Voids
The development of voids beneath roadways can lead to major pavement failures, a serious hazard. Voids typically develop because of subsidence and erosion of the base and subgrade materials. Void-related roadway problems have often developed near water supply pipes or drainpipes. Leaks, pipe breaks or dislocated joints allow fines to be carried away, resulting in local base or foundation erosion, and the formation of weak areas, which eventually become voids. Voids continue to increase in size until the load carrying capacity of the roadway is compromised.

Use of Ground Penetrating Radar (GPR)
The development of voids beneath roadways is a serious hazard, making their early detection an important aspect of infrastructure maintenance and remediation. Early identification of concealed subsurface voids under a roadway structure is critical to prevent major failures from occurring.

One of the most effective tools in use is ground penetrating radar (GPR). GPR has advanced to a level where the subsurface condition of a roadway can be diagnosed with confidence. GPR is a non-destructive geophysical device used for subsurface exploration and operates by transmitting an electromagnetic pulse from an antenna into the ground and then capturing the partial reflections from subsurface layers.

Interpreting Reflections
Interpreting these reflections includes measuring the arrival time and the amplitude and phase of the reflected signal. GPR technology is very effective in identifying areas with changes in physical properties, including potentially hazardous voids. Voids can be either air or water filled; each type of void has a very different GPR signature compared to typical highway materials.

Tomographic Imaging Using GPR
Tomographic imaging of subsurface pavement features using GPR has been pursued by TxDOT and the Texas Transportation Institute (TTI) for over two decades. The depth of GPR imaging depends on soil type and GPR antenna frequency. For example, clay soils with high moisture content will quickly attenuate the radar signal and decrease its depth of penetration.

NOTE 1: Use of high frequency antennas in the range from 1 to 2 GHz produces high resolution that can detect small anomalies, however, the depth of imaging is limited to approximately 2 feet.

NOTE 2: Use of low frequency antennas in the range from 10 to 400 MHz can penetrate tens to hundreds of feet, given soil conditions; however, the ability to locate small objects or anomalies is limited.
Antenna Frequency Requirements and GPR Systems
For highway pavements where the depths of interest vary from a few inches to 30 feet, two antennas may be required, one with a frequency around 1 GHz and one with a frequency around 200-400 MHz.

Depending on antenna type, GPR systems are classified as air-coupled or ground-coupled systems, as shown in Fig. 1A & B. TxDOT’s air-coupled systems (1 GHz) with the antennas 14 inches above the surface allow for highway speed surveys. In contrast, a ground-coupled system’s antenna fully contacts the ground, which limits the speed of the survey. The results presented in this article are limited to 400 MHz ground-coupled penetrating radar (GCPR) which scans approximately 10-20 feet of the top of the pavement structure (with typical Texas soils and degrees of saturation).

Interpretation of Ground-Coupled Penetrating Radar (GCPR) Surveys
TxDOT and TTI have successfully used the GPR technology to locate voids under roadway pavements. Both TxDOT and TTI own a 400 MHz ground-coupled penetrating radar (GCPR).

The GCPR surveys were performed at walking speed (~3 mph) by both TxDOT and TTI. The electrical properties (dielectric constant) of the subsurface layers influences both the magnitude and phase of the reflected signals.

In general, air voids and water filled voids are both detectable using GPR because the dielectric constants of air (1.0) and water (81) are substantially different from pavement materials [asphalt mix (4-7), Portland cement concrete (7-9), flexible base (7-10), cement-treated base (6-9)]. If the void is air-filled, a large negative peak will appear in the waveform. Conversely, a large positive peak in the waveform will appear when the void is water-filled.

Case Studies
The following are two successful case studies using 400 MHz ground-coupled penetrating radar (GCPR) to identify subsurface voids.

Case Study 1: A 6 ft. deep x 15 ft. long x 12 ft. wide Void Under US 290

Issues
TxDOT Austin District maintenance personnel observed the longitudinal joint for a continuously reinforced concrete pavement (CRCP) section had faulted and separated over a mechanically stabilized earth (MSE) retaining structure of US 290 in Southwest Austin. The fault and lane drop-off measured up to 6 inches and the joint separated up to 4 inches, as shown in Fig. 2. Example of Drop-off. Maintenance personnel applied a narrow asphalt concrete patch in the faulted area in an attempt to level off the affected area.

Concerns
The lane drop-off and longitudinal cracks near the MSE wall prompted district personnel to request an investigation to assess the safety of the structure and to determine if there were significant voids under the CRCP.
The main concern was the lane drop-off and longitudinal cracks near the inlet and storm drainpipe. These conditions may be associated with potential voids in the MSE structure backfill, making the MSE retaining structure unsafe.

**Tools and Methods Used to Gather Data**

A 400 MHz GCPR antenna was used to survey and map the subsurface condition. GCPR data was collected in the longitudinal direction parallel to the faulted joint and at selected transverse locations. The reflections from the rebar are readily visible as a series of hyperbolas as seen in Fig. 3A.

**Data Analysis**

A significant anomaly adjacent to the drainpipe was found, as shown in Fig. 3A. There is a clear change in the GCPR image at this location. The anomaly started directly under the CRCP. The anomaly showed a significant drop in material dielectrics. Based on the reflection pattern, a void was suspected.

The indication of the voids was an inversion of the GPR voltage, indicating a change in dielectric (high to low). There were inversions and significant negative reflections in the GPR image where the anomaly was located. Based on the GCPR image, the estimated size of the suspected void was significant.

While core samples were taken, a void approximately 6 feet deep, 15 feet long, and 12 feet wide was detected; the estimated void was approximately 1,080 ft.³ Fig. 3 displays graphics of the void. At the location of the void, the transverse storm drain had separated (See Fig 3C.). One theory is this separation caused water to erode the area around the drain resulting in fines being washed out through the drain.

A transverse storm drain was located underneath the concrete pavement near the end of the faulted joint. See Fig. 3A for GCPR data collected in this area. The GCPR data indicated an anomaly over the transverse storm drain as shown in Fig. 3.

**Data Trends**

Where the amplitude and travel time of the GPR return signals are continuous, it indicates areas are in good condition. However, where amplitude and signal travel time varies; the deteriorated area can be mapped.

**Conclusion**

In most cases, destructive testing such as coring is required for validation. Fig. 3C is a photo of a transverse storm drain that separated. It was verified that this separation caused water to erode the area around the drain. The resulting moisture intrusion in this area and moisture flow from the grassy median through the embankment into the void may have resulted in the embankment settling where the longitudinal joint faulted.

Fortunately, the disjointed storm pipe was identified before severe roadway failure occurred. Otherwise, the 1,080 ft.³ void could have grown in size until it eventually collapsed.

Figure 2. Example of Drop-off on Top of a Mechanically Stabilized Earth (MSE) Retaining Structure.
Case Study 2: A 135 ft.$^3$ Void Under Interstate 40 (I-40)

Issues
After a rainfall, Amarillo District maintenance personnel reported fines were observed on the I-40 pavement surface near a storm drainpipe. A typical cross section on I-40 consists of 6-inch hot-mix asphalt overlay on top of 8-inch continuously reinforced concrete pavement (CRCP). (See Fig. 4D.)

Near the location the fines were observed pumping out of the pavement was a storm drainpipe buried approximately 10 feet under the CRCP. Openings in the storm drainpipes were suspected for causing the washout.

Concerns
The Amarillo District personnel were concerned about roadway safety and requested a GCPR survey to determine if voids were under the CRCP. See Fig. 5 for the GCPR results. The reflections from the rebar are readily visible as a series of hyperbolas (See Fig. 5).

Data Analysis
A significant anomaly adjacent to the drainpipe was found as seen in Fig. 5. There was a clear change in the GCPR image at this location. The anomaly started directly under the CRCP. The anomaly showed a significant drop in material dielectrics. Based on the reflection pattern, it was suspected to be a void. Based on the GCPR image, the size of the suspected void was estimated to be significant.
Tools and Methods Used to Gather Data

A 10-foot steel rod was used to estimate the extent (depth) of the void. The 10-foot rod reached something solid at the depth of approximately 8 feet. This means there was over a 6-foot deep void immediately under the CRCP. One-inch diameter holes were drilled in other locations; no voids could be found.

Conclusion

Figures 4A and 4B show a 2-foot by 2-foot hole that was cut in the pavement at the void location. The purpose of the two-foot by two-foot hole was to examine the void condition and fill the void with cement grout. See Fig. 4D for a schematic of the void under the CRCP.

The original CRCP had bridged over the 6-foot deep void. Approximately 135 ft.³ of cement grout was used to fill the void. If the void under I-40 was not found and continued to grow in size, the roadway would have eventually collapsed.

This case study demonstrates the successful application of GCPR to locate voids that may lead to a serious safety hazard if not identified and repaired in time.

Figure 4. GCPR Survey on I-40 and 135 ft.³ Void Under Continuously Reinforced Concrete Pavement (CRCP)
Summary
Concealed voids in the subsurface of pavement structures may pose a safety hazard due to poor ride and/or structure collapse. Therefore, it is critical to identify the existence, location and size of the voids. It was found that GCPR can be utilized effectively to detect subsurface voids.

Contact Information
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