Introduction
This document provides an overview and methodology for scanning concrete with Ground Penetrating Radar (GPR), as it applies to the sawing and drilling industry.

GPR is an accepted and routinely used nondestructive method for imaging objects in concrete prior to cutting or coring. It is a safe application of radar regulated by the Federal Communications Commission in the U.S.

Fieldwork typically requires one operator. Imaging results are generated on-site for immediate mark out and analysis of targets in the selected area. The inspection, under normal circumstances, can be performed on one side of the slab, which permits slab-on-grade scanning. Some common applications of GPR include, but are not limited to:

- Locating reinforcing bars
- Locating post-tension cables
- Locating metallic and non-metallic conduits
- Detecting voids beneath slab-on-grade
- Slab thickness and cover depth to targets

This document covers methods of scanning, data interpretation and practical considerations when using GPR on a job site. This document is to be used as a general guide. GPR system operation will vary between manufacturers and models. It is very important that every operator of GPR equipment be trained and certified by the manufacturer of the equipment for the proper use of the equipment. The operator should, as a minimum requirement, have completed manufacturer training. The operator needs to know the limitations of the equipment and be able to interpret the data from the scans.

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1. Background Theory
GPR works by sending VHF and UHF radio waves into the subsurface (concrete) and measuring the travel time for the returning reflection (Figure 1). Reflections are caused when the GPR wave encounters a material with a different dielectric constant; or to put it simply, a change in material. Rebar, post-tension cables, conduits, bottom of slab and voids all generate reflections that are detected and shown on the GPR display. By continually moving the GPR antenna or antenna array along the concrete, you generate a cross-sectional view of data called a ‘line scan’. By systematically collecting several line scans of data in the X and Y directions, a ‘grid scan’ is performed. Line scan and grid scan are the primary methods for acquiring GPR data, and these methods will be explained in the next section.

![GPR wave reflecting off an embedded object](image)

**Figure 1: GPR wave reflecting off an embedded object**

1.1. Frequency
GPR antennas/transducers come in different frequencies, measured in Megahertz (MHz). This number refers to the center frequency of the antenna or antenna array at which most of the energy is concentrated.

In general, for radar technology, waves of higher frequency give better resolution but have limited penetration depth, as they attenuate faster. Conversely, waves of lower frequency allow you to see deeper into the concrete but cannot resolve finer features as well as higher-frequency waves. This trade-off between resolution and depth is the key trade-off of radar technology.

While this trade-off is given by physics, the performance of a GPR system is also related to the performance of its electronics: i.e., by its bandwidth and signal-to-noise ratio. The wider the bandwidth, the higher the resolution. The higher the signal-to-noise ratio, the clearer the data/image, and the larger the penetration depth. As a result, GPR systems with higher signal-to-noise ratio and wider bandwidth demonstrate better imaging capabilities.
1.2 Material Properties
The GPR response is governed by the physical properties of the material. Properties of the concrete such as electrical conductivity, aggregate size, air entrainment, water content and admixtures will impact the depth of scan capabilities. If a material is electrically conductive (such as relatively uncured/green concrete or saltwater), the electromagnetic energy of the radar waves is absorbed before it can travel very far into the material. As a rule of thumb, the greater the water content of the concrete, the greater the conductivity and the more difficult it will be to penetrate with GPR.

The upper limit for most practical work in concrete is 28 inches (700 millimeters), but quite often the limit will be less than this due to the aforementioned factors.

2. Line Scan
Line scans generate a cross-sectional view of data and a plan view, depending on the equipment manufacturer. Most GPR systems create the cross-sectional image in real-time as the GPR antenna or antenna array is pushed across the surface (Figures 2 and 3). In the cross-sectional image, position is displayed along the horizontal axis and depth along the vertical axis.

In relatively simple situations, line scan mode provides a fast method to locate objects. However, the line scan may require more interpretation than the grid scan mode. Line scan mode should be used as a reconnaissance scan when you first arrive at the job site. Even on sites where a grid scan is required, line scan can still provide additional helpful information such as target orientation. It is very important to know the target orientation, so the grid scan pad is properly aligned.

2.1. Settings
It is important to make sure that the parameters are set properly when collecting line scan data. Set the depth window or depth scale to ensure that everything in the slab can be seen. It is a good idea to set your depth to be at least 50% deeper than the expected depth of the objects. For example, if your slab is 10 inches in thickness, set your depth window to at least 15 inches.

The ‘Gain’ setting is used to highlight weaker targets that are usually found deeper in the concrete. It is designed to make deeper targets appear as bright as shallow targets. It is important to select an appropriate gain level without over-gaining (or clipping) the shallow data, and thereby making the image harder to interpret. Start with a low gain setting and then increase as necessary. Some GPR systems can automatically gain this data. Furthermore, some GPR systems provide an ability to change gain along the range axis that allows gaining data with a preference towards greater depths.
2.2. Operation

The GPR antenna or antenna array should be held in contact with the surface to achieve the best coupling and highest data quality. Air gaps between the bottom of the GPR antenna or antenna array and the surface reduces penetration into the concrete.

An example of line scan data is shown in Figure 3. The spikes that resemble inverted U’s are called hyperbolas. These are generated when the GPR antenna or antenna array crosses an object in the concrete, preferably at a perpendicular angle. If you cross an object at an oblique angle, the hyperbola widens (Figure 4). This is not desirable, as the clarity of the hyperbola diminishes and can lead to inaccurate depth estimates (more on this below). The solid black line mid-way down the screen corresponds to the bottom of a suspended slab.
Figure 4: Ways to cross a target (left)

Figure 4a: GPR line scan showing perpendicular and oblique crossing (right)—Notice how the hyperbola on the right is wider

Figure 4b, Data is of an antenna array collected line scan. Normal hyperbolas are shown as processed in the bottom half of the screen. Array data is shown on the top half of the screen detailing perpendicular targets as well as oblique (angled) targets.

All GPR systems contain a distance measuring encoder. Data is displayed in real-time as it is collected. To locate a target, simply pull the GPR system backwards. The distance measuring encoder will detect reverse motion, and an indicator will appear on the screen that shows the antenna position relative to the data (Figure 5).

It is important that the distance measuring encoder be periodically calibrated to ensure accuracy. Calibration involves pushing the GPR antenna or antenna array over a known distance. Follow the GPR manufacturer's calibration procedure or recommendations.
2.3. Determining Object Depth and Concrete Velocity (Dielectric Constant)

GPR systems measure the time it takes signals to travel into concrete, reflect from an object and return to the surface. To convert time to depth and measure the depth of an object, an accurate GPR velocity in the concrete must be determined. The velocity of the GPR wave in concrete will vary between different concrete pours, and is a function of the water content, aggregate type, admixtures and air entrainment. Some GPR systems may work on determining the dielectric constant instead, which is related to GPR wave velocity.

Follow the procedure below:

a. Always determine the depth of an object using line scan data (not from grid scan images).
b. Ensure that the line scan image has crossed the object perpendicularly, not obliquely.
c. Extract the velocity of the GPR wave in the concrete (or the dielectric constant of the concrete). Once the depth scale is generated based on the GPR velocity / concrete dielectric, the depth of the object can be read off the depth scale.
d. The best way to ensure the velocity/dielectric is accurate is by measuring the actual depth of an embedded object, or by measuring the slab thickness. If this is not possible, a computer processing technique called migration or hyperbola calibration can be used (Figure 6).
Figure 6: Hyperbola calibration to extract concrete velocity when not matched correctly (left), and when matched correctly (right)

NOTE: After fitting the hyperbola shape and moving it to the top of the hyperbola, the GPR velocity (or dielectric) of the concrete is displayed, as well as the approximate depth of the object. The hyperbola shape is determined by the velocity or dielectric constant. GPR systems incorporate software tools to derive the GPR wave velocity from the hyperbola shape.

A computer-generated hyperbola (the blue curved line or the yellow shaded areas in Figure 6) is first placed over an actual hyperbola. The 'tails' are moved in or out to best approximate the shape of the actual hyperbola. Fitting this hyperbola depends on two main factors: locating the top of the hyperbola and fitting the shape properly. Finding the top of the hyperbola depends on the data quality and target congestion. In complex situations, picking the top can be quite difficult. Fitting the shape of the hyperbola is dependent on how you determine a best fit. There is some interpretation involved, and accuracy is dependent on your consistency and attention to detail.

By matching the shape as accurately as possible, the GPR velocity / dielectric of the concrete is determined as well as the approximate depth of the object. Velocities are typically between 85 millimeters per nanosecond and 135 millimeters (3 to 5.5 inches) per nanosecond in concrete. If
using dielectric constant, values typically fall between 4 and 15 depending on the moisture content of the concrete (less well cured slabs will have a dielectric constant closer to 15 while older, well cured concrete will be closer to 4). The lower the dielectric constant of a material, the higher the GPR velocity, and the larger the achievable penetration depth.

Generally, absolute depths will have a tolerance of +/- 5–10%, while relative depths (between objects) will have an accuracy of +/- 1%, provided that the wave velocity / concrete dielectric has been calibrated accurately.

Some GPR systems are capable of automatically migrating data, and some are capable of doing so during measurement. Migrated data should be verified by the user. Check with the manufacturer to determine system capabilities.

3. Grid Scan
Grid sizes can vary, but the most common is the 24-inch by 24-inch (or 600 by 600 millimeter) square grid. The grid acts as a template to guide the scanning and reference objects back to the concrete surface. The grid should be centered on the area under consideration and oriented as perpendicular to the target object(s) as possible. Line scan mode (as described in Section 2) can be used to determine the general orientation of the object.

Once the grid is fixed to the concrete, you should set the parameters for the grid collection. Follow the same example from the line scan section (Section 2) and set the maximum depth to deeper than the deepest expected target. The on-board software will guide you to collect the lines on the grid in both directions (Figure 7). For each line, it is very important to ensure the starting position of the antenna or antenna array head is accurate and consistent from line to line. Push the antenna or antenna array straight along the line until it is complete. If there is an obstruction preventing the operator from finishing the line, the line will have to be prematurely ended and you should continue on to the next line.

Upon completion of all grid lines, process the data to generate plan maps. Ensure that the correct velocity is used before proceeding. Once the processing is complete, a series of plan maps will be visible on the GPR system screen. Each plan map shows a specific depth range (e.g. 1 to 2 inches), from which you can cut through and gain an idea of where objects are located (Figure 8).
If there is any doubt as to the authenticity of an object, it should be checked against the line scan data that composed the grid. If a hyperbola is visible in the line scan data, it should correspond with a target in the plan map. This acts as a 'sanity check' and is a good way to confirm what you are seeing in the plan maps. In Figure 9, the arrows show how the hyperbolas on the horizontal line scan manifest themselves as targets on the plan map view. Some GPR systems enable you to switch quickly between the line scan data view of each line, enabling the same investigation as the plan view.

Some systems allow you to superimpose a drill core over the grid, so you can visualize a safe place to core (Figure 10).
NOTE: Mark all objects on the concrete.

4. Practical Considerations
Understanding how to use GPR is an integral part of successful scanning, but it is as equally important to consider the practical side of being on-site and properly surveying the cutting area. Every site is different, and the following are some guidelines to keep in mind:

4.1. Before arriving at the jobsite, the following are some questions to ask the customer:
- Why does the customer need the area scanned (cutting, coring, or other)?
- How old is the concrete (wet concrete is a GPR limitation)?
- How thick is the concrete?
- Will the area be free of obstructions?
- Are there special safety considerations to be met?
- Is the scan area on a column, wall or ceiling?

4.2. When you first arrive at the site, a walk around should be performed. Useful information regarding the structure to be scanned will prove valuable when reaching conclusions about the targets in the scan area. Below are some good questions to ask once on site:
- Is the area to be scanned a slab on grade or a suspended slab?
- Is the underside of the slab or wall accessible to scan?
- Are there conduits connected to the underside or backside of the slab?
- Do any as-built drawings exist (keeping in mind, these maybe incorrect)?
- Could there be electrical conduits in the concrete?
- Could there be radiant floor heating in the slab?
- Has the concrete been scanned before (past problems)?
- How was the structure constructed (i.e., pan deck, pre-cast, post-tension, filigree or terrazzo)?
- Is there a support beam under the slab?
4.3. Make sure the floor/wall is clear of any debris that could interfere with scanning and the placement of a grid. Sweep the floor in the area to be scanned. Dusty or gritty surfaces can also cause a problem when taping down the grid and preparing for a grid scan.

4.4. When doing grid scans, align the grid properly, taking into account where the core needs to be located, the orientation of the rebar and any surface obstructions. Align the grid in such a way that you are always running GPR lines into an obstruction, rather than starting close to one.

4.5. Typical grid scans are 24-inch by 24-inch, but larger grid scans may give you the 'bigger picture' of what is located in the slab.

4.6. Use line scan mode to measure depth to targets, and to locate interfaces (bottom of slab).

4.7. Sometimes it is permissible to cut reinforcement. No GPR operator should offer anything more than an estimate when it comes to differentiating between rebar, post-tensioning and electrical conduit. Look for telltale signs of objects that deviate from the rebar pattern. Post-tension cables tend to be draped between columns, starting high near the beam/column line and draping progressively lower towards the center point between beam/column lines (the point of greatest slab deflection). Conduits may curve and take the most direct path from A to B. Non-metallic conduits also return a lower strength signal than metal objects and rebar.

4.8. When you have located all targets, the information should be marked on the floor. One way to do this is to punch holes in the grid and fill them with a marker. When the grid is lifted off you will be left with a series of corner reference points. Refer to CSDA-BP-017 for the proper markings.

4.9. Certified operator training is critical to the success of any concrete scanning project. You must have a firm understanding of the technology, the equipment, its strengths and limitations. Communication of the equipment’s capabilities and limitations must be clear to the end client, thus preventing the danger of overselling the technology.

5. Limitations
Some common limitations encountered when using GPR:

5.1. GPR does not measure diameter of objects, just their location. When marking information from hyperbolas in line scan mode, allow some margin on each side of the marks. Refer to CSDA-BP-017 for the marking of embedments. When viewing plan map images, remember these are pseudo-images. If the floor is marked as wide as the object width on the screen, this indicates to the coring operator to stay clear of that width when coring.

5.2. Bottom of slab is sometimes not easy to see in slab-on-grade situations. This is due to the interference of the wire mesh and the weak reflection from the concrete-gravel base interface.

5.3. GPR should not be performed on areas where standing water is present.
5.4. Because GPR is usually performed with one-side access, additional targets may lie in the "shadow" of targets nearer to the surface. Items such as conduits and post-tension cables may be directly underneath rebar and cannot be imaged with GPR.

![Diagram showing antenna direction and shadow effect on rebar and PVC under steel.]

5.5. A limitation distance adjacent to an obstruction (walls, conduits, studs, etc.) is present with GPR devices due to the orientation of the internal transmitter/receiver. Each limitation is unique to the specific devices of individual manufacturers.

5.6. Each GPR antenna or antenna array cannot image through metal wire mesh/metal fiber with specified spacing (i.e., chicken wire mesh). Consult with the manufacturer to determine these limitations specific to each antenna.

![Diagram showing antenna direction and 3" Topping Slab, 10" Precast with hollow cores and cables, and notes on bottom cables being difficult to see due to multiple target reflections above.]

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5.7. GPR cannot image through foam used within slabs or on roofs. On roofs, these areas need to be opened up by a qualified individual a minimum of 1 foot larger on all sides than the intended scanned area. For example, a required scan area of 2-foot x 2-foot should be opened to at least a 4-foot x 4-foot area. Foam placed internally in a slab requires scanning from both sides of the deck.

5.8. Ability to image on opposing side of air voids in concrete (i.e., hollow core slabs, CMU block walls) cannot be performed. Access to the opposite side is required to complete the scan.

5.9. Locating metal and PVC conduits in the “valleys” of corrugated steel decks is difficult and in some circumstances impossible. Efforts should be made to avoid drilling into these “valleys”.

5.10. Relatively uncured concrete is difficult and sometimes impossible to image due to the electrical conductivity of the material. Depending on concrete thicknesses and cure time it is recommended that no scanning occur within a minimum of 30 days after pouring. This time may need to be adjusted on a case-by-case basis and depending on the signal-to-noise ratio of the GPR system to be used.

Example of data collected from green concrete. Note that targets closer to surface are clearer than deeper targets.
5.11. Because GPR transmits a radio frequency, use of GPR falls under FCC Title 47 CFR15.5 “that devices may not cause interference and must accept interference from other sources”. Jobsite conditions may have radio frequencies from cell phones, two-way radios or other devices that may cause temporary interference.

6. Liability
Like any investigative tool, GPR is not perfect. It is subject to your interpretation skills and the physical limitations of the equipment. Regardless of the quality of the equipment, or how skilled you are, there are situations that just cannot be overcome (e.g. freshly-poured concrete, or steel-fiber-reinforced concrete). In addition, proper measurements must be taken when translating information from the GPR system to the floor.

It is important for you to understand this limitation and convey this to customers. It is recommended that you have a disclaimer included in the sub-contract or job form.

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