Brief

Research Report 03-008
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September, 2003

Application of Innovative Nondestructive Methods to Geotechnical and Environmental Investigations

Introduction

Recent technological advances in the area of geophysics have offered improved solutions and non-destructive methods to those responsible for determining the physical properties of subsurface materials. Particularly in the area of transportation, geologists must frequently characterize subsurface conditions in preparation for roadway design and construction. Depending upon site findings and their detail, decisions can then be made impacting construction cost, time, and safety. Nondestructive geophysical methods are capable of defining subsurface conditions and delineating underground anomalies, which can then be used as guidance for a site-specific drilling or excavating program. In contrast, typical intrusive procedures such as drilling or backhoe excavation are time consuming and costly when used for subsurface exploration. These methods can also cause damage to underlying features such as buried utilities. An efficient drilling plan, prepared as a result of applying nondestructive geophysical technology, reduces risk, liability, and cost, while obtaining pertinent subsurface information. This is especially important on highways, where the goal is to minimize traffic disruption and avoid pavement damage.

The high-resolution shallow reflection seismic, ground penetrating radar (GPR), electromagnetic (EM), and electrical resistivity techniques are each known geophysical methods capable of providing specific information concerning the physical properties (Table 1) of the shallow subsurface for geotechnical and environmental site characterizations. Each of these nondestructive geophysical methods (Figure 1) is designed to measure specific

Table 1
Summary of Four Commonly Employed Geophysical Surveying Methods

Geophysical Method	Measured Parameter	Physical Property or Properties	Physical Property Model	Typical Site Model
High Resolution Reflection Seismic	Travel times and amplitudes of reflected seismic energy.	Acoustic velocity and reflection amplitudes are functions of elastic moduli and density.	Acoustic velocity/depth model.	Geologic profile.
Ground Penetrating Radar	Travel times and amplitudes of reflected EM energy.	Dielectric constant, magnetic permeability, conductivity, EM velocity.	EM velocity/depth model.	Geologic profile.
Electro-magnetics	Response to natural/induced electromagnetic energy.	Electrical conductivity and inductance.	Conductivity/depth model.	Geologic/ hydrologic profile.
Electrical Resistivity	Potential differences in response to induced current.	Electrical resistivity.	Resistivity/depth model.	Geologic/ hydrologic profile.

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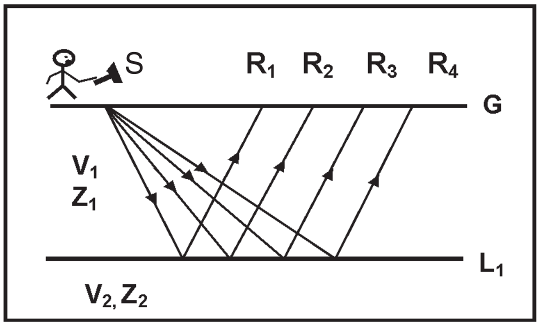
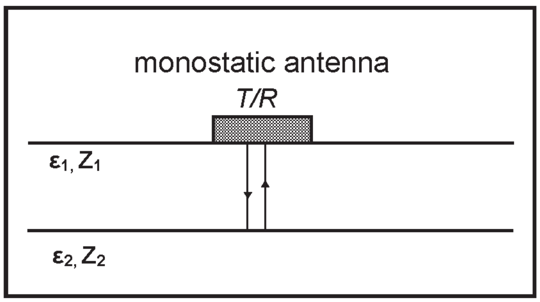
parameters. These measured parameters are related to the physical properties of the shallow subsurface and can be transformed into physical property models or more detailed typical site models (if additional geophysical or non-geophysical interpretational constraints are available).

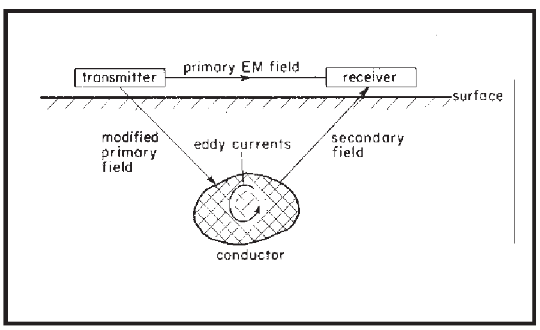
Figure 1
Generalized Overviews of Four Commonly Employed Geophysical Tools: Seismic Reflection, Ground-penetrating Radar (GPR), Electromagnetics (EM) and Electrical Resistivity.



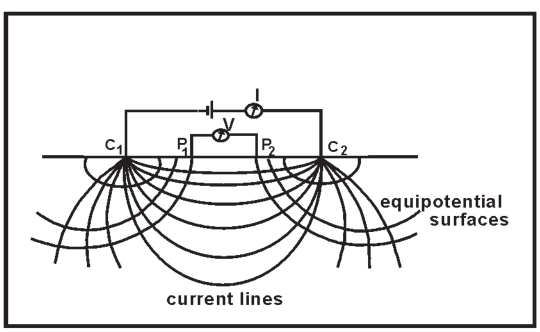
Seismic Reflection: Typically, acoustic pulses are generated at predetermined source locations (S) along the length of the reflection seismic profile. The travel times and amplitudes of reflected acoustic energy is recorded at predetermined receiver locations (R). The recorded travel time/amplitude information is used to generate a reflection seismic profile. These data can be transformed into a velocity/structure profile.



Ground-Penetrating Radar (GPR): Typically, pulsed electromagnetic energy is generated at predetermined station locations along the length of the GPR profile. The travel times and amplitudes of reflected EM energy is recorded by a monostatic transmitter/receiver. The recorded travel time/amplitude information is used to generate a reflection GPR profile. These data can be transformed into a velocity/depth profile.



Electromagnetics (EM): Typically, a receiver is used to measure the earth's response to natural or artificial, primary EM energy. The secondary EM field (generated by causative body) can be expressed in terms of an in-phase component and an out-of-phase component. These data can be interpreted, and in some instances, used to generate a conductivity/depth model of the subsurface.



Electrical Resistivity: Typically, current (I) is induced between paired electrodes (C_1, C_2). The potential difference (ΔV) between paired voltmeter electrodes P_1 and P_2 is measured. Apparent resistivity is then calculated (based on I, ΔV, electrode spacings). If the current electrode spacing is expanded about a central location, a resistivity/depth sounding can be generated. If the array is expanded and moved along the surface, a resistivity/depth profile can be created.

Project Description and Results

In an effort to better evaluate the utility of the four geophysical tools summarized in Table 1, the Missouri Department of Transportation and the Department of Geology and Geophysics, University of Missouri-Rolla, partnered together on several geophysical site characterization studies. Geotechnical conditions, objectives, and geophysical methodologies varied from study site to study site. The primary goal was to evaluate the utility of these four technologies from the perspective of application and cost-effectiveness.

Details and results of the site characterization studies along with background information on the four geophysical techniques studied can be found in the full report, Application of Innovative Nondestructive Methods to Geotechnical and Environmental Investigations, RDT03-008. The following are summaries of the site characterization studies conducted.

Ground Penetrating Radar (GPR): A Tool for Monitoring Bridge Scour

During the course of this study, GPR data were acquired across streams at ten different bridge sites in southeast and central Missouri. This research project demonstrates that the GPR tool can be effectively used to map the water bottom to depths on the order of 30 feet; in some instances, infilled scour features can also be imaged and mapped. The GPR tool is shown to have certain advantages over more conventional techniques. More specifically, it provides an essentially continuous lateral image of the water bottom. Additionally, the tool is non-invasive and does need to be coupled to the water surface.

Evaluation of GPR as a Tool for Determination of Granular Material Deposit Volumes

The objective was to use GPR to determine the thickness of residual "chat" (fine gravel-sized milled waste rock) deposited near abandoned lead-zinc mine workings in Joplin, Missouri, so that determinations could be made in terms of the volume of "chat" available for road construction fill. The contact between "chat" and the underlying soil was clearly identified on recorded GPR profiles and thicknesses were accurately measured (as demonstrated by ground-truthing).

Ground Penetrating Radar (GPR) and Reflection Seismic Study of Karstic Damage to Highway Embankments, Hannibal, Ralls County, Missouri

This effort involved the acquisition, processing and interpretation of reflection seismic and GPR data in support of ground integrity studies. More specifically, geophysical data were acquired across paved roadway and in the MoDOT right of way in an effort to determine the cause and areal extent of karstic distress. Interpretation of reflection seismic data indicated that channeled spring water and surface roadway run-off have contributed to underlying drainage problems, and GPR data acquired substantiated previous conclusions regarding the integrity of the area underlying the pavement.

Geophysical Site Characterization: Ground Penetrating Radar and Reflection Seismic Study of Previously Mined (Lead/Zinc) Ground, Joplin, Missouri

During the course of this study, a total of 14,600 lineal meters of shallow reflection seismic data, 9 downhole calibration checkshots, and 15,000 lineal meters of GPR data were acquired. The seismic data were acquired to map variable structure at the top of karstic Mississippian bedrock; the GPR data were acquired to identify and locate abandoned mine access and ventilation shafts in areas that were overlain by surficial milled ore (chat). Interpretations were confirmed by test boreholes and other invasive techniques.

Non-Invasive Detection and Delineation of Underground Storage Tanks

This study entails integrated EM/GPR investigations of abandoned gas station properties. Electromagnetic induction proved to be an excellent tool for rapidly detecting abandoned underground storage tanks. GPR proved to be an effective tool for delineating the areal extent of the tanks and estimating depth of burial. "Blind" excavation at abandoned gas station properties can result in the accidental rupturing of unknown fuel tanks and associated utility lines. Non-invasive geophysical studies, prior to excavation, can greatly reduce risk.

Integrated Geophysical Site Characterization

This study investigates the application of integrated GPR/reflection seismic/electrical resistivity near Cabool, Missouri with the goal of mapping karstic bedrock structure and identifying/delineating subsurface air-filled karstic cavities. Depth-to-bedrock estimates (based on geophysics) proved to be accurate. Follow-up invasive drilling (test boreholes) confirmed that two of the five most prominent geophysical anomalies in the study area were indeed attributable to the presence of subsurface voids. Extensively fractured bedrock was encountered at the other three test borehole locations.

In addition to the geophysical site characterization studies, a protocol for selecting appropriate geophysical methods and overviews of several typical geophysical methods were prepared and are also included in the full report. These include the following:

- *A Protocol for Selecting Appropriate Geophysical Surveying Tools Based on Engineering Objectrive an Site Characteristics*
- *Ground Penetrating Radar for Subsurface Investigations*
- *Overview of the Shallow Seismic Reflection Technique*
- *Subsurface Investigation with Electrical Resistivity*

Conclusions

The case studies included herein demonstrate that non-invasive geophysical technologies can often provide important and cost-effective information about the geotechnical nature of the shallow subsurface. However, the engineer responsible for a geophysical investigation should ask several pertinent questions in order to ensure the appropriate geophysical tools employed. Methodologies and "go"/"no go" decisions should be based on responses received. Questions to consider include:

- *What are the physical properties of interest?*
- *Which geophysical methods measure the physical properties of interest?*
- *Which techniques will likely provide the required spatial resolution and target definition?*
- *Which geophysical tools will perform well in the study area?*
- *Which techniques are most cost-effective?*
- *Which techniques will provide complementary data?*
- *What non-geophysical control is required to constrain the interpretation of acquired geophysical data?*
- *Is the overall program cost-effective?*

The supervising engineer should also remember that geophysical technologies provide "interpretations" – not "ground truth". In almost all instances, ground truth should be acquired prior to the onset of geophysical efforts in order to constrain "interpretations". Ground truth should also be acquired after interpretations are presented in order to verify reasonableness.

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