Uncovering the Hidden Secrets of Concrete: What GPR Can (and Can't) Reveal

Gain optimum results from your non-destructive testing of concrete structures

Ground penetrating radar (GPR) has quickly become a popular non-destructive method for concrete investigations due to its range of industry uses, from simple hit prevention to structural capacity analysis. GPR is the ultimate tool for object mapping in reinforced concrete, producing clear images of metal objects such as rebar or post-tensioned cables. GPR works so well at mapping reinforcement that sometimes the limitations on what it can and cannot find are forgotten. This can lead to incomplete information on what lies in the concrete. It is important to recognize the science behind a GPR scanning device to understand its capabilities and limitations, and what it can do for the operator.

GPR devices consist of one or more antennas containing a transmitter and receiver. The transmitter emits electromagnetic waves into the concrete and when the waves encounter material boundaries, a percentage of wave energy is reflected and received at the antenna. Reflection times and energy are recorded and when data is collected over a distance, a cross-sectional image of the concrete is made (Figure 1). Objects often display as hyperbolas, because as the device moves closer to the object, the arrival time of the returning wave decreases. When the device is directly over the object, the arrival time is the shortest it will be, which creates the hyperbola peak. As the device rolls away, the arrival time increases, and the second half of the hyperbola is formed. If the object is not a single point but constant over the scan length, like the opposite side of the concrete (backwall), there is no hyperbola formed. Instead, a constant reflection arrival time appears like a band on the cross section.

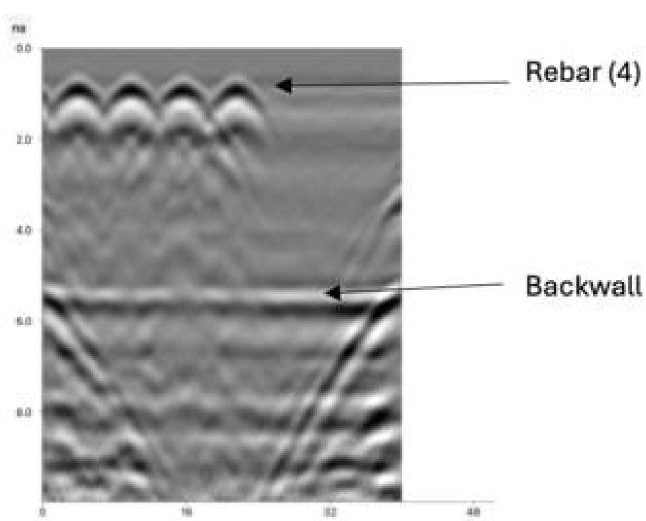

Figure 1: Typical GPR image, called radargram, with rebar and backwall

While waves reflect when encountering a material boundary, the crucial point is that wave reflection depends on a single material property — dielectric constant. Dielectric constant, or relative permittivity, is how well a material conducts electricity. Concrete typically has a value range of 7 to 12, depending on the mix design and water content. If the radar wave intersects with a material that has a significantly different dielectric constant as it travels through concrete, a portion of the wave energy will be reflected based on the extent of the difference. Metals are a fantastic electrical conduit and have an infinite dielectric constant. This infinite difference between concrete and is the reason for the strong return signal and clear hyperbola for steel reinforcements such as rebar.

Some other common materials found in concrete are air and plastic. Air can either be the opposing side of an elevated slab or a substantial internal defect like a lack of consolidation, honeycombing, or delamination crack. Air has a dielectric constant of 1 so the reflection is weaker than metals but is often still visible on the scan. However, these reflections are rarely clean hyperbolas. The opposing side of the concrete will appear as a banding as discussed previously. A void is rarely nicely shaped, and the hyperbola will more likely appear distorted (Figure 2). Plastic is commonly used for electrical conduit and has a dielectric constant of about 4. The difference between concrete and plastic is much smaller than other materials and is more difficult to pick out of a GPR scan due to its weak signal.

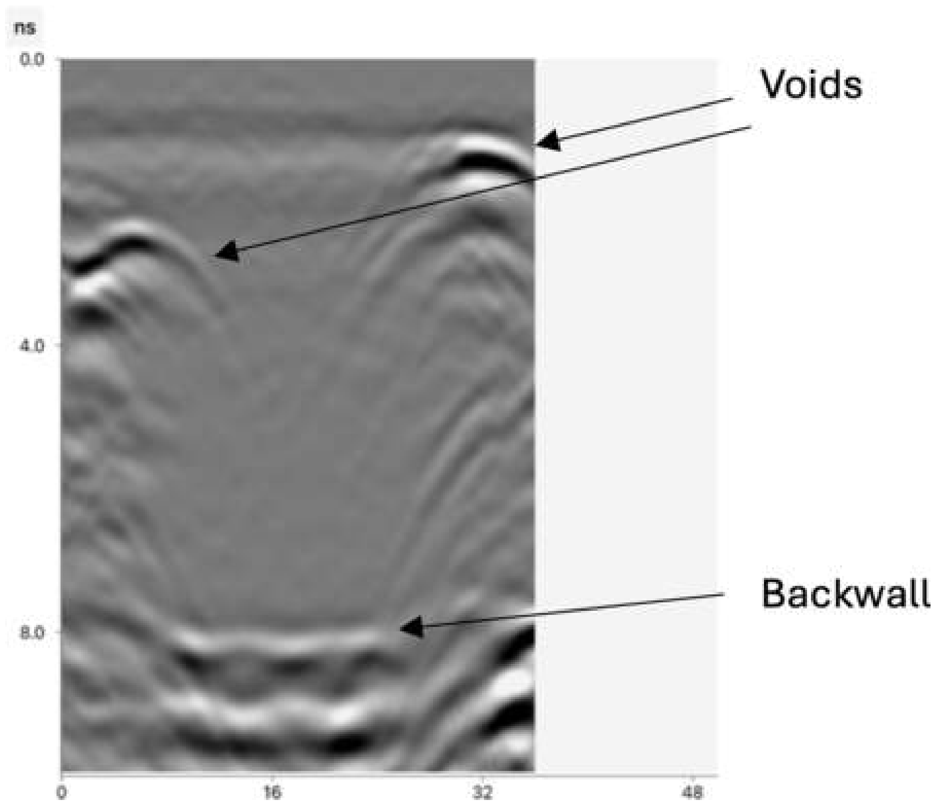

Figure 2: GPR scan showing air in concrete

Consider the equation below for the propagation velocity of a wave. Arrival time is measured by the device, and speed of light is a known value. If the dielectric constant is estimated, either by using hyperbola matching or calibrating off a known depth, the depth of any object can be calculated. Since the dielectric constant of concrete has a large range, it is important to calibrate for different concrete mixtures.

Equation 1:

$$v = \frac{d}{t} = \frac{c}{\sqrt{\varepsilon}}$$

Where;

v is the velocity of the wave

d is the distance to object

t is the arrival time

c is the speed of light

ε is the dielectric constant.

The water content of concrete can also affect the dielectric constant and should be calibrated for. Water has a dielectric constant of 81, which is much higher than concrete. When concrete is saturated, the dielectric constant of the system increases, and the water will scatter the wave energy. This creates blurry images that are difficult or impossible to interpret. GPR should not be used on fresh concrete, as the technology is significantly limited until the concrete is fully cured and the water content lowers.

GPR visualization depth depends on several factors, including those related to the structure, concrete, environment, and GPR device. Metal objects reflect 100% of the wave energy, meaning the metal object will appear clearly, but nothing below the metal will be seen. This can be a problem for visualizing stacked rebar or objects running below the rebar grid (Figure 3). This is a major problem with steel fiber reinforced concrete because the fibers will not allow the waves to pass, so there will be no visual depth penetration. Tight spacing of rebar can also be a problem where the wave does not have the space to pass through a grid effectively (Figure 3). Again, this can disguise any underlying objects including the backwall, making thickness measurements difficult. Some GPR devices can perform cross polarization, which rotates the antenna orientation so that more wave energy can pass beside an object. This results in a hyperbola with shorter tails for metal objects but can allow for a cleaner backwall.

Additional factors determining potential depth penetration are the saturation and quality of concrete. When GPR waves interact with the water, energy is lost, and depth penetration is reduced (Figure 3). With low-quality concrete there are more voids and cracks present, each with an additional boundary to cross and corresponding energy loss due to the reflection. The worse the concrete quality, the less depth penetration will be achieved.

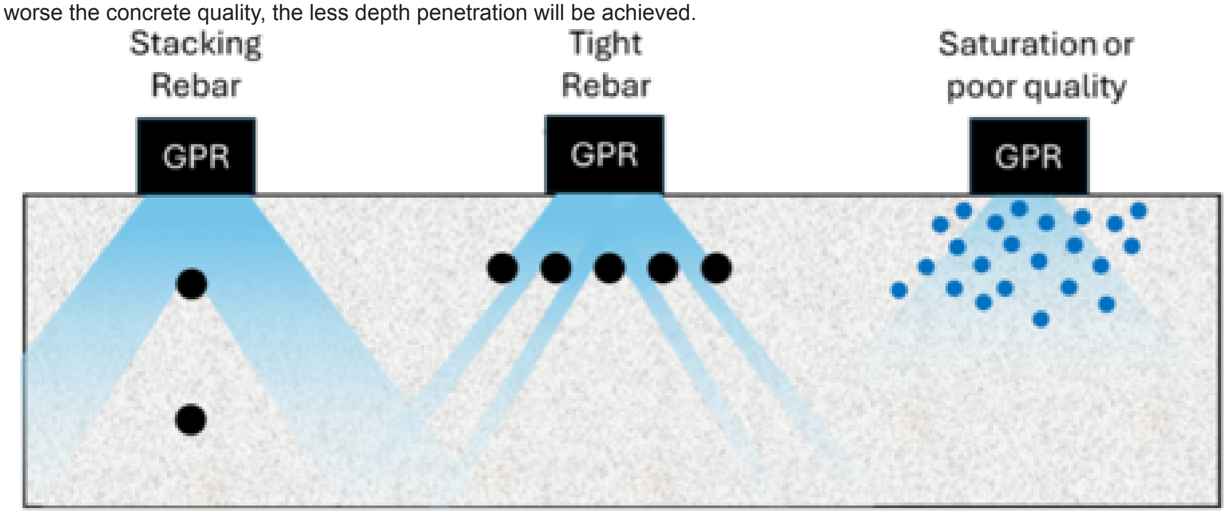

Figure 3: Factors limiting GPR imaging

There is some control available for depth penetration. When the transmitter emits electromagnetic waves, it is at a specific frequency, determining the number of waves occurring in a set period. This defines the resolution of the image. The higher the frequency, the better the resolution, but the shallower the depth penetration. Lower frequencies do not have crisp resolution but can image deeper objects. Some devices allow the user to choose the desired depth penetration by having multiple antenna options, each with a specific pulsed frequency. A newer method, called step frequency continuous wave, instead provides an ultrawide range of frequencies so that both resolution and depth penetration are achieved.

GPR is an excellent method for object mapping in the concrete industry. However, it is important to understand the limitations of the device, as well as the quality and condition of the concrete, to increase confidence in a scan. Calibrating the dielectric constant each time there is a change in concrete is critical for accurate depth estimations. Consider the quality and environment of the concrete to ensure the concrete is dry enough for a proper scan and to obtain desired depth penetration. Also, the chosen antenna frequency, either pulsed or step frequency, is important when prioritizing resolution or depth penetration.

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