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Standard penetration tests with torque measurement

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ABSTRACT: Recently, geotechnical engineers in Brazil have made the suggestion to supplement the conventional split spoon Standard Penetration Test (ASTM D1586) with a measurement of torque after driving. To perform the torque measurement, a rod adapter is attached to the top of the drill string and a simple torque wrench is used to rotate the spoon to obtain the maximum torque. The torque resistance is assumed to derive only from the interaction between 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. The torque measurement may have direct application in estimating skin friction for the design of driven pipe piles. A comparison of SPT-Torque tests and pile load tests performed in a sand is presented in this paper.

1 INTRODUCTION

A series of tests were performed to investigate values of unit skin friction obtained from the rotation of a Standard Penetration Test (SPT) split spoon to evaluate the rotational skin friction obtained from the measurement of the corresponding maximum torque. Tests were conducted at a site consisting of medium dense uniform fine to medium sand. Torque measurements were obtained in several test borings down to depths of 6.4 m using 50.8 mm spoons of different configurations, i.e., with and without liners, and with a spoon fitted with a solid 60^0 point to simulate a fully plugged spoon. Additional tests were performed using a larger 76.2 mm spoon to evaluate scale effects. In order to provide a comparison of the skin friction obtained from the SPT torque measurements with the dynamic advance of the spoon, tests were also conducted by installing the spoon with quasi-static penetration, rather than by driving. The force vs. penetration record of the spoon advance allows for an independent measurement of the spoon skin friction developed in the vertical direction. The test results are presented along with results of the lab and field characterization of the site and a comparison is made between the unit skin frictions obtained using the various spoon configurations. A final comparison is presented between the skin friction results obtained from the torque measurements and the results of steel pipe piles installed at the site and load tested in tension to failure.

2 SPT-T TEST - BACKGROUND

According to Decourt (1989), Ranzine (1988) was the first to suggest a simple modification to the SPT in which the traditional SPT is complemented by a torque measurement. That is, after driving the split spoon, torque is applied to the top of the drill rod string in order to rotate the spoon. Decourt and Filho (1994) have shown that the ratio of torque to SPT blowcount, N, (T/N with T measured in kgf-m) has proven useful in practice.

It can be argued that an advantage of the torque measurement is to add a static testing component to a test which results initially from a 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. In fact, the test only takes about another minute to perform. It seems logical that 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 variability. The torque may be affected if the spoon or rods wobble and contact between the spoon and soil is lost.

The torque measurement may have direct application for estimating skin friction of driven piles. Using the moment arm as the distance from the center of the spoon (where torque is applied) to the outside diameter, and neglecting any contribution from the soil at the end of the spoon, the unit skin friction may be given as:

$$f_s = (2T)/(\pi d^2 L) \quad [1]$$

where:

T = measured torque
d = diameter of spoon
L = length of the spoon driven

Equation 1 also neglects any contribution of skin friction from the inside of the spoon, which is likely to be the case if the spoon is used without liners and has an internal relief.

3 FIELD INVESTIGATION

A field investigation was performed to evaluate the unit skin friction measurements obtained with SPT-T tests and other variations of the SPT and to compare the test results with skin friction obtained from pile load tests. The test site and the tests performed are described in this section.

3.1 *Test Site*

The site investigated is located at the former U.S. Air Force Base in Plattsburgh, New York. The site is dominated by glacial and proglacial outwash and lake deposits. The surficial layer consists of a poorly graded fine to medium sand with a trace of silt and represents a glacial meltwater delta deposit. The sand is on the order of 27 m in thickness. The ground water table is typically located at a depth of around 12 m below the ground surface.

A large number of test borings were performed at the site to determine the characteristics of the deposit and to obtain samples for laboratory testing. A total of 141 sieve analyses were performed on individual samples collected at the site. The results indicate that the sand deposit is very uniform with a D_{50} = 0.4 mm, C_u = 2.0, C_c = 1.0, % Fines = 4, G = 2.67, e_{min} = 0.46, e_{max} = 0.91. The estimated in situ relative density is about 60%. The water content in the upper 10 m is on the order of 6 %.

3.2 *SPT-T Tests*

Torque tests were conducted by attaching a drill rod adapter to the top of the drill string immediately after driving the spoon a distance of 45 cm. A direct read torque wrench with a capacity of 41.5 kgf-m and a precision of 0.7 kgf-m was then connected to the drill rod adapter and the operator rotated the assembly (rods and spoon) to produce a failure. Occasionally, if the drill rod connections were not tight, some initial hand tightening of the string was needed. The assembly is usually rotated a full 180^0 until a maximum value of torque is obtained.

In some situations the soil was sufficiently stiff or dense so that the torque wrench capacity was reached before a failure occurred. In these cases, a torque transducer was attached to the top of the drill string and a long handle was then used to rotate the assembly. The torque is then read from a digital strain indicator. A schematic of the test arrangement is shown in Figure 1.

In most cases, it was found that the use of the direct read torque wrench was sufficient. The technique is simple to perform, inexpensive and easy to deploy and is therefore attractive for a field engineer. No attempt was made to regulate the rate at which the torque was applied as the focus of the torque measurement is on simplicity and rapid testing so as not to over complicate the procedure. Given the perceived crudeness of the SPT in general, this was considered sufficient. Torque was applied in a slow and steady manner so that rotation would be complete in about 15 sec. In order to be able to make a comparison between the SPT blowcount and the torque measurement, all SPT's reported in this paper were conducted by driving the spoon a distance of 45 cm using a CME automatic hammer.

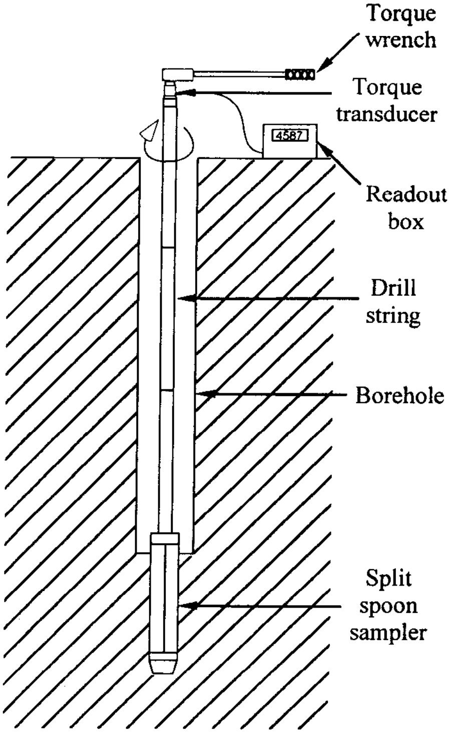

Figure 1. Schematic of SPT-T test arrangement.

3.3 *SPT-THRUST Tests*

SPT-Thrust Tests were also conducted in order to obtain a comparative measurement of the quasi-static thrust required to advance the spoon. Similar tests have been reported by Schmertmann (1979) and to the authors' knowledge are the only such tests reported in the literature. After lowering the spoon into the borehole, a strain-gauged load cell was threaded onto the top of the drill string. Thrust was applied by the hydraulic feed of the drill rig and the quasi-static pushing thrust was measured at each 76 mm of penetration using a digital readout strain indicator. This arrangement is shown in Figure 2.

Schmertmann (1979) suggested that if a plot of the thrust vs. penetration were made, the results would show a linear relationship between the thrust and penetration. As the spoon is penetrated into the subsurface, the contact area of the spoon with the soil increases thus increasing local skin friction. Extrapolation of the data to zero penetration would then give an estimate of the thrust needed to overcome the end bearing produced from the projected end area of the spoon. The difference between the extrapolated end thrust and the total thrust after a full 45 cm penetration would be the total thrust attributed to the local skin friction on the outside of the spoon. (This neglects a small amount of thrust from the internal part of the shoe.)

3.4 *SPT-PULL Tests*

In some cases, after either applying the torque in an SPT-T test or after conducting an SPT-Thrust Test, the load cell at the top of the drill string was used as a tension load cell to measure the maximum pulling force required to remove the spoon as shown in Figure 2. After pulling the spoon, the assembly was suspended above the bottom of the borehole to obtain a measure of the total mass of the assembly. Since there is no end bearing when the spoon is in tension, all of the pulling force can be attributed to local side friction acting on the outside of the spoon. These measurements provided yet another comparison for spoon skin friction obtained from both the SPT-T and SPT-Thrust Tests.

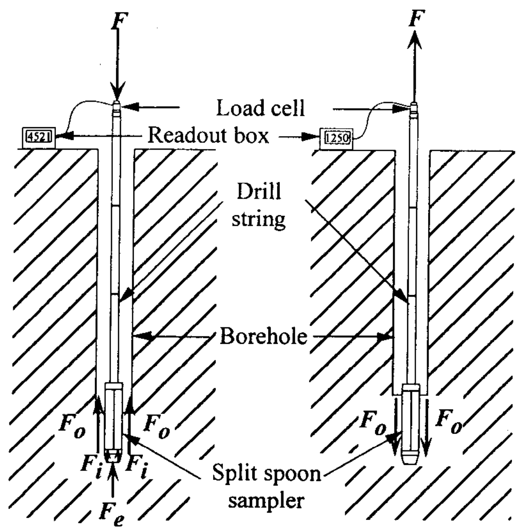

Figure 2. Test arrangements for SPT-Thrust and SPT-Pull tests with load and frictional forces acting on the spoon.

3.5 *Pile Load Tests*

In order to provide a basis for comparison of the skin friction values measured in the field tests, a series of prototype-scale tension pile load tests were conducted on several small diameter pipe piles installed at the site. Pile characteristics are given in Table 1. Both open end and closed end piles were tested. All piles were allowed to rest for a period of 30 days prior to testing. Axial tension tests were then performed until failure. Table 2 gives a summary of the load tests and the calculated average unit skin friction based on the measured failure load and the calculated external surface area.

Table 1. Summary of pipe pile characteristics.

Pile	L (m)	OD (mm)	ID (mm)	Type
1	6.1	73.0	-	closed
2	6.1	88.9	-	closed
3	6.1	114.3	-	closed
4	6.1	73.0	60.3	open
5	6.1	88.9	76.2	open
6	6.1	114.3	101.6	open
7	6.1	88.9	-	closed
8	6.1	44.5	-	closed

Table 2. Pile failure load and unit skin friction.

Pile	Failure Load (kN)	f_s (kPa)
1	208	148.7
2	86	50.5
3	197	90.0
4	232	165.9
5	484	284.3
6	234	106.9
7	398	233.8
8	109	127.9

4 COMPARISON OF SKIN FRICTION

Figure 3 presents the results from typical SPT-T tests obtained using an unlined spoon. The values of unit skin friction obtained from Equation 1 are shown in Figure 3 and are similar in magnitude to the unit skin friction obtained from electric CPT's performed at the site. The average recovery recorded from the SPT's presented in Figure 3 was 90%, indicating that the spoon was advanced unplugged in this sand. Similar tests using a spoon with brass liners gave nearly identical recovery, blowcounts, and torque results suggesting that in this sand, the use of liners does not significantly affect either N or f_s.

To investigate the influence of spoon plugging on the measured unit skin friction, a 60^0 conical point was fabricated and threaded onto the end of the spoon in place of the standard shoe. This allowed the spoon to act in a completely plugged manner. Figure 4 shows a comparison of the unit skin friction obtained from the unlined and plugged spoons. There is very little difference in the recorded values, and in fact the spoon with the conical point actually gives lower unit skin friction in many cases.

A comparison of the SPT-T, SPT-Thrust, and SPT-Pull tests for unlined spoons is shown in Figure 5. It can readily be seen that the pull and torque tests give similar values of unit skin friction throughout the profile, but the thrust tests tend to give consistently higher values of unit skin friction. It is suspected that in this case, the extrapolation technique does not give an accurate measure of spoon end bearing. Recall that this procedure assumes that the end bearing will be a constant with advance of the spoon; the only increase in thrust being the result of the accumulation of side friction. If the end bearing is not constant but increases as spoon penetration proceeds then the extrapolated end bearing will be too low and the calculated side resistance will be too high. This appears to be an area that requires more detailed work.

In order to investigate if the unit skin friction is a fixed quantity or is dependent on spoon size, a series of SPT-T tests were conducted using a 76.2 mm spoon without liners. A comparison between the standard 50.8 mm spoon and a 76.2 mm spoon unit skin friction is shown in Figure 6. With the exception of some points in the lower part of the profile, there appears to be only a minor effect of size on the unit skin friction in this sand.

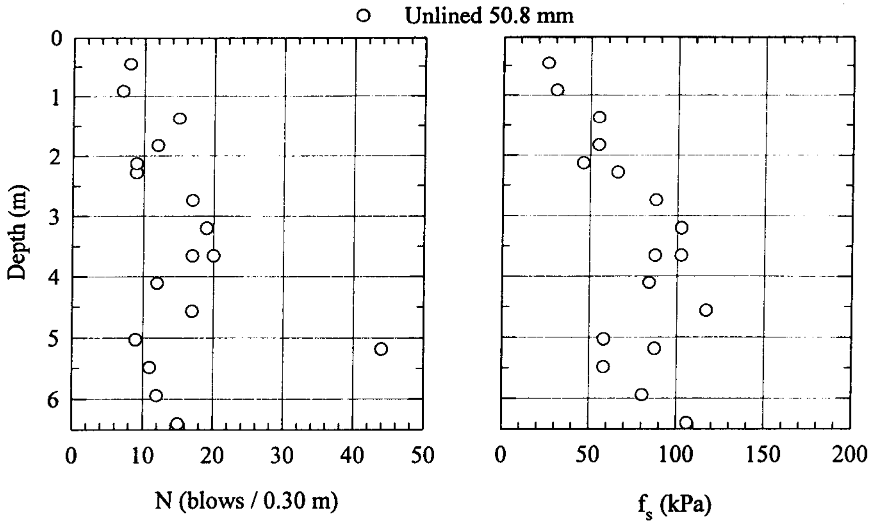

Figure 3. N-values and unit skin friction estimates from 50.8 mm SPT-T tests conducted at the site.

It can be seen from comparing the results of the pile load tests given in Table 2 and the results presented in Figures 3,4, and 6 that the measured average unit skin friction values obtained from the prototype pile tension tests are within the range of unit skin friction measured in the SPT-T tests. This is encouraging and suggests that the SPT-T data may be used for estimating the skin friction of driven piles in sand. However, it should be noted that the pile tests themselves produced some uncertain trends and the influence of pile size, pile plugging, L/d, and other factors should be taken into account for design.

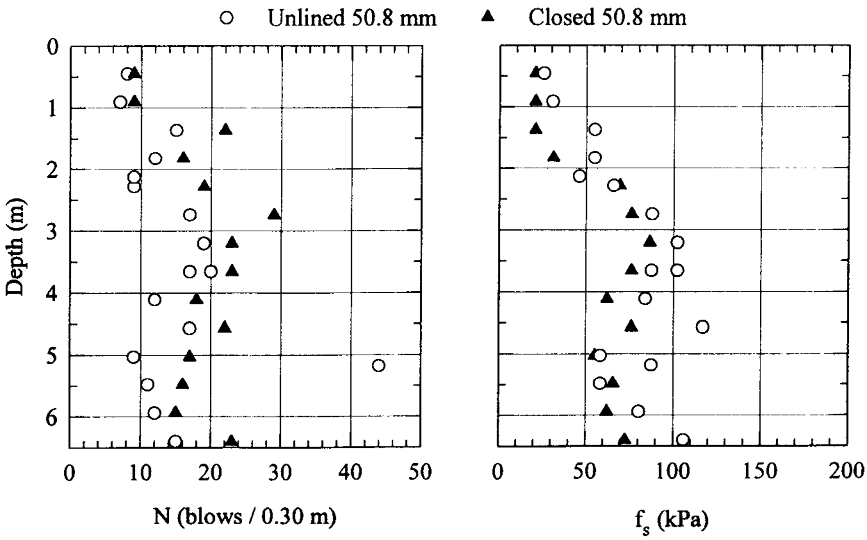

Figure 4. N-values and unit skin friction from SPT-T tests for an open and closed 50.8 mm spoon.

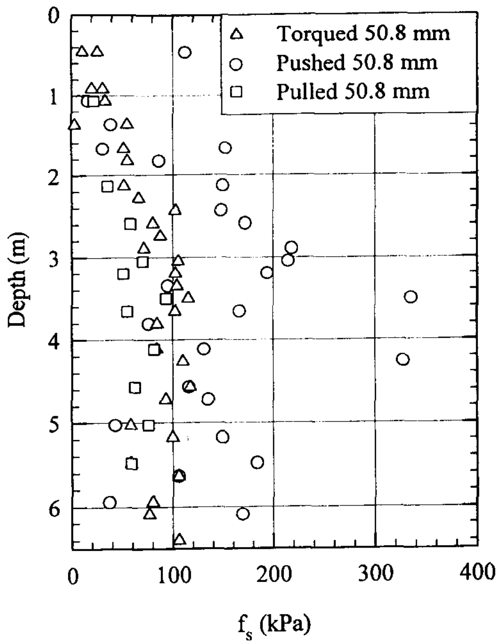

Figure 5. Unit skin friction determined by the SPT-T, SPT-Thrust, and SPT-Pull tests.

Empirical approaches to the design of driven piles based on SPT N values have been suggested, e.g., Meyerhof (1976) based on observations of full-scale performance. Figure 7 shows a comparison of measured unit skin friction from the SPT-T tests and the 60% energy corrected SPT blowcount, N_{60}. The recommendation presented by Meyerhof (1956,1976) for estimating unit skin friction from SPT N values is shown for comparison. The average trend line suggested by the SPT-T data from this site gave a unit skin friction about 2 times that suggested by Meyerhof (1956,1976). One possible explanation for this is that the SPT N values used by Meyerhof (1956,1976) were likely obtained in earlier years using *either a Donut or Pinweight Hammer* and therefore the N values would be artificially high as a result of lower energy levels produced by these two types of hammers. Additionally, Meyerhof suggested the correlation shown in Figure 7 essentially represents a conservative "lower bound" value for bored piles. Inspection of the test data presented by Meyerhof shows that the majority of driven pile data fall above this line.

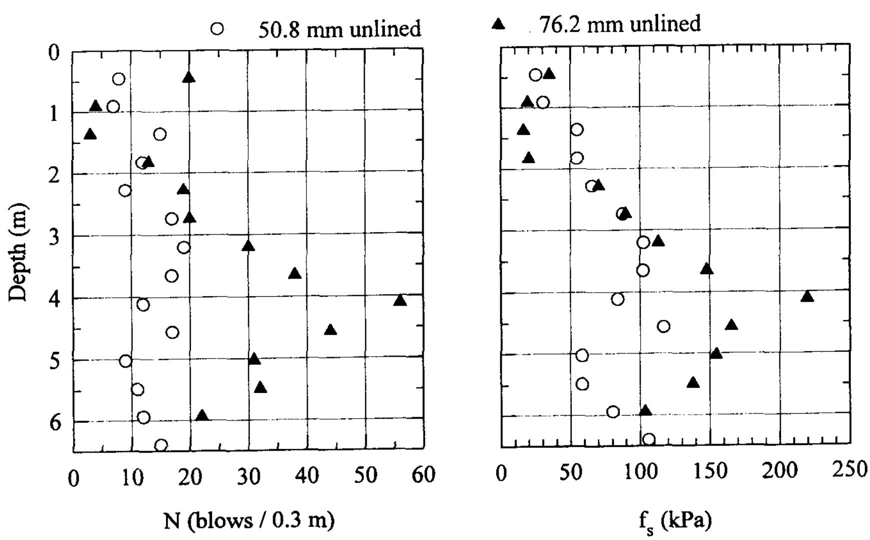

Figure 6. SPT N-values and unit skin friction determined torsionally for 50.8 and 76.2 mm split spoons.

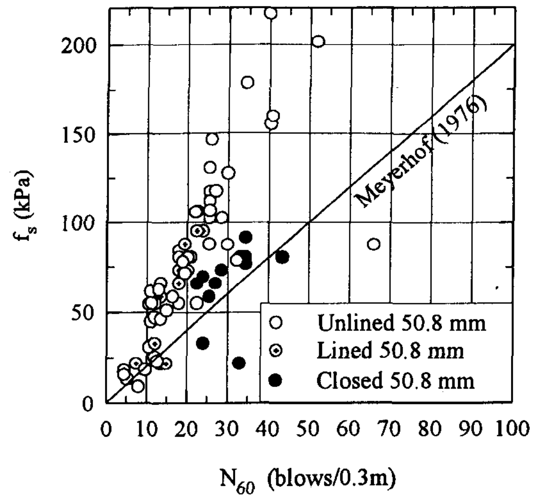

Figure 7. Comparison of unit skin friction versus N_{60} values with the Meyerhof (1976) correlation.

5 SUMMARY AND CONCLUSIONS

The results of SPT-Torque tests conducted in this fine to medium sand suggest that the calculated unit skin friction values are similar in magnitude to average unit skin friction obtained from prototype scale pile load tests. The torque test is simple to perform and does not detract from the standard SPT test procedure. In the sand tested, changes in the spoon geometry or plugging did not have a pronounced effect in measured spoon skin friction. That is, there is strong evidence that the dynamic measurement of the test is directly correlated to the static skin friction acting on the outside of the spoon. This was initially suggested by Schmertmann nearly 20 years ago. The results presented in this paper and performed at a number of other sites by the authors may help to provide a justification for the empirical use of SPT results for design of piles. Ongoing additional research will help further verify this phenomenon.

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