Subsurface Site Investigations with Cone Penetration Testing

Louisiana Develops Cost-Efficient Procedures for Bridge Projects

MURAD ABU-FARSAKH, MARK MORVANT, AND ZHONGJIE ZHANG

Abu-Farsakh is Assistant Professor, Research; Morvant is Associate Director, Research; and Zhang is Pavement and Geotechnical Research Administrator, Louisiana Transportation Research Center, Louisiana State University, Baton Rouge.

Site investigations identify the soil engineering properties that affect the design and construction of transportation infrastructure. A site investigation commonly costs 1 percent to 5 percent of a total project. The Louisiana Department of Transportation and Development (DOTD) spends millions of dollars annually on site investigations that require subsurface exploration. The quality of the subsurface exploration has a direct effect on the quality and efficiency of the design and construction of foundations.

Problem

Conventional site investigation with soil borings and laboratory testing is expensive and time consuming, and sometimes the procedures require highly skilled and experienced technicians. Therefore, performing tests that yield satisfactory results is not always economical, and some degree of interpretation is required—which often leads to conservative engineering designs.

A 3- to 5-person crew, for example, can complete 5 to 8 soil borings in one week, depending on the depth of the boring. Laboratory testing for cohesive soils typically will take an additional two weeks. The laboratory tests are performed on small, undisturbed, and intact samples extracted from the borings. Yet almost all recovered samples have some degree of disturbance from the sampling, handling, transportation, and test preparation. As a result, the laboratory-derived soil parameters do not accurately represent the in situ conditions.

Solution

In situ tests such as the cone penetration test (CPT) or piezocone penetration test (PCPT) are an alternative to laboratory testing. Performed under in situ stresses and boundary conditions, the tests can provide rapid, accurate, and reliable results in assessing the engineering properties of soil.

The CPT is a robust, simple, and economical test that can provide continuous soundings of subsurface soil with depth. The CPT advances a cylindrical rod with a cone tip into the soil (Figure 1). During penetration, the cone penetrometer measures the cone tip resistance, the sleeve friction, and—when the PCPT is used—the excess pore water pressures. These measurements can be used for detailed soil stratification and to evaluate different soil properties. Because of the soft nature of soil deposits in Louisiana, the CPT and PCPT are excellent tests for subsurface investigation and site characterization.

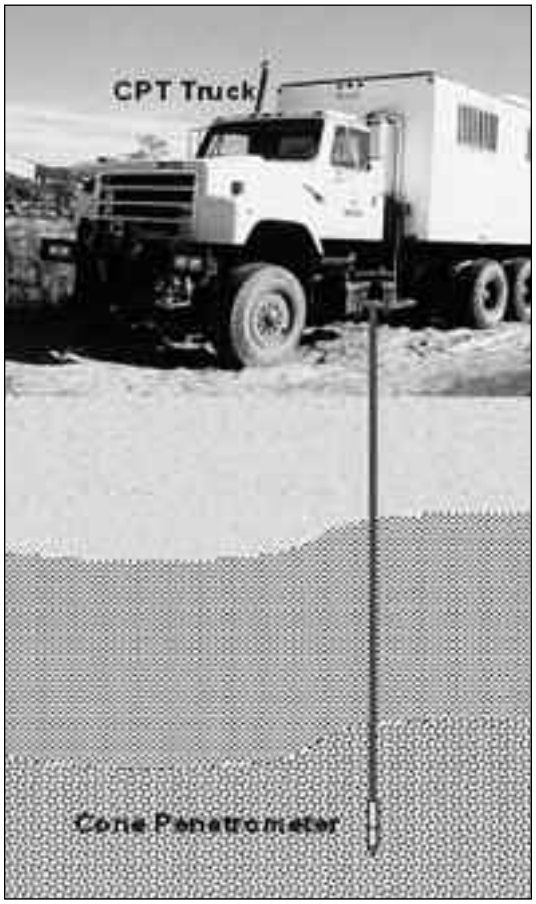

FIGURE 1 Cone Penetration Test System

FIGURE 2 Pile Driving on the I-310/US 61 Interchange near New Orleans

Research Efforts

Louisiana DOTD began to implement the CPT technology in the mid-1980s. At first, the technology was limited to identifying elevations of dense sand layers for pile foundations. Soil borings were taken during the design phase to estimate pile lengths, and CPTs were conducted during bridge construction to define pile tip elevations for plan lengths (Figure 2).

Since then, the Louisiana Transportation Research Center (LTRC) has conducted several research projects to develop tools and methods for implementing the CPT and mini-CPT technology for other types of Louisiana soils (*1, 2*). To facilitate the implementation, Louisiana DOTD developed several Visual Basic software tools for use in geotechnical engineering analysis and design.

Soil Classification

The identification and classification of soil types was one of the earliest applications of the CPT technology. Several soil classification methods were developed by correlating CPT and PCPT data profiles with databases of soil types collected from soil borings.

The Louisiana Soil Classification by Cone Penetration Test (LSC-CPT) Program was developed to provide geotechnical engineers with a useful tool for subsurface soil identification. The program includes five different CPT classification systems; Figure 3 shows an example of LSC-CPT soil classification with the Robertson et al. method.

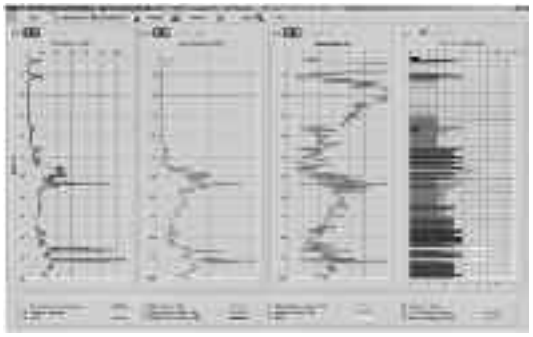

FIGURE 3 LSC-CPT Soil Classification Using Robertson et al. Method

Prediction of Pile Capacity

Since Louisiana subsoils often are soft, highway bridges and other transportation structures typically are supported with pile foundations. Accurately estimating the load capacity for friction piles is always a challenge. Louisiana DOTD pile design has relied on static analysis from laboratory data and the standard penetration test. Several methods have been proposed to predict pile capacity using the CPT data.

LTRC conducted a research project to identify the most appropriate CPT methods for estimating the ultimate axial load-carrying capacity of driven, precast concrete piles in cohesive soils (*3*). The ultimate pile capacities predicted from eight CPT methods were evaluated, and three CPT methods were selected for implementation in Louisiana soils: the French Central Bridge and Pavement Laboratory (or LCPC) method, De Ruiter and Beringen, and Schmertmann methods.

To facilitate Louisiana DOTD's implementation of the CPT technology for pile design and analysis, the three methods were coded into a Visual Basic Microsoft Windows program, called Louisiana Pile Design by CPT (LPD-CPT). The program provides the design engineers with ultimate capacity profiles and depths for piles.[1]

The Federal Highway Administration and the American Association of State Highway and Transportation Officials have mandated use of the load and resistance factor design (LRFD) methodology for all new bridges—including substructures—as of October 1, 2007. To implement the CPT technology in the LRFD design of driven piles, LTRC conducted research to calibrate the resistance factors for the CPT design methods in the LPD-CPT.

Evaluation of Soil Properties

Several methods have been developed to evaluate different soil properties based on correlations between CPT or PCPT data and laboratory test results. Although some of these results may correlate closely, existing models should be calibrated or new models developed from local databases and experience. LTRC therefore conducted three research projects.

One project established a correlation between the 2-cm² mini-CPT data and the resilient modulus (M_r) of subgrade soil for pavement applications (*4*). The

[1] The LPD-CPT and other CPT programs are available as free downloads from the LTRC website, www.ltrc.lsu.edu.

CPT testing on South Louisiana marsh deposits.

second project evaluated the constrained modulus (M) and other consolidation parameters (c_v, overconsolidation ratio [OCR]) needed for estimating the magnitude and rate of consolidation settlement for embankments on cohesive soils from CPT data (5).

The findings from these two projects are being implemented into software for estimating the magnitude and time rate of consolidation settlement in symmetric and asymmetric embankments. The software also includes an option of profiling with depth the undrained shear strength, constrained modulus, coefficient of consolidation, and OCR of subsurface soils based on established correlations from CPT data.

The third project deals with the calibration of the cone tip factor (N_k) for various soil types, to improve the prediction of the undrained shear strength of soils.

Application and Cost Benefit

Louisiana DOTD has used CPT technology for soil classification and pile design on more than 80 percent of its recent bridge projects, to reduce or supplement standard soil borings. The site investigation for the 18-mile LA-1 elevated bridge currently under construction between Golden Meadow and Port Fourchon required 99 soil borings and 124 CPT soundings. The reduction in the number of standard borings saved more than $1 million dollars.

CPT technology also is saving time and money on the reconstruction of the I-10 Twin Span Bridge over Lake Pontchartrain, which was ravaged by Hurricane Katrina in August 2005. The dense deposit underlying much of the site can vary up to 16 feet within a single footing area. Multiple CPT probes are being used within the cap footprint to define the bearing layer of sand deposits and to reduce pile cut-offs and buildups.

The cost of the CPT soundings on this project was less than 25 percent of the cost for soil borings. These savings, plus the savings for pile order lengths and construction time, are estimated at more than $1 million dollars.

Future Research

LTRC will continue to conduct research projects to develop, refine, and expand the CPT technology for geotechnical applications. One project scheduled for 2008 will examine the use of PCPT technology for predicting pile setup. Another project will evaluate the spatial variability of soil within a site for reliability analysis, to calibrate corresponding LRFD resistance factors.

In addition, LTRC is planning to upgrade the LPD-CPT software to include steel-driven piles and drilled shafts, plus a new CPT method based on piezocone penetration measurements using effective cone tip resistance (q_c).

For more information, contact Mark J. Morvant, Associate Director, Research, Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808, telephone 225-767-9124, e-mail markmorvant@dotd.la.gov.

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Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail gjayaprakash@nas.edu).