SPT-CPT CORRELATIONS

By P. K. Robertson,[1] R. G. Campanella,[2] M. ASCE, and A. Wightman[3]

ABSTRACT: A method for estimating equivalent Standard Penetration Test (SPT) *N*-values from Cone Penetration Test (CPT) data has been presented accounting for variations in soil grain size and SPT energy input. A discussion is given regarding the problems associated with the SPT and how these relate to SPT-CPT correlations. A historical review of SPT-CPT correlations is presented with additional recent data that include energy measurements during the SPT. An example is given to illustrate how the SPT data can be rationalized using energy corrections. Also, a chart is provided to estimate mean grain size from CPT data.

INTRODUCTION

The Standard Penetration Test (SPT) is the most commonly used in-situ test in North America. It is estimated that up to 90% of conventional foundation design in North America is accomplished by using the SPT *N* value (18). Despite continued efforts to standardize the SPT procedure there are still continued problems associated with its repeatability and reliability.

The Cone Penetration Test (CPT) is becoming increasingly more popular as an in-situ test for site investigation and geotechnical design. The authors believe this test is unequalled with respect to the delineation of stratigraphy and the continuous rapid measurement of parameters like cone bearing, q_c, and sleeve friction, f_s. The procedure and equipment of the quasi-static electric Cone Penetration Test (CPT) are easily standardized (1). The most significant advantages of the CPT are its simplicity, repeatability, accuracy and continuous record (36,34).

Significant improvements have been made recently in the interpretation of CPT data (31). However, many geotechnical engineers have developed considerable experience with design based on local SPT correlations. With time, direct CPT design correlations will also be developed based on local experience and field observation (43,12). However, with the initial introduction of CPT data there is a need for reliable SPT-CPT correlations so that CPT data can be used in existing SPT data based design correlations. This paper presents a review of available SPT-CPT correlations and reviews how these correlations could be applied to geotechnical design.

STANDARD PENETRATION TEST (SPT)

The SPT was developed in 1927 and is presently practiced worldwide to a greater extent than any other soil test. The test is made by dropping

[1]NSERC University Research Fellow, Civ. Engrg. Dept., Univ. of British Columbia, Vancouver, B.C.

[2]Prof. and Head of Civ. Engrg. Dept., Univ. of British Columbia, Vancouver, B.C.

[3]Manager, Geotech. Div., Klohn Leonoff Consulting Engineers, Vancouver, B.C.

Note.—Discussion open until April 1, 1984. To extend the closing date one month, a written request must be filed with the ASCE Manager of Technical and Professional Publications. The manuscript for this paper was submitted for review and possible publication on November 2, 1982. This paper is part of the *Journal of Geotechnical Engineering*, Vol. 109, No. 11, November, 1983. ©ASCE, ISSN 0733-9410/83/0011-1449/$01.00. Paper No. 18348.

BACK

a "free" falling hammer weighing 63.5 kg (140 lb) onto the drill rods from a height of 0.76 m (30 in.). The number of blows, N, necessary to achieve a penetration of 0.30 m (1 ft) (below the seating drive of 0.15 m) of a standard sample tube, is regarded as the penetration resistance, in blows per foot. The hammer is generally lifted by a rope and cathead system.

Numerous studies have shown considerable variability in the procedures and equipment used in this supposedly standardized test. Considerable improvements in the understanding of the dynamics of the SPT have occurred in recent years (41,17,18). Schmertman (38) concludes that SPT results may be influenced by such factors as:

1. The size of the drill hole.
2. The number of turns of the rope around the cathead.
3. The length of the drill rods.
4. The use of drilling mud versus casing to support the walls of the drill hole.
5. The use of non-standard sampling tubes.
6. The depth range over which the penetration resistance is measured (0–0.30 m or 0.15 m–0.45 m).

Schmertmann (38) and Kovacs and Salomone (18) identify the most significant factor affecting the measured N-value as the amount of energy delivered to the drill rods.

Kovacs (17) has shown that the energy delivered to the rods during a SPT can vary from about 30%–80% of the theoretical maximum, 475 J (4,200 in.-lb). The energy delivered to the drill stem varies with the number of turns of rope around the cathead and varies with the fall height, drillrig type, hammer and anvil type, and operator characteristics. Kovacs and Salomone (18) suggest that a nominal two turns of a rope around the cathead would minimize the effect of operator performance characteristics on the delivered energy. When using the rope and cathead procedure with two turns of the rope the typical energy delivered from a standard donut type hammer is about 50%–60% of the theoretical maximum (18). Schmertmann (37) has suggested that based on limited data, an efficiency of about 55% may be the norm for which it can be assumed that many North American correlations were developed.

It is clear there is a need for increased standardization when using the SPT. The Japanese have standardized the hammer, anvil and drill rod since 1961 (16). Several studies have concluded that an energy standard should be adopted as a criterion for SPT. Kovacs and Salomone (18) have suggested the development of a National Average Energy (NAE). Once established, the NAE could be used for standardizing the SPT or correcting blow count data, or both, for a common energy. The NAE would also allow comparisons of SPT data with empirical correlations in North America and other countries. If adopted the NAE may conceivably be close to the 55% level suggested above. With the existence of a fairly inexpensive and easy to use energy calibration unit (13) many researchers consider that measured energy correction factors will lead to more repeatability and reliability of the SPT N-values in the future (5,18).

Kovacs work shows that in general a safety hammer has a slightly

larger efficiency than the standard donut hammer. Douglas (10) has shown that the automatic-release trip hammer has an efficiency approximately 1.4 times that of the standard donut hammer. Douglas (10) also suggests that the efficiency decreases with increasing soil density.

Cone Penetration Test (CPT).—Many of the cone penetration devices were developed and used in Europe but are not gaining increasing acceptance in North America. The main reasons for the increasing interest in CPT are, the simplicity of testing, the low cost, continuous profile, reproducibility of results and the test data is more amenable to rational analysis.

A cone with a 10 cm^2 base area and an apex angle of 60° is accepted as standard and has been specified in the European and American Standards (15,1). The friction sleeve, located above the conical tip and of the same diameter, has a standard area of 150 cm^2. The mechanical cones (2) require a double rod system for their telescopic action. The electrical cones (8) have friction sleeve and tip advanced continuously with a single rod system. The electric cones have built-in load cells that record continuously the end resistance (q_c) and side friction (f_s), while some also record inclination and pore pressure as well (4). The load cells can be made in a variety of capacities depending on the strength of the soils to be penetrated. An electric cable usually connects the cone with the recording equipment at ground surface.

The electric cone offers obvious advantages, such as, a rapid procedure, continuous recording, high accuracy and repeatability, potential for automatic data logging, reduction and plotting, and the possibility of incorporating additional sensors in the cone.

The factors affecting the measured parameters from electric cones have been discussed in detail by Campanella, Robertson and Gillespie (5).

SPT-CPT Correlations.—The SPT is still the most commonly used in-situ test in North America. However, despite continued efforts to standardize the SPT procedure, there are still continued problems associated with its repeatability and reliability. However, many geotechnical engineers have developed considerable experience with design methods based on local SPT correlations. With time, direct CPT design correlations will also be developed based on local experience and field observation. However, with the initial introduction of CPT data, there is a need for better SPT-CPT correlations so that CPT data can be used in existing SPT data based design correlations.

A considerable number of studies (see Fig. 1) have taken place over the years to quantify the relationship between SPT N values and CPT cone bearing resistance, q_c. A wide range of q_c/N ratios have been published leading to much confusion. The variations in published q_c/N ratio can be rationalized somewhat by reviewing the derived q_c/N ratios as a function of mean grain size (D_{50}), as shown in Fig. 1. It is clear that the q_c/N ratio increases with increasing grain size. The scatter in results appears to increase with increasing grain size. This is not surprising since penetration in gravelly sand ($D_{50} \approx 1.0$ mm) is significantly influenced by the larger gravel sized particles, not to mention the variability of delivered energy in the SPT data. Also sand deposits in general are usually stratified or non-homogeneous causing rapid variations in CPT tip resistance. There was also some difficulty in defining the D_{50} from some

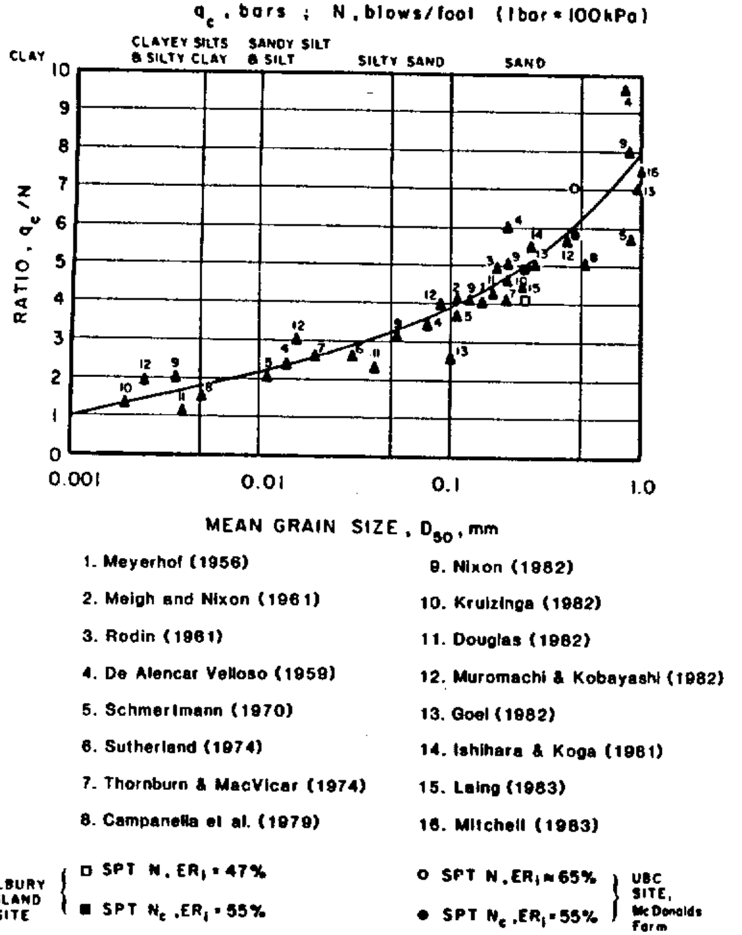

FIG. 1.—Variation of q_c/N Ratio with Mean Grain Size

of the references.

Work by Martins and Furtado (21) and Douglas (10) has shown that the q_c/N relationship also varies with SPT hammer type and to some extent with soil density. The q_c/N ratio is significantly affected by SPT hammer type since this effects the energy transmitted to the rods. Most of the data shown in Fig. 1 was obtained using the standard donut type hammer with a rope and cathead system. Schmertmann (37) has also shown that q_c/N increases in sensitive clays.

Several sites in the Fraser River Delta area, near Vancouver, have provided additional SPT and CPT data. A site on Tilbury Island in the Fraser River Delta also provided energy measurements for the SPT data. The energy measurements were made using an SPT Force Calibrator produced by Binary Instruments Inc. (13). The SPT calibrator is an analog computer with some digital control that measures the energy (ER_i) in the drill rods below the anvil, by means of a load cell, for each blow of

BACK

the hammer. The device provides the means to measure the percent of 475 J (4,200 in.-lb) transmitted through the rods.

The site on Tilbury Island consists of a thick deltaic fine sand deposit below a depth of about 7 m. The average grain size (D_{50}) for the sand deposit was about 0.25 mm. The sand was overlain by about 7 m of a soft interbedded silt, clay and sand deposit. Groundwater level was approximately 1.5 m below ground surface. SPT's were performed using several different rotary drillrigs (Longyear 34, 38 and Mayhew 1000) and operators. Both standard donut and safety hammers were used. The hammers impacted on anvils attached to a string of Aw drill rods. The spoons used were standard 2 in. type with split liners. Two nominal turns of the rope around the cathead were used to operate the hammers. The Longyear drillholes were drilled using drilling mud and casing. The casing was retracted 0.6 m prior to each SPT test. Holes drilled with the Mayhew 1000 were supported by bentonite mud only. Considerable variation in measured SPT *N* values were observed using the different operators and hammer types. To obtain the CPT-SPT correlations, Cone Penetration Testing (CPT) was performed using the research vehicle and 5-channel electric cone developed at the University of British Columbia (UBC). Full details of the cone and equipment are given by Campanella and Robertson (4).

Energy Variations.—The variation of the average measured energy ratio (ER_i) with SPT *N* value using the donut hammer for the sand is shown in Fig. 2. The average energy was 47% of the theoretical maximum. The theoretical maximum was calculated using the assumed 0.76 m fall of the hammer. Each data point represents one SPT test and is the average of individual energy measurements for each hammer blow. A total of

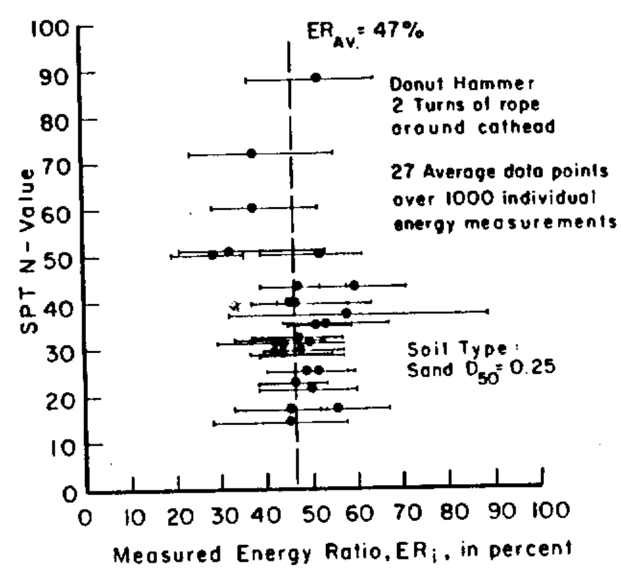

FIG. 2.—Measured Average Energy Ratio for SPT *N* Values Using Donut Hammer, Tilbury Island

over 1,000 individual energy measurements were made to compile Fig. 2. A considerable range in energy measurements was recorded with maximum and minimum values of 89% and 19%, respectively.

The mean value of the q_c/N ratio for the sand deposit was 4.2. Considerable scatter was found in the q_c/N ratio for the overlying silt clay deposit due to the interbedded nature of the deposit. Therefore, only the data for the sand deposit are presented here.

The SPT N values for the donut hammer were corrected to an energy ratio level of 55%. The correction was carried out assuming a linear variation of N value with energy as suggested by Schmertmann and Palacios (42). The resulting q_c/N_c ratio, using corrected N values (N_c), was 4.9. The two ratios are also shown on Fig. 1.

SPT Hammer Comparison.—Fig. 3 shows SPT results from one borehole (8217) where a safety and donut hammer were used for alternate tests at about 0.5 m spacing. Energy measurements were made for each hammer blow. The average overall energy ratio levels for the hammers were 43% and 62% for the donut and safety hammers, respectively. Fig. 3 shows clearly that the donut hammer SPT N values are consistently higher than the safety hammer N values. When both hammer N values are corrected to an energy ratio level of 55%, the apparent variation in SPT is rationalized and a consistent SPT N value profile is obtained. This is illustrated by the SPT profiles shown in Fig. 3. Using the corrected N_c values, considerably less scatter in the SPT results was observed.

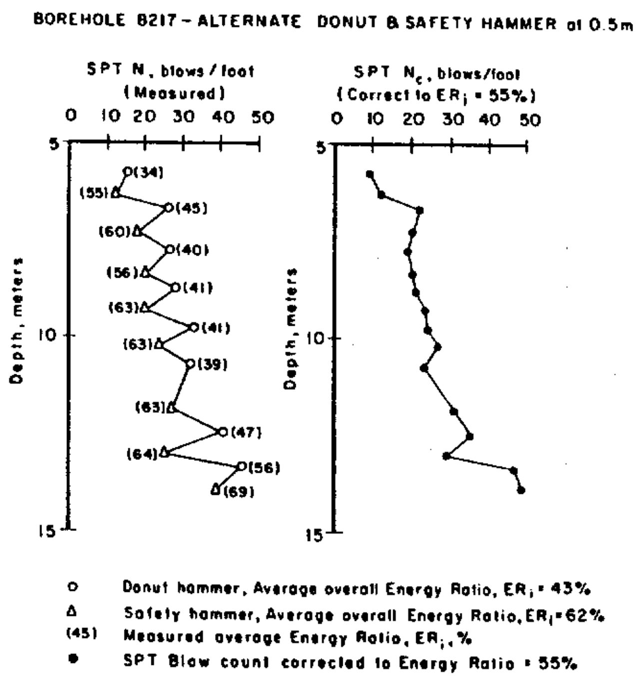

FIG. 3.—Comparison of SPT *N* Values Using Alternate Donut and Safety Hammer with Energy Corrected N_c Values

Based on the studies shown by Kovacs and Salomone (18) it would appear that the average energy level of the SPT data using the donut hammer from the Tilbury Island site was slightly on the low side for the 2 turns of the rope procedure. This is confirmed by the q_c/N ratio of 4.2, which appears to be slightly lower than the historical average (Fig. 1). However, when the SPT N values are corrected to an energy level of 55% the q_c/N_c ratio agrees remarkably well with the historical data.

Other Comparisons.—Additional SPT and CPT data were obtained from the UBC research site for in-situ testing, which is located on an abandoned farm (McDonald's Farm) near the Vancouver International Airport. The site is located between the North Arm and Middle Arm of the Fraser River on the north side of the main Fraser River Delta, approximately 8 km west of the Tilbury Island site. Full details of the site and ground conditions are given by Campanella and Robertson (4). The upper 2 m of the site consists of soft, compressible clays and silts. A sand deposit exists from 2 m to 13 m below ground surface. The sand has a medium to coarse grain size (D_{50} = 0.45 mm) with thin layers of medium to fine sand. Groundwater is approximately 1 m below existing ground surface.

SPT N values were obtained using a BBS-37A rotary drillrig supplied and operated by the B.C. Ministry of Highways and Transportation. One turn of the rope around the cathead was used to operate the standard safety hammer. The hole was drilled using drilling mud and casing. Unfortunately, no energy measurements were made since the SPT calibrator was not available at that time. This rig and operator will be calibrated in the future. In the meantime, the work by Kovacs and Salomone (18) would indicate that using the one turn of the rope around the cathead procedure and a safety hammer produces an energy level of 20% larger than using two turns of the rope. Therefore, the energy level can be assumed to be about 65%–70%.

The average q_c/N ratio for the sand deposit (D_{50} = 0.45 mm) was 7, as shown on Fig. 1. If the N values are corrected to an energy level of 55% the q_c/N_c ratio becomes 5.7, as shown on Fig. 1.

The high energy SPT data using 1 turn of the rope around the cathead produced a q_c/N ratio significantly higher than the historical average. However, when the SPT N values were corrected to an energy level of 55%, the q_c/N_c ratio again agrees remarkably well with the historical data.

Recent additional SPT and CPT data has been obtained from another site located in the Fraser River Delta area. The site will be referred to as the Jacombs Road site and consists of 4.5 m of organic sandy silts overlying about 15 m of medium to medium-fine sand. The average energy for the SPT tests was 56% with a mean value of q_c/N in the sand deposit (average D_{50} = 0.23 mm) of 4.4. Correcting the N-values to an ER_i = 55% gave no significant change in mean q_c/N value. The values of 4.4 for q_c/N and 0.23 mm for D_{50} lie only slightly below the curve in Fig. 1 (Laing, 1983), therefore providing additional energy evidence supporting the historical data.

The above examples when seen in the context of Fig. 1 appear to indicate that the average energy ratio of 55% suggested by Schmertmann may represent the energy level associated with many of the SPT based empirical design correlations.

Standard Penetration Test Calibrator.—Energy measurements for this paper were obtained using the Binary Instruments Model 102 Standard Penetration Test Calibrator. The calibrator system consists of a load cell which is placed in the drill rods below the anvil. The load cell is connected by cable to an instrument box that performs the necessary functions to obtain ER_i.

During some of the energy measurements at the Jacomb's Road site a digital oscilloscope was connected to the calibration unit to assess the accuracy of the instrument box. The oscilloscope provided a trace of the force-time record for each hammer blow. Analyses of the records showed that the instrument box provided energy ratios (ER_i) which were always within ±5% of the calculated energy ratios using the oscilloscope traces over a wide range of energies, N values and depths (20).

Conclusion

Fig. 1 can therefore be used to convert CPT data to equivalent SPT N values for 55% efficiency. To estimate the mean grain size from CPT data use can be made of the classification chart shown in Fig. 4. The classification chart in Fig. 4 has been adapted from the chart proposed by Douglas and Olsen (9) for standard electric cones. The classification chart in Fig. 4 should be used as a guide to grain size. The writers consider that the addition of pore pressure measurements during cone penetration can significantly improve the soil classification. For mechanical cone data use can be made of classification charts by Schmertmann (39), Searle (33) or Muromachi and Atsuta (25). The friction ratio using the UBC electric cone for the sand deposits at Tilbury Island and McDonald's Farm was about 0.5% with an average q_c of around 135 bars (13.5 MPa).

If local design correlations have been developed based on SPT data obtained using alternative procedures such as a trip hammer or procedures other than the rope and cathead technique, the q_c/N ratios shown in Fig. 1 may be slightly in error. If a trip hammer was used it is likely that the energy level would be higher than the average 55% level by a factor of about 1.4 (10). Therefore, q_c/N ratios would be slightly higher than those shown in Fig. 1.

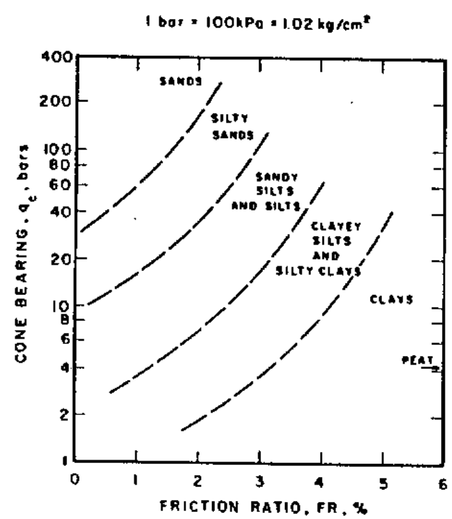

FIG. 4.—Simplified Soil Classification Chart for Standard Electric Friction Cone. (Adapted from Douglas and Olsen, 1981)

It is important that geotechnical engineers are aware of the average energy level on which local SPT design correlations have been based. It is hoped that this paper will provide some guidelines as to how to correlate CPT data to equivalent SPT N-value based on an understanding of SPT energy level.

Acknowledgment

The assistance of the British Columbia Ministry of Highways and Public Works is most appreciated. Special thanks are extended to the British Columbia Hydro and Power Authority whose project on Tilbury Island provided much of the data on SPT Energy measurements and correlations reported herein. The work of Nancy Laing is also appreciated.

Appendix.—References

1. American Society for Testing and Materials, Designation: D 3441-79, "Deep, Quasi-Static, Cone and Friction, Soil and Rock, Cone Penetration Tests of Soil," ASTM Standards, Part 19, Building Stones, 1982, pp. 524–531.
2. Begemann, H. K., "The Friction Jacket Cone as an Aide in Determinating the Soil Profile," *Proceedings 6th International Conference on Soil Mechanics and Foundation Engineering*, Univ. of Toronto Press, Vol. 1, Sept., 1965, pp. 17–20.
3. Campanella, R. G., Berzins, W. E., and Sheilds, D. H., "A Preliminary Evaluation of Menard Pressuremeter, Cone Penetrometer and Standard Penetration Tests in the Lower Mainland, B.C.," Univ. of B.C. Civil Engrg. Dept., Soil Mechanics No. 40, 1979.
4. Campanella, R. G., and Robertson, P. K., "Applied Cone Research," Symposium on Cone Penetration Testing and Experience" Geotechnical Engineering Division, ASCE, Oct., 1981, pp. 343–362.
5. Campanella, R. G., and Robertson, P. K., "State of the Art in In-situ Testing of Soils: Developments since 1978," Engineering Foundation Conference on Updating Subsurface Sampling of Soils and Rocks and Their In-situ Testing, Santa Barbara, Calif., Jan., 1982.
6. Campanella, R. G., Robertson, P. K., and Gillespie, D., "Cone Penetration Testing in Deltaic Soils," Canadian Geotechnical Journal, Vol. 20, Feb., 1983.
7. De Alencar Velloso Di., "O ensaio de diepsondeering e a determinacao da capacidade de carga do solo," Rodovia, 29, 1959.
8. de Ruiter, J., "Electric Penetrometer for Site Investigations," *Journal of the Soil Mechanics and Foundations Division*, ASCE, Vol. 97, No. SM2, Feb., 1971, pp. 457–472.
9. Douglas, B. J., and Olsen, R. S., "Soil Classification Using Electric Cone Penetrometer," Symposium on Cone Penetration Testing and Experience, Geotechnical Engineering Division, ASCE, St. Louis, Oct., 1981.
10. Douglas, B. J., "SPT Blowcount Variability Correlated to the CPT," *Proceedings of the 2nd European Symposium on Penetration Testing*, Amsterdam, Holland, May, 1982.
11. Ghosh, N., "Correlation of Predicted and Measured Settlements in Full Scale Loading on Sand Fill," *Proceedings of the 2nd European Symposium on Penetration Testing*, Amsterdam, Holland, May, 1982.

12. Goel, M. C., "Correlation of Static Cone Resistance with Bearing Capacity," *Proceedings of the 2nd European Symposium on Penetration Testing*, Amsterdam, Holland, May, 1982, pp. 263–270.
13. Hall, J. R., "Drill Rod Energy as a Basis for Correlation of SPT Data," *Proceedings of the 2nd European Symposium on Penetration Testing*, Amsterdam, Holland, May, 1982.
14. Ishihara, K., and Koga, Y., "Case Studies of Liquefaction in 1964 Niigata Earthquake," Soils and Foundations, JSSMFE, Vol. 21, No. 3, Sept., 1981.
15. ISSMEE, Report of the Subcommittee on Standardization of Penetration Testing in Europe," Proceedings of 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, 1977.
16. Japanese Standards Association, Japanese Industrial Standard, JIS A 1219-1961, "Method of Penetration Test of Soils," 1976.
17. Kovacs, W. D., Salomone, L. A., and Yokel, F. Y., Energy Measurements in the Standard Penetration Test, U.S. National Bureau of Standards, Building Science Series 135, 1981.
18. Kovacs, W. D., and Salomone, L. A., "SPT Hammer Energy Measurements," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 108, No. GT4, Apr., 1982.
19. Kruizinga, J., "SPT-CPT Correlations," Proceedings of the 2nd European Symposium on Penetration Testing, Amsterdam, Holland, May, 1982.
20. Laing, N. L., "An Examination of the Standard Penetration Test with Comparisons to Other In-situ Tests," B.A.Sc. Thesis in Geological Engineering, The University of British Columbia, Vancouver, British Columbia, Canada, 1983.
21. Martins, J. B., and Furtado, R., "Standard Penetration Test and Deep Sounding Test Foundation Engineering," 3rd Reg. Conf. Africa Soil Mechanics and Foundations Engineering, Salisbury, Zimbabwe, Vol. 2, No. 101, 1963.
22. Meigh, A. C., and Nixon, I. K., "Comparison of In-situ Tests of Granular Soils," Proceedings of 5th International Conference on Soil Mechanics and Foundation Engineering, Paris, France, 1961.
23. Meyerhof, G. G., "Penetration Tests and Bearing Capacity of Cohesionless Soils," Soil Mechanics Foundation Division, ASCE, Vol. 82, No. 1, 1956.
24. Mitchell, J. K., Civil Engineering Department, University of California, Berkeley, personal communication regarding SPT-CPT data for a clean quartz river sand, 1983.
25. Muromachi, T., and Atsuta, K., "Soil Classification with R_f Value of Dutch Cone," Sounding Symposium, Tokyo, Japanese Society of Soil Mechanics and Foundation Engineering, Tokyo, Japan, 1980.
26. Muromachi, T., and Kobayash, S., "Comparative Study of Static and Dynamic Penetration Tests Currently in Use in Japan," Proceedings of 2nd European Symposium on Penetration Testing, Amsterdam, Holland, May, 1982.
27. Nixon, I. K., "Standard Penetration Test—State-of-the-Art-Report," *Proceedings* of the 2nd European Symposium on Penetration Testing, Amsterdam, Holland, May, 1982.
28. *Proceedings* of the European Symposium on Penetration Testing, ESOPT I, Published by National Swedish Building Research, Stockholm, Sweden, June, 1974.
29. *Proceedings* of the Second European Symposium on Penetration Testing, ESOPT II, Amsterdam, The Netherlands, A. A. Balkema, May, 1982.
30. *Proceedings* 10th ICSMFE, Soil Exploration and Sampling, Session 7, Vol. 2, Stockholm, Sweden, 1981, pp. 409–586.
31. Robertson, P. K., and Campanella, R. G., "Interpretation of Cone Penetration Tests, Part I (Sand); Part II (Clay)," Canadian Geotechnical Journal, Vol. 20, No. 4, Nov., 1983.
32. Rodin, S., "Experiences with the Penetrometer with Particular References to the Standard Penetration Test," *Proceedings* of 5th International Conference on Soil Mechanics and Foundation Engineering, Paris, France, 1961.

33. Searle, I. W., "The Interpretation of Begemann Friction Jacket Cone Results to Give Soil Types and Design Parameters," *Proceedings* of 7th ECSMFE, Brighton, Vol. 2, 1979, pp. 265–270.
34. Schaap, L. H. J., and Zuidberg, H. M., "Mechanical and Electrical Aspects of the Electric Cone Penetrometer Tip," Proceedings of the 2nd European Symposium on Penetration Testing, Amsterdam, Holland, May, 1982.
35. Schmertmann, J. H., "Static Cone to Compute Static Settlement Over Sand," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 96, No. SM3, 1970, pp. 1011–1043.
36. Schmertmann, J. H., "Measurement of In Situ Shear Strength," Proceedings of the Specialty Conference on In Situ Measurement of Soil Properties, ASCE, Vol. 2, Raleigh, N.C., 1975, pp. 57–138.
37. Schmertmann, J. H., "Predicting the qc/N Ratio," Final Report D-636, Engineering and Industrial Experiment Station, Department of Civil Engineering, University of Florida, Gainesville, Fla., 1976.
38. Schmertmann, J. H., "Use the SPT to Measure Dynamic Soil Properties?—Yes, But . . .!" Dynamic Geotechnical Testing, ASTM STP 654, American Society for Testing and Materials, 1978, pp. 341–355.
39. Schmertmann, J. H., "Guidelines for Cone Penetration Test, Performance and Design," Federal Highway Administration, Report FHWA-TS-78-209, Washington, D.C., July, 1978.
40. Schmertmann, J. H., "Statics of the SPT," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 105, No. GT5, May, 1979, pp. 655–670.
41. Schmertmann, J. H., and Palacios, A., "Energy Dynamics of SPT," *Journal of the Geotechnical Engineering Division*, ASCE, Vol. 105, No. GT8, 1979, pp. 909–926.
42. Sutherland, H. B., "Granular Materials," Review Paper, Session 1, Conference on Settlement of Structures, Cambridge, U.K., 1974.
43. Thornburn, S., "The Performance of a Four-Story Building Founded on Late Glacial Clays Compared with CPT Predictions," *Proceedings* of 2nd European Symposium on Penetration Testing, Amsterdam, Holland, May, 1982.
44. Thornburn, S., and MacVicar, R. S. L., "The Performances of Buildings Founded on River Alluvium," *Proceedings*, Cambridge Conference on Settlement of Structures, Paper v/12, 1974.

BACK