IN SITU GEOTECHNICAL TESTING USING LIGHTWEIGHT PLATFORMS

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ABSTRACT

In situ testing in geotechnical engineering has traditionally been carried out using relatively heavy equipment. Smaller soil exploration rigs, such as Geoprobe® soil probing units, have most often been used in environmental site characterization. However, several advances in equipment design now allow these smaller units to be used for some geotechnical work, including cone penetration tests (CPT) and dynamic penetration (DP) tests.

Soil probing machines are ideally suited for performing dynamic probing, which is an alternative to the Standard Penetration Test (SPT). Like the SPT, dynamic penetration super-heavy (DPSH) uses a hammer that delivers energy to the rod string by dropping a 140-pound weight from a height of 30 inches. Unlike the SPT, a solid cone is driven instead of a split spoon sampler. Soil samples are not brought to the surface, so a continuous record of penetration is recorded without tripping tool strings in and out of the borehole. A drop hammer with an automatic tripping mechanism was designed and built to easily attach to a Geoprobe soil probing machine.

The CPT is a reliable and cost-effective method for determining sub-surface stratigraphy as well as obtaining many geotechnical parameters. CPT probes are pushed into the ground at a constant 2 centimeters per second (cm/s) rate, rather than with the use of a drop hammer to advance the tool string, as with the SPT. Unlike the SPT, CPT provides a continuous, detailed log of the soil. Anchored soil probing units have been used to perform CPT tests in many areas of the United States. Anchoring is straightforward; two or three anchors are screwed into the ground to provide the necessary reaction force for pushing the probe. Three well-placed anchors can provide up to 9 tons of reaction force.

Soil probing machines have been used for geotechnical testing in many different soil types across the United States. Lightweight soil probing units will increasingly be used to push CPT probes and perform DP tests because of their relatively low mobilization costs and because of the large number of units that are available to project planners.

Introduction

In situ testing in geotechnical engineering has traditionally been carried out using relatively heavy equipment. The SPT is typically performed using a drill rig, and, in the United States, CPT has been performed mainly with ballasted CPT rigs. Smaller soil exploration rigs, such as Geoprobe soil probing units (Figure 1), have most often been used in environmental site characterization. However, several advances in equipment design now allow these smaller units to be used for some geotechnical work.

In areas where suitable soils occur, CPT has gained popularity among geotechnical engineers. The most common land-based rigs for CPT are heavy trucks that are ballasted to weights of 15 to 20 tons. However, it is not always necessary to use such heavy, specialized equipment for CPT. CPT probes have been successfully pushed by drill rigs and anchored soil probing units.

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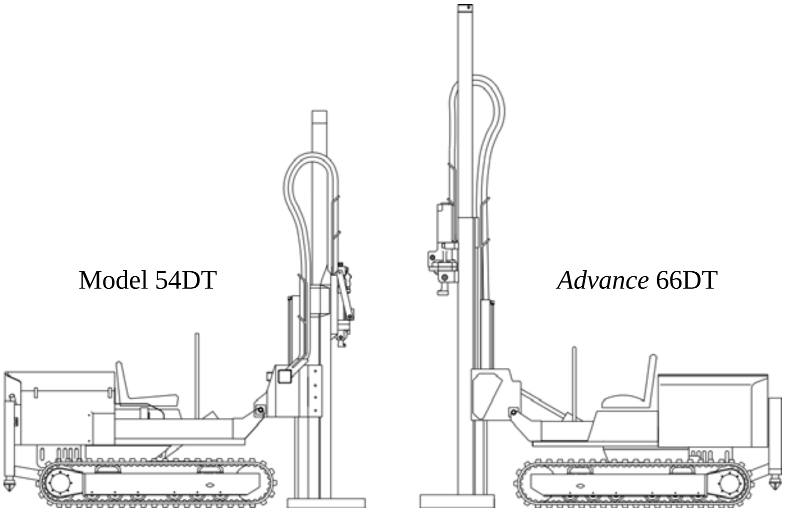

Figure 1. Geoprobe Model 54DT and *Advance* 66DT track machines. Geoprobe soil probing units are also mounted in pickups, vans, and on skid steers.

Light platforms, like the Geoprobe, are also ideally suited for performing dynamic probing (DP), which is an alternative to the SPT. The International Society for Soil Mechanics and Foundation Engineering (ISSMFE) has outlined a procedure called dynamic penetration super-heavy, or DPSH. DPSH is designed to closely simulate the dimensions of the SPT. Like the SPT, DPSH uses a hammer that delivers energy to the rod string by dropping a 140-pound weight from a height of 30 inches. A blow count (N) value is computed by summing the blow counts for a 12-inch penetration interval.

Unlike the SPT, a solid cone is driven instead of a split spoon sampler. Soil samples are not brought to the surface, so a continuous record of penetration is recorded without tripping tool strings in and out of the borehole.

Interpretation and Applicability of the CPT Results

The CPT is very useful in environmental and geotechnical characterization. It can be used to determine soil types, thickness and lateral extent of soil layers, depth to bedrock, and location of the ground water table. The CPT is also used to determine some geotechnical parameters, and provide results for direct geotechnical design. Table 1 summarizes the applicability of the CPT for deriving some soil parameters. Table 2 shows the applicability of using the CPT for various geotechnical design problems.

Table 1. Applicability of CPT for deriving soil parameters (from Lunne, et.al, 1997)

	Initial state parameter					Strength parameters		Deformation Characteristics			Flow Characteristics	
Soil Type	γD_r	ψ	K_o	OCR	S_t	s_u	ϕ'a	E, G	M	G_o	k	c_h
Clay	3-4		4-5	2-3	2-3	1-2	3-4	4-5	4-5	4-5	2-4	2-3
Sand	2-3	2	4-5	4-5			2	2-4	2-4	2-3		

Applicability rating: 1 High reliability; 2 High to moderate reliability; 3 Moderate reliability;
4 Moderate to low reliability; 5 Low reliability.

γ = soil unit weight
St = sensitivity
a = attraction
k = permeability
ϕ' = drained friction angle

D_r = relative density
su = undrained shear strength
E = Young's modulus
OCR = overconsolidation ratio

ψ = state parameter
K_o = coefficient of earth pressure at rest
G_o = Small strain shear modulus
c_h = coefficient of consolidation

Table 2. Applicability of the CPT for geotechnical design (from Lunne, et.al, 1997)

	Pile Design	Bearing Capacity	Settlement	Compaction control	Liquefaction
Sand	1-2	1-2	2-3	1-2	1-2
Clay	1-2	1-2	3-4	3-4	
Intermediate Soils	1-2	2-3	3-4	2-3	

Applicability rating: 1 High reliability; 2 High to moderate reliability; 3 Moderate reliability;
4 Moderate to low reliability; 5 Low reliability.

Mitchell and Brandon (1998) identify several phases of geotechnical earthquake engineering where the CPT can be used reliably and economically. The identified phases include soil profiling, identification of critical strata, liquefaction potential assessment, and the design and evaluation of ground improvement for mitigation of ground failure risk.

The CPT test is valuable in many geotechnical designs, and the number of direct design procedures is increasing. The continuous, detailed nature of the CPT results is having a significant effect on the geotechnical industry. Increasing capabilities and applications for CPT testing will enhance the popularity of the CPT (Rohde, 1998).

CPT Equipment

The soil logs that are illustrated in this paper were all collected using Geoprobe soil probing machines. The probes on these units were all anchored using soil anchors with 4-inch outside diameter (OD) augers. The anchors were turned into the ground using the rotary hex drive of the machine. The various probes had total down forces of 16,000 lb., 18,000 lb., and 30,000 lb. Depending on soil type at the surface, the Geoprobe machines most often achieved around 17,000 to 18,000 pounds of reaction force with their anchors (Figure 2).

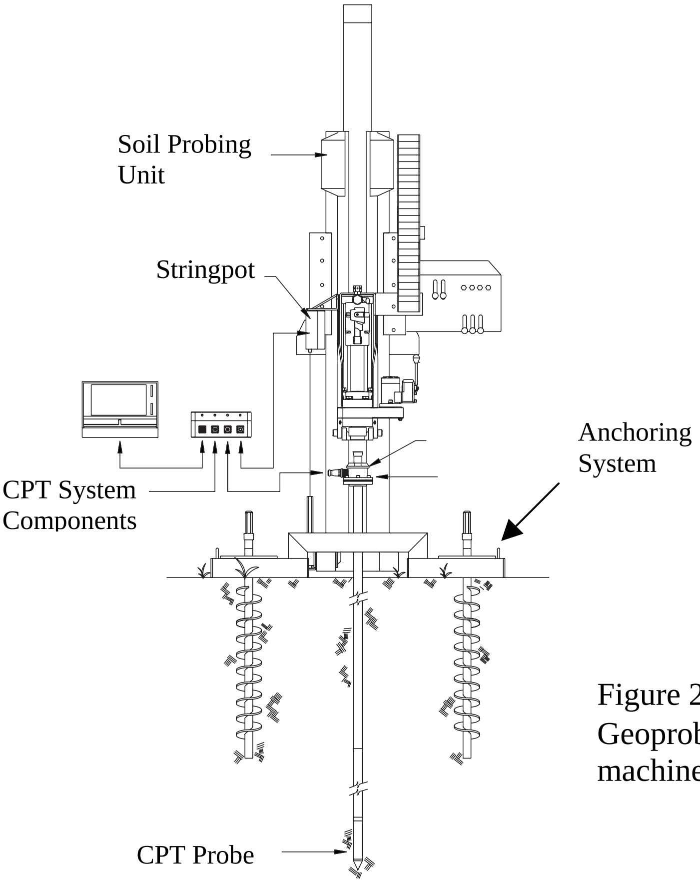

Figure 2. Anchored Geoprobe® soil probing machine with CPT.

The CPT system that was used was the cordless CPT manufactured by Geotech AB of Sweden. With the cordless CPT, data measured at the probe is transformed into a sound signal. The signal is transferred along the sounding rods to a microphone between the top rod and the probing machine. The microphone in turn sends the signal to a laptop computer via a computer interface.

Cordless CPT offers many advantages over conventional CPT systems that use a cable for data transmission. With this cordless system, the entire CPT sounding process is simplified; the operator does not have to manage data cable as the rods are tripped in and out of the boring. Rod handling is efficient and the risk of cable damage is eliminated. This added convenience is especially nice on a machine that is not solely dedicated to CPT work. Since the rod-bore is free and clear, it can be used for lubrication grouting as the rods are pushed into the ground and for retraction grouting as the rods are pulled from the borehole to seal the boring.

The CPT probe measured tip resistance and sleeve friction using separate strain gage load cells. Pore pressure was measured using a saturated filter, which was located behind the cone tip. This type of cone is called a piezocone or CPTU. The CPT system used for the cases noted in this paper was equipped with individual sensors for point resistance (q_c), sleeve friction (f_s), pore pressure (u), and tilt. Two probes were used, one with maximum tip resistance of 50 Mega-Pascals (MPa), and one with maximum tip resistance of 100 MPa. 100 MPa and 50 MPa are roughly equivalent to 10 and 5 tons, respectively. The 50 MPa cone is recommended mainly for use in softer soils, such as clays, silts, and loose sands, while the 100 MPa cone can be used in denser, harder soils.

DPSH Equipment

For DP, an automatic drop hammer was manufactured to fit on a Geoprobe machine (Figure 3). The hammer had an automatic tripping mechanism that dropped a 140-lb. weight at a rate of no faster than 30 blows per minute. The hammer ran using the auxiliary hydraulics on the probing unit. The safety of the hammer operator was of great concern, so the entire hammer was encased within a solid steel and steel mesh shroud.

Electrical controls were added in order to simplify use of the hammer. Also, a proximity sensor was installed that automatically counted the number of blows of the hammer. The depth of penetration and speed of penetration were measured using a stringpot. These two features enable the user to have their field computer automatically keep track of blow counts. Another proximity sensor was installed that automatically stopped the hammer when the rod was driven its full length. This design allowed the user to merely start the hammer at the top of a new rod and have the computer and controls take care of data collection and stopping the hammer. An emergency stop button was also incorporated so that the hammer could be stopped manually at any time during testing.

The dimensions of the DPSH probe were taken from the ISSMFE standard (2” OD, 90° apex angle, 2” mantle length, tapering to 1.25” OD at the top of the probe). The probe used for the cases in this paper was modified to include a dipole electrical conductivity sensor. This addition did not change the dimensions of the probe, but it did add additional capabilities for determining lithology (Christy, et.al., 1994). With the addition of the soil conductivity sensor, the computer logging system gave real-time display of soil blow count, speed of penetration, and electrical conductivity. All of these parameters were graphed in real-time with depth during testing.

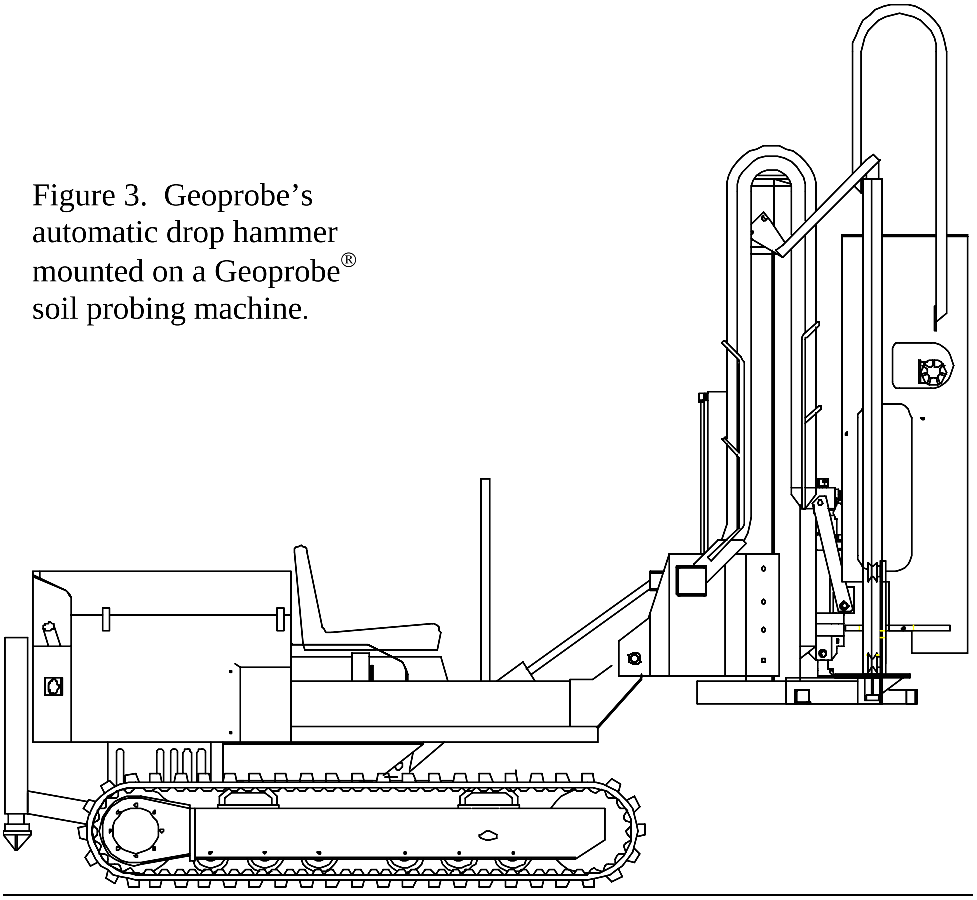

Figure 3. Geoprobe's automatic drop hammer mounted on a Geoprobe® soil probing machine.

CPT Logging

CPT probing is generally limited to soils that do not contain much gravel. This limitation does not only apply to lightweight platforms, as the same gravelly soil will limit the push of a large CPT truck. Soil probing machines have successfully pushed the CPT in many areas of the U.S. and in many different soil types. Recently, a probe was pushed to 112 feet by an anchored Geoprobe unit in Louisiana. The following examples are logs that have been taken using a Geoprobe machine. These particular logs have been chosen with the idea of showing probing results in different soil types.

Salina, Kansas

The first example of a CPT log is from Salina, Kansas (Figure 4). The 100 MPa CPT probe was used during this test. A tracked Geoprobe soil probing unit was anchored with three screw anchors.

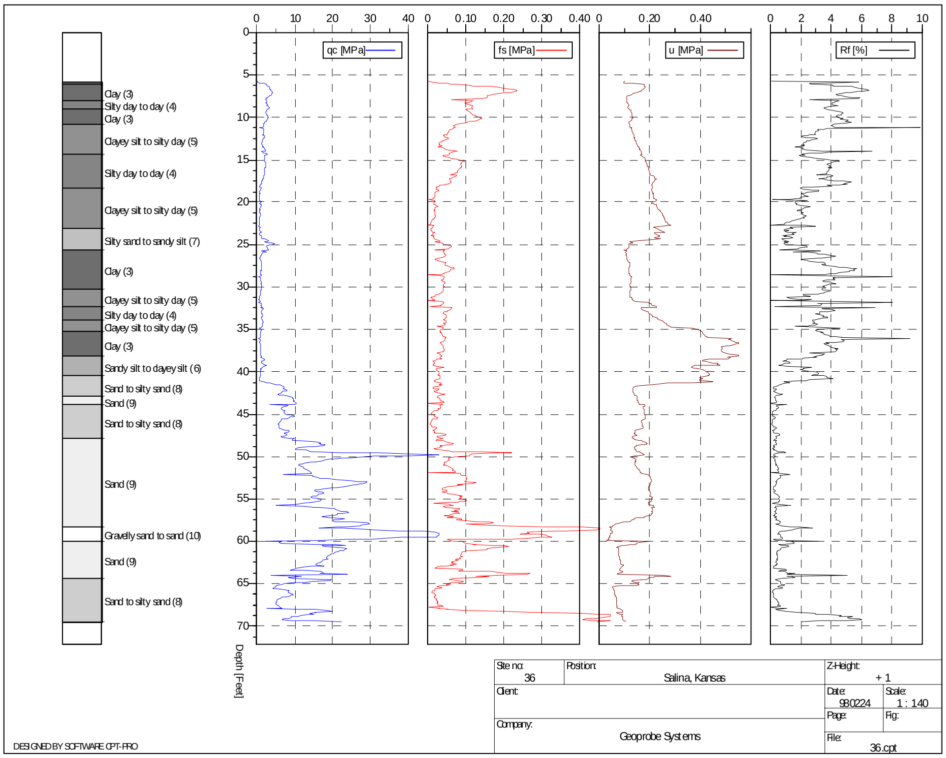

Figure 4. A CPT log from Salina Kansas. Equipment: Geoprobe soil probing unit pushing a Geotech AB cordless CPT probe. q_c = tip resistance, f_s = sleeve friction, u = pore pressure, and R_f = friction ratio.

The area where the CPT test was run is an alluvial valley area, and the soils are typical alluvial soils. The log shows approximately 40 feet of mainly silty clays overlying ~30 feet of medium to very dense sands. A thin silty sand layer can be seen at 25 feet. The probe met refusal at 69 feet when it encountered the shale bedrock. The tip sensor measured a maximum of 78 MPa resistance at bedrock before the push was halted.

The pore pressure response shows fairly high generated pore pressures in many of the finer grained soils and either static or negative generated pore pressures in the underlying sands. These results are typical, with clays and silty clays showing undrained behavior, and sands showing a drained response to testing. Many of the sharp changes in pore pressure can be seen at clay/sand contacts.

The soil types encountered at this site are classified according to behavior type based on the classification procedure of Robertson, et. al., 1986. Other calculations that can easily be carried out are SPT N-value, undrained shear strength of fine grained soils (Robertson and Campanella, 1989), and friction angle of coarse grained soils (Robertson and Campanella, 1983).

All of the soils at this site have been thoroughly sampled and they have been logged extensively using electrical conductivity (Ec) probes. The CPT results mirror the soil sample logs, as well as the Ec logs. Generally, conductivity values are highest in clays and lowest in sands and gravels. Intermediate soils such as silts or silty sands will have EC values corresponding to their content of fine grained materials.

Atlanta, Georgia

The second CPT case was logged in Atlanta, Georgia (Figure 5). The 50 MPa cone was used for this test, and refusal was met when tip resistance increased suddenly to 48 MPa at 27.5 feet. The first 3 to 4 feet of soil at this site was a fill with occasional boulders, cobbles, and bricks. A hole was augered through this fill before the CPT test was begun. Soils encountered at this site were predominantly silts and sands. Soil response was within expected ranges and, accounting for site heterogeneity, was similar to other tests run at the site.

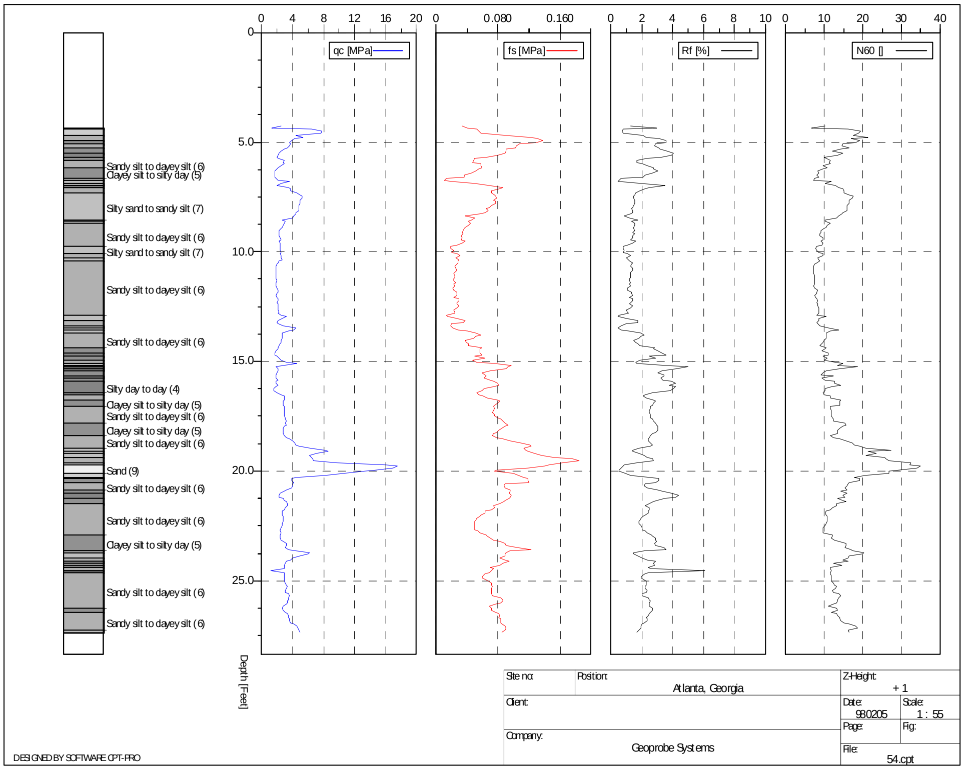

Figure 5. CPT log from Atlanta, Georgia. Equipment: Geoprobe soil probing unit pushing a Geotech AB cordless CPT probe. The graphs include soil behavior type, tip resistance, sleeve friction, friction ratio, and SPT blow count correlation according to Robertson and Campanella, 1986.

Des Moines, Iowa

Three CPT logs were taken at an environmental contaminated site in Iowa. The three tests were spaced along a 200-foot North-South line near the Des Moines River. At each location, a CPT probe was pushed and an Ec probe was driven. At the third location, some soil samples were taken to check the results of the CPT and Ec logs. The CPT results at this site are shown in Figure 6. Soil behavior types were calculated and brought into Surfer® for Windows® where they were plotted as a North-South cross-section (Figure 7). A similar cross-section was generated from the Ec data and is displayed in Figure 8. The cross section generated from CPT data closely resembles the Ec cross section. All CPT and Ec results were well within expected ranges for alluvial soils.

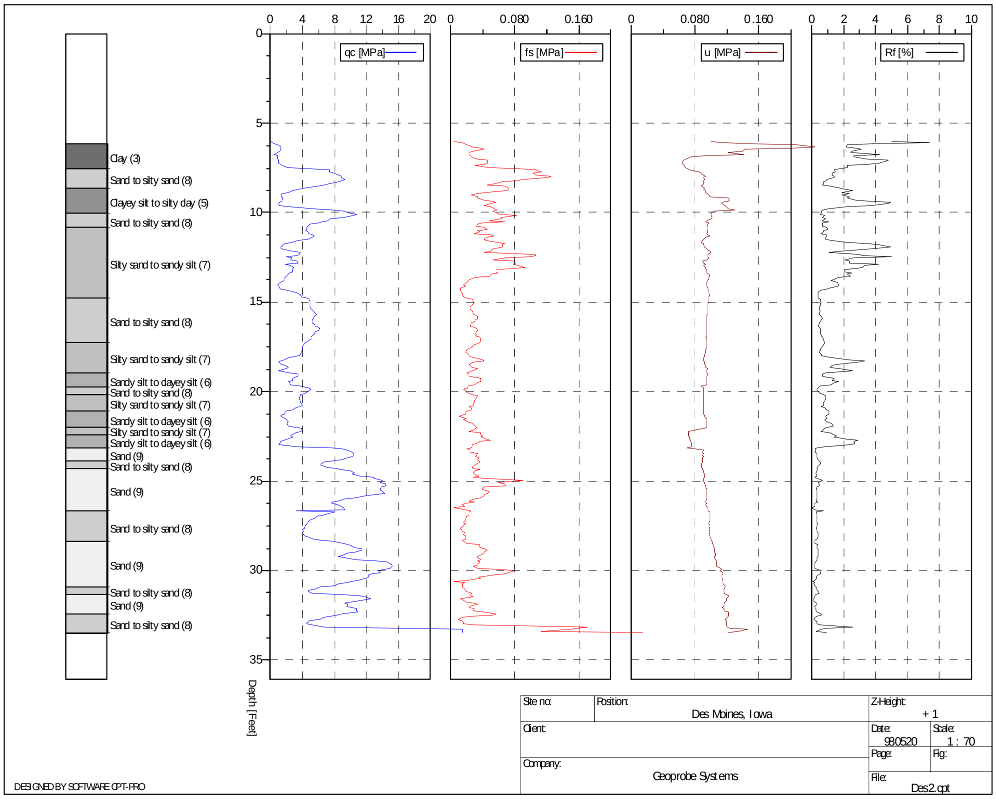

Figure 6. CPT log number 2 from Des Moines, Iowa. Equipment: Geoprobe soil probing unit pushing a Geotech AB cordless CPT Probe. The graphs show soil behavior classification, tip resistance, sleeve friction, pore pressure, and friction ratio.

At location 3, soil samples were taken at 18-22 feet and 24-28 feet. The purpose of these samples was to visually confirm some of the soils identified by the CPT and Ec probes. The CPT results indicated a silt/sand contact at 20 feet. The first soil sample confirmed that the contact existed and that a silty clay soil was deposited over a fairly clean sand. The second soil sample consisted of a poorly graded sand for the entire sample length. This mirrored the results of the CPT and Ec logs.

All three CPT tests at this site were stopped at a gravel layer located at 29-30 feet. The soil probing machine remained anchored, but the inclination of the probes increased sharply when the gravel layer was penetrated. Rather than risk damage or loss of the probe, the tests were stopped at this layer.

DPSH Testing

DP was completed at various sites throughout the Midwest, and always on a Geoprobe soil probing unit. Numerous DP tests were done at each site in order to gauge the repeatability of the test results. The results of the DPSH tests were compared to expected SPT N-values that were calculated using CPT data.

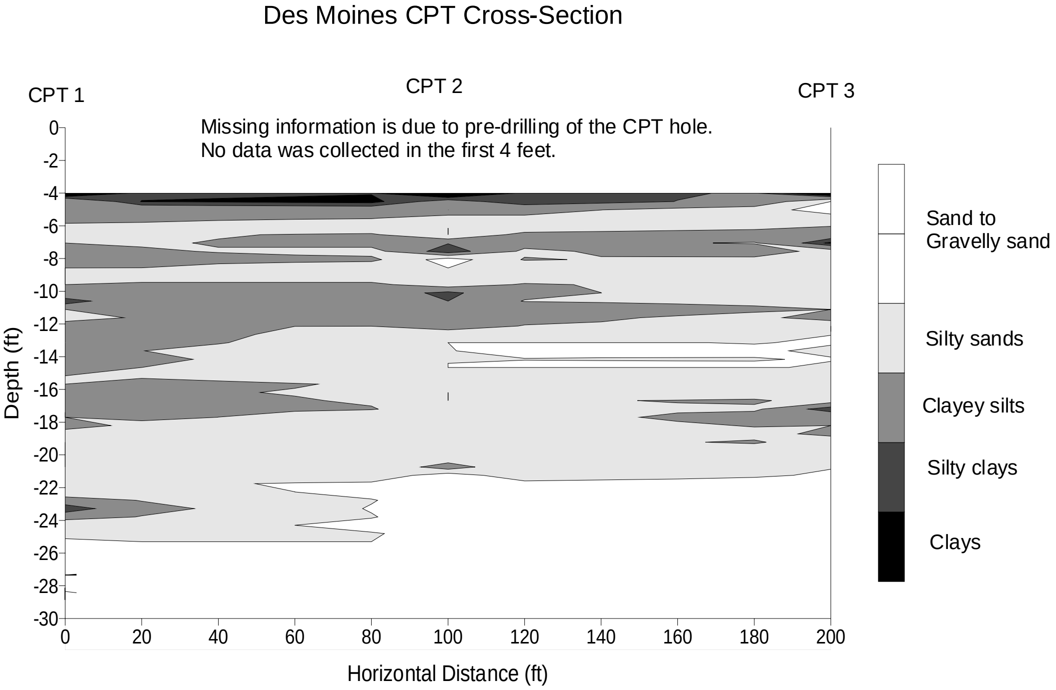

Figure 7. Des Moines, Iowa cross-section of soil behavior types determined by CPT testing.

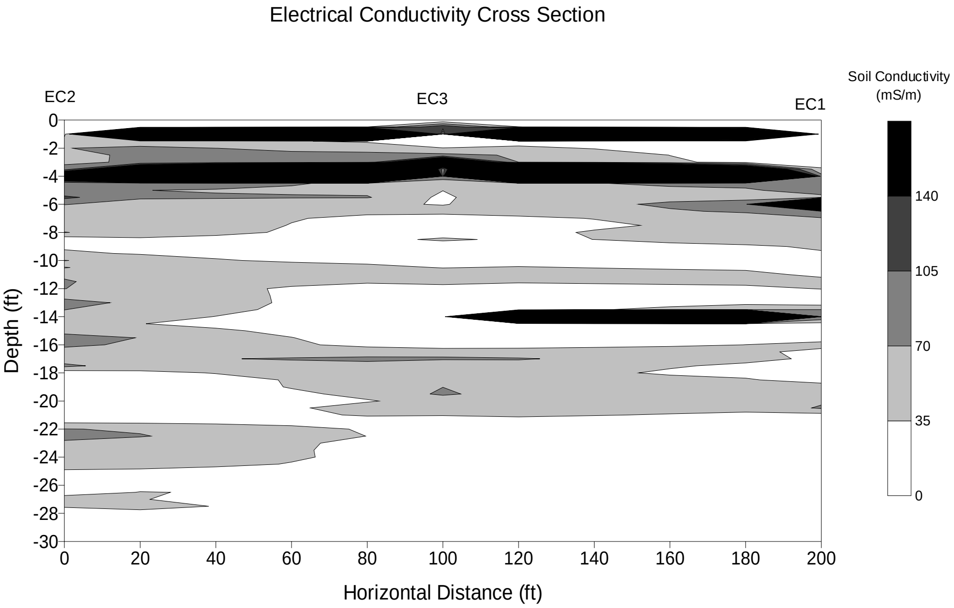

Figure 8. Des Moines, Iowa cross section of electrical conductivity results. Lighter areas represent soils with lower fines grained particle content (i.e., gravels, sands, silty sands)

Figure 9 shows a typical display that is seen during DPSH testing. Conductivity, speed of penetration, and blow count information is graphed in real-time with depth. Blow counts are shown as blows per 6 inch interval. To arrive at an N-value that corresponds with an SPT test, two successive 6 inch intervals must be added together. The conductivity results show the soil type that is penetrated, while the speed of penetration and the blow count show that soil's resistance to penetration.

The results of DPSH testing were quite repeatable. Successive tests taken in the same vicinity showed results that were very similar. The automatic hammer kept the hammer energy constant throughout the test. The continuous nature of the test also led to repeatable results, as some of the variability associated with the SPT test, such as drilling method used, how well the hole is cleaned, and presence/absence of drilling mud (Coduto, 1994) was eliminated. The main potential source of error in the DPSH test is the starting inclination of the rods. This error would mainly be in the recorded depth compared to the actual depth of penetration. Figure 10 shows two logs taken at the same site approximately 30 feet from each other. These two tests show very similar results, as expected.

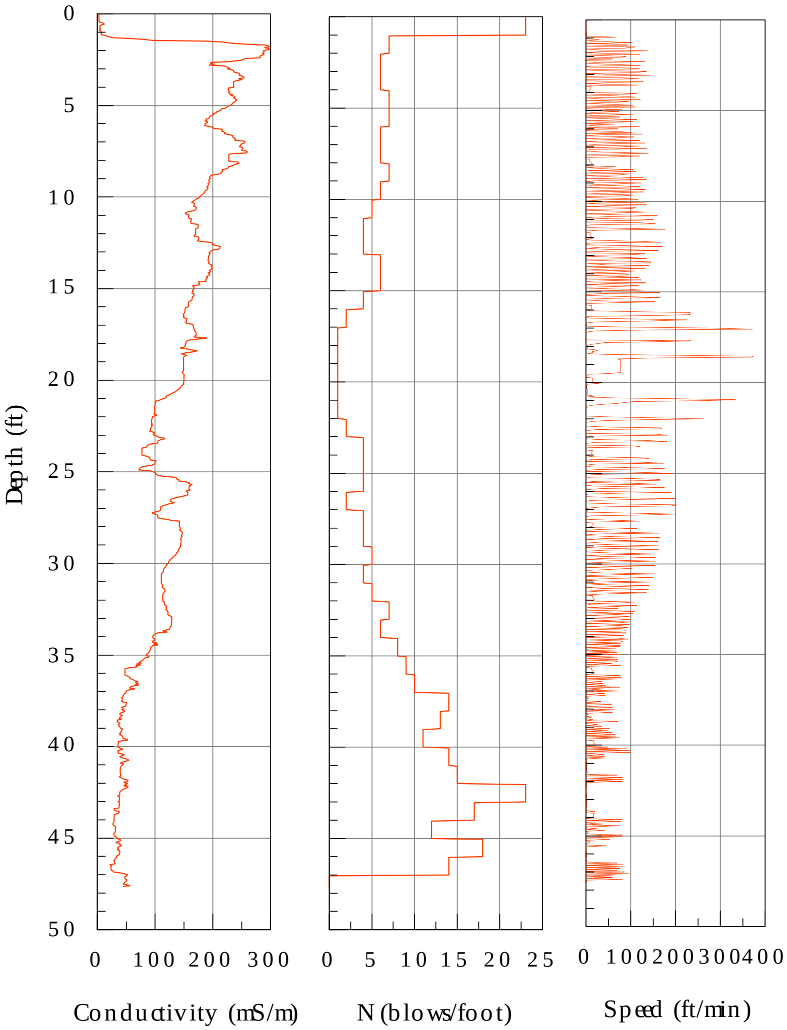

Figure 9. Data from a DPSH test. Soil conductivity, blow count, and speed of penetration is graphed with depth.

There are several procedures that can be used to estimate SPT N-values from CPT results. Jefferies and Davies (1993) suggest that their method provides a better estimate of the SPT N-values than the actual SPT test because of problems with the repeatability of the SPT. Whether this claim is true or not, this method has been shown to provide good estimates of SPT N-values. Figure 11 shows DPSH results compared to CPT N-Value estimates. The DPSH results are very similar to the SPT N-values predicted by the CPT test. The SPT value estimates results tend to confirm that the DPSH probe design simulates the N-value results obtained with a split spoon sampler, at least in the soils that were tested.

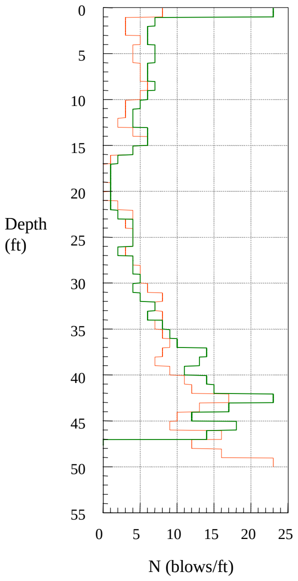

Figure 10. Two DPSH tests performed ~30' from each other demonstrate the repeatability of the tests.

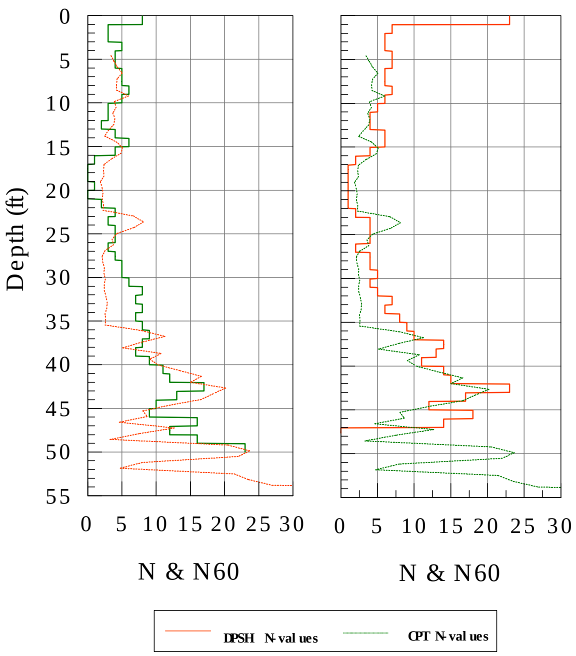

Figure 11. DPSH results compared to SPT N-values that were calculated using CPT N_{60} results.

Conclusion

In situ geotechnical testing can easily and effectively be carried out using lightweight rigs and soil probing units. CPT testing, usually performed using heavy trucks, can be carried out using anchored lightweight units, such as Geoprobe soil probing machines. In many situations, lightweight rigs can push probes to the same depths as large CPT trucks. Lightweight rigs are easier to mobilize and much easier to maneuver on site, especially at undeveloped sites.

Soil probing machines have pushed CPT probes in many different soil types across the United States. The data collected is a useful tool for environmental and geotechnical site characterization and geotechnical design. Lightweight soil probing units will increasingly be used to push cones because of their relatively low mobilization costs and because of the large number of units that are available to project planners.

Automatic trip hammers attached to soil probing machines can be used to perform dynamic penetration testing, an internationally recognized alternative to standard penetration testing. In many situations, the use of soil probing machines may be an inexpensive alternative to larger drill rigs. The smaller crew sizes and increased mobility of lightweight probe units will be an asset to many projects.

Geotechnical work does not have to be performed with only drill rigs and CPT trucks. The advancements discussed in this paper will enable smaller, lightweight soil probing machines to find a niche within the geotechnical arena.

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