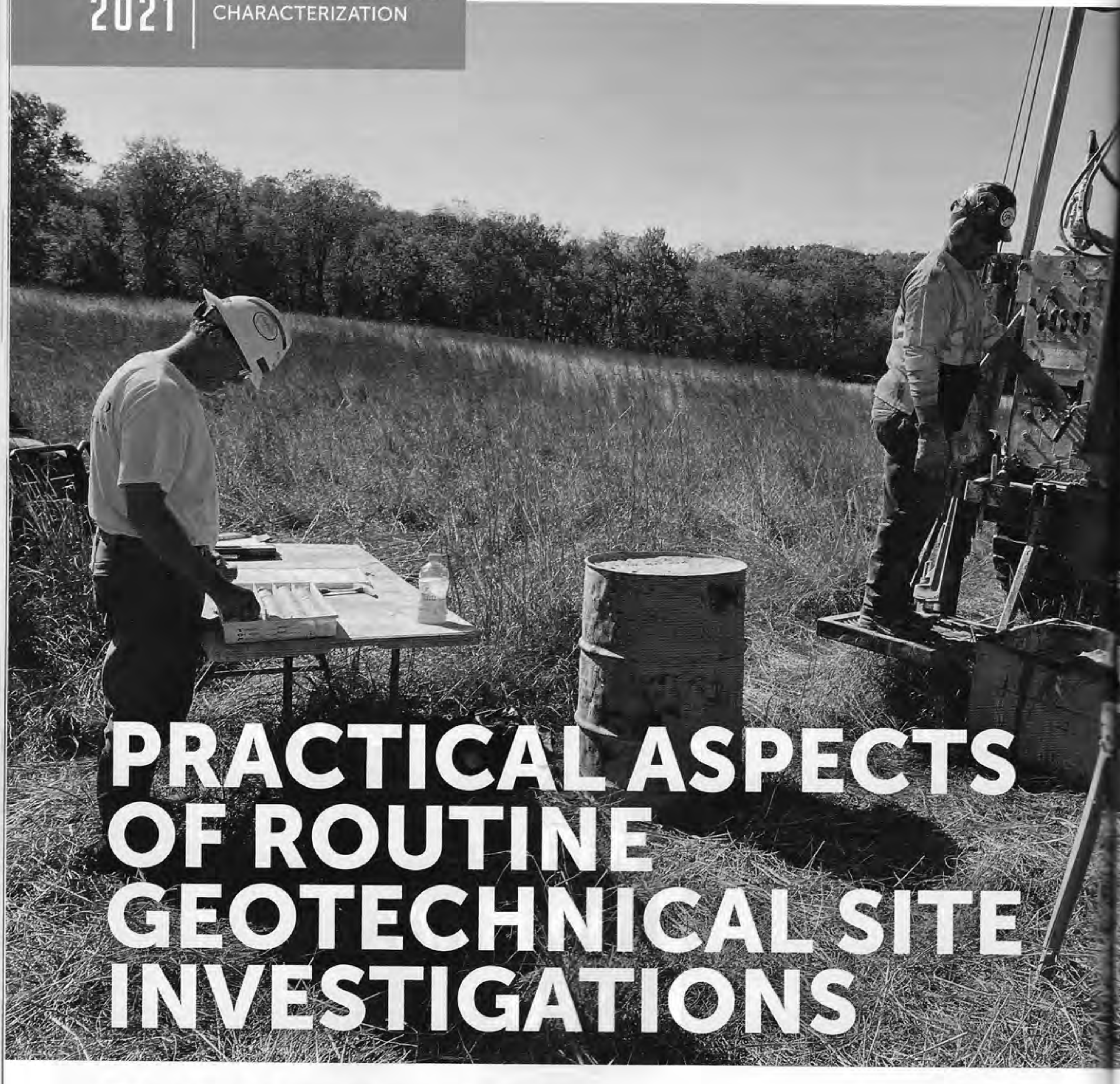

PRACTICAL ASPECTS OF ROUTINE GEOTECHNICAL SITE INVESTIGATIONS

THEY SHOULD BE ANYTHING BUT BORING!

(Photo courtesy of Zachary Pickering, Strata Earth Services, LLC.)

By Alan J. Lutenegger, PhD, PE, F.ASCE

It's likely that on any given day there are hundreds of geotechnical site investigations in progress in North America alone. While many of these investigations are carried out in support of large projects, such as multispan bridges, multistory commercial structures, and industrial facilities, let's face it — most investigations are associated with smaller, "routine" projects that may only involve one day of test drilling using traditional truck-, track-, or skid-mounted drill rigs. Site investigation budgets may be small, necessitating less sophisticated approaches not involving advanced sampling techniques, in-situ testing, or laboratory testing. Lightly- and moderately-loaded structures represent the majority of field activities performed by many geotechnical consultants. Large projects, and those involving relatively high and/or complex loadings, are less frequent and usually demand a more rigorous site investigation approach, along with a more detailed laboratory testing program to evaluate soil conditions and soil behavior.

But regardless of size, every geotechnical project is important and should have an adequate site investigation to characterize the subsurface conditions and to provide the engineer with quality information that's needed to complete the required design. Routine projects, or those having a relatively limited scope of study, would typically include lightly loaded single-story commercial or residential structures, communication towers, shallow slope failures, or swelling soil problems. Similarly, projects involving a limited exploration depth, such as roadways and buried utilities, also might be considered as "routine." Even though they may be smaller in scale, so-called routine projects are no less important than large projects with large budgets and extensive site investigations — at least in the eyes of the owner and triers of fact when problems are alleged. All geotechnical projects are important and deserve to be approached with the same degree of care, regardless of scope or perceived importance.

The most critical design issues are obviously not the same for every project. Sometimes, bearing capacity and settlement might be the critical elements, while other designs may need to address issues like swelling potential, slope stability, or ground improvement. So the extent and type of investigation depends on the needs of the project, the anticipated loads, tolerable settlements, and, of course, the geology of the project site.

Like it or not, the majority of geotechnical site investigations still rely on the standard penetration test (SPT) and sampling of fine-grained soils using thin-walled push tubes

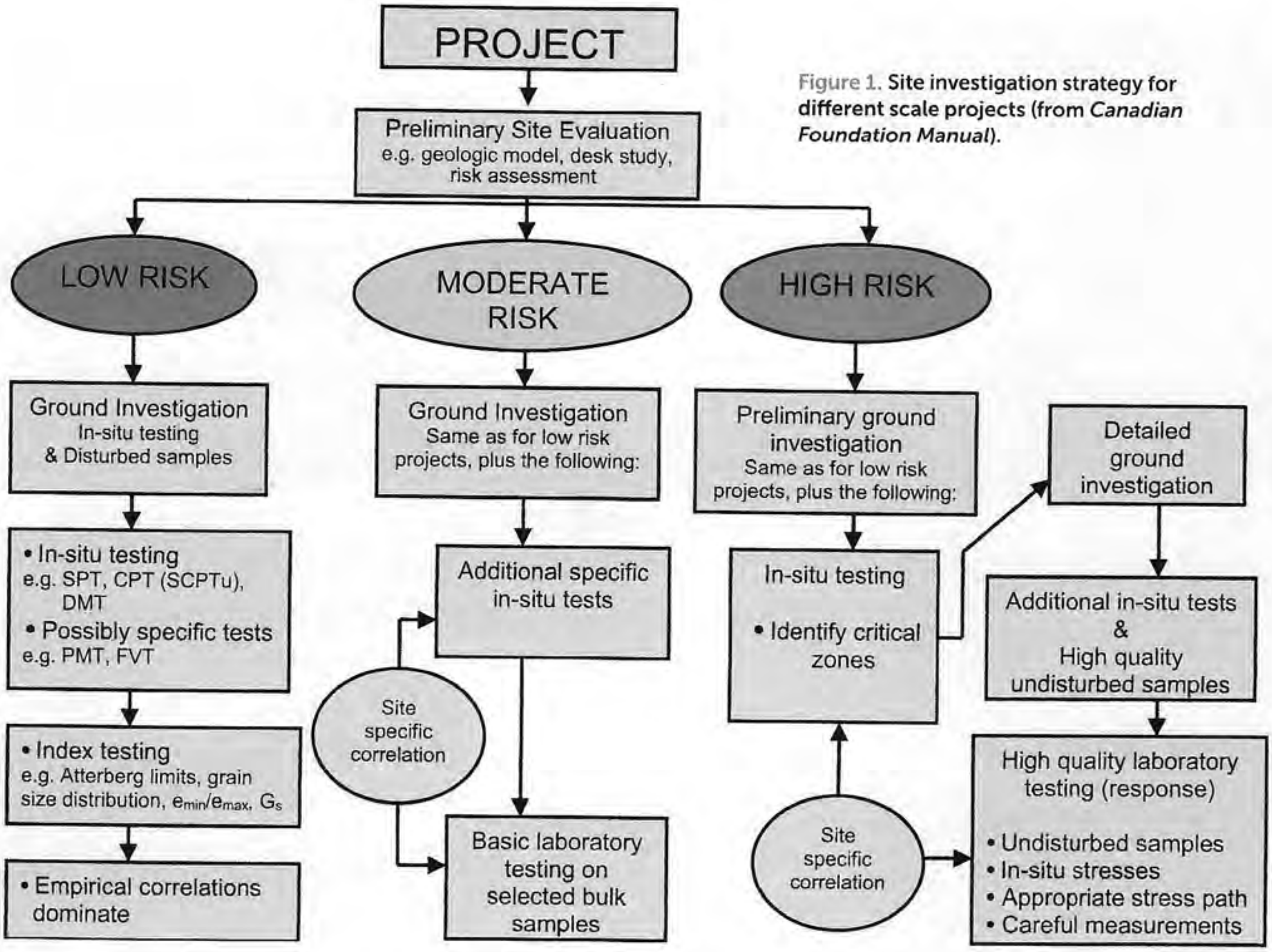

Figure 1. **Site investigation strategy for different scale projects (from *Canadian Foundation Manual*).**

(Shelby tubes). In their 2007 paper "Measuring the Risk of Geotechnical Site Investigations," Goldsworthy et al. showed that using the SPT may lead to a more conservative foundation design with higher costs, largely because of the higher uncertainty assigned to the SPT as compared to other site investigation methods like cone penetrometer testing (CPT) or dilatometer testing (DMT). However, with better control on the SPT, and especially with the use of a calibrated automatic hammer, this uncertainty has been reduced substantially in the past 15 years.

While field practices vary somewhat geographically, and some areas tend to promote more advanced site investigation techniques, economics often dictate gravitating toward this simple and traditional approach. However, "simple" does not have to mean less reliable or lower quality. Routine projects may be treated somewhat casually by some engineers, as they typically face fewer technical challenges and may only pose concerns with respect to building code compliance, the potential for construction problems, or the potential for litigation.

The chosen approach to site investigations and geotechnical characterization often depends on the perceived risk, and even though all projects are important, they do not all have the same consequence of failure. The *Canadian Foundation Manual* has suggested that projects be categorized as either Low Risk, Moderate Risk, or High Risk. The site investigation strategy will and should be different for each category (Figure 1). Most routine projects fall into the Low Risk category.

We all are likely aware of the trend toward routine geotechnical investigations being awarded on the basis of competitive bidding, where selection of the engineer and the proposed site investigation scope is based on price alone. In many cases, the scope of the investigation, including the number, location, and depth of test borings, is defined a priori by the client, with no input from a geotechnical professional. Are borings at each corner and the center of a proposed structure enough? Maybe they're actually too much! Rather, it depends on the project's site geology, the project's needs, and the engineer's experience and professional judgment.

What's Wrong with Current Practice, and How Can Routine Practice Be Improved?

In 2004, Professor Jorj Osterberg made a number of observations about the process of conducting site investigations for geotechnical practice in his paper "Geotechnical Engineers, Wake-up — The Soil Exploration Process Needs Drastic Change." In it, Osterberg says that because soil boring contracts are usually awarded to the lowest bidder, "there is no incentive to do good quality work, and there is every incentive to somehow get a hole down as quickly as possible without regard to obtaining the best soil and rock samples, water level readings, and collateral information. As a result, perched water tables, important soil layers, and other important information are often missed."

Below are the deficiencies raised by Osterberg:

1. Soil boring methods, soil and rock sampling, and the quality of work have not changed much in the last 50 years, despite the availability of more and better tools, and newer and better techniques. This is due mostly to the almost universal process of awarding exploration contracts to the lowest bidder. Also, the geotechnical engineer doesn't seem to demand anything better.
2. Much of the geotechnical engineering involved in subsurface characterization is being done by non-geotechnical engineering firms that mostly are not qualified.
3. Geotechnical engineers often do only what they are asked to do and don't assert themselves on matters and decisions that are clearly geotechnical.
4. Drillers often lack proper training and are not informed as to what is expected of them and what they should look for. They do not record important information on their daily log sheets — information that could possibly be important and useful to the geotechnical engineer.

Figure 2. An engineer performs an SPT-Torque test using an analog torque wrench.

5. Soil and rock samples are frequently classified by unqualified personnel. Soil samples and classifications are often not checked or inspected by the geotechnical engineer.
6. Geotechnical engineers can be unaware of laboratory testing procedures, and seldom visit the lab to observe the actual testing.
7. The importance of redundancy in subsurface exploration is underestimated.
8. "People problems" are underestimated and often ignored. Examples include a general lack of communication between the field and the office personnel; design personnel not sharing important information needed by field personnel to carry out their responsibilities; and field personnel not sharing important field observations with those in charge.
9. Geotechnical engineers generally lack sufficient knowledge of geology.

In addition, based on my observations over the past 45 years, I would add one more common deficiency:

10. Many geotechnical engineers lack sufficient understanding and field experience in site investigation methods, and leave much of the work and important decisions to the driller.

Unfortunately, as far as I can determine, the issues Osterberg raised many years ago are still largely prevalent in the majority of current routine geotechnical practice.

For some routine projects, the geotechnical engineer may not be able to observe the site investigation because of budgetary considerations, which means that they must rely on the driller's observations and notes. In this case, the driller's boring logs must be accurate and complete.

What Can Engineers Do to Improve Quality for Routine Projects?

First, engineers need to understand the geology of the site so that any unusual conditions can be quickly identified and addressed in the planned subsurface exploration program. This takes both training and experience. What

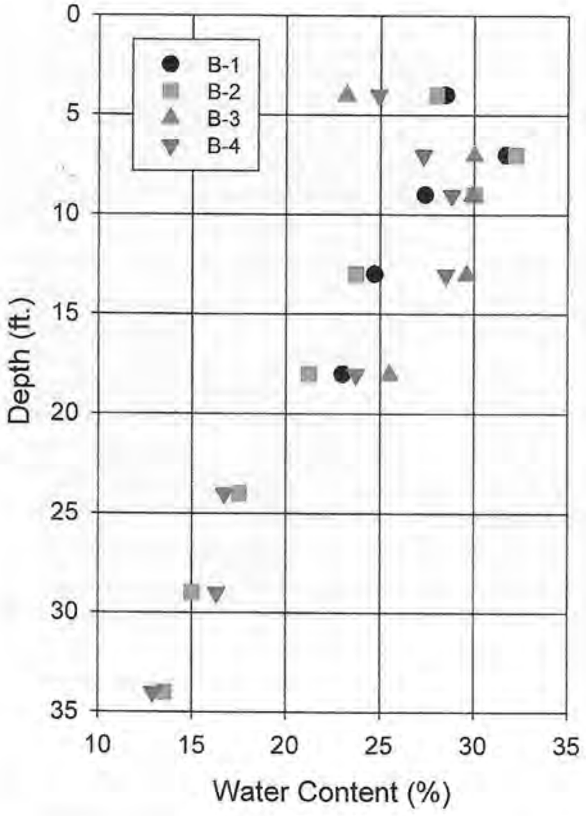

Figure 3. **Water content variation from four test borings.**

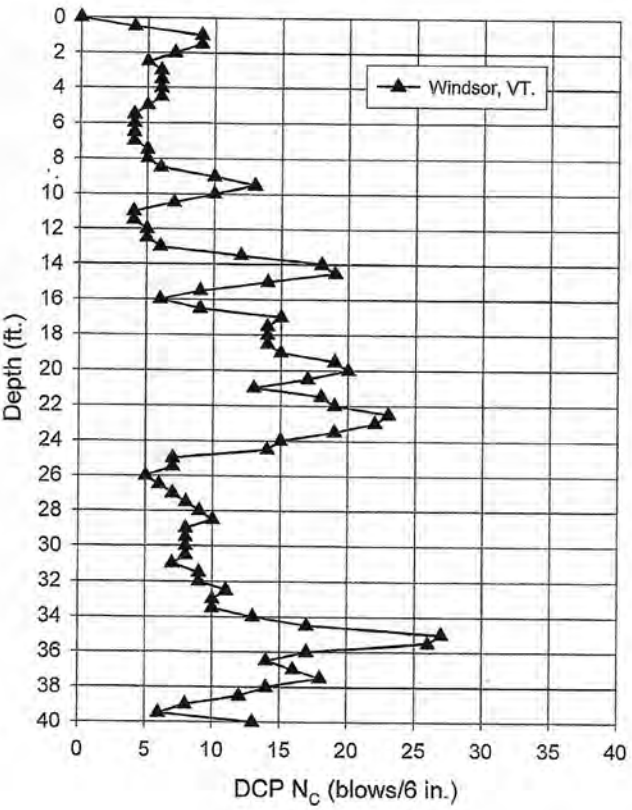

Figure 4. **The results of dynamic cone penetration (DCP) tests in alluvial sands, Windsor, VT.**

layers are expected at the site, and what are their intrinsic variabilities? Can geotechnical engineers enhance their services on routine work to maximize the outcome of the site investigation while staying within a project's budget? Can they still feel comfortable that a reliable investigation can be achieved without an overly conservative recommendation resulting from a limited investigation?

Not every project has the budget to support using CPT or DMT, both of which are excellent tools. More often than not, engineers must simply rely on the SPT. This means that SPT tests must be performed correctly and consistently. Best SPT practices can be summarized as:

1. Only use an automatic hammer that's calibrated annually.
2. Record the serial number of the hammer so the energy calibration can be traced.
3. Record the size of drill rods used.
4. Always record and report 6-in. incremental blow counts because they actually help show development of SPT penetration resistance.
5. Always measure and report the sample recovery because it can identify unusual conditions, such as gravel particles that often result in poor recovery. Recovery should be plotted and shown graphically in the report.

In addition to these practices, data from the SPT can be enhanced substantially using two simple modifications that don't have an impact on the standard procedure:

1. After driving the spoon, incorporate the SPT-Torque (SPT-T) procedure for all SPTs (Figure 2). The test provides an additional quasi-static measurement after the traditional SPT drive without modifying the SPT procedure. With minimal equipment, the test is fast, adding only about two extra minutes after completing the SPT. The results have been shown to provide very useful information on soil behavior and soil-to-steel unit side resistance, and SPT-T use is likely to continue to expand in the future.
2. For some projects, record the SPT spoon penetration record on a few drives, i.e., record the penetration for each hammer drop to obtain a record of cumulative drive distance vs. cumulative number of drops. These results have been useful in estimating some important soil and rock parameters and have been used to estimate capacity of deep foundations.

Both of these practices are simple to perform and help provide useful information on soil uniformity within the drive and some basic soil properties. Here are some additional simple suggestions I've used in the past on routine projects to improve the quality of site investigation practice with minimal additional expense:

1. Determine the water content on every sample. Of all geotechnical laboratory tests, water content is one of the easiest, least expensive, and least subject to errors. The results should then be presented graphically in the report (Figure 3). Water content can be used to provide a simple evaluation of both vertical and lateral variability across the site. The figure shows the variation in water content obtained in two shallow and two deep borings for a routine project, consisting of a single-story, lightly loaded commercial structure with a slab-on-grade foundation. The project is in an area where the geology is well known to the engineer and where a number of previous investigations had been performed. The data are from a combination of SPT and thin-walled tube samples. The results show the variability in the upper 20 ft and the change with depth. In this case, a stratigraphic break occurred at a depth of about 21 ft.
2. Consider using a dynamic cone penetrometer (DCP) to enhance the value of test borings. When performed using a drill rig, no special equipment is needed except for a 60°, 2.5-in.-diameter cone that is placed on the end of standard AW drill rods. Using an SPT automatic hammer, the number of blows for each 6-in. drive interval are counted, with the drive usually starting at the ground surface. Figure 4 shows some typical results obtained in an alluvial deposit of stratified sand and silty sand in Windsor, VT. The 40-ft drive took about 20 minutes and helped enhance the profiling over SPT samples taken at 5-ft intervals, showing several layers within the deposit. The results can be used to quickly show vertical variations in driving resistance, and can also be used to estimate a number of soil parameters and behavior, such as liquefaction potential in coarse-grained soils.
3. For rapid initial index measurements of shear strength in fine-grained soils, the pocket vane test appears to be more accurate and reliable than the pocket penetrometer, which has been around since at least 1957. The pocket vane also has a wider range of applicability and may be used to obtain a measure of sensitivity by placing a remolded sample of soil in a small plastic cup and performing a remolded test. Whenever a pocket vane test is performed, a water content sample should be taken. Collectively, these data may help define a general relationship between undrained shear strength and water content within a given layer.
4. In coarse-grained soils, sieve analyses on select samples may be useful for estimating other geotechnical parameters, using percent fines, D_{50}, and uniformity coefficients.
5. In fine-grained soils, Atterberg liquid and plastic limits (LL and PL) should be performed on select samples. The one-point liquid limit procedure using either the Casagrande cup or fall cone can be used to reduce testing time. Together with water content, LL and PL can be used to calculate the liquidity index (LI), which is useful in estimating stress history and undrained shear strength.
6. Water levels should always be recorded on the field boring log, and, ideally, measurements should be taken at the end of drilling, at the end of the day, and the following day, if possible.

With limited data, engineers must often rely on high-quality empirical correlations on similar materials to estimate some geotechnical parameters that may not be measured directly in the lab because of budget constraints. But, engineers must also understand the limitations of the empirical approach. Resources like the updated correlations presented in the most recent edition of the FHWA *Geotechnical Engineering Circular (GEC) No. 5* (2017) can be used to check the validity of tests that are conducted, and to estimate parameters for which testing has not been conducted. Correlations presented in the 1950s and 1960s are generally unreliable and should not be used.

Details Make the Difference

Routine projects represent the most frequent work performed by many geotechnical engineers and should be performed with the same level of care and quality as every investigation. Some simple practices can be used by the geotechnical engineer to improve and enhance the work while providing additional useful subsurface information with minimal additional effort and cost. If not performed with the same level of care as larger projects, small projects are likely to lead to more frequent post-construction problems. From the site investigation to the geotechnical report, qualified personnel need to be involved at every level of the work.

ALAN J. LUTENEGGER, PhD, PE, F.ASCE, is emeritus professor of civil & environmental engineering at the University of Massachusetts in Amherst, MA. His research interests include in-situ testing and geotechnical site investigations, foundation behavior, ground improvement, problematic soils, screw-piles, and helical anchors. He can be reached at *lutenegg@ecs.umass.edu*.