Enhanced Site Characterization in Residual Soils Using the SPT- T and Drive Cone Tests

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ABSTRACT

The Standard Penetration Test with Torque (SPT-T) gives a useful measurement when characterizing residual soil deposits without compromising the original ASTM test procedure. The SPT-T takes about one minute to perform after the standard SPT is conducted. The torque measurement obtained from rotating the split spoon after the full 45.7 cm (18") penetration can give a good qualitative and quantitative description of the soil. When supplemented with Drive Cone Penetration Tests (DCPT), site characterization can be completed relatively quickly and inexpensively. The DCPT's give a valuable addition to site characterization in residual soils since a more continuous profile of penetration resistance is obtained. Both of these tests can be performed using routine drilling equipment and only minor additional equipment. The "penetrability" of the SPT can also give qualitative differentiation between soil and rock which is useful in residual soil deposits. A case study is presented that utilized SPT-T and DCPT tests to supplement a site investigation in McLean, Virginia. The results obtained in this case study are used to illustrate how these simple in situ tests can enhance site characterization in residual profiles.

INTRODUCTION

Traditional site characterization in residual soils often rely on the Standard Penetration Test (SPT) due to the highly variable nature of the soil and the versatility of the SPT. Other more sophisticated in situ tests (i.e., Cone Penetration Test, Dilatometer Test, Pressuremeter Test) can be difficult to deploy in some cases considering the weathered profile of the soil mantle, transition zone, and the parent rock, but the ruggedness of the SPT ensures that a site characterization can be

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completed. The use of the SPT in residual soils may be misleading if high N-values are recorded and little to no soil recovery is obtained. The question arises; is the material soft rock or hard soil? Large N-values may not necessarily indicate a competent soil. A simple technique for enhancing the value of the SPT and its applicability in residual soils is to supplement the SPT with a torque test after driving. The use of the Standard Penetration Test with Torque measurements (SPT-T) in residual soils is potentially very useful for complimenting a site investigation. A modification at the end of the Standard Penetration Test (SPT) is performed to give valuable qualitative and quantitative information about the soil deposit. Supplemented with Drive Cone Penetration Tests (DCPT), a thorough site investigation of a residual soil can be achieved both quickly and economically. This paper gives a description of the SPT-T and DCPT procedures and presents results obtained from a geotechnical site investigation in a typical Piedmont residual soil at the Federal Highway Administration - Turner Fairbank Highway Research Center (TFHRC) in McLean, Virginia.

BACKGROUND

Site Description

The site is located in McLean, VA approximately 24 km (15 miles) northwest of Washington, D.C. The location of the site is on the northern tip of the Piedmont Province as shown in Figure 1.

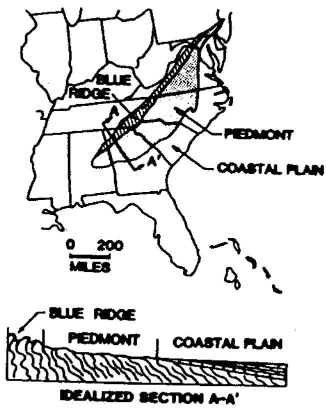

Figure 1. Location and idealized section of Piedmont and Blue Ridge (from Sowers and Richardson 1983).

The Piedmont Province or Piedmont geologic region is in the southeastern United States and consists of a broad strip approximately 161 km wide and 1290 km long wedged between the Blue Ridge Mountains to the west and Coastal Plain to the east (Barksdale et al. 1982). The region is underlain by metamorphic rocks, predominantly gneisses and schists, of early Paleozoic age or older. Younger intrusive bodies of granite and similar silic rocks and occasional smaller bodies of mafic rocks, such as gabbro of late Paleozoic age, are scattered within the region (Sowers and Richardson 1983). Typically, the residual soils are 6.1 to 24 m (20 – 80 ft) thick and are composed of silty fine to medium sands and sandy silts that are often partially saturated (Barksdale et al. 1982). The local geology at the test site is described as the Worcester Higgins formation composed predominately of weathered schist with a high amount of micaous sediment throughout (Adams 1997).

Development of the SPT-T

The SPT-T is the standard SPT procedure described in ASTM D 1586–84, with an added modification that incorporates a measurement of torque required to rotate the sampler after driving is complete. The measurement, representing the frictional resistance between the sampler and the soil, may be used qualitatively as a classification tool as described by Décourt and Filho (1994) or may be converted quantitatively into unit skin friction used to estimate the frictional capacity of driven pipe piles (Lutenegger and Kelley 1998).

The idea of complementing the traditional SPT with torque measurements was initially proposed by Ranzine (1988). The torque ratio (TR) is defined as the ratio between the measured torque and the N-value (T/N) and was used by Décourt and Filho (1994) to distinguish collapsible from non-collapsible soils. The torque measurement may also be used as a quality control measure to identify unusual blowcount values. A common situation occurring in many soils is the presence of gravel and cobbles in a sand layer. The larger diameter particles cause an "artificial" increase in the N-value, which does not necessarily correspond to the soil having a higher relative density or friction angle. This anomaly can be detected since the TR will usually be less than one (Décourt and Filho 1994).

It can be argued that an advantage of the torque measurement is to add a quasi-static testing component to a test that results from an initial dynamic phase. While most of the soil structure may be destroyed during installation of the spoon, the torque measurement may act in a region where the soil retains much of its original fabric and is only partially remolded. The torque measurement appears to be a novel addition to the SPT, which does not detract from the standard test procedure and requires only minimal additional effort. After penetration of the SPT sampler, the torque test only takes about another minute to perform. While the actual N value obtained from the SPT may be subject to wide variations because of differences in test equipment and field practice, the torque measurement may be subject to less test variability because of fewer operator controlled test variables. The torque measurement may be affected if the spoon or rods wobble during driving and contact between the spoon and soil is lost (Lutenegger and Kelley 1998). The actual variability due to the test procedure appears to be minimal.

Development of the DCPT

The DCPT is a good supplement to the SPT for site investigations, especially for highly variable soils. A drive cone can be deployed rapidly without having to remove a sampler from the subsurface after each 45.7 cm (18 in.) of penetration thus giving a more continuous profile. The Drive Cone Penetration Test is performed by driving a steel conical tip attached to rods into the ground using a drop weight.

Recording the number of blows required to drive a cone tip a specified distance into the ground gives the penetration resistance of the soil. DCPT's are commonly used throughout many parts of the world, but appear to be less common in the U.S. (Steffanoff et al. 1988). Different test configurations involving different hammer masses, fall heights, cone diameters, etc. are available. According to Steffanoff et al. (1988), the DCPT configuration used in this investigation would be considered as "Super-Heavy". There are numerous correlations from DCPT data to SPT N-values in the literature but most are site specific.

TEST PROCEDURES

SPT-T

In the SPT-T, a conventional Standard Penetration Test (ASTM D1586) is supplemented with a measurement of torque after driving the split spoon. To perform the torque measurement, a rod adapter is attached to the top of the drill string and a torque wrench is used to rotate the rods and spoon to obtain the maximum torque as shown in Figure 2. The torque resistance is assumed to derive only from the interaction between the external surface of the spoon and the surrounding soil. This procedure in no way compromises the current standard SPT practice, but provides an additional quasi-static measurement following the dynamic measurement of the spoon penetration. Normally, a half turn of the drill rods is sufficient to determine the peak value of torque.

SPT-T's were performed using a Central Mine Equipment 75 (CME-75) Drill Rig, 9.5 cm (3 3/4 in.) hollow stem augers (HSA), AW Drill Rods, 63.5 kg (140 lb.) safety hammer with a rope and cathead, and a 50.8 mm (2 in.) split-barrel sampler. The Torque wrench used to measure the maximum torque was a Socket Extension Reaction Torque Sensor (SERTS) rotated with a 19 mm (¾ inch) drive extender. The torque sensor has a range of 0-69.2 kg m (0-500 ft lb.) and was obtained from OMEGA Company. The torque sensor was wired to a P-3500 Micromeasurement strain indicator box and the highest digital value on the LCD read-out was recorded during the torque rotation of the spoon.

Drive Cone Penetration Test (DCPT)

DCPT's were performed using the SPT hammer and AW drill rods. The cone tip used in this investigation had an apex angle of 60° and a diameter of 63.5 mm (2 ½ in). The cone tip was made from heat-treated steel, which ensured little deformation of the tip while performing the test. The number of blows needed to drive the cone a distance of 15.2 cm (6 in.) was recorded. When performing a DCPT, the rod friction must be eliminated in order to obtain a true penetration resistance of the soil to the conical tip. Lutenegger (1999) suggests that if the cone/rod diameter (C/R) ratio is on the order of 1.3, there will be little or no significant effect of rod friction in most granular soils. AW rods were used for this investigation resulting in a C/R ratio of 1.4. During each test, the entire drill string was turned by hand before attaching the next drill rod in order to verify the absence of rod skin friction.

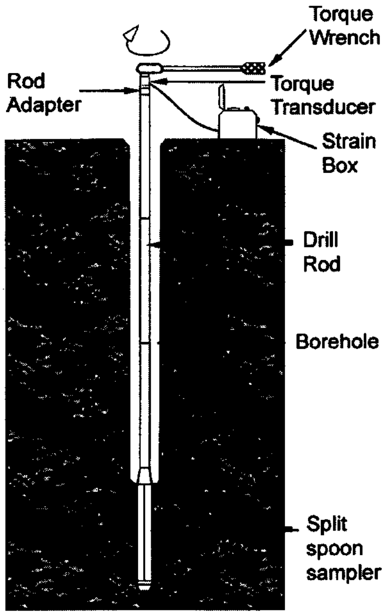

Figure 2. Schematic of the SPT-T procedure (after Lutenegger and Kelley 1998).

PRESENTATION AND DISCUSSION OF RESULTS

Soil Description

Soil samples obtained from the SPT-T profiles consisted of light tan to yellow orange fine sand, some silt, and some mica in the upper 3.0 m (10 ft) and white fine sand, black fine sand (granite rock appearance) with a trace olive gray fine sand and mica from 3 to 7.6 m (10 to 25 ft) below grade. The average water content of the soil between 0.61 to 6.1 m (2 to 20 ft) below grade was 20% and the average water content of the soil between 6.1 to 7.9 m (20 to 26 ft) below grade was 10%. There was no groundwater present in any of test borings during or after completion. The residual soil at a depth of 7.0 m was identified as a "Very High" rating of rock penetrability as described by Kotzias and Stamotopoulos (1978). This rating was determined by the "penetrability" of the SPT sampler as described later in this paper. Using an identification system also from penetrability measurements from Douglas (1983), the deposit at 7.0 m was identified as "very weak rock".

In Situ Tests

The in situ tests performed at the TFHRC test site were divided into two test locations, Location A and B. The two locations are approximately 450 m (1500 ft) apart, roughly at the same mean elevation above sea level, and are underlain by the same geology. Table 1 presents a summary of the in situ tests performed at both test locations.

Table 1. Description of the In Situ Tests performed at the TFHRC.

Test ID	Test Type	Date Performed	Depth at End of Test (m)	Location I.D.
B-1a	SPT-T; 2" split spoon	3/17/97	6.4	Location A
B-2a	SPT-T; 2" split spoon	3/17/97	6.4	Location A
B-1b	SPT-T; 2" split spoon	12/17/97	8.1	Location B
B-2b	SPT-T; 2" split spoon	12/17/97	8.1	Location B
B-3b	SPT; 2" split spoon	12/18/97	6.6	Location B
B-4b	SPT-T; 2" split spoon	3/17/99	8.1	Location B
B-5b	SPT-T; 2" split spoon	3/17/99	8.1	Location B
B-6b	SPT-T; 3" split spoon	3/18/99	7.3	Location B
DCPT-1a	DCPT	3/17/97	4.7	Location A
DCPT-2a	DCPT	3/17/97	4.6	Location A
DCPT-3a	DCPT	3/17/97	4.9	Location A
DCPT-1b	DCPT	3/17/99	6.1	Location B
DCPT-2b	DCPT	3/18/99	6.1	Location B

Seven SPT-T profiles and five DCPT profiles were performed as part of the site investigation.

SPT-T and SPT

Figure 3 presents the SPT N_{60} (standard blow count adjusted to 60% hammer efficiency) values and percent recovery plotted as a function of depth. It can be seen that the blowcounts increase gradually from a blow count of 10 to 40 in the upper part of the profile and then show a dramatic increase to over 100 at a depth below grade of 6.1 m (20 ft). The recovery averages around 80% near the surface and 100% throughout the rest of the profile. A test boring profile was also conducted using a 76 mm (3-inch) diameter split spoon at Location B to determine any scale effects with unit skin friction. It should be noted that the 76 mm (3-inch) split spoon N-values are generally greater than the 50.8 mm (2-inch) split spoon profiles which is to be expected.

SPT-T Frictional Resistance

Lutenegger and Kelley (1998) presented an equation that was used in this investigation to estimate unit skin friction for deep foundation design from SPT-T data. Using the moment arm as the distance from the center of the sampler to the outside surface of the barrel, and neglecting any contribution from the soil at the end of the spoon, the unit skin friction, f_s can be defined as:

$$f_s = \frac{2T}{\pi d^2 L} \qquad [1]$$

where:
T = measured torque,
d = diameter of spoon,
L = length of penetration.

Figure 4 (a) and (b) present the N_{60} and f_s values as a function of depth obtained from the SPT-T borings. The N_{60} and f_s values increase with depth and there appears to be no size effect between the 50.8 mm and 76 mm (2- and 3-inch) split spoon f_s values. As can be seen on Figure 4 (a) and (b), there is a significant trend between f_s and N_{60} which is also presented in Figure 5a. This suggests that the blowcount value obtained from the SPT is largely derived from side frictional resistance as previously shown by Schmertmann (1979). As can be seen in Figure 5a, there is a clear relationship between f_s and N_{60}. Figure 5b presents the normalized behavior of f_s and N_{60} values. As the N_{60} values increase the normalized f_s reduces to about 4. This is logical since there should be an upper bound of penetration resistance that gives a limiting value of unit skin friction (approximately N_{60} = 100).

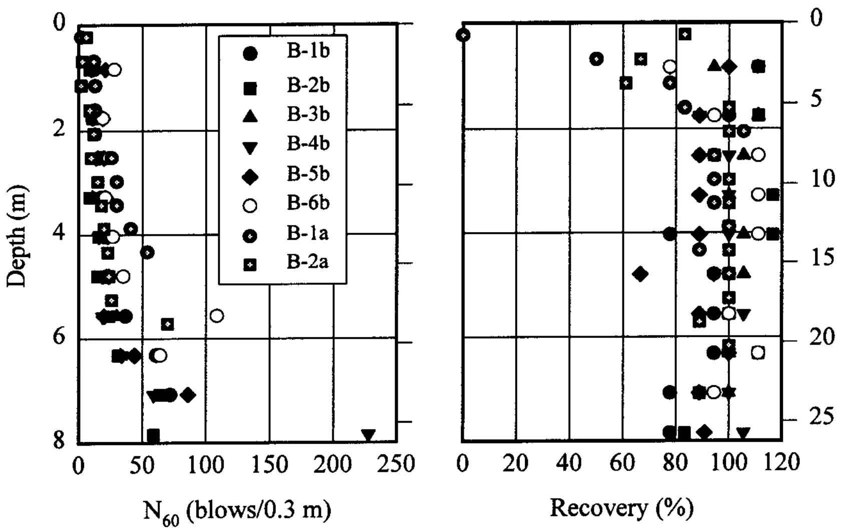

Figure 3. Depth versus N_{60} and Recovery for all SPT-T and SPT's conducted.

The concept of relating unit skin friction of driven piles in sand to SPT N-values is not unique and has been suggested by Meyerhof (1956, 1976) and others. The trend of increasing f_s with increasing N again suggests that the SPT is largely a skin friction test.

The torque ratio as described by Décourt and Filho (1994) was examined to show the qualitative value of the SPT-T for this investigation. The torque measurements were converted to kgf m and the N_{60} values were converted to N_{72} (Standard blow count adjusted to 72% hammer efficiency) values in order to compare with the Décourt and Filho (1994) data. As seen on Figure 6, the upper 6.1 m (20 ft) has an average T/N ratio of around 1.5 and below 6.1 m (20 ft) the ratio becomes 1.0; where the soil transitions into rock. These results are consistent with the observations made by Décourt and Filho (1994) in a residual soil deposit in Brazil.

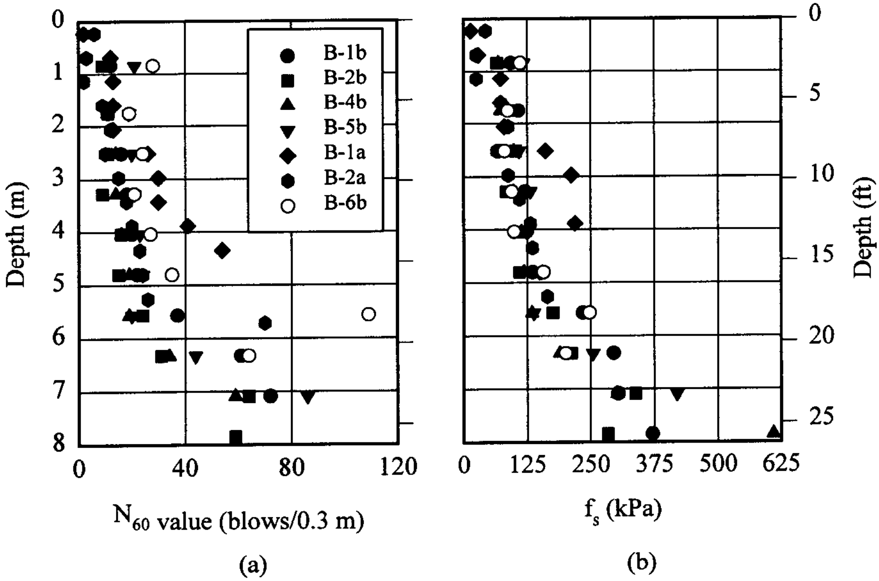

Figure 4. (a) Depth versus N_{60} (b) Depth versus f_s values.

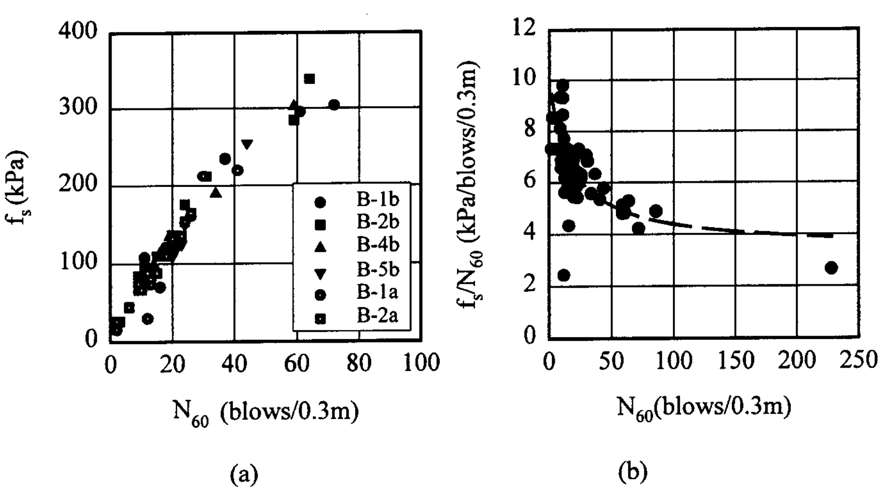

Figure 5. (a) f_s versus N_{60} (b) Normalized f_s versus N_{60}.

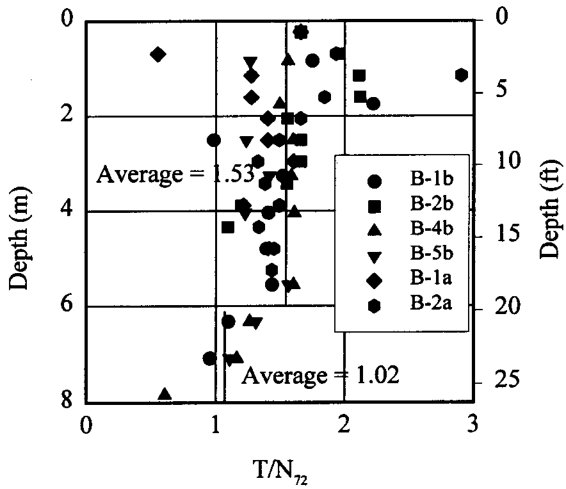

Figure 6. Depth versus Torque Ratio for the test site.

SPT Penetrability

Kotzias and Stamatopoulos (1980) suggested that the SPT might also be used to classify and indicate general properties of soft rock. The SPT "Penetrability" is defined as the penetration of the spoon, in centimeters, produced by 60 standard blows (Kotzias and Stamatopoulos 1980). Kotzias and Stamatopoulos (1978) noted a general demarcation between "soil" and "rock" by distinguishing "soil" as those materials having greater than 30 cm penetration per 60 blows. Penetration less than 30 cm per 60 blows is then defined as "rock". In this investigation, Boring B-5b had penetrability measurements recorded and "rock" was encountered at 7.0 m (23 ft) below grade. The penetrability was 25 cm/60 blows, which indicates "Very High" penetrability according to the suggested rating by Kotzias and Stamatopoulos (1978). This procedure may be useful in site investigations of residual soil in order to delineate the transition zone / parent rock boundary.

Douglas (1983) also presented a useful guide for identifying the relative strength of rock using SPT "Penetrability". This classification measures the penetration in millimeters per 50 blows of the SPT hammer. Penetration in Boring B-5b at 50 blows was 215mm, which is classified as "very weak rock" by Douglas (1983).

DCPT

A total of 5 DCPT profiles were performed in this investigation. The results shown in Figure 7a indicate that DCPT-1a developed rod friction during the test, which may have resulted from driving the cone tip at a slight angle from vertical. This rod friction was observed by the inability to rotate the rods after driving the cone tip only 3.0 m (10 ft) below grade. A comparison between Figure 4a and Figure 7a indicates that the SPT and DCPT profiles are similar in shape, thus a correlation between the SPT N_{60} data and the penetration resistance of the cone tip was made. Figure 8 presents the site-specific comparison of the correlated SPT data to the actual SPT data for this residual soil deposit.

The use of the DCPT is economically valuable for a geotechnical investigation since the average time to perform a single DCPT profile to 6.1 m (20 ft) is about 20 minutes compared to approximately 1 hour necessary to conduct a SPT profile to the same depth. Using a site-specific DCPT to SPT correlation, which can be easily obtained, "equivalent" SPT blow count data can be collected quickly using the DCPT.

Another useful method for delineating the soil mantle / transition zone / parent rock boundaries is to locate changes in slope of the DCPT cumulative penetration resistance. Figure 7b presents the cumulative penetration resistance profile with a zone boundary identified by the intersection of two slopes. As can be seen in this figure, two slopes intersect at approximately 3.75 m below grade. This is interpreted as the boundary between the soil mantle and the transition zone. The boundary between the transition zone and the parent rock is identified by the TR in Figure 6 at approximately 6.0 m (20 ft) below grade. As previously noted, the SPT penetrability method determined a depth to rock at approximately 7.0 m (23 ft) below grade. This corresponds with the change in SPT-T Torque Ratio as shown in Figure 6. The Torque Ratio provided too much scatter to define a boundary between the soil mantle and the transition zone. This transition is not seen in Figure 7b because all DCPT profiles were terminated at the transition zone / parent rock boundary.

DCPT data may also be presented by calculating r_d, the unit dynamic penetration resistance as defined by Bolomey (1974):

$$r_d = \frac{Mgh}{Ae} \quad [2]$$

where:

M = Mass of hammer (kg)
g = Acceleration due to gravity (m/s^2)
h = Height of fall of the hammer (m)
A = Area at the base of the cone (m^2)
e = Average penetration (m/blow)

The r_d value represents the driving work done by the cone tip when penetrating the ground and can be used to compare and interpret different test configurations of the DCPT.

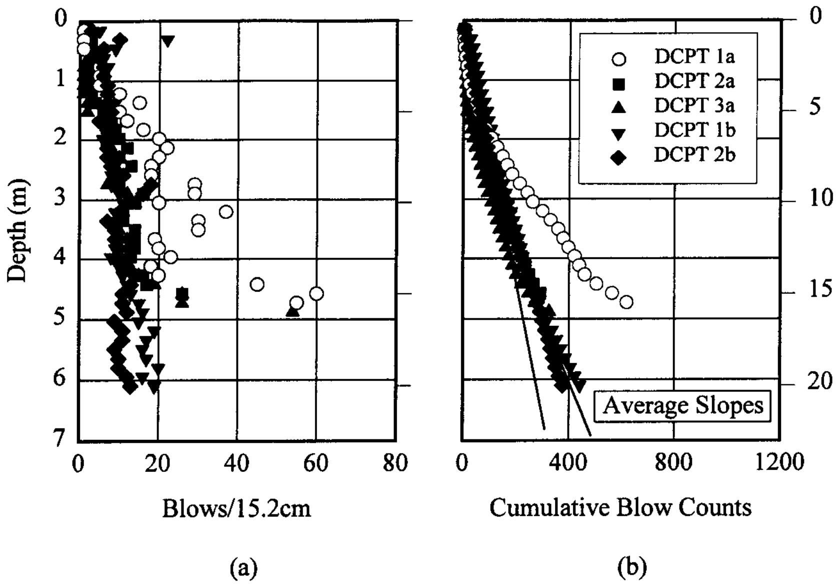

Figure 7. (a) Depth versus Penetration Resistance (b) Cumulative Penetration Resistance from DCPT data.

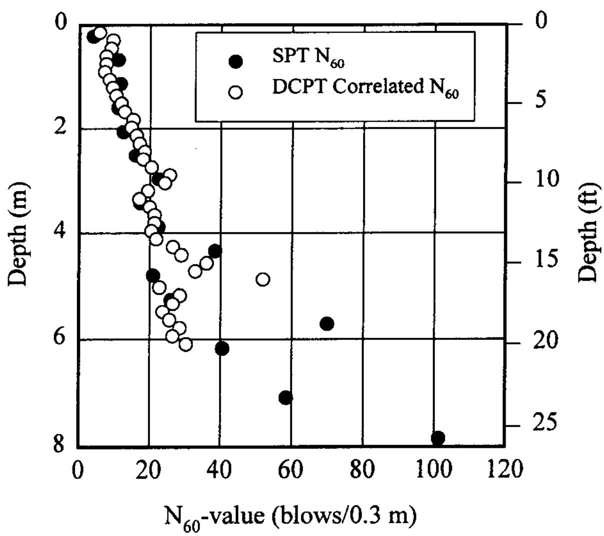

Figure 8. SPT and DCPT N_{60} data comparison.

SUMMARY AND CONCLUSIONS

A site investigation in McLean, VA was conducted using the Standard Penetration Test with Torque measurements and Drive Cone Penetration Test. The location of the site is on the northern tip of the Piedmont Providence, a known residual soil deposit. The test results indicate that these two methods of site investigation can provide useful information for geotechnical engineers. The SPT-T requires a simple procedure at the end of the Standard Penetration Test and can give valuable qualitative and quantitative data in residual soil deposits. With limited effort, Drive Cone Penetration Tests give additional data that provide a more complete site investigation in residual soils that can be completed both quickly and economically. Since residual soils can be so highly variable, these additional rapid and inexpensive in situ tests can improve the quality and increase the amount of data obtained in geotechnical site investigations.

ACKNOWLEDGEMENTS

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