Best Practice Guide for Scanning Concrete Using Ground Penetrating Radar (GPR)

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Ground Penetrating Radar (GPR) is a valuable non-destructive testing method widely used in construction and infrastructure projects to scan concrete structures for the presence of utilities, services, and reinforcement bars (rebar).

GPR technology uses electromagnetic waves to penetrate concrete and produce a subsurface image, making it an essential tool for ensuring safety and efficiency in construction and renovation projects.

This best practice guide will provide guidelines on the effective use of GPR for scanning concrete to locate and communicate the position of services, reinforcing and other Embedments.

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1. Introduction

Scope

This best practice covers the use of ground penetrating radar, and other non-destructive scanning and locating tools over concrete to take ***Locates*** of objects, hazards, and risks embedded in or attached to a concrete element or geometry such as concrete thickness and basic construction details.

It also covers the definition of ***clearance*** areas, absent of hazard or embedment.

This best practice is not intended to cover all aspects of GPR, EM or any other technology for durability, condition assessment, or any other applications.

It is also not intended to address interpretation of GPR data or all aspects of report creation or safety on site and during penetration of concrete.

2. Terminology

Concrete Scanning

The use of GPR, Electromagnetic or other hardware to non-destructively locate embedded objects, material boundaries and geometry of a concrete element.

Scan Area

The region in which an operator has completed multiple individual GPR, EM and alternative hardware scans to mark the position of and/or document ***Locates*** and any required or available ***Clearance*** areas.

A ***scan area*** may be the area around a proposed core hole, a requested area, or an area representative of a typical region of a structure.

Scan Operator

The individual or team physically on site, operating GPR and Electromagnetic locating equipment, marking or documenting results.

Client

The customer who commissioned the scan and would be the recipient of a report or other documentation.

Penetration Contractor

As most ***concrete scanning*** works is completed before cutting, sawing drilling, demolition or other penetration of the concrete, the ***penetration contractor*** refers both to the company, and the onsite worker who breaks the concrete surface in any way.

Locate

The position of one embedded object or surface, such as a reinforcing bar, post tension cable, change in material, or thickness measurement of concrete.

Locate Quality

Locate Quality is a measure of how certain the Position, Depth and Type is, it is informed by the limits of the hardware used, and modified by the opinion and experience of the Scan Operator.

Clearance

A clearance is an area inside and behind the concrete a Scan Operator has declared Empty of all embedded or hidden targets and hazards.

3. Equipment

GPR Equipment

Ground Penetrating Radar (GPR) is a non-invasive geophysical method used to inspect the subsurface of concrete structures. It is beneficial for locating utilities, services, and reinforcement bars within concrete, and for measuring the depth of material changes such as between concrete and air or ground interfaces.

Frequency

Higher frequency GPR will provide better resolution (a sharper image with more distinction between resolution) but penetrate to a shorter depth. Lower frequencies offer deeper penetration but reduced resolution.

Typical GPR hardware for Concrete Scanning applications will have a practical maximum penetration of 350-700 mm. ***Scan operators*** must confirm in each ***scan area*** the maximum depth they can identify a clear target and not provide ***clearance*** deeper without more information.

Larger cart-mounted GPR with lower frequency content may provide deeper penetration, but radar performance limits or prevents the location of individual, small-diameter targets at this range.

The location and depth penetration limitations of GPR cannot be overcome where the physics of material permittivity, target size, depth, or material mean targets cannot be found.

Antenna Footprint

The antenna frequency often determines the footprint of the antenna. A smaller antenna may allow for better access to congested scans, such as in closets and close to walls.

Scans of 20 cm or less should be treated carefully, if an antenna cannot be passed over a point of interest, only indirect information is available for interpretation, ***Locate*** and ***Clearance Quality*** will be lower.

User Interface

Scan Operators must understand the functions of their chosen GPR system for data collection, processing, and interpretation. This may include settings of Gain, Dielectric, Background Removal, Zero Point

Limitations

1. GPR technology alone does not provide meaning on what Type of target has been located, an operator must not rely only on the shape and intensity of a single GPR reflection.
    a. Type is commonly confirmed by the pattern of many GPR reflections in multiple lines of GPR data, interpreted along a ***scan operators'*** understanding of how a similar structure is constructed, engineering drawings, visual evidence and/or complimentary hardware such as EM location tools.
2. GPR is most effective at locating metallic Embedments.
    a. Non-metallic targets are visible, but the apparent strength of the reflection may be 50%, 30% or less of a similarly deep object made of metal.
    b. Some of the most important and dangerous hazards may present as a weak reflection in GPR Data.
3. Densely packed reinforcing stops the signal passing behind, hiding targets deeper.
    a. In some cases, both sides of the concrete may be scanned.
    b. Without penetration past first layer, a ***scan operator*** cannot be declared a full depth ***clearance***.
4. GPR Hardware with Passive Power Cable Detection are limited to locating shallow electrical services which are energised and connected to a sufficient current draw.
    a. If a power cable is Live, but not connected it will not provide signal to a Passive Power Cable Detection sensor.
    b. Operators must not consider absence of Passive Power Cable Detection as indicating there is no power conduit inside or beneath a concrete element.
5. Accurate depth measurement with GPR requires the correct “Dielectric Constant” settings.
    a. Depth measurements with GPR that has not been adjusted for a Scan Area is always approximate, and Depth ***locate quality*** is low.
    b. The operator should be aware of how their GPR presents the zero point and, hence, the accurate position of the top of the target. This can be difficult with polarised data display, and a working knowledge of an A-scan is required.
6. Potential sources of interference include high moisture content, shielding by impervious materials (i.e. floor coverings, metal plates, grates and boxes), steel fibre-reinforced concrete, radio signals, airwaves, and high dielectric admixtures, aggregates or linings.

Other Sensors

Whenever possible, corroborate GPR findings with other non-destructive testing methods, such as electromagnetic wands, cover meters and position-locating equipment for transferring position above and below the slab.

Calibration and Quality Control

To maintain the accuracy of GPR data, calibration and quality control are necessary:

Regular Calibration:

Calibrate the GPR equipment regularly according to the manufacturer's guidelines to ensure accurate distance measurement (wheel encoder) and data quality.

Quality Assurance:

Establish a quality control process to check and validate the GPR equipment's performance periodically.

4. Definitions

Locate

The position of one embedded object or surface, such as a reinforcing bar, post-tension cable, change in material, or thickness measurement of concrete.

A locate is the Position, Depth and Type of target, interpreted by the ***scan operator***. It will also have an implied or explicit ***locate quality***. A Unique Identifier may also be useful for communication, reporting, or digitising.

A ***locate*** is most commonly drawn on the surface of the concrete, e.g. "Black Line for Rebar"(Position is where the black line covers, depth is unknown unless annotated, and the Type is Rebar).

A ***locate*** would also include notes in a report of the structure detail, e.g. "Slab is 200 mm thick"(Position is the area of the Slab, Depth is 200 mm, Type is Concrete Thickness).

Locate Quality

Locate Quality is a measure of how certain the Position, Depth and Type are. It is informed by the limits of the hardware used and modified by the opinion and experience of the Scan Operator.

Client and Scanning Contractors will assume that a Locate has 100% certainty unless informed otherwise. All implicit Locates must be 100% certain of Position and Type. Depth is implicitly "Unknown" unless written.

An Uncertain Locate quality is best stated by multiple Types and Hazard Warnings. For example, a wide "Potential Power" mark in regions a GPR or EM wand’s Passive Power Location triggered.

The precision of the depth of a locate is controlled by the technology used. GPR is typically no better than ±5-10 mm, EM location wand worse, and some technologies like Cover Meter better.

When uncertain, ***locate quality*** should be Explicitly stated, for example, "Potential Rebar, PT or Hazard" rather than "Rebar".

Clearance

A clearance is an area inside, and behind the concrete a ***scan operator*** has declared empty of all embedded or hidden targets and hazards.

Areas without a ***clearance*** have not been declared empty and should not be penetrated.

A clearance has an Extent, Depth and must have an explicit ***clearance quality***.

Clearance may be indications of core hole location with diameter, an "empty" Box that has been confirmed as clear, or

A ***clearance*** may also be instructions on what distance from l***ocates*** marked inside a comprehensively marked Scan Area may be considered empty.

A Unique Identifier may also be useful for communication, reporting or digitising.

Clearance Quality

Clearance quality is a measure of how certain the Extent and Depth of a ***clearance*** is, it is informed by the limits of the hardware used and modified by the opinion and experience of the Scan Operator.

Clearance quality is best given as facts, for example if the ***scan operator*** has confirmed a GPR system has penetrated a whole concrete Element and is certain there are no targets in their ***clearance***, communicate "Scan clear to full depth".

Another example; a dense rebar layout close to the surface of a concrete beam has the potential to hide Objects or Hazards below, communicate "Scan clear to First Rebar" and make sure the ***penetration contractor*** has this information, or consider an alternative ***clearance*** location.

If you do not have proof a machine has scanned the full depth of a scan, you must not communicate "scan clear to full depth". ***Clearance*** quality is defined first by hardware performance, without proof, extra scans, or other hardware the ***scan operator*** must not provide ***clearance*** beyond a machine limits.

In this situation an operator may need to confirm the element thickness visually, scan again from below, use alternative tools, or provide the depth of the last certain locate signal so the ***Penetration Contractor*** may work to protect their safety and the structures.

Clearance Quality may also contain visually confirmed facts such as “clear beneath”.

Pre-Scan Preparation

Before using GPR to scan concrete for services and rebar, it's crucial to prepare thoroughly.

Scan operators should work from an expected list of Embedments and Hazards, marking or documenting ***locates*** of all targets and then selecting ***clearances***.

5. Site Assessment

- Identify the scanning area and establish the project's goals and objectives this is best achieved by meeting with stakeholders i.e. the client, owners, trades etc.
- Review available construction drawings, as-built plans, and other information.
  - Perform a walk around the structure, noting lighting, plant, as well as structural features, obstructions and surface finish.
    - This should be performed above and below the scan area if possible. Particular note should be taken of hazards, tight scanning areas and sources of interference.
- Perform long(several meters) reconnaissance GPR scans in all directions.
  - The purpose of reconnaissance is to understand the structures' construction. Try to identify rebar layouts, Post Tensioning Tendons, Conduits, Beams and any other details. They may pass into a required ***scan area***.
- Assess the exposure and condition of the concrete. High moisture or contaminant levels, as well as the concrete's age, are of particular concern.

6. Data Collection

Proper data collection is the core of successful concrete scanning with GPR.

With GPR results a blank scan does not show nothing, it shows that nothing has been located.

If a ***scan operator*** cannot find evidence of an expected target, it does not mean it is not inside the scan area; it means it has not been found.

In this situation, the Scan Area should be expanded, and further long scans taken to locate expected targets in nearby concrete.

Line Scanning / B Scanning

A line scan is the typical image produced by a GPR. It is a side elevation through the slab over the line of the scan. Line scans can be viewed in both standard and migrated views. The user would typically scan in both directions (X and Y) over the area of interest. The scan pattern must ensure that all targets that could be reasonably seen by the GPR are crossed.

Where clearing a slab penetration site, at least 3 scans should be performed over the location in both directions at least 1-1.5m long. If the scanning indicates the penetration must be moved, the process must be repeated in the new location.

Area Scanning / Grid Scanning / C Scanning

An area scan is performed by projecting or drawing an XY grid over an area. Typical line spacings are 100mm, but smaller spacing may be required where targets are at an angle to the scan line. Area Scans can be performed quickly with multi-channel GPR.

Area scans are good where a layout is complex with diagonal or curved targets. They are also very useful for projects requiring a report.

The user must be familiar with the setting required to produce area scans, paying particular attention to the dielectric and the presence of artefacts.

Metadata

Record essential metadata, including the date, time, location, and equipment settings for each scan. Take photos of all ***scan areas*** and record notes on each ***locate*** and ***clearance*** within them.

Scan data should be stored after the project for review where necessary.

7. Data Interpretation

During and after collecting GPR data, the interpretation process is vital for extracting meaningful information.

Interpretation Expertise

A Scan Operators expertise and experience must be sufficient to identify utilities, reinforcing and other targets within the concrete with confidence.

They shall be able to identify rebar, metallic pipes, non-metallic conduit, post-tensioning, pre-tensioning, beams, columns, footing, toppings as well as the base of the concrete.

Analysis

Identify potential targets, hyperbolic reflections indicate circular objects within the concrete, flat reflections layers, and abnormal reflections from irregularly shaped reflectors.

A comparison of multiple parallel lines of data must be used to confirm the direction of linear targets.

Visualisation tools may assist to create subsurface images, depth slices, AR projections, and 3D renderings. These tools help in understanding the location and orientation of services and reinforcing.

8. Marking and Reporting

Accurate marking and documentation are essential for project management and decision-making. Follow these best practices:

Marking

The purpose of marking is that a ***client*** or ***penetration contractor*** can understand the position of ***locates***, and the cleared, empty regions indicated by ***clearances***. Marking must make explicit:

- The Position, Depth and Type of locates, along with ***locate quality*** information.
- The Area, Depth and ***clearance quality*** of ***clearances***.

Looking only at the marking an observer should be able to understand the position of all positively located targets, and if there are any 100% empty regions ready for penetration.

Where expected targets were not located, hazards are located or the ***Scan Operator*** has any uncertainty this must also be clear from marking.

Client and Penetration Contractors make critical safety decisions on ***Scan Areas*** and must understand where there are risks.

Reporting

Where appropriate, detailed reports should be provided to all stakeholders documenting the scanning area, scan results, data interpretations, and any identified hazards or utilities.

Digital Documentation

The GPR operator and their employers shall maintain digital records of all scans, interpretations, and findings for future reference and audits. Where possible, the information shall be stored as a digital twin of the structure for future works and decision-making.

Collaboration:

Collaborate with other stakeholders in the project to ensure that the GPR results are incorporated into the construction or renovation plans.

9. Conclusion

By following the best practices outlined in this guide, a ***scan operator*** can ensure clear communication of findings and risks to all stakeholders.

Comprehensive site assessment, proper equipment selection, methodical data collection, expert interpretation, and thorough marking, documentation and communication are crucial to achieving success with GPR concrete scanning.