TECH**BRIEF**

Availability, Feasibility, and Reliability of Available Nondestructive Evaluation Technologies for Detecting and Locating Buried Utilities

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This document is a technical summary of the Federal Highway Administration report on the *Availability, Feasibility, and Reliability of Available Nondestructive Evaluation (NDE) Technologies for Detecting and Locating Buried Utilities* (forthcoming).

OBJECTIVE

The Federal Highway Administration (FHWA) conducted research on the use of promising nondestructive evaluation (NDE) techniques for the detection of buried underground utilities (Reiter et al. forthcoming). The research objectives were as follows:

- Identify promising technologies that merit expanded application and mainstream deployment by State departments of transportation (DOTs).
- Assess the capabilities of NDE technologies under controlled laboratory conditions to establish performance baselines and compare the strengths and weaknesses of each technique.
- Conduct real-world field tests of NDE technologies at sites with well-documented locations of buried utilities.
- Recommend NDE technologies by describing their ideal parameters and testing conditions and determining the advantages and limitations of each one.

KEY TAKEAWAY

The most promising researched and tested technologies were step-frequency and multifrequency ground-penetrating radar (GPR), frequency-domain electromagnetic (FDEM) method, and multichannel analysis of surface waves (MASW).

INTRODUCTION

Modern NDE technologies offer an expanding suite of geophysical techniques to detect and locate buried utilities. This project focused on identifying promising technologies that merit expanded application and mainstream deployment by State DOTs. Since the Second Strategic Highway Research Program (SHRP 2) Project R01: *Encouraging Innovation in Locating and Characterizing Underground Utilities* was published in 2009 (Sterling et al. 2009), new approaches in GPR and acoustic technology have become

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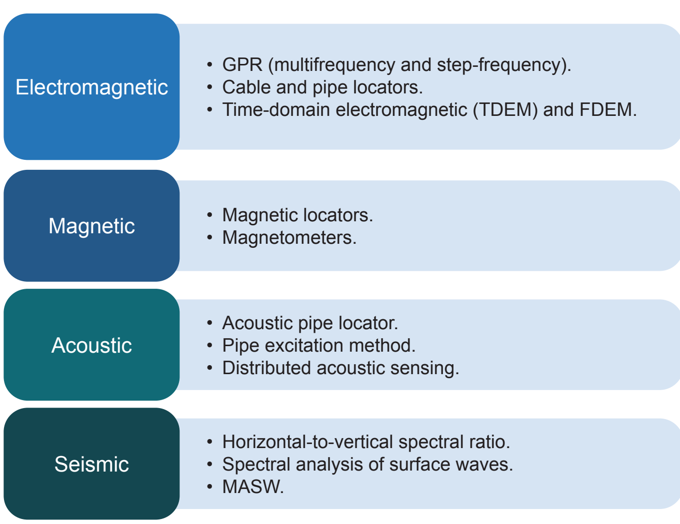
more widely available, while other electromagnetic and seismic methods have been identified as worth further investigation. Building on SHRP 2, the project team researched, identified, and tested various NDE technologies to compile a concrete recommendation plan for each method investigated.

METHODOLOGY

The first phase of this project involved an indepth literature review to identify current and emerging NDE technologies that could improve the detection and location of underground utilities. The project team reviewed technologies across four geophysical domains: electromagnetic, magnetic, acoustic, and seismic (figure 1). The team gathered capability information for NDE mapping techniques across a diverse array of conditions and applications. Some of the identified NDE technologies, such as traditional GPR methods and pile-and-cable locators, have already been broadly deployed in subsurface utilities location projects. Other technologies, such as step-frequency GPR and MASW, show increasing promise in field tests and continue to undergo improvements in data acquisition and high-resolution mapping.

In the project's second phase, the team assessed the capabilities of NDE technologies under controlled laboratory conditions to establish a performance baseline and compare the strengths and weaknesses of each technique. The project team built a set of soil-filled enclosures and emplaced utility pipes of varied types, depths, and diameters in different soil conditions and burial configurations. NDE technologies from the four geophysical domains were tested to determine their baseline characteristics in the soil enclosures.

Figure 1. Graphic. Overview of methods researched and evaluated.



Source: FHWA.

The last phase of the project included real-world field tests of five NDE technologies at sites having well-documented locations of buried utilities with different material types and emplacement conditions.

INFORMAL POLLING OF STATE DOTS

To ensure the true needs of the States were considered during the investigation of current and emerging NDE technologies, the project team polled representatives from nine State DOTs for their input on what approaches and technologies they use in buried utility location. The following questions are examples from the poll:

- Do you deploy NDE technologies internally or outsource the work?
- What are the most reliable data-processing methods? What are the challenges?
- Which NDE technologies do you use regularly? Which technologies do you trust?
- What are the most significant factors when considering new technologies (e.g., cost, training, processing time, reliability)?

Using both a written and verbal polling process, the project team received a significant amount of informative feedback from the State DOT offices. Some key findings included the following:

- States consistently place their highest trust in GPR technology and traditional line locators.
- The precision and accuracy of NDE technology are the most important factors when considering new technologies.
- Interest exists in the development of new NDE technologies and automated systems.
- Most States are challenged by the need for roadway closures with nonvehicle-mounted technology.

CONTROLLED LAB TEST OF NDE TECHNOLOGIES

While the literature search and industry review yielded important findings on the state and availability of modern NDE technologies for locating buried utilities, the next step in this study evaluated several technologies side by side to determine their efficacy under controlled test conditions. The methods selected for evaluation during this part of the project included GPR, FDEM, horizontal-to-vertical spectral ratio (HVSR), and acoustic pipe locator (APL). They were chosen for their ability to be used on grade without the need for utility exposure, their relevant equipment and systems being readily available in the market for use, and their established procedures and processes for deployment.

The project team developed a laboratory testing plan to thoroughly evaluate each of the different selected NDE technologies. To assess the effectiveness of each NDE technology in a controlled setting, a matrix of specimens was designed and tested using typical utility pipes of varying sizes buried in different soil conditions and burial configurations. A combination of soil-filled enclosures was also designed, built, and tested under different controlled configurations. Four specimen types were investigated: fine-grained cohesive soil, coarse-grained cohesionless soil, two layers of cohesive soil at the bottom and cohesionless soil on top, and two layers of cohesionless soil at the bottom and cohesive soil on top.

The laboratory specimens were designed and built at a North Carolina DOT (NCDOT) indoor facility in coordination with the NCDOT Materials and Test Unit. Nine utilities of varying materials and dimensions were buried in each enclosure. Utility pipes were placed into holes on each side of a given base frame such that they entered one side of the base and exited the other side (figure 2).

The project team found GPR to be the most effective of all the methods evaluated in this test bed environment. GPR was capable of successfully locating both polyvinyl chloride (PVC) and metallic pipes down to 6-ft depths (figure 3). GPR fared better on the cohesionless soil compared to the cohesive soil due to moisture retention in the soil, which introduces noise. FDEM was successful at detecting metallic buried utilities at up to 2-ft depths. Relative conductivity measurements for the steel pipes decreased with increasing pipe depth. The APL and HVSR techniques were inconclusive in this setting, which may be due to reflections off the side of the soil boxes interfering with the signals of interest.

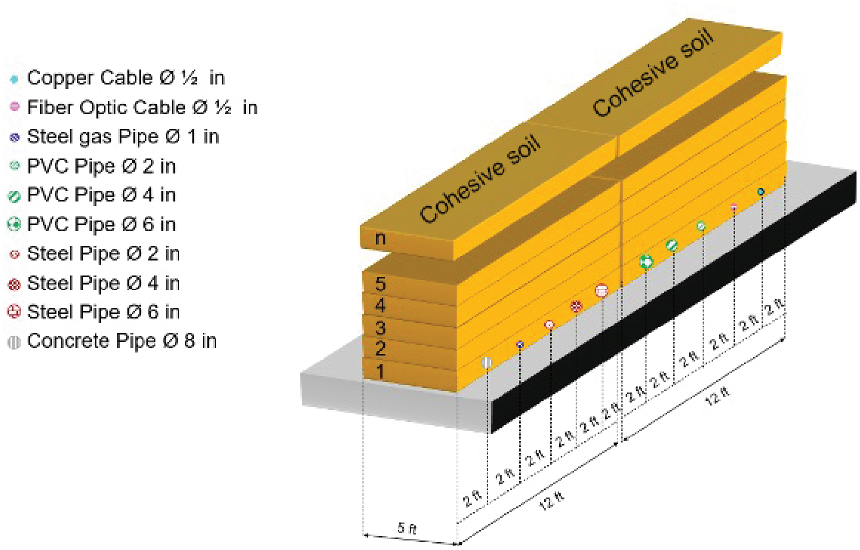
REAL-WORLD FIELD EXPERIMENT OF NDE TECHNOLOGIES

Based on the results from the controlled lab experiments, the team field-tested a variety of NDE technologies in southern Virginia. The Virginia DOT (VDOT) identified field sites with well-documented buried utilities and accessible locations for NDE technology tests. VDOT provided a list of possible field sites with buried utilities that varied in material type (PVC versus metal), diameter, and depth (shallow versus deep). The field team selected three VDOT-approved locations with similar sets of buried utilities, including PVC water and sewage pipes from 1 to 10 ft below the ground surface. Field testing focused on four NDE technologies, including two electromagnetic techniques (step-frequency GPR and FDEM) and two seismic/acoustic techniques (MASW and APL).

GPR RESULTS

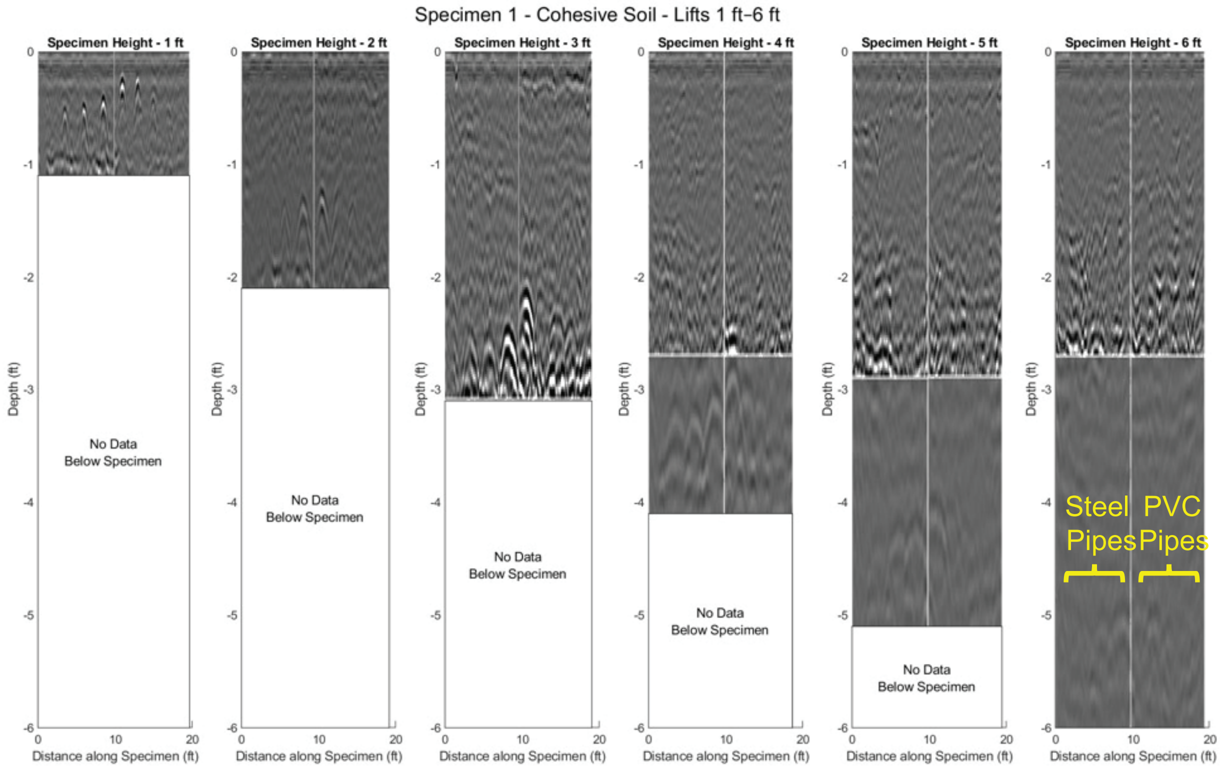
Several general observations can be made about the performance of the multifrequency GPR system, GSSI UtilityScan®, at the three field sites. First, the system performed GPR scans in nonideal environments with varying and uneven surface conditions without a

Figure 2. Illustration. Soil box specimen.



Source: FHWA.
⌀ = diameter; PVC = polyvinyl chloride.

Figure 3. Image. GPR scans collected on cohesive soil test specimens.



Source: FHWA.

reduction in data quality or system performance. The UtilityScan GPR is easy to operate. A single technician can push the antenna cart along a scan line and review data in realtime. Second, the UtilityScan system uses a dual-frequency antenna that produces two channels of output at different frequencies, which provides better resolution of subsurface features. For example, the UtilityScan system detected PVC water lines at relatively shallow depths despite the nonconductive material type. However, the system did not consistently detect PVC water lines at relatively deep depths, most likely because of the increased depth of pipe and the nonconductive pipe material type.

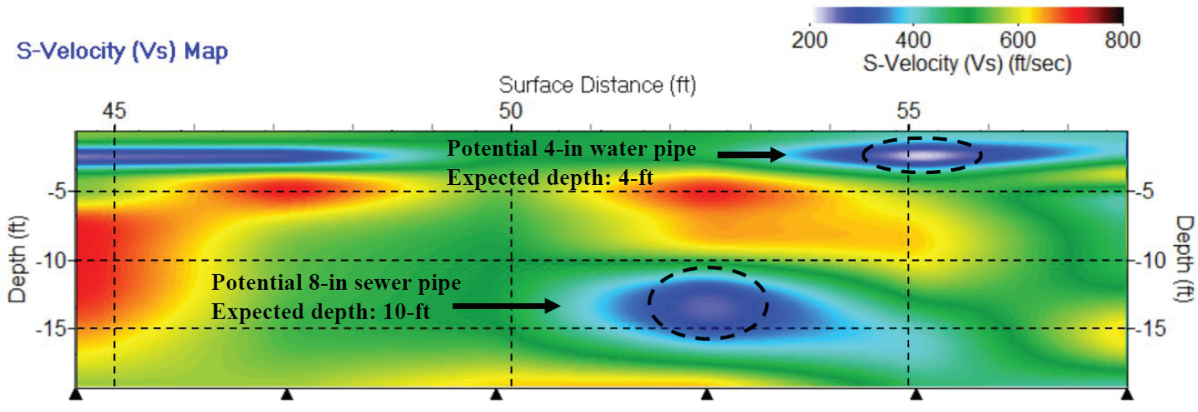
In contrast, the Kontūr™ 3D-Radar GPR system did not perform as well as the UtilityScan GPR system. Although the 3D-Radar GPR is deployable in high-traffic settings and at typical roadway speeds, it requires considerable setup and tuning to ensure high-quality data collection. The system benefits from GPS data encoding, which is an advantage over the UtilityScan GPR system, because it minimizes the need for handwritten field notes on scan-start and scan-stop positioning. The Kontūr system also detected PVC water lines at relatively shallow depths despite the nonconductive material type, but it did not detect the deeper PVC water lines due to nonconductive pipe material and the increased depth of the utility lines.

MASW RESULTS

MASW technology can detect and approximately locate utility lines, particularly with the right acquisition strategies. In particular, using “shoot-through” or roll-along MASW acquisition strategies led to clear detections of utilities at one of the VDOT sites. This setup involves moving and striking the hammer source at a set interval across the entire 24-geophone array. Geophone spacing and the appropriate source weights are key parameters for a successful application of MASW to detect buried utilities. Using this application, the field team found that a 1.5- to 4-lb hammer weight and 1- to 3.3-ft geophone spacing were optimal for utility detection at depths from 3 to 10 ft.

Located utilities included 4-inch diameter water lines at 3.3- and 4-ft depths and an 8-inch diameter sewer line at a depth of 10 ft (figure 4). Using the shoot-through approach produced accurate results within 1–3 ft of the known buried depth. Because only the successful

Figure 4. Image. Two-dimensional shear-velocity profile (ft/s) with depth (ft) versus survey location (ft) at a field test site in Carrollton, VA.



Source: FHWA. (created using MASW ParkSEIS © version 1.01 (Park Seismic LLC. n.d.)).
Vs = shear velocity.

shoot-through approach was used on 3 out of 26 tested buried utilities, additional research is recommended to validate the success of the technique. Additionally, while the MASW method can successfully image the locations and depths of buried utilities, it is unable to resolve pipe diameters with confidence. The MASW technology is not suitable as a standalone detection method of underground utilities without further research, but it can be used as an auxiliary method to increase confidence in the results from other NDE technologies or as an alternative method when GPR or other methods are unsuccessful.

RECOMMENDED NDE TECHNOLOGY AND NEXT STEPS

This study researched several recommended NDE technologies that are capable of detecting and locating buried utilities. GPR remains the most reliable and consistent NDE method available for the buried-utility application. This study demonstrated the current state of the art in GPR technology (multifrequency GPR and stepped-frequency GPR) as an established and reliable method for utility location, especially for dry environments without clay present. FDEM was successful in surveys of metallic utilities and for obtaining depth of burial of the pipe and ground conductivity. This can include the presence of disturbed soil that can be indicative of buried pipe of any kind, including PVC. The project team recommends FDEM for detection of shallow metallic pipes, but the lack of a real-time display reduces its effectiveness for utility location. The application of the TDEM method is well demonstrated for the detection of metallic pipes as well, but it was not tested in this project (Sterling et al. 2009).

Seismic methods, such as MASW, proved to be a new emerging technology for NDE, given their success at locating buried utilities at one of the field sites in southern Virginia. Although MASW should not yet be considered as a standalone NDE technology for buried utility detection and location, it is the most promising non-GPR technology investigated in this project. Further investigation of best-practice acquisition strategies and improved data processing could place MASW well ahead of other NDE technologies, particularly for nonconductive pipe materials emplaced at depths below approximately 4 ft. Seismic methods are not limited by moisture and soil type, which also makes them an attractive alternative method when GPR fails.

By conducting fundamental, comprehensive research of existing and emerging NDE technologies, this project successfully tested and identified various NDE technologies to detect and locate different types of buried utilities. Table 1 lists the various technologies, setup parameters, ideal testing conditions, and the researchers' recommendations.

The researchers recommended the following next steps:

- Perform further field evaluations for all NDE technologies across an extensive range of geological environments (e.g., high clay content, wet soil) and different utility types.
- Investigate MASW as a promising complementary NDE technique.
- Develop ensemble techniques to boost utility detection and location performance with existing sensor technologies.

Table 1. NDE technologies setup, parameters, ideal test conditions, and recommendations for utility detection.				
Method	**Technology**	**Suggested Setup and Usage Parameters**	**Ideal Conditions**	**Recommendations**
GPR	Multifrequency impulse GPR Stepped-frequency GPR	Use wide spectral band wherever possible. Prioritize low frequencies in the 100–400 MHz range. Use operator-driven GPR for rugged and nonideal field conditions. Use vehicle-mounted GPR under ideal conditions for high-speed data collection.	Homogeneous soil conditions with little to no clay. Dry environments. Relatively flat, firm, and even surface conditions for scanning.	GPR recommended for detection of buried utilities, particularly for metallic pipes.
Electromagnetic technologies	Pipe and cable locators	Cycle through frequency-detection modes on the locator to identify the most effective mode for a utility type.	Homogeneous soil conditions with little to no clay. Dry environments.	Recommended for detecting active cables or where connection can be made to the buried utility to support the locator. Passive location modes are not recommended for detecting unpowered utilities.
	FDEM	Cycle through frequency-detection modes on the locator to identify the most effective mode for a utility type.	Homogeneous soil conditions with little to no clay. Dry environments. Relatively flat, firm, and even surface conditions for scanning.	Recommended for detection of shallow, metallic pipes. Lack of a real-time display reduces its effectiveness for utility location.
Acoustic technologies	APL	Select 6-ft instrument spacing to ensure an effective density of data points. Select deep-mode data collection to ensure instrument captures effective depth.	Homogeneous soil conditions with little to no clay Dry environments. Relatively flat, soft, and even surface conditions for scanning.	Inconclusive for utility detection.
Seismic technologies	MASW	Minimum of 24 geophones and a shoot-through approach recommended. Source weight between 1.5 and 4 lb for pipes < 15 ft.	Pipe depths from 3 to 12 ft. Sensor locations on soil, grass, or asphalt. Good impedance contrast between utility and soil.	MASW recommended for further testing with shoot-through acquisition geometry.
	HVSR	Requires at least four broadband sensors at a minimum spacing equal to the pipe diameter.	General location of utilities must be known due to the time required to apply the technique (~30 min/site).	Inconclusive for utility detection.

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