// As We See It

Is Understanding the Stress History and Behavior of Soft Soils at Risk of Taking a Back Seat?

By Suzanne Lacasse, PhD, F.ASCE, F.CAE, NAE, and Nadim F. Fuleihan, Sc.D, PE, RPEQ, M.ASCE

From Downtown Oslo: Drilling of tieback anchors in sheet-pile-supported deep excavation in soft clay, with ground improvement measures implemented locally. (Photo courtesy of the Norwegian Geotechnical Institute.)

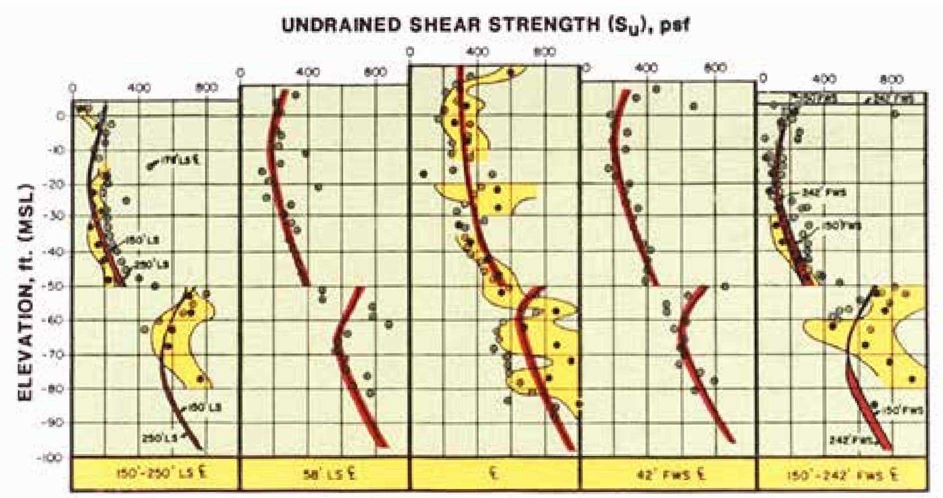
Our profession has greatly evolved as we move forward into the 21st century, 106 years after Karl Terzaghi came to the United States, and nearly 100 years since the publication of his first masterpiece, *Erdbaumechanik (Soil Mechanics)*, which revolutionized soil mechanics. Everywhere Terzaghi worked (Royal Ottoman College of Engineering in Istanbul [now the Istanbul Technical University], MIT, and Harvard), he set up a laboratory to measure soil properties.

Many of the remarkable advancements in geotechnical engineering since the early days are due to the revolution in computers and information technology in all aspects of our practice, including possibilities for very thorough and detailed calculations and evaluations of performance in 3D. Today, our profession is moving toward machine-learning applications and multi-data through the internet, including handling big data issues. We are at a crossroad, with a paradigm shift from verifiable dedicated systems toward large, anonymous distributed systems with vast numbers of measurements and data.

We wish that these new developments flourish, but fundamentals must not be forgotten. A basic understanding of the behavior of soft soils remains absolutely necessary in our profession — but is it at risk of taking a back seat to technical computations and newer developments?

"If Soft Clay Deposits Could Talk…"

If only soft clay deposits could talk, like the Atchafalaya and New Orleans flood-protection levee sites or the Norwegian embankments on sensitive clays, what would they say? They would tell us how important it is



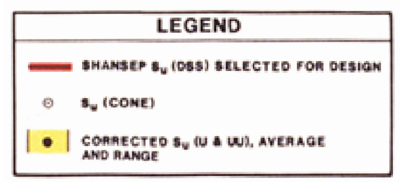


Figure 1. **Undrained shear strength profiles for a levee reach in the Atchafalaya Basin in Louisiana. SHANSEP strengths at the levee centerline and offsets were derived from evaluation of stress history and Direct Simple Shear (DSS) undrained testing to establish a normalized relationship between DSS strength and OCR. SHANSEP S_u(DSS) strengths correlated well with undrained strengths from CPT s_u(cone), and moderately well with Unconfined (U) and Unconsolidated Undrained (UU) strengths, s_u(U & UU), after empirically correcting for effects of sample disturbance and high strain rates. (Graphic courtesy of Ardaman & Associates, Inc.)**

to thoroughly understand their geology and stress history, and to use a proven methodology like Professor Chuck Ladd's SHANSEP approach (Stress History and Normalized Soil Engineering Properties – Figure 1). Geotechnical engineers need to have a sense of how soil behaves by "touching and feeling a sample," and understanding which in-situ and laboratory tests are specifically needed to determine representative soil properties and to establish the most representative stress history and corresponding shear-strength profile.

Prediction of Failure Load for a Shallow Foundation on Clay

Soft ground presents challenging construction problems, such as excessive, time-dependent foundation settlements, and bearing capacity and stability-type foundation failures. At a recent prediction exercise of a shallow foundation on clay (1.8-m square, 1.5-m below grade) at the Australian National Field Testing Facility, 50 predictors made Class A (i.e., *a priori*) predictions of the load at failure[1]. The predictors came from 13 countries, including 23 practitioners, 16 academics, and 17 students. The soil properties were reasonably well characterized with laboratory and in-situ tests. The undrained triaxial compression shear strength of the clay was 10-12 kPa.

The measured failure load was 205 kN, yet the Class A predicted failure loads ranged widely from 130 to 2,229 kN. The mean predicted failure load was 404kN, and the median was 333kN. Amazingly, seven predictions exceeded 500 kN! Some predictors used advanced, state-of-the-art, finite-element computer programs, while others relied on simpler bearing-capacity equations to calculate the failure load. Surprisingly, the predictions were very far apart despite the fact that the most accurate (200 kN) and the least accurate (2,239 kN) predictors reportedly used the same bearing capacity equation. The predicted settlement of the foundation at various stress levels was also much higher than measured for most predictors.

The range in predicted failure load is alarmingly large. Twenty-nine Class A predictors (almost 60 percent of the participants) gave an ultimate load greater than 300 kN. One wonders why a simple back-of-the-envelope verification for the ultimate bearing capacity, Q_u, was not done using the relationship A N_c s_u, where A is the area of the foundation, N_c is the bearing capacity factor = 6, and s_u is the undrained shear strength. A hand-calculation should have tipped off the predictors that a load above 250 kN would not be reasonable (even after allowing for an N_c value somewhat higher than 6).

In his keynote lecture for GeoCongress 2013, Professor Mike Duncan recommended that more than one computer code be used when doing geotechnical calculations to check "that you have not missed anything of importance." We would like to add: "Always check the result with a simple back-of-the-envelope calculation!" Today, it is not the software used that differentiates between consultants. The knowledge and experience of the personnel using the software and the appropriateness of the specific soil models and parameters adopted make the whole difference between "a dangerous robot" and a reputable consultant. Although the tools used today are much more sophisticated than earlier, experience, judgment, and thorough quality control remain as important as ever.

In Praise of Testing and Good, Reflected, and Clearly Presented Data

To determine soft-ground properties and establish the stress history and relevant shear strength profile, engineers need to interpret good-quality test results, and in most cases, verify them with well-established correlations. To create a design, the engineer needs good, precise graphs of the soil properties. An undrained shear strength without reference to how it was measured is worthless. So is the preconsolidation stress without an indication of the quality of the soil specimen. And so is the effective overburden stress without a reference to the in-situ pore pressure and how it was measured or assessed. The meticulous presentation of data, even though considered "old-fashioned" by some, is crucial. Also, many more of our young graduates need to become interested in laboratory testing and the interpretation of test results! Unfortunately, most academic institutions and many geotechnical firms have moved away from that important element of our profession.

The selection of soil parameters from laboratory and in-situ tests results for geotechnical design still involves a high degree of subjectivity. This "subjectivity" should be influenced by an understanding of how soft soil behaves, supported by solid experimental evidence and well-established correlations. For example, the influence of strain rate on the key mechanical parameters of soft clays, such as the preconsolidation stress and undrained shear strength, is not well rooted in geotechnical practice, and strength and stress anisotropy is still too often forgotten.

In summary, our profession should refocus on a complete understanding of the stress history and behavior of soft ground. We ought to remind ourselves that we have a substantial responsibility for safeguarding the safety of people and property. We need to become intimate with the deposits we are evaluating and continue to rely on experience, peer review, and simple order of magnitude hand-calculation checks.

Let's also remember that in order to be successful, a geotechnical engineer has to bridge between the fields of science and art, to assess the geology and soil-structure as well as soil-water interaction, and rely in large part on gut feeling, moderated with local experience and expertise. GS

[1] Doherty, J.P., S. Gourvenec, and F.M. Gaone, (2018). "Insights from a Shallow Foundation Load-Settlement Prediction Exercise." *Computers and Geotechnics.* 93: 269-279.

SUZANNE LACASSE, PhD, F.ASCE, F.CAE, NAE, is the former managing director and now a consultant for the Norwegian Geotechnical Institute in Oslo, Norway. She can be reached at *suzanne.lacasse@ngi.no.*

NADIM F. FULEIHAN, Sc.D, PE, RPEQ, M.ASCE, is senior consultant and president of Ardaman & Associates Inc., in Orlando, FL, where he is in charge of major geotechnical engineering projects. He can be reached at *nfuleihan@ardaman.com.*