Detecting Anomalous Inclusions in Soil Profiles: Encouraging the Use of Geophysics to Solve Engineering Problems

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Citation Information


http://dx.doi.org/10.2113/JEEG10.2.83
Detecting Anomalous Inclusions in Soil Profiles: Encouraging the Use of Geophysics to Solve Engineering Problems

Editorial

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ABSTRACT

Geotechnical site investigations often do not take full advantage of geophysical methods. As examples, when delineating cemented strata and when detecting shallow cavities, investigations can be enhanced greatly for low additional cost by incorporating seismic surface-based measurements.

Introduction

The standard of practice for a typical geotechnical site investigation in preparation for conventional construction is usually centered upon drilling. Drill cuttings are logged for geological characteristics, penetration resistances are measured, moisture conditions are noted, and samples are collected for laboratory testing. For a lightly loaded structure, drillholes need be no deeper than about 6 m. In a residential development, less than one drillhole per structure might be required.

Over the years the practice gradually grows more sophisticated. Geophysical methods are used more often now than in the past, but the change comes slowly and erratically. Practicing engineers remain largely unaware of the advantages and limitations of geophysical methods. Geophysical methods are still not emphasized in most civil engineering curricula. It is little wonder, then, why geophysics does not play a more prominent role in the site investigation plans of geotechnical engineers.

The Problems and Proposed Solutions

One class of problems in geotechnical site characterization that is not yet solved and can clearly benefit from the use of geophysical methods is the exploration of discontinuous inclusions of contrasting stiffness. Consider two examples: cemented lenses in soil profiles and shallowly buried cavities. For engineers, capacity for detailed imaging is less important than cost, speed, reliability, and accessibility of a method to estimate presence and extent. Because they can be implemented rapidly and affordably, surface-based seismic measurements can be part of the solution.

Detecting Cemented Soils

Arid-climate alluvial deposits with ample supply of soluble calcium carbonate can contain heavily cemented strata. The cemented zones tend to be laterally extensive and up to 3 m thick. They appear in coarse- or fine-grained media, including soft clay. Their strength and stiffness can exceed that of concrete. In Las Vegas, Nevada, they occur in multiple layers from the surface to depths of many tens of meters. Knowledge of the presence and extent of cemented soils is of importance to the geotechnical engineer. Cemented soils contribute significant strength, stiffness, and load-distribution capacity for foundation support. On the other hand, when the assignment is to clear the way for underground development, they prove difficult and expensive to excavate, requiring explosives, percussive rams, line drilling, and “headache balls.” When cemented soils are unexpectedly encountered, schedules are extended and costs escalate. For example, in one recent construction project, a cost overrun of almost $500,000 (U.S.) resulted when extensive shallow deposits of cemented materials were encountered, necessitating a redesign of the foundation and base of a building (Di Edoardo, 2001).

Surface waves can be applied to delineate depths and thicknesses of cemented layers. We choose the SASW method (Stokoe et al., 1994), which yields a one-dimensional profile of shear wave velocity through inversion of data collected at the ground surface using proven
techniques with source energy that can be impulsive, random, or stacked coherently. We use a forward model that represents plane-wave propagation of fundamental-mode Rayleigh waves through a system composed of homogeneous isotropic horizontal layers. In complex profiles containing stiff inclusions, the inverted solution is nonunique (Luke et al., 2003). To converge on the proper solution, we use inversion by simulated annealing. This process permits us to incorporate prior knowledge of the site by specifying ranges of velocity and layer geometry within which the solution is expected to be found. This level of assumption is justified even at preliminary stages of site investigation because in developed areas, a great deal of prior knowledge exists from investigations of neighboring sites. As site investigation continues, borehole data provide additional information that can be used to further constrain the search. The utility of the surface wave measurements for overall site characterization at this point is to confirm the lateral extent of the layering encountered through drilling. Of course, the shear wave velocity profile is also a goal in itself for its use in seismic response analyses and its correlation to mechanical properties needed to calculate foundation strength and stiffness.

The process is illustrated in an example from the Las Vegas Springs Preserve (Fig. 1). Our inverted shear wave velocity profile can be compared to independent velocities measured by the crosshole method and to boring logs. The two uppermost cemented layers are clearly identified.

Detecting Cavities

Shallow cavities pose a hazard to human safety and engineering infrastructure due to their capacity to cause sudden surface collapse. Sinkholes above karst features occasionally swallow houses, and collapses above shallow abandoned mines threaten highways. In the desert setting, loss of coarse-grained soils by piping beneath a cemented cap can cause sudden surface collapse. The ability to detect these hazards before catastrophe occurs would be extremely valuable. A rapid screening tool for surface-collapse hazards could drive planning decisions for new development. For existing development, such a tool could be used to alert engineers to potential hazards and help them focus resources for hazard mitigation.

Many geophysical tools are useful for cavity detection. Each has distinct advantages, yet there remains ample room for improvement. We are exploring surface-based seismic methods as the basis for a fully automated method of rapid screening for cavities (Luke and Tsarev, 2000). This would be used, for example, along highways traversing suspect ground. The survey would flag “trouble spots” that would then receive more careful investigation.

Using testing techniques similar to the SASW method, we measure phase lag-frequency functions for vertical ground motion between receiver pairs along a linear array using a constant offset. Data are compared for measurements with source energy applied on opposite sides of the receiver pair. In the presence of a cavity, energy contributions from direct and scattered body waves and higher-mode surface waves will be significant. Otherwise, the response should be dominated by surface waves.

Cavities are indicated by reductions in phase difference caused by the presence of higher-velocity body waves and higher-mode surface waves, phase differences between a given receiver pair due to the direction of wave travel, and patterns among adjacent stations. We are now developing diagnostics using time-frequency analyses to distinguish different components of the wave train. These techniques are borrowed directly from signal processing methods well established in reflection seismic processing and interpretation.
and other fields. We will also analyze the frequency content of the phase shifts to estimate depth and extent of the cavity.

An automated algorithm is used to reduce data, compute discriminators, and establish the likelihood of cavity presence as a function of position along an array. Assessment of the likelihood of the presence of a cavity is best established through calibration, but defaults can be generated based on known or assumed background conditions and cavity geometry.

The process was tested on two buried 0.6-m diameter barrels at the Engineering Geophysics Test Site on the UNLV campus (Fig. 2). The barrels were located with a lateral accuracy of 1 m, with one presumably false positive reading.

**Closure**

Certain needs for geotechnical site investigation can and should be met through the use of geophysical methods. We show two examples using surface-based seismic measurements where important simplifications are made to allow valuable, affordable outcomes. To promote such progress, we must continue to facilitate interaction between geophysicists and engineers.

**Acknowledgments**

We acknowledge assistance of UNLV students Haiyan Liu, Issa Lutfi, Richard Stone, Bjorn Sundquist and Gennady Tsarev. Funding was provided by the National Science Foundation under Grant No. CMS-9734000 and the Las Vegas Valley Water District.

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