radar (GPR), which is not yet being used largely in civil engineering applications in India. But over the last few years, GPR, a versatile and most powerful NDT instrument, has emerged from the shadows of geo-physical applications for civil engineering applications.

The application of GPR for surveying roads, highways and airports pavement generally includes measuring pavement thickness, detecting voids beneath pavements, identifying and classifying defects and damages, distinguishing the location of reinforcing bars in concrete, identifying pavement structure changes, mapping underground utilities and bridge inspection. Using the GPR, the volumetric water content in structures, sub-structures, foundations and soil can be measured.

Besides these civil engineering applications, it has varied applications which include; locating the buried services, detecting the buried voids or cavities, mapping bedrock depth or faults and finding fracture zones in rocks. Other applications include geotechnical foundation investigations, archaeological, environmental and hydrogeological surveys. The GPR methodology and technology used in civil engineering can be compared to those employed in such areas as, archaeological prospecting and cultural heritage diagnostics, detection of explosive remnants of war and humanitarian demining, localization of buried and trapped people, geology and geophysics, agriculture surveys, environment research, forensics and security.

GPR can be applied in general without surface preparation by sliding the antenna over the surface. Fast data collection allows covering a large area in reasonable time.

Due to the nature of electromagnetic waves, it can be used for concrete and masonry structures; radar waves cannot however, penetrate metals. Any metallic layer, e.g. a metal sheet or a metallic tendon duct is an impenetrable boundary. However, reinforcement which leaves gaps between the rods can be passed by radar waves within limits.

Impulse (or pulse) radar systems are the most widely used type and operate by transmitting numerous small pulses. Another less commonly used method is continuous-wave (CW-GPR) method, which uses sinusoidal radio waves of a single frequency.

The penetration depth and the resolution obtained with GPR depend primarily on (a) the transmitting frequency of the antenna, (b) the electrical properties of the medium and (c) the contrasting electrical properties of the target.

The propagation of electromagnetic waves in solids depends on the dielectric constant (relative permittivity) of the material. The permittivity of the material basically describes how the dielectric field in the material is following the applied electric field of the waves. The permittivity is a complex number and the real part determines the propagation velocity in the material. Generally, there is a direct relationship between the transmitter frequency and the resolution that can be obtained; conversely there is an inverse relationship between frequency and penetration depth. The depth of the GPR survey depends on the transmitting frequency, the transmitted power and the conductivity of the ground or medium investigated. Depth range varies from 25 mm to 40 m, but is typically 0.1–5 m for most geotechnical applications. However, the deeper penetration is possible with lower frequencies (e.g. 25–100 MHz), provided the ground is not too conductive.

By forming COST Action TU1208, Australia, USA and a few leading European nations, are making efforts to exchange and increase scientific-technical knowledge and experience of GPR techniques in civil engineering, as well as to promote the effective use of this safe and non-destructive technique in the monitoring of systems. In this interdisciplinary action, advantages and limitations of GPR will be highlighted, leading to the identification of gaps in knowledge and technology. The objective of this task force is to standardize the test parameters of GPR as follows:

- Networking for the design, realization and optimization of innovative GPR equipment;
- Design, realization and testing of innovative GPR equipment dedicated for civil engineering applications;
- Selection of the most suitable antenna frequency and bandwidth that impose the resolution and penetration range to be featured by the system.

The integration of GPR with other NDT techniques useful for civil engineering tasks has significant importance. Among such techniques there are ultrasonic testing, radiographic testing, methods employing surface waves, approaches involving the using of an open co-axial probe combined with a vector network analyzer, liquid-penetrant testing, magnetic-particle testing, acoustic-emission testing and eddy-current testing.

Ground Penetrating Radar and its Applications in Civil Engineering

[Extracted from The Indian Concrete Journal, November2007, pp.35-40]

1.0 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.

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 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.

2.0 Principle of 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. The principle of radar surveying is shown in a schematic diagram in Fig. 1.

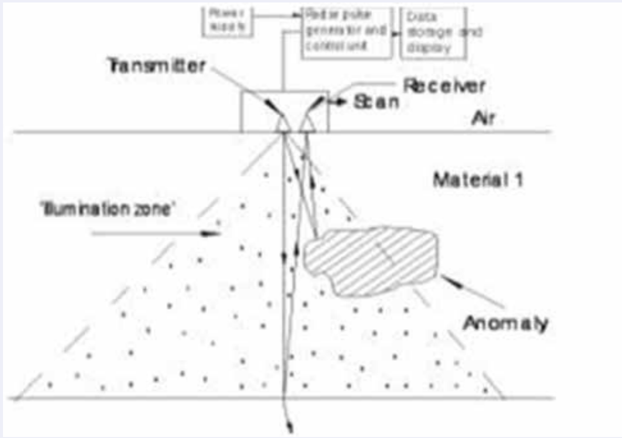


Fig. 1: Principle of radar surveying

GPR equipment contains three basic units such as:

- Antennas
- Control units
- Recorder and display unit

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.

Electromagnetic pulses of frequency 500MHZ to 3000 MHZ from radar transmitter are directed into the material having a pulse duration of $\leq$ 1 ns (nano seconds). The waves propagate through the material until a boundary of different electrical characteristics is encountered, reflected at interface of different layer and reinforcement along its travel path (Fig. 1).

The signal recorded is usually referred to as a scan or trace. They are referred as B scans and C scans. B scans normally give sectional view, whereas C scans give plane view. C scans are obtained by a combination of B & D scans. The scan is in the form of 3D images.

Although 3D GPR images have been successful in showing orientation and location of embedded targets internal voids identification is difficult to be identified

Several GPR systems are available commercially with image processing software to help interpret the data obtained. The antenna comprises basically a transmitter and a receiver, and utilizes 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. Fig. 2 shows a typical GPR system with antenna mounted on a cart and processor for scanning. Fig. 3 shows a latest model of GPR for scanning.

Fig. 2: A GPR survey for concrete structures

2.1 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. Antennas 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. The general features of a few typical antennas are indicated in Table 1.

Table 1. Typical characteristics of antenna

Frequency MHz	Pulse duration, ns	Penetration depth, m	Size, mm	Weight, kg
1500	0.6	0.5	40 x 100 x 165	2.0
1000	1.0	0.75	40 x 100 x 165	2.0
900	1.1	2.0	80 x 200 x 330	3.4
400	2.5	5.0	170 x 300 x 300	6.4
200	5.0	9.0	300 x 600 x 600	17.7
80	12.0	20.0	1200	
40	25.0	40.0	2400	
20	50.0	150.0	4800	
15	60.0	200.0	6000	

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 up to about half a meter generally, while a 15 MHz antenna can penetrate up to 200 m. However, deeper penetration of about twice the values indicated in Table 1 is possible depending upon the materials.

Fig. 3: Latest Model of GPR

Similarly, the pulse duration of an antenna with 1,500 MHz frequency is 0.6 ns, while that of a 15 MHz antenna is 60 ns. The dimensions and weight of the antenna decreases with the increase in frequency. The configuration of antenna with frequency smaller than 100 MHz is different from that of high frequency antenna. The transmitter and receiver of high frequency antenna are encased in a strong housing, and can be dragged over the surfaces. Low frequency antennas (frequency less than 100 MHz) are generally mounted on a shaft while scanning. A typical 15 MHz antenna has two elements of 600 mm on each side of the small housing for electronic elements, while the transmitter and receiver are mounted on the telescopic antenna elements of about 2,400 mm with a distance of 3 m between them.

The antenna 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 antenna can be moved over vertical surfaces and even ceilings, if necessary. The antenna can also be mounted on a motor vehicle, and driven over the surfaces to be monitored, especially road and bridge surfaces.

2.2 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 dielectric 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 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, antennas of the same frequencies for deeper penetration are also available.

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

3.0 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 dielectric 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 coupling of antenna with the surface due to possible air gap between the antenna and test surfaces causes a small initial error depending upon the distance between the antenna dipoles (transmitter – receiver offset). The larger the distance between antenna dipoles, the greater will be the coupling depth. A 1.5 GHz antenna has a dipole distance of about 60 mm, while a 400 MHz antenna has an offset of about 160 mm. The coupling distances between the images obtained by different antennas will be different and this has to be considered while estimating the depths of objects.

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.

4.0 Reinforcement Scanning in Concrete Elements

The images obtained depend upon the shape of the objects as well. The longitudinal and transverse reinforcing bars are marked by a profile taken by a GPR survey as shown in Fig. 4.

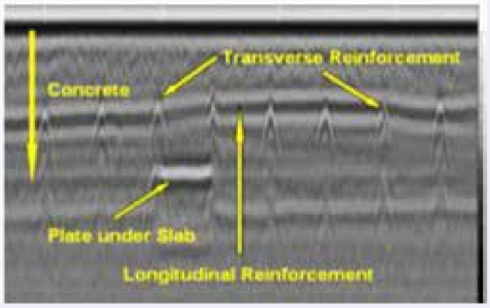


Fig. 4: Longitudinal and transverse reinforcing bars profiling during a GPR survey

Similarly the reinforced concrete column can be scanned by a 1.5 GHz antenna. The antenna, with a selected dielectric constant of 6 and penetration depth o f 500 mm, should be moved along the height of the column.

The transverse reinforcement in the column is usually marked by the series of hyperbolic reflections, while the band above the hyperbolas indicates the concrete surface. The antenna emits energy in the form of a cone, and is interrupted by the round object as the antenna is moved over the surface. Consequently, the energy is reflected continuously at the concrete – reinforcing bar interface as the antenna is moved over the bar, leading to the parabolic profile of the reflected energy.

It should also be noted that the profile offered by a reinforcing bar is circular when the dipoles (transmitter-receiver) are parallel to the bar, and results in a hyperbolic reflected image. If the bar is perpendicular to the dipoles, a continuous layer boundary is obtained.

A roof slab was scanned to locate the reinforcement details using a 1.5 GHz antenna and shown in Fig. 5.

The image can be also viewed in different colour modes to note the details. With an Ekko mapper software the images are sliced into 4 parts (0 to 30 mm depth, 30 to 60 mm depth, 60 to 90 mm depth and 90 to 120 mm dept for detail analysis as shown in Fig. 6.

The reflections of the transverse bars with a concrete cover spalling of concrete reinforcement corrosion can be seen at 90-120 mm depth of concrete surface in

Fig. 6. The spacing of the ties can also be noted from the horizontal distances marked in the figure in 0 to 30 mm depth. GPR is useful to locate bars at different levels below the surface.

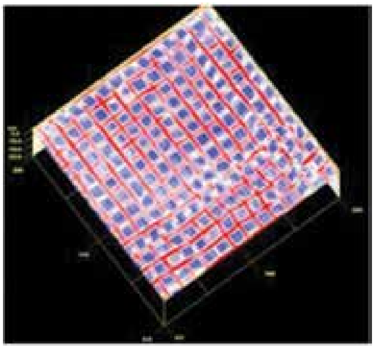


Fig. 5: C-scan – Reinforcements in a Slab

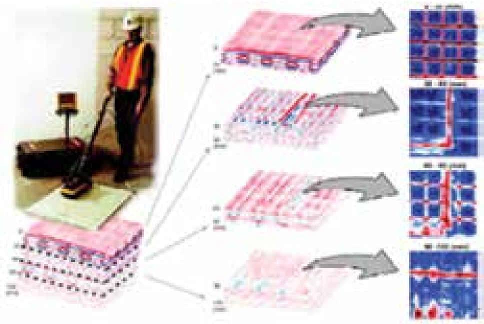


Fig. 6: Ekko Mapper software

Similarly one of the deck slab of a bridge was scanned to check the voids which were also cross checked with extracted core samples as shown in Fig. 7. The GPR images at location 1, 2, 3(left side image) are correlated with the core samples (right side image) at same place. It was observed exactly similar nature of voids in core samples as being observed in GPR survey.

GPR is supported by powerful software for image processing as shown in Fig. 8. The images scanned in orthogonal directions are stored as grid data, and processed to form a three dimensional image for detail analysis and interpretations of results.

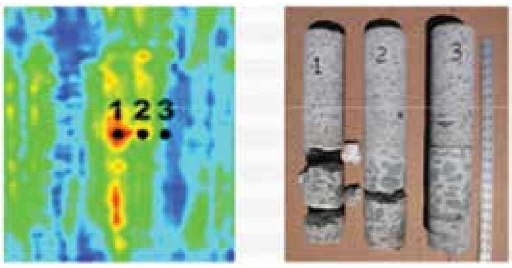


Fig. 7: Verification of concrete deterioration by GPR and core samples

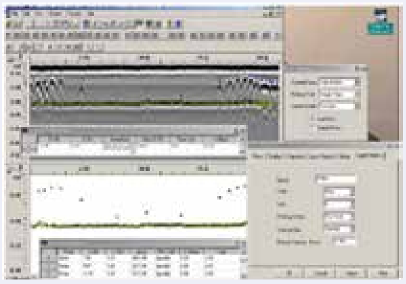


Fig. 8: Processed data from one scan line

5.0 Outcomes of GPR Survey and Reporting

A GPR survey report should normally describe in the following:

- Outline of the survey objectives.
- Description of survey method used.
- Type of GPR equipment used, including antenna frequencies and recording time range.
- Data processing routines applied.
- Survey results including location map
- Interpretation
- Classification or coding of results (if required).
- Conclusions and recommendations (if appropriate).

A site plan showing the location of the survey lines and the raw GPR profiles are normally the minimum outputs required. Map scales, the compass direction and relevant geographical site features should be marked on the plans and radargrams to assist interpretation. Where nontechnical persons may use the outcomes of the report, it may appropriate to include a cautionary warning that GPR profiles show the intensity of electromagnetic waves reflected from objects both under the survey lines and also possibly from above the ground. Therefore some spurious features appearing on the radargrams may not always appear to be consistent with subsurface structures.

6.0 Conclusion

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.

GPR is yet another valuable tool in the repertoire of civil engineers for non-destructive testing and quality control.

Ground Penetrating Radar Applications

[Excerpts from http://www.malags.com/home and Application of Ground Penetrating Radar to Civil and Geotechnical Engineering" by Richard J. Yelf, http://www.emph.com.ua/18/pdf/yelf_01.pdf]

1.0 Introduction

Ground Penetrating Radar (GPR) is a safe, non-destructive and non-invasive imaging technique that can be effectively used for advanced inspection of composite structures and for diagnostics affecting the whole life-cycle of civil engineering works.

GPR provides high resolution images of structures and subsurface through wide-band electromagnetic waves.

2.0 Application

GPR is an effective tool for subsurface inspection and quality control on engineering construction projects. The numerous applications of GPR include the following:

- Mapping pipes (including PVC pipes), cables and other buried objects.
- 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.
- Mapping cavities or voids beneath road pavements, runways or behind tunnel linings.
- To monitor the condition of railway ballast, and detect zones of clay fouling leading to track instability.
- 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.
- Inspection and quality control of pre-cast concrete structures, such as bridge deck beams.
- Detection of zones of honeycombing, voiding and chloride attack in concrete.
- Mapping zones of deterioration and delamination on bridge decks.

Besides these applications it can be employed for geotechnical foundation investigations, mapping geological information, hydrogeological studies, investigation of active geological fault zones, archaeological studies, forensic studies, as well as for several other purposes.

The key advantages in subsurface investigations: Locates metallic as well as non-metallic utilities – Easy user interface – Portable – Low cost GPR solution for the utility locate professionals – Fast – precise locating.

Some of these applications in civil engineering field along with their specific advantages have been discussed briefly:

2.1 Utility Locating

The utility buried services are assets that need to be protected, whilst to the construction industry they can represent a major hazard. Precise and reliable information about the presence, location and depth of these metallic and non-metallic utilities and other buried infrastructure is therefore essential and can be easily located by a GPR survey (Fig. 1).

Fig. 1: GPR survey for locating utility services on a road

2.2 Utility Mapping

To locate and map utilities before any excavation begins is a concern to everyone involved. GPR is a beneficial tool due to its capability to locate both metallic and non-metallic utilities. When using GPR, both position and depth can be marked out on site and later also visualized into 3D reports (Fig. 2).

Fig. 2: GPR survey for utility mapping and their location mapping (bottom drawing) along with their 3D view of the location (top right)

2.3 Buried Void Detection

Buried voids are a hazard, both to engineers and the general public. They can impede construction operations, undermine building foundations and be the cause of destructive ground subsidence. Problems associated with hidden voids come in many forms. Naturally formed cavities and sinkholes in karstic limestone terrain, unknown basements and culverts, abandoned wells and mineshafts, all of which present possesses serious hazards can be detected by a GPR survey (Fig. 3).

Fig. 3: GPR survey for detecting buried voids below the ground surface

2.4 Underground Storage Tank (UST) Location

GPR can locate Underground Storage Tanks (UST) and any associated underground piping. This non-destructive inspection and geophysical survey can determine the location and depth of a UST or provide the location of a former tank vault (Fig.4).

Fig. 4: GPR survey for detecting underground storage tank

2.5 Tunnel Assessment Surveys

To investigate possible quality deterioration within and above tunnels, GPR has proven to be an effective tool. When using GPR the condition of lining, location of hidden construction shafts, voids and delamination (Fig. 5) can be made both safe and cost-effective.

The key advantages such as: Ground penetrating radar is the most well-established technique because of its rapid data acquisition and versatility.

Fig. 5: GPR survey for detecting defects in a tunnel

2.6 Post- Pre-tension Cable Location

The imaging system allows scanning concrete structure simply and safely and presents data clearly for real-time and in-the-box data acquisition, display and analysis.

Key advantages: GPR is a real-time NDT technique that quickly locates the position of post tension cables (Fig.6), rebar, and electrical conduits embedded in concrete, eliminating dangers associated with cutting or drilling and the high costs required for their repair if cut or damaged.

Fig. 6: GPR survey for locating post-pre- tension cables

2.7 Rebar Location

Ground Penetrating Radar is an effective tool for detection of embedded rebar in concrete (Fig. 7) floors and walls. GPR can detect the depth and orientation of electrical conduit, utility cables and water lines.

Key advantages: Ground Penetrating Radar (GPR) is a valuable tool in commercial construction. It's a safe, non-destructive method for detecting hidden elements in concrete.

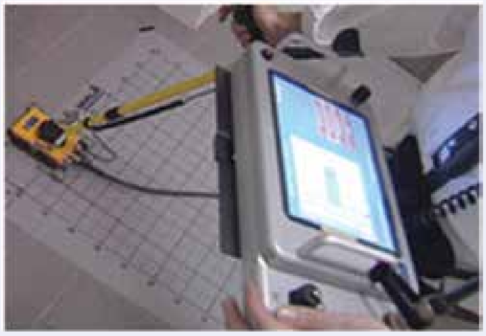


Fig. 7: GPR survey for locating embedded rebars in concrete

2.8 In-Slab Conduit Location

GPR is used to locate electrical conduits embedded in or below slabs (Fig. 8) prior to saw cutting or core drilling, thereby minimizing the risk of electrocution to the operator and reducing the risk of building systems shutdowns.

Key advantages: Accurate target location within a concrete slab on-grade, wall, or supported slab can be achieved more quickly, safely, and economically with GPR instead of other existing techniques.

Fig. 8: GPR survey for locating embedded electrical conduits in concrete

2.9 Void Detection in Concrete

The presence of voids in concrete which impacts the structural stability can be detected by a GPR survey (Fig.9). Key advantages such as: GPR is superior to radiography (X-Ray—the only other NDT technique capable of "seeing" through a structure) in speed, efficiency, and cost-effectiveness.

Fig. 9: GPR survey for detecting voids inside concrete

2.10 Slab Thickness Measurement

GPR can determine and record the slab thickness (Fig.10) for both slab-on-grade and suspended slabs, determine rebar depth to measure concrete cover in slabs, beams, and columns.

Fig. 10: GPR survey being used for measuring the depth of RCC slab

Key advantages: GPR is a safer and less disruptive than X-Raying. GPR equipment is safe to use around people without any safety constraints or setup requirements. Because of these features, interruption of operations can be eliminated or minimized.

2.11 Concrete Evaluation

GPR is a great tool for concrete evaluation and to determine concrete deterioration (Fig.11), slab thickness, rebar spacing, bar elevation, and amount of concrete cover over the rebar.

The key advantages such as: – A fully integrated GPR solution for concrete imaging, – Collecting data three different measurement modes, – Providing the highest resolution and detail of data, – Combines both GPR and EM technology simultaneously, – Multiple antenna frequencies.

Fig. 11: GPR survey being used to evaluate the deterioration of RCC slab

2.12 Road Evaluation

Pavement engineers use ground penetrating radar to determine physical properties and characteristics of the pavement (Fig.12) or subgrade. GPR helps engineers to determine the thickness of a pavement structure without resorting to excavation. A test method and the procedure are given in ASTM D 4748 for the non-destructive determination of thickness of bound pavement layers using short-pulse radar. This test method permits accurate and non-destructive thickness determination of bound pavement layers. This test method is widely applicable as a pavement system assessment technique.

Fig. 12: GPR survey being used to evaluate the characteristics of road pavement

Key advantages: A new breakthrough in GPR infrastructure technology for evaluating pavement, base and sub-base thicknesses. It is an extremely portable, user-friendly and cost-effective ground coupled platform that provides unmatched performance.

2.13 Bridge Deck Evaluation

The GPR technology can be used without the costly removal of the asphalt overlay in bridge deck (Fig.13). Quantitative data results can be compared from one year to the next. In addition construction companies that have been contracted to repair bridges can also use GPR to identify specific areas in need of repair. This allows companies to repair specific problem areas with bridges. Ease of repair will help in the problematic funding issues currently plaguing many DOT's.

Fig. 13: GPR survey can be used to evaluate the condition of bridge deck

2.14 Railway Ballast Evaluation

Ground Penetrating Radar is an excellent non-destructive tool to inspect miles of railroad track (Fig.14) in a matter of minutes. It is capable of looking into the ground and quickly and accurately analyzing miles of data to determine where undercutting procedures should be focused.

Fig. 14: GPR survey being used to evaluate the railway ballast

2.15 Runway Evaluation

Airport managers are now expending significant efforts to ensure that operating pavements are adequately engineered, or are reconstructed to cope with such demands. It is vital to detect at an early stage, defects such as sub-surface voids, rocking pavement slabs and de-bonding of materials and layers within the pavement and its sub-base. As increased traffic volumes and growth in aircraft movements restrict access to runways and other areas, rapid yet comprehensive survey techniques that avoid disturbing existing paved surfaces are becoming extremely valuable.

GPR survey can be used to evaluate the condition of runway pavement of an airport (Fig. 15).

Fig. 15: GPR survey being used to evaluate the runway pavement of airport

3.0 Types of GPR Products

IDS GPR products and services for the Civil Engineering industry are based on two different kinds of technologies that meet the varying needs and necessities of the customers. The first category is on-contact application such as Aladdin, RIS Hi-BrigHT, RIS One & RIS Plus where these GPR systems can use the combination of multiple frequency antennas to provide faster and more accurate inspections. The 2nd category is remote based application known as Interferometric Radar solution such as IBIS-FL and IBIS-FS and these radars can be operated remotely and there is no need for direct contact with the target being monitored. This technology allows the remote monitoring of movements of structures such as dams, bridges, towers, buildings with sub-millimeter accuracy.

4.0 Limitations

- GPR does not work well in saline conditions, in high-conductivity media and through dense clays which limit signal penetration.
- Highly trained personnel needed for application of this instrument.
- The detail calibration procedures have not been standardized.

5.0 Conclusion

GPR is a powerful diagnostic tool for civil and geotechnical engineering. 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 or concrete sample as applicable must be recommended.

GPR Application – Case Studies

Case Study-1: Understanding the Relationship between GPR & Rebar Corrosion

[Excerpts from the paper published in R. N. Raikar Memorial International Conference and Dr. Suru Shah Symposium on "Advances in Science & Technology of Concrete" organized by India Chapter of American Concrete Institute,2013,p.140-144]

1.0 Introduction

Non-destructive testing (NDT) methods are often used to quantify damage on bridge decks, and this case study focuses on two of the more commonly used methods: half-cell potential (HCP) and ground penetrating radar.

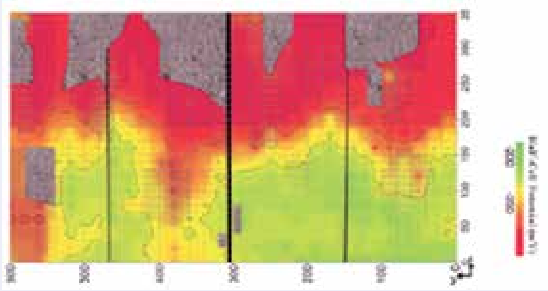
(GPR) conducted in one of the bridge deck slab in Maine, USA. The half-cell potential method is a slower, point by-point method used to identify areas of active corrosion within a bridge deck by using measurement thresholds provided in ASTM C876. This method uses a reference electrode, which sits on top of the concrete surface and is connected to the positive terminal of a voltmeter, with the negative terminal connected to an exposed rebar. The idea is to measure the electrochemical potential difference which develops as a part of the corrosion process.

2.0 Assessment by NDT

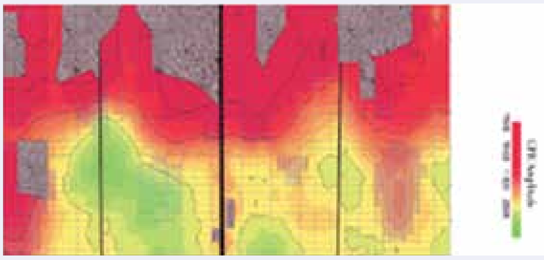
GPR data was collected using a 2.6 GHz GSSI ground coupled antenna and a SIR-3000 controller. Scans covered the entire wearing surface from curb to curb with a 300 mm offset between scans lines. Half-cell potentials were collected over the entire wearing surface as well, but on a 1.2 m grid. A visual inspection was also conducted on bridge deck, and the boundaries of all patching locations visible on the deck surface were mapped. All of the data was taken with reference to the same origin and grid so that during the processing of the data sets, the researchers retained the ability to overlay sets of data for comparison.

In deck slabs of the bridge the amplitudes associated with the rebar locations and the HCP measurements were contour plotted on plan area maps (Fig. 1a and 1b). In order to determine the correlation between the methods, and an associated GPR threshold, the contour plotting program was used to determine a depth corrected GPR amplitude and HCP measurement was taken at every 400 mm, over the entire area of the slabs. This was done so that the methods could be compared spatially since they were obtained on separate grids.

A qualitative assessment of the GPR and HCP by contour plots for the two heavily patched bridge decks demonstrates the ability of these technologies to expose the patched regions. It is expected that the patches areas with newer concrete would have higher half-cell potentials (indicating lower corrosion), and higher GPR amplitudes than the original bridge deck (because chlorides have more time to penetrate older concrete), but this isn't true for every patch.



(a) Half-cell corrosion potentials



(b) GPR rebar level attenuation

Fig. 1b: Contour plotting of half-cell potential (1a) and GPR attenuation (1b) of deck slab of a bridge

A qualitative assessment of the colour contour plots of the deck slabs demonstrates that both methods expose deterioration in the same area. In general, the upper half of the slabs can be considered corroded because this area has the lowest potentials and the most rebar level GPR attenuation. Additionally, the strong similarity between the methods suggests that GPR is a good indicator of active rebar corrosion.

To quantify the deterioration of bridge, the GPR and HCP plot for the deck slabs was generated based on data extrapolated and interpolated every 400 mm spatially throughout the slabs (Fig. 2).

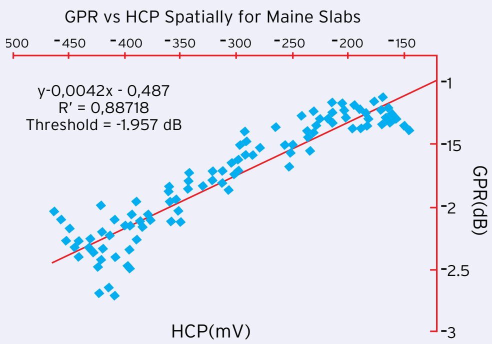


Fig. 2: Correlation curve between half-cell potential readings and GPR attenuation

Once the data was plotted for each deck, a line of best fit was determined for each plot using a least squares approach. Additionally, a correlation coefficient and an associated threshold were computed for each deck as well. The threshold was computed based on the equation of the line of best fit. According to ASTM C876, areas of concrete where HCP measurements are below -350 mV have a 90% probability of experiencing active corrosion.

Therefore, -350 mV was the HCP threshold used in the regression equations to compute each GPR rebar level threshold. Each of the computed thresholds is displayed on their respective plot.

3.0 Conclusion

The correlation coefficient for the decks for the Maine slabs was 88%. These coefficients show that GPR can be indicative of areas which are actively corroding, and those areas can be distinguished using the computed GPR thresholds. In other words, GPR rebar level measurements below the computed threshold will be considered corroded and those above the threshold will be considered healthy. If the measurements are displayed in a colour contour plot, those values below the threshold would be placed in red (corroded), and those above would be placed in yellow and green (healthy).

Based upon the NDT report where severe corrosion of reinforcement was established, the bridge deck in Maine was demolished in October 2010, after 28 years of service, and replaced with a new deck.

Case Study-2: Radar for the Evaluation of Concrete Structures– Influence of Reinforcements and Ducts

[Excerpts from the paper published in Proceedings of International Conference on "Rehabilitation and Restoration of Structures" held at IIT Madras, Chennai", 2013, p.541-542]

1.0 Introduction

A reinforced concrete slab of a building was evaluated with the GPR using 1.6 GHz antenna. The slab was divided into grids of 100 X 100mm in plan and the radar data was collected in both the directions. Fig. 1 shows the line scan obtained over a line. The inverted hyperbolas indicate the presence of the reinforcements. From Fig. 1, it can be seen that the cover to the reinforcement is not uniform. The data was processed using.

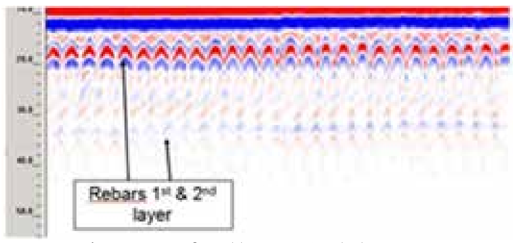


Fig. 1: Line scan for the RCC slab

RADAN software and the C-scans, i.e., the sections parallel to the reinforcements were obtained. Figs. 2 and 3 show the presence of top and bottom layers of reinforcement. The second layer is not clear because of the reflection of the radar signals from the first layer. The spacing of the reinforcement obtained is 150 mm and was correlating well with the actual provided in the slab.

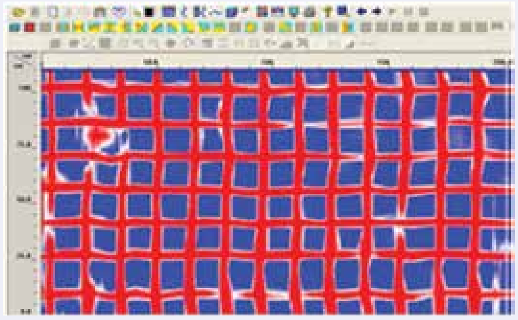


Fig. 2: C-scan – Top layer of rods

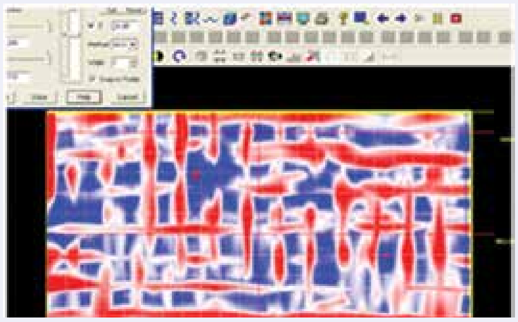


Fig. 3: C-scan – Bottom layer of rods

The B-Scan and C-scan images obtained using radar demonstrated that GPR is the best NDT method for the determination of reinforcements and ducts in concrete structures.

Various parameters were considered namely reinforcement meshes, ducts and voids. These were located effectively and the efficiency of GPR in locating buried targets was proved experimentally.

2.0 Conclusion

- Top and bottom layer of the specimen were obtained using the RADAR technique effectively, but the second layer was not as clear as the first layer. This was due to the fact the intensity of waves was initially lost due to reflection from the 1st layer itself.
- For determining the location and position of the duct, reinforcement spacing and location with respect to duct influence the output images were obtained.
- Grid spacing for collecting data is also another important parameter influencing the data. From the processed data, it can be inferred that grid spacing ranging between 100 mm to 200 mm was found to be effective.
- It can be concluded that a minimum spacing of 4 cm for

32 mm diameter bar and 5 cm for 8 mm diameter bar is possible with radar technique.

- When two metal targets such as two layers of reinforcement or a combination of duct and reinforcements are closely spaced, the results obtained are not clear and accurate due to multiple reflections.

Case Study-3: Rebar Detection using GPR An Emerging Non Destructive QC Approach

[Excerpts from International Journal of Engineering Research and Applications (IJERA),Vol. 1, Issue 4, pp. 2111-2117]

1.0 Scope in India

The use of GPR for road survey is in use for the last three decades in different parts of world but in India this concept is very new and currently not in use for routine survey purposes for the evaluation of flexible and rigid pavements. As a result it has got enormous scope of implementation for various survey purposes efficiently and cost effectively. It will be helpful as a diagnostic tool for early forecasting of road and structure damage and destruction. At the same time the verification of various design parameters can be assessed non-destructively after the construction which is a new approach for structural quality control.

2.0 GPR survey of reinforced cement concrete pavement-1

Data have been collected from various sites at New lecture Hall at IIT Roorkee campus in grid as well as line format with the objectives to accurately detect the presence and depth of rebars and estimation of slab thickness of the reinforced rigid pavements using 1000 MHz ground coupled antenna based GPR. The obtained image is clearly able to delineate the subsurface information with different layer information. The interface between the various layers and the width of the individual layers are quite clear.

Data has been collected in grid format of dimension 2 m x 2 m with inter line spacing of 100 mm between two adjacent lines in both the X as well as Y directions. The details of the pavement cross section as per documents are (1) top layer reinforced cement concrete (RCC) layer of thickness 100 mm (2) second layer is Portland cement concrete (PCC) layer of thickness 100 mm (3) third sand layer of 30-40 mm for leveling (4) fourth layer of bricks of thickness 100 mm – 150 mm and the last layer is soil layer as per the documents. Rebars are arranged in an array form having separation of 270 mm between two adjacent rebars. GPR profiles of both vertical cross section and horizontal cross section are collected and are shown in Fig. 1a and Fig. 1b. The rebars have been observed clearly and non-destructively with the exact dimension of spacing between the two adjacent rebar lines. The dimensional measurements have been found significantly correct matching to the dimensions present in the construction drawings. 2D analysis of the obtained data has been conducted by the dedicated software (EKKO_VIEW and EKKO_Mapper) for processing of ground data. Different sections of the RCC road with their different material and their thicknesses have been shown in Fig. 1a. If such information is available without digging, it can become boon in next generation quality checks. The interface between the RCC and PCC layer is clearly seen in Fig. 1a. The soil layer is clearly visible because of its distinct signature which is seen at the bottom of the Fig. 1a, wherever there is a difference of electrical properties (dielectric constant) between different layers. It is reflected in the images in terms of dark lines or fringes between the two layers which can be seen in the same Fig. 1a.

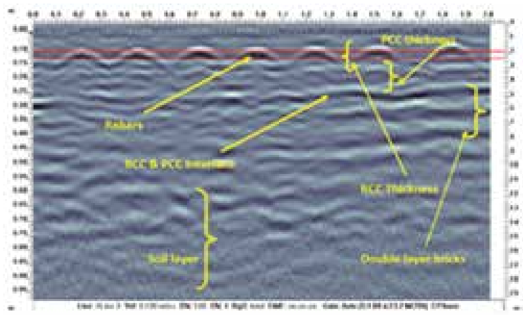


Fig. 1a: RCC pavement profile collected by 1000 MHz antenna based GPR

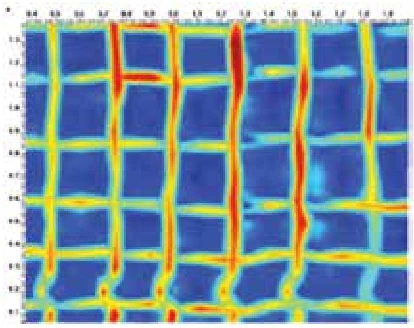


Fig. 1b: 2D horizontal plot of rebar array in RCC pavement collected by GPR

3.0 GPR survey of reinforced cement concrete pavement-2

Another RCC pavement has been studied at Rajeev Gandhi bhawan IIT Roorkee campus to obtain the rebar image. This area has been chosen to check the ability of GPR in the region having closely spaced service lines/ rebars. Clear rebar image is obtained with the correct dimension of its array. The correctness of dimension is because of high resolution of antenna used and proper velocity calibration. Data has been collected in grid format of dimension 1 m x 1 m with inter line spacing of 10 cm between two adjacent lines in both the X as well as Y direction. Then the data had been processed using dedicated softwares, EKKO_View and EKKO_Mapper. Two GPR profiles of the same vertical cross section are shown in Fig. 2a and Fig. 2b and the 2D plan view of pavement cross section showing rebar plan with clear dimensional details have been shown in Fig. 2c.The pavement is having double layers of rebars, which indicates that two slabs are used for the pavement.

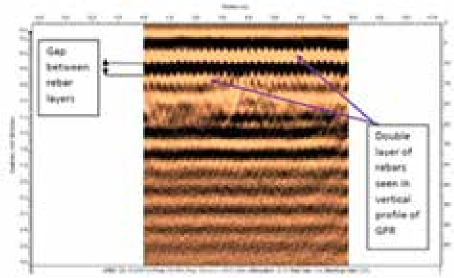


Fig. 2a: GPR profile of double layers of rebar. Data taken by 1000 MHz antenna based GPR

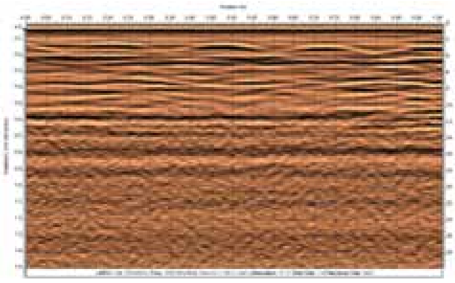


Fig. 2b: RCC profile having double layers of rebar. Data taken by 1000 MHz antenna based GPR

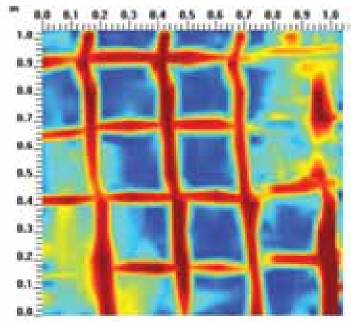


Fig. 2c: Cross sectional RCC profile having rebar. Data taken by 1000 MHz GPR. (Grid1x1)

4.0 Discussion

From the images obtained as in Fig. 1a and Fig. 2b after the survey of the RCC roads using 1000 MHz antenna, it can be seen that the GPR is capable of identifying the interfaces between the different layers having substantially different dielectric constant (an electrical property). And because of this, GPR can be utilized for the estimation of the thicknesses of these layers with appropriate correctness. It has been seen that the GPR gives very good images of the metal objects like rebars in the RCC roads. The gap between the rebars lines can also be identified with ease. Greater resolution is obtained due to the use of high frequency 1000 MHz antenna. If the same study would have been carried out using a lower frequency antenna like 250 MHz, then there could be a possibility that the small rebars might have been skipped during detection process. On should never go for line data acquisition when small pipe lines or thin telephone cables are present under the ground as generally these service lines are skipped by the operators; grid format provides larger probability of identification of these features. And if data is being obtained in grid format then also the line spacing between two consecutive GPR survey lines must be kept small so that the smallest of the small service lines are not skipped.

The image is to be observed carefully when two layers of rebars are present one below the other in order to detect both the rebar layers simultaneously. Because it is a well known fact that metals reflect the radar signals so it becomes difficult for the signal to penetrate further into the deeper levels making the deeper objects unclear

5.0 Conclusion

Non-destructive approach of GPR has been successfully implemented to detect the subsurface anomalies and ground layer structures, using this approach; it has been possible to monitor the various pavement features as given below, without digging the pavement surface.

- The presence of rebars, which were covered with the RCC layer, could be detected clearly with ease and this is noticeable in the pavement profile collected by GPR in the form of ripples as shown in Fig. 3a.
- The rebar plan map with its array dimension (270 mm by 270 mm) is non-destructively detected and which can be seen in the Fig. 1b and Fig. 2c. Therefore, there isn't any need of physically excavating the road to observe the presence and measure their array size.
- The position of rebar from the top surface is seen at 100 mm in the depth profile of pavement as can be seen in the Fig. 1a.
- Two layers of rebar could also be detected as seen in Fig. 2a. It can be seen in the form of triangular shaped ripples separated by second black thick strip. Though double layer rebar detection is little difficult if the antenna frequency is lowered as its resolution becomes poorer.
- The masking effect of rebars on the relatively deeper objects is observed clearly in Fig. 2a in which some utility objects lying below the second layer of rebar and in the middle of the depth profile is not identified clearly.
- GPR provides an efficient and versatile means for detecting rebars in the reinforced cement concrete slabs in rigid pavements along with their real depths and rebar array dimension. Single layer and double layer rebars have been successfully detected due to the use of advanced hardware and software features of the system being used. The rebar features have been easily identified without disturbing the road users, without destruction of the pavement and in shortest possible time leading to a

cost effective solution for the pavement evaluation. This is the reason why the developing countries like India must use GPR for routine pavement monitoring and hence its use can be recommended for this purpose. Its payback period will be short if its cost of purchase is compared with the equivalent economic gain during each evaluation work on the huge road networks in the country. But GPR technology is still not in use for pavement related work in India. In fact, road construction agencies in India like, National Highway Authority of India (NHAI) under Ministry of Road Transport & Highways, Public works Departments (PWD) under state government and other private construction companies of India still rely on drilling, sampling and testing for both flexible as well as rigid pavements. Although, few private companies use electromagnetic principle based ferroscan rebar scanner for building wall, roof and floor investigation in terms of presence of rebars but they do not investigate rebars for pavement as that can scan up to only a few meters, so not useful for kilometers of highway lengths.

Case Study-4: Application of GPR for detection of cracks in basement slab

[Excerpts from International Journal of Engineering Research and Applications (IJERA),Vol. 1, Issue 4, pp. 2111-2117]

1.0 Introduction

Non-destructive testing is one of the most important means which supervisor, diagnose and evaluate the quality of the reinforced concrete. The testing results will be important gist of preservation and maintenance of the concrete structure. In view of the complicated property of the reinforced concrete and the limitation of testing site environment, some routine testing method such as, for example, ultrasonic testing, pulse-echo testing and infrared ray testing, can't be put to use or obtain scheduled testing purpose. Ground penetrating radar (or GPR for short) is non-destructive testing technique of non-metallic structure and it has been widely applied in engineering and environment surveys.

There was seepage phenomenon of groundwater in concrete soleplate of the Shanghai Jinwantan Square, China. The thickness of the soleplate was 2.1 m, all the concrete was simultaneous paved and the total area is 8000 m^2. Because of the temperature changing during the solidification, parts of the concrete soleplate came into being small cracks. It was necessary to make sure the outstretched depth and the crack extend direction in concrete soleplate.

GPR data were collected using pulse EKKO-IV and pulse EKKO-1000 systems that were manufactured by Sensor & Software Inc. (Canada). Equipment components include a system unit enclosure case (250 x 160 x 160 mm), a set of shielded antenna having 25-1200 MHz center frequency and 20 m antenna control/power/data optical fibers. The antenna was connected to the GPR system unit via the fiber, allowing the antenna to be towed by a small simple tractor-trailer across the test plots.

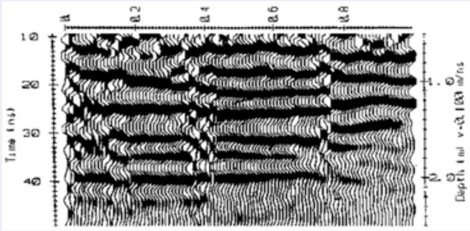


Fig. 1: GPR testing image of the cracks

2.0 Testing the GPR on crack of the concrete

A pulse EKKO-1000 GPR from Sensors & software Inc. was used for non-destructive testing. The antenna had center frequency of 900 MHz. All of the data were acquired using common-offset reflection profiling method. A series of single line tests was completed to optimize acquisition parameters, and used these results to design 3-D surveys. The step size data is 0.01 m and the transmitter-receiver separation data is 0.17 m. Fig. 1 is one of the GPR testing images. The GPR reflection images were analyzed to make sure the position and outstretched depth of the cracks.

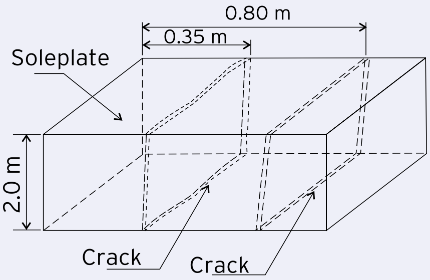


Fig. 2: 3-D representation image of the cracks

In Fig. 1 the in phase axes of the reflected wave were unbalanced on the horizontal position of the 0.38 m and 0.78 m, which showed that the two parts of the concrete existed cracks. In the vertical direction the unbalance didn't disappear until 40ns (~2.0 m depth), which showed that the cracks had extended to the bottom of the concrete soleplate. Fig. 2 is the 3-D representation image acquired by synthetically analysis with other testing line results.

3.0 Conclusion

Ground penetrating radar has widely used in geophysical surveys. GPR was primarily focused on mapping structures in the ground; more recently GPR has been used in non-destructive testing of the non-metallic structures. The application in non-destructive testing of reinforced concrete is a new task and study field. The practical engineering applications established that GPR is a better method of non-destructive testing of reinforced concrete.

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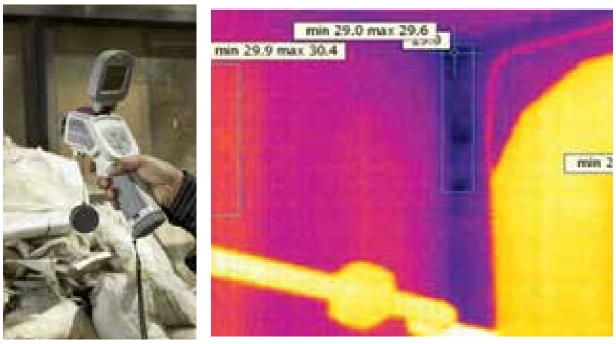

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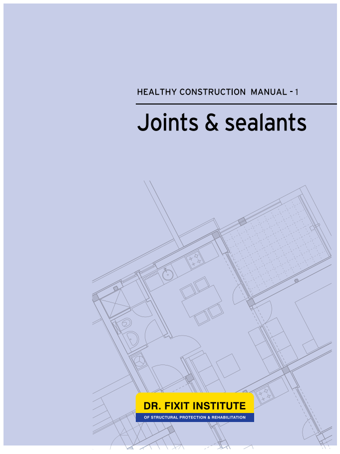

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(For Concrete & Masonry Surfaces)

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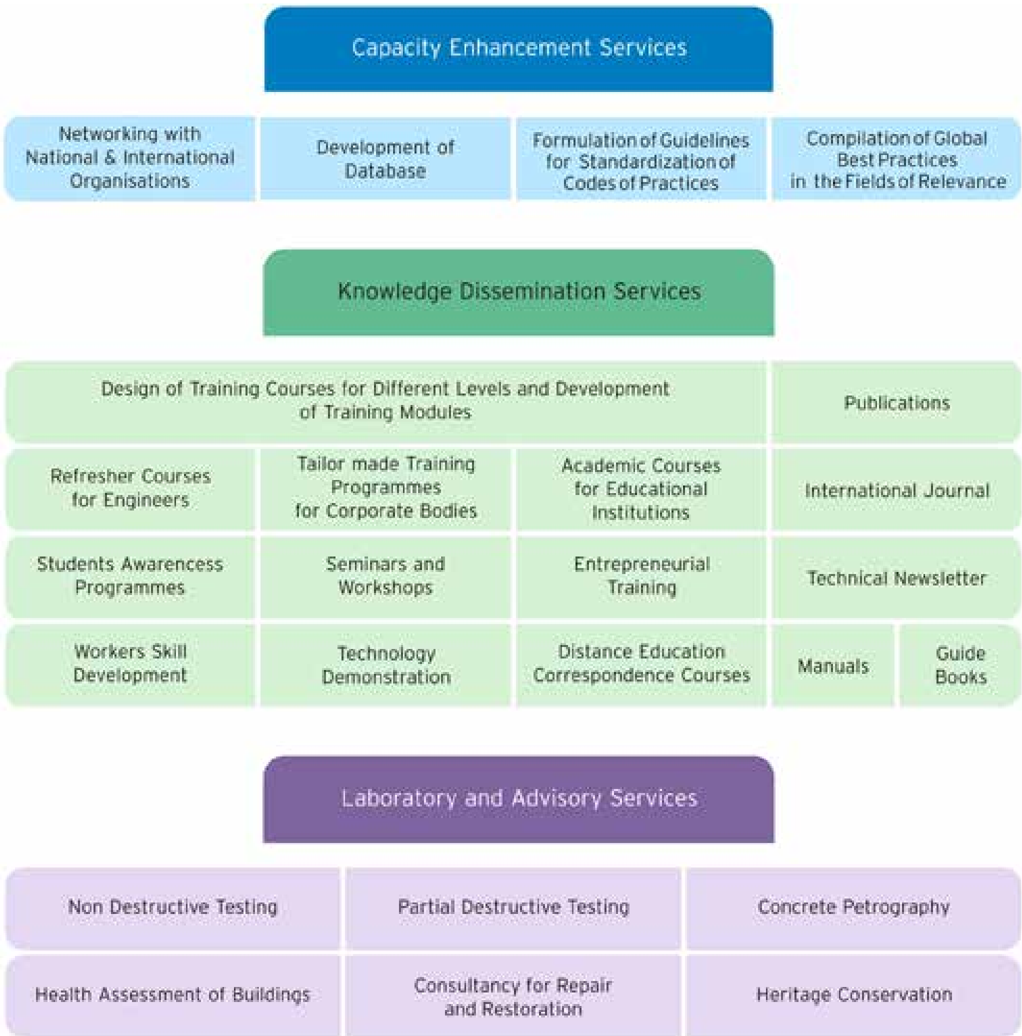

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