INTERPRETATION OF THE DISCONTINUOUS MECHANICAL CONE PENETRATION TEST IN NORTHEASTERN OKLAHOMA ALLUVIAL SOILS

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OKLAHOMA ALLUVIAL SOILS

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Norman N. Durham
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To my mother

Agatha Nevels

for her love and encouragement

and

To my professor and adviser

Dr. Joakim Laguros

University of Oklahoma

for his teaching, inspiration, guidance,

and friendship

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CHAPTER I

INTRODUCTION

Penetration testing involves pushing or driving a steel cone and rods into the subsurface profile and monitoring the resistance to penetration mobilized by the soil. Penetration testing represents a significant and integral part of in situ tests performed for geotechnical engineering purposes. In response to the variety of problems and soil conditions, engineers have developed numerous types of penetration test equipment and methods. The simplest way to classify the different methods is by the method of tip advancement. The most prevalent types of penetration tests that have evolved over the years are the dynamic and quasi-static penetrometer tests (1). A commonly used dynamic penetration test in the United States and throughout the world is the Standard Penetration Test (SPT), ASTM D 1586-84 (2). The Cone Penetration Test (CPT) as prescribed in ASTM D 3441-86 (3) is the accepted quasi-static penetration test in the United States.

The CPT method has variously been called the Static Penetration Test, Quasi-Static Penetration Test, Dutch Cone Test, Dutch Sounding Test, and Dutch Deep Sounding Test. The term quasi-static refers to the method and the rate of tip advancement--hydraulic or mechanical jacking at a rate of 1 to 2 cm/sec.

The Cone Penetration Test as defined in AASHTO D 3441-86 is a test method that covers the determination of end bearing and side friction, the components of penetration resistance which are developed during the steady, slow penetration of a rod into the soil. This test method includes the use of both cone and friction-cone penetrometers of both the mechanical and electrical types. These are the most widely used types of cone penetrometers. Various other options in recent years have been added to produce piezometric, thermal conductivity, nuclear, seismic acoustic, and permeability cones. Most notable of the newer cone options is the piezocone; however, there are currently no American test standards for these cone variations.

The objective of this research is to evaluate possible relationships between the cone penetration test (CPT) of the mechanical cone type and typical alluvial clay soils of northeastern Oklahoma. In particular, this research will consider the following: the adaptability, in general, of the mechanical cone penetration test (MCPT) in Oklahoma soils and geologic formations, development of localized correlations between soil classification and cone data, evaluation of lithological and stratigraphical interpretations of cone resistance diagrams, development of SPT-N value and cone resistance relationships, evaluation of potential correlation between soil shear strength and consolidation properties with cone data, and finally review results of some case histories.

CHAPTER II

LITERATURE REVIEW

Mechanical Cone Development

Historical Review

The idea of determining soil parameters by pushing rods into the ground is a very old one. The method developed by Collin in France in 1846 used a Vicat-type needle of 1 mm in diameter and weighing 1 kg to estimate the cohesion of different types of clay of various consistency (4). From that date until 1932, numerous variations in the cone penetration method were developed in Europe, especially in Sweden, Norway, and the Netherlands. In 1917, for example, the Swedish Railroads standardized a method of sounding which is still in use today. It consisted of pushing a metal rod, 19 mm in diameter, with loads of 5, 15, 25, 50, 75, and 100 kg. When refusal was encountered with a load of 100 kg, the rods were rotated, either manually or by machine, in order to advance the rods further. Sanglerat (4) gives an extensive accounting of the early development stages of the mechanical cone penetrometer.

Between 1932-1937, Barentsen (5) in the Netherlands, while associated with N. V. Goudsche Machinefabriek, developed and patented a sleeve-type apparatus--the first quasi-static cone penetrometer in a form recognizable today (see Appendix A). Initially, the apparatus consisted of a simple cone where the load on the cone was measured as it was advanced ahead of outer tubes. Then the total load was measured as the cone and outer tubes were advanced together. Following the development of this simple cone, Vermeiden (6) of the Delft Soil Mechanics Laboratory designed a mantle cone in 1948 (see Appendix A) to prevent soil particles from entering the space between the cone and the push rods. Accuracy in penetration resistance was immensely improved over that of the simple cone described in Appendix A. Similar ideas on the improvement of Barentsen's simple cone were made by Plantema (7) using a slightly different cone configuration at about the same time. A friction sleeve to measure local skin friction over a short length above the cone was introduced by Begemann (8) in Indonesia in 1953. At that time, Begemann's research was being conducted on three variants of what was called the "adhesion jacket cone" to determine the most effective location of adhesion jacket relative to the cone tip (see Figure 1). Further refinements continued by Machinefabriek of Gouda, Netherlands, in conjunction with the Soil Mechanics Laboratory of the Technical University at Delft in the Netherlands, in developing what was now termed the "friction" jacket cone. The mechanical cone development culminated with the improvements by Machinefabriek to conform with Begemann's 1965 recommendation (9) (see Appendix B). The Hogentogler & Co., Inc. (10) reports that Machinefabriek started supplying mechanical cones that met the specification NEN 3680 of the Delft Ground mechanics (LGM) of Holland in 1976. Due to this new specification, the shape of the mantle in the friction-sleeve cone was changed to conform to the Dutch mantle cone.

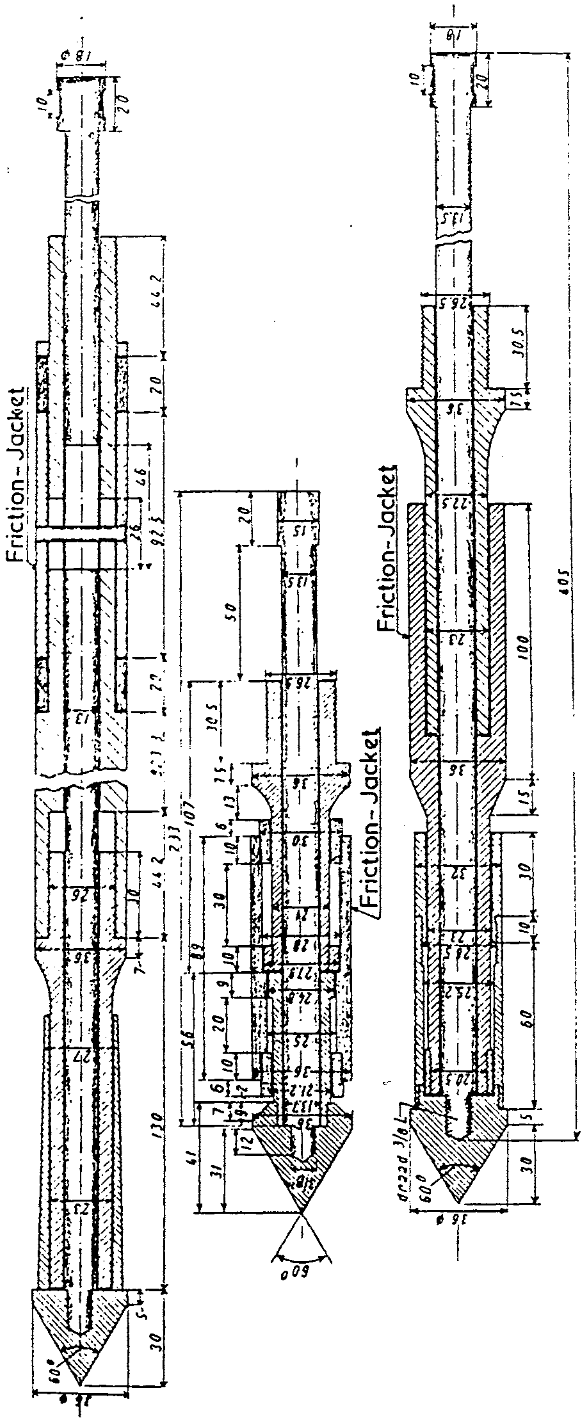


Figure 1. Three Types of the New Friction Jacket-Cone (8).

There have been numerous mechanical cones developed and used by many countries throughout the world. Sanglerat (4) presents a comprehensive review of cone penetrometer testing and various cone developments throughout the world. However, when one considers the more recent cone development, it is the Dutch apparatus manufactured by Machinefabriek and patented in the Netherlands by the Soil Mechanics Laboratory of Delft that are the most widely used and popular mechanical cone penetrometers. Its use has spread worldwide. Schmertmann (11) is credited with introducing the MCPT into the United States in the middle 1960s.

Beginning with the work of Geuze in 1948, as noted by Sanglerat (4), the electric cone development has shadowed that of the mechanical cone. The electrical cone came into more general use in the late 1960s. Only limited discussion will be addressed to the electric cone in this research study.

Role of the Cone Penetration Test

The CPT has three main applications:

1. Determine the soil profile and identify soils present
2. Interpolate ground conditions between control boreholes
3. Evaluate the engineering properties of the soils and to assess bearing capacity and settlement.

Its value must be seen within the framework of the overall geotechnical investigation. The role of the CPT is one of enhanced definition of site conditions.

The qualitative use of the CPT in the first two roles is of tremendous value and has been described by numerous researchers and practitioners (4, 11, 12). The CPT is the only investigative technique that provides an accurate continuous or virtually continuous profile of soil stratification. By performing a number of cone penetration tests (soundings) over a site, a picture can be obtained of the uniformity of soil conditions. Based on that information, a detailed soil exploration program can then be designed, including sampling of specific critical layers and possibly other in situ testing. The identification of soils is achieved by means of empirical correlation between soil type and the ratio of the local side friction to cone resistance (skin friction ratio) considered in relation to the cone resistance.

With regard to the third application, the assessment of engineering properties is more complicated in view of the many soil parameters that determine the cone resistance. However, much success has been achieved with the correlation of the CPT and some important soil parameters such as undrained shear strength of clay (11, 12). Assessment of engineering properties of soils has been based on empirical correlations. The important soil engineering parameters are: angle of internal friction and deformation characteristics in cohesionless soils, and undrained shear strength and modulus in cohesive soils. Practical applications of the CPT include the assessment of ultimate bearing capacity and settlement of footings and piles (11, 12). Again, these are based on empirical correlation with the CPT.

The use of mechanical cone penetration testing in light of these three applications has great potential for cost and time savings. Robertson (13) reviewed the perceived applicability of the major types of in situ test methods, which includes the mechanical cone penetrometer (see Table I). It is evident from Table I that the mechanical cone penetrometer can make a significant contribution to a geotechnical study.

Test Standardization

Standardization of test procedures for CPT has been an on-going process. Two of the currently used test standards for cone penetration testing are the European Recommended Standard (ERS) and the American Society of Testing of Materials ASTM D 3441-86 (see Appendices A and B, respectively).

Efforts to standardize methods of penetration testing date back to the 4th Conference of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE) in London in 1957. At that time an ISSMFE subcommittee on static and dynamic penetration testing methods was established to study the various test methods with the intent of achieving standardization. Recommendations from this subcommittee led to the publication of the European Recommended Standard (ERS) in 1977. Of significance, this standard recommended what is called the standard tip geometry as shown in Figure 1 of Appendix A. The ERS recognized the continued use of mechanical cones and allowed the use of nonstandard cones as referenced in Section 10. It is further required by ERS that a deviation from the standard tip geometry and test procedure should be stated when presenting CPT results. The ISSMFE is continuing to work on an internationally acceptable reference test.

The ASTM D 3441 standard was tentatively adopted in 1975 and approved as a test standard in 1979. The current standard was reapproved in 1986 as ASTM D 3441-86 (see Appendix B). Of significance,

TABLE I

IN SITU TEST METHODS AND THEIR PERCEIVED APPLICABILITY, 1986 (13)

	Geotechnical information													Ground conditions						
Test method	Soil type	Profile	Piezometric pressure (u)	Angle of friction (ϕ)	Undrained shear strength (S_u)	Density (D_r)	Compressibility (m_v, C_c)	Rate of consolidation (C_v, C_h)	Permeability (k)	Modulus: shear and Young's (G, E)	*In situ* stress (K_0)	Stress history (OCR)	Stress–strain curve	Hard rock	Soft rock—till, etc.	Gravel	Sand	Silt	Clay	Peat—organics
Dynamic cone (DCPT)	C	B	—	C	C	B	—	—	—	C	—	—	C	—	C	B	A	B	B	B
Static cone:																				
Mechanical	B	A	—	B	C	B	C	—	—	C	C	C	—	—	C	—	A	A	A	A
Electronic friction (CPT)	B	A	—	B	C	B	C	—	—	B	C	C	—	—	C	—	A	A	A	A
Electronic piezo	B	A	A	B	B	B	C	A	B	B	C	B	B	—	C	—	A	A	A	A
Electronic piezo/friction (CPTU)	A	A	A	B	B	B	C	A	B	B	C	B	B	—	C	—	A	A	A	A
Electronic seismic/piezo/friction (SCPTU)	A	A	A	B	B	B	C	A	B	A	B	B	B	—	C	—	A	A	A	A
Acoustic probe	B	B	—	C	C	C	C	—	—	C	—	C	—	—	C	—	A	A	A	A
Flat plate dilatometer (DMT)	B	A	C	B	B	C	B	—	—	B	B	B	B	—	C	—	A	A	A	A
Field vane shear (VST)	C	C	—	—	A	—	—	—	—	—	C	B	—	—	—	—	—	B	A	B
Standard penetration test (SPT)	A	B	—	B	C	B	—	—	—	B	—	C	—	—	C	B	A	B	C	C
Resistivity probe	B	B	—	B	C	A	C	—	—	C	—	—	—	—	C	—	A	A	A	A
Electronic conductivity probe	A	B	—	C	C	A	B	—	—	B	C	C	C	—	—	—	A	A	A	B
Total stress cell	—	—	—	—	—	—	—	—	—	—	B	B	—	—	—	—	—	C	A	A
K_0 stepped blade	—	—	—	—	—	—	—	—	—	—	B	B	—	—	—	—	B	A	A	B
Screw plate	C	C	—	C	B	B	B	C	C	A	C	B	B	—	—	—	A	A	A	A
Borehole permeability	C	—	A	—	—	—	—	B	A	—	—	—	—	A	A	A	A	A	A	B
Hydraulic fracture	—	—	A	—	—	—	—	C	C	—	B	B	—	B	B	C	C	B	A	C
Borehole shear	C	C	—	B	C	—	—	—	—	C	—	C	—	B	B	C	B	B	C	C
Prebored pressuremeter (PMT)	B	B	—	C	B	C	C	C	—	A	C	C	C	A	A	B	B	B	A	B
Push-in pressuremeter (PPMT)	A	B	B	C	B	C	C	A	B	A	C	C	C	—	—	—	B	A	A	B
Full-displacement pressuremeter (FDPMT)	C	B	B	C	B	C	C	A	B	A	C	C	C	—	—	—	A	A	A	A
Self-boring pressuremeter (SBPMT)	B	B	A	A	B	B	B	A	B	A	A	A	A	—	C	—	B	A	A	A
Self-boring devices:																				
K_0 meter	B	B	—	—	—	—	—	—	—	—	A	A	—	—	—	—	B	A	A	A
Lateral penetrometer	B	B	—	B	B	B	—	—	—	B	C	C	C	—	—	—	B	A	A	A
Shear vane	B	B	—	—	A	—	—	—	—	—	C	B	—	—	—	—	B	A	A	A
Plate test	B	B	—	C	B	B	B	C	C	A	B	A	C	—	—	—	B	A	A	B
Seismic cross/downhole/surface	C	C	—	—	—	—	—	—	—	A	—	—	—	A	A	A	A	A	A	A
Nuclear probes	—	—	—	B	—	A	—	—	—	—	C	—	C	—	—	—	A	A	B	A
Plate load tests	C	C	—	C	B	B	B	C	C	A	C	B	B	B	A	B	B	A	A	A

NOTE: A = high applicability, B = moderate applicability, C = limited applicability, — = not applicable.

this test standard allows the use of both cone and friction-cone penetrometers of both the mechanical and electrical type and acknowledges that test results will differ depending on which devices and procedures are used. Mechanical cones, herein, generally refer to the Dutch mantle and Begemann friction sleeve cones shown, respectively, in Figures 1 and 2, Appendix B.

There has been interest by some groups to bring the ASTM standard in line with the recommended European Standard (14). The main argument is that ASTM in effect recognizes two separate standards. Several investigations (1, 15, 16) have recognized that the mechanical cone penetrometers will continue to have a significant usefullness because of their relative ruggedness, simplicity, and initial cost--very much similar to the continued use of the Standard Penetration Test, ASTM D 1586-84.

Equipment

CPT Apparatus: The mechanical cone penetration test apparatus generally consists of a thrust machine and a reaction system (rig) and a penetrometer with measuring and recording equipment.

Machines available generally have a thrust in the range of 2-3/4 to 20 tons. They are discussed under three categories: light, medium, and heavy. A light rig is used in the exploration of weak soil layers and generally is one rated up to a capacity of 2-3/4 tons. Penetration is limited to a short distance into medium-dense sands or stiff clays. They are often light, portable, and hand operated through a chain drive (see Figure 2). A medium size rig is one rated to a capacity of 11 tons, and reasonable penetration can be obtained in stiff clays and

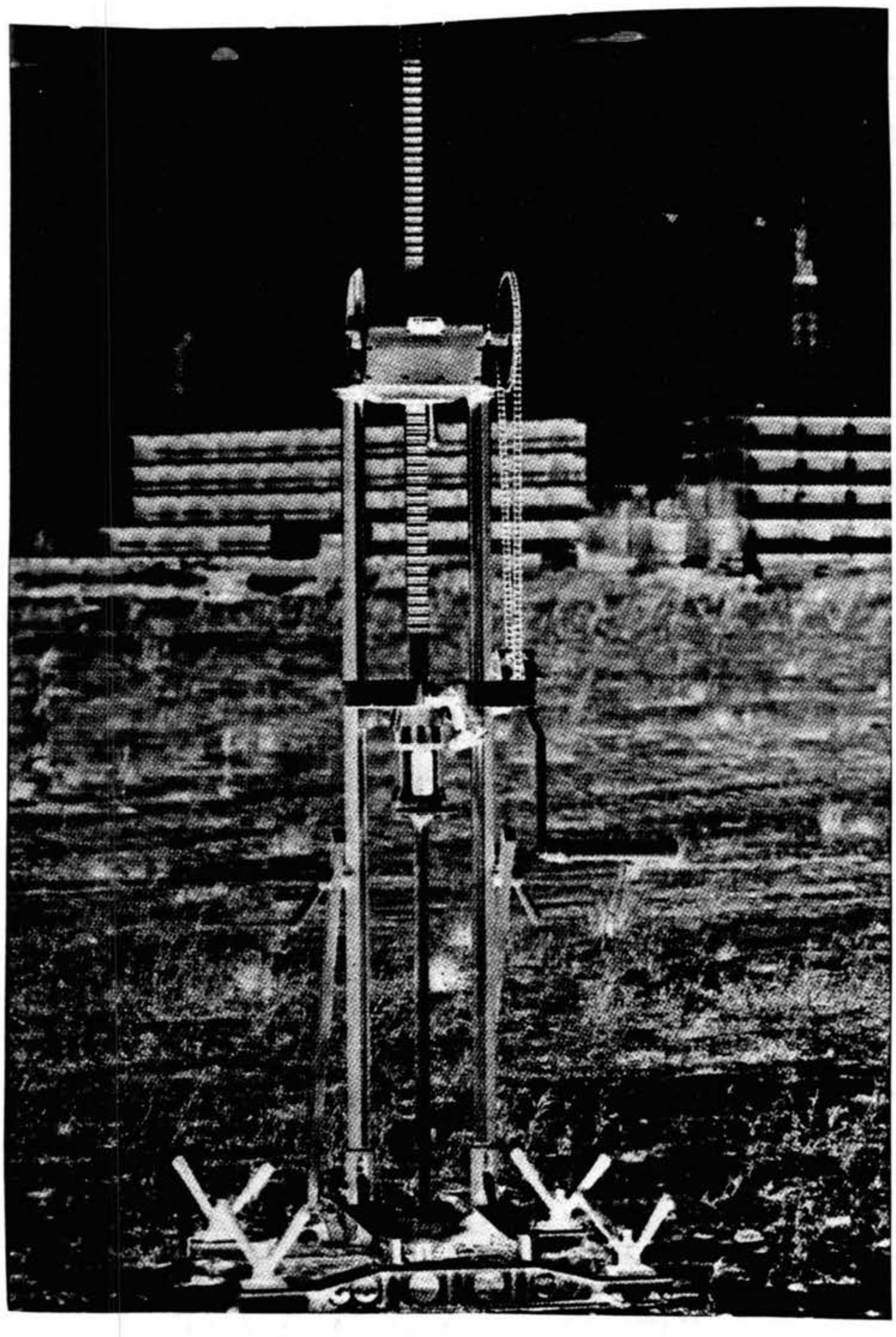


Figure 2. Hogentogler Model No. E5301 Hand-Operated 2.75-Ton Dutch Cone Penetrometer (10)

medium-dense sands for depths up to 65 feet. They can be mounted on a trailer with screw anchors or in a specially designed truck or tractor ballasted with sufficient weight or with screw anchors. Penetration is usually achieved by a hydraulic jacking system (see Figure 3). A heavy rig is one that has capacity up to 20 tons, which is considered a maximum practicable limit to avoid buckling of the rods. They are generally mounted on a heavily ballasted truck within an enclosed area but can also be trailor-mounted (see Figures 4 and 5). They are used for all deep penetration into sands and clays. The power for penetration is usually obtained from a hydraulic clamping device.

A very popular, economical, and extremely useful cone penetrometer is the mechanical cone conversion package (see Figure 6). This package converts a standard drill rig quickly and easily into a cone penetration thrust machine. The conversion package consists of mantle and friction sleeve cones, one meter length sounding rods, a hydraulic load cell (11 or 20 tons), gauges, and accessories and spare parts. The conversion kit allows the cone penetrometer testing and boring program to be performed jointly. The hydraulic load cell is connected to the drive head of the drill unit. The downward force of the drill unit provides the penetrating force for cone testing. Manufacturers of these conversion packages recommend a minimum of 10,000 pounds pull down force. The greater the drill unit's down-force and the heavier the drill, the greater the depth of penetration capability. Drnevich (17) presents details on converting a conventional drilling rig for cone penetration testing. Appendix C (Figure 7) presents a a typical schematic of a drill rig conversion.

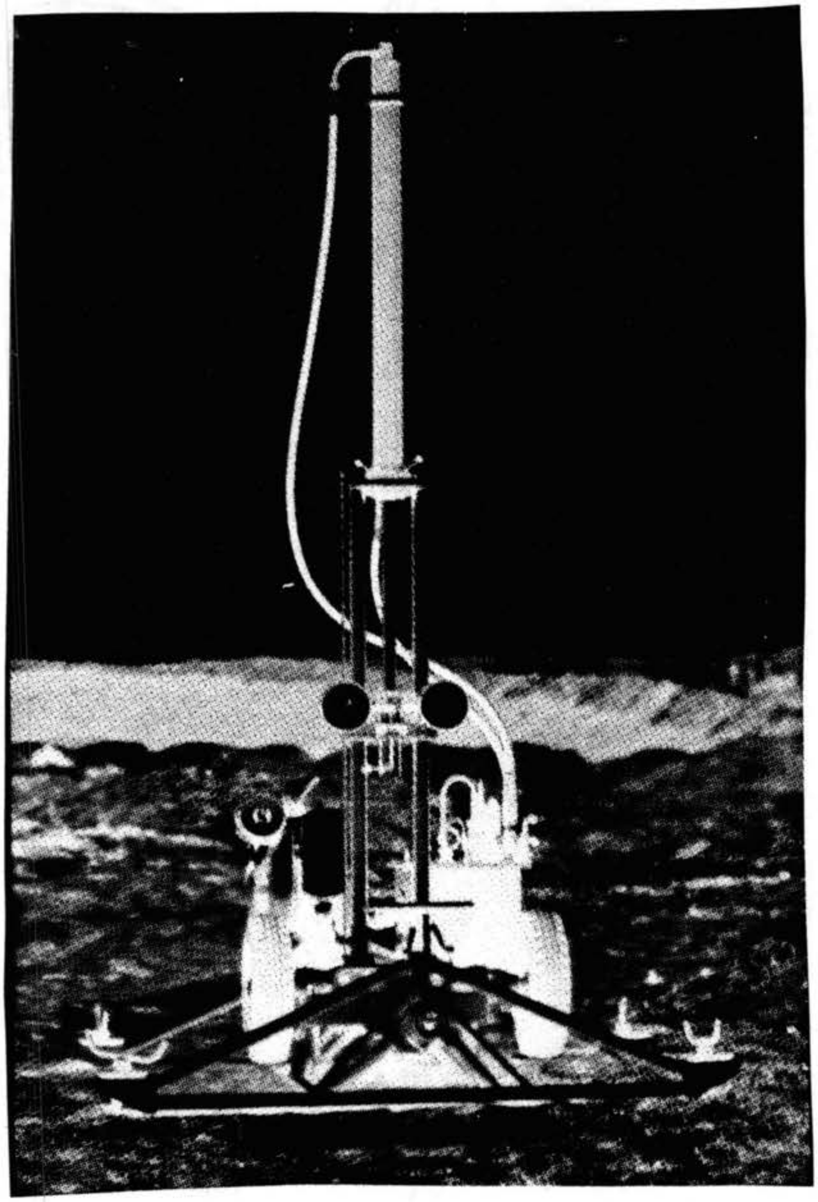


Figure 3. Hogentogler Model No. E5401
Dutch Cone Penetrometer,
11-Ton Capacity (10)

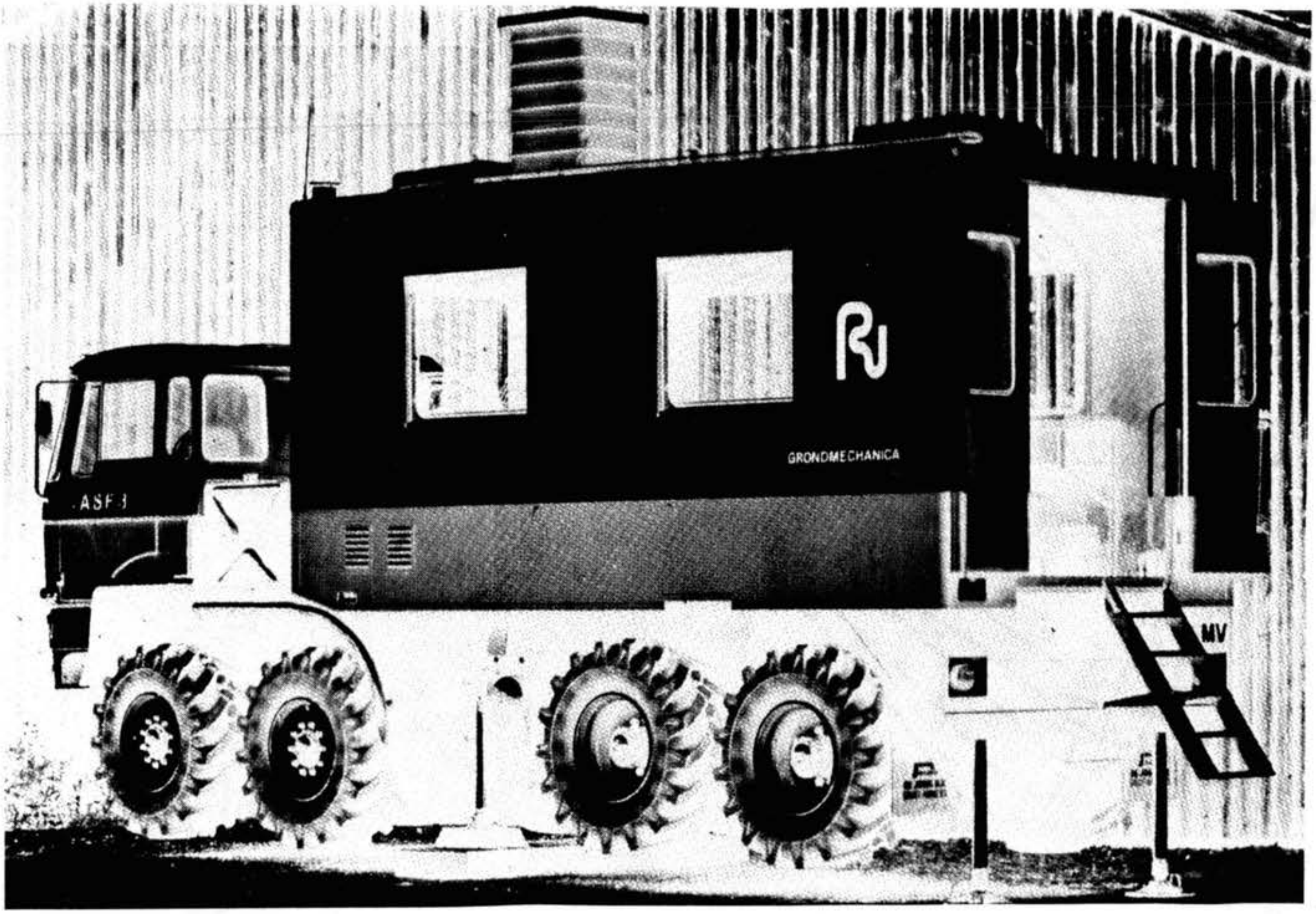


Figure 4. Special Sounding Truck (10)

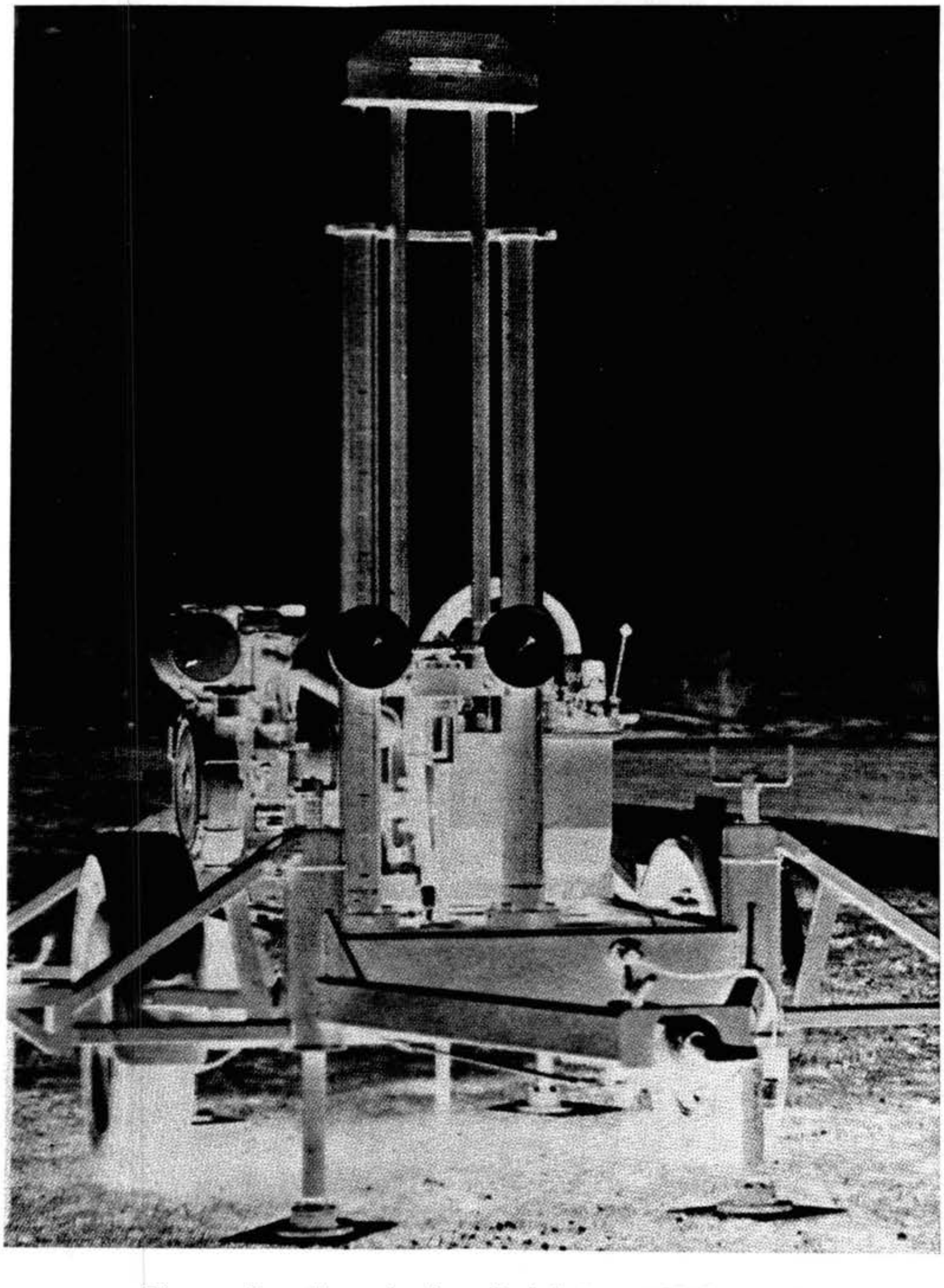


Figure 5. Hogentogler Model No. E5501 Dutch Cone Penetrometer, 20-Ton Capacity, Trailer Mounted (10)

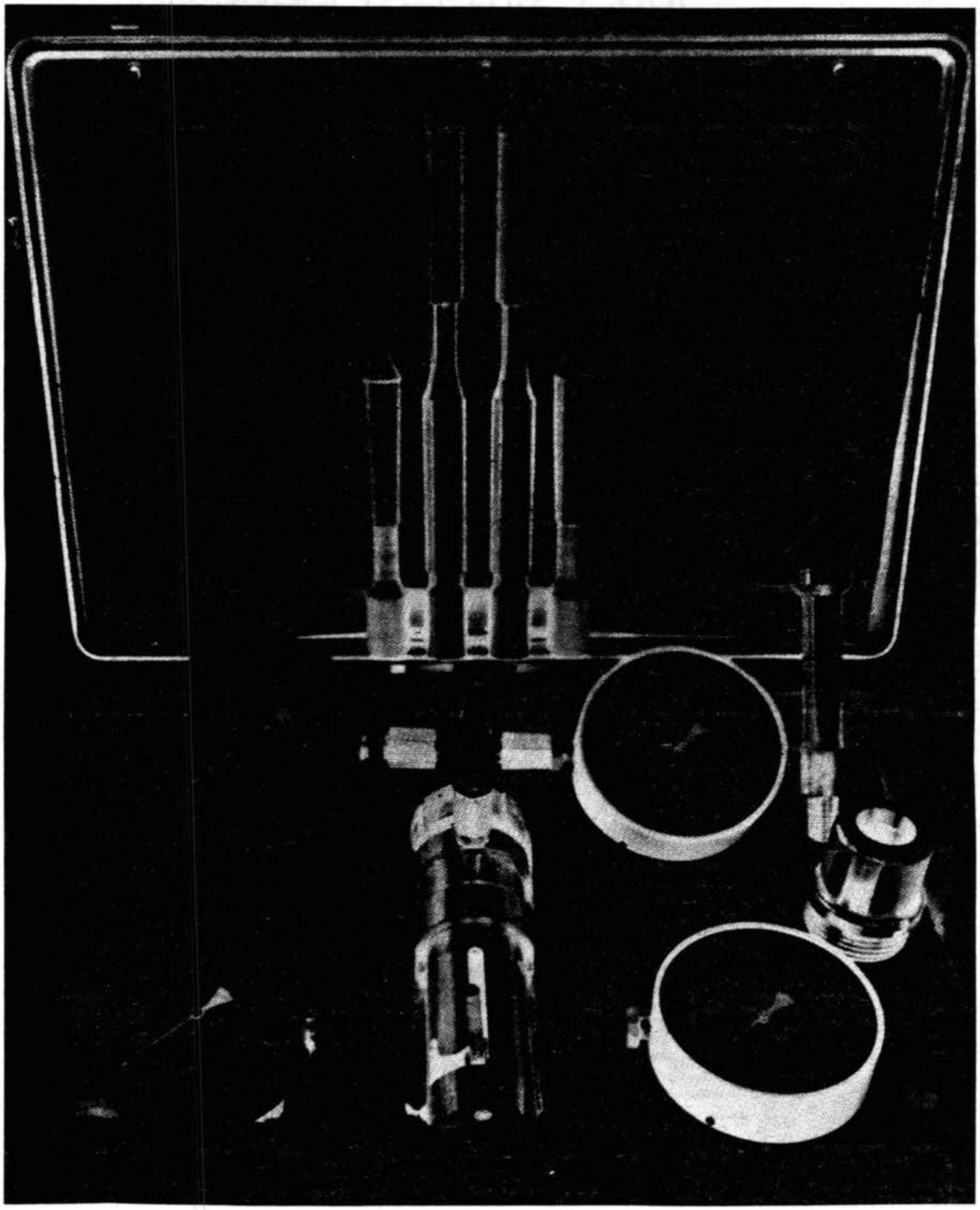


Figure 6. Hogentogler Model No. E5701 Dutch Cone Conversion Package (10)

The ASTM makes no stringent requirement on the thrust machine other than that the machine shall provide a continuous stroke preferably over a distance of one push rod length. Advancement of the tip must also be at a constant rate.

The standard push rod is made of high tensile steel and has a length of one meter. ASTM requires the rods to be smooth and have flush fitting joints. The diameter of standard inner rods is specified as between 0.5 and 1.0 mm less than the internal diameter of the push rods, and it is usually made of polished steel so as to reduce friction between the push rod and inner rod. To increase the depth of penetration and not reduce any differences between the resistance components, a special rod called a "friction reducer" is introduced into the string of push rods. The friction reducer is a rod (usually a short section of rod) which has an enlarged diameter or special projection. A friction reducer that has been found to be very effective in clayey soils is shown in Figure 7 (4). One that has been found to work well in sandy soils is the "cam friction reducer" shown in Figure 8 (18). ASTM D 3441-86 allows the use of such rods in the push rod string no closer than 1.3 feet above the base of the mantle mechanical cone or 1.0 feet above the top of the friction sleeve for the friction sleeve cone mechanical cone. Nominal dimensions for push rods used in mechanical cone testing are given in Figure 9.

Penetrometer Tips: Penetrometers are of two main types, mechanical and electrical. They can further be subdivided into those for measurement of cone resistance only and those for measurement of both cone resistance and local side friction. In mechanical penetrometers, the forces required to mobilize cone resistance and local side fric-

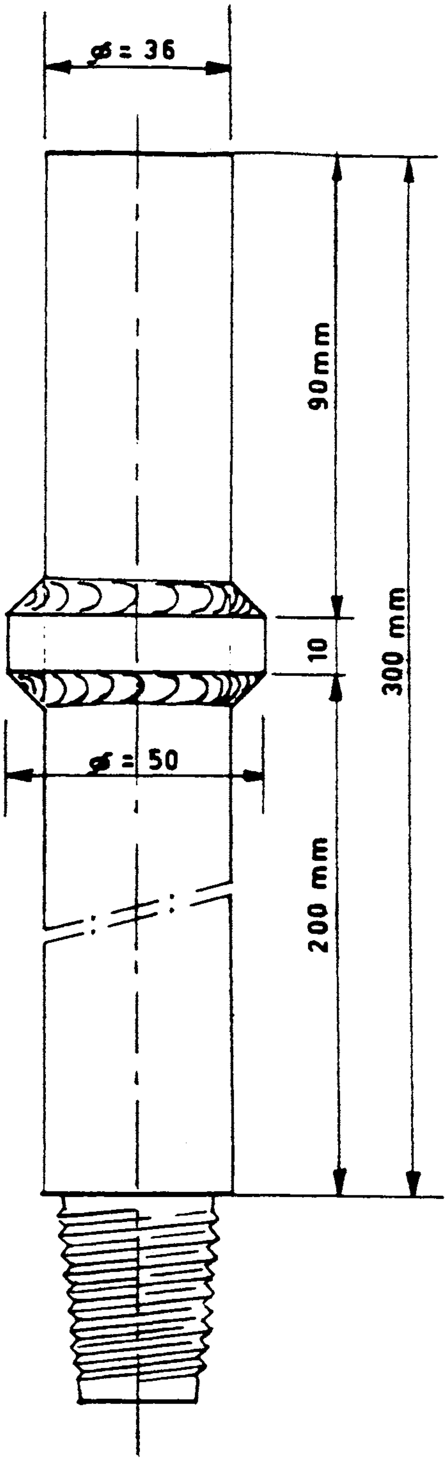


Figure 7. Spacer-Ring Connection to Reduce the Effects of Side Friction (4).

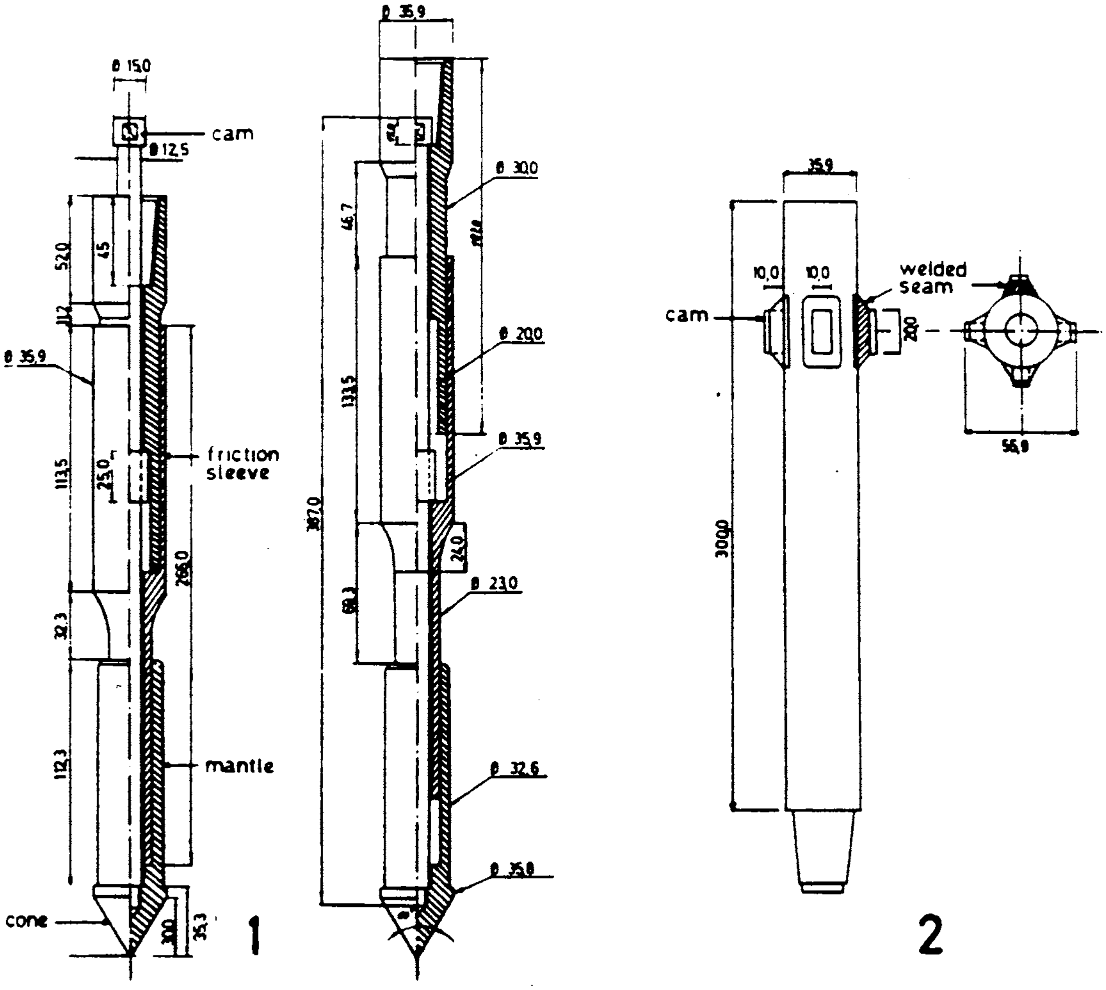


Figure 8. Begemann Friction Sleeve Penetrometer Tip (1) and Cam Friction Reducer (2, 18)

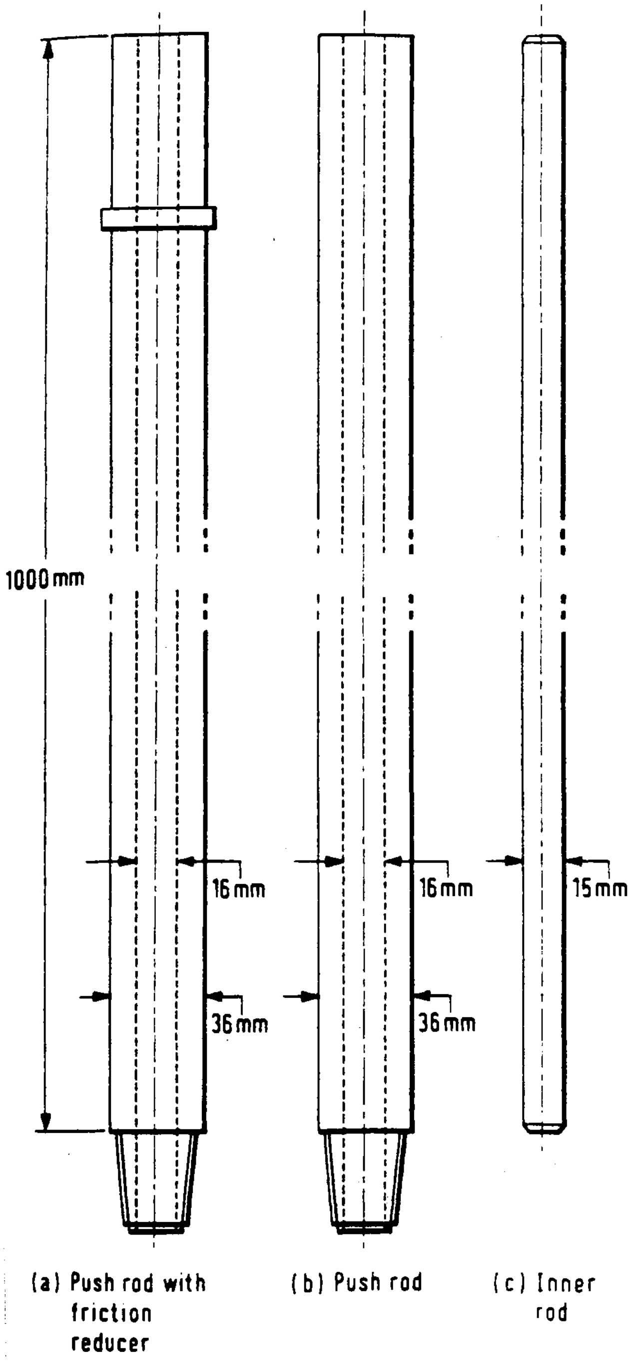


Figure 9. Penetrometer Rods (12)

tion are applied to the tip through the interaction of push rods and inner rods and measured at the surface. With electric penetrometers, penetration is achieved by the application of force to the push rods. Forces are measured by electrical resistance strain gauges built into the tip, and measurements are transmitted to the surface through an electrical cable. Dimensions and specifications of the mechanical and electrical cones (tips) are given in ASTM 3441-86.

Similarities in the basic dimensions between mechanical and electrical cones are the following: the cone tip has a 60^0 point angle, a projected cone surface area of 10 cm^2, cone base diameter of 35.7 mm, and a friction-sleeve surface area of 150 cm^2. Differences are the tip geometry and method of operation as discussed in Appendix B. Rol (19) conducted research comparing cone resistance in sand with three CPT-tips, two of which were the standard electric cone and mechanical friction-sleeve of the Begemann type. Results indicate that differences do exist and can be attributed mainly to friction between push rods and inner rods of mechanical cones. Differing cone geometrics also affect cone resistance and interpretation in normally and overconsolidated clays; however, there are other factors involved (12).

CPT Procedure

Extent of CPT Use: Early use of the mechanical cone was applied to extensive studies of soft or weak soils in Holland and Belgium (4). Application of the mechanical CPT has spread from principally recent alluvial normally consolidated clays and sands to overconsolidated alluvial clays and sands, residual clays, and older geologic formations. The mechanical cone is not used generally for rock exploration, although very soft and/or weathered rock have been investigated. Searle (20), for example, has studied the interpretation of the mechanical cone in chalk (carbonate siltstone). Schmertmann (11) indicates as a rough guide to the penetration limit is that 10-ton equipment can just penetrate a 5-foot layer of Standard Penetration Test (SPT) N = 100 sand at a depth of 25 feet. Ramage and Williams (21) report that, depending upon the machine used, the CPT is restricted to material with a SPT blowcount of less than 70 to 90 blows per foot. The CPT is rather restricted in penetrating gravel. Ramage and Williams also indicate that the ability of the mechanical cone to penetrate is limited to material that contains less than 45 percent of 1/2-inch or smaller gravel. Based on this literature review, it does appear that the applicability of the mechanical cone test has increased substantially in the material types now being investigated as compared to its original use in Holland.

Operation of Equipment: Detailed operational procedure for the mechanical cone is presented in Appendices A, B, and C. Basically, the procedural steps as outlined by de Ruiter (15) for the mantle and friction-sleeve mechanical cones are as follows:

Mantle Cone:

(a) The cone can be advanced 7 cm by means of the inner rods and a representative cone resistance value is recorded for that interval.

b) After advancing the cone, the outer rods are generally pushed down 20 cm, over the last 12 cm of which cone and rods move together. The procedure is then repeated so that intermittent readings are obtained at intervals of 20 cm.

Friction-Sleeve Cone:

a) The outer rods are kept stationary. The inner rods are pushed down and advance the cone 4 cm. In that interval the cone resistance is recorded.

b) The inner rods are advanced another 4 cm. The cone engages the friction sleeve and they move down together. The combined value of cone resistance and friction on the sleeve is recorded.

c) The outer rods are pushed down 20 cm along the friction sleeve over the last 16 cm and the cone over the last 12 cm. Subsequently, the procedure can be repeated.

Schematically, these steps are shown in Figures 1 and 2 of Appendix C. They are often referred to as the 20 cm steps. The ASTM specification requires that the measuring interval shall not ordinarily exceed 8 inches (20 cm). With the mechanical cone, the step can be completed in a 10 cm interval for more clarity with little or no loss in precision in the cone or friction resistances (18). For the mechanical cone, the operation is termed discontinuous due to the telescoping penetration of the cone by the inner rods followed by the friction sleeve moved by the push rods to close the step. This operation results in the measurement of the cone resistance first, followed by the combined friction and cone. The local friction is taken as the difference between the combined cone and friction resistance and the preceding cone resistance measurement. In contrast to the mechanical cone, the electric cone tip and friction resistances are measured continuously. The term continuously more correctly means that the resistances are recorded simultaneously at intervals as specified in the ASTM standard. For light penetrometer rigs the mechanical cone is advanced by hand operation of a chain drive; in the medium and heavy penetrometer rigs penetration is obtained by the use of a hydraulic ram.

Recording Results: Options for recording and processing mechanical cone data are shown schematically in Figure 10. With most mechanical penetrometers, readings are taken from a hydraulic pressure gage and recorded manually. Details and specifications for typical hydraulic pressure gauges are given in Appendix C. A typical field record sheet is shown in Figure 8 of Appendix C. From the field record sheet, data processing and plotting can be done manually (Path A1, Figure 10) or by computer (Path A2, Figure 10). However, with some mechanical cone penetrometers, the loads transmitted by the rods are measured electrically and fed into a signal amplifier/conditioner unit (Path B, Figure 10). They can then be plotted on an analogue chart recorder for subsequent digitizing and computer processing in the office (Path B1, Figure 10), or treated in the same way as signals from an electric penetrometer (Path B2, Figure 10). Schmertmann (22) reports that friction-ratios measured by the above systems when plotted show insignificant differences with perhaps electronically determined ratios more consistent. A typical plotting format that aids in the interpretation of the mechanical cone is given in Figure 11. Units for the cone and friction resistance are reported in tons or kPa per unit area with depth in feet or meters as per ASTM D 3441-86.

Accuracy and Calibration: The major factors that affect the accuracy of the mechanical cone include the following:

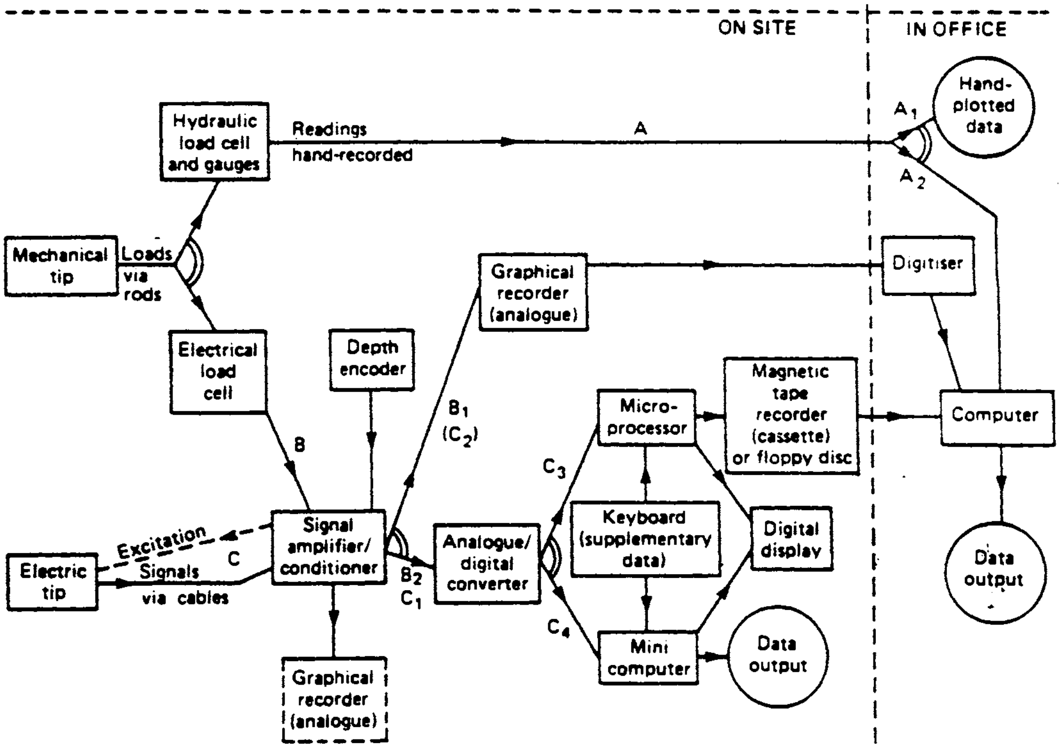
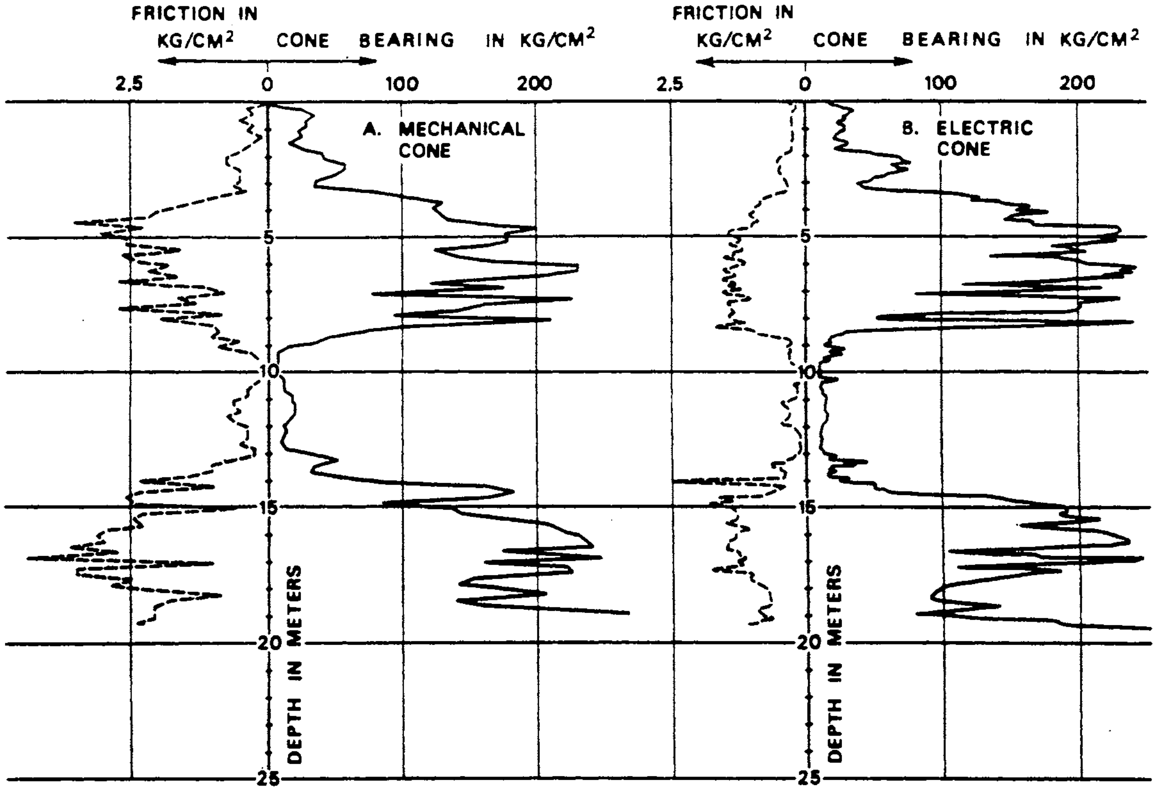


Figure 10. Possible Arrangements for Recording and Processing CPT Data (12)



A. MECHANICAL CONE, DISCONTINUOUS READINGS
B. ELECTRIC CONE, CONTINUOUSLY RECORDED

Figure 11. Penetrometer Tests With Friction Measurement (15)

Rate of penetration

Inner rod friction

Weight of inner rod

Jamming

Wear of cone dimensions

Distance between cone and friction sleeve

Drift of tip

Research indicates that the cone resistance tends to increase with the penetration rate for both clays and sands (12, 23). Small variations in the speed relative to the standard rate of 2 cm/sec have no significant influence on cone resistance. ASTM D 3441 standard which allows a variation of ±25 percent appears fully acceptable (23). Inner rod friction is a much discussed topic in mechanical cone testing. Care must be taken that the inner rods are free of soil particles and corrosion and lubricated before insertion into the push rods. A procedure for estimating the inner rod friction in a homogeneous is presented in Figure 9 of Appendix C. Additional inner rod friction develops due to penetrating hard layers and at great depths, because of elastic compression, causes shortening of the inner rod (15). This elastic compression further shortens and eliminates the free stroke for the cone measurement. Appendix C, Figures C1 and C2, contains a procedure for compensation of elastic compression rod shortening. Meigh (12) suggests the mechanical cone should not be used for depths greater than 20 m in order to avoid inner rod friction. Van den Berg (16) reports some manufacturers are now producing a highly polished surface on inner rods and the inner surface of the push rods which they claim virtually eliminates inner rod friction.

For improved accuracy at low cone resistance values, a correction of the cone data is required to account for the accumulated weight of the inner rod from the cone tip to the topmost rod. For very soft clays, Schmertmann (1) indicates the practice of using aluminum inner rods. Soil particles between sliding surfaces or bending of the tip may jam the mechanism during many extensions and collapses of the telescoping mechanical tip. The sounding has to be stopped as soon as uncorrectable jamming occurs.

Measurements become less accurate if the dimensions of the cone depart appreciably from the ASTM D 3441-86 standard due to wear or by damage. Of particular importance is the surface roughness of the cone and the friction sleeve. Parez (24) and Durgunoglu and Mitchell (25) have conducted research showing the effect of shape and base roughness of the cone tip upon penetration resistances.

In the case of the friction sleeve cone, the frictional resistance applies to the soil at some distance above the soil in which the cone resistance was obtained at the same time. When comparing the cone resistance with friction resistance and/or friction ratio, the proper vertical distance must be considered between the base of the cone and mid-height of the friction sleeve. For example, Figure 12 clearly shows that the local friction resistance measured in the third step has to be compared with the cone resistance in the first step. Depret (18), in his research on the influence of the measuring step in mechanical penetration tests, points out the importance of proper comparison. Drift of the sounding rods and cone tip can cause bending of the rods, resulting in friction development between the inner and outer rods. Drift of the rods from the vertical occurs in very deep

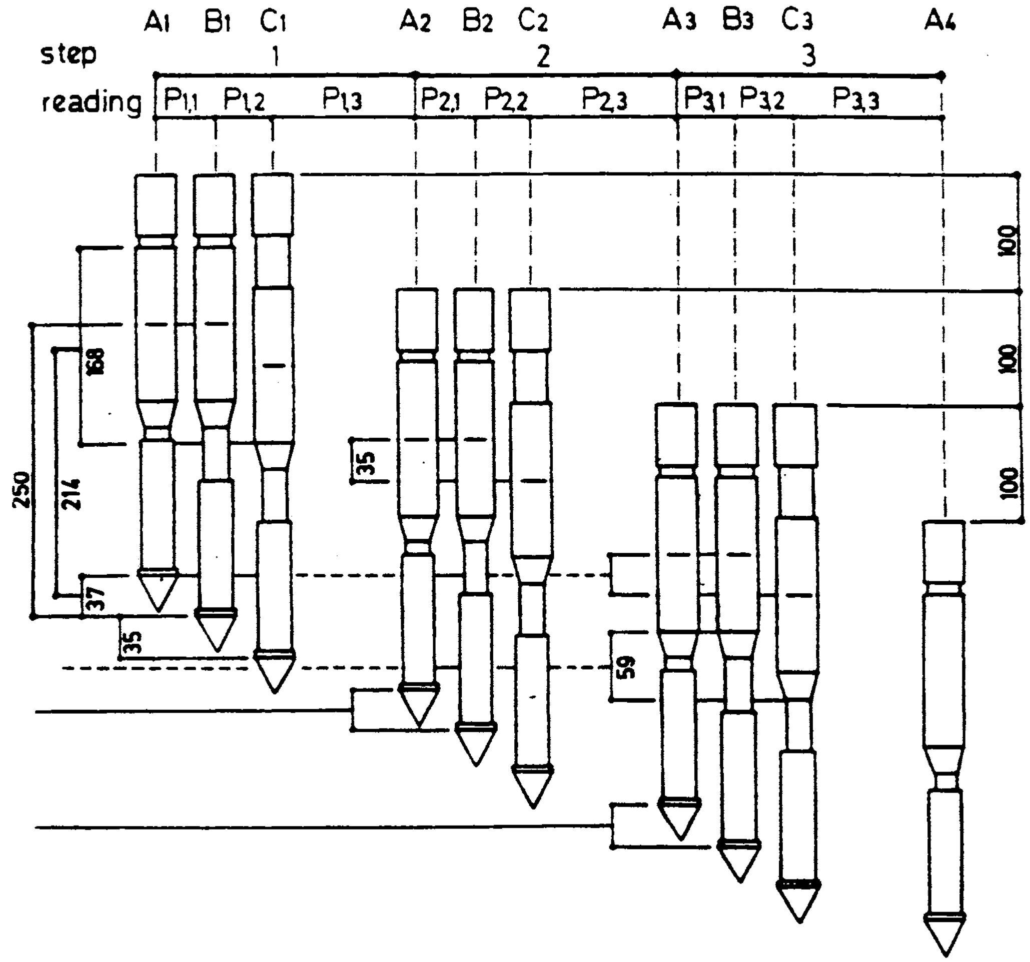


Figure 12. Readings of Resistance in 10 cm Measuring Steps (18)

soundings and when passing through or alongside obstructions such as boulders, soil concretions, thin rock layers, and inclined dense strata. For penetration depths exceeding about 40 feet, the tip will probably drift away from a vertical alignment (3).

The traditional method of measuring cone resistance is rather simple, but it does require a double string of rods which can introduce a number of errors. However, if used in a careful and competent manner, and if attention is paid to specification detail and calibration, the method can be fully adequate. Experience of a great number of investigators over many years has shown that reliable results are obtained provided that tests are executed with proper care (15).

A comparison of the difference in the values of the cone and friction resistances between those measured with the mechanical and those measured with the electrical penetrometers is to be expected for two reasons: first is the influence of the penetrometer shape; second is the difference in the method of advancement of the cone (15). However, de Ruiter (15) and Van den Berg (16) can find no systematic difference between the cone resistance values from the mechanical and electrical penetrometers, as noted in Figure 11. In contrast to the cone resistance, marked differences are found in the magnitude of the friction resistance as measured with the Begemann mechanical penetrometer and with the electric penetrometer. A comparison of the two friction graphs in Figure 11 indicates that on average the friction resistance of the electric cone is only about half of the mechanical cone. Numerous other comparisons found the same approximate ratio (26, 27). The large difference in friction can be explained mainly by the end resistance on the lower edge of the friction sleeve. In clays this will be of minor importance, but in cohesionless soils it may affect the result appreciably.

CPT Soil Classification

Soil classification from CPT data has been traditionally obtained from the magnitude of cone resistance and more specifically from their friction ratio (the ratio of local side friction to cone resistance, f_s/q_c).

A soil classification scheme using mechanical cones was first formulated by Begemann (9). Begemann developed his scheme from approximately 250 comparative friction cone penetration soundings and accompanying borings which cone resistance is compared to local side friction (see Figure 13). The graph with lines that relate to the percentage of soil particles less than 16 μ is the basic figure. Figure 13 shows the names of soil types used by the Delft Soil Mechanics Laboratory on the basic graph. Schmertmann (11) extended Begemann's work to include an interpretation of density or stiffness (see Figure 14) in terms of cone resistance and friction ratio. Searle (20) included the results of further field measurements and expanded the Begemann and Schmertmann charts (see Figure 15). This approach differed from the previous ones in that soil type was directly related to friction ratio.

The basis for soil classification by a cone penetrometer is the analogy that it models a driven pile. The ratio of skin friction to tip resistance has been found to be approximately 5 percent for clay and 1 percent for sand. This analogy is applied to a cone penetrometer and termed the friction ratio. The friction ratio (FR) is a

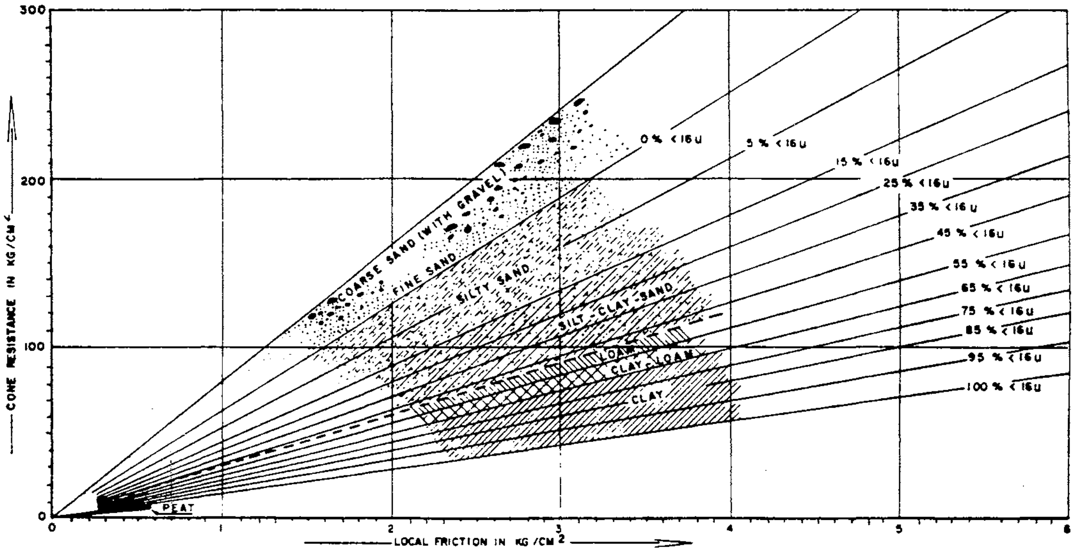


Figure 13. Graph Showing Relationship Between Cone Resistance, Local Friction, and Soil Type (9)

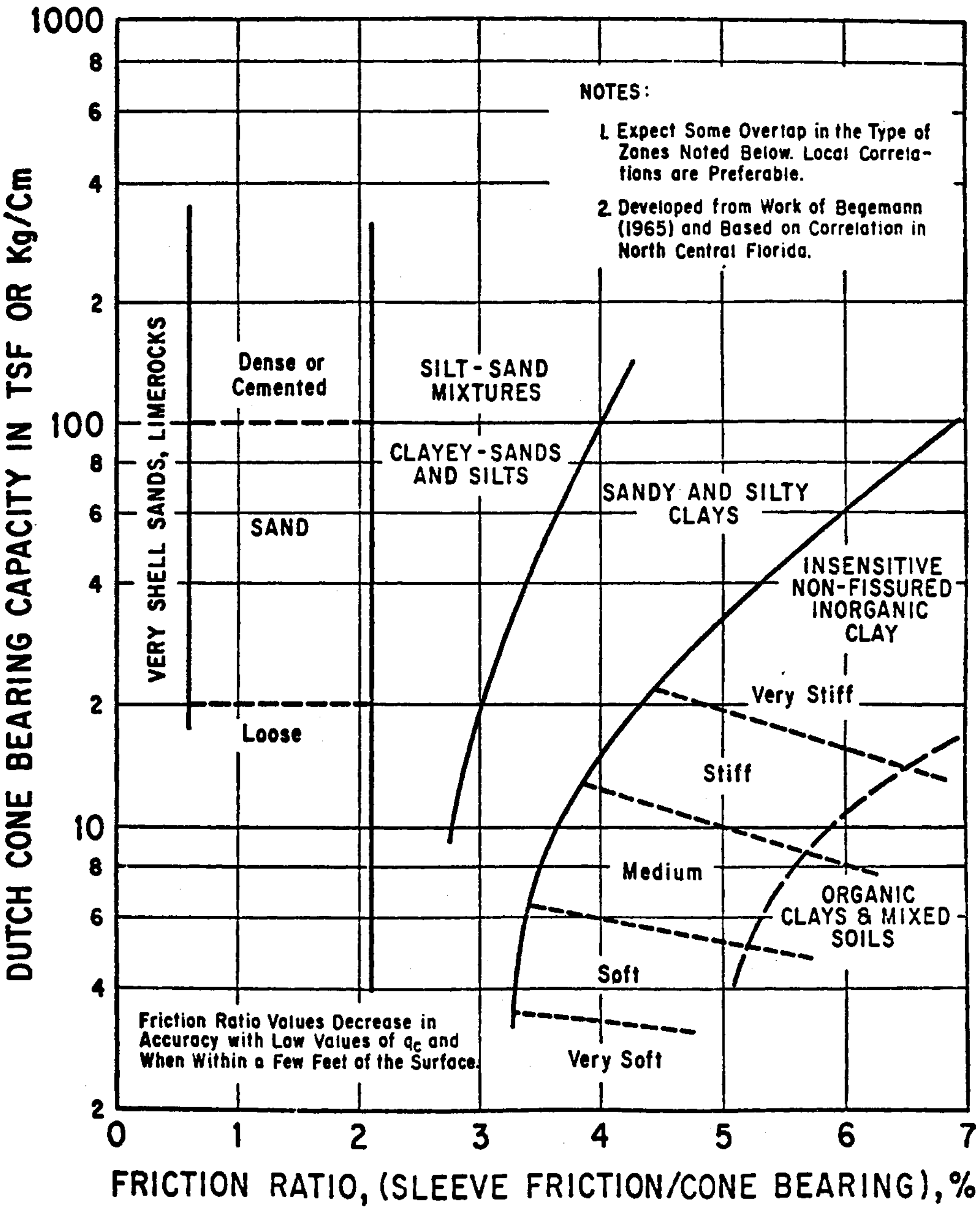


Figure 14. Guide for Estimating Soil Type From Dutch Friction-Cone Ratio (Begemann Mechanical Tip) (11)

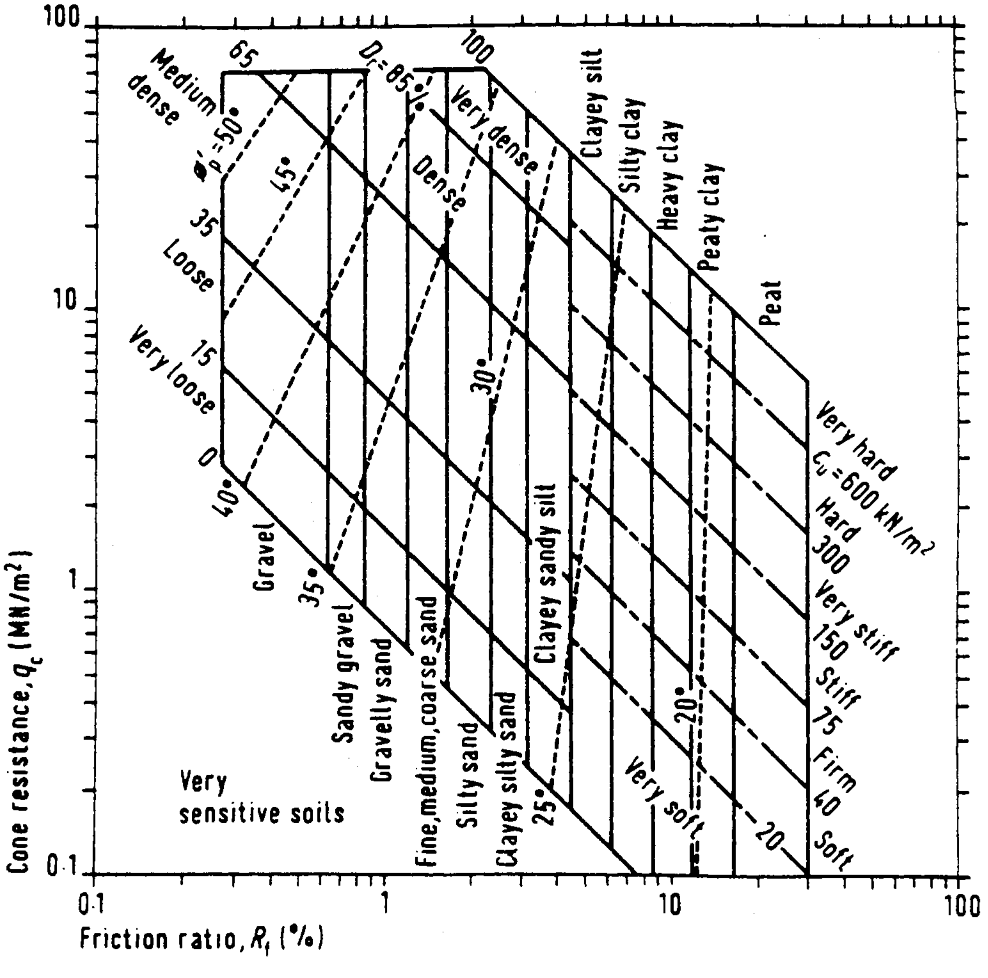


Figure 15. Identification of Soils Using the Dutch Mechanical Friction-Sleeve Penetrometer (20)

characteristic of the soil type but can vary depending on the cone configuration used (4). In general, it has been found that the higher the FR, the greater the percentage of fines in the soil--particularly cohesive fines. As reported by Sanglerat (4), extensive correlation between various investigators has led to general acceptance of friction ratios for different soil types (see Table II).

Most investigators (4, 11, 12) point out that the above listed classification schemes are guidelines and recommend deriving correlations based on local conditions by direct comparison with one or more test borings, preferably by continuous sampling.

Cone resistance responds to soil changes with 5 to 10 diameters above and below the cone, the distance increasing with increasing stiffness. This leads to some inaccuracies in locating soil interfaces as noted earlier. Very thin layers can be missed. A thin layer of sand within a clay stratum may not be detected if it is less than 4 inches thick and a clay layer within sand may not be detected if it is less than 6 to 8 inches thick. However, the accuracy of CPT logging is considered better than conventional boring and sampling (5 foot interval sampling).

SPT-CPT Correlation

Because of the extensive use of the standard penetration test (SPT) in the United states, it is of interest to develop a correlation between the SPT blow count (N-values) and the cone resistance. Sanglerat (4) discusses these correlations in detail. The correlations generally take the form:

TABLE II

FRICTION RATIOS--SOIL TYPE (4)

FR	Soil Type
0.0-0.5%	Ordinarily indicates soft rock, shells, or loose gravel
0.5-2.0%	Ordinarily indicates sands or gravels
2.0-5.0%	Clay-sand mixtures and silts
>5.0%	Clays

$$q_c = nN \tag{1}$$

where n varies from 2 for clays to 10 for sands. Schmertmann (28) presented some theoretical correlation between SPT and cone sounding data and indicated a decreasing q_c/N ratio with increasing cohesiveness of the soil. He also has found that the ratios of ($N_{06\text{-}12\ \text{in.}}/N_{12\text{-}18\ \text{in.}}$) correlate well with the FR. Further research by Schmertmann resulted in the development of an equation giving the N value as a function of cone resistance (q_c) and friction ratio (FR) that is applicable in any type of soil. This equation can be formulated as follows:

$$N\ (\text{SPT}) = (A + B \times \text{FR}\ \%)\ q_c, \tag{2}$$

where A and B are constants.

Begemann, as reported by Schmertmann (29), has found closer correlation between local friction (f_s) and SPT resistance N, than between cone resistance, q_c and N. For insensitive clay, the q_c/N ratio is potentially very useful to correlate between clay consistency and estimated undrained shear strength from local correlations with N or from generalized correlations. The correlations in Table III by Terzaghi and Peck were reported by Sanglerat (4). In more recent research Robertson and Campanella (30) show that q_c/N ratios are a function of the mean grain size (D_{50}) (see Figure 16). Here again, one can see that q_c/N is generally low for clays and higher for sands.

Estimation of Undrained Shear Strength

An early application of the cone penetration test was in the evaluation of undrained shear strength (c_u) of clays (31). The esti-

TABLE III

SPT "N" RESISTANCE AND UNCONFINED COMPRESSIVE STRENGTH IN CLAYEY SOILS

N	Consistency	Unconfined Compressive Strength in Clayey Soils (q_u in tsf)
2	Very Soft	0.25
2-4	Soft	0.25-0.50
4-8	Medium Soft	0.5-1.0
8-15	Stiff	1.0-2.0
15-30	Very Stiff	2.0-4.0
Over 30	Hard	4.0-8.0

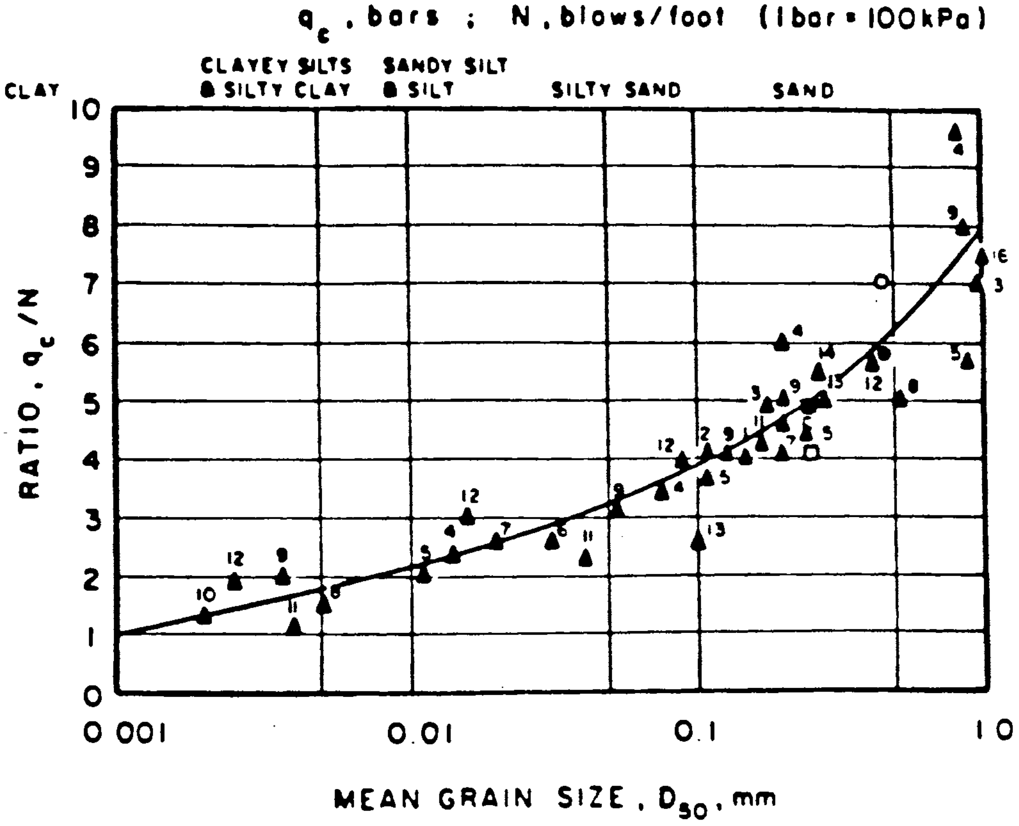


Figure 16. Variation of q_C/N Ratio With Mean Grain Size (30)

mation of the undrained shear strength in clays using mechanical cones is based on the classical bearing capacity equation

$$q_u = cN_c + \alpha \, DN_q + \frac{1}{2} \alpha \, BN_\alpha \qquad (3)$$

where c equals cohesion of the soil; B equals the width of the footing; D equals depth of embedment of footing; α equals density of soil; and N_c, N_q, N are dimensionless coefficients. From Equation (3) for frictionless soil ($\phi = 0$) the equation reduces to

$$q_u = cN_c + \alpha D \qquad (4)$$

For the mechanical cone resistance (q_c) and undrained shear strength (s_u) of a cohesive soil, Equation (4) can be rewritten as

$$q_c = c_u \, N_k + \alpha Z \qquad (5)$$

where αZ is the total vertical stress, and N_k is the cone factor analogous to the bearing capacity factor, N_c. In terms of undrained strength, Equation (5) is then

$$c_u = \frac{q_c - \alpha z}{N_k} \qquad (6)$$

Due to the difficulty of measuring piezometric levels in clays, many researchers (32, 33, 34) neglect αz, thereby giving a much simplified formula for undrained shear strength as

$$c_u = \frac{q_c}{N_k} \qquad (7)$$

However, N_k is not a constant. Some of the main factors affecting N_k according to Meigh (12) are as follows:

1. Method and reliability of measurement of c_u
2. Shape of the penetrometer

3. Rate of penetration
4. Strength anisotropy
5. Macrofabric of the clay and its stiffness ratio (the ratio of shear nodules to undrained shear strength)

Schmertmann (11) also presents additional variables that can affect N_k (see Table IV).

The N_k for overconsolidated clays is distinctly higher than N_k for normally consolidated clays, and it is generally higher when q_c is measured with the mantle or friction-sleeve cone rather than with the electric cone as referenced in Appendix B. Except for some highly sensitive clays, the cone factor, N_k, is higher than the theoretical value of N_c (usually taken as 9) for both normally and overconsolidated clays (12). This is partly the result of skin friction acting on the mantle (which varies with sensitivity of clay) and partly because pore pressure buildup is smaller with the intermittent action of the mechanical penetrometer than with the continuous action of the electric penetrometer. Meigh (12) indicates further that except for some highly sensitive clays, N_k is higher than the theoretical value of N_c because the CPT rate of shearing is approximately 100 times faster than in a field vane or a laboratory compression test. Briaud (35) presents some evidence of the effect of the rate of loading on the undrained shear strength and how it affects the cone resistance, q_c.

For normally consolidated clays, Meigh (12) reports an average N_k of 17.5 with most of the results falling in the range of 15 to 21. Sanglerat (4) reports N_k to be between 15 and 18. For overconsolidated clays the macrofabric (secondary clay structure, i.e., fissures, slickensides) has a marked effect on the cone factor, N_k, making

TABLE IV

SOME VARIABLES THAT INFLUENCE N_k (11)

Variable	Approx. N_c Factor Potential	Direction	Notes
1. Changing the test method for obtaining reference s_u	2 to 3	Better sampling, thinner vanes, use of s_{uPMT} all decrease N_c	See Eq. (4)
2. Clay stiffness ratio = G/s_u	3.0	Increases with increasing stiffness	Vesic (1972)
3. Ratio increasing/decreasing modulus (E^+/E^-) at peak s_u	3.0	Decreases with decreasing ratio	Ladanyi (1967)
4. Effective friction, $\tan\phi$	2 to 3	Increases with increasing ϕ	Janbu (1974)
5. K_o or OCR	3.0	Increases with increasing K_o or OCR	Janbu (1974)
6. Shape of penetrometer tip	2.0	Clay adhesion on mantle of mechanical tips increases N_c	Example in Amar et al. (1975, Figure 2)
	1.5	Reduced diameter above cone can decrease N_c in very sensitive clays	Schmertmann (1972b)
7. Rate of penetration	1.2	Increasing rate increases N_c	Viscous, no pore pressure effects
8. Method of penetration	1.2	Continuous (electrical tips) penetration decreases N_c compared to incremental (mechanical tips) because of higher pore pressures	

interpretation of shear strength more difficult and uncertain than in normally consolidated clays. Marsland and Quaterman (36) present in their research three fissure and/or discontinuity patterns (see Figure 17). As observed in this figure, for case (a), the cone resistance reflects the effect of fissures on the strength of the clay mass. For case (b), the cone resistance only partly reflects the effect of fissures. Case (c) indicates widely spaced fissures. In other research, Marsland (37) further shows the influence of fissures by comparing vane shear test results with various sized triaxial specimens (see Figure 18). Other researchers (38, 39) indicate good correlation between q_c and pressuremeter results. The N_k range reported by Meigh (12) for stiff fissured overconsolidated clays is 27±3. Sanglerat (4) shows N_k values ranging from 22 to 26 for stiff clays.

Compressibility of Clay, Overconsolidation Ratio, Sensitivity

The conventional cone penetrometer, measuring q_c and f_s, does not lend itself to reliable estimates of clay compressibility. Only indirect methods have been developed by Schmertmann (11) and Sanglerat (4). Schmertmann's approach is based on estimating the overconsolidation ratio (OCR) to predict clay compressibility. In Sanglerat's approach, an empirical relationship was developed mainly for the mantle cone between the coefficient of constrained modulus (m_v) and tip resistance (q_c) to estimate clay compressibility.

Some recent research by Tavenas and Leroueil (40) and by Mayne (41) used the cone penetration test to index the in-situ overconsolidation ratio which affects clay settlement predictions. Schmertmann

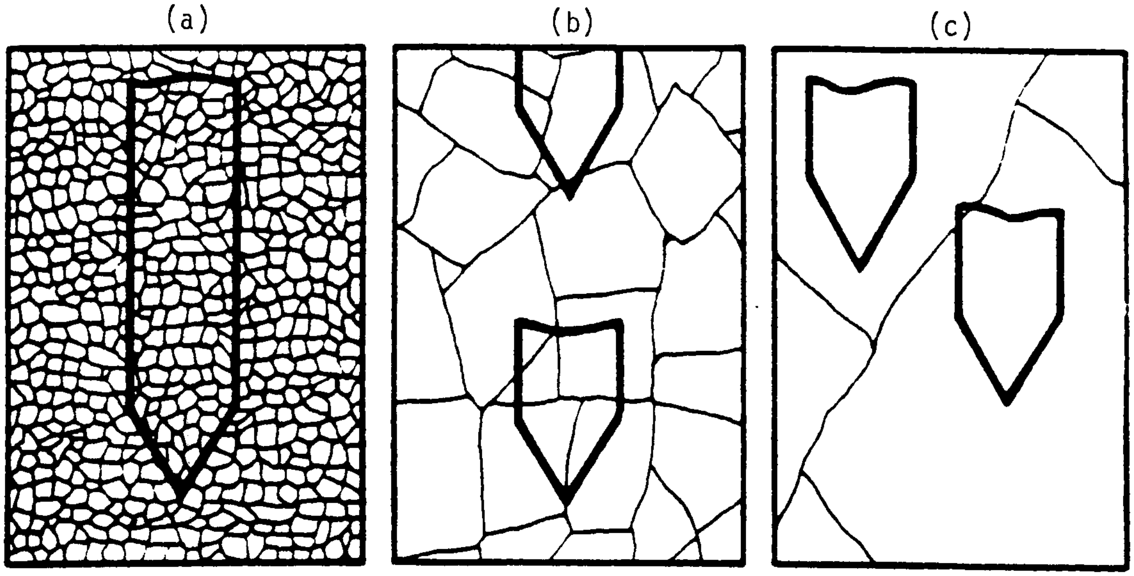


Figure 17. Fissure Patterns in Overconsolidated Clays Related to Scale of Cone Penetrometer Tip (36)

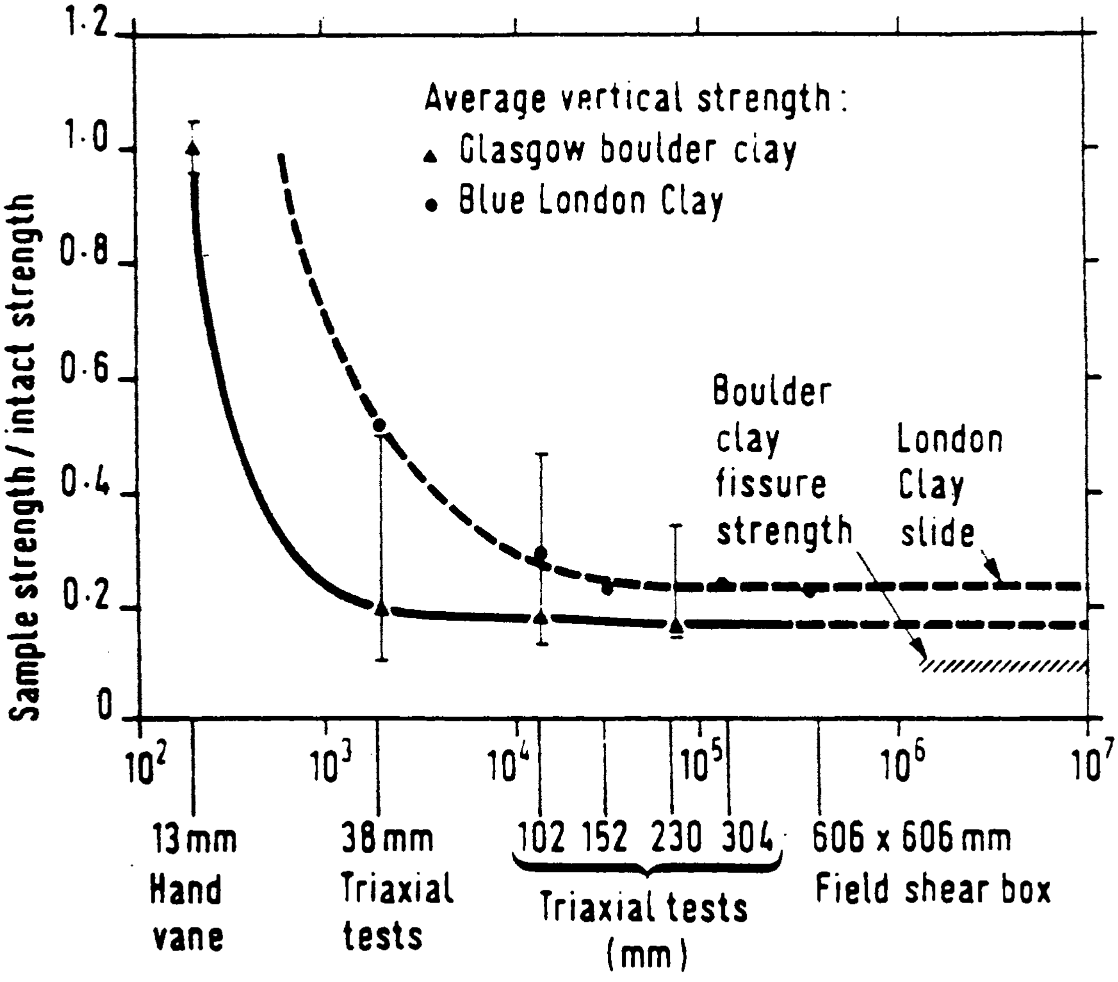


Figure 18. Effect of Sample Size on Undrained Shear Strength of London Clay (37)

(11) and Robertson and Campenella (31) report correlations between clay sensitivity and FR and q_c.

CHAPTER III

RESEARCH PROGRAM

Introduction

As indicated, the purpose of this research is to characterize typical Eastern Oklahoma alluvial soils and develop localized relationships between mechanical cone penetrometer parameters, q_c and f_s, and the following: soil classification, SPT, undrained shear strength, and clay compressibility through the estimate of OCR. There is need for conducting research of this nature in order to expand the data base on the merits and limitations of the mechanical cone penetrometer. This equipment is simple in operation and has significant practical use in many geotechnical engineering applications under various geologic conditions. Cone penetrometer equipment and methods have become increasingly more sophisticated (15, 30, 31). However, it is believed that a proper perspective of the increased technological advances in the cone penetrometer should be one of enhancement and not total replacement of the mechanical cone with more advanced types.

CPT Test Equipment and Procedure

The cone equipment used in this research was the mantle and friction-sleeve mechanical (Model No. E5705) and the electric cone

(Model No. 57035) supplied by the Hogentogler & Co., Inc. The friction-sleeve used has the tapered mantle conforming to the LGM specification NEN 3680 which was referenced earlier. The hydraulic system of a CME 75 conventional drilling rig was used along with the necessary conversion kit to advance the cones. A cam friction reducer was used in all soundings. Recording of q_c and f_s was done by manually reading hydraulic pressure gauges (direct reading of tip force in Newtons). The actual equipment--cones, rods, and friction reducer, hydraulic load cell and gauges, and CME 75 rig--used in this research are shown in Figures 19, 20, 21, and 22, respectively.

The cone equipment and procedure followed ASTM D 3441-86. Careful attention was paid to Section 6 of ASTM D 3441-86 at all sounding locations.

Test Sites

The test sites for this research were selected to study typical alluvial clays formed on broad floodplains in the northeastern quarter of Oklahoma. Generally, the streams and rivers in this region are low gradient tributaries of the Arkansas River. Typically, these alluvial clays are found to occur to depths of 50 feet. They are highly plastic, desiccated, firm to stiff clays that tend to become soft and nonstructed with depth. Three sites were mapped according to the USDA Soil Conservation Service as Osage soil series, one as a Lela, and one as a Waynoka soil series (see Figure 23). The sites are named for the closest community within the vicinity (see Figure 23 for general locations).

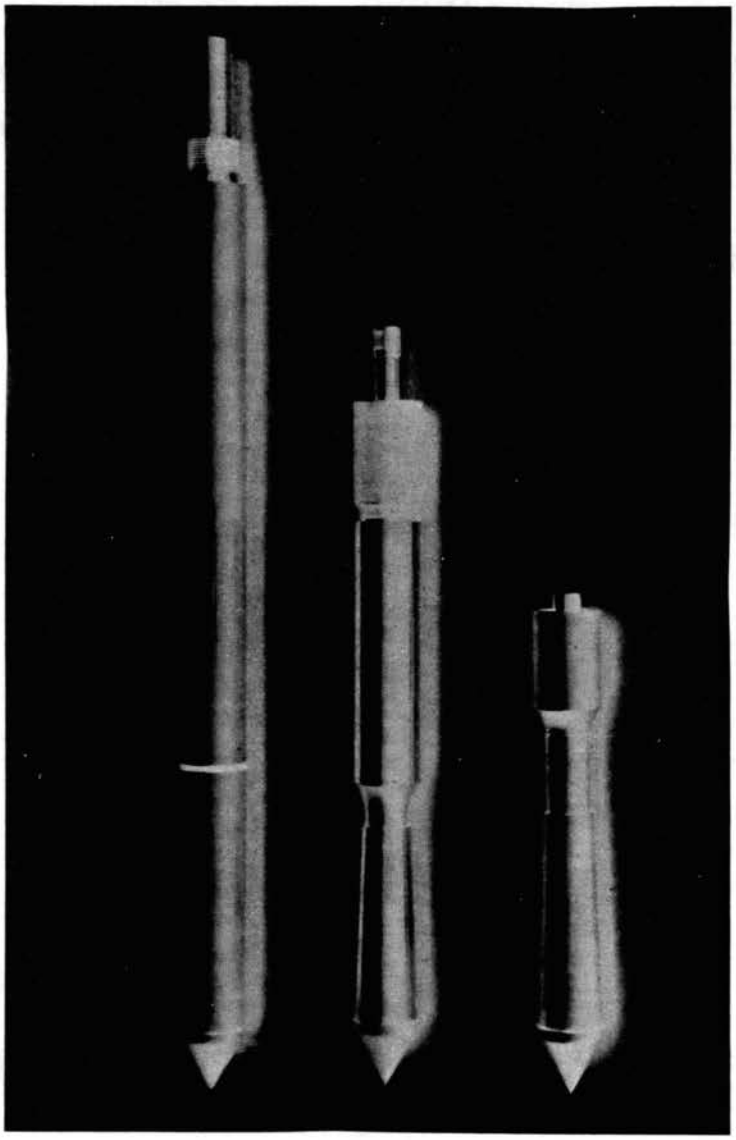


Figure 19. Mechanical and Electrical Cones

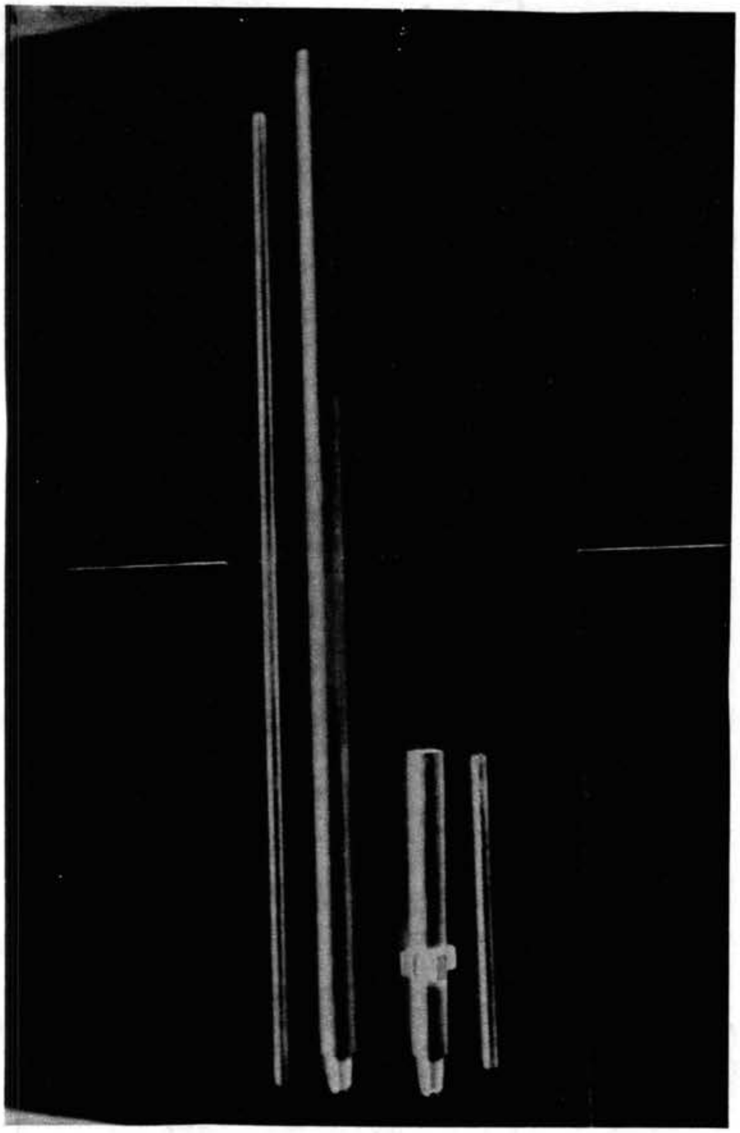


Figure 20. Rods and Friction Reducer

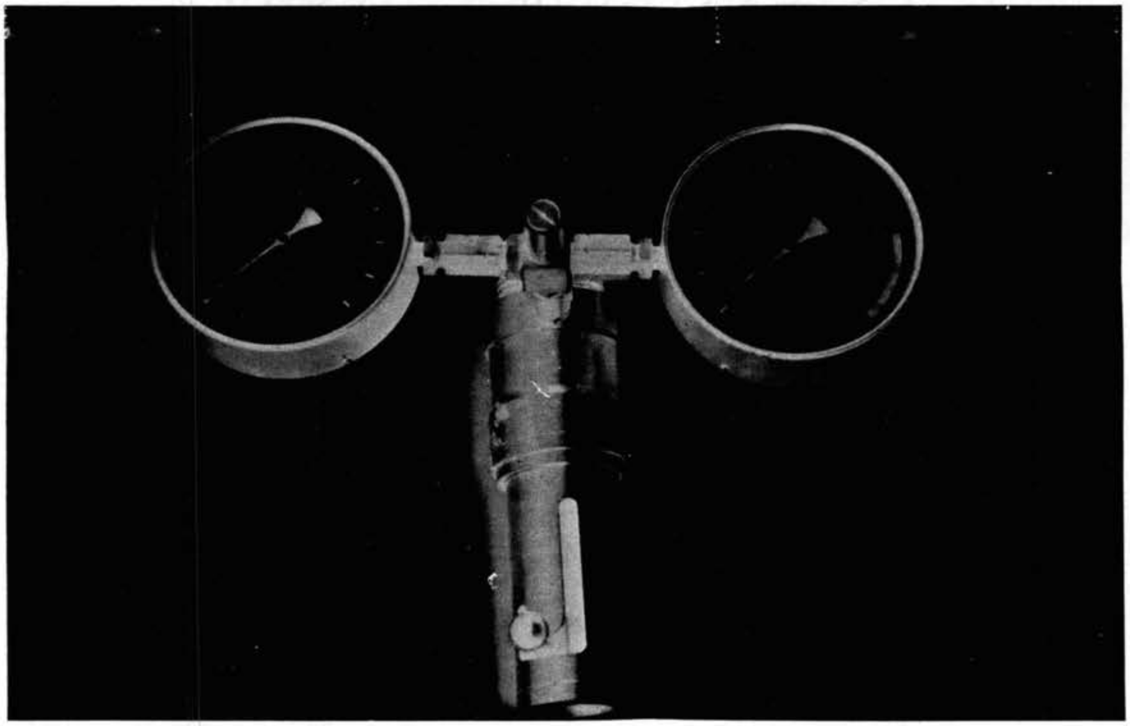


Figure 21. Hydraulic Load Cell and Gauges

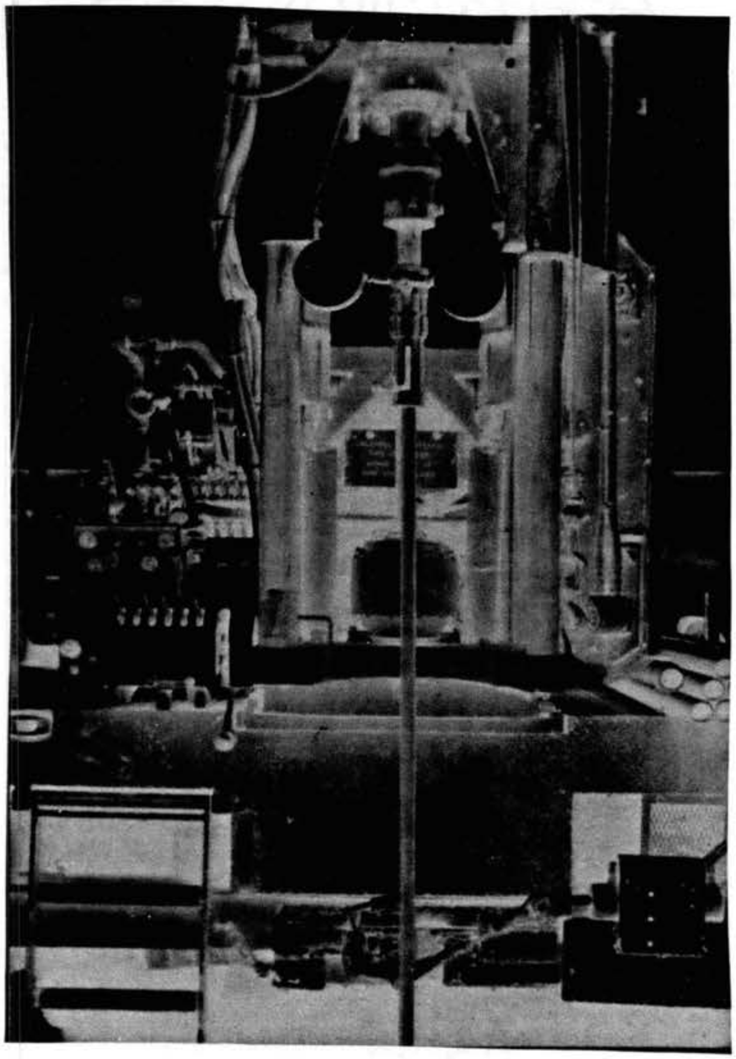


Figure 22. CME Model 75 Drill Rig

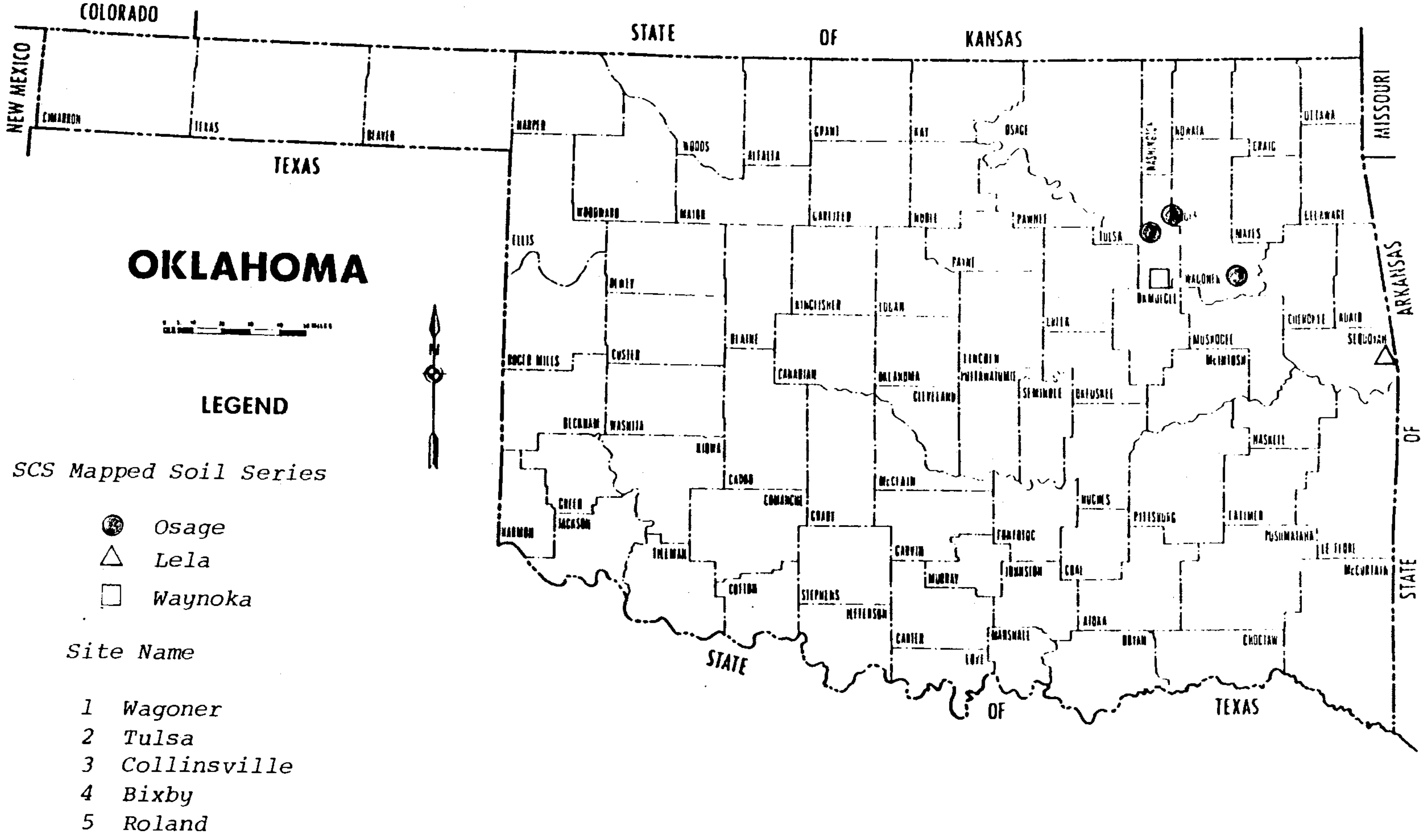


Figure 23. Test Site Locations

Testing Program

The testing program involved cone penetrometer testing and correlation at all sites with special in-depth study at the Wagoner and Tulsa site locations. The testing program included field sampling, in situ testing, tests for index and engineering properties, and an analysis of the typical macro-structure for these alluvial clays.

Field Sampling: At each site, continuous SPT borings were made according to ASTM D 1586-84 test specification. An exception to the test specification that was applied to all SPT borings was the use of a 2-inch O.D. split spoon sampler without a liner. A CME automatic hammer system was used at all SPT borings to insure more consistent N-resistance values. At the Wagoner site, two additional borings were made by continuously pushing, respectively, 5-inch O.D. and 3-inch O.D. thin-walled sample tubes according to ASTM D 1587-83 specification. Also at the Wagoner site the CME continuous tube sample system (2-5/8-inch thick-walled tube) was used to take continuous, disturbed samples with depth in a companion testing boring near each SPT boring. This was done to carefully log the structure of the alluvial soils. At the Tulsa site, two additional borings were made by pushing a 3-inch O.D. thin-walled sample tube taking samples at two foot intervals with depth, according to ASTM D 1587-83 specification.

In Situ Test: The in situ tests performed include the cone penetrometer test (CPT), standard penetration test (SPT), and the Menard pressuremeter test (PMT). Table V indicates at each site the total number of CPT soundings, SPT borings, and test borings for PMT. Plan layouts indicating the location of all field sampling and in situ

TABLE V

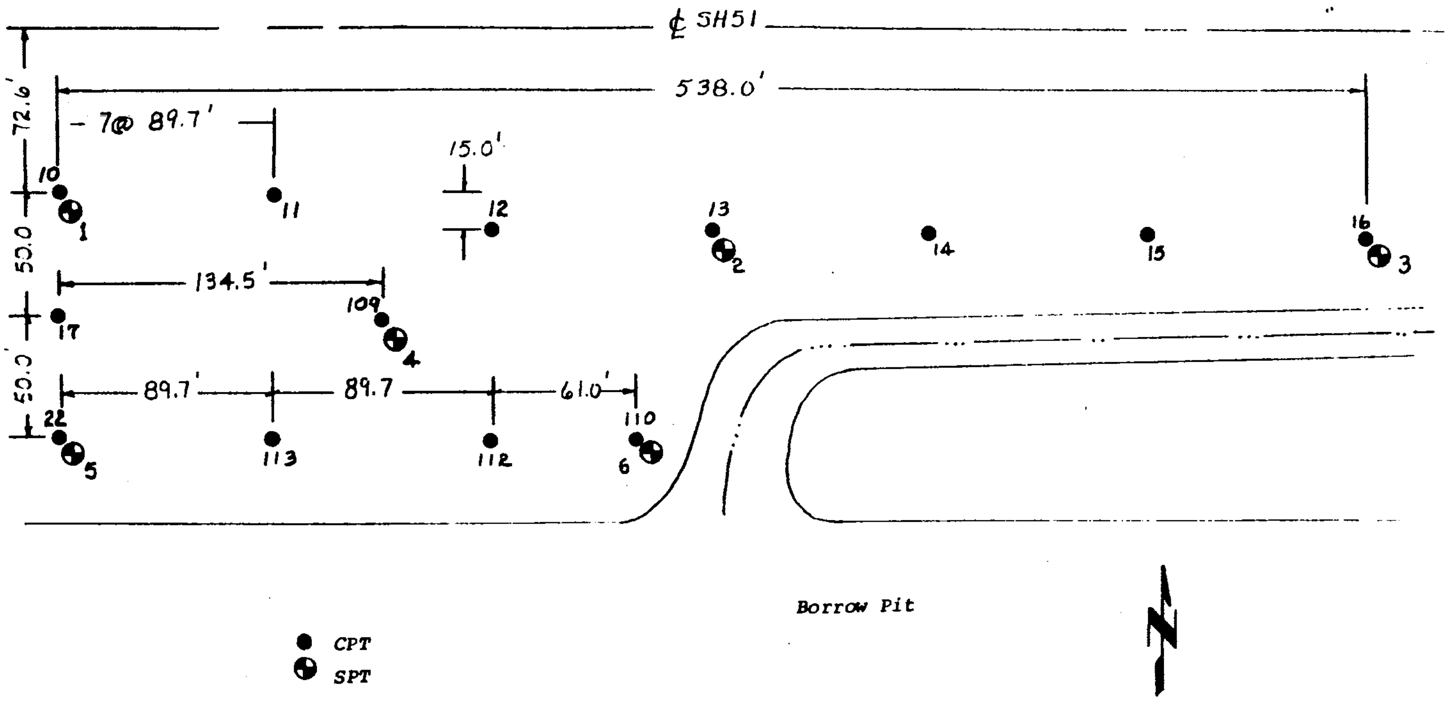
NUMBER OF IN SITU TEST LOCATIONS

Test Site No.	Location	CPT (Mechanical)	CPT (Electrical)	SPT	PMT
1	Wagoner	14	3	6	4
2	Tulsa	2	1	2	2
3	Collinsville	2		2	
4	Bixby	1		1	
5	Roland	1		1	

tests for the Wagoner and Tulsa sites are presented in Figures 24, 25, and 26, respectively. The location of SPT borings and mechanical CPT soundings are noted on the boring logs.

The CPT soundings were made at all sites adjacent to completed test borings according to ASTM D 3441-86 test procedure. Additionally, three mechanical Dutch mantle and four electric cone soundings were made according to ASTM D 3441-86 test procedure at the Wagoner and Tulsa sites for comparison with the mechanical friction sleeve cone. The SPT "N" resistance values were as noted earlier conducted continuously according to ASTM D 1586-84 at all sites. The Menard pressuremeter test (PMT) was made at four borings at the Wagoner and Tulsa sites to measure the in situ undrained shear strength. The test was conducted at three-foot intervals in each boring according to ASTM D 4719-87. To insure as precise a measurement of undrained shear strength as possible, the borings were made with a hand auger.

Test for Engineering Properties: Atterberg Limits (LL, PL) were conducted according to ASTM D 4318-84 specification. All specimens were seasoned 24 hours before running tests. Particle size analysis of all samples was made according to ASTM D 422-63 (Reapproved 1972) specification. A measure of the consistency of these alluvial soils is represented by the liquidity index (42) and by correlation with the SPT "N" resistance values (see Table III). One-dimensional consolidation tests were conducted according to ASTM D 2435-80 specification to quantify the typical stress history of these alluvial clays. Correlation of the undrained shear strength based on laboratory tests with total cone resistance values from CPT soundings was made by undrained unconsolidated (UU) triaxial tests. Tests were performed on



Test site layout referenced to CPT Locations.

Mean Elevation 522.25 feet with maximum differential between SPT and CPT of 0.85 feet.

60 Scale

Figure 24. Plan Layout of SPT and CPT (Friction Sleeve) Locations at Wagoner Site.

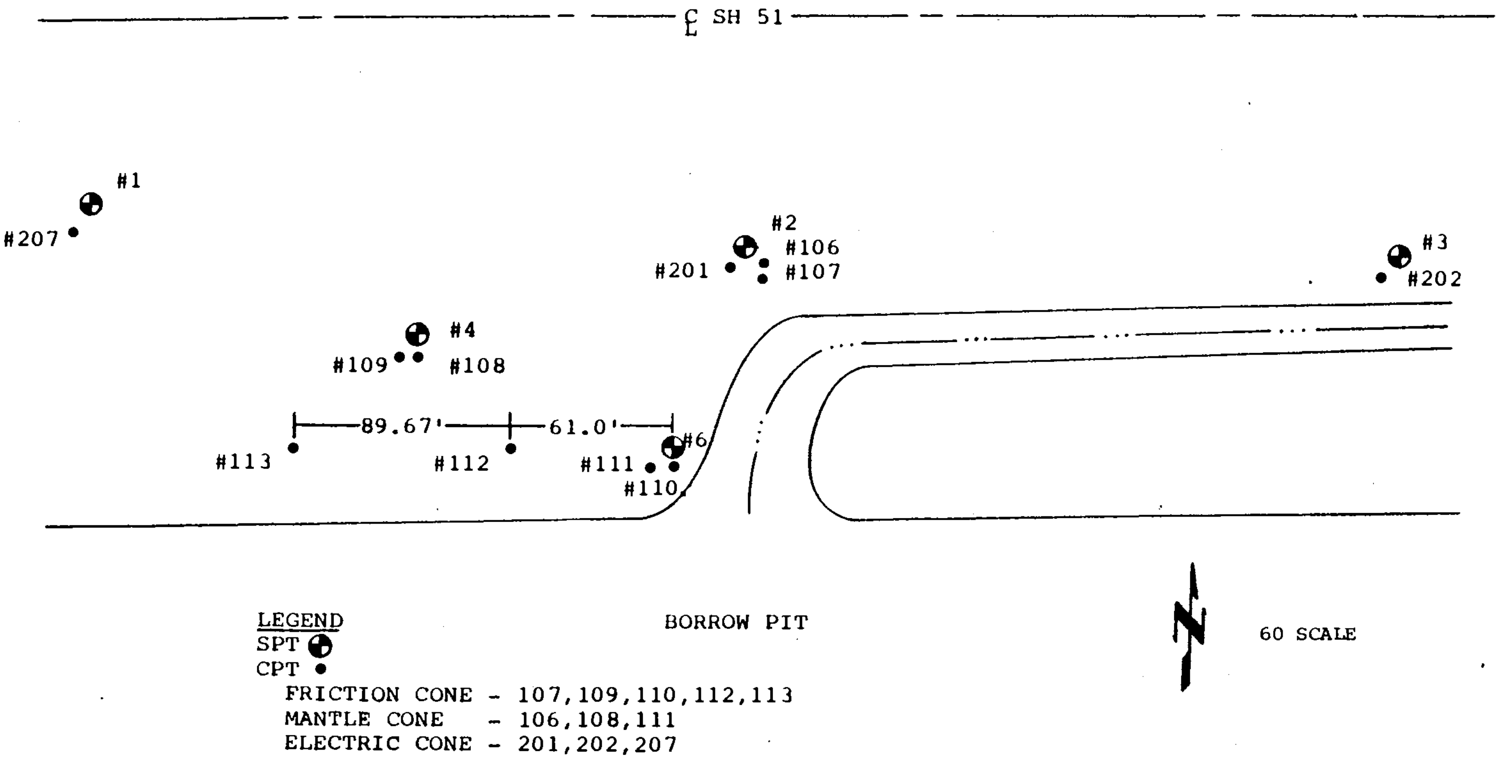


Figure 25. Plan Layout of CPT Locations Used for Cone Resistance Comparison and PMT Locations at Wagoner Site

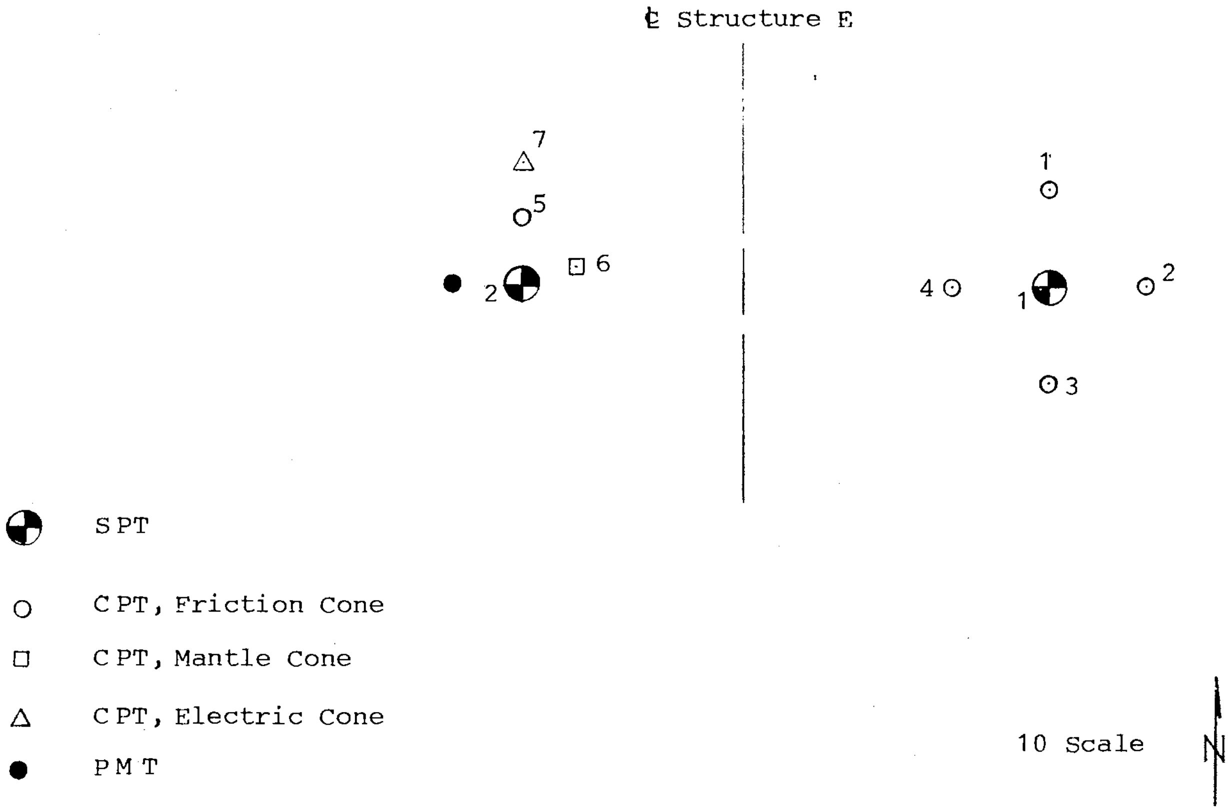


Figure 26. Plan Layout of SPT, CPT, and PMT Locations at Tulsa Site

1.4-inch diameter specimens according to ASTM D 2850-87 specification. Tests were also conducted on single 2.8-inch diameter specimens in a multi-stage loading (43).

Clay Structure Analysis: Detailed field and laboratory observations were made on all samples for structure according to ASTM D 2488-84. In addition, typical structural patterns were photographed with depth on partially air-dried samples.

CHAPTER IV

PRESENTATION OF RESULTS

Introduction

The results of the testing program are presented in this chapter. These results cover boring log and physical property data, in situ tests, tests for engineering properties, and clay structure documentation. The results present collective and site specific data.

Boring Logs and Physical Properties

Boring logs and physical property data for these alluvial soils are tabulated in Tables D1 through D12 (see Appendix D). Typical boring log and physical property data are shown graphically in Figures 27, 28, and 29.

In Situ Tests

The in situ tests performed at these sites were the Standard Penetration Test (SPT), mechanical and electric cone penetrometer tests (CPT), and the Menard pressuremeter test (PMT).

SPT: The SPT data are presented in Tables D1 through D12 (see Appendix D). The SPT "N" resistance value is tabulated in these tables at the end of the test depth.

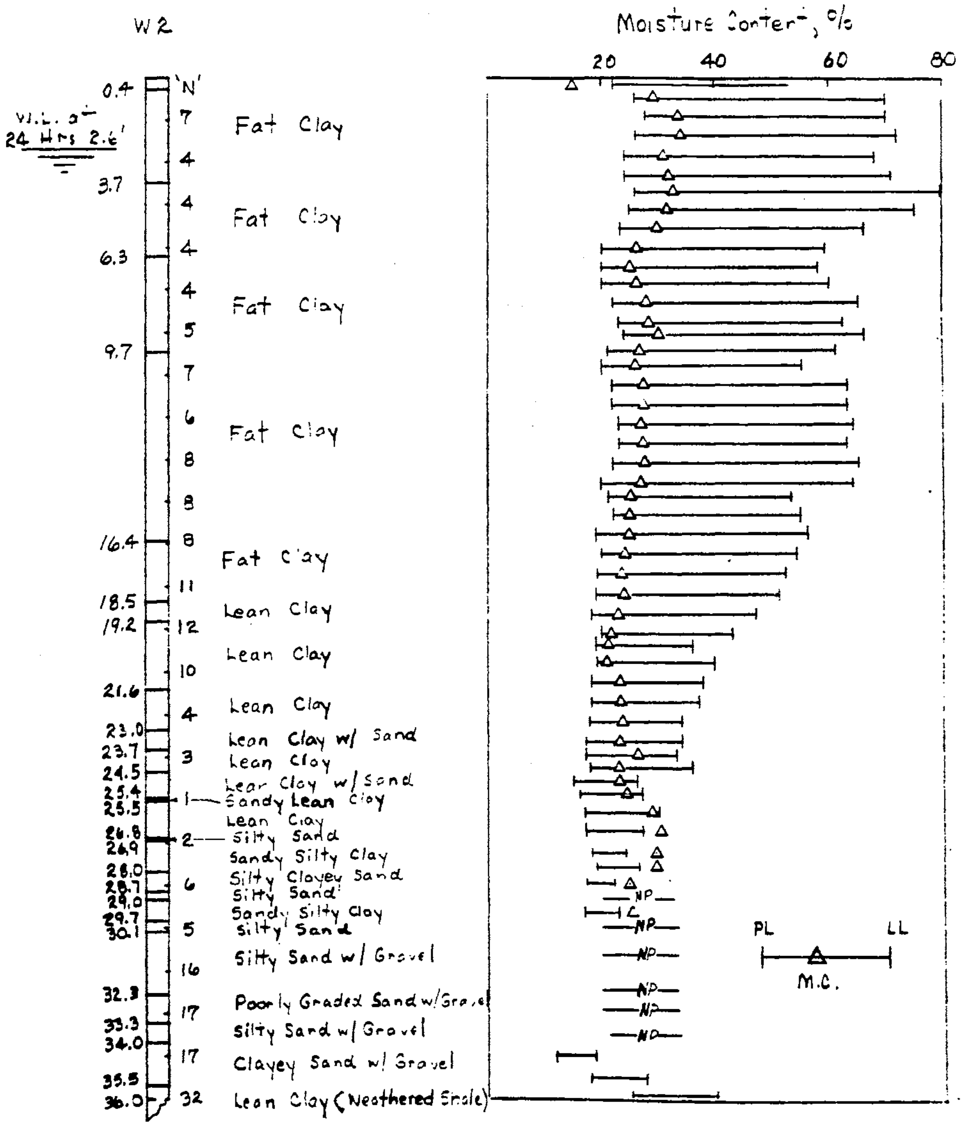


Figure 27. Boring W2 at Wagoner Site

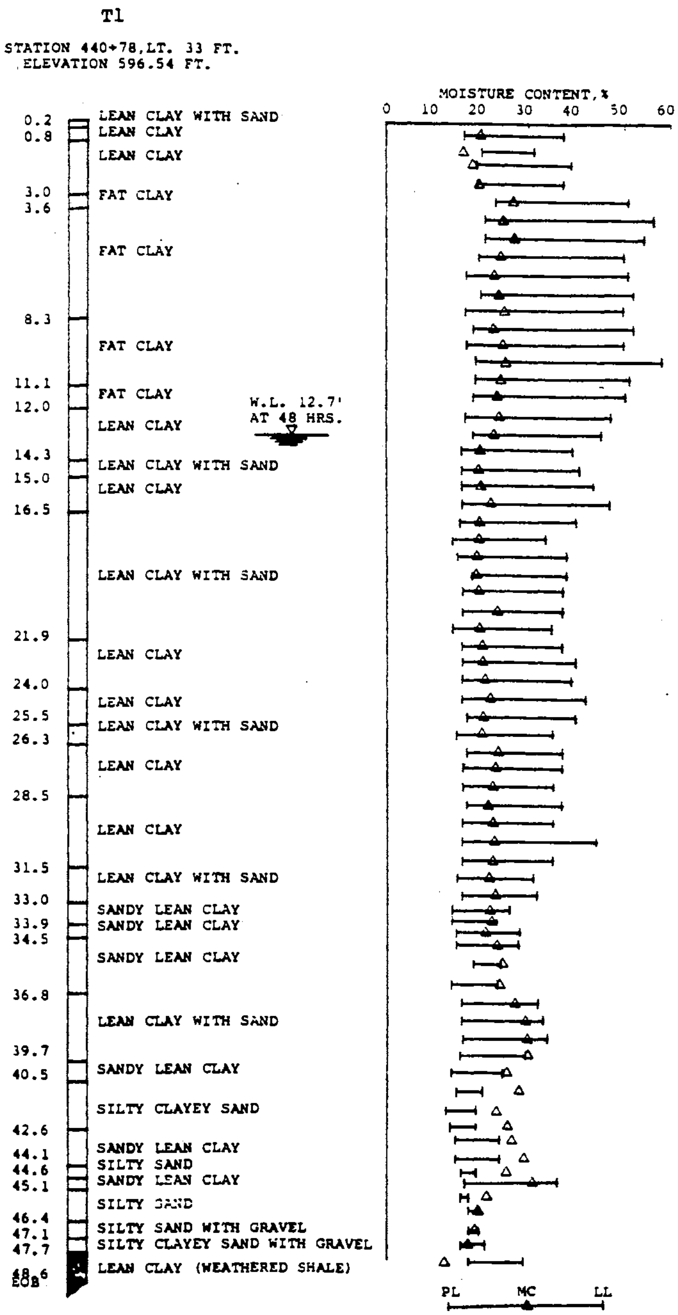


Figure 28. Boring T1 at Tulsa Site

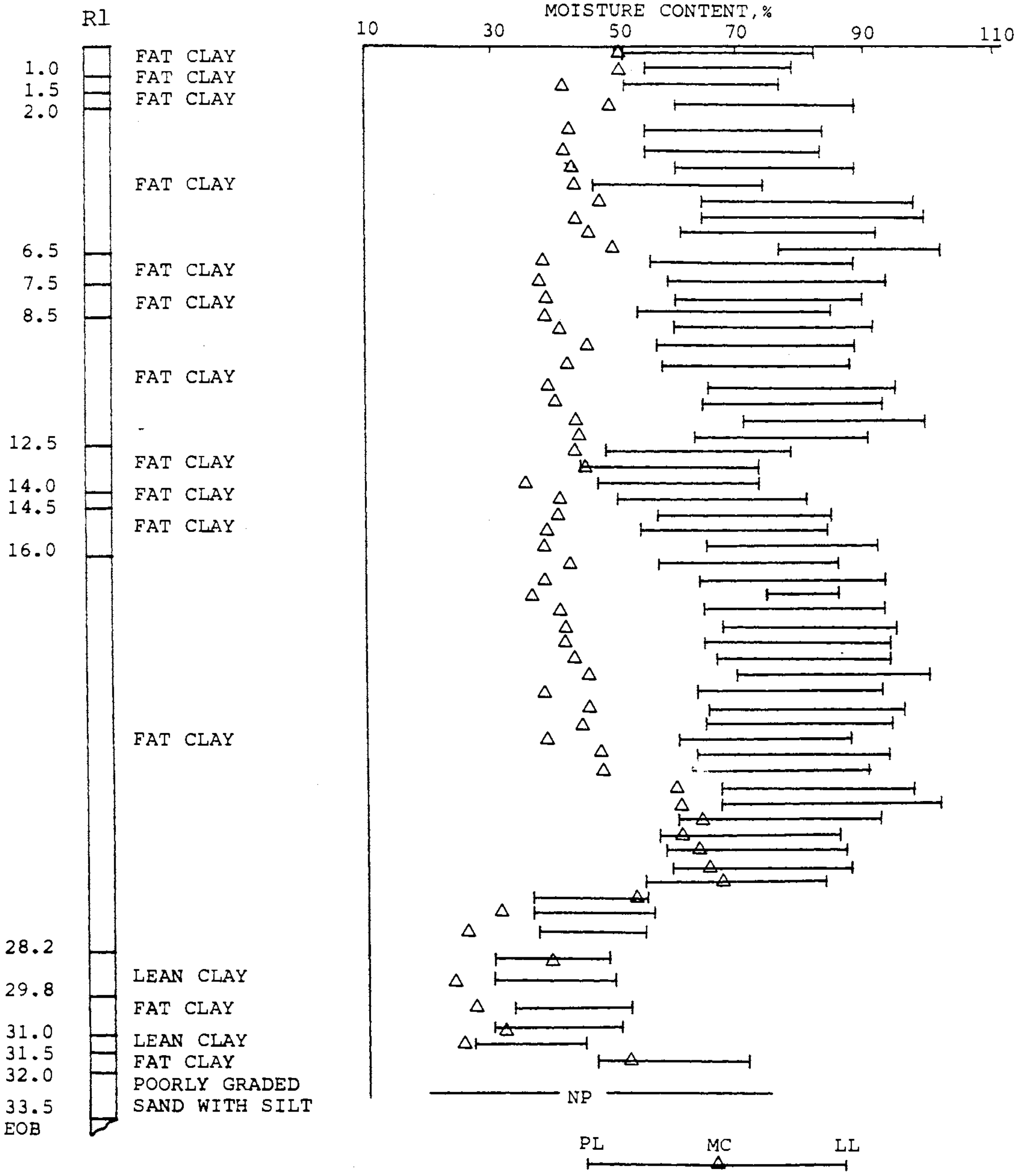


Figure 29. Boring R1 at Roland Site

CPT: The CPT data are tabulated in Tables E1 through E12 (see Appendix E). Typical graphical presentation of these data is presented for sounding W22 at the Wagoner site in Figures 30, 31, and 32.

PMT: Undrained shear strength based on PMT test data is given in Table VI. A typical graphical presentation of a typical PMT test parameter is shown in Figures 33a, b, and c.

Comparative Data: The variation in the SPT "N" resistance value for all SPT borings at the Wagoner site is given in a composite "N" versus depth profile in Figure 34. Variations in the cone resistance and local friction with depth at the Wagoner site is shown in Figures 35 and 36. Additional comparative cone data indicating the relative uniformity of the subsoil at the Wagoner site are presented in Tables F1 through F7 (see Appendix F). A comparison made between the cone resistance of the Dutch mantle and the friction sleeve mechanical cones for lean and fat clays at the Wagoner and Tulsa sites is presented in Tables G1 through G3 (see Appendix G). Typical graphical presentations of the cone resistance comparison are shown in Figures 37 and 38 for the Tulsa site. A comparison of the cone resistance between the friction sleeve mechanical cone and electrical cone for the Wagoner and Tulsa sites is given in Tables H1 through H4 (see Appendix H). Graphically, the electric cone data are shown in Figure 39 for W201 at the Wagoner site. A summary of these q_c ratios is presented in Tables VII and VIII, respectively.

The stress history, specifically the overconsolidation ratio (OCR) typical of these alluvial clays, is shown in Table IX with depth for boring, T1 at the Tulsa site (see also Figure 28). A typical consolidation test showing the calculation for the preconsolidation pres-

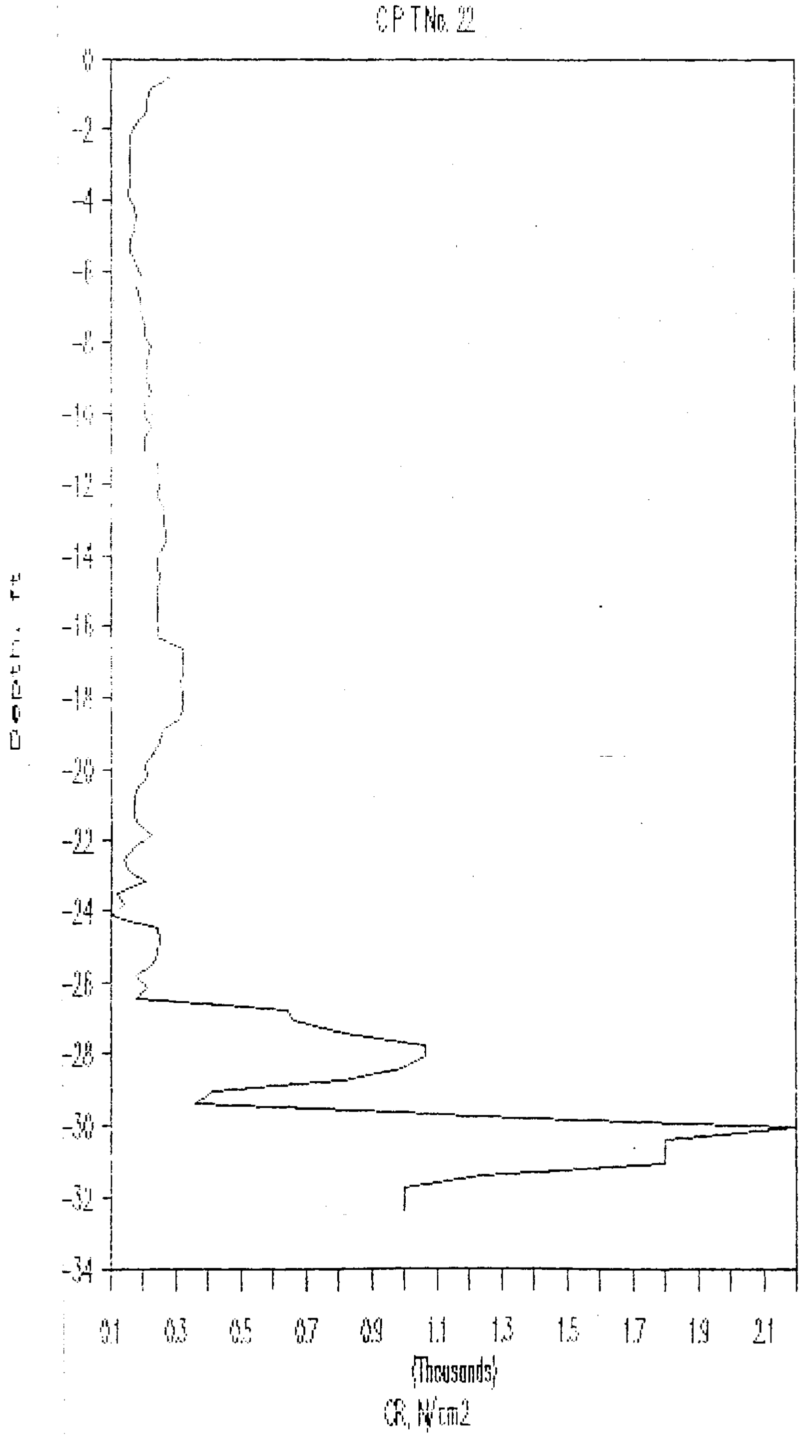


Figure 30. Cone Resistance (q_c) Versus Depth, W22 Wagoner Site

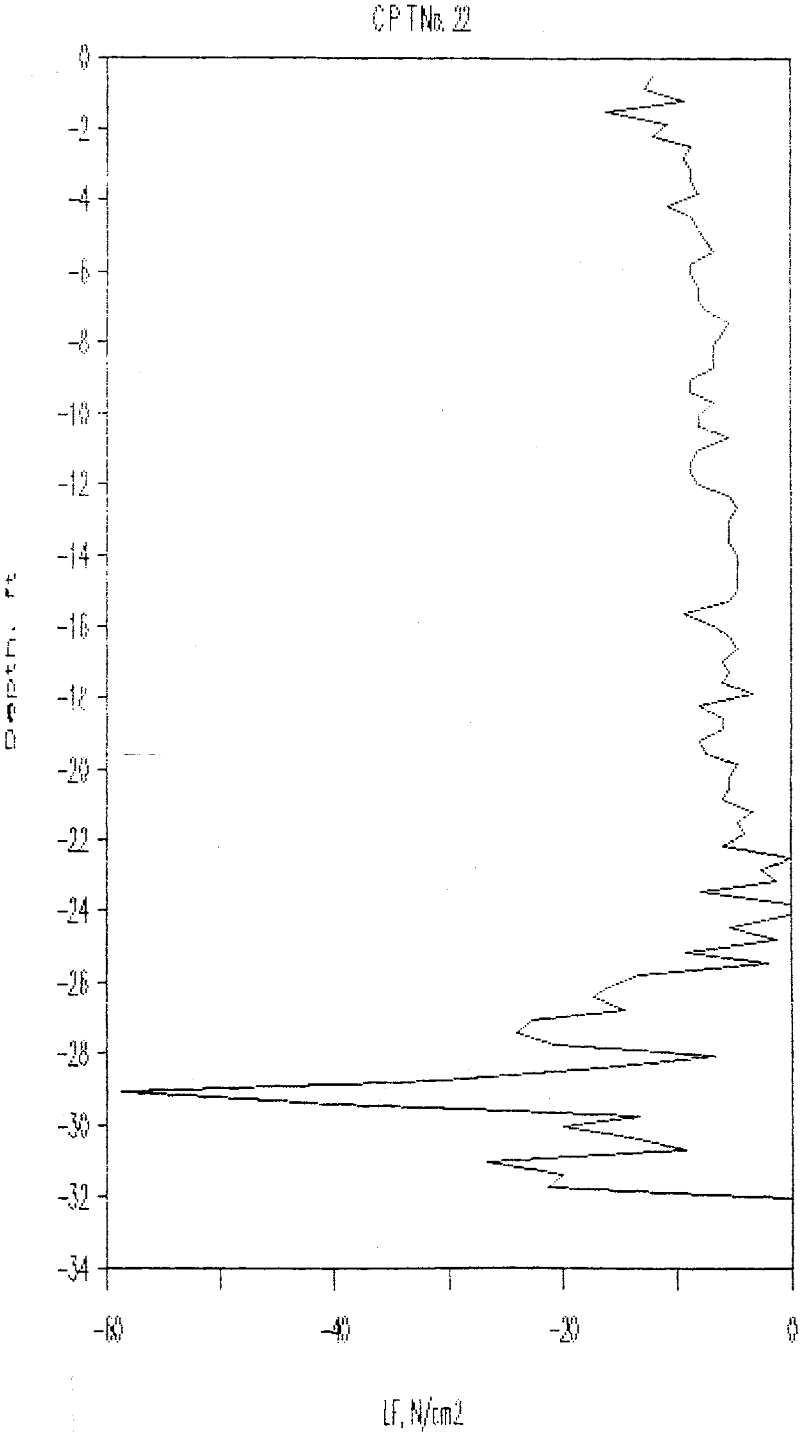


Figure 31. Local Friction (f_s), W22 Wagoner Site

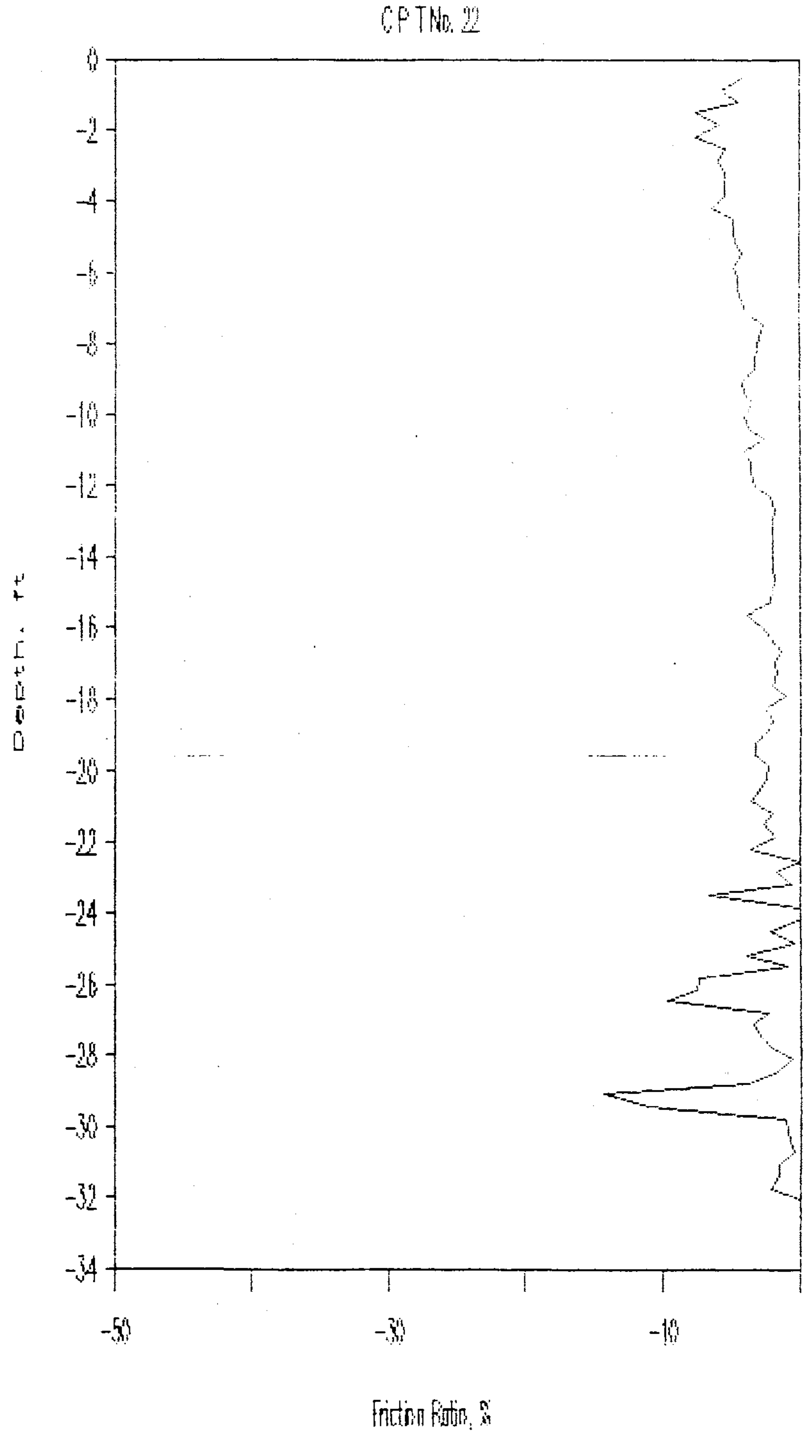


Figure 32. Friction Ratio (FR),
W22 Wagoner Site

TABLE VI

UNDRAINED SHEAR STRENGTH BASED ON PMT DATA FROM WAGONER AND TULSA SITES

Location	Sample No.	Depth (ft)	a_c (tsf)	P_L (tsf)	P_o (tsf)	S_u (1)	S_u (2)	$N_k{}^a$ (1)	$N_k{}^a$ (2)	$N_k{}^b$ (1)	$N_k{}^b$ (2)
Wagoner, SPT No. 1	1	2.1	36.0	3.33	0.20	0.50	0.77	71.8	46.6	72.0	46.8
Wagoner, SPT No. 1	2	5.1	27.2	3.75	0.20	0.57	1.16	47.4	23.3	47.7	23.4
Wagoner, SPT No. 1	3	8.1	20.9	4.05	0.33	0.60	1.00	34.3	20.6	34.8	20.9
Wagoner, SPT No. 2	1	2.1	11.0	2.40	0.33	0.33	0.68	33.0	16.0	33.3	16.2
Wagoner, SPT No. 2	2	5.0	14.6	3.25	0.30	0.48	0.90	30.0	16.0	30.4	16.2
Wagoner, SPT No. 2	3	8.0	17.8	4.15	0.28	0.62	1.24	28.2	14.1	28.5	14.3
Wagoner, SPT No. 2	4	11.0	20.4	5.13	0.43	0.76	1.64	26.3	12.2	26.7	12.4
Wagoner, SPT No. 2	5	13.8	20.4	5.50	0.78	0.76	1.83	26.2	10.9	26.7	11.1
Wagoner, SPT No. 2	6	16.7	21.4	5.88	0.79	0.82	1.58	25.4	13.2	26.1	13.5
Tulsa, SPT No. 1	1	3.7	18.8	4.30	0.60	0.60	1.23	31.0	15.1	31.3	15.2
Tulsa, SPT No. 2	2	6.8	17.8	5.01	0.80	0.68	1.28	25.6	13.6	26.2	13.9
Tulsa, SPT No. 3	3	9.8	24.0	7.16	1.10	0.98	1.59	23.9	14.7	24.5	15.1
							Averages	33.6	18.0	34.0	18.3

Notes: S_u (1)--Undrained shear strength based on PMT limiting pressure.

S_u (2)--Undrained shear strength based on Gibson and Anderson (44).

${}^aN_k$ (1)--Factor based on using S_u (1) in Equation (6).

(2)--Factor based on using S_u (2) in Equation (6).

${}^bN_k$ (1)--Factor based on using S_u (1) in Equation (7).

(2)--Factor based on using S_u (2) in Equation (7).

a) Limiting Pressure Method of Estimating S_u is based on P_o and P (Taken from plots of V-P and Inverse V-P).

b) Gibson and Anderson Method of Estimating S_u plots p-$\log_e$ $\Delta v/v$ from the Plastic Phase. S_u found as the slope of the line (7).

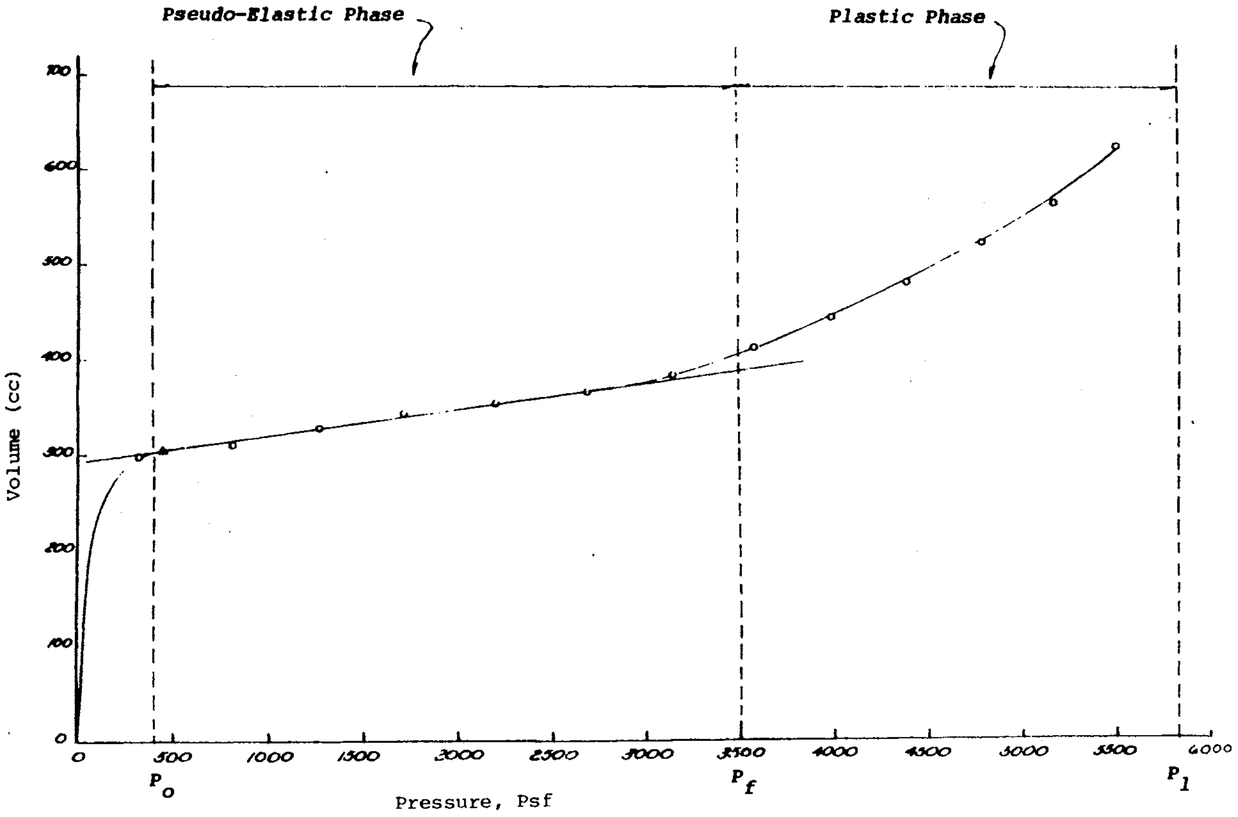


Figure 33. Volume Versus Pressure at Depth of 8.1 Feet Near SPT 1 at Wagoner Site.

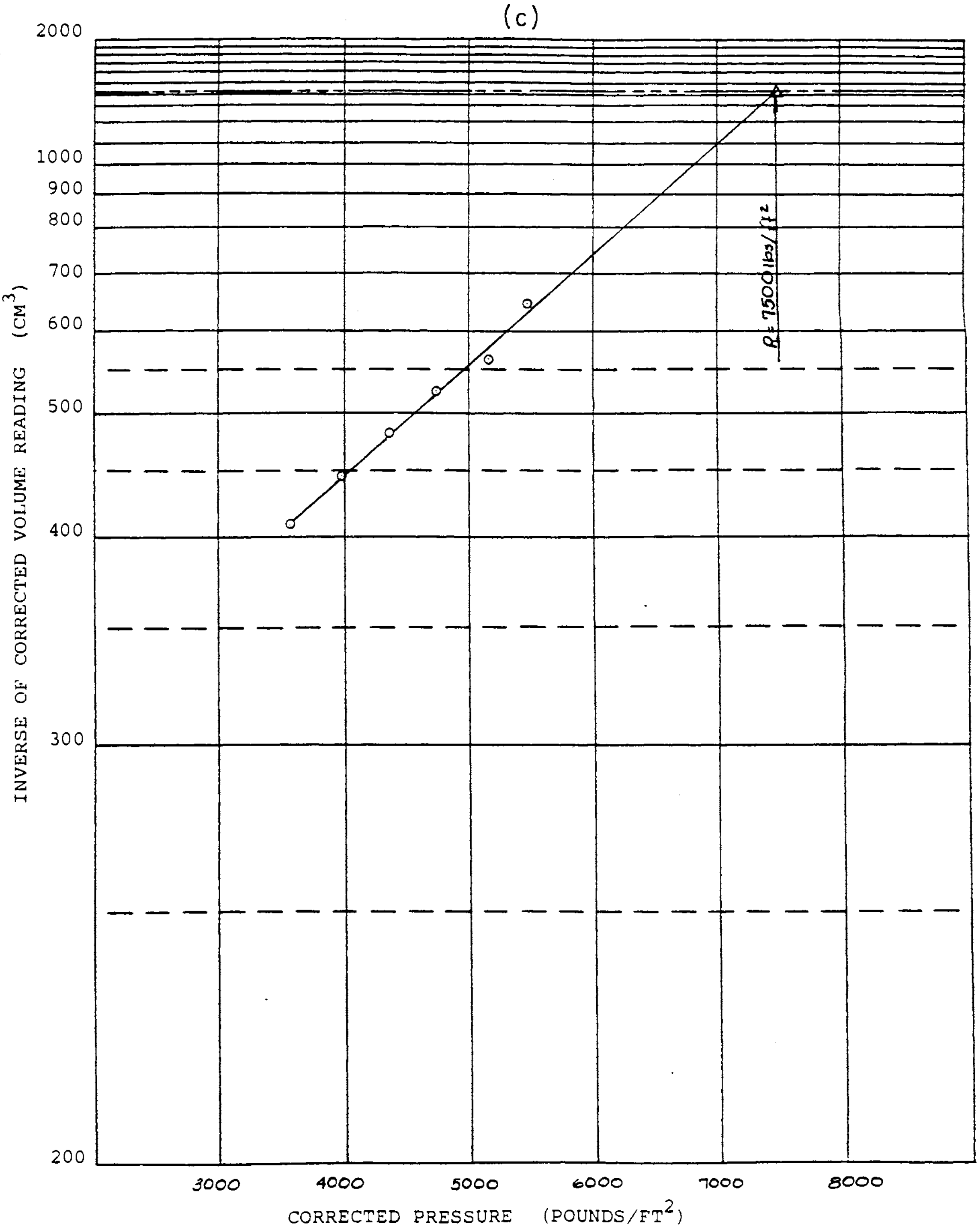


Figure 33. Continued

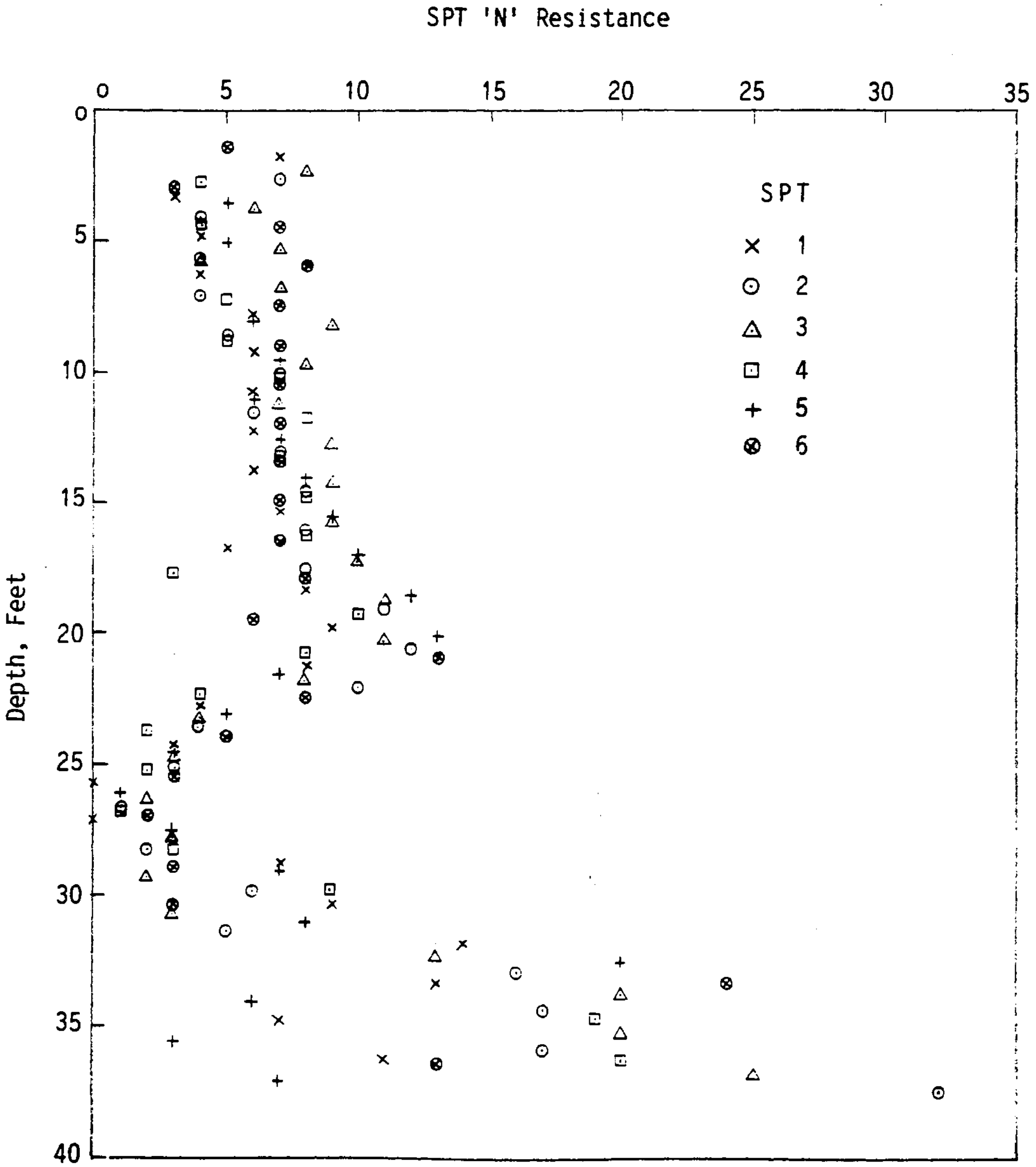


Figure 34. Composite SPT "N" Resistance Versus Depth, Wagoner Site

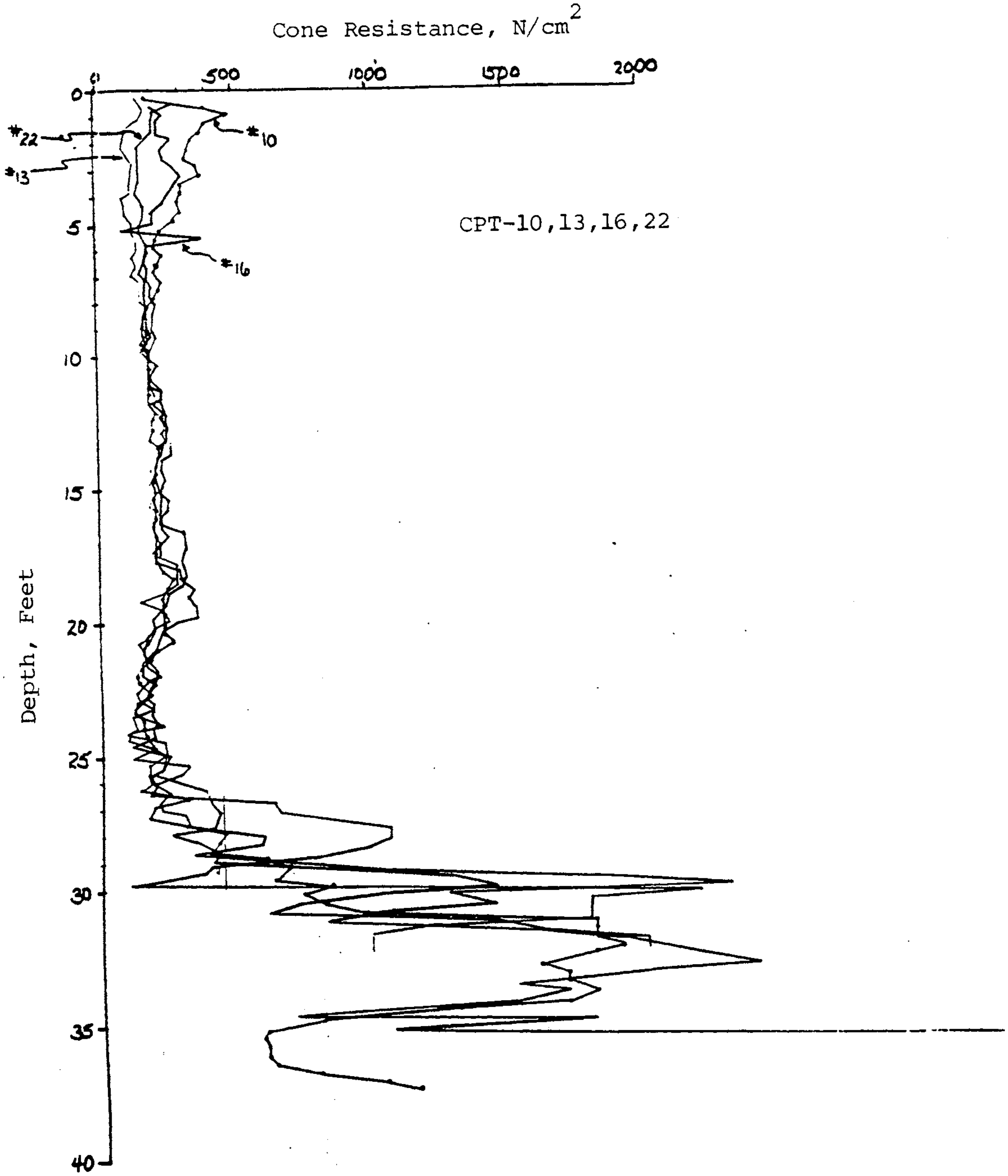


Figure 35. Variation of Cone Resistance With Depth at Wagoner Site

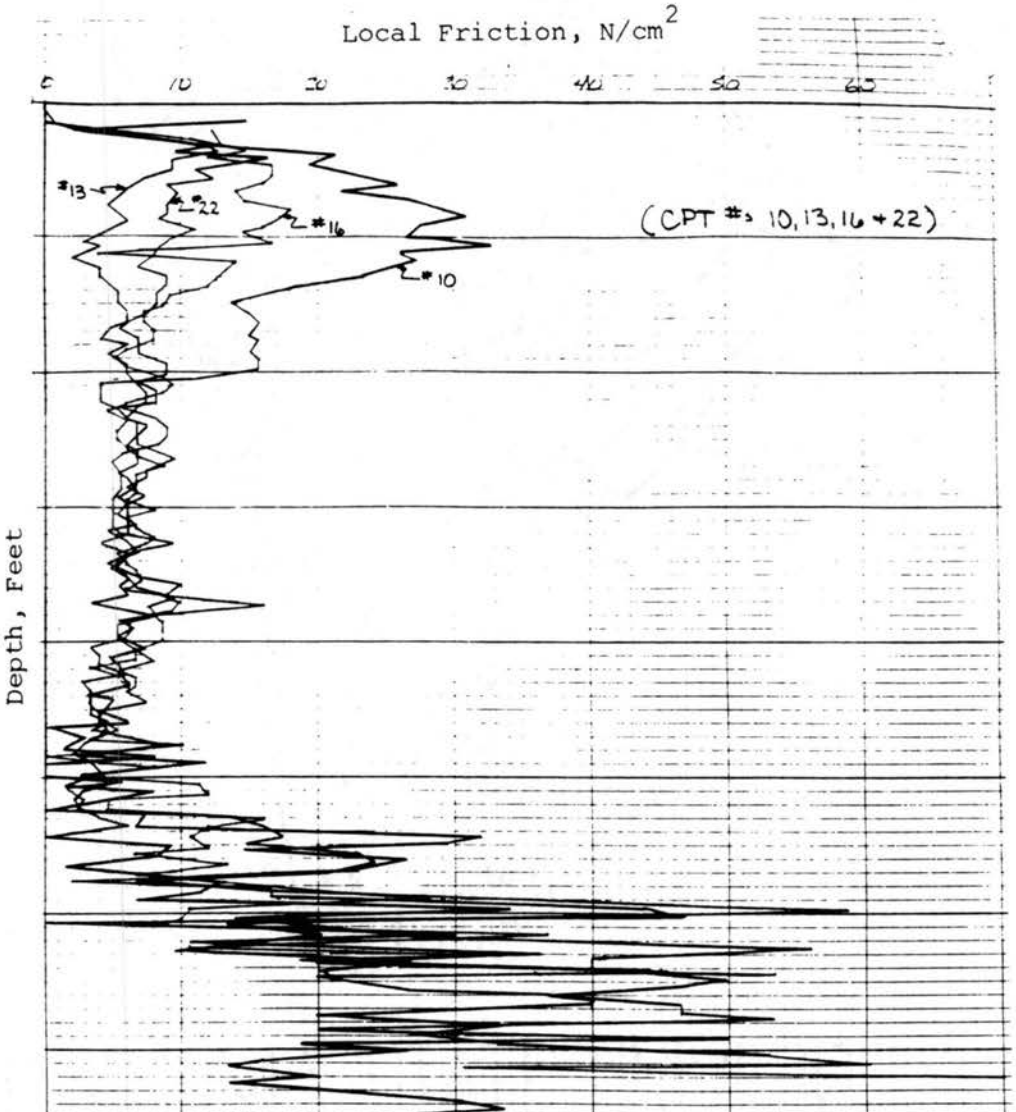


Figure 36. Variation of Local Friction With Depth at Wagoner Site

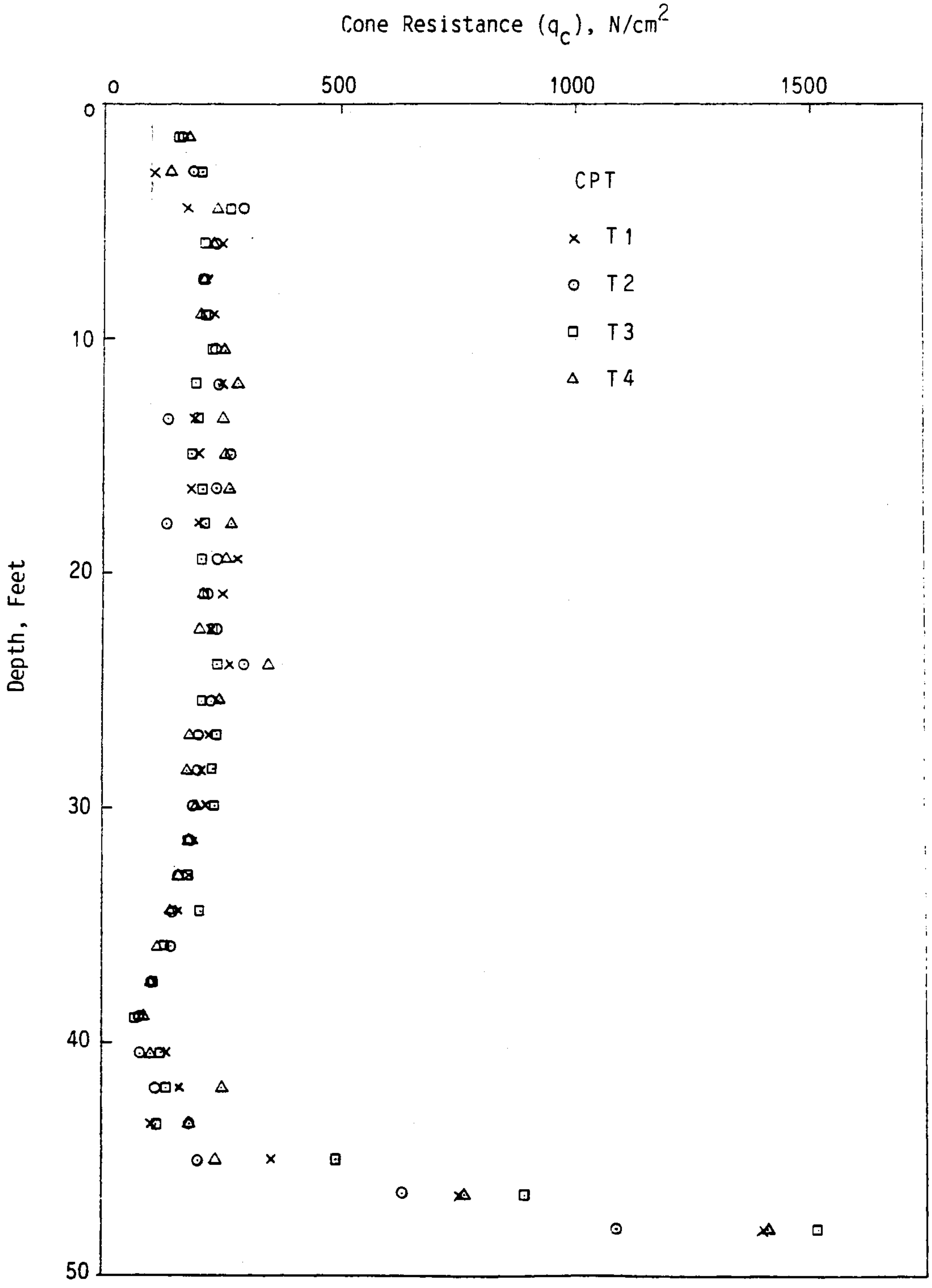


Figure 37. Cone Resistance Versus Depth, Tulsa Site

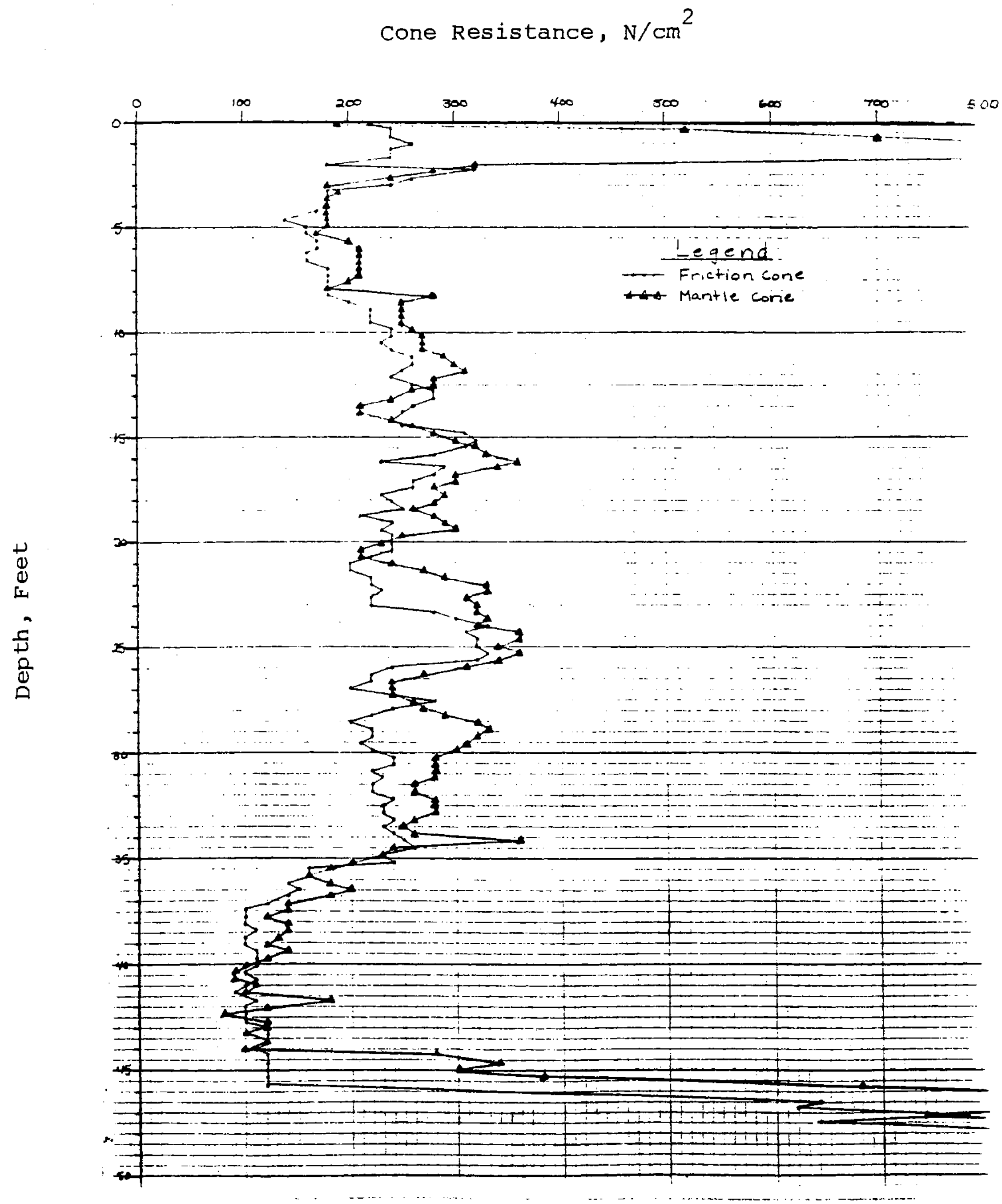


Figure 38. Comparison of Cone Resistance Between CPT 5 and 6 at Tulsa Site

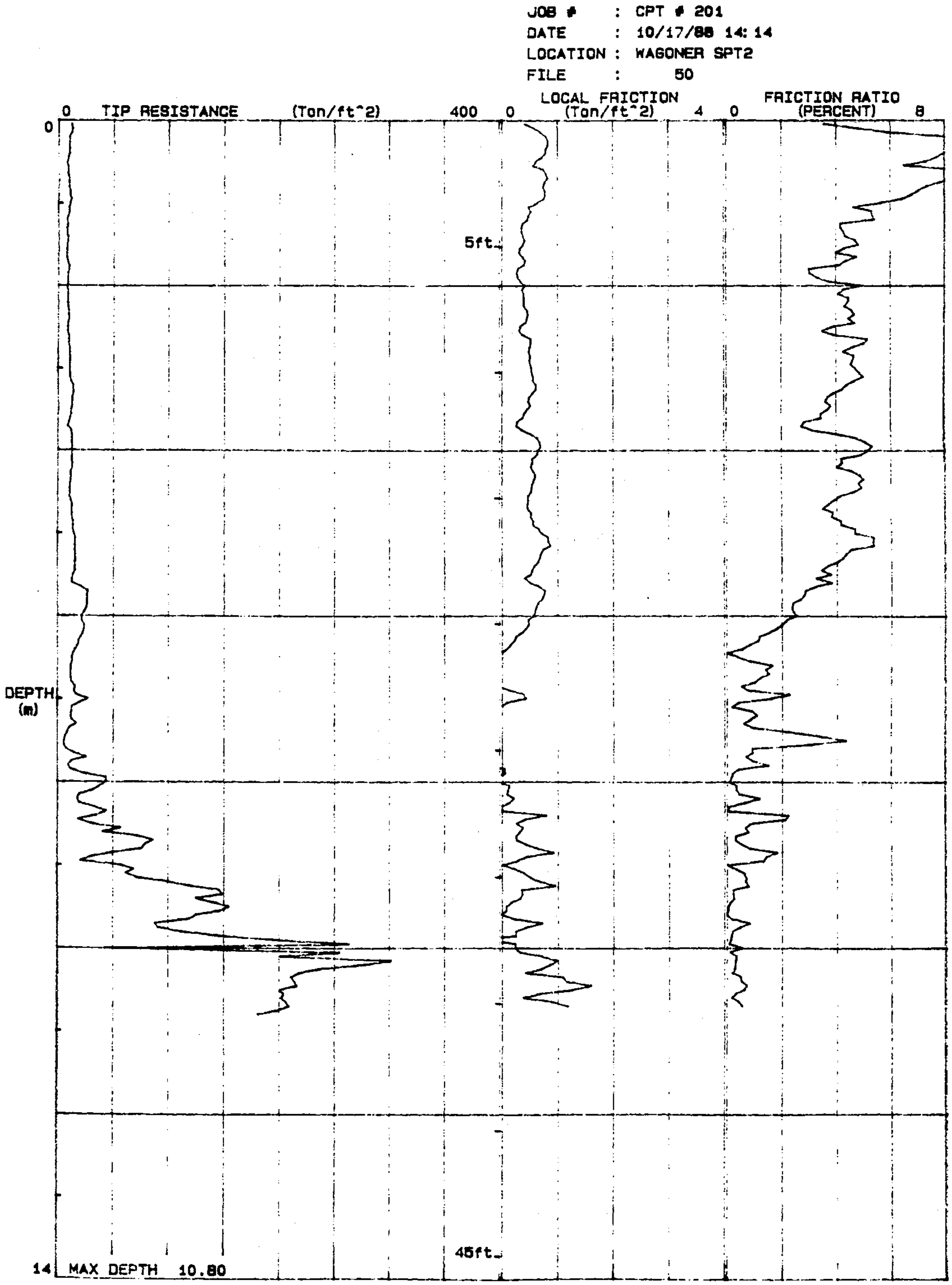


Figure 39. Electric Cone Data for W201

TABLE VII

SUMMARY FOR q_c MANTLE/q_c FRICTION

From Table	For CH Soils Range	Average	Std. Dev.	For CL Soils Range	Average	Std. Dev.
8-A	1.7222-0.8333	1.1535	0.2516	2.3000-0.8462	1.2510	0.4274
8-B	1.4000-0.8750	1.1194	1.1194	1.9000-0.8750	1.1189	0.3275
8-C	1.2400-0.7500	1.0862	0.1363	3.7692-0.8400	1.2473	0.5019
		1.1197			1.2057	

TABLE VIII

SUMMARY FOR q_c FRICTION/q_c ELECTRIC

From Table	For CH Soils			For CL Soils		
	Range	Average	Std. Dev.	Range	Average	Std. Dev.
8-D	3.7778-1.0952	1.9917	0.7059	2.3000-1.3000	1.6377	0.3189
8-E	2.4444-1.1000	1.5969	0.3241	2.2500-0.5926	1.2043	0.5013
8-F	3.1667-1.1111	1.4668	0.4621	1.6111-1.1250	1.3628	0.1845
8-G	1.7857-1.1250	1.3253	0.1961	2.3846-0.3059	1.2542	0.4402
		1.5959			1.3648	

TABLE IX

OVERCONSOLIDATION RATIO VERSUS DEPTH FOR BORING T1 AT TULSA SITE

Sample No.	Depth (ft)	γ_{wet} (pcf)	σ'_{vo}	σ'_p	OCR
2A	1.1	119.9	0.07	3.6	51.40
5A2	1.3		0.08	3.1	38.75
5C1	7.3		0.45	3.7	8.20
2B	9.3	125.1	0.58	3.9	6 72
5D3	13.2		0.80	2.9	3.62
2C	13.7	126.6	0.82	3.3	3.79
5E1	17.1		0.93	3.5	3.76
2E	21.2	128.8	1.06	3.6	3.40
2F	25.9	128.4	1.22	3.2	2.62
5G1	27.2		1.26	3.5	2.78
5H1	32.1		1.42	3.1	2.18
2H	35.6	126.1	1.53	3.4	2.22
5I3	37.7		1.60	2.9	1.81

sure, P'_0, is presented in Figure 40 for the Tulsa site. A summary of the unconsolidated undrained (UU) triaxial tests for the Wagoner and Roland sites is given in Table X. A typical UU triaxial test is presented in Figure 41.

The clay structure of test samples was documented in photographs shown in Figures 42 through 48. The samples were allowed to air dry and photographs show secondary structure development during the drying process. Also presented in Table XI is the detailed log description for the fat clay in boring W2 at the Wagoner site typical of these alluvial clays indicating the type and depth of secondary structure.

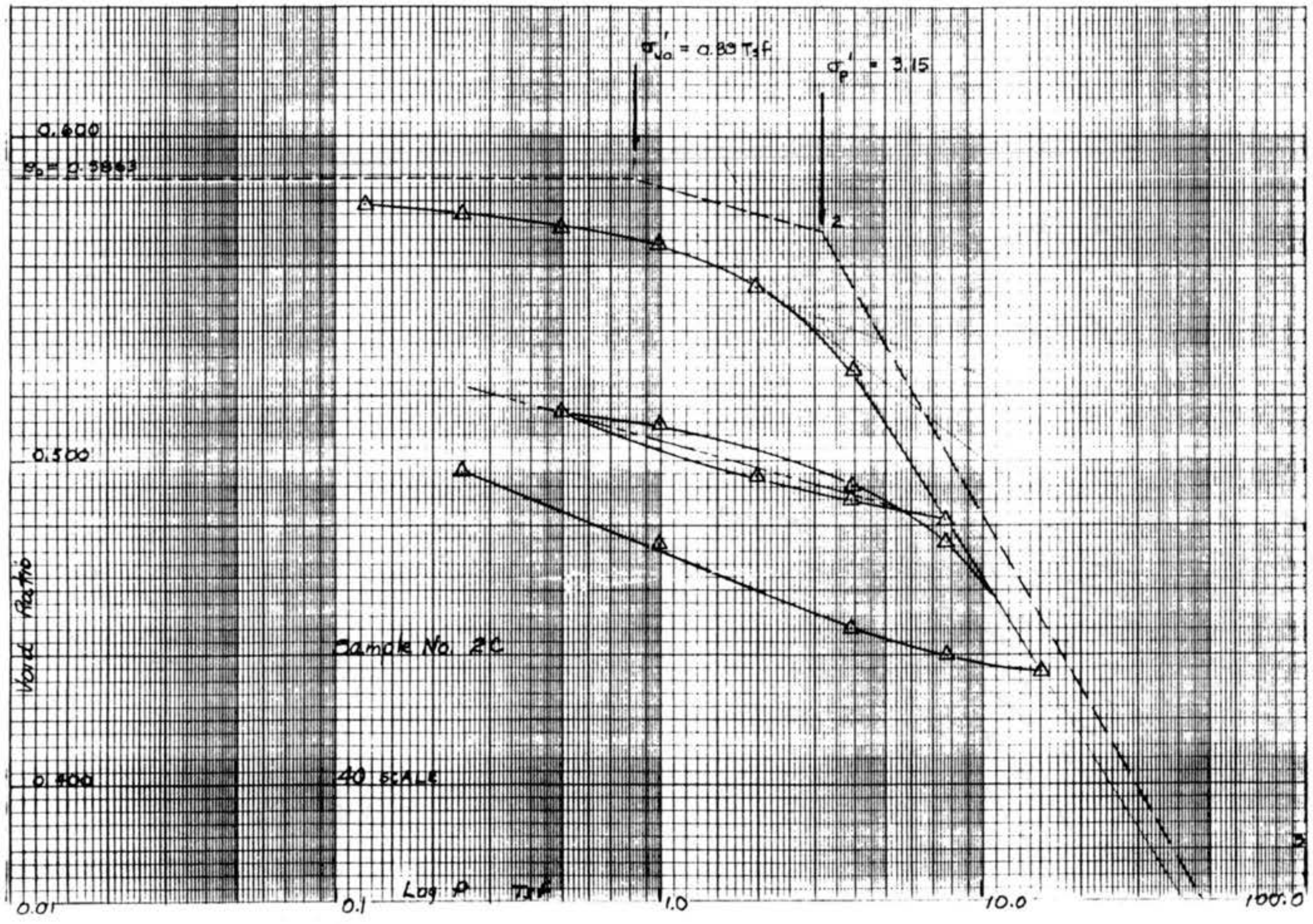


Figure 40. Consolidation Test, Tulsa Site.

TABLE X

SUMMARY OF UNCONSOLIDATED UNDRAINED (UU) TRIAXIAL TEST DATA

Location	Sample No.	Type of UU[a] Triaxial Test	Depth (ft)	Wet Unit Weight (pcf)	S_u (tsf)	q_c (tsf)	N_k[b]	
							(1)	(2)
Wagoner	308	MS (2.8 in.)	2.0	113.5	0.82	18.8	22.9	22.8
"	309	MS "	2.8	115.7	1.40	20.9	14.9	14.8
"	341	MS "	4.0	116.6	0.28	25.1	89.6	88.8
"	342	MS "	6.0	122.1	0.41	16.7	40.7	39.9
"	314	MS "	6.8	121.9	0.52	15.7	30.2	29.4
"	315	MS "	7.6	118.9	0.28	15.7	56.1	54.5
"	317	MS "	8.8	125.9	0.38	16.7	43.9	42.6
"	320	MS "	10.8	125.3	0.64	18.8	29.4	28.4
"	321	MS "	11.6	124.7	0.63	18.3	29.0	27.9
					Average N_k		39.6	38.8
Wagoner	323	ASTM (1.4 in.)	12.8	123.6	0.28	21.4	76.4	73.7
"	324	ASTM "	13.6	124.4	0.42	19.8	47.1	45.2
"	326	ASTM "	14.8	125.6	0.34	21.4	62.9	60.3
Roland	1E	ASTM "	25.2	122.6	0.20	25.1	125.5	117.8
"	1EEE	ASTM "	26.5	137.3	0.33	20.4	61.8	56.6
"	1F	ASTM "	30.7	130.3	0.20	6.3	31.5	21.5
"	1C	ASTM "	15.8	105.6	0.26	18.8	72.3	69.1
					Average N_k		68.2	63.5

[a] MS--Multi-stage UU triaxial (43); ASTM--ASTM D2850-87.

[b] (1) $N_k = \frac{q_c}{S_u}$; (2) $N_k = \frac{q_c - \frac{\gamma h}{2000}}{S_u}$.

Sample No. 341, Reference Table 10

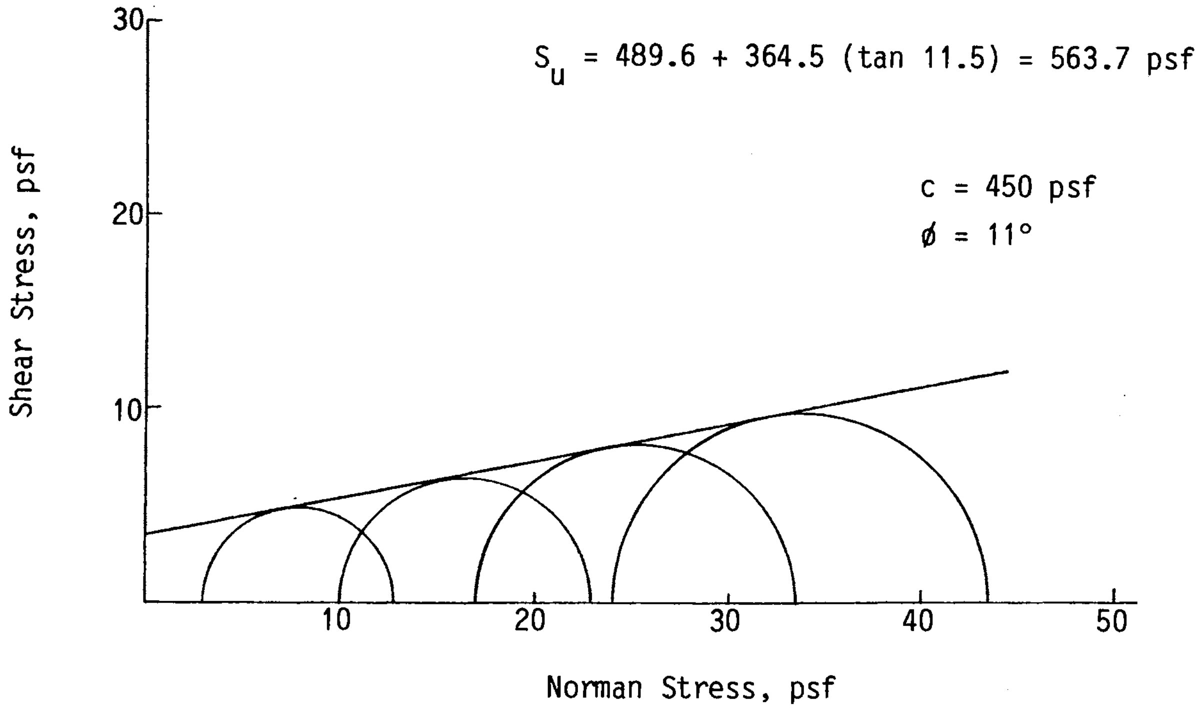


Figure 41. UU Triaxial Test Data

Figure 42. Secondary Clay Structure, Fissures, Sample 8A at Boring W4, Wagoner Site

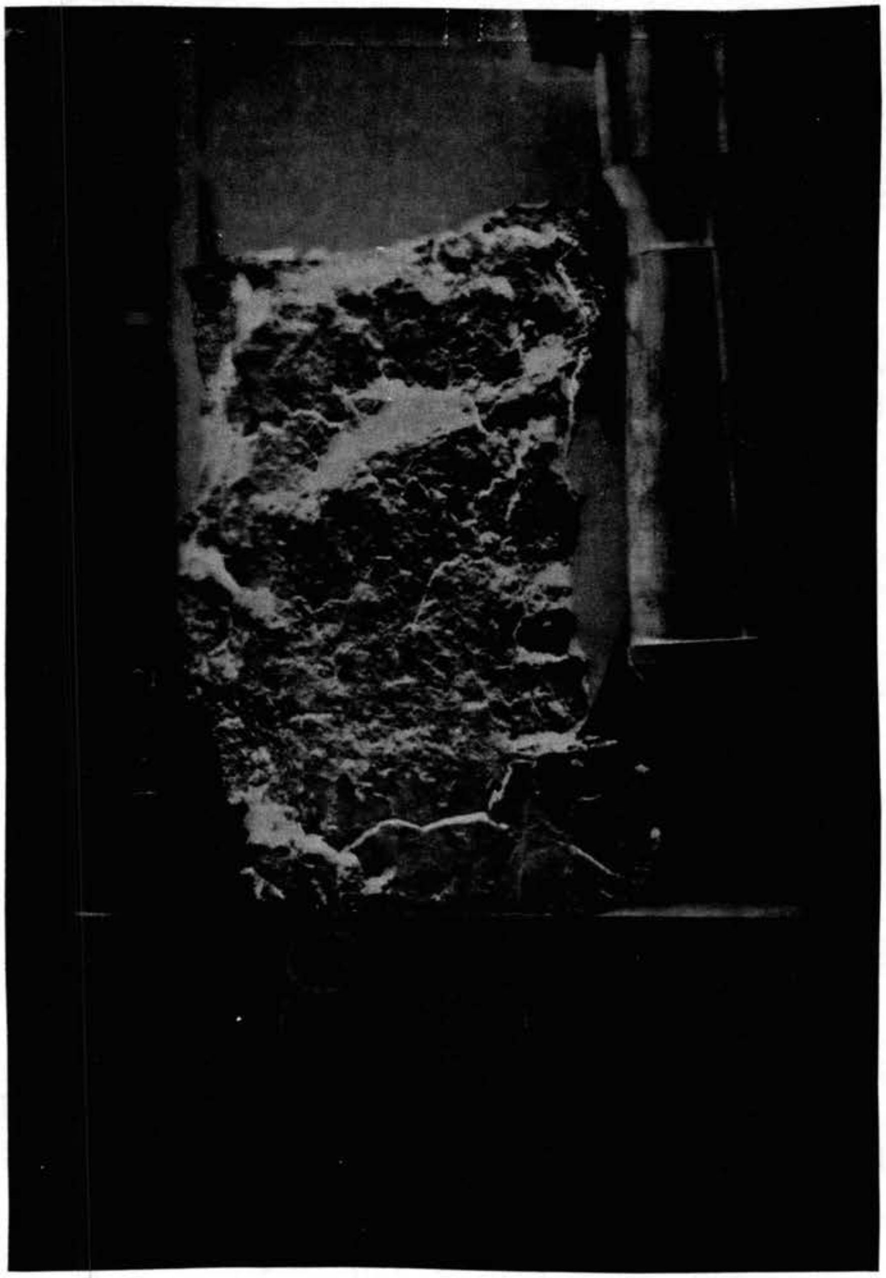


Figure 43. Secondary Clay Structure, Fissures, Sample 8B at Boring W4, Wagoner Site

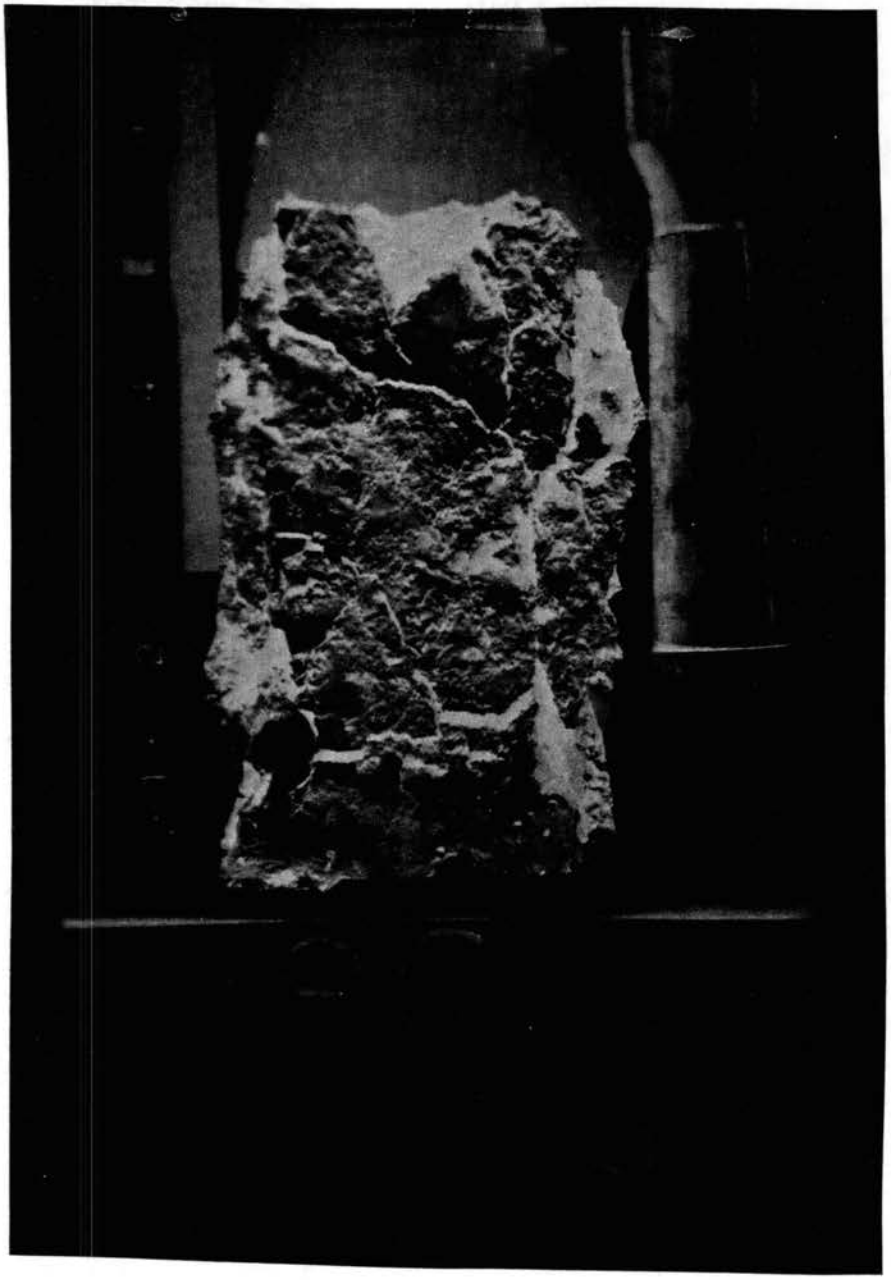


Figure 44. Secondary Clay Structure, Fissures and Slickenside, Sample 8C at Boring W4, Wagoner Site

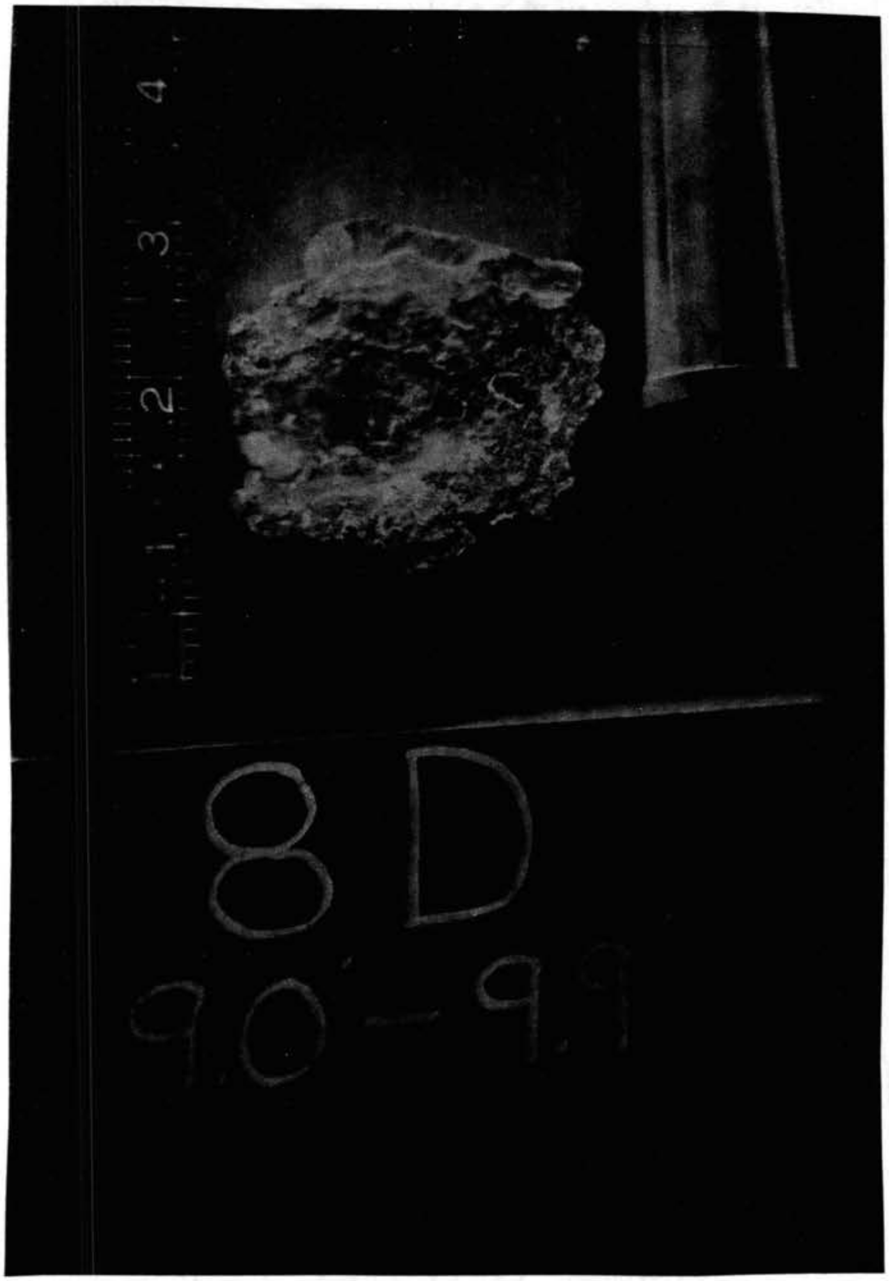


Figure 45. Secondary Clay Structure, Slickenside, Sample 8D at Boring W4, Wagoner Site

Figure 46. Secondary Clay Structure, Fissures, Sample 8E at Boring W4, Wagoner Site

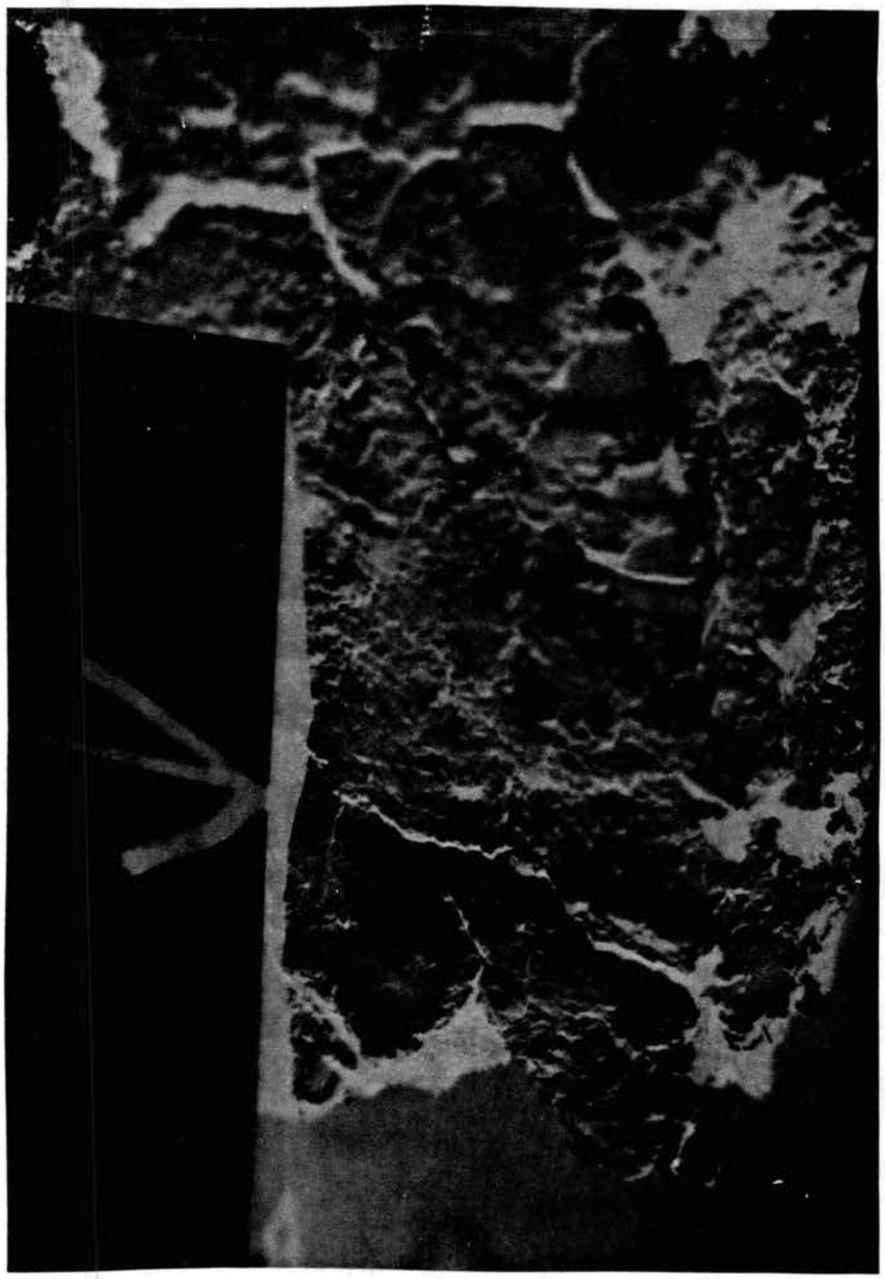


Figure 47. Secondary Clay Structure, Slickenside, Sample Depth 13-15 Feet at Boring W4, Wagoner Site

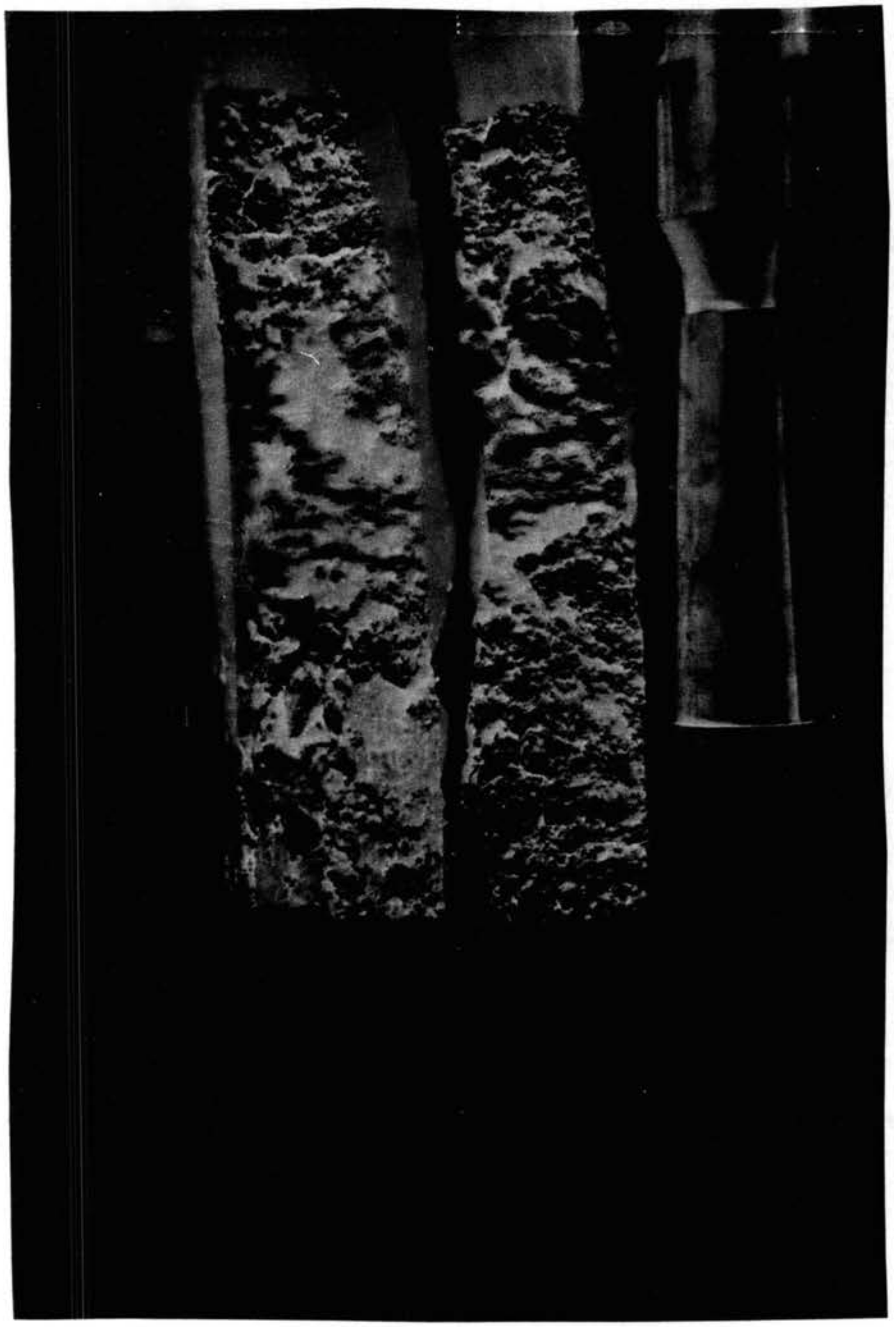


Figure 48. Secondary Clay Structure, Blocky, Sample 8H at Boring W4, Wagoner Site

TABLE XI

DETAILED BORING LOG DESCRIPTION (ASTM D 2488-84) FOR W2, WAGONER SITE

Depth (ft)	Description
0.0-3.7	**Fat Clay**, very dark gray (10YR3/1) mottled with dark yellowish brown (10YR3/6) maximum particle size 3/8 inch subrounded chert gravel, trace of gravel, approximately 3% in the top 0.0-0.4 feet, approximately 2% sand predominately fine, 98% highly plastic fines, dry to moist, medium stiff to soft, blocky with black (10YR2/1) iron concretions and roots, no HCL reaction, alluvial clay (CH).
3.7-6.3	**Fat Clay**, mottled very dark gray (10YR3/1), very dark grayish brown (10YR3/2) and with few specks dark yellowish brown (10YR3/6), maximum particle size, coarse sand size, approximately 2% sand predominately fine, 98% highly plastic fines, moist with wet joints, soft, blocky with black (10YR2/1) iron concretions and roots, no HCL reaction, alluvial clay (CH).
6.3-9.7	**Fat Clay**, mottled dark gray (10YR4/1), dark grayish brown (10YR4/2), and dark yellowish brown (10YR3/6), maximum particle size 3/8 inch subrounded chert gravel, trace of gravel, approximately 2% at 7.5-8.2 and 8.9-9.2 feet, approximately 5% sand, 95% highly plastic fines, moist with wet joints, soft to medium stiff, blocky with few black (10YR2/1) iron and pale brown (10YR6/3) calcium carbonate concretions and some decayed roots and slickensides, no HCL reaction in clay matrix, strong reaction in calcium carbonate concretions, alluvial clay (CH).
9.7-16.4	**Fat Clay**, mottled dark gray (10YR4/1) brown (10YR4/3) and dark yellowish brown (10YR4/6), maximum particle size, coarse size, approximately 2% sand predominately fine size, 98% highly plastic fines, moist with wet joints, medium stiff, blocky with slickensides, with few black (10YR2/1) iron and soft pale brown (10YR6/3) calcium carbonate concretions, no HCL reaction in clay matrix, strong reaction in clay matrix, strong reaction in calcium carbonate concretions, alluvial clay (CH).
16.8-17.8	**Fat Clay**, mottled gray (10YR5/4) dark gray (10YR4/1) and brown (10YR4/3) same as in 9.7-16.4 feet. Note: Colors into the clay below.
17.8-18.5	**Fat Clay**, mottled light gray (5YR6/1), brown (10YR5/3) and dark yellowish brown (10YR4/6) same as in 9.7-16.4 feet.

CHAPTER V

ANALYSIS AND DISCUSSION OF RESULTS

Introduction

The purpose of this research was to add to the knowledge concerned with interpretation of the mechanical cone penetration test data by studying potential correlations with the basic cone parameters, cone resistance (q_c) and local friction (f_s), and engineering parameters of northeastern Oklahoma alluvial soils. The alluvial soil sites chosen were representative of soils that have experienced stability and settlement problems due to highway embankment loads. The selection of the mechanical cone for use in this research study as opposed to other more advanced cone types was due to the simplicity of equipment and operation. In addition, it is felt that Oklahoma alluvial soil types preclude the use of more sophisticated cones such as the piezocone.

The major emphasis was placed on the evaluation of cone parameters of the clay soils found at these sites. There is limited inference to other soil types due to the small number of sampling sites. The correlations and analysis include the following:

1. Soil classification using the CPT
    a. A comparison between coarse and fine grain soils.

   - b. Applicability of the Begemann, Schmertmann, and Searle classification schemes.
   - c. A comparison of cone resistance, local friction, and friction ratio for the lean and fat clays studied.
2. Correlation of CPT with Atterberg limits and clay consistency.
3. Comparison of the friction sleeve cone, Dutch mantle cone, and electric cone.
4. Correlation between the SPT "N" value and CPT "q_c" value for lean and fat clays in the study area.
5. Correlation of the CPT cone factor N_k and undrained shear strength, s_u.
   - a. Analysis using small diameter UU triaxial data and large diameter multi-stage triaxial data.
   - b. Analysis using pressuremeter test data (PMT).
   - c. Analysis using backcalculated undrained shear strength from embankment slope failures.

The analysis of the data for these correlations was based on comparing all cone resistance and local friction values for each soil type as logged in the companion test borings and averaged cone resistance and local friction within a test or sample length. For the case of q_c/N ratio comparison, the cone resistance values were averaged over the length of the SPT test. Also in the shear strength-cone resistance analysis, the cone resistance was averaged over the laboratory test sample length or length of the PMT test probe.

Appendix F presents the cone data as compiled in the field and shows the adjustments made to correlate cone resistance and local friction at the same depth interval. Analysis and graphical presentation of all data were accomplished by an IBM main frame computer through a statistically oriented program language called SAS and SAS graph.

Soil Classification With CPT

A comparison between coarse and fine grained soils for this study is presented in Figures 49, 50, 51, and 52. Figure 49 presents cone resistance in descending order for Unified Soil Classification System soil types. This confirms material presented in the literature, that in general, coarse grained soils have substantially higher cone resistances than fine grained soils. Lower friction ratios for coarse grained soils as compared to fine grained soils are also reported in the literature. Figure 52 indicates this general trend for the soils in this research study.

The Begemann, Schmertmann, and Searle CPT soil classification schemes were applied to all test borings and corresponding mechanical cone soundings (reference Appendices D and E, respectively). Poor agreement was found in all cases in the direct application of both the Begemann and Schmertmann soil classification schemes. For example, note the contrasts in Table XII for the Begemann classification scheme as compared to actual logged data. The Searle classification scheme, however, appears somewhat more consistent as compared to actual logged boring descriptions (see Table XIII). The Searle classification method does delineate between coarse grained and fine grained soils around a friction ratio of 2.4 (see Figures 53 and 54).

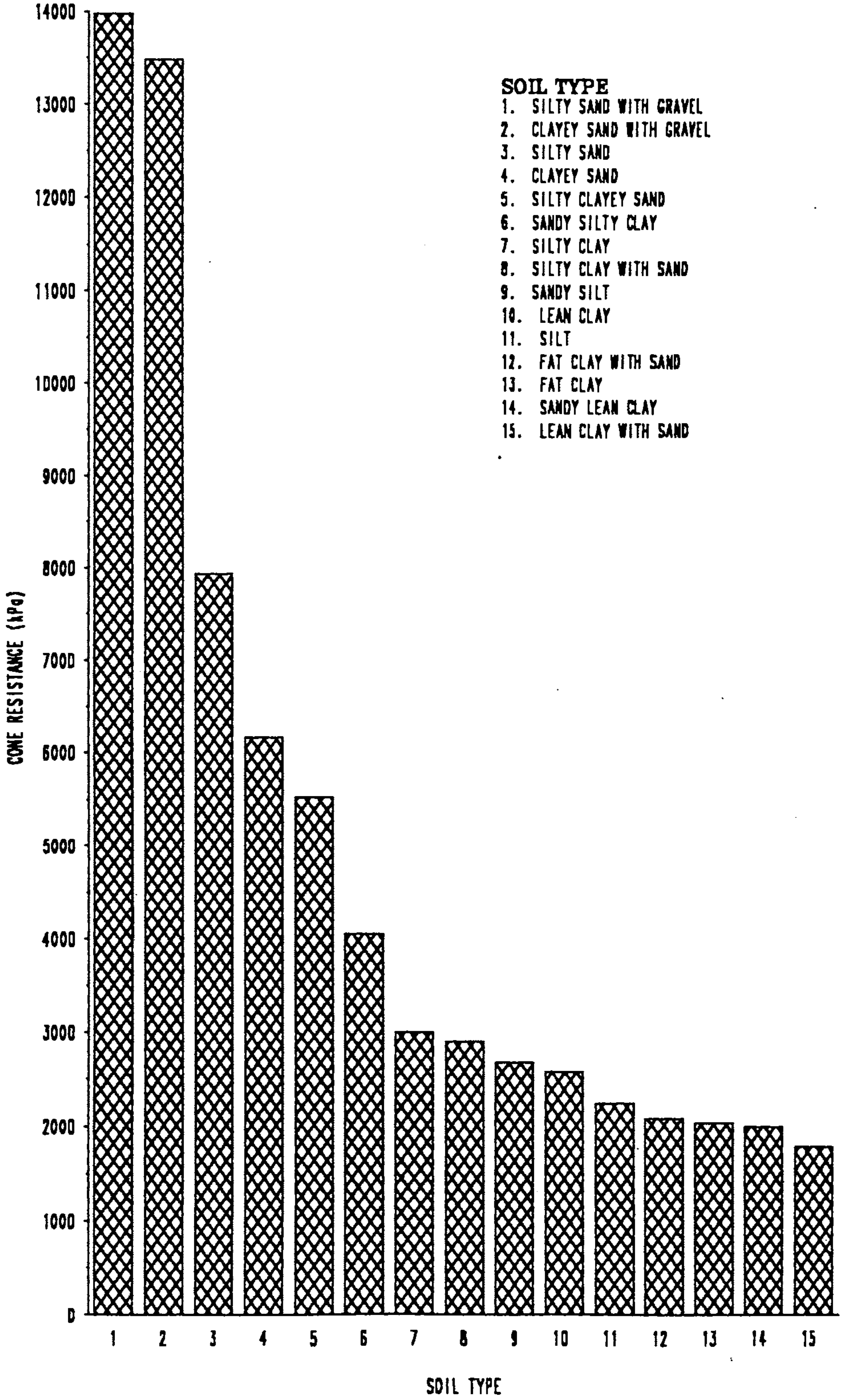
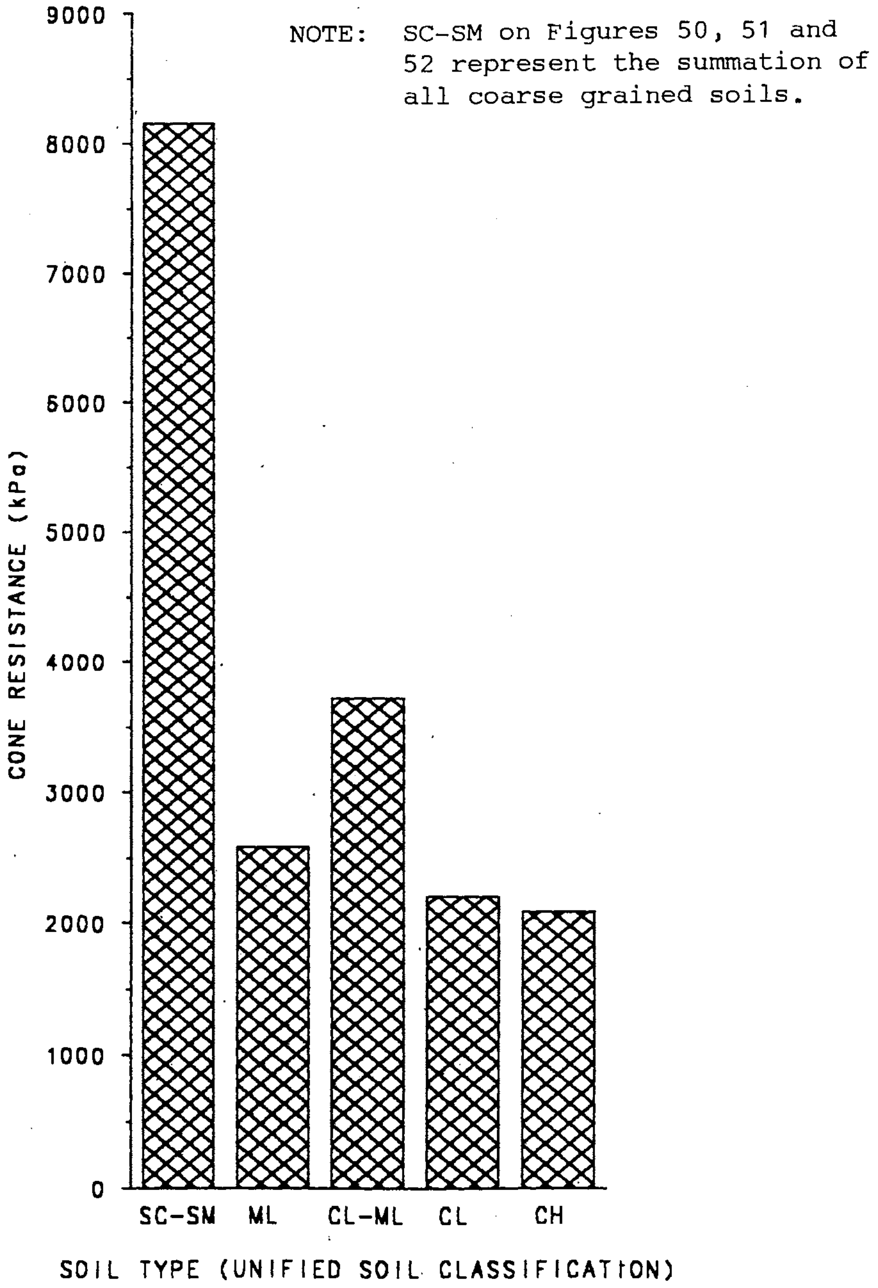


Figure 49. Variation of Cone Resistance With Soil Type (Unified Soil Classification) in Descending Order



NOTE: SC-SM on Figures 50, 51 and 52 represent the summation of all coarse grained soils.

Figure 50. Cone Resistance Versus Soil Type (Unified Soil Classification)

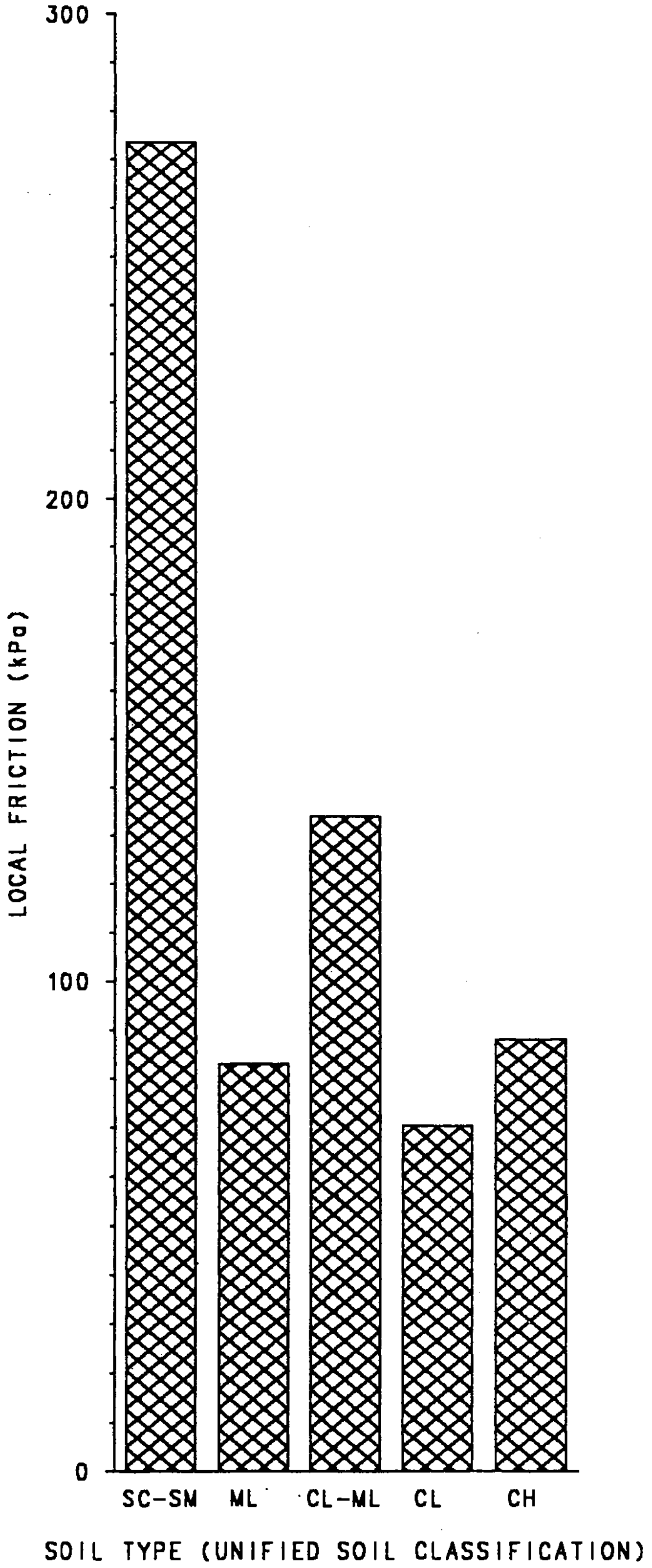


Figure 51. Local Friction Versus Soil Type (Unified Soil Classification)

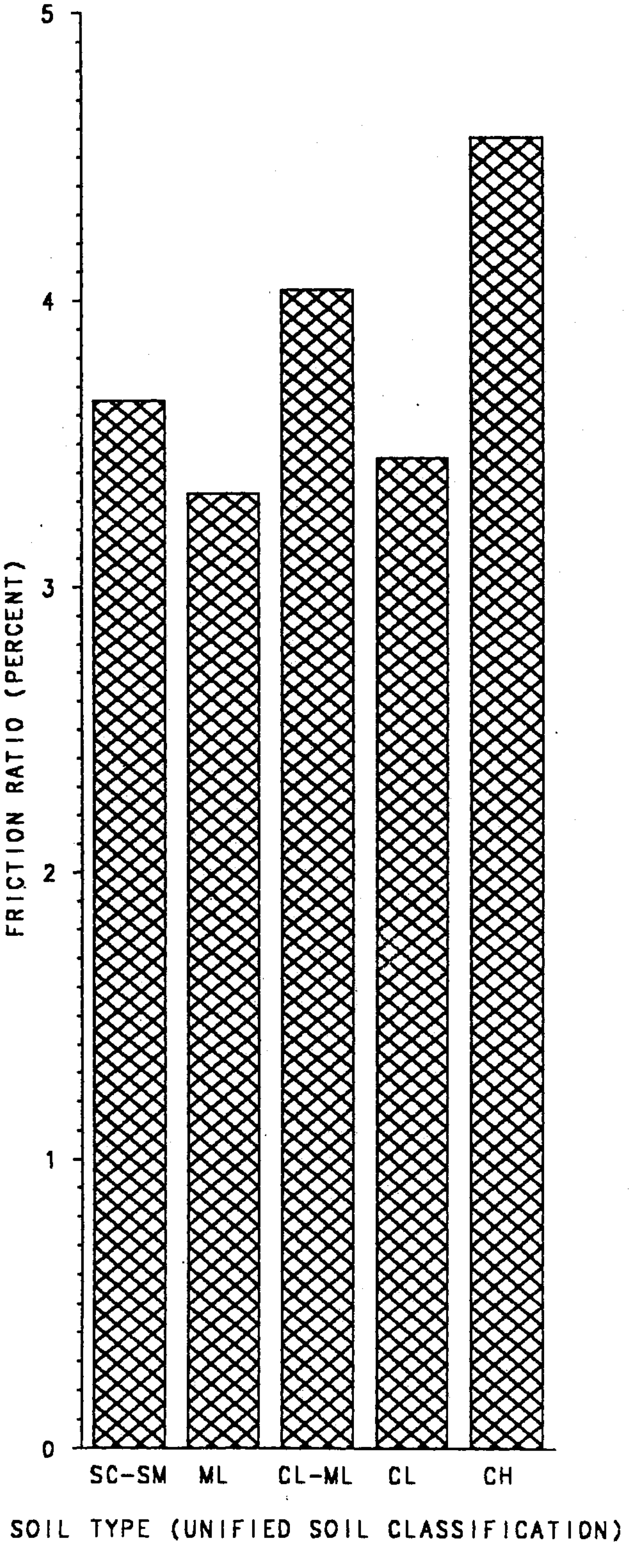


Figure 52. Friction Ratio Versus Soil Type (Unified Soil Classification)

TABLE XII

COMPARISON OF DIRECT APPLICATION OF THE BEGEMANN CLASSIFICATION SCHEME AND LOGGED BORING DESCRIPTION FOR CPT NO. 13/BORING NO. 2, WAGONER SITE

Depth (ft)	Boring Log	Cone Resistance (q_c, kg/cm)	Local Friction (f_s, kg/cm^2)	Soil Classification
0.33		16	0.000	---
0.66		18	0.067	--- (plots above chart)
0.98		16	0.267	Sand + 10% < 16 μ
1.31		12	1.067	--- (plots below chart)
1.64	Fat Clay	11	1.267	--- (" " ")
1.97	to 18.5	10	0.933	--- (" " ")
2.30		11	0.933	--- (" " ")
2.62		14	0.733	Clay (95% < 16 μ)
2.95		14	0.600	Clay (75% < 16 μ)
3.28		13	0.533	Clay (70% < 16 μ)
3.61		13	0.467	Clay (55% < 16 μ)
3.94		10	0.533	Clay (95% < 16 μ)
4.27		11	0.600	Clay (97% < 16 μ)
4.59		11	0.467	Clay (80% < 16 μ)
4.92		14	0.267	Sand + 15% < 16 μ
5.25		14	0.400	Loam + 50% < 16 μ
5.58		15	0.200	Fine Sand + 0% < 16 μ
5.91		15	0.400	Sand + 40% < 16 μ
6.23		14	0.400	Loam 50% < 16 μ
6.56		15	0.467	Loam 50% < 16 μ
6.80		14	0.533	Clay (68% < 16 μ)
7.22		16	0.533	Loam + 54% < 16 μ
7.55		16	0.600	Clay (65% < 16 μ)
7.87		16	0.600	Clay (65% < 16 μ)
8.20		18	0.467	Sand + 35% < 16 μ
8.53		17	0.400	Sand + 35% < 16 μ

TABLE XII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c) kg/cm	Local Friction (f_s, kg/cm^2)	Soil Classification
8.86		18	0.600	Clay (55% < 16 μ
9.19		19	0.467	Sand + 20% < 16 μ
9.51		18	0.600	Clay (55% < 16 μ)
9.84		18	0.600	Clay (55% < 16 μ)
10.17		18	0.667	Sand + 24% < 16 μ
10.50		19	0.733	Sand + 27% < 16 μ
10.83		19	0.733	Sand + 27% < 16 μ
11.15		20	0.667	Sand + 15% < 16 μ
11.48		21	0.600	Sand + 7% < 16 μ
11.81		20	0.667	Sand + 15% < 16 μ
12.14		22	0.667	Sand + 40% < 16 μ
12.47		23	0.600	Sand + 30% < 16 μ
12.80		22	0.667	Sand + 40% < 16 μ
13.12		23	0.667	Sand + 30% < 16 μ
13.45		22	0.533	Sand + 22% < 16 μ
13.78		20	0.600	Sand + 45% < 16 μ
14.11		19	0.667	Clay (70% < 16 μ
14.44		20	0.533	Sand + 37% < 16 μ
14.76		19	0.600	Loam + 52% < 16 μ
15.09		20	0.533	Sand + 37% < 16 μ
15.42		19	0.667	Clay (70% < 16 μ)
15.75		21	0.467	Sand + 17% < 16 μ
16.08		20	0.600	Sand + 45% < 16 μ
16.40		20	0.667	Sand + 15% < 16 μ
16.73		21	0.600	Sand + 7% < 16 μ
17.06		22	0.533	Sand + 22% < 16 μ
17.39		21	0.667	Sand + 45% < 16 μ
17.72		22	1.000	Clay (75% < 16 μ)
18.04		28	0.867	Sand + 47% < 16 μ)

TABLE XII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c, kg/cm)	Local Friction (f_s, kg/cm^2)	Soil Classification
18.37		28	0.933	Loam + 50% < 16 μ
18.70	Lean Clay	28	0.933	Loam + 50% < 16 μ
19.03		23	0.533	Sand + 17% < 16 μ
19.36		15	0.667	Sand + 35% < 16 μ
19.68		22	0.600	Sand + 35% < 16 μ
20.01		24	0.333	Fine Sand + 0% < 16 μ
20.34		19	0.400	Sand + 20% < 16 μ
20.67		17	0.400	Sand + 35% < 16 μ
21.00		13	0.600	Clay (85% < 16 μ
21.33		15	0.267	Fine Sand + 0% < 16 μ
21.65		17	0.333	Sand + 14% < 16 μ
21.98		20	0.333	Sand + 4% < 16 μ
22.31		19	0.333	Sand + 10% < 16 μ
22.64		17	0.467	Sand + 42% < 16 μ
22.97		16	0.333	Sand + 25% < 16 μ
23.29	Lean Clay	11	0.533	Clay (95% < 16 μ)
23.62	w/Sand	11	0.867	--- (plots below chart)
23.95	Lean Clay	22	0.267	--- (plots above chart)
24.28		10	1.200	--- (plots below chart)
24.61	Lean Clay	9	0.400	Clay (95% < 16 μ)
24.93	w/Sand	18	0.133	--- (plots above chart)
25.26		11	0.800	--- (plots below chart)
25.59	Sandy Lean Clay	31	0.467	Fine Sand 0% < 16 μ
25.92	Lean Clay	28	0.000	---
26.25		17	0.733	Clay (80% < 16 μ)
26.57		25	0.667	Sand + 32% < 16 μ
26.90	Silty Sand	20	3.200	--- (plots below charts)
27.23	Sandy Silty	21	2.933	--- (plots below charts)
27.56	Clay	30	1.467	Clay (85% < 16 μ)

TABLE XII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c, kg/cm)	Local Friction (f_s, kg/cm^2)	Soil Classification
27.89		32	2.667	--- (plots below charts)
28.22	Silty Clayey Sand	58	2.267	Clay (80% < 16 μ)
28.54		57	0.200	--- (plots above charts)
28.87	Silty Sand	32	1.667	Clay (90% < 16 μ)
29.20	Sandy Silty Clay	60	1.667	Sand + 37% < 16 μ
29.53		104	4.400	Clay + 70% < 16 μ
29.86	Silty Sand	180	4.667	Sand + 30% < 16 μ
30.18	Silty Sand w/Gravel	230	0.000	---
30.51		125	3.000	Sand + 20% < 16 μ
30.84		144	1.067	--- (plots above charts)
31.17	Silty Sand w/Gravel	104	3.733	Loam + 53% < 16 μ
31.50		82	1.867	Sand + 21% < 16 μ
31.82		160	4.667	Sand + 40% < 16 μ
32.15		190	2.000	--- (plots above charts)
32.48	Poorly Graded Sand w/ Gravel	200	2.667	Coarse Sand w/Gravel + 0% < 16 μ
32.81		220	4.000	Sand + 4% < 16 μ
33.14		240	4.000	Sand + 2% < 16 μ
33.46	Silty Sand w/Gravel	200	2.000	--- (plots above charts)
33.79		150	3.333	Sand + 15% < 16 μ
34.12	Clayey Sand w/Gravel	170	2.667	Sand + 1% < 16 μ
34.45		150	3.333	Sand + 15% < 16 μ
34.78		70	5.333	--- (plots below charts)
35.10		180	6.000	Sand + 48% < 16 μ
35.43		104	3.067	Sand + 40% < 16 μ
35.76	Shale	300	10.667	--- (LF > 6.0)
36.09		380	8.000	--- (LF > 6.0)

TABLE XIII

COMPARISON OF DIRECT APPLICATION OF THE SEARLE CLASSIFICATION SCHEME AND LOGGED BORING DESCRIPTION FOR CPT NO. 13/BORING NO. 2, WAGONER SITE

Depth (ft)	Boring Log	Cone Resistance (q_c, MPa)	Local Friction (f_s, kg/cm^2)	Soil Classification
0.33	Fat Clay to	1.6	0.00	---
0.66	18.5	1.8	0.37	Very Sensitive Soils
0.98		1.6	1.67	Loose F.M.C. Sand
1.31		1.2	8.89	Firm Heavy Clay
1.64		1.1	11.52	" " "
1.97		1.0	9.33	" " "
2.30		1.1	8.48	" " "
2.62		1.4	5.24	Firm Clayey Silt
2.95		1.4	4.29	Med. Dense Clayey Sandy Silt
3.28		1.3	4.10	" " " " "
3.61		1.3	3.59	" " " " "
3.94		1.0	5.33	Soft Clayey Silt
4.27		1.1	5.45	Firm Clayey Silt
4.59		1.1	4.24	Loose Clayey Sandy Silt
4.92		1.4	1.90	Loose Silty Sand
5.25		1.4	2.86	Loose Clayey Silty Sand
5.58		1.5	1.33	Loose F.M.C. Sand
5.91		1.5	2.67	Loose Clayey Silty Sand
6.23		1.4	2.86	" " " "
6.56		1.5	3.11	" " " "
6.89		1.4	3.81	Med. Dense Clayey Sandy Silt
7.22		1.6	3.33	" " " " "
7.55		1.6	3.75	" " " " "
7.87		1.6	3.75	" " " " "
8.20		1.8	2.59	Loose Clayey Silty Sand
8.53		1.7	2.35	" " " "

TABLE XIII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c, MPa)	Local Friction (f_s, kg/cm^2)	Soil Classification
8.86		1.8	3.33	Med. Dense Clayey Sandy Silt
9.19		1.9	2.46	Loose Clayey Silty Sand
9.51		1.8	3.33	Med. Dense Clayey Sandy Silt
9.84		1.8	3.33	" " " " "
10.17		1.8	3.70	" " " " "
10.50		1.9	3.86	" " " " "
10.83		1.9	3.86	" " " " "
11.15		2.0	3.33	" " " " "
11.48		2.1	2.86	Med. Dense Clayey Silty Sand
11.81		2.0	3.33	Med. Dense Clayey Sandy Silt
12.14		2.2	3.03	Med. Dense Clayey Silty Sand
12.47		2.3	2.61	" " " " "
12.80		2.2	3.03	" " " " "
13.12		2.3	2.90	" " " " "
12.45		2.2	2.42	" " " " "
13.78		2.0	3.00	" " " " "
14.11		1.9	3.51	Med. Dense Clayey Sandy Silt
14.44		2.0	2.67	Med. Dense Clayey Silty Sand
14.76		1.9	3.16	" " " " "
15.09		2.0	2.67	" " " " "
15.42		1.9	3.51	" " " " "
15.75		2.1	2.22	Med. Dense Silty Sand
16.08		2.0	3.00	Med. Dense Clayey Silty Sand
16.40		2.0	3.33	Med. Dense Clayey Sandy Silt
16.73	Fat Clay	2.1	2.86	Med. Dense Clayey Silty Sand
17.06		2.2	2.42	" " " " "
17.39		2.1	3.17	" " " " "
17.72		2.2	4.55	Firm Clayey Silt
18.04		2.8	3.10	Med. Dense Clayey Silty Sand

TABLE XIII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c, MPa)	Local Friction (f_s, kg/cm^2)	Soil Classification
18.37		2.8	3.33	Med. Dense Clayey Sandy Silt
18.70	Lean Clay	2.8	3.33	" " " " "
19.03		2.3	2.32	Med. Dense Clayey Silty Sand
19.36		1.5	4.44	Firm Clayey Silt
19.68		2.2	2.73	Med. Dense Clayey Silty Sand
20.01		2.4	1.39	Loose F.M.C. Sand
20.34		1.9	2.11	Loose Silty Sand
20.67		1.7	2.35	Loose Clayey Silty Sand
21.00		1.3	4.62	Firm Clayey Silt
21.33		1.5	1.78	Loose Silty Sand
21.65		1.7	1.96	" " "
21.98		2.0	1.67	Loose F.M.C. Sand
22.31		1.9	1.75	Loose Silty Sand
22.64		1.7	2.75	Loose Clayey Silty Sand
22.97		1.6	2.08	Loose Silty Sand
23.29	Lean Clay	1.1	4.85	Soft Clayey Silt
23.62	w/Sand	1.1	7.88	Firm Silty Clay
23.95	Lean Clay	2.2	1.21	Loose Gravelly Sand
24.28		1.0	12.00	Firm Heavy Clay6
24.61	Lean Clay	0.9	4.44	Soft Clayey Silt
24.93	w/Sand	1.8	0.74	Very Loose Sandy Gravel
25.26		1.1	7.27	Firm Silty Clay
25.59	Sandy Lean	3.1	1.51	Loose F.M.C. Sand
25.92	Clay	2.8	0.00	" " "
26.25	Lean Clay	1.7	4.31	Firm Clayey Silt
26.57		2.5	2.67	Med.Dense Clayey Silty Sand
26.90	Silty Sand	2.0	16.00	Very Stiff Peaty Clay
27.23	Sandy Silty	2.1	13.97	" " " "
27.56	Clay	3.0	4.89	Stiff Clayey Silt

TABLE XIII (Continued)

Depth (ft)	Boring Log	Cone Resistance (q_c, MPa)	Local Friction (f_s, kg/cm^2)	Soil Classification
27.89		3.2	8.33	Very Stiff Silty Clay
28.22	Silty Clayey Sand	5.8	3.91	Med. Dense Clayey Sandy Silt
28.54		5.7	0.35	Loose Gravel
28.87	Silty Sand	3.2	5.21	Stiff Clayey Silt
29.20	Sandy Silty Clay	6.0	2.78	Med. Dense Clayey Silty Sand
29.53		10.4	4.23	Dense Clayey Sandy Silt
29.86	Silty Sand	18.0	2.59	Dense Clayey Silty Sand
30.18	Silty Sand w/Gravel	23.0	0.00	---
30.51		12.5	2.40	Dense Clayey Silty Sand
30.84		14.4	0.74	Med. Dense Sandy Gravel
31.17	Silty Sand w/Gravel	10.4	3.59	Dense Clayey Sandy Silt
31.50		8.2	2.28	Med. Dense Silty Sand
31.82		16.0	2.92	Dense Clayey Silty Sand
32.15		19.0	1.05	Med. Dense Gravelly Sand
32.48	Poorly Graded Sand w/ Gravel	20.0	1.33	Dense F.M.C. Sand
32.81		22.0	1.82	Dense Silty Sand
33.14		24.0	1.67	Dense F.M.C. Sand
33.46	Silty Sand w/Gravel	20.0	1.00	Med. Dense Gravelly Sand
33.79		15.0	2.22	Dense Silty Sand
34.12	Clayey Sand w/Gravel	17.0	1.57	Dense F.M.C. Sand
34.45		15.0	2.22	Dense Silty Sand
34.78		7.0	7.62	Hard Silty Clay
35.10		18.0	3.33	Dense Clayey Sandy Silt
35.43		10.4	2.95	Dense Clayey Silty Sand
35.76	Shale	30.0	3.56	Very Dense Clayey Sandy Silt
36.09		38.0	2.11	Very Dense Silty Sand

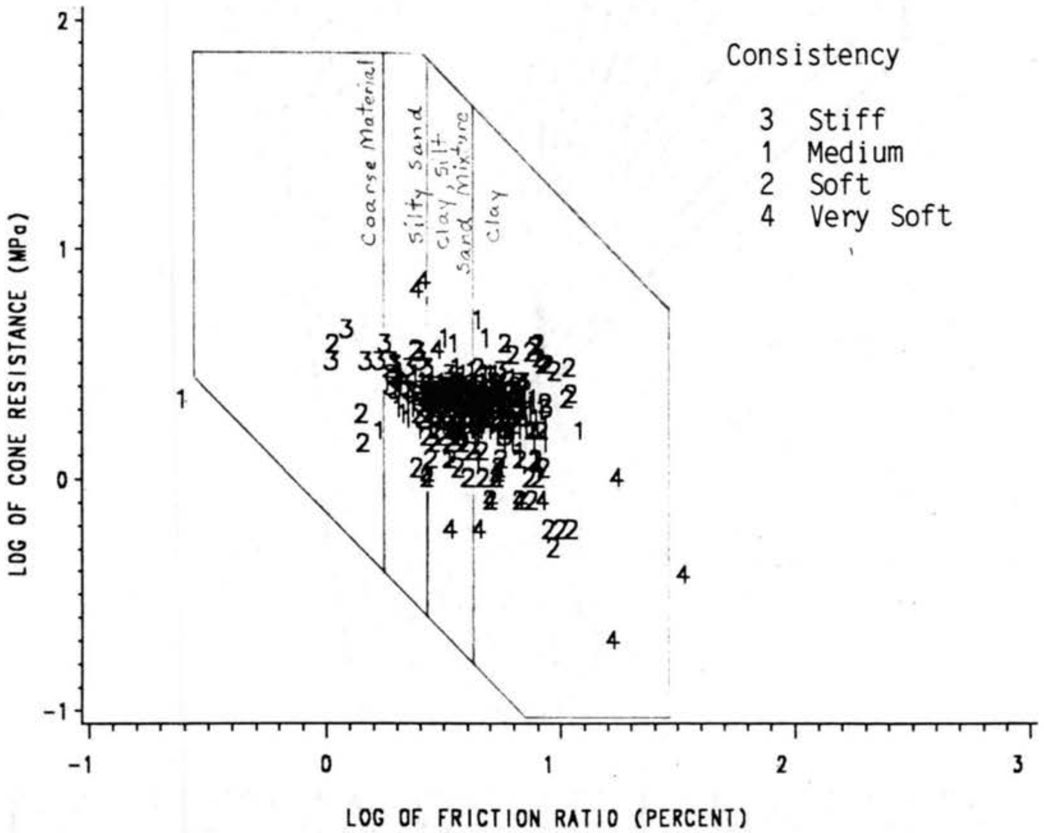


Figure 53. Log of Cone Resistance Versus Log of Friction Ratio for CH Soils

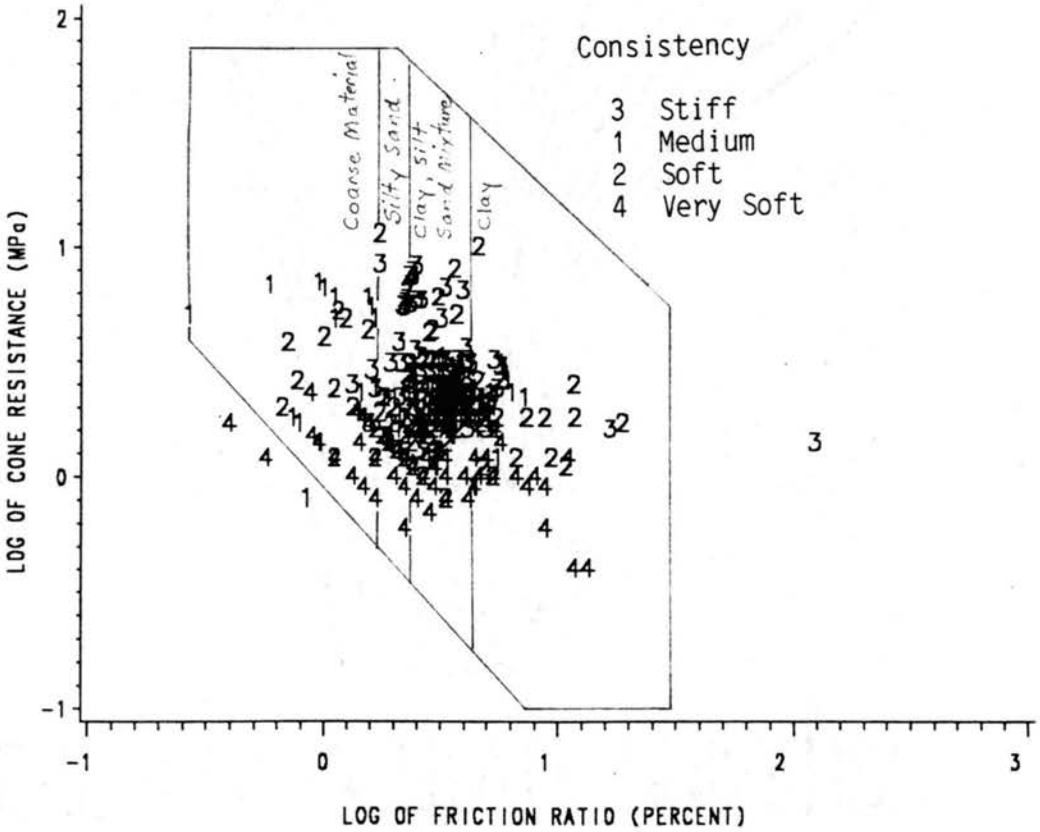


Figure 54. Log of Cone Resistance Versus Log of Friction Ratio for CL Soils

A comparison of the histograms of cone resistance, local friction, and friction ratios for all lean and fat clay data indicates the mean and standard deviation (see Figures 55 through 60). All clay data appear to follow a normal distribution based on plotting percent cumulative frequency from the histogram data of Figures 55 through 60 on normal probability paper. Figures 61 and 62 present a percent cumulative frequency versus friction ratio diagrams for all fat clay data, as an example. All other histogram data showed similar results. The friction ratios for lean and fat clay, from all sites were found to be the following:

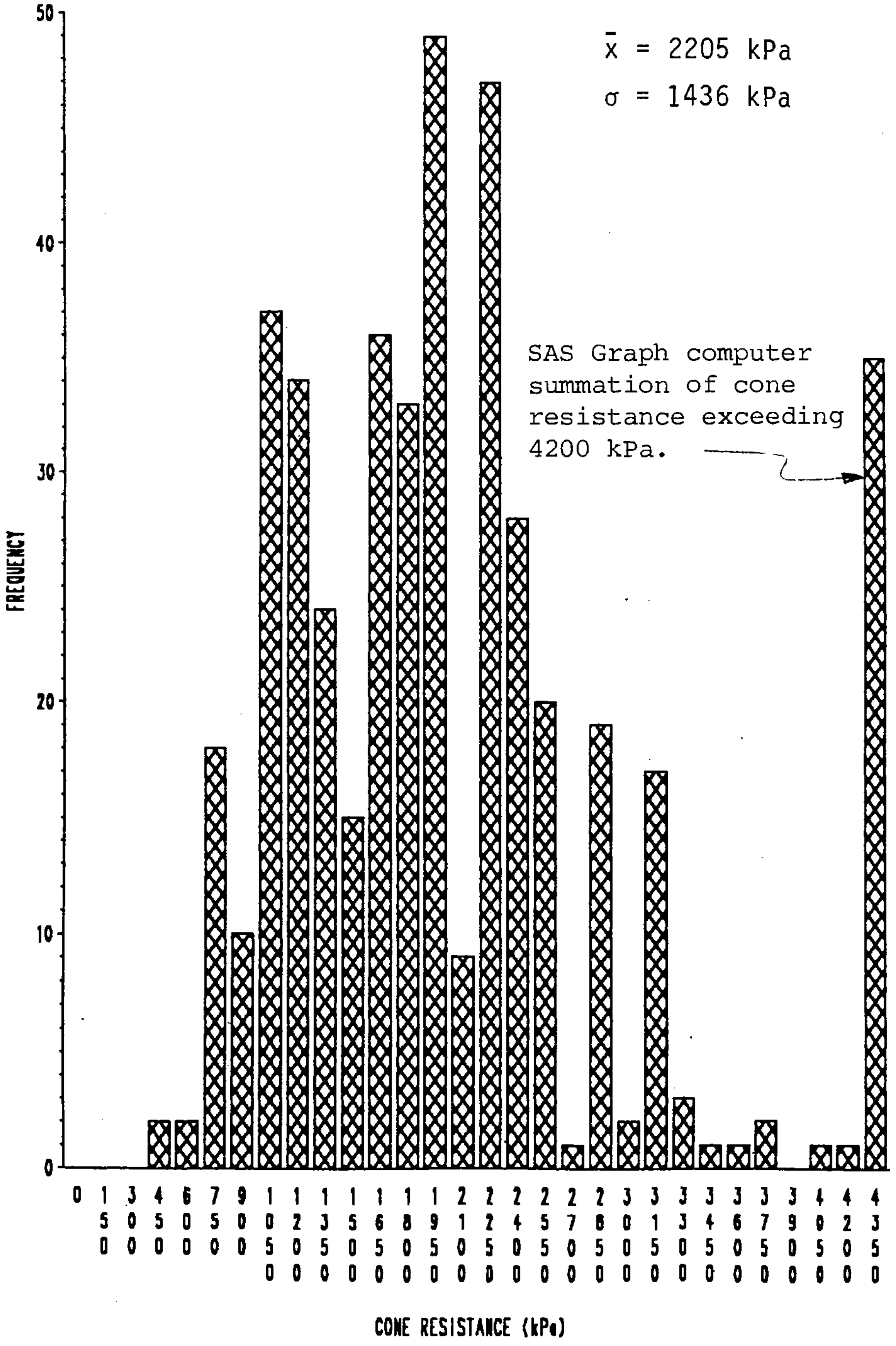
Clay	Mean	Standard Deviation
Lean	x = 3.5	$\sigma = \pm 6.1$
Fat	x = 4.6	$\sigma = \pm 2.4$

A similar comparison was made by the use of histograms of cone resistance, local friction, and friction ratios for all lean and fat clay at the Wagoner site (see Figures 63 through 68). The data again appear to follow a normal distribution based on plotting percent cumulative frequency from the histogram data of Figures 63 through 68 on normal probability paper. The friction ratios for all lean and fat clay at this specific site were found to be the following:

Clay	Mean	Standard Deviation
Lean	x = 2.9	$\sigma = 2.0$
Fat	x = 4.5	$\sigma = 1.9$

The friction ratios reported here for these fissured lean and fat clays are somewhat lower than reported by Sanglerat (reference Table II) and considerably lower than indicated by Searle's chart (reference Figure 15). Results found in this study tend to agree with the fric-

Note: Last bar on following histograms are SAS Graph computer summations.


$\bar{x}$ = 2205 kPa

σ = 1436 kPa

SAS Graph computer summation of cone resistance exceeding 4200 kPa.

Figure 55. Histogram for Cone Resistance of Lean Clay From All Sites

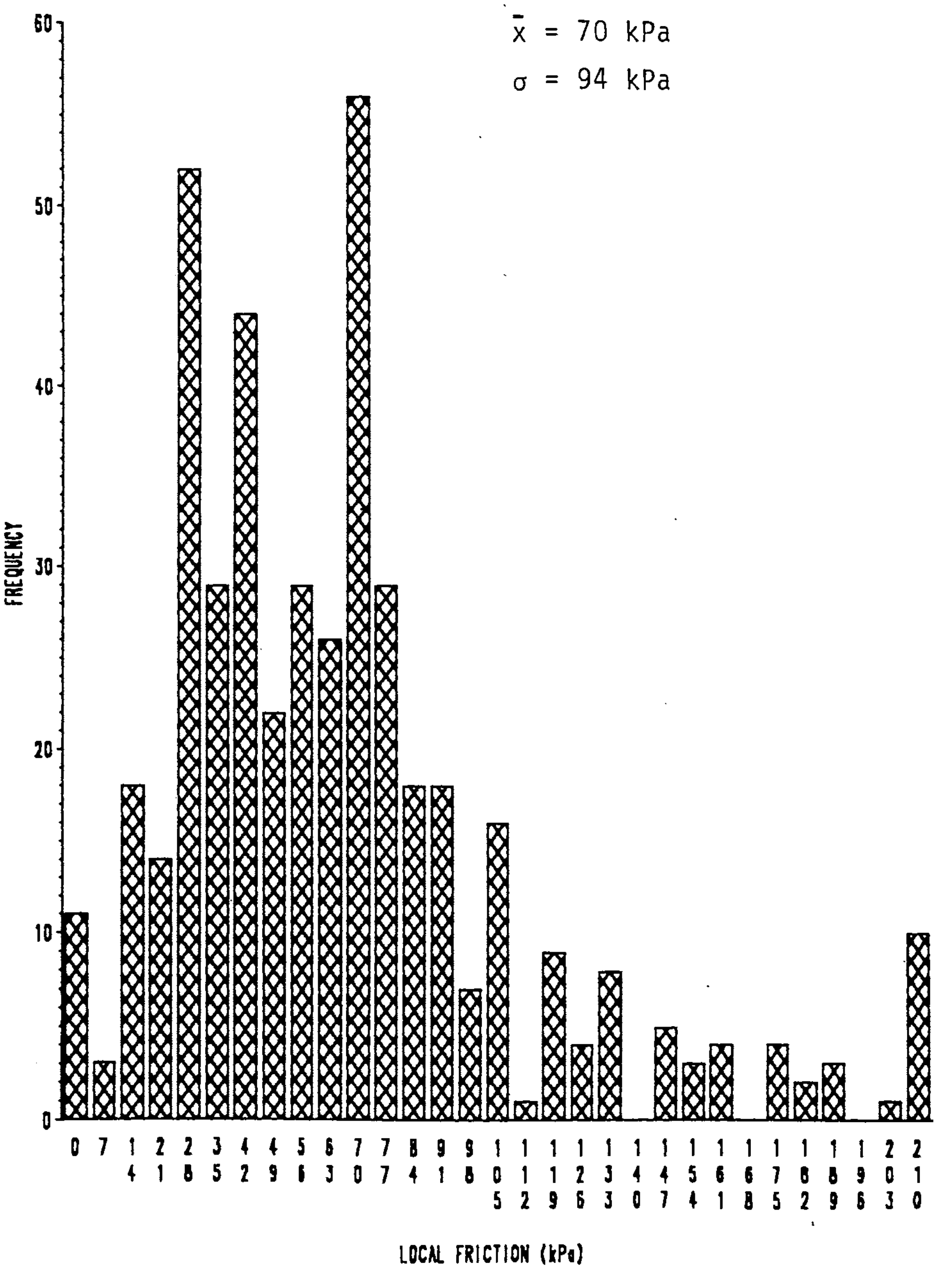


Figure 56. Histogram for Local Friction of Lean Clay From All Sites

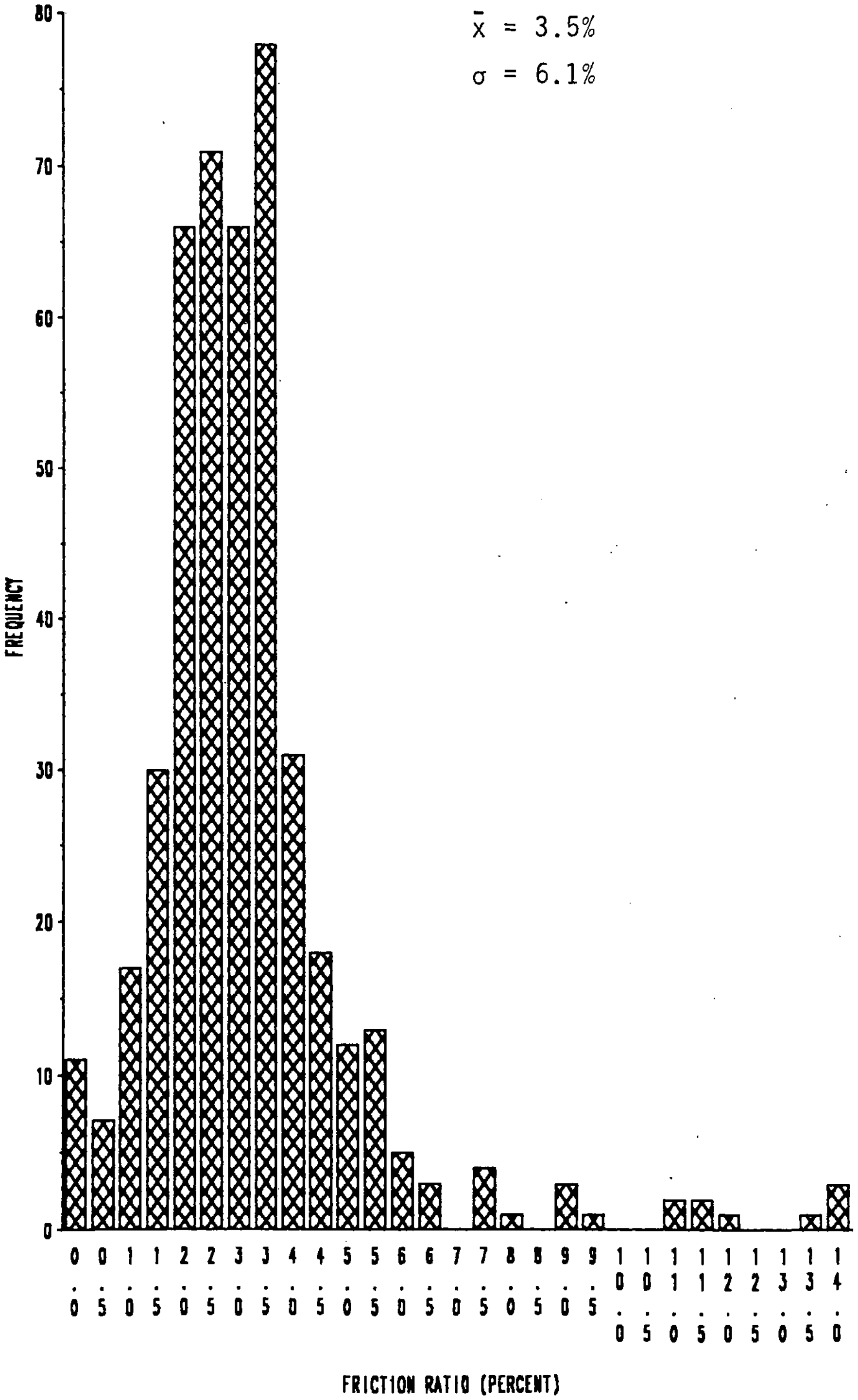


Figure 57. Histogram for Friction Ratio of Lean Clay From All Sites.

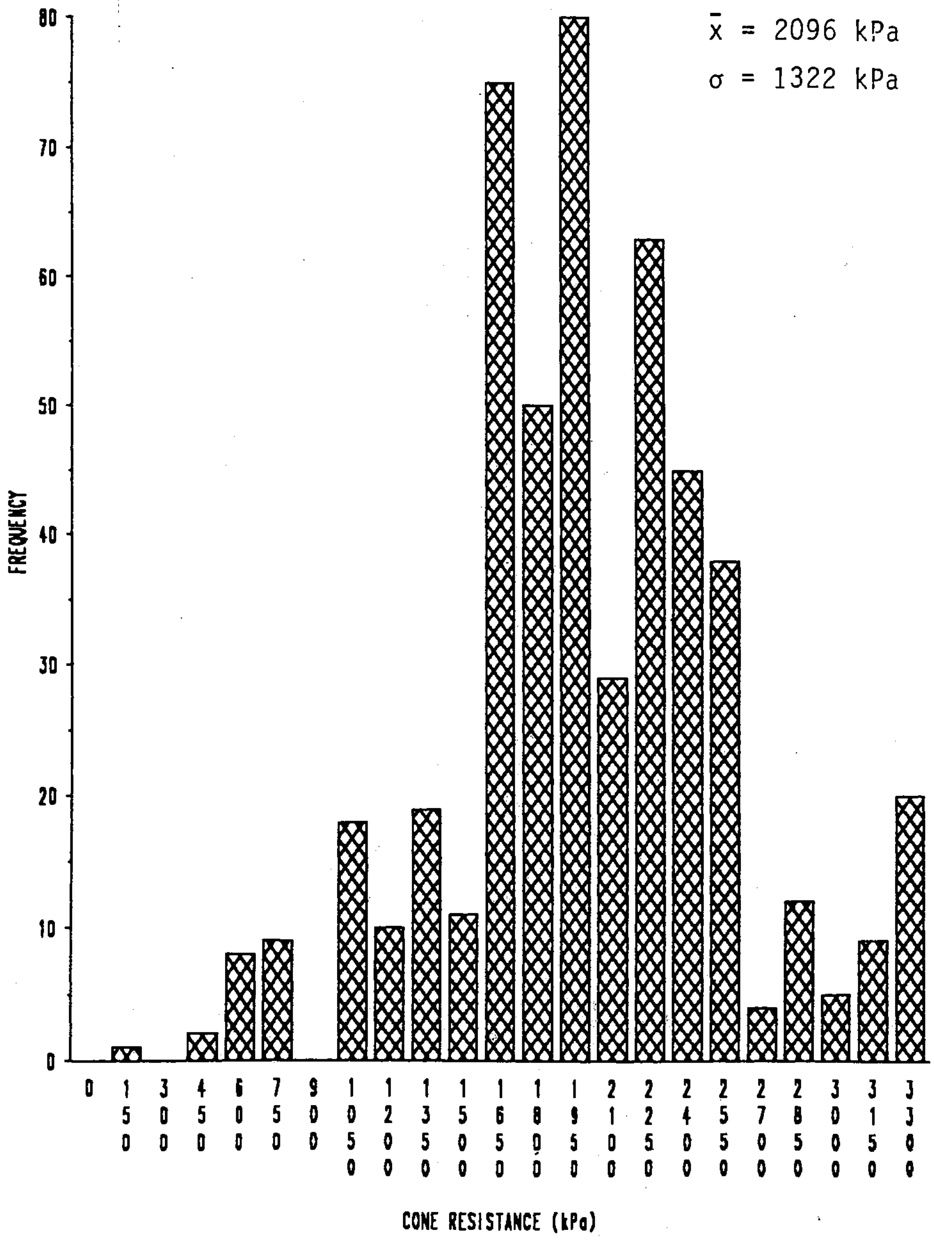


Figure 58. Histogram for Cone Resistance of Fat Clay From All Sites

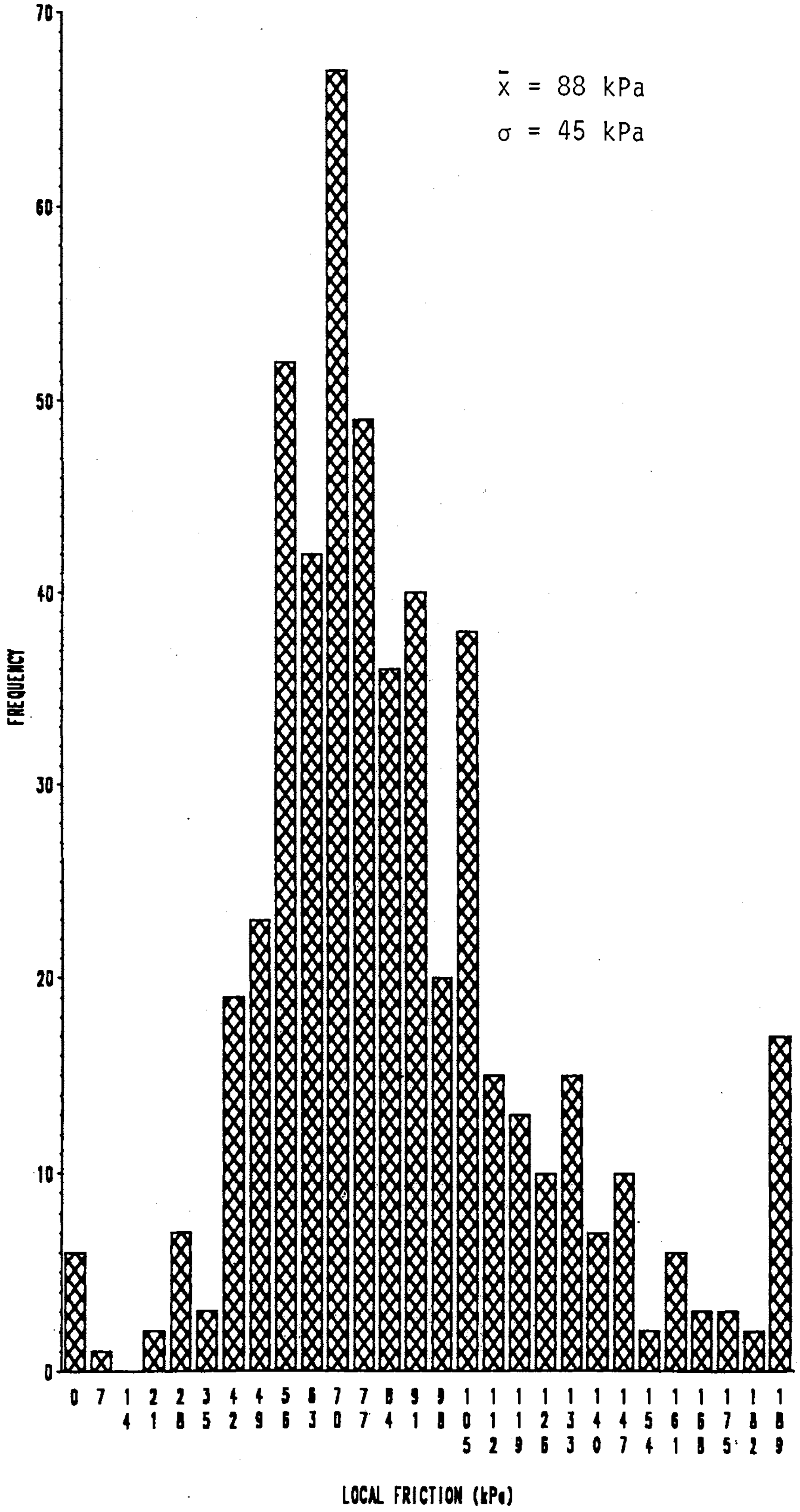


Figure 59. Histogram for Local Friction of Fat Clay From All Sites

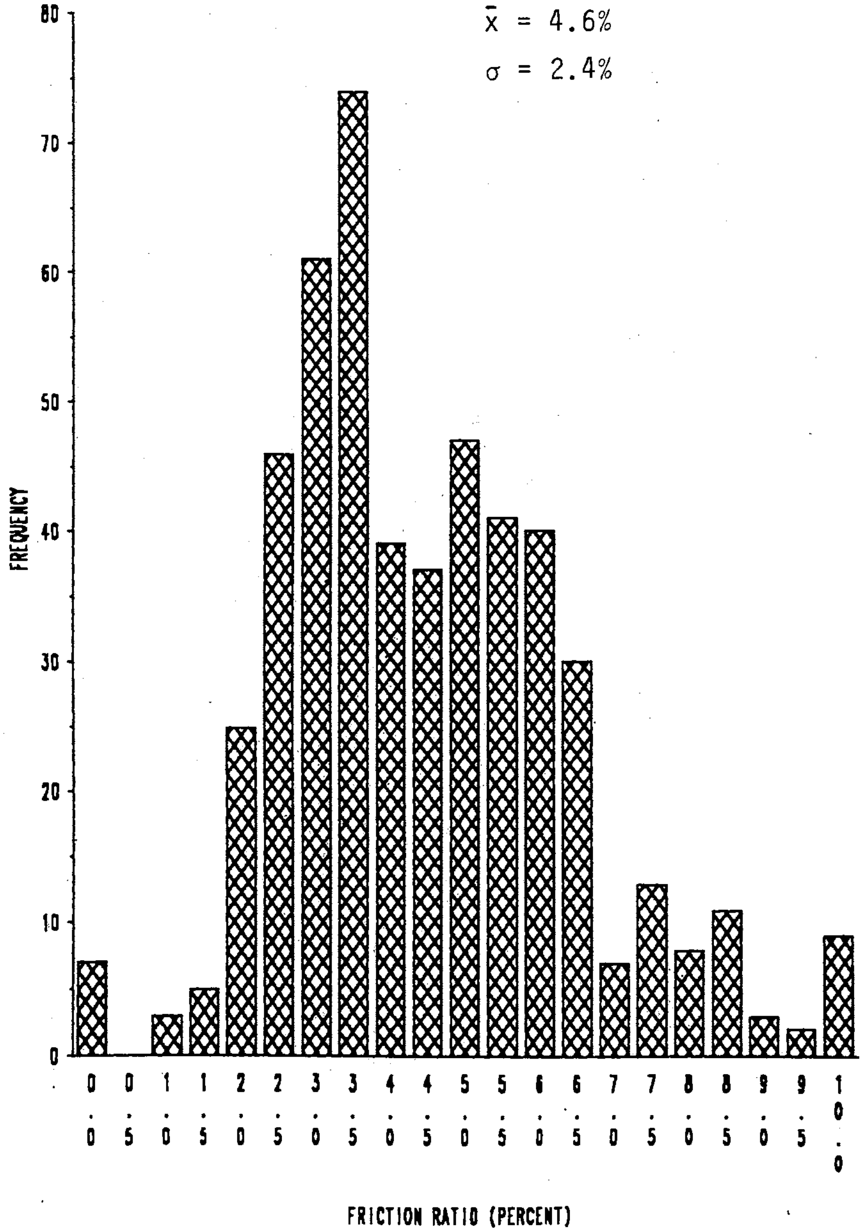


Figure 60. Histogram for Friction Ratio of Fat Clay From All Sites

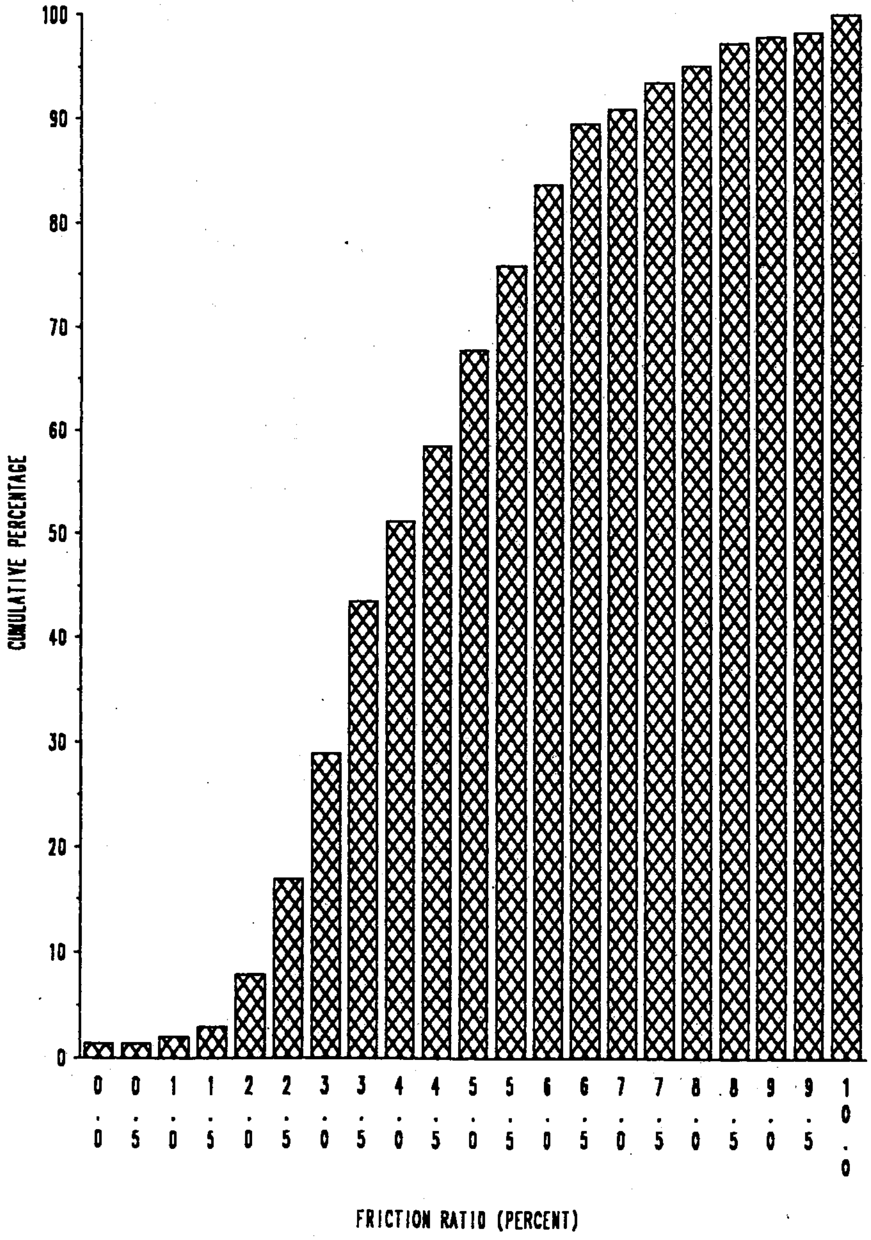


Figure 61. Cumulative Frequency Diagram for Friction Ratio of Fat Clay From All Sites

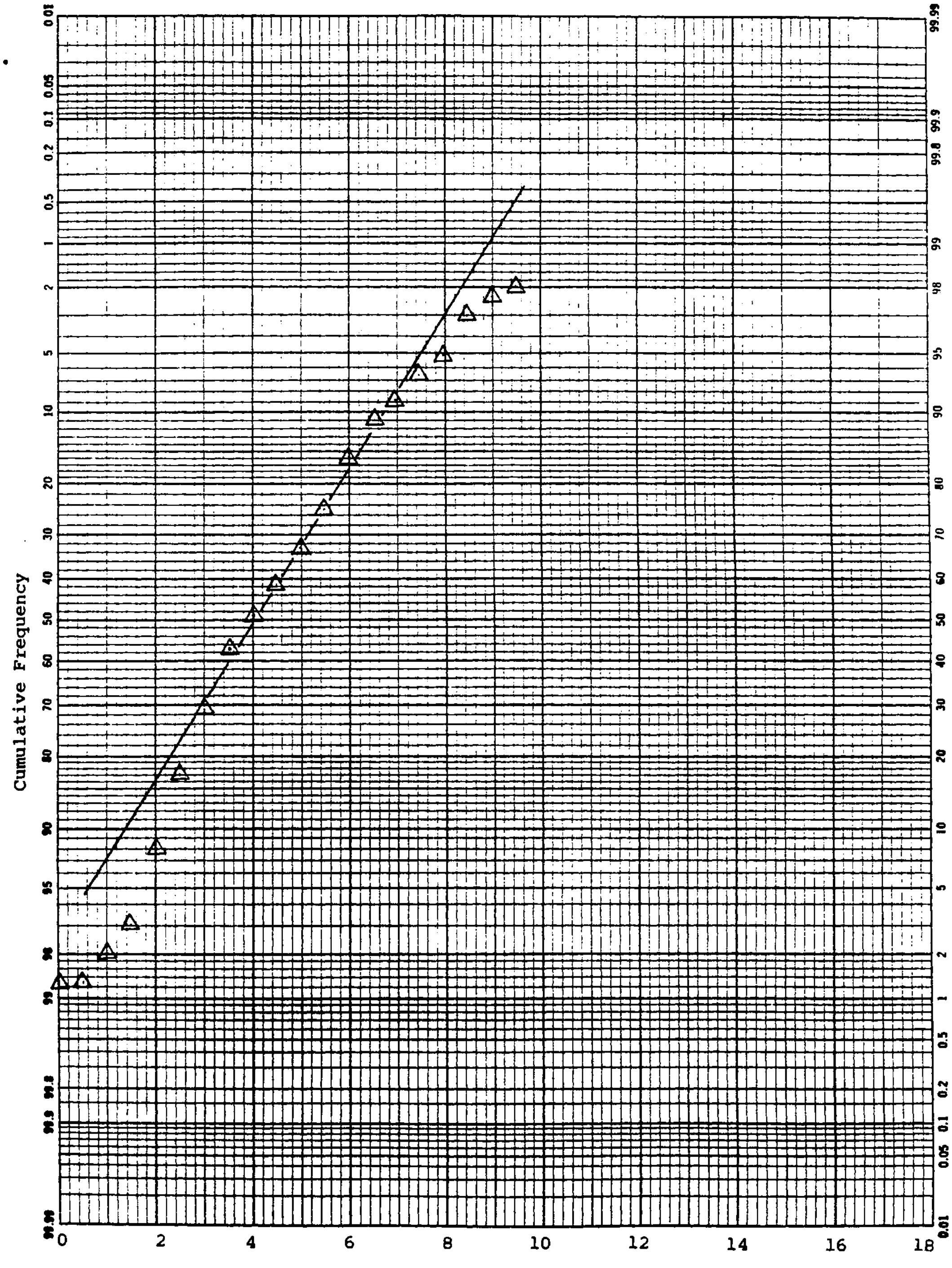


Figure 62. Cumulative Frequency Diagram for Friction Ratio of Fat Clay From All Sites Plotted on Normal Probability Paper

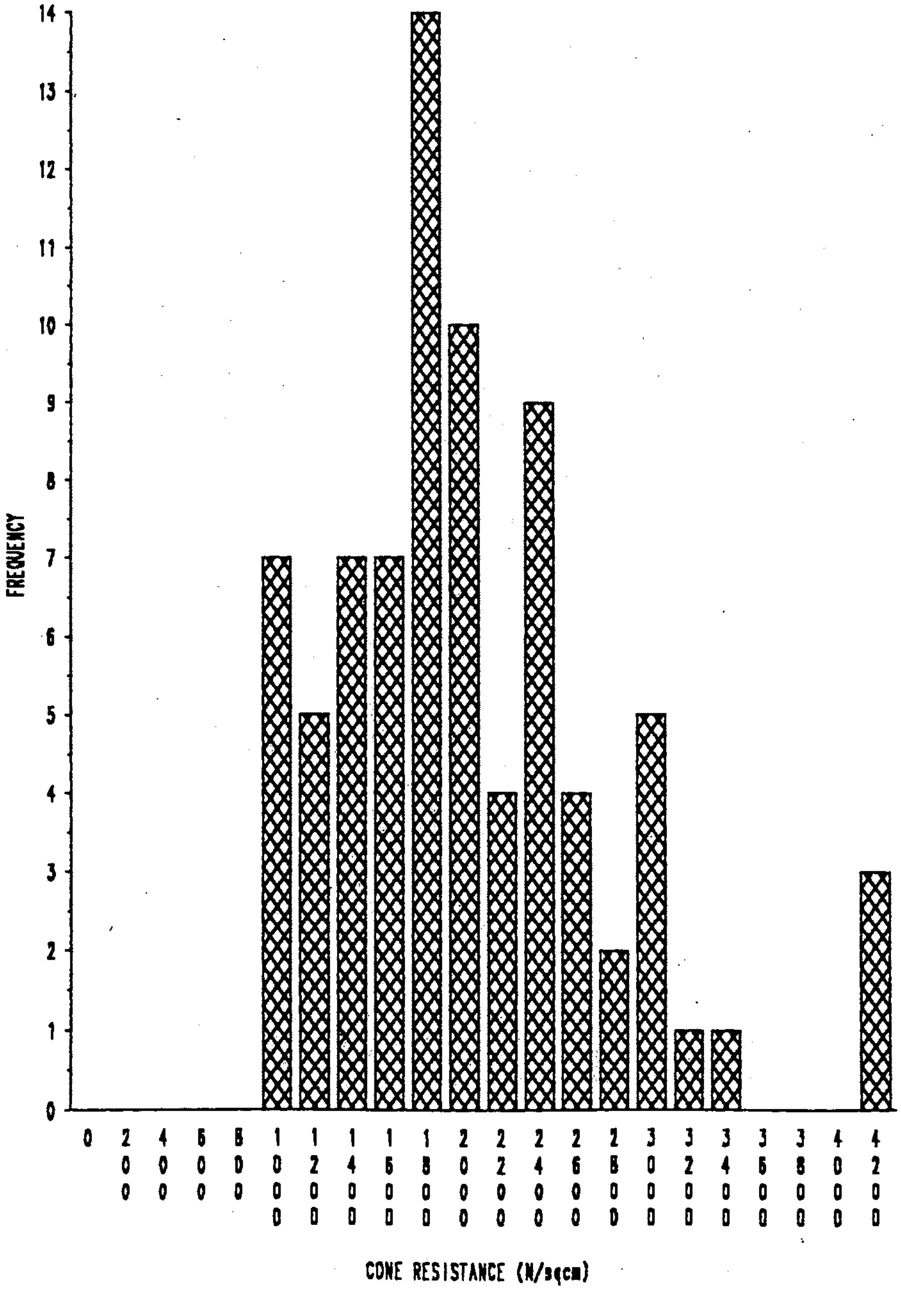


Figure 63. Histogram for Cone Resistance of Lean Clay From Wagoner Site

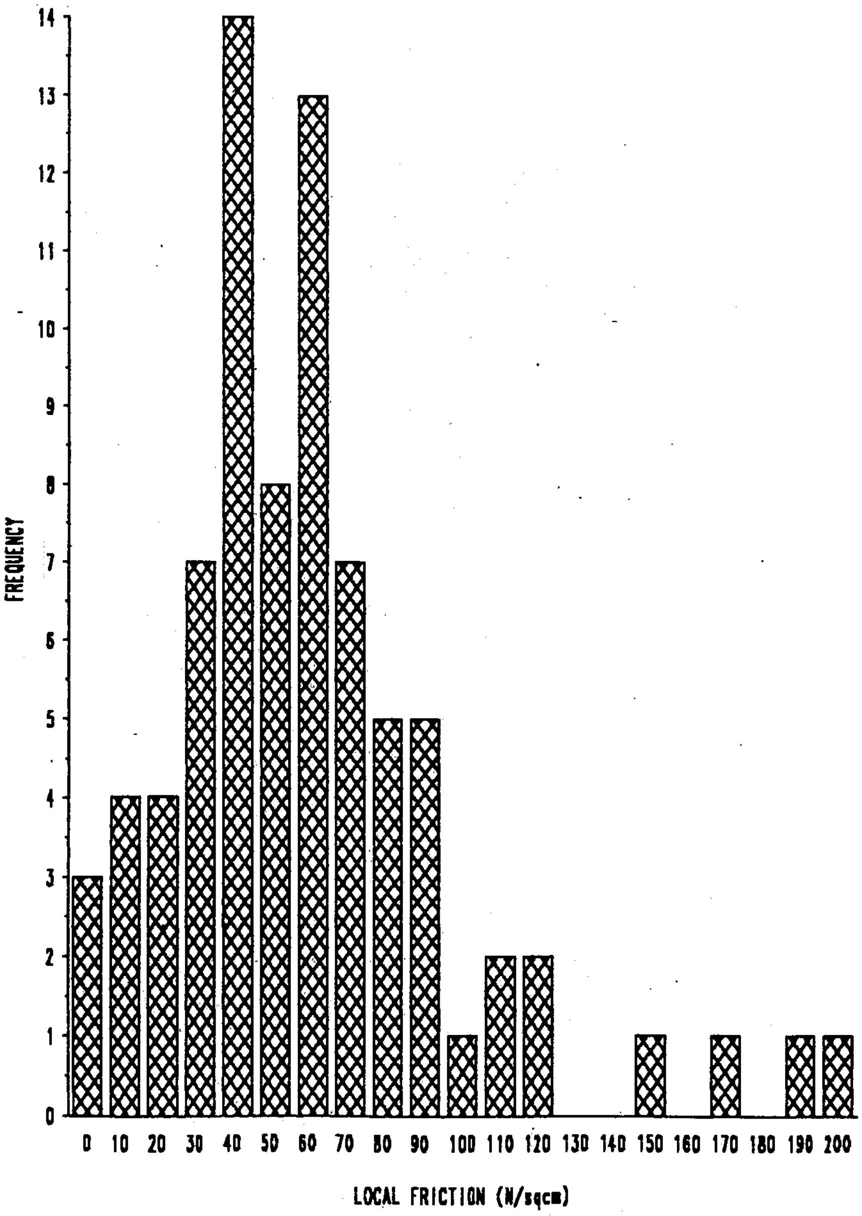


Figure 64. Histogram for Local Friction of Lean Clay From Wagoner Site

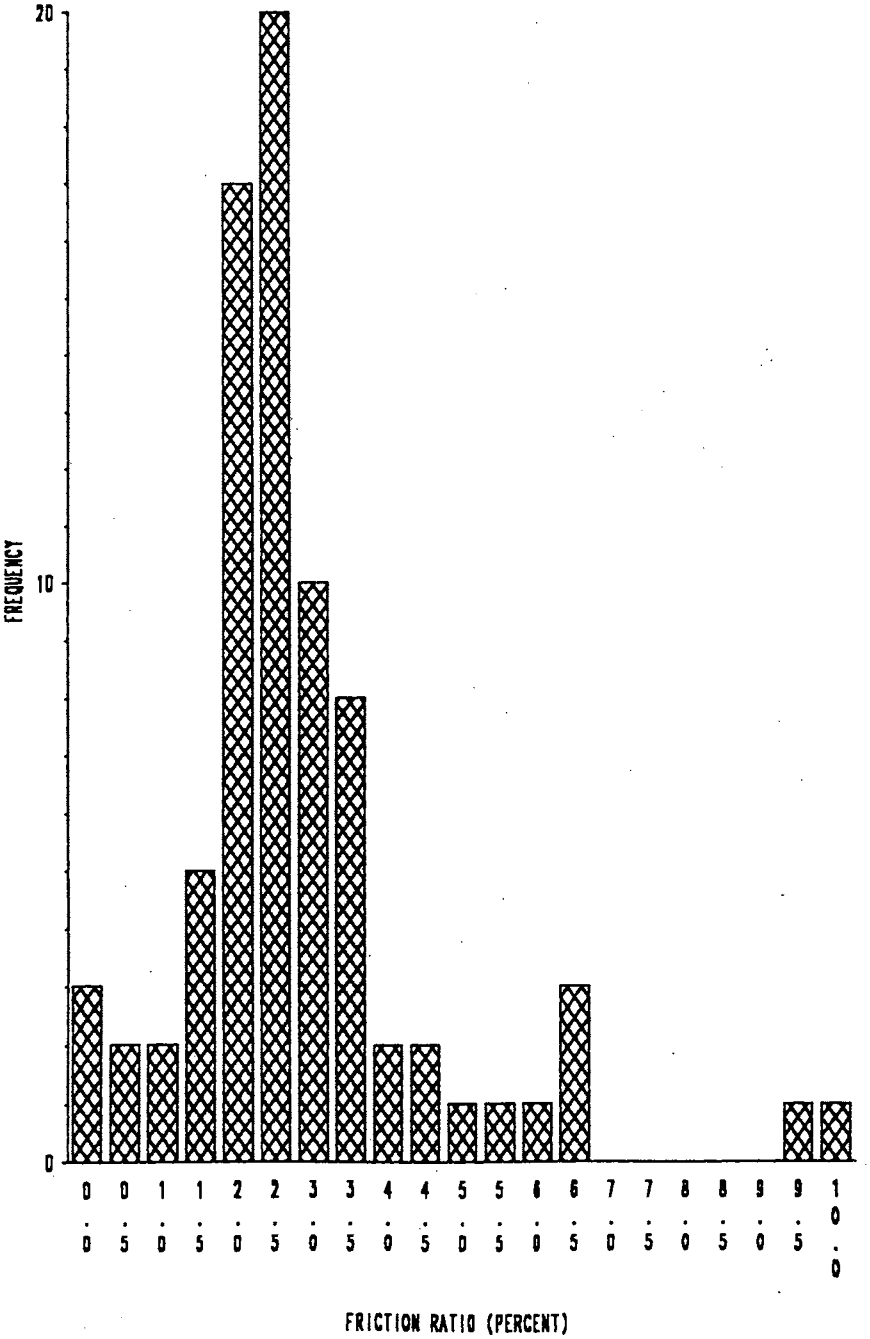


Figure 65. Histogram for Friction Ratio of
Lean Clay From Wagoner Site

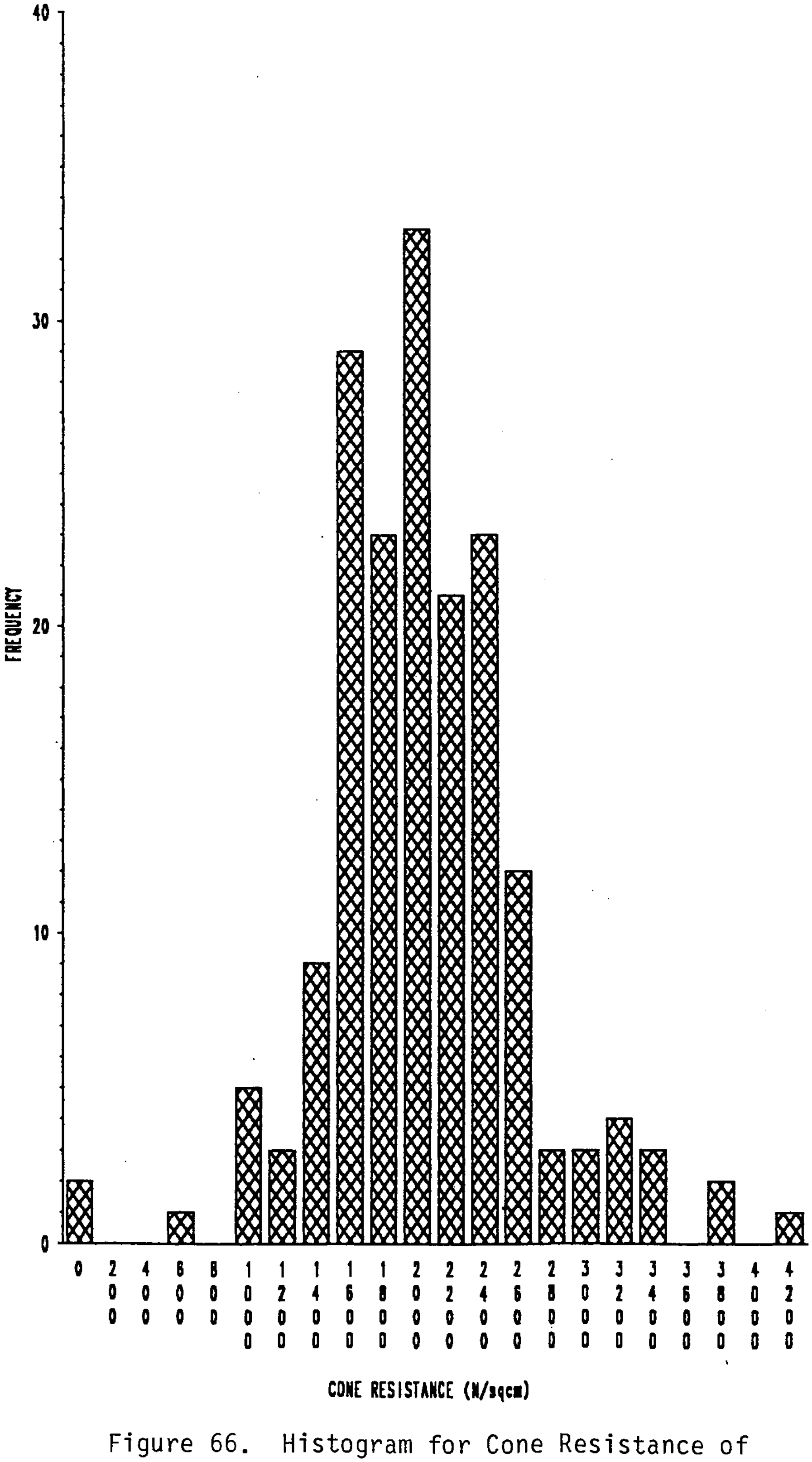


Figure 66. Histogram for Cone Resistance of Fat Clay From Wagoner Site

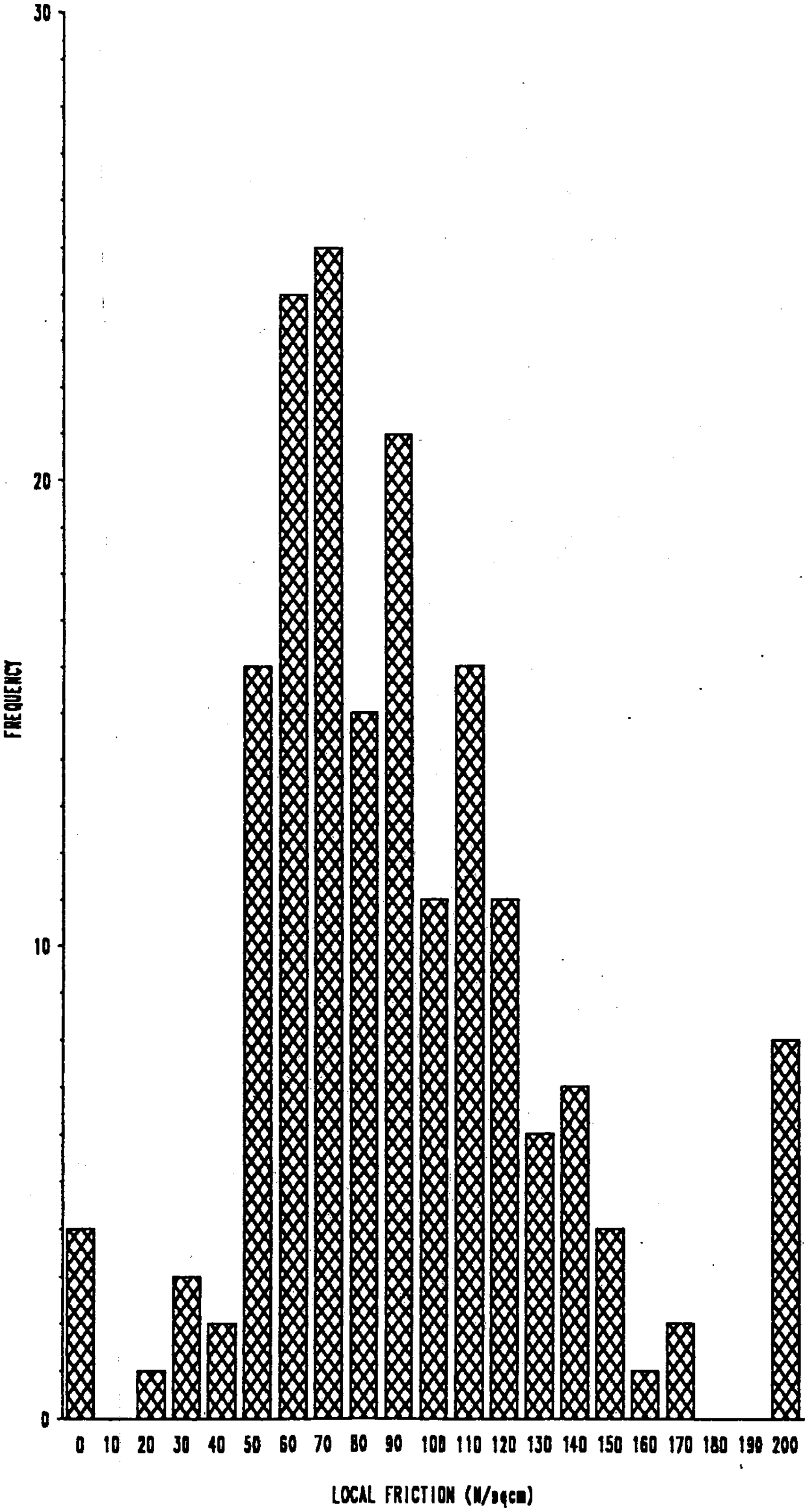


Figure 67. Histogram of Local Friction for Fat Clay From Wagoner Site

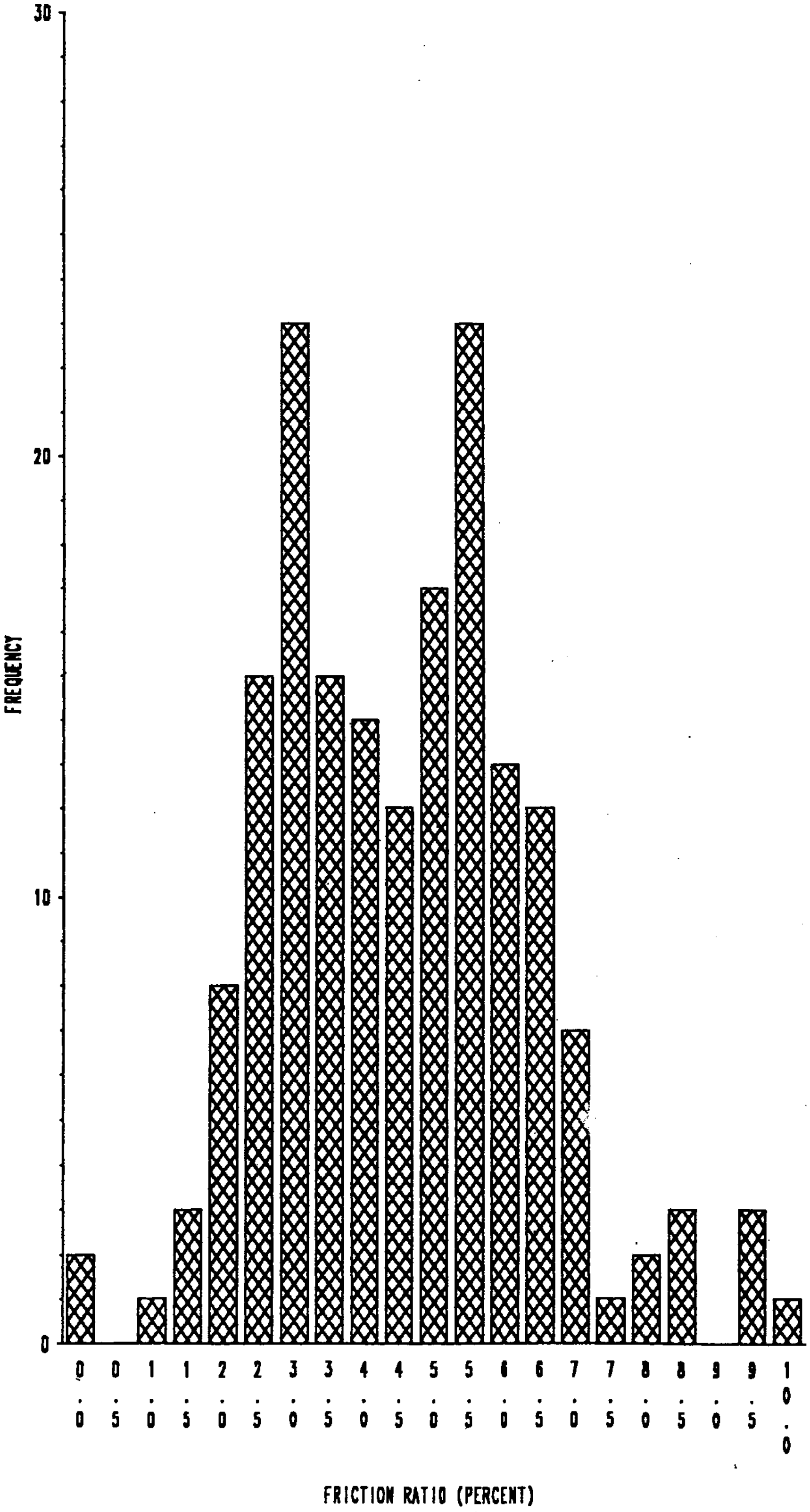


Figure 68. Histogram for Friction Ratio of Fat Clay From Wagoner Site

tion ratios reported by Cancelli (34) for overconsolidated alluvial clays.

Begemann's research (9) indicated that the slope of an arithmetic plot of cone resistance versus local friction remains approximately constant with soil type. The results in the form of a regression line and equation from a method of least squares analysis of lean and fat clay from all sites and the Wagoner site are given in Figures 69 through 72. It can be observed that the slopes from these regression lines do not correspond to the slope of clay soils indicated in the Begemann's soil classification scheme. This would help explain the poor correlation indicated in Table XII.

CPT Correlation With Atterberg Limits and Clay Consistency

An attempt was made to correlate the cone resistance with the Atterberg limits (LL and PL) and clay consistency as referenced by the liquidity index (L_I). There has been some research indicating linear relationships between cone resistance and relative consistency which is the reciprocal of the liquidity index (45). Liquidity index has replaced the older term, relative consistency, as a measure of clay consistency. However, only a vague trend was noted; see typical relationship in Figure 73 for the cone resistance versus liquidity index for Wagoner lean and fat clays. No correlations were believed possible without a more sophisticated statistical analysis. An indication of some possible general relationship between the cone parameters and clay consistency is shown in Figure 74. This figure relates cone

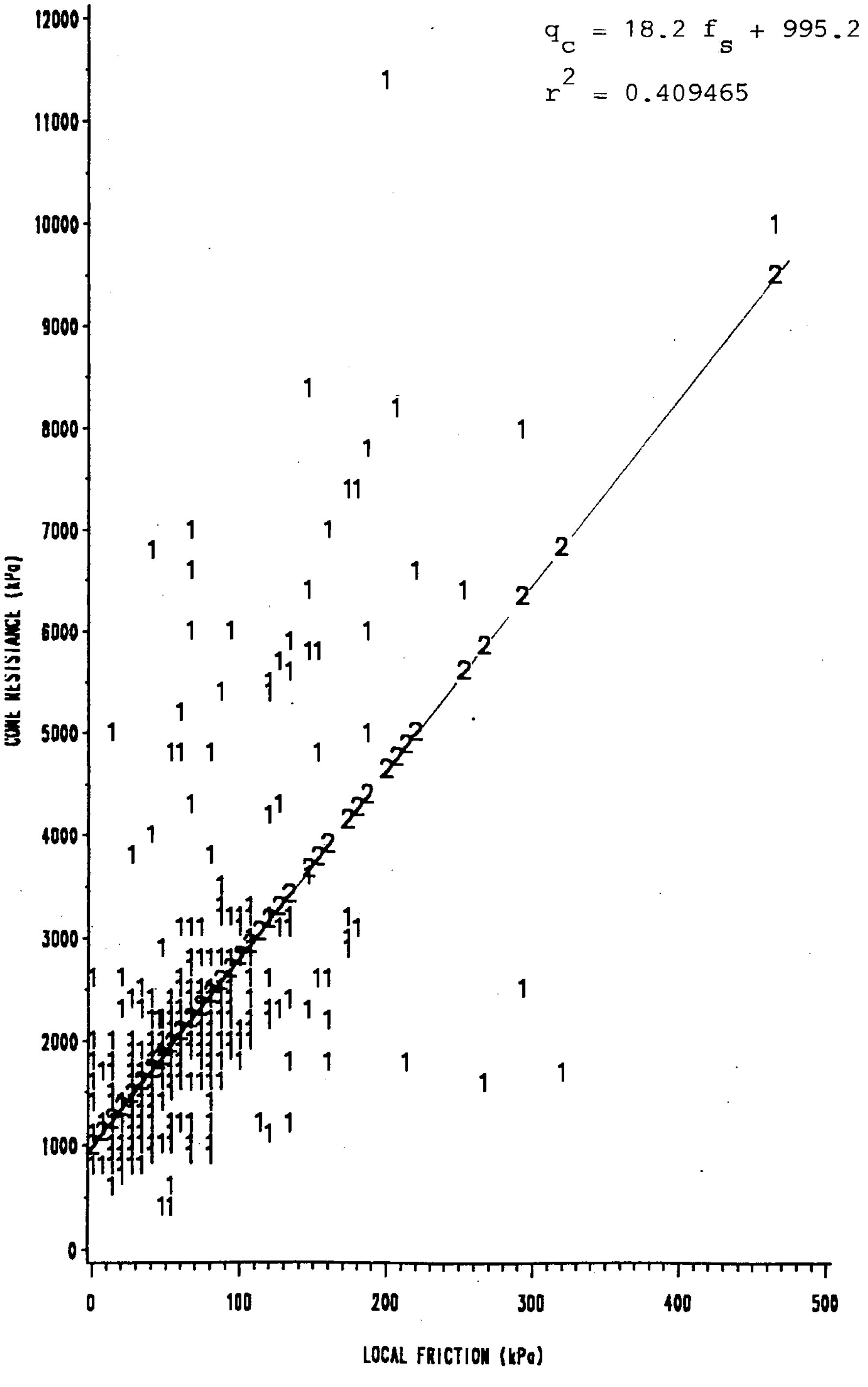


Figure 69. Relationship Between Cone Resistance (q_c) and Local Friction (f_s) for Lean Clay Data From All Sites

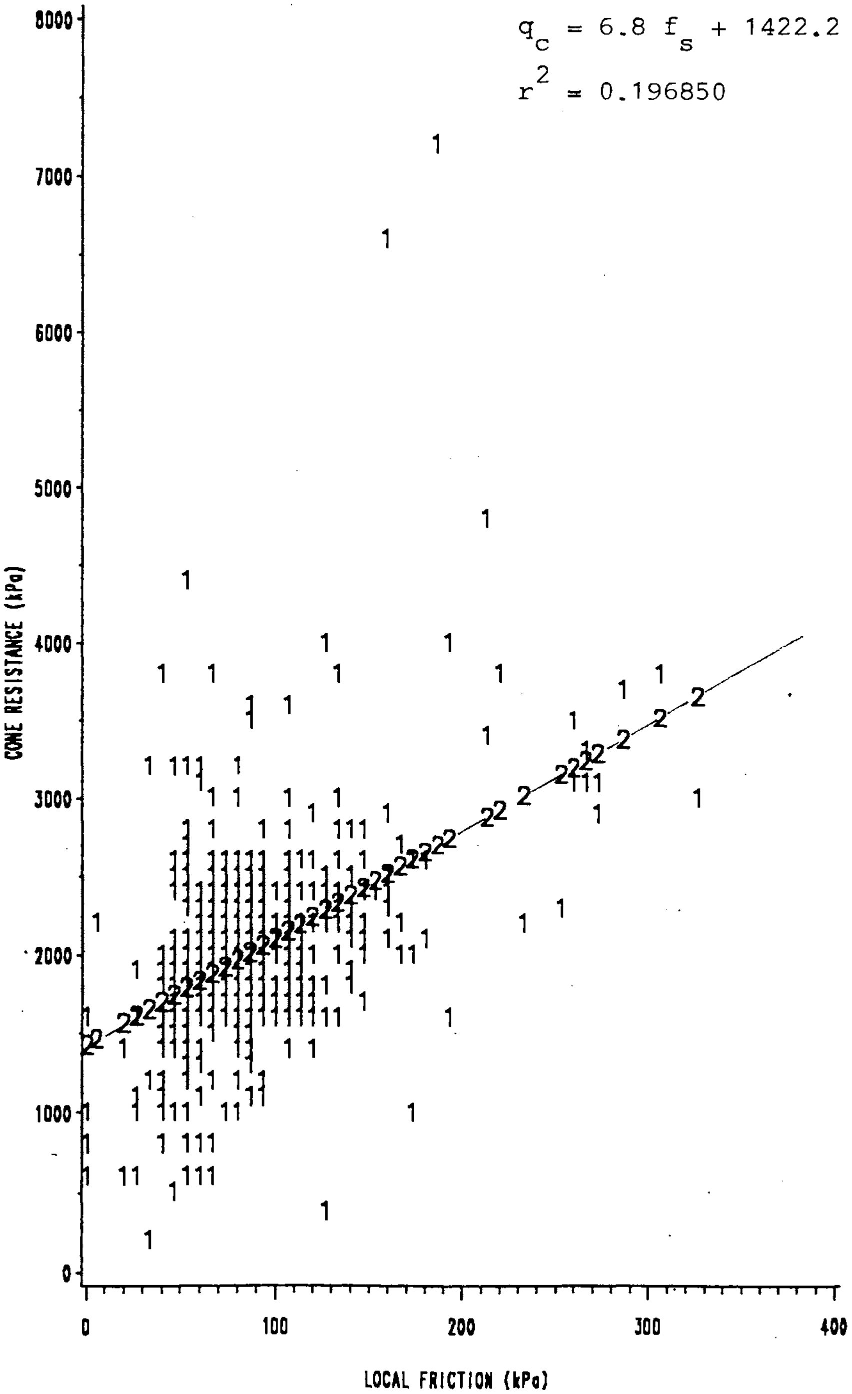


Figure 70. Relationship Between Cone Resistance (q_c) and Local Friction (f_s) for Fat Clay Data From All Sites

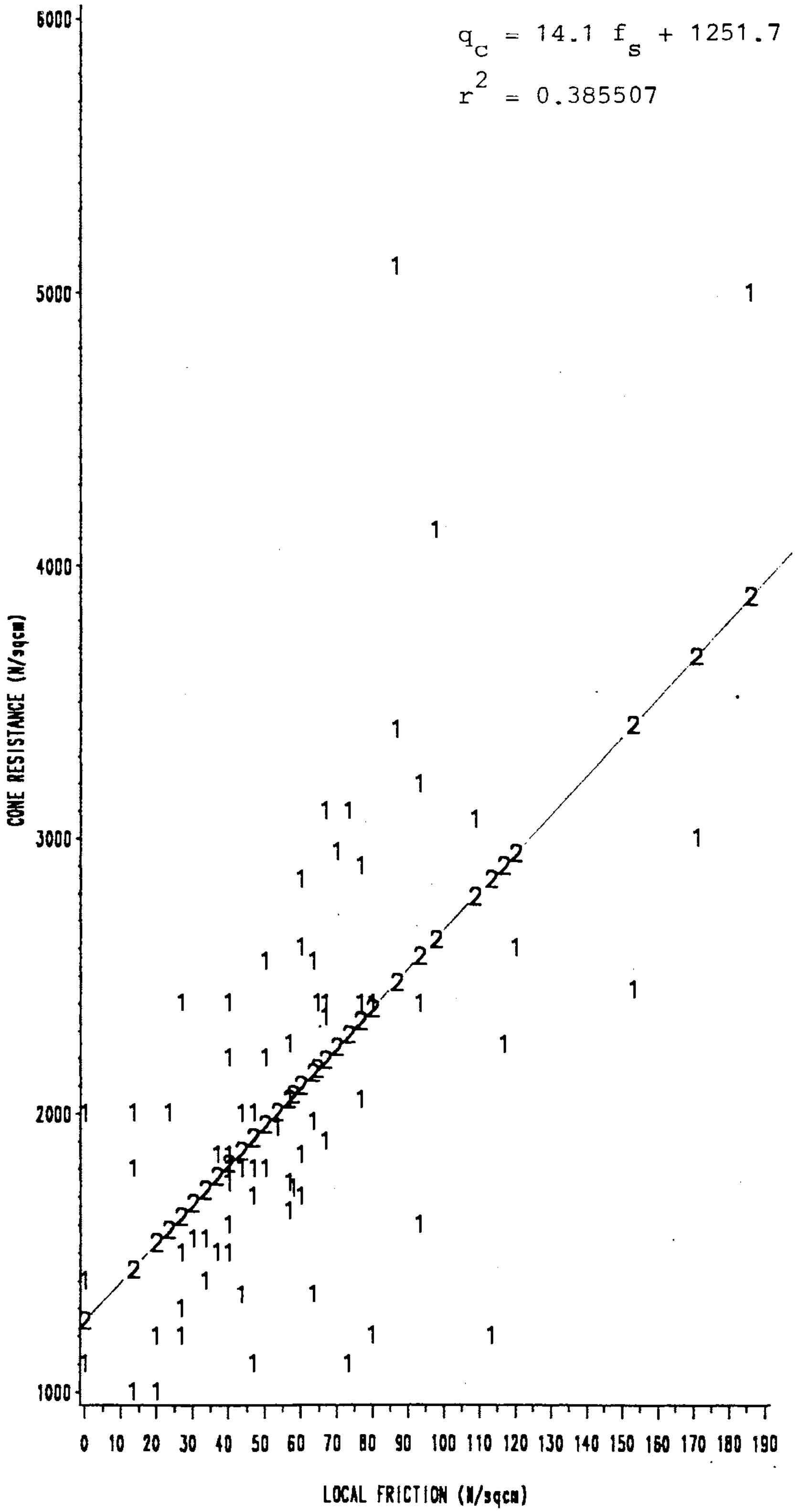


Figure 71. Relationship Between Cone Resistance (q_c) and Local Friction (f_s) for All Wagoner Lean Clay Data

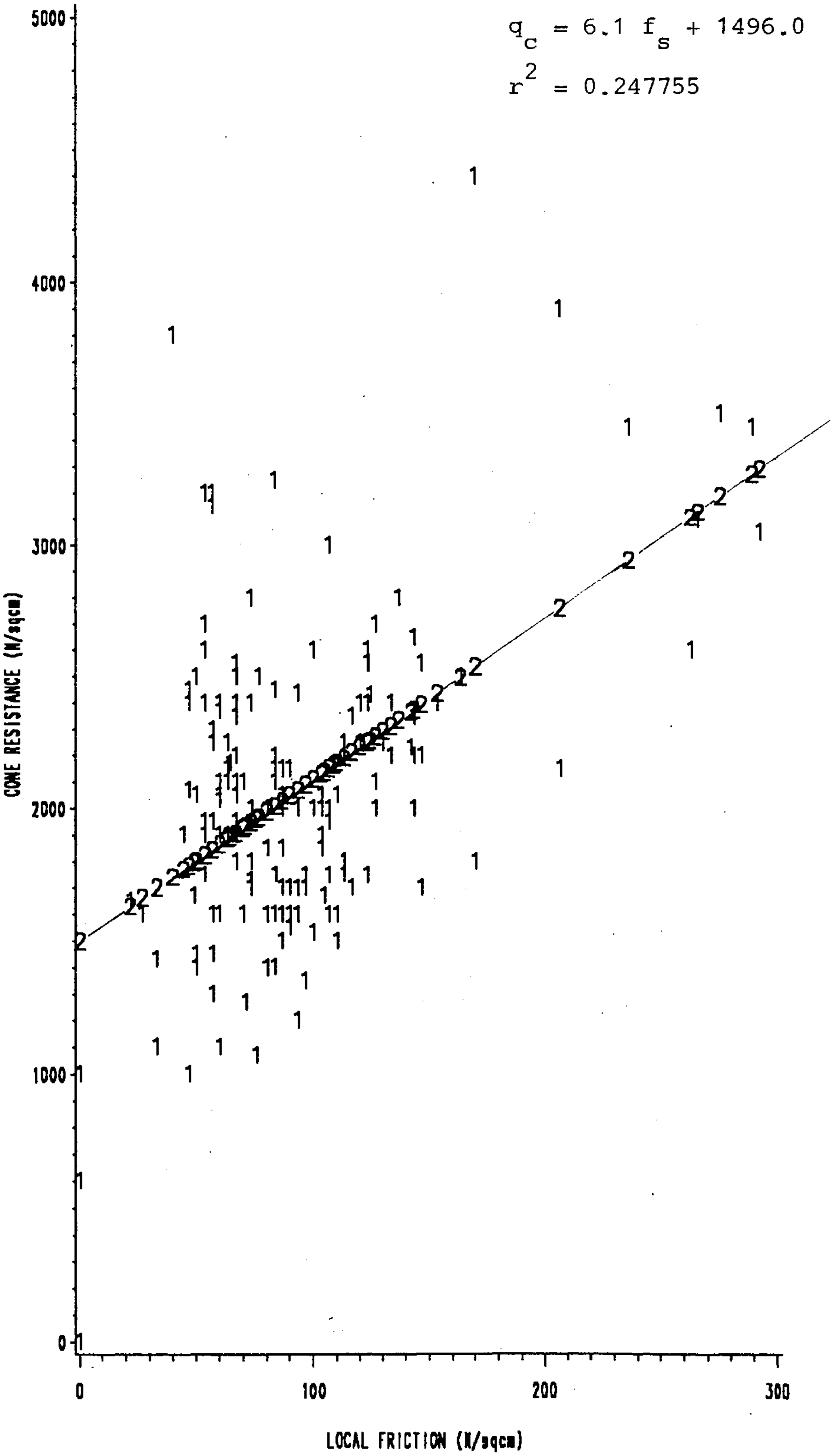


Figure 72. Relationship Between Cone Resistance (q_c) and Local Friction (f_s) for All Wagoner Fat Clay Data

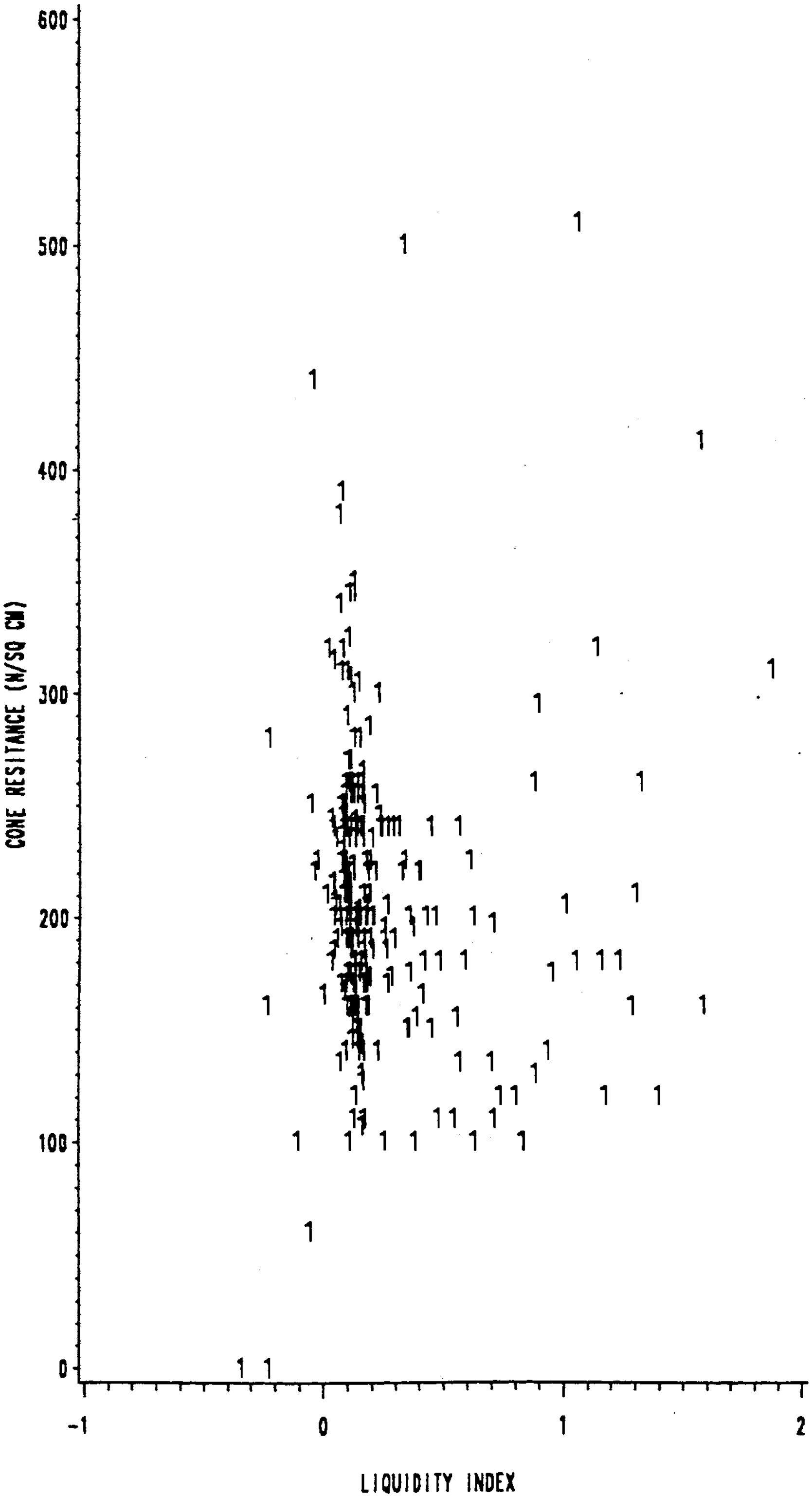


Figure 73. Cone Resistance Versus Liquidity Index for Wagoner Lean and Fat Clays

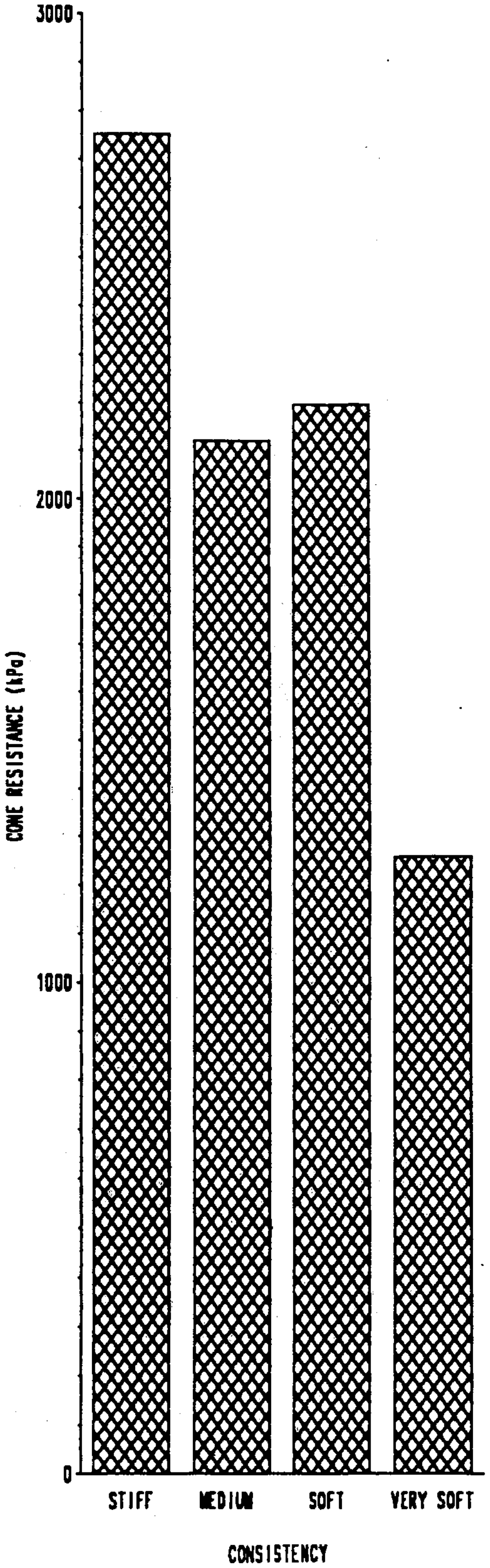


Figure 74. Cone Resistance Versus Clay Consistency Based on SPT Correlation From Table 3

resistance local friction and friction ratio to clay consistency as defined through correlation with the SPT (see Table III).

Cone Resistance Comparison Between Different Cone Tips

A correlation was made between cone resistance measured by the Dutch mantle cone and friction sleeve mechanical cone, and between the friction sleeve mechanical cone and the electric cone for lean and fat clays. Results are given in the form of q_c ratios in which the value of q_c (electric) is taken as unity (see Tables VII and VIII). The ratios indicate that the cone resistances are nearly the same for the Dutch mantle and friction sleeve mechanical cone:

$$\frac{q_c \text{ mantle}}{q_c \text{ friction sleeve}} = 1.11, \text{ Average for CH soils}$$

and

$$\frac{q_c \text{ mantle}}{q_c \text{ friction sleeve}} = 1.21, \text{ Average for CL soils}$$

The significance of the Dutch mantle and friction sleeve comparison is that the effect of clay filling the space between the point of the penetrometer and the friction sleeve is of minor importance for the clays in this study which is in agreement with previously reported literature. Results from the ratio of the friction sleeve mechanical cone to the electric cone are as follows:

$$\frac{q_c \text{ friction sleeve}}{q_c \text{ electric}} = 1.5959, \text{ Average for CH soils}$$

and

$$\frac{q_c \text{ friction sleeve}}{q_c \text{ electric}} = 1.3648, \text{ Average for CL soils}$$

These ratios indicate that friction sleeve cone resistance is larger than the electric cone resistance by a range of 36 to 60 percent. These cone ratios are attributed to the additional friction and bearing between the point of the penetrometer and the friction sleeve as compared with the cylindrical, straight shaft electric cone (see Appendix B).

SPT-CPT Correlation

Relationships between the cone resistance and SPT "N" resistance are presented in the form of histograms of q_c/N ratios which also indicate the mean and standard deviation. These comparisons are shown in Figures 75 through 78. Results indicate that the q_c/N ratio data follow a normal distribution based on plotting percent cumulative frequency from the histogram data of Figures 75 through 78 on normal paper. Figures 79 and 80 present percent cumulative frequency versus q_c/N diagrams for lean clay at Wagoner site. The q_c/N ratios for the clays studied were found to be the following:

Type	Mean	Standard Deviation
All lean and fat clay	$\bar{x} = 6.3$	$\sigma = 6.5$
All Wagoner clay	$\bar{x} = 5.8$	$\sigma = 5.4$
All lean clay, Wagoner	$\bar{x} = 6.9$	$\sigma = 5.2$
All fat clay, Wagoner	$\bar{x} = 3.5$	$\sigma = 1.7$

These data indicate ranges of q_c/N that were somewhat higher than is generally reported in the literature; however, peak q_c/N ratios from histograms were similar to those reported.

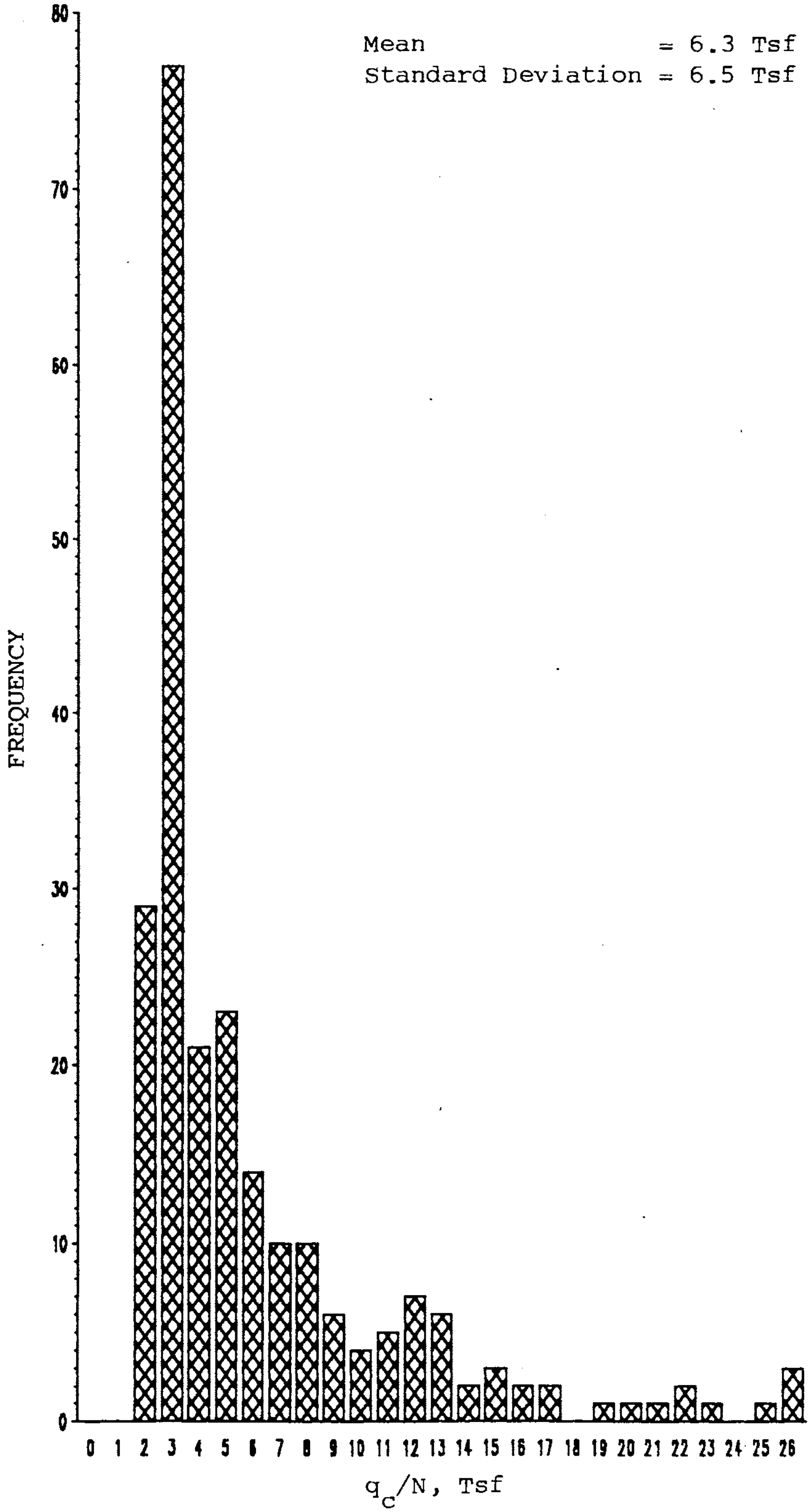


Figure 75. Histogram for q_c/N of Lean and Fat Clay From All Sites

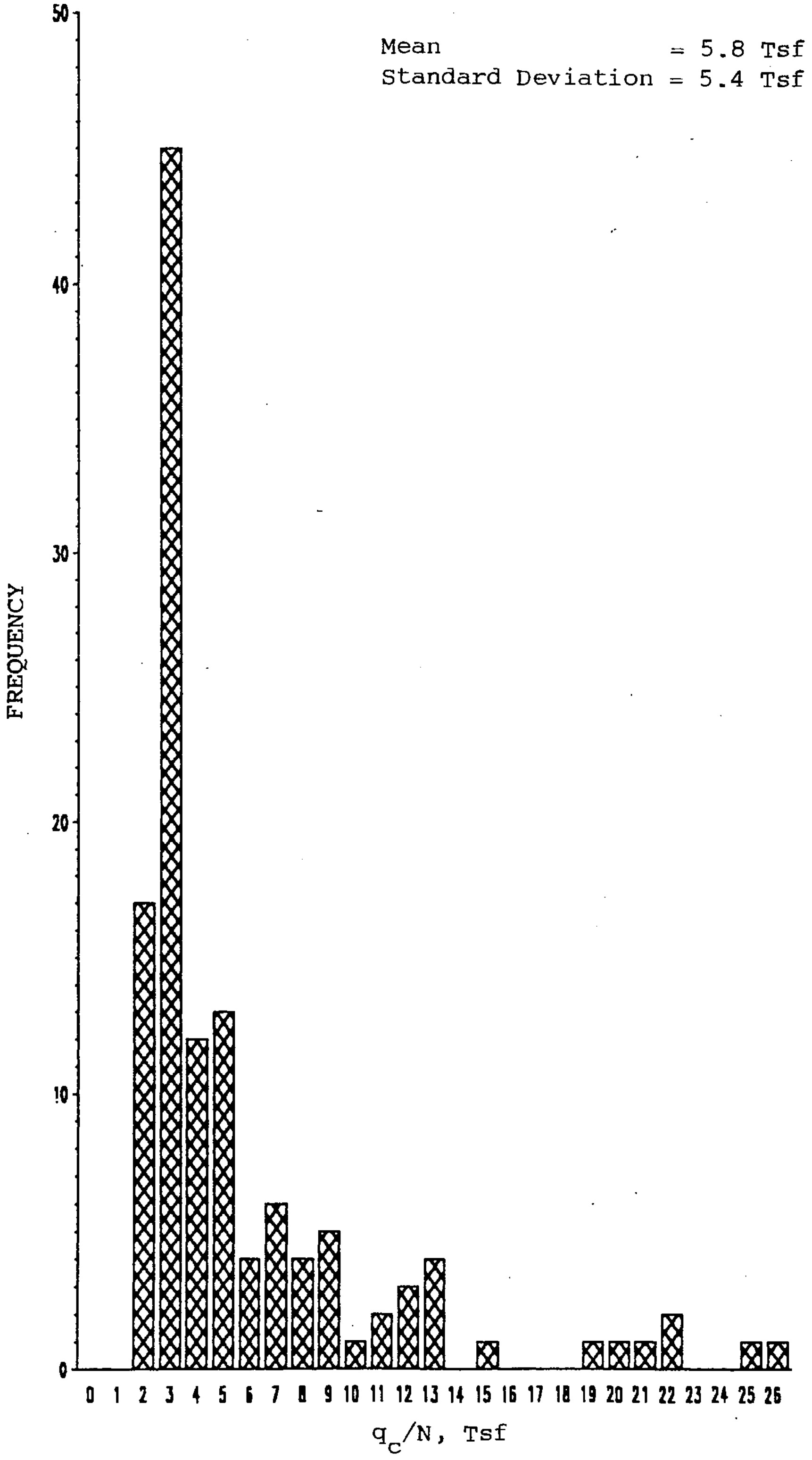


Figure 76. Histogram for q_c/N of Lean and Fat Clay From Wagoner

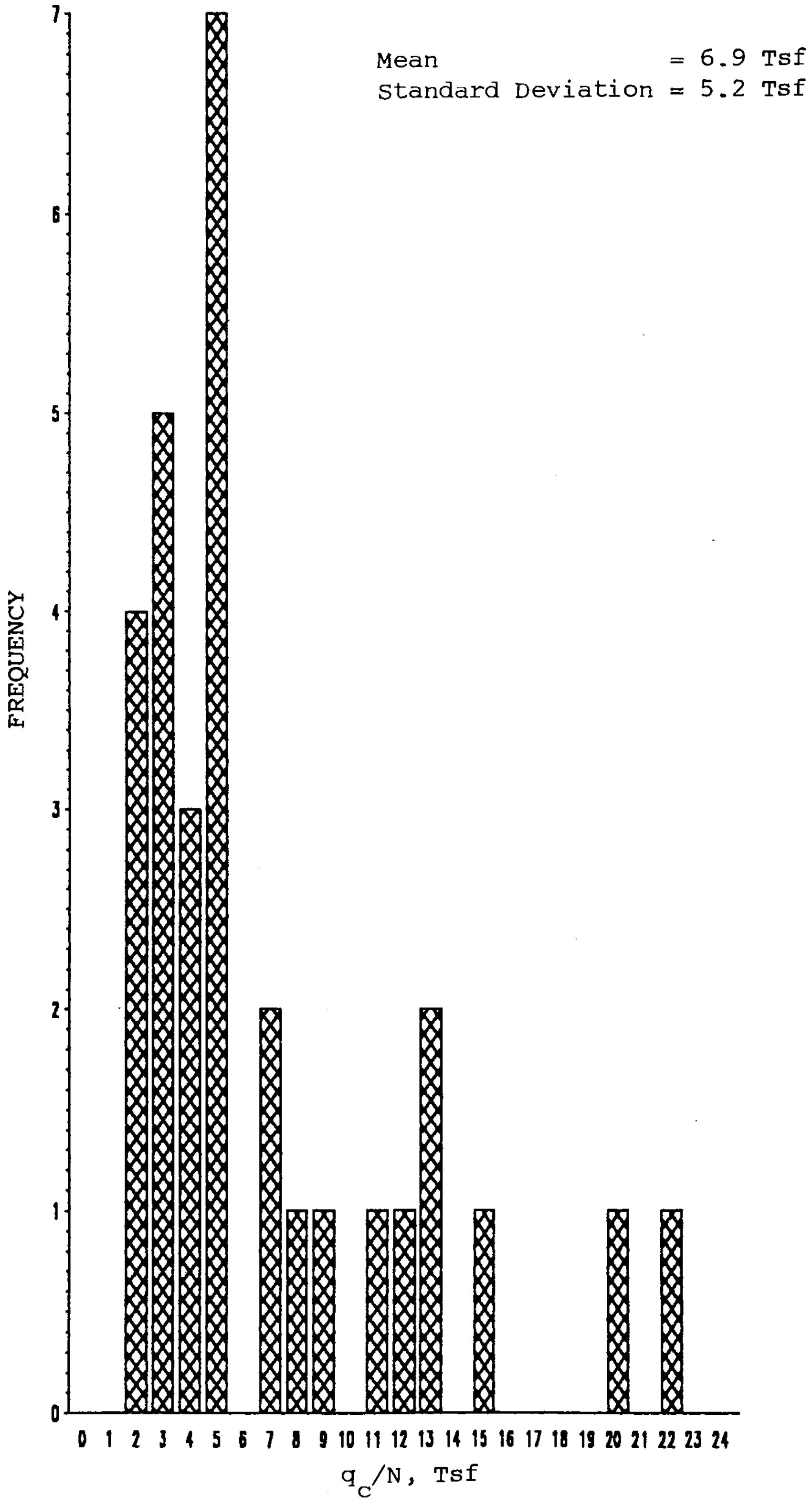


Figure 77. Histogram for q_c/N of Wagoner Lean Clay

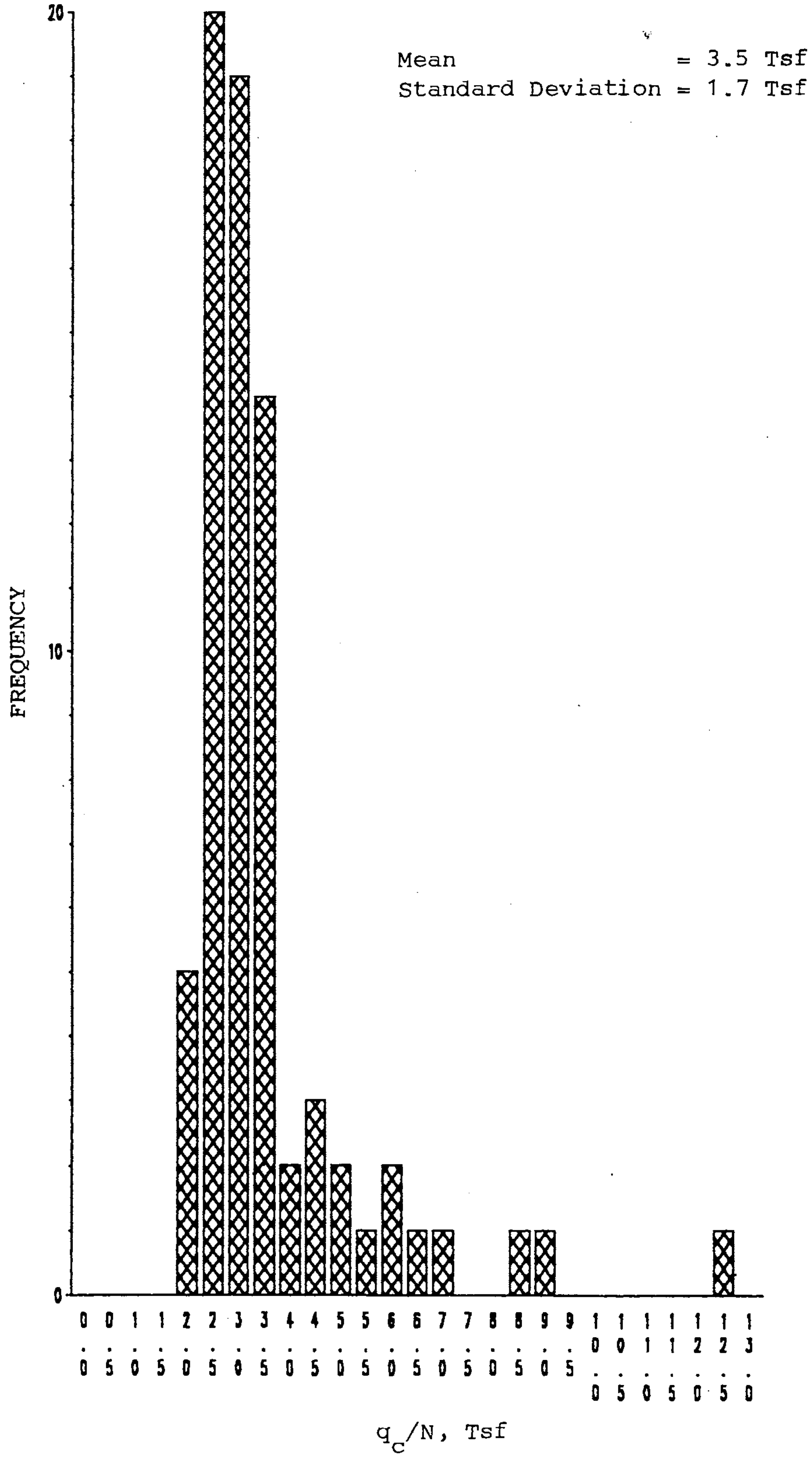


Figure 78. Histogram for q_c/N of Wagoner Fat Clay

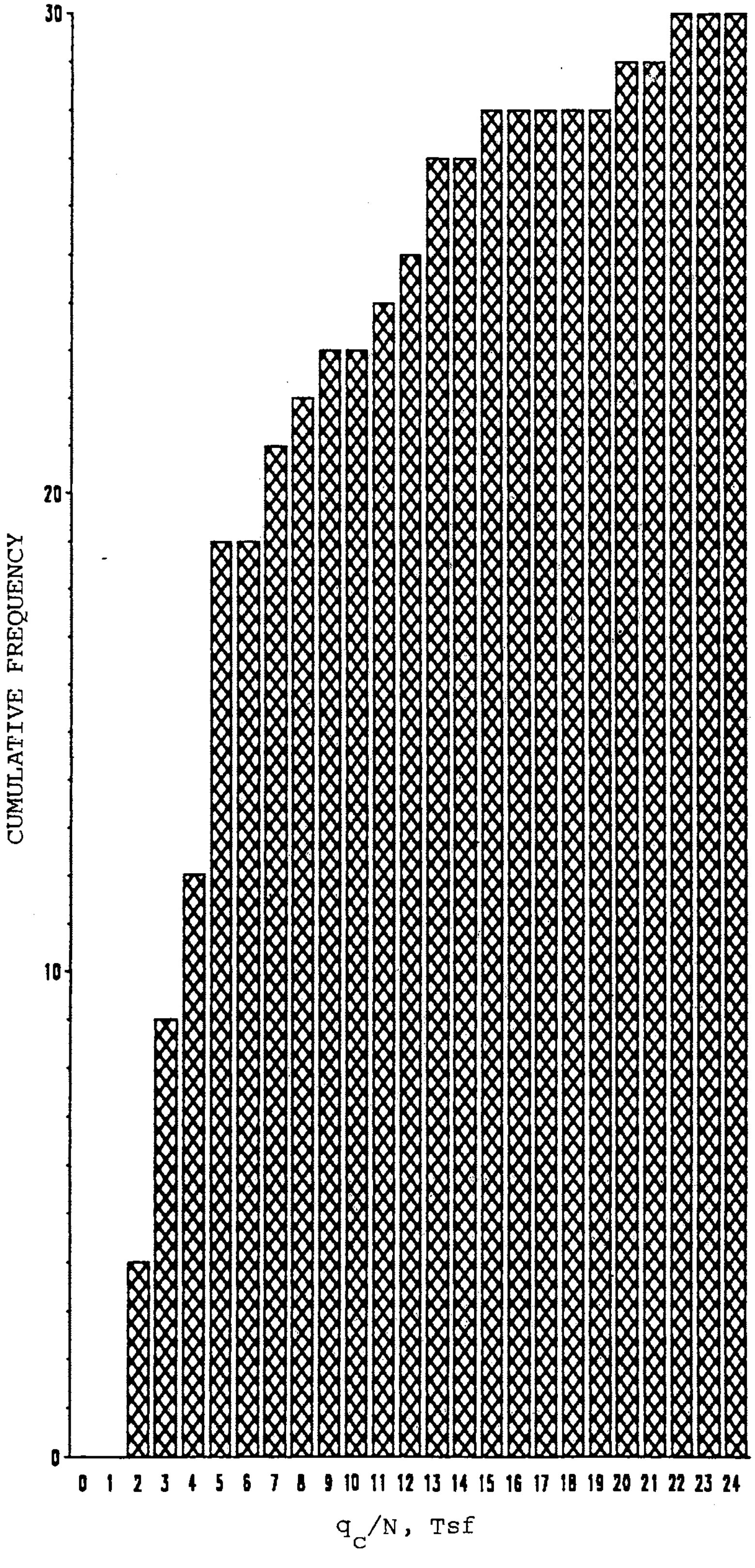


Figure 79. Cumulative Frequency Diagram for q_c/N of Wagoner Lean Clay

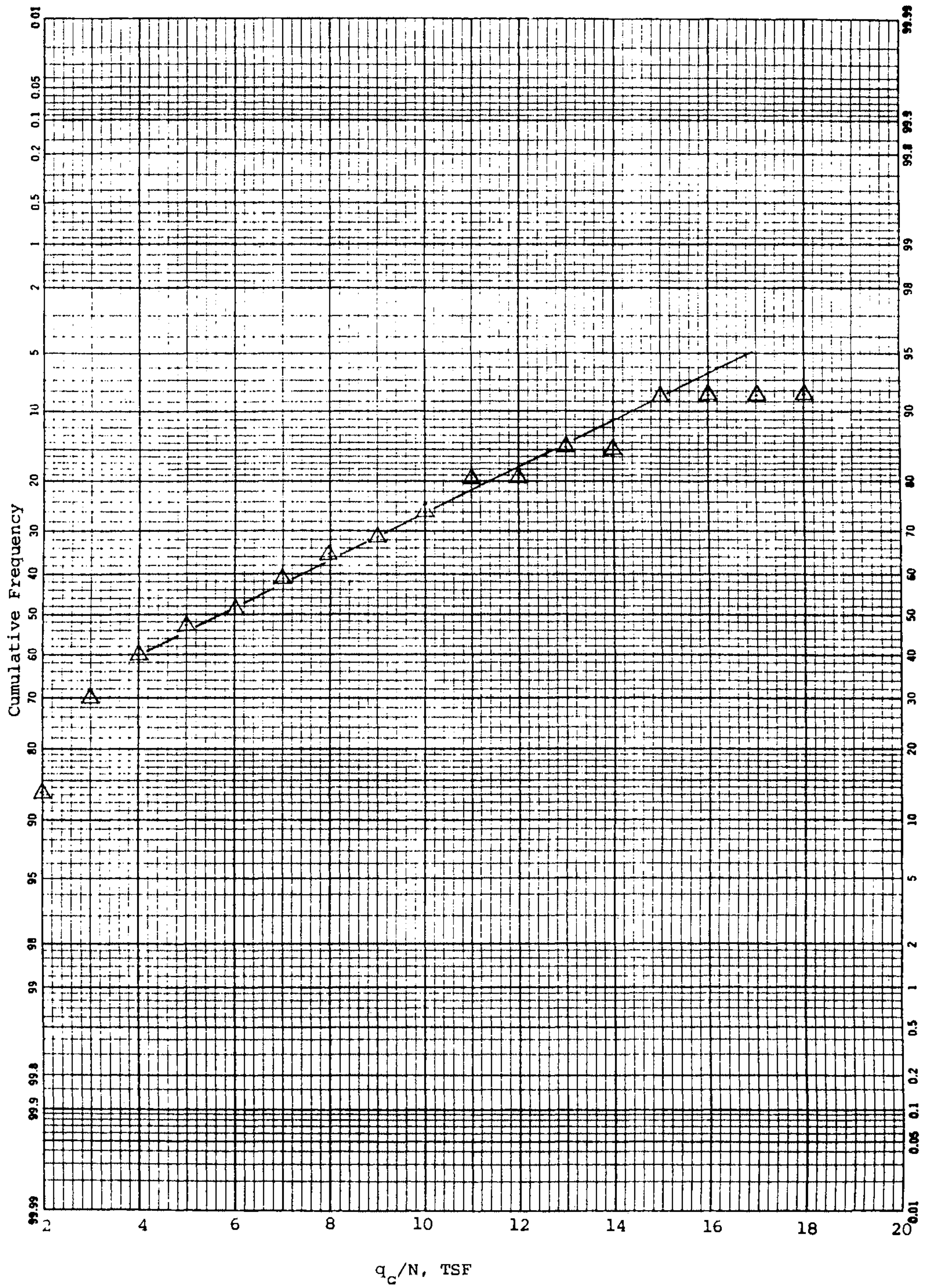


Figure 80. Cumulative Frequency Diagram for q_c/N of Wagoner Lean Clay

Correlations between cone resistance (q_c) and SPT-N-value were further investigated by linear comparisons for lean and fat clays at the Wagoner site. Figures 81, 82, and 83 indicate the results in the form of a regression line and equation from a method of least squares analysis of lean and fat clay from the Wagoner site.

Correlation of CPT and Undrained Shear Strength

A study of the relationship of undrained shear strength (s_u) and cone resistance (q_c) has traditionally involved the determination of the N_k factor from Equations (6) and/or (7). The development of the N_k factor depends upon a reference method for estimating in situ shear strength. The methods of estimating in situ shear strength used in this research include the following methods:

1. UU triaxial compression tests using 1.4 and 2.8 diameter specimens.
2. In situ PMT based on (a) limiting pressure derived from the pressuremeter test data and appropriate PMT correlation factor, N_p; and (b) the Gibson and Anderson method (44) by plotting $p - \log_e \Delta V/V$ PMT data and estimating s_u from the slope of the tangent portion of the $p - \log_e \Delta V/V$ curve.
3. Backcalculation of s_u from two embankment foundation soil slope failure case histories investigated by the author (46).

The UU triaxial test results from Table X show the influence of the secondary structure and disturbance on these clays in the difference in s_u. The s_u determined by 2.8-inch diameter UU triaxial test specimen was on average lower than that determined by 1.4-inch diameter UU triaxial test specimens. The resulting average N_k from Equa-

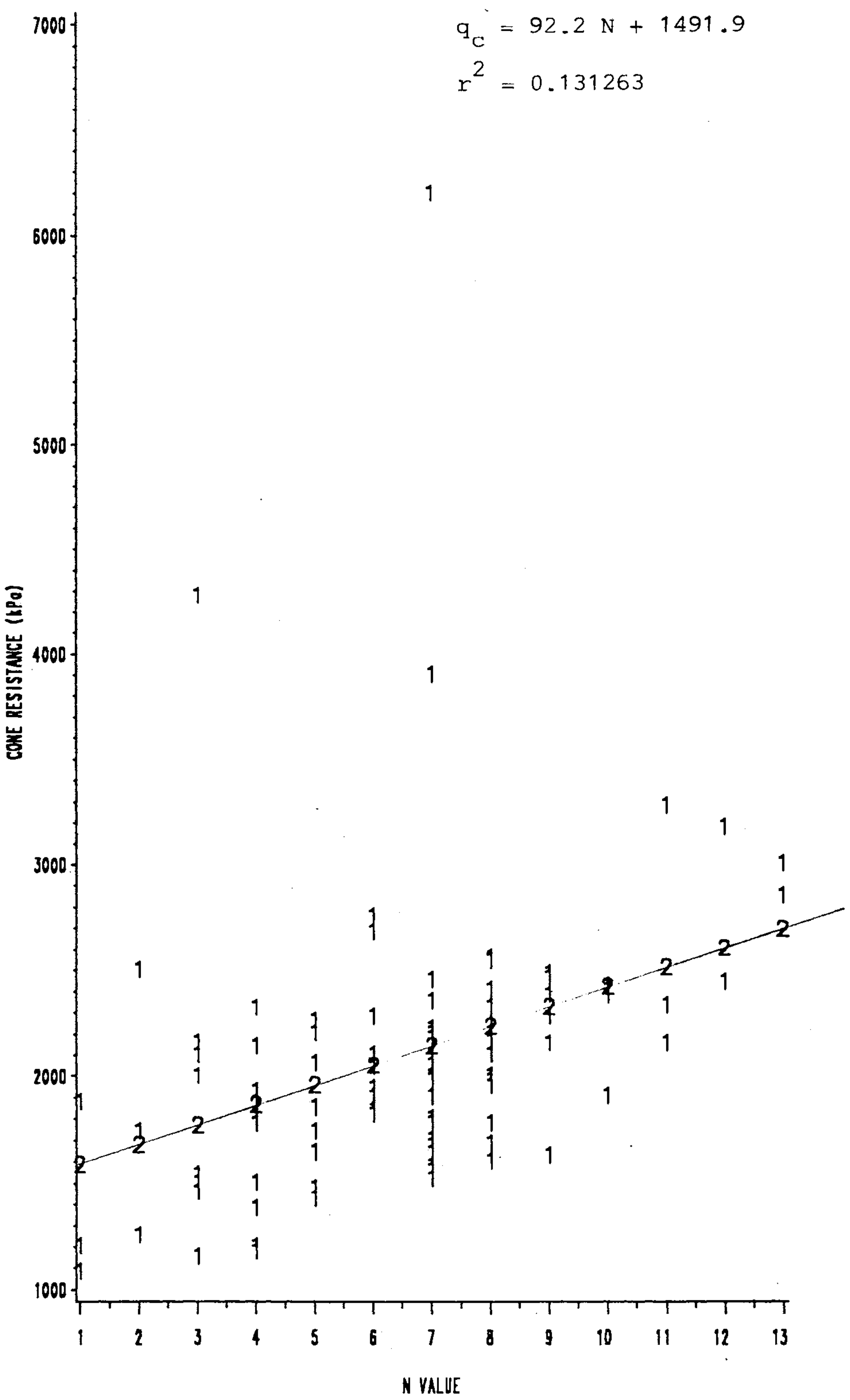


Figure 81. Relationship Between Cone Resistance (q_c) and SPT N Value for Wagoner Lean and Fat Clay

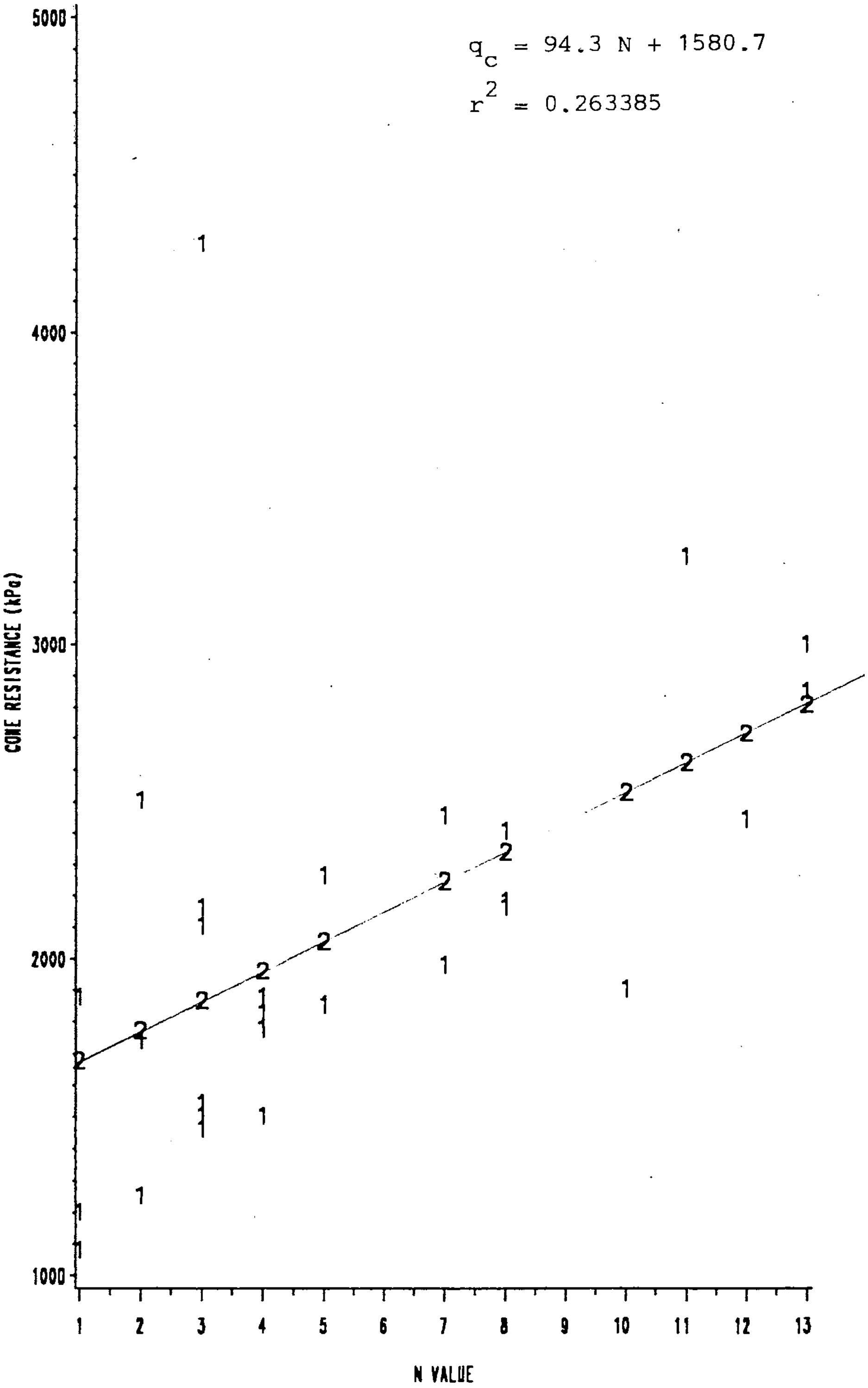


Figure 82. Relationship Between Cone Resistance (q_c) and SPT N Value for Wagoner Lean Clay

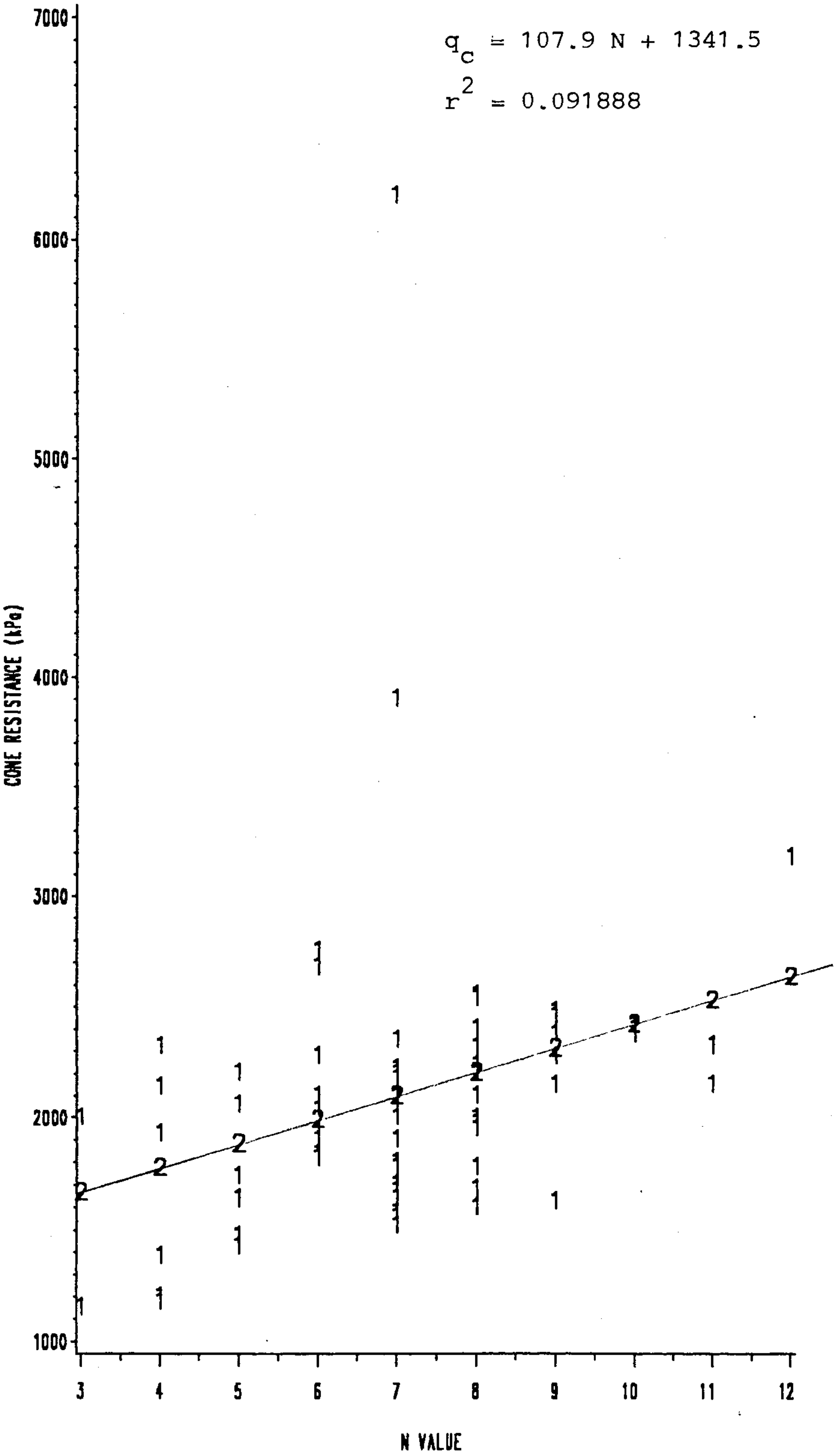


Figure 83. Relationship Between Cone Resistance (q_c) and SPT N Value for Wagoner Fat Clay

tions (6) and (7) for the larger 2.8-inch diameter test specimens is closer to the values reported in the literature for fissured clays than the average N_k for 1.4-inch test specimens. Also indicated in Table X is that Equations (6) and (7) show essentially the same N_k values.

The s_u estimated from pressuremeter tests with depth indicate similar N_k values to those obtained from 2.8-inch diameter UU triaxial test specimens (see Table VI). However, Marsland and Randolph (47) point out that s_u determined by the Gibson and Anderson method overestimates s_u for stiff fissured clays. They recommend using the limiting pressure approach and an appropriate PMT N_p correlation factor in the s_u equation (see Table VI). The value of N_p correlated with large plate bearing tests and applicable to fissured clays is 6.2. Substituting s_u (PMT) based on limiting pressure into Equation (7) gives values of N_k that are compatible with those reported in the literature (see Table VI). A plot of undrained shear strength (s_u) and cone resistance (q_c) shows the variation in N_k with regard to the reference s_u used (see Figures 84 and 85). It appears that the wide scatter is influenced by inappropriate reference s_u.

Backcalculated undrained shear strength from two failed slopes was used to estimate the s_u based on a $\phi = o$ approach for arriving at an average mobilized shear strength along the slippage plane. Extensive details were applied to define a failure surface for embankment /foundation slope failures at the Wagoner and Roland sites. Backcalculated shear strength from these slides was used to estimate the N_k from Equations (6) and (7). Results indicate an $N_k = 34$ for the Wagoner slide and $NB_k = 42$ for the Roland slide.

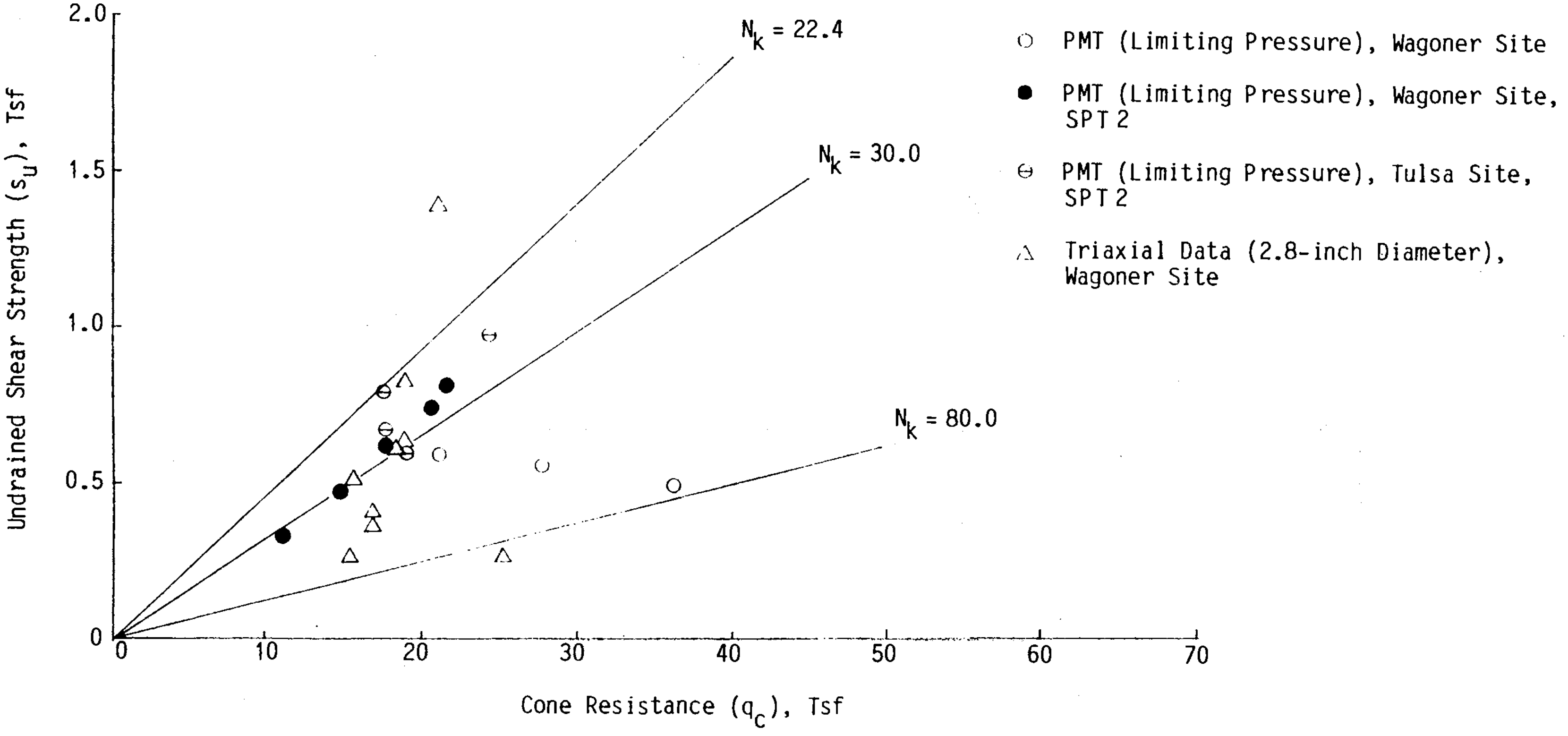


Figure 84. Relationship Between Undrained Shear Strength and Cone Resistance

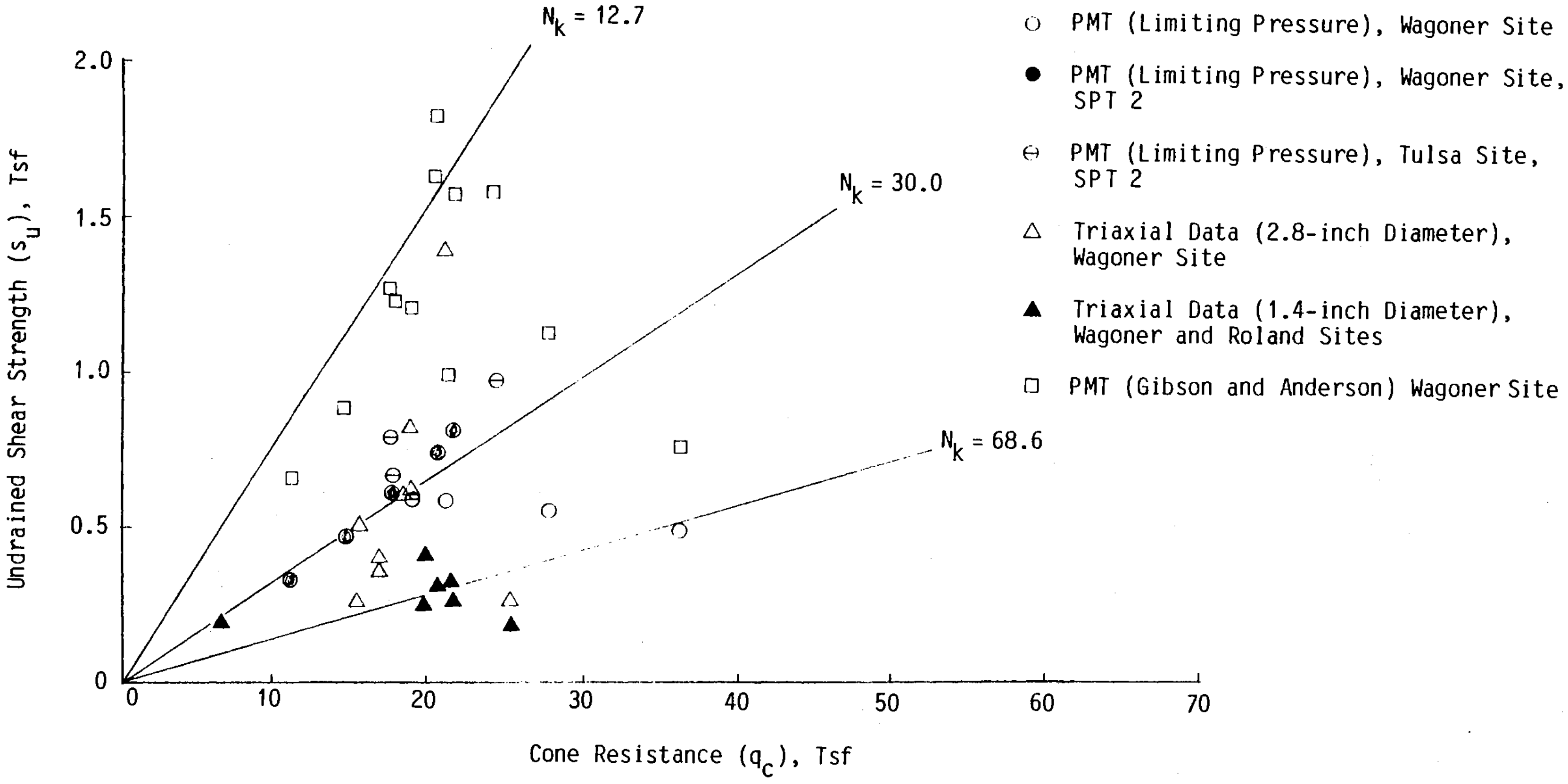


Figure 85. Relationship Between Undrained Shear Strength and Cone Resistance, All Data

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this investigation were to determine possible relationships between the cone penetration test results and typical engineering parameters for alluvial soils. Basic considerations were correlations between CPT data and soil classification, relationships with CPT data and Atterberg limits and clay consistency, a comparison of CPT tip geometry with regard to cone resistance, development of a q_c/N ratio for lean and fat clays, and development of relationships between undrained shear strength and cone resistance.

Conclusions

The results of the testing program and analysis of data obtained indicate the following conclusions:

1. Sufficient data were analyzed to characterize the alluvial soils as, typically, highly plastic desiccated firm to stiff clay that tends to become soft and nonstructed with depth. The stress history as indicated by the OCR from Table IX is typical of the alluvial clays with depth. All clays were found to have a secondary structure consisting of cracks, joints, fissures, and slickensides. The depth of the secondary structure influence decreases, slowing with depth.

2. The direct application of the Begemann and Schmertmann CPT soil classification schemes gives generally inconsistent log descriptions when compared to detailed boring logs. However, they can qualitatively separate fine and coarse grained soils. The Searle classification appears to be most suitable for the study area soils. An examination of Figures 53 and 54 shows a tendency to fall to the left side with respect of the vertical limits traced on the chart for clay soils. This means that the measured values of the local friction are relatively low in comparison with cone resistance. Also, the fact that these clays are overconsolidated, which results in less possible deformation, can increase cone resistance without any appreciable increase of the local friction. The friction ratios for lean and fat clays tend to match those reported in the literature. The dispersion of the data within one standard deviation is fairly well defined. The data for lean and fat clays appear to follow a normal distribution. For a 95 percent confidence level, the friction ratios have a narrow range. This suggests that the friction ratios for lean and fat clays overlap. This is evident also by Figures 53 and 54.
3. A correlation between CPT cone resistance and Atterberg limits and clay consistency was not possible with this sample population. The dispersion of the data was considered the reason for a lack of correlation; however, there were some vague trends suggested in some of the CPT-SPT boring and sampling combinations.

4. A comparison of cone resistance measured by different cone types supports expected trends. The Dutch mantle and friction sleeve cones gave essentially the same cone resistance. Internal friction of the inner rods nor that associated with friction sleeve did not appear to be significant. The friction sleeve and electric cone comparison followed the trend reported in the literature but by a higher percentage.
5. The relationship between CPT and SPT, based on the mean and standard deviations in this study, indicate higher q_c/N ratios for lean and fat clays than reported in the literature. However, peak values of q_c/N are nearly identical. Some moderately good linear correlations were found between cone resistance and N resistance (reference Figures 81, 82, and 83). Comparison between local friction and SPT N resistance showed no significant correlation. These findings appear to contradict Begemann's conclusion (29) in that he showed the correlation to be much better between local friction and SPT N resistance. One might conclude that CPT cone resistance is more proportional during driving to the end resistance of the SPT sampler. Note that the horizontally projected area of the SPT sampler equals 10.7 cm^2--nearly the same as the 10.0 cm^2 of the CPT cone. The linear correlation between cone resistance and SPT N resistance would appear attributable to the preconsolidation state of the soils which results in less possible deformation as noted in item 2.

6. A relationship between CPT cone resistance and undrained shear strength, N_k factor, was found to be influenced by the following:
    a. Sample size, based on the 1.4- and 2.8-inch diameter comparisons, affects the estimate of N_k. The 1.4-inch size sample size does take into account secondary clay structure.
    b. The scale effect of these clays' secondary structure relative to the size of the cone resistance was estimated to range between scales (a), (b), and (c) of Figure 17. The (a) scale could be observed in the upper four feet of the soil profile (B-horizon). The (b) scale was predominately found in the majority of the soil profile. Below approximately 18 to 20 feet the scale was found to transition from (b) to (c) scale. These observations were based on intensive logging detail.
    c. Estimated N_k values based on Equations (6) and (7) were essentially the same, based on results shown in Tables VI and X.
    d. The N_k factor for the Wagoner site based on 2.8-inch diameter triaxial test specimens averaged 39. The N_k factor based on PMT averaged 34. By using backcalculated undrained shear strength data from a slope failure at the Wagoner site, the N_k factor was estimated at 34. These N_k values are slightly higher than what has been reported in the literature (12). However, based on three separate approaches, the N_k values fall into a narrow range.

e. The clay stiffness and structure within the top 4.0 to 5.0 feet apparently influenced these average N_k values. However, neglecting the top three N_k values (Equation 2) did not significantly lower the N_k average.

Recommendations

1. The data base should be expanded to refine the correlations for more northeastern quarter alluvial clays that have the physical property and engineering characteristics of the study area soils.
2. There appears to be a significant impact of preconsolidation on the cone parameters. In any future studies, correlation of OCR with cone parameter should be investigated.
3. With a larger data base more sophisticated statistical procedures may in future studies indicate relationships between cone parameters and Atterberg limits and clay consistency.
4. The correlation between N_k and undrained shear strength should be further studied to delineate ranges for fissured clays.

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APPENDIX A

EUROPEAN RECOMMENDED STANDARD, 1977

Report of the Subcommittee of Standardization

of Penetration Testing in Europe

9th INTERNATIONAL CONFERENCE ON SOIL MECHANICS

AND FOUNDATION ENGINEERING, 1977

APPENDIX A

RECOMMENDED STANDARD FOR THE CONE PENETRATION TEST (CPT)

CONTENTS

1. SCOPE

The cone penetration test consists in pushing into the soil, at a sufficiently slow rate, a series of cylindrical rods with a cone at the base, and measuring continuously or at selected depth intervals the penetration resistance of the cone, and if required the total penetration resistance and/or the friction resistance on a friction sleeve.

Cone penetration tests are performed in order to obtain data on one or more of the following subjects:

1) the stratigraphy of the layers, and their homogeneity over the site

2) the depth to firm layers; the location of cavities, voids and other discontinuities

3) soil identification

4) mechanical soil characteristics

5) bearing capacity of piles

2. DEFINITIONS

2.1 CPT stands for Cone Penetration Test and includes what has been variously called Static Penetration Test, Quasi Static Penetration Test and Dutch Sounding Test.

2.2 Penetrometer (apparatus): an apparatus consisting of a series of cylindrical rods with a terminal body, called the penetrometer tip and the measuring devices for the determination of the cone resistance, the local side friction and/or the total resistance.

2.3 Penetrometer tip.

2.3.1 Penetrometer tip proper: the terminal body at the end of the series of push rods, which comprises the active elements that sense the cone resistance, and the local side friction resistance.

2.3.2 Conventional penetrometer tip: by convention, if the length of the part of the penetrometer tip proper located above the cone is smaller than 1000 mm, the push rod length to be added to the length of the penetrometer tip in order to obtain a length of 1000 mm.

2.4 Cone: the part of the penetrometer on which the end bearing is developed.

According to the design of the apparatus the following are distinguished:

2.4.1 Fixed cone penetrometer tip: the cone can only be subjected to micro relative displacements with respect to the other elements of the tip.

According to the shape of the cone the following are distinguished

2.4.3 Simple cone in which the cylindrical prolongation above the conical part is generally equal to the diameter of the cone base.

2.4.4 Mantle cone: a cone which is prolonged with a more or less cylindrical sleeve, whose length is larger than the diameter of the base of the cone: this sleeve is called the mantle.

2.5 Friction sleeve: The section of the penetrometer tip upon which the local side friction to be measured is developed.

2.6 System of measurement.

The system includes the measuring devices themselves and the means of transmitting information from the tip to where it can be seen or recorded. For example the following can be distinguished:

2.6.1 Electric penetrometer: which uses electrical devices such as strain gauges, vibrating wires, etc..., built into the tip.

2.6.2 Mechanical penetrometer: which uses a set of inner rods to operate the penetrometer tip.

2.6.3 Hydraulic and pneumatic penetrometer which uses hydraulic or pneumatic devices built into the tip.

2.7 Push rods: the thick walled tubes or rods used for advancing the penetrometer tip and, in addition, to guide and shield the measuring system.

2.8 Inner rods: solid rods which slide inside the push rods to extend the tip of a mechanical penetrometer.

2.9 Thrust machine: the equipment that pushes the penetrometer into the soil. The necessary reaction for this machine is obtained by dead weight or/and anchors.

2.10 Friction reducer: narrow local protuberance outside the push-rod surface, placed at a certain distance above the penetrometer tip, and provided to reduce the total friction on the push-rods.

2.11 Continuous and discontinuous penetration testing (see note 1 - para.11).

2.11.1 Continuous penetration testing: a penetration test in which the cone resistance is measured, while the elements of the penetrometer have about the same rate of penetration.

2.11.2 Discontinuous penetration testing: a penetration test in which the cone resistance is measured, while the other elements of the penetrometer tip remain stationary. When a friction sleeve is also included the sum of the cone resistance and resistance on the sleeve is measured when both cone and friction sleeve are pushed down, while the other elements of the penetrometer tip remain stationary.

2.12 The cone resistance q_c.

The cone resistance is obtained by dividing the total force acting on the cone Q_c, by the area of the base of the cone A_c

$$q_c = Q_c : A_c$$

This resistance is expressed in Pa, kPa or MPa x).

2.13 The local side friction f_s: the local unit side friction is obtained by dividing the force Q_s, needed to push down the friction sleeve, by its surface area A_s

$$f_s = Q_s : A_s$$

The local resistance f_s is expressed in Pa, kPa or MPa x).

2.14 Total force Q_t: the force needed to push cone and push-rods together into the soil. Q_t is expressed in kN.

2.15 Total side friction Q_{st}: this is generally obtained by subtracting the total force on the cone Q_c, from the total force Q_t

$$Q_{st} = Q_t - Q_c$$

Q_{st} is expressed in kN, as are Q_t and Q_c. Certain penetrometers allow Q_{st} to be measured directly.

2.16 Friction Ratio R_f and Friction Index I_f (see note 2 - para. 11).

2.16.1 Friction Ratio R_f: the ratio of the local side friction f_s to the cone resistance q_c, measured at the same depth, expressed as a percentage.

2.16.2 Friction index I_f: the ratio of the cone resistance q_c to the local side friction f_s, measured at the same depth.

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x) 1 Pa (Pascal) = 1 $N m^{-2}$

3. RECOMMENDED STANDARD PENETROMETER

3.1 General geometry of the penetrometer tip.

In the recommended standard penetrometer testing, penetrometer tips with or without a friction sleeve can be used (Fig. 1a and Fig. 1b)

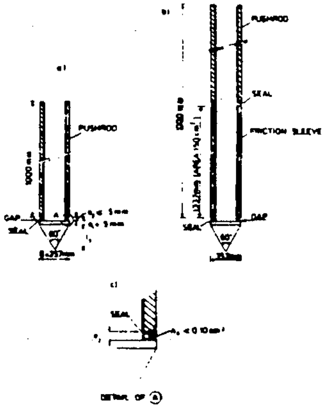


Fig 1. Recommended standard penetrometer with a fixed cone and without (a) or with (b) a friction sleeve.

The penetrometer tip must have the same diameter as the cone over a length of 1000 mm above the cone base. The gap between the cone and the other elements of the penetrometer tip should be kept to the minimum necessary for the operation of the sensing devices, and designed and constructed in such a way as to prevent the entry of particles. This is also to apply to the gaps at either end of the friction sleeve, if one is included, and the other elements of the penetrometer tip. The axes of the cone, the friction sleeve if included and the body of the penetrometer tip, must be coincident.

In the case of a penetrometer tip without a sleeve, its diameter shall be the same as that of the base of the cone with a tolerance of -0.3 mm and +1 mm, over a length of 1000 mm (≈ 30 times the diameter of the base).

In the case of a penetrometer tip with a friction sleeve, the part of the penetrometer tip located above the friction sleeve shall have the same diameter as the friction sleeve over a length of 450 mm (≈ 12 times the diameter of the base) with a tolerance of +0.3 mm. The other parts of the penetrometer tip must also correspond with the above conditions for a penetrometer tip without a sleeve.

3.2 The cone.

The diameter of the base of the cone is 35.7 mm. The apex angle of the cone is 60°.

The cone is to be continued by a cylindrical extension (Fig. 2); the height e_1 of this extension is 5 mm.

Manufacturing tolerances

on the diameter of the base of the cone +0.3 mm

$35.7\ mm \leq \Phi \leq 36.0\ mm$

on the height of the cone +0.3 mm

$31.0\ mm \leq l_1 \leq 31.3\ mm$

roughness of the cone < 5 µm.

Operating tolerances

wear on the diameter of the base of the cone -1 mm

$34.7\ mm \leq \Phi \leq 36.0\ mm$

wear on the height of the cone -7 mm

$24.0\ mm \leq l_1 \leq 31.3\ mm$

wear on the length of the cylindrical extension -2 mm

cones with a visible asymmetrical wear are to be rejected.

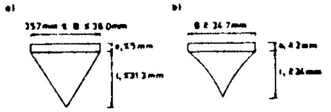


Fig 2. Manufacturing (a) and operating (b) tolerances of the recommended standard cone.

3.3 Gap and seal above the cone (Fig. 1).

The gap between the cone and the other elements of the penetrometer must not be larger than 5 mm.

The seal placed in the gap should be properly designed and manufactured in order to prevent the entry of soil particles into the penetrometer tip. It must have a deformability many times larger than that of the sensing devices. The cross-sectional area A_e of the gap remaining after deduction of the area occupied by the seal must be smaller than [illegible] cm² (see cross-hatched area in Fig 1c). The outer limits of the gap are to be shaped in such a way that the measurements are not affected by the possible entry of soil particles.

3.4 Sensing devices.

The sensing device should be designed to measure the cone resistance without being influenced by a possible eccentricity of that resistance.

3.5 Friction sleeve (Fig. 1b)

The diameter of the friction sleeve is to be manufactured and the sleeve retained in operation, only so long as it is at least the same value as the base of the cone, with a tolerance of +0.35 mm.

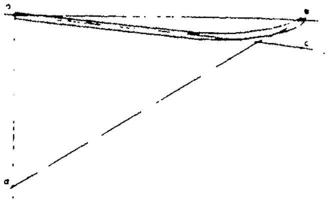
The surface area of the friction sleeve shall be 150 cm² with a tolerance of ±2%. The surface of the friction sleeve shall have a manufactured surface roughness of 0.5 um (see note 3 para. 11) with a tolerance of ±50% in the direction of its longitudinal axis. In operation this roughness shall not become smaller than 0.25 um. The projection above and below the friction sleeve shall correspond with the other parts of the penetrometer tip.

The friction sleeve is to be located immediately above the cone (Fig. 1b). The annular spaces between the friction sleeve and the other part of the penetrometer tip and their seals must conform to the same specifications as described under 3.3.

3.6 Push rods.

The push rods are screwed or attached together to bear against each other and to form a rigid-jointed series with a continuous straight axis. The deviation from the axis should not exceed 4‰ x) for the five lower push rods of the series and 8‰ x) for the remainder. The manner in which the "deviation" is determined is shown in Fig. 3

When measuring the total friction with push-rods their diameter over the total length shall be 36 mm with a tolerance of ±1 mm.



$\frac{bc-ad}{ab}$ ≤ 4‰ FOR THE 5 LOWER PUSHRODS
≤ 8‰ FOR THE OTHER PUSHRODS

Fig 3. Determination of the deviation from the straight axis for push-rods.

3.7 Measuring equipment.

The resistances are to be measured by devices attached to the cone and the friction sleeve if included, and the signals are to be transmitted by a suitable method to a data recording system.

Exclusive recording of test results on a tape, which does not permit direct accessibility to the data, is not recommended.

3.8 Thrust machine.

The machine shall be able to provide a stroke preferably of one meter, and shall push the rods into the soil at a constant rate of penetration. The thrust machine shall be anchored and/or ballasted such that it does not move relative to the soil surface during the pushing action.

3.9 Friction reducer.

If a friction reducer is included, it should be located at least 1000 mm above the base of the cone.

4 STANDARD TESTING PROCEDURE

4.1 Continuous testing.

The standard testing procedure is that of continuous penetration testing, in which the measurements are made while all elements of the penetrometer have the same rate of penetration.

4.2 Verticality

The thrust machine is to be erected to obtain a thrust direction as near vertical as practicable. The maximum acceptable deviation of the thrust direction from the vertical is 2%. The axis of the push-rods must coincide with the thrust direction.

4.3 Rate of penetration.

The rate of penetration is the rate of the downward movement of the element of the penetrometer under consideration at the time the force on that element is measured.

The rate of penetration is 2 cm/sec with a tolerance of ± 0.5 cm/sec. This rate must be maintained during the entire stroke, even if readings are only taken at intervals.

4.4 Interval of readings.

A continuous reading is recommended. In no case shall the interval between the readings be more than 20 cm.

4.5 Measurement of the depth.

The depths are to be measured with an accuracy of at least 10 cm.

5. PRECISION OF THE MEASUREMENTS

Taking into account all possible sources of error (parasitical frictions, errors of the recording devices, eccentricity of the load on the cone resp. the sleeve, temperature differences, etc...) the precision to be obtained should not be worse, than the larger of the following values:

5% of the measured value
1% of the maximum value of the range.

The precision must be verified in the laboratory or in the field taking into account all possible disturbing influences.

6. PRECAUTIONS, CHECKS AND VERIFICATIONS

6.1 Before the CPT is made, the straightness of the push-rods, particularly of the lower five rods of the series, has to be checked. A method of checking the straightness consists in standing the push-rod vertically, spinning it, and observing whether it wobbles while it is rotating. If the wobble is noticeable, the push-rod should be discarded.

6.2 Regular inspections are to be made for wear (of the cone and friction sleeve).

6.3 It is also necessary to check that the CPT test is not performed too close to existing boreholes or other penetrometer tests. For CPT tests with extended penetration it is recommended not to go closer than 25 boring diameters from uncased and unfilled boreholes, or at least 1 m from previously performed CPT tests.

6.4 The seals between the different elements of a penetrometer tip are to be regularly inspected to determine their quality. Prior to use the seals are to be checked to determine if soil particles are present.

6.5 Where the signals of the measuring devices built into the penetrometer tip are transmitted to the surface by an electric cable, it should be continuous, and consequently prethreaded through the push-rods.

6.6 Electric penetrometer tips should be temperature compensated. If the shift observed after extracting the tip is so large that the conditions of accuracy as defined under para. 5 are no longer met, the test should be discarded.

6.7 The friction sleeve transducer must operate in such a way that only shear stresses, and not normal stresses, are recorded.

7. CALIBRATION

7.1 When manometers are being used, they are to be recalibrated at least every 6 months.

For each type of manometer there must be two identical units, each with its own calibration, available with the machine. At regular intervals the manometer used in the tests shall be checked against the reserve manometer.

7.2 The calibration of load cells or proving rings should be verified at least every 3 months.

Regular checks on the site with an appropriate field control unit are recommended.

8. SPECIAL FEATURES

8.1 Push-rod guides.

Guides should be provided for the part of the push-rods protruding above the soil and for the push-rod length in water in order to prevent buckling.

8.2 Inclinometers.

In order to obtain more precise information

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x) These deviations corresponds in case of an even curvature to a deflexion of 1-2 mm in length on the drift of the push-rods into the soil. Inclinometers may be built into the penetrometer tip.

The need of such information depends on the soil conditions and increases with increasing depth of the test.

8.3 Push rods with smaller diameters.

In order to decrease the skin friction on the rods, use can be made of push-rods with a smaller diameter than that of the penetrometer tip. The distance between the smaller diameter push-rods and the cone base should be at least 1000 mm.

9. REPORTING OF RESULTS

9.1 The following information shall be reported on the graphs of the measurements:

1. In order to state that the penetrometer and the test procedure are completely in agreement with the recommended Standard, each graph shall be marked with the letter S.
   After this letter will be added one of the following letters indicating the system of measurement:

   M = mechanical
   E = electric
   H = hydraulic
2. The date of the test and the name of the firm.
3. The identification number of the CPT test and the location of the site.
4. The depth from which a friction reducer, or push-rods with a reduced diameter, have been used. The depth at which the push-rods have been extracted over a limited height in order to break the lateral resistance, after which the push-rods have again been pushed into the soil.
5. Any abnormal interruption from the normal procedure of the CPT test.
6. Observations made by the operator such as soil type, sounds from the extension rods, indications of stones, disturbances, etc.
7. Data concerning the existence and thickness of fill, or existence and depth of an excavation, and level of the CPT test with respect to the original or artificial soil surface.

9.2 Besides the information indicated in para. 9.1, the internal files should also mention:

1. The identification number of the penetrometer tip used.
2. The name of the operator in charge of the crew which performed the test.
3. The dates and reference numbers of the calibration certificates for the measuring devices.

9.3 The following scales are recommended for the presentation of the graphs:

Depth scale: 1 unit length (arbitrary) for 1 m
Cone resistance q_c: the same unit length for 2 MPa
Local side friction f_s: the same unit length for 0.5 MPa
Total penetration force Q_t the same unit length for 5 kN
Total friction Q_{st}: ditto

So long as the above mentioned relationships between the scales along the vertical and horizontal axis are respected, the scales can be chosen arbitrarily in such a way that standard sized sheets can be used.

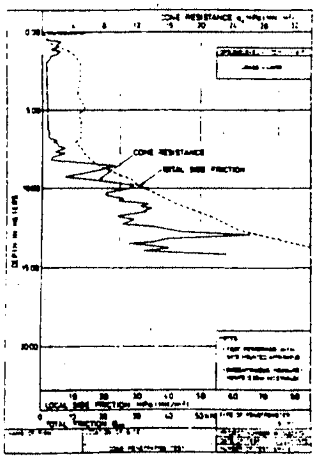

Fig. 4 An example of the presentation of test results from a CPT test.

9.4 Site plan.

For every investigation which is carried out, a clear site plan shall be drawn, with clear reference points in order that the locations of the penetrometer tests are accurately plotted.

Also when made in conjunction with borings the time sequences are to be indicated of the performance of the borings and CPT tests.

9.5 Besides the information mentioned under para. 9.1, it is recommended that the elevation of the soil-surface at the location of the test is given. In addition, where appropriate the following information should be given:

(a) The readings of the inclinometer, if taken.
(b) All checks made after extracting the push-rods, the conditions of the push-rods and the penetrometer tips.
(c) The depth of the water in the hole remaining after withdrawal of the penetrometer, or the depth at which the hole collapsed.
(d) Whether or not the testhole has been backfilled, and if so by which method.

10. DIVERGENCES FROM THE STANDARD RECOMMENDED

10.1 General.

A general and very important specification is, that all divergences from the Recommended Standard are to be described explicitly and completely on the test graphs. In order to simplify these remarks the names or symbols defined in para. 10.5 can be used.

10.2 Divergences only related to the dimensions and the shape of the cone.

10.2.1 Diameter of the base of the cone.

In order to be able to penetrate deeper in certain cases a cone with a smaller base can be used. In order to be able to include the measuring device, or to be able to drive the penetrometer tip through hard layers with less danger of damage occurring to the tip, cones with larger diameters are used.

10.2.2 Apex angle of the cone.

To decrease the possibility of damage, an apex angle of 90° can be used.

10.2.3 Tolerances.

All tolerances specified for the Recommended Standard, are to be adapted in direct proportion to the diameter.

10.2.4 Symbols.

Tests performed with a diverging cone cannot be represented by the letter S, as they differ from the Standard. If all other elements are identical as in the Standard, they can be indicated by the letters M, E, H, but followed by the indication B = and α = giving the values of the diverging characteristics of the cone.

10.3 Divergences only related to the location or dimensions of the friction sleeve.

10.3.1 If the friction sleeve, contrarily to the Recommended Standard, is not placed immediately above the base of the cone, the minimum distance (h) between that base, and the lower end of the friction sleeve should be three times the diameter of the base.

10.3.2 Surface of the sleeve.

When using a cone having a base diameter of 35.7 mm, but with a friction sleeve of a length other than the Recommended Standard, then the surface area of the sleeve should not be larger than 350 cm², and not smaller than 100 cm².

When using a cone with a base diameter different from the Recommended Standard, the surface area of the sleeve should be adjusted proportionally to the surface area of the base of the cone.

10.3.3 Symbols.

Tests performed with a diverging friction sleeve cannot be represented by the letter S, as they differ from the Recommended Standard. If all other elements are identical as in the Recommended Standard, they can be indicated by the letters M, E, H, but followed by the indication:

height of lower end of sleeve h =
surface area of the sleeve A_s =

10.4 Discontinuous testing with freee cone penetrometer tips.

10.4.1 With a free cone penetrometer tip, either continuous or discontinuous testing is possible. The manner in which the test is performed should be described in the report and on the test graphs.

10.4.2 Discontinuous testing.

In the case of discontinuous testing, although the rate of downward movement due to the thrust machine is known, the rate of penetration of the free cone at the point of rupture of the soil can be different to that of the movement due to the thrust machine. They only correspond when there is continuous downward movement of the push-rods.

When testing discontinuously the minimum movement to be imposed on the cone or on the friction sleeve is [illegible] times the diameter of the cone (see note - para. [illegible]).

10.5 Table of traditional penetrometer tips diverging from the Recommended Standard

The penetrometer tips actually in use in several countries, and diverging from the Recommended Standard, are given below. They are indicated by a name, and a symbol which has been added to permit abbrevations when referring to them on the test graphs.

10.5.1 Mechanical penetrometer tip - note 5 para. 11.

M1 The Dutch mantle cone penetrometer tip (Fig. 5)
M2 The Dutch friction sleeve penetrometer tip (Fig. 6)
M3 The U.S.S.R. mantle cone penetrometer tip (Fig. 7)
M4 The simple cone penetrometer tip (Fig. 8)
MS 1 The Andina cone penetrometer tip (Fig. 9a)
MS 2 The Andina friction sleeve cone penetrometer tip (Fig. 9b)

10.5.2 Electric cone penetrometer tip.

E1.1 The Delft electric penetrometer tip (Fig. 10a)
E1.2 The Delft friction sleeve electric penetrometer tip (Fig. 10b)
E2 The Degebo friction sleeve electric penetrometer tip (Fig. 11)

10.5.3 Hydraulic penetrometer tip.

H1.1 The Parez hydraulic penetrometer tip (Fig. 12a)
H1.2 The Parez friction sleeve hydraulic penetrometer tip (Fig. 12b)

10.6 Precision of the measurements.

When testing diverges from the Recommended Standard two classes of precision are defined:

- the normal precision class: see section 5
- the lower precision class: the precison obtained should not be worse than the larger of the following values
  - 10% of the measured value
  - 2% of the maximum value of the range

In all such cases the class of precision of the tests shall be indicated in the report and on the test graphs.

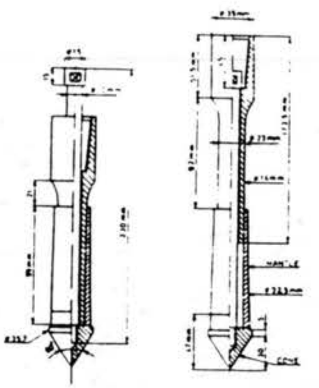

Fig. 5 The Dutch mantle cone penetrometer tip. Symbol: M1.

10.7 Static dynamic penetrometers and preboring cone penetrometers.

Penetration can be increased by the use of static dynamic penetrometers and also by the use of penetrometers equipped with preboring tools.

It must be clearly indicated in the report and on the test graphs when such equipment has been used.

10.8 Precautions, checks and verifications.

10.8.1 Mechanical penetrometers.

10.8.1.1 Push-rod:

There should not be any protruding edge on the inside of the push-rods at the screw connection between the rods (Fig. 13).

10.8.1.2 Inner rods

The diameter of the inner rods shall be 0.5 to 1 mm less than the internal diameter of the push-rods. The inner rods must slide very easily through the push-rods.

The ends of the inner rods should be exactly at right angles to the axis of the rod and be machine-tooled to a smooth surface.

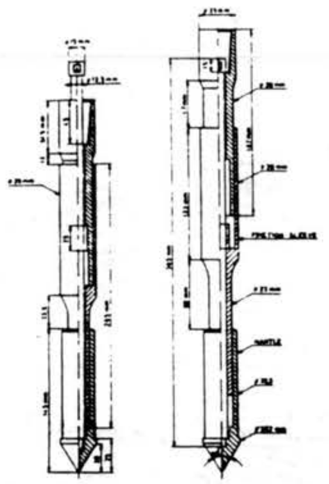

Fig. 6 The Dutch friction sleeve penetrometer tip. Symbol: M2.

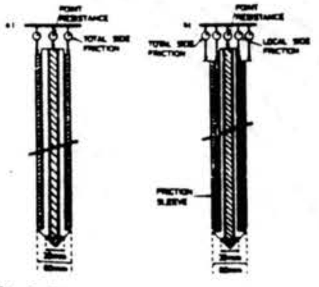

Fig. 9 The Andina cone penetrometer tip (a) and the friction sleeve cone penetrometer tip (b). Symbols: MS.1 and MS.2 respectively.

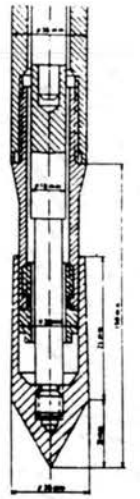

Fig. 7 The U.S.S.R. mantle cone penetrometer tip. Symbol: M3.

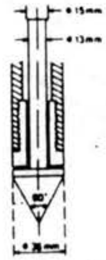

Fig. 8 The simple cone penetrometer tip. Symbol: M4.

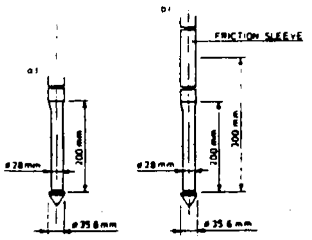

Fig. 10 The Delft electric penetrometer tip (a) and the friction sleeve electric penetrometer tip (b).
Symbols: E1.1 and E1.2 respectively.

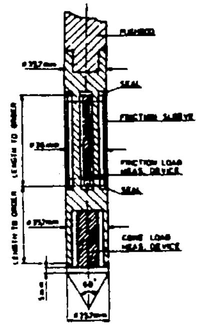

Fig. 11 The Degebo friction sleeve electric penetrometer tip.
Symbol. E2.

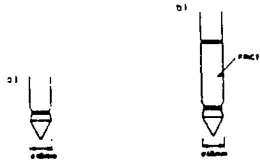

Fig. 12 The Parez hydraulic penetrometer tip (a) and the friction sleeve hydraulic penetrometer tip (b).
Symbols: H1.1 and H1.2 respectively.

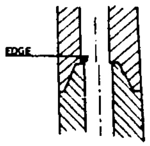

Fig. 13 There should not be any protruding edge at the screw connections between the rods.

The rods must not screw together or be joined in any way which gives them an additional degree of freedom as this has been found to increase the parasitical friction between the rods and the tubing. Before and after the test a check will be made that the inner rods slide very easily in the push-rods, and that the cone and the friction sleeve move easily with respect to the body of the penetrometer tip. For improved accuracy at low values of the resistances, the thrust data registered at the surface should be corrected for the total weight of the inner rods in the case of the cone resistance, and for that of the push-rods and inner rods in the case of the total resistance.

11. EXPLANATORY NOTES AND COMMENTS

Note 1: Definitions 2.1

The denominations "continuous" and "discontinuous" penetration testing are not quite correct, and the denomination "penetration testing with simultaneous pushing, and non-simultaneous pushing of cone and push rods", would be more adequate. However, the denominations "continuous" and "discontinuous" have been maintained, as they are already well established.

Note 2: Definitions 2.15

The friction ratio R_f, being the ratio of the local side friction f_s to the cone resistance q_c, has to be expressed as a percentage in order to obtain a figure larger than one. Although in the past the friction ratio has been mostly used, there is a tendency to use the friction index I_f, being the ratio of the cone resistance q_c to the local side friction f_s, and which gives directly a figure larger than one. This is the reason why the two quantities have been included in the definitions.

Note 3: The friction sleeve 3.5

The roughness is defined as the mean deviation of the real surface of a body from the mean plane. The roughness is expressed in micrometers (μm).

Note 4: Discontinuous testing 10.4.2

In the case of mechanical penetrometer tips, in order to be certain that the cone and the friction sleeve move sufficiently with respect to the push-rods, due account is to be taken of the elastic shortening of the inner rods. Therefore, at the surface the movement of the inner rods relative to the push-rods must be at least equal to the sum of the minimum imposed movement of the cone plus the elastic shortening of the inner rods.

Note 5: Mechanical penetrometer tips 10.5.1

Continuous testing with a mechanical penetrometer tip is not recommended for high accuracy, as the movement of the inner rods to the push-rods can change its sense at different depths, increasing the margin of the error due to the parasitical internal friction. Furthermore it is necessary to check at least every meter during the test that the inner rods are still free to move relative to the push-rods.

Note 6: 10.5.1 M4

In the case of the simple cone special precautions have to be taken against soil entering the sliding mechanism and affecting the resistance. After extracting the penetrometer tip a check is to be made, in order to be certain that the cone-stem still moves completely freely relative to the bush.

APPENDIX B

ASTM D 3441-86 SPECIFICATIONS

Designation: D 3441 – 86

Standard Test Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil[1]

1. Scope

1.1 This test method covers the determination of end bearing and side friction, the components of penetration resistance which are developed during the steady slow penetration of a pointed rod into soil. This method is sometimes referred to as the "Dutch Cone Test," or "Cone Penetration Test," and is often abbreviated as the "CPT."

1.2 This test method includes the use of both cone and friction-cone penetrometers, of both the mechanical and electric types. It does not include data interpretation. It also includes the penetrometer aspects of piezocone soundings, but does not include the details of piezometer construction, location, measurement, or data interpretation.

NOTE 1—The European Standard for the CPT uses a tip of right cylindrical shape as shown in Fig. 3, as their reference test against which other CPTs may be compared.

1.3 Mechanical penetrometers of the type described in this method operate incrementally, using a telescoping penetrometer tip, resulting in no movement of the push rods during the measurement of the resistance components. Design constraints for mechanical penetrometers preclude a complete separation of the end-bearing and side-friction components. Electric penetrometers are advanced continuously and permit separate measurement of both components. Differences in shape and method of advance between cone penetrometer tips may result in significant differences in one or both resistance components.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Definitions

2.1 *cone*—the cone-shaped point of the penetrometer tip, upon which the end-bearing resistance develops.

2.2 *cone penetrometer*—an instrument in the form of a cylindrical rod with a conical point designed for penetrating soil and soft rock and for measuring the end-bearing component of penetration resistance.

2.3 *cone resistance or end-bearing resistance*, q_c—the resistance to penetration developed by the cone, equal to the vertical force applied to the cone divided by its horizontally projected area.

2.4 *cone sounding*—the entire series of penetration tests performed at one location when using a cone penetrometer.

2.5 *electric penetrometer*—a penetrometer that uses electric-force transducers built into a nontelescoping penetrometer tip for measuring, within the tip, the component(s) of penetration resistance.

2.6 *friction-cone penetrometer*—a cone penetrometer with the additional capability of measuring the local side friction component of penetration resistance.

2.7 *friction-cone sounding*—the entire series of penetration tests performed at one location when using a friction-cone penetrometer.

2.8 *friction ratio*, R_f—the ratio of friction resistance to cone resistance, f_s/q_c, expressed in percent.

2.9 *friction resistance*, f_s—the resistance to penetration developed by the friction sleeve, equal to the vertical force applied to the sleeve divided by its surface area. This resistance consists of the sum of friction and adhesion.

2.10 *friction sleeve*—a section of the penetrometer tip upon which the local side-friction resistance develops.

2.11 *inner rods*—rods that slide inside the push rods to extend the tip of a mechanical penetrometer.

2.12 *mechanical penetrometer*—a penetrometer that uses a set of inner rods to operate a telescoping penetrometer tip and to transmit the component(s) of penetration resistance to the surface for measurement.

2.13 *penetrometer tip*—the end section of the penetrometer, which comprises the active elements that sense the soil resistance, the cone, and in the case of the friction-cone penetrometer, the friction sleeve.

2.13.1 *Discussion*—The addition of a piezometer to the electric penetrometer tip permits the measurement of pore water pressure during and after stopping tip penetration. A penetrometer including a piezometer is known as a piezocone penetrometer, or just piezocone.

2.14 *piezocone sounding*—the entire series of penetration tests performed at one location when using a piezocone penetrometer.

2.15 *push rods*—the thick-walled tubes, or other suitable rods, used for advancing the penetrometer tip to the required test depth.

3. Significance and Use

3.1 This test method supplies data on the engineering properties of soil intended to help with the design and construction of earthworks and the foundations for structures.

3.2 This test method tests the soil in place and does not obtain soil samples. The interpretation of the results from this method requires knowledge of the types of soil penetrated. Engineers usually obtain this soil information from parallel borings and soil sampling methods, but prior information or experience may preclude the need for borings.

3.3 Engineers often correlate the results of tests by this test method with laboratory or other types of field tests, or directly with performance. The accuracy of such correlations will vary with the type of soil involved. Engineers usually rely on local experience to judge this accuracy.

3.4 Most engineers with offshore experience have found this test method suitable for offshore use.

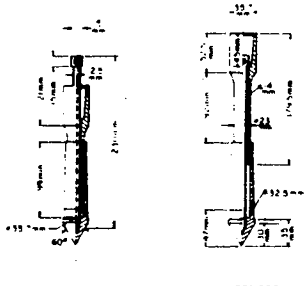

FIG. 1 Example of a Mechanical Cone Penetrometer Tip (Dutch Mantle Cone)

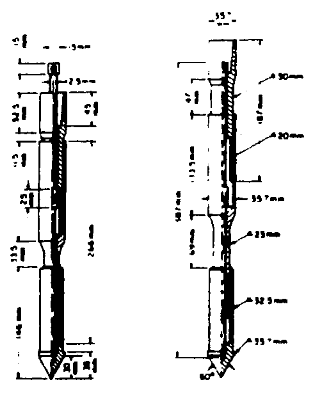

FIG. 2 Example of a Mechanical Friction-Cone Penetrometer Tip (Begemann Friction-Cone)

4. Apparatus

4.1 *General*

4.1.1 *Cone*—The cone shall have a 60° (±5°) point angle and a base diameter of 1.406 ± 0.016 in. (35.7 ± 0.4 mm) resulting in a projected area of 1.55 in.² (10 cm²). The point of the cone shall have a radius less than ⅛ in. (3 mm).

NOTE 2—Cone tips with larger end areas may be used to increase measurement sensitivity in weak soils. Experience with electrical tips with end area between 0.78 in.² (5 cm²) and 3.10 in.² (20 cm²) has shown that they produce data similar to the 1.55 in.² (10 cm²) standard provided they maintain the same tip geometry. Cone tip sizes in this range can be used for special circumstances provided the cone tip and friction sleeve (if any) area is noted.

4.1.2 *Friction Sleeve*, having the same outside diameter +0.024 to −0.000 in. (+0.5 to −0.0 mm) as the base diameter of the cone (see 4.1.1). No other part of the penetrometer tip shall project outside the sleeve diameter. The surface area of the sleeve shall be 23.2 in.² (150 cm²) ±2 %.

4.1.3 *Steel*—The cone and friction sleeve shall be made from steel of a type and hardness suitable to resist wear due to abrasion by soil. The friction sleeve shall have and maintain with use a roughness of 20 µin. (0.5 µm) AA, ±50 %.

4.1.4 *Push Rods*—Made of suitable steel, these rods must have a section adequate to sustain, without buckling, the thrust required to advance the penetrometer tip. They must have an outside diameter not greater than the diameter of the base of the cone for a length of at least 1.3 ft (0.4 m) above the base, or, in the case of the friction-cone penetrometer, at least 1.0 ft (0.3 m) above the top of the friction sleeve. Each push rod must have the same, constant inside diameter. They must screw or attach together to bear against each other and form a rigid-jointed string of rods with a continuous, straight axis.

4.1.5 *Inner Rods*—Mechanical penetrometers require a separate set of steel, or other metal alloy, inner rods within the steel push rods. The inner rods must have a constant outside diameter with a roughness, excluding waviness, less than 10 µin. (0.25 µm) AA. They must have the same length as the push rods (±0.004 in. or ±0.1 mm) and a cross section adequate to transmit the cone resistance without buckling or other damage. Clearance between inner rods and push rods shall be between 0.020 and 0.040 in. (0.5 and 1.0 mm). See 6.8.1.

4.1.6 *Measurement Accuracy*—Maintain the thrust-measuring instrumentation to obtain thrust measurements within ±5 % of the correct values.

NOTE 3—Special, and preferably redundant, instrumentation may be required in the offshore environment to assure the accuracy and the proper operation of all the remote systems involved.

4.2 *Mechanical Penetrometers*

4.2.1 The sliding mechanism necessary in a mechanical penetrometer tip must allow a downward movement of the

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[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and Related Field Testing for Soil Investigations.

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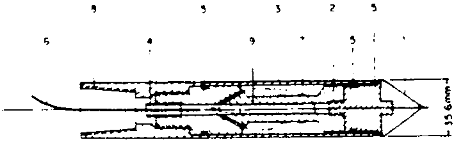
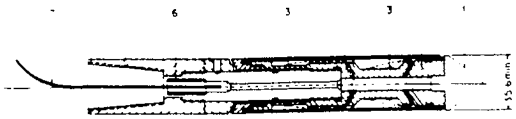


1 Conical point (10 cm²)
2 Load cell
3 Protective mantle
4 Waterproof bushing
5 O-rings
6 Cable
7 Strain gages
8 Connection with rods
9 Inclinometer

FIG. 3 Electric-Cone Penetrometer Tip



1 Conical point (10 cm²)
2 Load cell
3 Strain gages
4 Friction sleeve (150 cm²)
5 Adjustment ring
6 Waterproof bushing
7 Cable
8 Connection with rods

FIG. 4 Electric Friction-Cone Penetrometer Tip

cone in relation to the push rods of at least 1.2 in. (30.5 mm).

NOTE 4—At certain combinations of depth and tip resistance(s) the elastic compression of the inner rods may exceed the downward stroke that the thrust machine can apply to the inner rods relative to the push rods. In this case, the tip will not extend and the thrust readings will rise elastically to the end of the machine stroke and then jump abruptly when the thrust machine makes contact with the push rods.

4.2.2 Mechanical penetrometer tip design shall include protection against soil entering the sliding mechanism and affecting the resistance component(s) (see 4.2.3 and Note 5).

4.2.3 *Cone Penetrometer*—Figure 1 shows the design and action of one mechanical cone penetrometer tip. A mantle of reduced diameter is attached above the cone to minimize possible soil contamination of the sliding mechanism.

NOTE 5—An unknown amount of side friction may develop along this mantle and be included in the cone resistance.

4.2.4 *Friction-Cone Penetrometer*—Figure 2 shows the design and action of one telescoping mechanical friction-cone penetrometer tip. The lower part of the tip, including a mantle to which the cone attaches, advances first until the flange engages the friction sleeve and then both advance.

NOTE 6—The shoulder at the lower end of the friction sleeve encounters end-bearing resistance. In sands as much as two thirds of the sleeve resistance may consist of bearing on this shoulder. Ignore this effect in soft to medium clays.

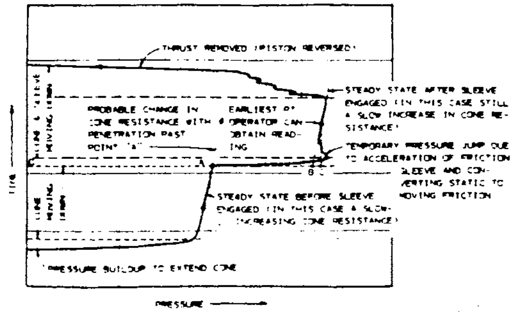
4.2.5 *Measuring Equipment*—Measure the penetration resistance(s) at the surface by a suitable device such as a hydraulic or electric load cell or proving ring.

4.3 *Electric Penetrometers*

4.3.1 *Cone Penetrometer*—Figure 3 shows one design for an electric-cone penetrometer tip. The cone resistance is measured by means of a force transducer attached to the cone. An electric cable or other suitable system transmits the transducer signals to a data recording system. Electric-cone penetrometers shall permit continuous advance and recording over each push rod-length interval.

4.3.2 *Friction-Cone Penetrometer*—The bottom of the friction sleeve shall not be more than 0.4 in. (10 mm) above the base of the cone. The same requirements as 4.3.1 apply. Figure 4 shows one design for an electric friction-cone penetrometer tip.

4.3.3 *Other Penetrometers*—Electric penetrometers may include other transducer measurements as well as, or instead of, the friction sleeve measurement. Common ones are inclinometers to assist with the alignment control of the tip (see



NOTE—"a-a" represents the correct cone resistance reading just before the pressure jump associated with engaging the friction sleeve during the continuing downward extension of the tip. "a-b" is the correct friction resistance if the friction sleeve could be engaged instantaneously and the cone plus friction resistance read instantaneously. However, the operator cannot read a pressure gage dial until it steadies, such as at point "c". By this forced wait, the operator has introduced a friction resistance error of "b-c". The operator must read the gage as soon as possible after the jump to minimize this error. Erratic or abrupt changes in cone resistance may make this error unacceptable.

FIG. 5 Annotated Chart Record of the Pressure Changes in the Hydraulic Load Cell Measuring Thrust on Top of the Inner Rods During an Example Extension of the Mechanical Friction-Cone Penetrometer Tip

3) and piezometers to provide additional data on soil stratigraphy and behavior.

4.4 *Thrust Machine*—This machine shall provide a continuous stroke, preferably over a distance greater than one push rod length. The machine must advance the penetrometer tip at a constant rate while the magnitude of the thrust required fluctuates (see 5.1.2).

NOTE 7—Deep penetration soundings usually require a thrust capacity of at least 5 tons (45 kN). Most modern machines use hydraulic systems with 10 to 20-ton (90 to 180-kN) thrust capability.

4.5 *Reaction Equipment*—The proper performance of the static-thrust machine requires a stable, static reaction.

NOTE 8—The type of reaction provided may affect the penetrometer resistance(s) measured, particularly in the surface or near-surface layers.

5. Procedure

5.1 *General*

5.1.1 Set up the thrust machine for a thrust direction as near vertical as practical.

5.1.2 *Rate of Penetration*—Maintain a rate of depth penetration of 2 to 4 ft/min (10 to 20 mm/s) ±25 % when obtaining resistance data. Other rates of penetration may be used between tests.

NOTE 9—The rate of 2 ft/min (10 mm/s) provides the time the operator needs to read properly the resistance values when using the mechanical friction-cone penetrometer. The rate of 4 ft/min (20 mm/s) is suitable for the single resistance reading required when using the mechanical cone penetrometer and provides for the efficient operation of electric penetrometers. The European standard requires 4 ft/min (20 mm/s).

NOTE 10—Rates of penetration either slower or faster than the standard rate may be used for special circumstances, such as pore pressure measurements. This is permissible provided the rate actually used and the reason for the deviation is noted on the test record.

NOTE 11—Pore pressures generated ahead of and around the penetrating cone or friction cone penetrometer tip can have an important effect on the q_c and f_s values measured. Piezocone tips with simultaneous pore pressure measurement capability have proven useful to help evaluate such effects and to provide additional data about the stratigraphy and engineering properties of the soils penetrated.

5.2 *Mechanical Penetrometers*

5.2.1 *Cone Penetrometer*—*(1)* Advance penetrometer tip to the required test depth by applying sufficient thrust on the push rods, and *(2)* Apply sufficient thrust on the inner rods to extend the penetrometer tip (see Fig. 1). Obtain the cone resistance at a specific point (see 5.2.3) during the downward movement of the inner rods relative to the stationary push rods. Repeat step *(1)*. Apply sufficient thrust on the push rods to collapse the extended tip and advance it to a new test depth. By continually repeating this two-step cycle, obtain cone resistance data at increments of depth. This increment shall not ordinarily exceed 8 in. (203 mm).

5.2.2 *Friction-Cone Penetrometer*—Use this penetrometer as described in 5.2.1 but obtain two resistances during the step *(2)* extension of the tip (see Figs. 2 and 5). First obtain the cone resistance during the initial phase of the extension. When the lower part of the tip engages and pulls down the friction sleeve, obtain a second measurement of the total resistance of the cone plus the sleeve. Subtraction gives the sleeve resistance.

NOTE 12—Because of soil layering, the cone resistance may change during the additional downward movement of the tip required to obtain the friction measurement.

NOTE 13—The soil friction along the sleeve puts an additional overburden load on the soil above the cone and may increase cone resistance above that measured during the initial phase of the tip extension by an unknown but probably small amount. Ignore this effect.

5.2.3 *Recording Data*—To obtain reproducible cone-resistance test data, or cone and friction-resistance test data when using a friction-cone tip, record only those thrust readings that occur at a well-defined point during the downward movement of the top of the inner rods in relation to the top of the push rods. Because of the elastic compression of inner rods (see Note 4) this point ordinarily should be at not less than 1.0 in. (25 mm) apparent relative movement of the inner rods. When using the friction-cone penetrometer, this point shall be just before the cone engages the friction sleeve.

Note 14—Figure 5 shows one example of how the thrust in the hydraulic load cell can vary during the extension of the friction-cone tip. Note the jump in gage pressure when the cone engages the sleeve.

5.2.3.1 Obtain the cone plus friction-resistance reading as soon as possible after the jump so as to minimize the error described in Fig. 5. Unless using continuous recording as in Fig. 5, the operator should not record a cone plus friction resistance if he suspects the cone resistance is changing abruptly or erratically.

5.3 *Electric Penetrometers*

5.3.1 If using continuous electric cable, prethread it through the push rods.

5.3.2 Record the initial reading(s) with the penetrometer tip hanging freely in air or in water, out of direct sunlight, and after an initial, short penetration, test hole so that the tip temperature is at soil temperature.

5.3.3 Record the cone resistance, or cone resistance and friction resistance, continuously with depth or note them at intervals of depth not exceeding 8 in. (203 mm).

5.3.4 At the end of a sounding, obtain a final set of readings as in 5.3.2 and check them against the initial set. Discard the sounding, and repair or replace the tip if this check is not satisfactory for the accuracy desired for the resistance component(s).

6. Special Techniques and Precautions

6.1 *Reduction of Friction Along Push Rods*—The purpose of this friction reduction is to increase the penetrometer depth capability and not to reduce any differences between resistance components determined by mechanical and electric tips as noted in 1.3. To accomplish the friction reduction, introduce a special rod with an enlarged diameter or special projections, called a "friction reducer," into the string of push rods or between the push rods and the tip. Another allowable method to reduce friction is to use push rods with a diameter less than that of the tip. In accordance with 4.1.4, any such projections or changes in diameter must begin no closer than 1.0 ft (0.3 m) from the base of the cone or the top of the friction sleeve when using cones with the standard 4.1.1 diameter. For other cones (see Note 2) use no closer than 8 diameters.

Note 15—Non-mechanical techniques to reduce friction, such as the use of drilling mud above the tip, are also allowable.

6.2 *Prevention of Rod Bending Above Surface*—Use a tubular rod guide, at the base of the thrust machine, of sufficient length to prevent significant bending of the push rods between the machine and the ground surface.

Note 16—Special situations, such as when working through water will require a special system of casing support to restrict adequately the buckling of the push rods.

6.3 *Drift of Tip*—For penetration depths exceeding about 40 ft (12 m), the tip will probably drift away from a vertical alignment. Occasionally, serious drifting occurs, even at less depth. Reduce drifting by using push rods that are initially straight and by making sure that the initial cone penetration into soil does not involve unwanted, initial lateral thrust. Passing through or alongside an obstruction such as boulders, soil concretions, thin rock layers, or inclined dense layers may deflect the tip and induce drifting. Note any indications of encountering such obstructions and be alert for possible subsequent improper tip operation as a sign of serious drifting.

Note 17—Electric penetrometer tips may also incorporate an inclinometer to monitor drift and provide a warning when it becomes excessive.

6.4 *Wear of Tip*—Penetration into abrasive soils eventually wears down or scours the penetrometer tip. Discard tips, or parts thereof, whose wear changes their geometry or surface roughness so they no longer meet the requirements of 4.1. Permit minor scratches.

6.5 *Distance Between Cone and Friction Sleeve*—The friction resistance of the sleeve applies to the soil at some distance above the soil in which the cone resistance was obtained at the same time. When comparing these resistances for the soil at a specified depth, for example when computing friction ratios or when plotting these data on graphs, take proper account of the vertical distance between the base of the cone and the midheight of the friction sleeve.

6.6 *Interruptions*—The engineer may have to interrupt the normal advance of a static penetration test for purposes such as removing the penetrometer and drilling through layers or obstructions too strong to penetrate statically. If the penetrometer is designed to be driven dynamically without damage to its subsequent static performance (those illustrated herein in Figs. 1 to 4 are not so designed), the engineer may drive past such layers or obstructions. Delays of over 10 min due to personnel or equipment problems shall be considered an interruption. Continuing the static penetration test after an interruption is permitted provided this additional testing remains in conformance with this standard. Obtain further resistance component data only after the tip passes through the engineer's estimate of the disturbed zone resulting from the nature and depth of the interruption. As an alternative, readings may be continued without first making the additional tip penetration and the disturbed zone evaluated from these data. Then disregard data within the disturbed zone.

Note 18—Interruption of the piezocone sounding after a push allows the engineer to examine the dissipation of positive or negative excess pore water pressure.

6.7 *Below or Adjacent to Borings*—A cone or friction-cone sounding shall not be performed any closer than 25 boring diameters from an existing, unbackfilled, uncased boring hole. When performed at the bottom of a boring, the engineer should estimate the depth below the boring of the disturbed zone and disregard penetration test data in this zone. The depth may vary from one to five diameters. Where the engineer does not have sufficient experience with this variable a depth of at least three boring diameters should be used.

6.8 *Mechanical Penetrometers*

6.8.1 *Inner Rod Friction*—Soil particles and corrosion can increase the friction between inner rods and push rods, possibly resulting in significant errors in the measurement of the resistance component(s). Clean and lubricate the inner rods.

6.8.2 *Weight of Inner Rods*—For improved accuracy at low values of cone resistance, correct the thrust data to include the accumulated weight of the inner rods from the tip to the topmost rod.

6.8.3 *Jamming*—Soil particles between sliding surfaces or bending of the tip may jam the mechanism during the many extensions and collapses of the telescoping mechanical tip. Stop the sounding as soon as uncorrectable jamming occurs.

6.9 *Electric Penetrometers*

6.9.1 *Water Seal*—Provide adequate waterproofing for the electric transducer. Make periodic checks to assure that no water has passed the seals.

Note 19—Some electric tip sleeve designs are not compensated for hydrostatic end area effects and require a calibration correction. Determining the net end area of the cone under hydrostatic pressure also requires a hydrostatic calibration measurement. The tip manufacturer can usually supply these calibration correction constants. Their importance increases as the soil being tested becomes weaker.

7. Report

7.1 *Graph of Cone Resistance, q_c*—Every report of a cone or friction-cone sounding shall include a graph of the variation of cone resistance (in units of tons or kPa) with depth (in feet or metres). Successive cone-resistance test values from the mechanical cone and friction-cone penetrometers, usually determined at equal increments of depth and plotted at the depth corresponding to the depth of the measurement, may be connected with straight lines as an approximation for a continuous graph.

7.2 *Friction-Cone Penetrometer*

7.2.1 *Graph of Friction Resistance, f_s*—In addition to the graph of cone resistance (7.1) the report may include an adjacent or superposed graph of friction resistance or friction ratio, or both, with depth. Use the same depth scale as in 7.1 (see 6.5).

7.2.2 *Graph of Friction Ratio, R_f*—If the report includes soil descriptions estimated from the friction-cone penetrometer data, include a graph of the variation of friction ratio with depth. Place this graph adjacent to the graph for cone resistance, using the same depth scale (see 6.5).

7.3 *Piezocone Penetrometer*—In addition to the 7.1 and 7.2 report requirements, a piezocone sounding shall include a parallel graph, to the same depth scale, of measured pore water pressure during the penetration versus depth. Excess pore water pressure versus time plots may also be constructed at those depths where the piezocone sounding is interrupted (see Note 1).

7.4 *General*—The operator shall record his name, the name and location of the job, date of sounding, sounding number, location coordinates, and soil and water surface elevations (if available). The report shall also include a note as to the type of penetrometer tip used, the type of thrust machine, tip and thrust calibration information, or both, any zero-drift noted, the method used to provide the reaction force, if a friction reducer was used, the method of tip advancement, the method of recording, the condition of the rods and tip after withdrawal, and any special difficulties or other observations concerning the performance of the equipment.

7.5 *Deviations from Standard*—The report shall state that the test procedures were in accordance with this Test Method D 3441. Describe completely any deviations from this test method.

8. Precision and Bias

8.1 Because of the many variables involved and the lack of a superior standard, engineers have no direct data to determine the bias of this method. Judging from its observed reproducibility in approximately uniform soil deposits, plus the q_c and f_s measurement effects of special equipment and operator care, persons familiar with this method estimate its precision as follows:

8.1.1 *Mechanical Tips*—Standard deviation of 10 % in q_c and 20 % in f_s.

8.1.2 *Electric Tips*—Standard deviation of 5 % in q_c and 10 % in f_s.

Note 20—These data may not match similar data from mechanical tips (see 1.3).

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

APPENDIX C

EXCERPTS FROM HOGENTOGLER OPERATION PROCEDURES MANUAL

OPERATION PROCEDURES FOR
THE DUTCH CONE PENETROMETER
CONVERSION KIT

I. INTRODUCTION:

The Dutch Cone Penetrometer or quasistatic cone penetrometer is a device for obtaining in-situ subsurface data in a variety of soils. Useful design data can be obtained in most types of soil the equipment can penetrate. The chief advantage of the Dutch Cone Penetrometer is its ability to retrieve large quantities of useful data at an economical cost.

A few specific applications for the Dutch Cone Penetrometer are:

1. Determination of the uniformity and continuity of soil deposits; i.e., stratigraphy.
2. Definition of soil type; e.g., sand, clayey silt, etc.
3. Obtaining in-situ engineering soil parameters.
4. Design of pile foundations.
5. Compaction control where soils are compacted by a variety of methods.

The following procedures are applicable to the operation of the Dutch Cone Penetrometer Conversion Kit sold by Hogentogler and Company. The procedures are also applicable to the trailer and skid mounted penetrometers sold by Hogentogler and Co. with the exception of the operation of their hydraulic loading systems; reference should be made to the respective operators' handbooks for proper use of these other types of penetrometer systems.

The Dutch Cone Penetration Test consists of the measurement of the resistance to penetration of a hardened steel device of standard dimensions as it is forced into the subsurface at a fixed, predetermined rate.

All penetrometer tests should be conducted in accordance with ASTM D 3441-75T "Deep Quasi-Static Cone and Friction-Cone Penetration Tests of Soil." A copy of this specification is contained in Appendix A.

II. CONVERSION EQUIPMENT AND ITS FUNCTION:

The conversion kit converts a standard core or auger drill quickly and easily to a Dutch Cone Penetrometer tester. To perform the penetrometer conversion the following pieces of equipment are supplied with the Dutch Cone Penetrometer Conversion Kit:

2 - mantle cones
2 - friction jacket cones
25 - one meter sounding tubes and rods
1 - 11 ton hydraulic load cell and gauges
1 - pulling device
1 - 75 mm inner rod extension
2 - 15 mm inner rod extensions
1 - continuous sounding ring
1 - depth indicator gauge
1 - friction reducing section of sounding tube
2 - spare gauges
1 - carrying case

Note: A mounting bracket is used to attach the load cell to the drill rig. The bracket is fabricated by the customer because its configuration depends on the customer's drill rig model.

The above components are interchangeable with those components found on the trailer and skid mounted 11 ton Dutch Cone Penetrometer rigs.

The functions of each piece of equipment is as follows:

A. Hydraulic Load Cell

The 11 ton hydraulic load cell contains two gauges; a low range measuring 0-100 kgf/sq cm and the high range measuring 0-600 kgf/sq cm. The low pressure gauge is protected against overload by an automatic shut off. Any reading over 80 kgf/sq cm is read on the high pressure gauge. The area of the load cell piston is 20 cm^2. The pressures read on the gauges in kgf/cm^2, when multiplied by 20 cm^2, represent the downthrust in kgf being applied.

B. Mantle Cone

The mantle cone is a cone shaped device which is pushed into the subsurface a total stroke of 7 cm during which a resistance to its penetration is read on the load cell gauges. The cone consists of a 60 degree (apex angle) cone with a projected end area of 10 sq cm. The cone resistance is defined as the downthrust divided by the end area. Figure 1 shows the sequence of operation and the calculations necessary to determine cone resistance.

C. Friction Jacket Cone

The friction jacket cone is a mantle cone as described above with the addition of a cylindrical jacket of 150 sq cm surface area mounted above the cone. A value of cone resistance to penetration and a value of local friction of the soil on the jacket is obtained at each test. The test procedure is similar to the one for the mantle cone, except that the resistance for the first 3.5 cm of stroke is provided by the cone point alone. Subsequently the cone engages the friction jacket and drags it along; the resistance during the last 3.5 cm of stroke is the combined cone resistance and jacket friction resistance. The local friction is obtained by subtracting the cone resistance from the combined resistance, and dividing by the surface area of 150 sq cm. Figure 2 shows the sequence of operation and the calculations required to obtain the cone resistance and the local friction values.

D. Sounding Tube and Inner Rod

The sounding tubes are connected to the mantle cone or friction jacket cone and are used to push the cone into the subsurface. Each sounding tube is one meter in length with a 36 mm O.D. by 16 mm I.D. and weighs 6.65 kg. Also, each sounding tube contains a 15 mm diameter rod (inner rod) which fits into the 16 mm I.D. hole of the sounding tube. The rod weight is 1.40 kg. The inner rod is used to advance the cone or cone and friction jacket during the performance of the test.

E. Friction Reducing Section

The friction reducing section is a length of sounding tube (having the same diameters) with the addition of an enlarged area at the top of the section. The purpose of the enlarged area is to ream the hole made by the cone. The enlarged hole reduces the soil friction on the sounding tubes, which allows the cone to penetrate to deeper depths. Figure 3 shows a sketch of a friction reducing section and how it should be mounted to the cone.

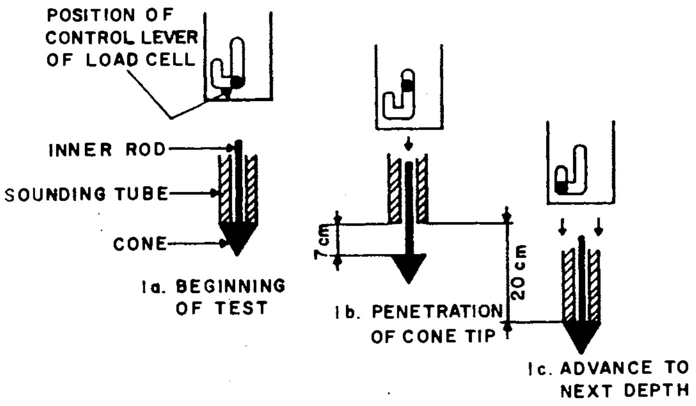
F. Pulling Device

The pulling device is used to extract the sounding tubes and cone when the sounding is completed. The device consists of a head which fits into the same mounting bracket hole as the load cell occupies. A tube extractor fits into the head and is threaded into the sounding tubes (see Figure B3. parts

SCHEMATIC ILLUSTRATION OF INCREMENTAL SOUNDING WITH MANTLE CONE

FOR OPERATING INSTRUCTIONS SEE CHAPTERS IV AND V

INCREMENTAL SOUNDING WITH MANTLE CONE



TOTAL DOWN THRUST IN kgf = READING ON THE PRESSURE GAUGE MULTIPLIED BY 20.

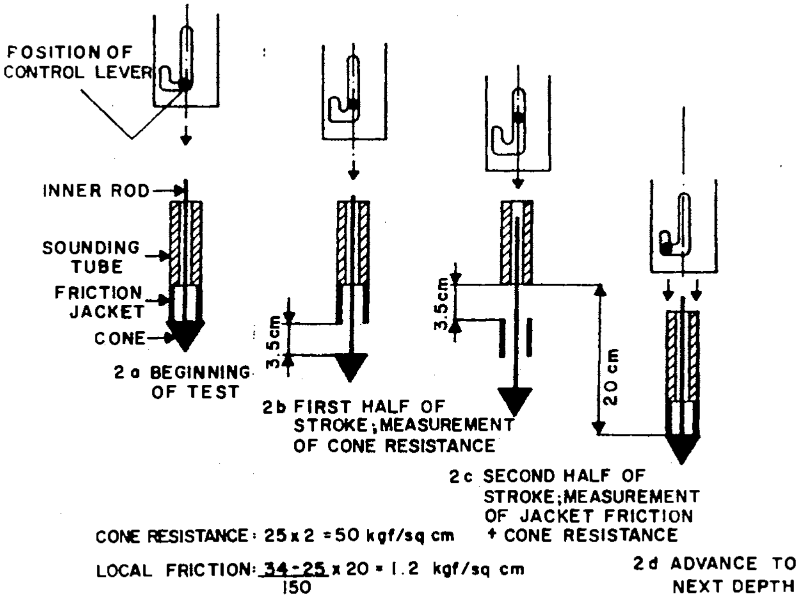
CONE RESISTANCE IN kgf/sq.cm. = READING ON THE PRESSURE GAUGE MULTIPLIED BY 20/10, OR 2.

FOR EXTENSION OF INNER RODS UNDER EXTREME CONE RESISTANCE-DEPTH RATIOS SEE FIGURE C1 IN APPENDIX C.

FIGURE 1

INCREMENTAL SOUNDING WITH FRICTION JACKET CONE

EXAMPLE: READING ON GAUGE = 25 kgf/sq cm FOR CONE
READING ON GAUGE = 34 kgf/sq cm FOR CONE PLUS FRICTION JACKET



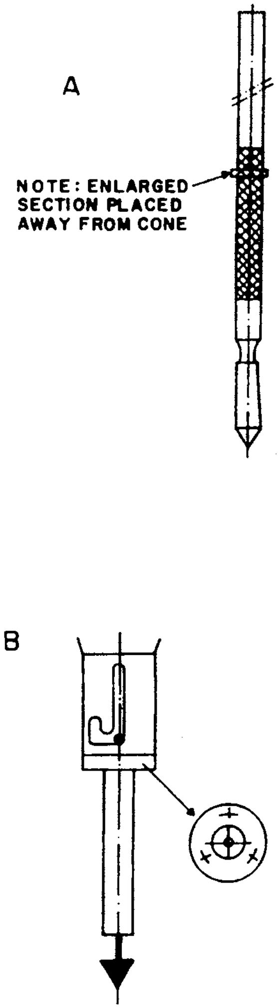
CONE RESISTANCE: 25 x 2 = 50 kgf/sq cm

LOCAL FRICTION: $\frac{34-25}{150} \times 20 = 1.2$ kgf/sq cm

FACTOR 20 = CROSS SECTION OF LOAD CELL PISTON IN sq cm
FACTOR 150 = AREA OF FRICTION JACKET IN sq cm

FOR EXTENSION OF INNER RODS UNDER EXTREME CONE RESISTANCE DEPTH RATIOS SEE FIGURE C2 IN APPENDIX C

FIGURE 2



NOTE: ENLARGED SECTION PLACED AWAY FROM CONE

A FRICTION REDUCING TUBE MAY BE USED (FIG. B4) FOR REDUCING LATERAL FRICTION ON THE SOUNDING TUBES.

CONTINUOUS SOUNDING WITH JACKET CONE

1. FIT CONTINUOUS SOUNDING RING TO THE MEASURING DEVICE.
2. EXTEND PRESSURE ROD BY MEANS OF THE EXTENDING ROD. (75 mm).
3. ADVANCE CONE INTO GROUND AT FIXED RATE AND OBSERVE GAUGE READINGS AT INTERVALS, SUCH AS 20 cm.

FIGURE 3

Number 18 and 19, Appendix B). The hydraulic system of the drill is used to extract the sounding tubes.

G. Continuous Sounding Ring Plate

The continuous sounding ring plate is attached to the bottom of the load cell (See Figure B3). The ring is used when continuous sounding using the mantle cone is desired (See Section V). Continuous sounding is a procedure whereby cone resistance is observed periodically as the cone is pushed into the soil without interruption.

H. 75 mm Inner Rod Extension

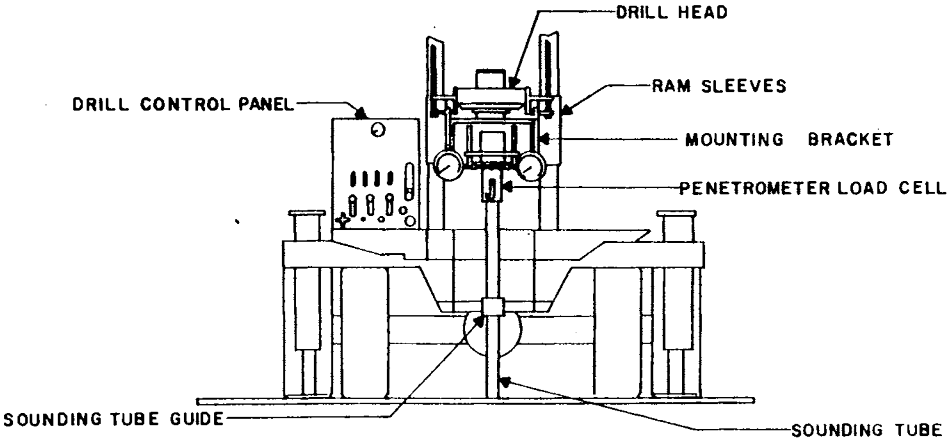
Continuous sounding with the mantle cone requires the use of a 75 mm long by 15 mm diameter inner rod extension which is used in conjunction with the continuous sounding ring (described above). The purpose of the rod extension is to extend the inner rod (See D above) so it contacts the actuating mechanism of the load cell.

I. 15 mm Inner Rod Extension

Under extreme cone resistance the inner rods are subjected to forces which will cause them to shorten elastically. The 15 mm rod extensions are used to compensate for the elastic shortening (See Appendix C). Alternatively, a single overlength sounding rod may be used for the same purpose.

J. Depth Indicator Gauge

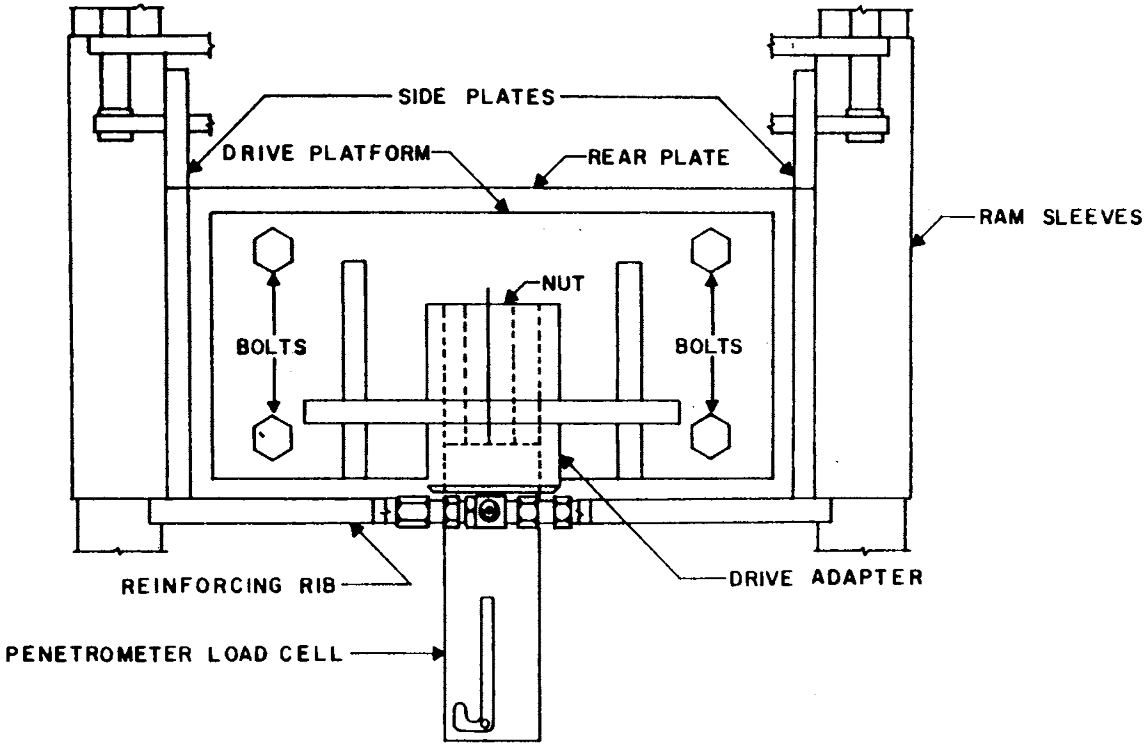
The depth indicator gauge is a 1^+ meter long slender rod containing depth indicating grooves machined into it every 10 cm. A heavy base is also provided to keep the gauge from tipping over. The gauge is located next to the sounding tubes so the operator can visually determine how far the sounding tubes should be pushed into the subsurface between tests (test is normally performed every



REAR VIEW OF DRILL WITH
PENETROMETER LOAD CELL ATTACHED

NO SCALE

FIGURE 4

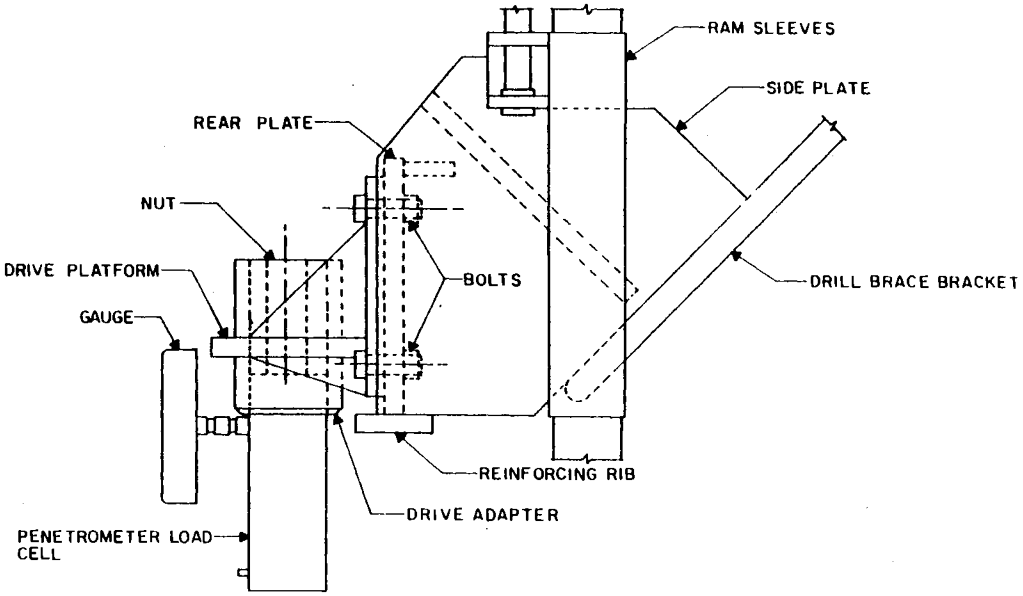


NOTE: PRESSURE GAUGES NOT SHOWN

FRONT VIEW OF CONVERSION ASSY

NO SCALE

FIGURE 5



SIDE VIEW OF CONVERSION ASSY

FIG E 6

20 cm).

III. EQUIPMENT MOUNTING AND CALIBRATION

The conversion is performed by mounting a bracket (customer fabricated) to the rear of the drill head, onto which the 11 ton hydraulic load cell is attached. The hydraulic ram system on the drill rig is then utilized to push the Dutch Cone Penetrometer into the subsurface. Mounting of the conversion package on a sliding base drill is illustrated in Figures 4, 5 and 6. Figures 5 and 6 illustrates the method of attachment of the load cell to the mounting bracket. Brackets mounting through the drill spindle are used on drills not containing a sliding base.

Generally, the bracket is left mounted permanently on drills with sliding bases whereas on non-sliding base drill rigs the bracket will have to be removed each time the operation is changed from penetrometer testing to drilling. Assistance in the design and fabrication of a bracket to fit each customer's drill rig is provided by Hogentogler and Company.

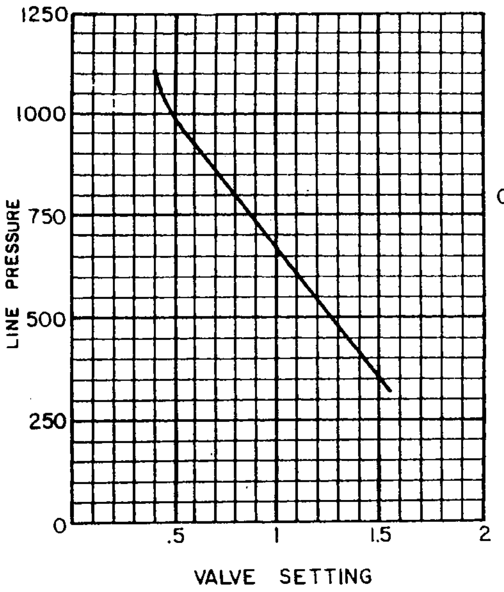
Figure 4 also illustrates a sounding tube guide (also fabricated by the customer). The purpose of the sounding tube guide is to prevent the sounding tubes from buckling. This is particularly important on drill rigs which are elevated considerably above the ground surface; i.e., all terrain vehicles. The guide should be 3 to 4 inches in length and contain a center hole with a diameter of 1-5/8 inch minimum. On auger drills the sounding tube guide can be attached to the auger guide mount.

Generally, the greater the pulldown force and the heavier the drill, the greater will be the penetration capability of the penetrometer into the subsurface strata. In order for the drill-mounted conversion kit to have adequate penetration capability, the drill should have a minimum pulldown force of 10,000 pounds. The drill and drill carrier should also have enough weight to resist the upward reaction force of the hydraulic rams on the penetrometer without lifting the drill rig off its leveling jacks. This resisting weight of the drill and carrier should equal or exceed the pulldown force of the drill (minimum 10,000 pounds). Where the weight of the drill and carrier is not sufficient to resist the total pulldown force of the drill, various methods have been employed to supplement this lack of weight. The most popular are:

1. Add extra weights to the drill rig
2. Anchoring the drill rig to a string of augers drilled into the subsurface
3. Anchoring the drill rig to a one or two flight, large diameter (8 - 12 inch) auger which is placed in the subsurface

The most effective of the above methods is the third one. Such an auger can be fabricated from a piece of drill rod (Aw or Nw) to which is welded 1/4 inch plate steel to form the auger flights. Anchoring augers are available from Hogentogler and Company. To utilize the anchor it is first turned into the subsurface by the drill after which the drill is moved over the anchor and the anchor attached to the drill by a chain or cable. The amount of resistance against the upward force of the penetrometer, added to the drill rig is a function of the size of the anchor, its depth and the type of soil it is placed into.

To properly control the rate of penetration of the cone and friction jacket during testing (2 cm/sec or up to 1 inch per sec) the drill feed rate will have to be adjusted. One method of calibrating the feed rate to determine the adjusted setting is illustrated in Figure 7 for a hydraulic feed system. Figure 7 contains a graph of the hydraulic feed cylinder pressure versus the setting of a flow control valve placed in the hydraulic line (to the feed cylinder). A hydraulic cylinder feed pressure sufficiently high to overcome the anticipated soil resistance is selected. Then the flow control valve is adjusted to admit fluid to the cylinder at a rate which will result in a penetration rate of 2 cm/sec. Most late model



FEED RATE:
0.066 Ft./SEC.
OR
2cm/SEC.

LINE PRESSURE	VALVE SETTING
350	1.5
450	1.35
550	1.18
650	1.02
750	0.86
850	0.70
950	0.55
1050	0.42
1150	0.37

FEED RATE CALIBRATION

FIGURE 7

drills are equipped with flow control valves containing numbered valve opening settings. Other calibration methods will have to be devised for each type and make of drill. A fortunate aspect of ASTM D 3441-75T is that it allows a ± 25% variation in the rate of cone penetration which will enable the crude feed rate calibration to meet the specification. The desired 2 cm/sec rate of penetration corresponds to 1 inch/sec at the upper limit of tolerance.

IV. PREPARATION FOR SOUNDING

In preparation to the start of sounding the following steps should be followed:

1. Attach the load cell to the conversion bracket as illustrated in Figure 4 through 6 and as discussed in Section III above.
2. Level the drill rig both side to side and front to back.
3. Run the load cell to its highest position above the ground surface.
4. Connect the friction reducing section with its inner rod to the mantle cone or friction jacket cone as illustrated in Figure 3A.
5. Connect additional sounding tubes with their inner rods to the friction reducing section and cone so the total length approximately equals the distance between the load cell and the ground surface (Step 3). Check to see that the inner rods and all moving parts of the mantle cone or friction jacket cone move easily. Hand tightening (shoulder to shoulder) of the sounding tubes is all that is required if the threads are kept clean and oiled.
6. Slip the sounding tube guide over the sounding tubes.
7. Stand the sounding tubes, friction reducing section, cone and sounding tube guide vertically below the load cell.
8. Connect the sounding tube guide to its mount on the drill.

9. Lower the load cell onto the top of the sounding tubes until the top sounding tube fits snugly into the bottom of the load cell.
10. Using a two foot carpenter's level or plumb bob on a string suspended from the load cell, plumb the sounding tubes, friction reducing section and cone. Plumb in two directions: perpendicular to centerline of drill and parallel to centerline of drill.
11. Measure the length of the extended mantle cone or extended friction jacket cone (from cone tip to connection with the friction reducing section). Also with the friction jacket cone extended measure the distance from the cone tip to the center of the friction jacket. Record these lengths for later use in data reduction in order to know the exact depth at which each test was performed.
12. Using the drill's hydraulic feed system, push the mantle cone or friction jacket cone into the soil until the connection of the cone and friction reducing section is at the ground surface.
13. If desired, place the depth indicator gauge rod next to the sounding tubes by pushing it into the soil. The top of the rod should be in alignment with the top of the friction reducing section. An alternative to the use of the depth indicator gauge is to mark the sounding tube and friction reducing section every 20 cm with chalk.
14. Place the control lever on the load cell in the short slot (located on the left side). The drill head may have to be raised slightly to relieve load on the sounding tubes in order to allow the lever to be moved.
15. Complete the blanks at the top of the field data form (Figure 8) and place other information requested in Section 6.3 of ASTM D 3441 under "remarks". Also note whether the test is continuous or incremental if the mantle cone is

being used.

V. TEST PROCEDURES:

Two testing procedures will be presented in this section. They are:

A. Continuous sounding

B. Incremental sounding

The continuous sounding procedure is only applicable to the mantle cone. The continuous sounding procedure presented below is not in accordance with ASTM D-3441 but is a procedure used successfully in Europe and is useful when sounding with the mantle cone. The procedure outlined below for incremental sounding follows ASTM D-3441.

A. Continuous Sounding - The following steps are performed after completion of Step 15, Section IV.

1. Raise the hydraulic load cell off the sounding tubes.

2. Attach the continuous sounding ring plate to the bottom of the load cell as shown in Figure 3.

3. Disconnect a section of sounding tube and insert the 75 mm inner rod extender. Reconnect the sounding tube.

4. Lower the hydraulic load cell down and insert the extended inner rod into the center hole of the continuous sounding ring. Move the control lever on the long slot (on the right side).

5. Continue to lower the load cell until the sounding tube engages the continuous sounding ring.

6. Recheck the plumbness of the sounding tubes as set forth in Step 10, Section IV.

7. Using the feed rate calibration chart developed in Section II, select the proper setting of the flow control valve.

8. Start the pushing of the sounding tubes and record the gauge reading at every 20 cm mark on the sounding tube or depth indicator gauge. Monitor the feed pressure and adjust the flow control valve as needed (calibration chart) to obtain the 2 cm/sec penetration rate. In lieu of the calibration chart, a stop watch may be used to time the penetration of each 20 cm increment of sounding tube. This will allow adjustment of the feed rate (2 cm/sec) so that each 20 cm increment of sounding tube requires 10 seconds to penetrate into the subsurface. Record each gauge reading in column 2 of the field data form (Figure 8). Also record the depth of the cone in column 1. Note, the depth recorded in column 1 should be the length of the sounding tubes in the soil (at the point of testing) plus the length of the extended mantle cone. Alternatively, the length of the cone may be accounted for later in data reduction.

9. Add sounding tubes (with inner rods) as required. Mark the sounding tube every 20 cm if applicable. Proceed with testing to desired depth.

B. Incremental Sounding - The following steps are performed after completion of Step 15, Section IV.

1. Check to see that the control lever on the load cell is in the small slot (on the left).

2. Push the sounding tubes into the subsurface to the first 20 cm mark.

3. Raise the load cell slightly and simultaneously shift the lever on the load cell to the large slot on the right. This will allow the inner rod to be pushed, extending the mantle cone (or cone and friction jacket).

4. Using the feed rate calibration chart (developed as set forth in Section III), select the proper setting of the flow control valve. Feed pressure will have

Load Cell Gauges

Old Gauges - Kgf/cm²
New Gauges - 1000 N

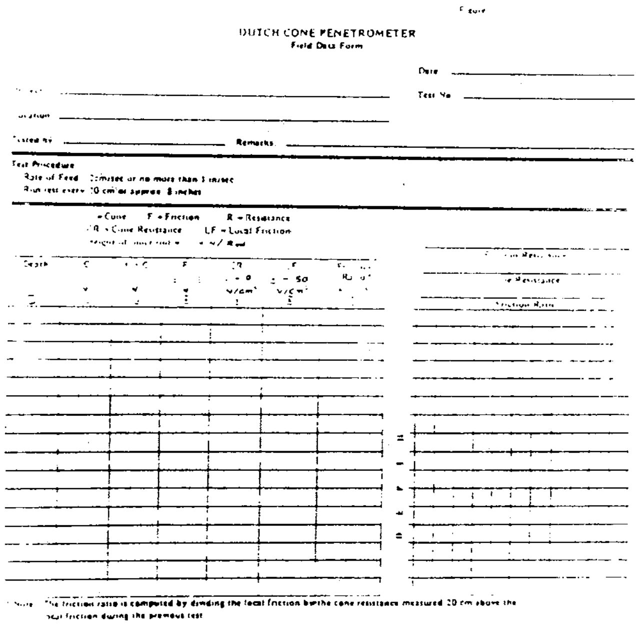
The old gauges were confusing for two reasons. First, a kilogram (Kg) is a unit of mass, not force. Therefor, the "f" subscript (Kgf) was used, since force is what is really desired. Secondly, that pressure reading of Kgf/cm² was a measurement of oil pressure in the load cell, not cone pressure at the tip or sleeve.

The new gauges are calibrated in units of force, newtons (N), and are also calibrated to give a direct reading of tip force. For example, a reading of 34,000 N means a force of 34,000 N is applied. Multiplying by 20 is no longer necassary. To get tip pressure or friction sleeve pressure in N/cm², simply divide by the tip area (10 cm²) or friction sleeve area (150 cm²) respectively.

It is recommended that newtons be used to log cone data. A sample log sheet is provided on the back.

However, to continue using Kgf/cm² tip pressure is really quite simple:
Example: Old gauge reads 25Kgf/cm²
25Kgf/cm² x 20cm² (piston area) ÷ 10cm² (tip area) = 50 Kgf/cm²
Example: New gauge reads 5000 N
5000 N ÷ 10 N/Kgf * ÷ 10 cm² (tip area) = 50 Kgf/cm²

*approximation within the accuracy of the gauges



Figure

DUTCH CONE PENETROMETER
Field Data Form

Date ______
Test No ______
Location ______
Tested by ______ Remarks ______

Test Procedure
Rate of Feed 2cm/sec or no more than 1 in/sec
Run test every 20 cm or approx. 8 inches

= Cone F = Friction R = Resistance
LF = Local Friction

Note: The friction ratio is computed by dividing the local friction by the cone resistance measured 20 cm above the local friction during the previous test

Figure 8

DUTCH CONE PENETROMETER
Field Data Form

Date ______________________

roject. ______________________ Test No ______________________

ocation ______________________

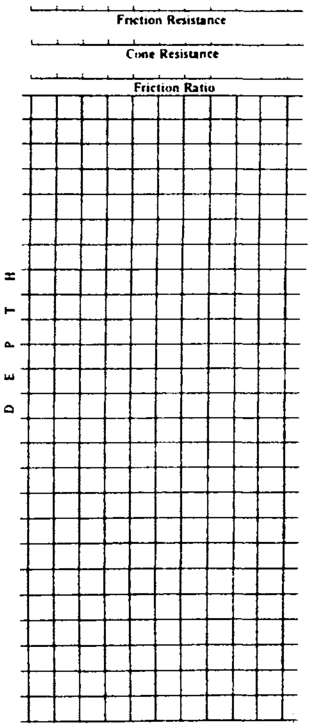
ested by: ______________________ **Remarks:** ______________________

est Procedure:
Rate of Feed: 2cm/sec or no more than 1 in/sec
Run test every 20 cm or approx. 8 inches

C – Cone F – Friction R – Resistance
CR – Cone Resistance LF – Local Friction
Weight of inner rod – 0.14 Kg/cm² /rod length

Depth ①	C Kg/cm2 ②	F + C Kg/cm2 ③	F ③ – ② Kg/cm2 ④	CR ② × 2 Kg/cm2 ⑤	LF ④ × 0.133 Kg/cm2 ⑥	Friction Ratio* ⑥ / ⑤ ⑦

THE COMPUTATION IN COLUMN 5 IS NO LONGER NECESSARY
AS ALL GAUGES ARE NOW DIRECT READING.
PLEASE DISREGARD THIS COMPUTATION.



* Note: The friction ratio is computed by dividing the local friction by the cone resistance measured 20 cm above the local friction during the previous test.

to be estimated initially and the flow control valve adjusted after the initial test and thereafter as the feed pressure changes during the pushing of the cone and friction sleeve. A better method of selecting the proper feed rate (2 cm/sec) is during the pushing of the sounding tubes. The proper feed rate is selected as set forth under Step 8 of the continuous sounding procedure (above).

5. At the calibrated rate of penetration, push the inner rod taking reading on the gauges at:

<u>Mantle Cone</u> - After approximately 1 inch of relative movement of inner rod. Read gauge and record in column 2 of the field data form. (Figure 8)

<u>Friction Jacket Cone</u> - The cone reading should be taken before the cone engages the friction sleeve which will be noted by a jump (increase) of the gauge reading. Record this first reading in column 2 of the field data form (Figure 8). After the cone engages the friction sleeve, obtain a reading on the gauges. This second reading represents the cone plus friction sleeve resistances. Record this reading in column 3 of the field data form (Figure 8). Also record in column 1 the depth (length of sounding tubes in the soil at the time of the test plus the average length of the extended friction jacket cone) at which the cone and friction jacket gauge readings were obtained. Alternatively, the length of the extended friction jacket cone may be accounted for later in data reduction. In non-homogeneous soil deposits or for more refined data the exact depths of the cone and friction jacket will have to be recorded in column 1. The exact depths are the length of sounding tubes in the soil at the time of the test plus:

1. Length of friction jacket cone extended
2. Length to center of extended friction jacket

Note:

Readings should be taken on the 0-100 kgf/sq cm gauge up to 80 kgf/sq cm. Readings over 80 kgf/sq cm should be made from the high pressure gauge (0-600 kgf/sq cm).

6. When the full stroke of the inner rod has been reached, the gauge readings will increase substantially because the entire string of sounding tubes is being forced into the ground. At his point stop penetration of the inner rods and raise the load cell an amount sufficient to shift the lever on the load cell to the small slot on the left. The sounding tubes can now be pushed to the next 20 cm mark. During the pushing of the sounding tubes to the next test depth, the cone or cone and friction sleeve are automatically collapsed in preparation for the next test.

7. When the full down stroke of the drill has been reached, raise the load cell sufficiently to connect another sounding tube and inner rod. Lower the load cell, (mark rod every 20 cm if applicable) and proceed with the test.

8. Repeat Steps 4 through 7 until the desired depth of sounding has been reached.

VI. CONCLUSION OF TEST

As soon as possible after the conclusion of the test, the sounding tubes should be extracted. Failure to extract the sounding tubes immediately may result in skin friction "set-up" along the tubes' surfaces which could prevent extraction. The following steps to

conclude the test should be followed:

1. Raise the hydraulic load cell off the sounding tubes and remove the load cell from its bracket (Figure 4 and 6).

2. Secure the extractor head in the mounting bracket hole previously occupied by the load cell. Figure B3 part Number 19, of Appendix B shows the extractor head.

3. Place the tube extractor (Figure B3 part Number 18, Appendix B) into the extractor head. The threaded end of the tube extractor will be threaded into the top sounding tube.

4. A rod wiper or old piece of tire can be slipped over the top of sounding tubes and fixed in place. This will clean the exterior of the sounding tubes during extraction.

5. Lower the extractor head and tube extractor sufficiently to allow the extractor to be threaded into the top sounding tube.

6. Using the drill's hydraulic system raise the extractor head, tube extractor and sounding tubes sufficiently to allow removal of the sounding tube section. Care should be used when unthreading and removing the sounding tube so that the inner rod does not fall out onto the operator and cause injury, or onto the soil. Also a pipe vise or other device may have to be fastened to the sounding tubes remaining in the soil so that they do not slip down into the sounding hole where they could not be retrieved.

7. Repeat Steps 4 and 5 until all the sounding tubes and the cone have been extracted.

8. Remove the extractor head and tube extractor.

9. It is good practice to clean the sounding tubes of exterior dirt and to remove and wipe clean the inner rods when not being used almost daily. Lightly oil the inner rod before reinserting into the sounding tube. A spray lubricant is ideal for use on the inner rods. Clean and dry thoroughly, and inspect the mantle cone or friction jacket cone for worn parts or any binding of the moving parts. Replace all worn parts and lubricate all internal moving parts of the mantle cone or friction jacket cone. See

Figures B4, B5 and B6, Appendix B, for views and part's names of the mantle cone and friction jacket cone.

VII. CALCULATIONS AND REPORTING

Figure 8 is a copy of a self explanatory field data form. By progressing from column 1 to 7 and following the calculations at the top of each column the cone resistance, local friction and friction ratio are computed. Further brief explanations of the calculations will be given below.

The data collected during the field operations include gauge readings for the cone, and cone plus friction jacket, resistances. This data is placed in columns 2 and 3 of Figure 8, respectively and is in the units of kilograms force per square centimeter (kgf/sq cm). If a mantle cone is used, data is entered in column 2 only.

The area of the measuring plunger in the hydraulic load cell is 20 square centimeters. The area of the cone is 10 square centimeters. Thus to compute the pressure on the cone, multiply the gauge reading pressure (column 2) by two (20/10) to yield the cone pressure (column 5) in kilograms per square centimeter (kgf/sq cm).

When a friction jacket cone is used, a gauge value will also be obtained for the combined cone plus the friction jacket resistance (column 3). To determine the gauge reading for the friction jacket only, subtract the cone gauge reading (column 2) from the gauge reading obtained for the cone plus friction jacket (column 3). This value is recorded in column 4 of Figure 8. Since the measuring plunger in the hydraulic load cell is 20 square centimeters, the total force (kgf) required to move the friction jacket is obtained by multiplying the gauge reading for the friction jacket by 20. Dividing this result by 150 square centimeter area of the friction jacket yields the local friction in kilograms per square centimeter (kgf/sq cm). The above computations are combined into the factor 0.133 which is multiplied by column 4 to obtain the local friction value in column 6 of Figure 8. Another important computation is the ratio of the cone resistance (column 5) to the local friction (column 6), which is referred to as the friction ratio (column 7). Remember that the friction ratio must be determined from values of cone resistance and local friction measured at the same depth in the soil stratum.

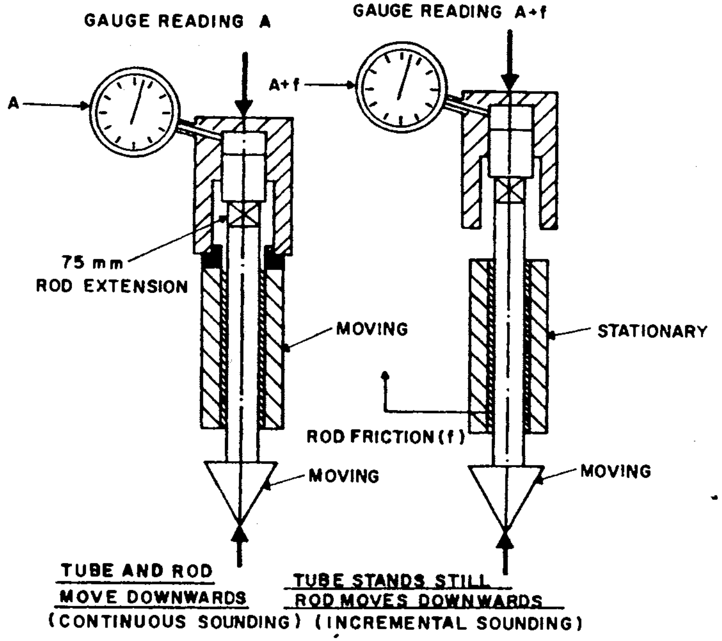
Superimposed plots of the cone resistance, local friction and friction ratio versus depth should be included in the final reporting of the field data. Figure 8 provides a graph for these plots although a more refined graph may be required for further office analysis. For non-homogenous soil deposits it will probably be necessary to use exact depths for the cone and friction jacket rather than using an average depth for both readings. (See Section V, Incremental Sounding) This is particularly important in computing the friction ratio for non-homogenous soils. For an accurate friction ratio in non-homogenous soil deposits, the cone resistance and local friction values should be as close to the same depth as possible.

VIII. SPECIAL PROCEDURES

The following special procedures are applicable under unusual circumstances and are not generally required:

A. Drift of the sounding tubes may become a problem in very deep soundings and when passing through or alongside of obstructions such as boulders, soil concretions, thin rock layers and inclined dense strata. Drift of the sounding tubes results in bending of the tubes and the development of friction between the inner wall of the sounding tube and the inner rod. The magnitude of this inner wall friction could have a significant effect on the gauge readings obtained for cone resistance and local friction values. Generally drift of the sounding tubes should be minimized but if circumstance dictate otherwise and the sounding cannot be terminated and reinitiated, Figure 9 should be consulted to determine the magnitude of the inner rod friction.

CHECKING OF ROD FRICTION
(IN HOMOGENEOUS LAYERS)



TO DETERMINE THE MAGNITUDE OF THE INNER ROD FRICTION f IN A HOMOGENEOUS SOIL, PERFORM THE FOLLOWING STEPS:

1. DETERMINE THE CONE RESISTANCE (GAUGE READINGS) BY BOTH THE CONTINUOUS AND INCREMENTAL SOUNDING METHODS (SECTION V)
2. THIS WILL YIELD GAUGE READINGS OF A AND (A+f) RESPECTIVELY
3. TO FIND f; f = (A+f) - (A)
4. CORRECT ANY SUSPECTED VALUE OF GAUGE READINGS OBTAINED BY INCREMENTAL SOUNDING.

FIGURE 9

B. A sounding should not be performed any closer than the zone of influence of an unbackfilled uncased boring.

C. If penetration tests are to be performed below such subsurface obstructions as very dense sand and hardpan, the obstructions will have to be bored through. Hollow stem augers work extremely well in these circumstances, particularly if the surrounding material needs to be cased in order to keep the bore hole open. When the obstruction has been drilled through by the hollow stem auger, the penetrometer testing can then proceed through the center of the hollow stem auger. Generally, in deep borings some form of rod support will have to be provided inside the hollow stem augers to avoid buckling of the sounding tubes.

Data from the penetrometer should not be used until it is out of the disturbed zone of the auger. This distance should be three boring diameters as a minimum below the bottom of the auger.

D. As the force on the inner rod increases due to increasing cone resistance, or cone and friction jacket resistance, the inner rods tend to shorten (Hooke's Law). At a point depending on the force on the rods and their length, a piece (15 mm long) of inner rod will have to be added to compensate for the rod shortening. Appendix C, Figures C1 and C2 contains calibration charts for determining the length of inner rod to add for the mantle and friction jacket cone, respectively. Appendix C also contains information on the use of Figures C1 and C2.

IX. MAINTENANCE

Periodic maintenance which should be performed on the Dutch Cone is as follows:

A. Wear and scour of the penetrometer tip and friction sleeve will occur. These components should be replaced when the geometry and surface roughness no longer meet the requirement of Section 3.1 of ASTM D 3441-75T (Appendix A).

B. The mantle cone and friction jacket cone should be cleaned, dried and oiled after each sounding. All moving parts should move freely.

C. The cut-off pressure at which the 0-100 kgf/sq cm gauge should no longer register and the 0-600 kgf/sq cm gauge should be read is approximately 80 kgf/sq cm. Adjusting screw 7 (Figure B1, Appendix B) regulates this cut-off pressure. This cut-off pressure should be adjusted as required.

D. After each test all sounding tubes should be cleaned and checked for straightness and fractures (around threads). Replace any sounding tubes which are bent or fractured. Keep the threads cleaned and well oiled so threading and unthreading can be performed easily.

E. Keep the inner rods clean and lubricated. A spray lubricant applied once a day will assure relatively frictionless movement of the inner rods.

F. The oil level in the hydraulic load cell should be checked periodically. To make this check:

1. Place lever C, (See Figure 10) in the left hand slot.
2. Exert a force on the load cell by pushing the penetrometer and sounding tubes into the soil.
3. During the force exertion, measure the distance that lever C moves upward. This distance should be no more than 10 millimeters. If this distance is more than 10 millimeters, add oil to the cell.

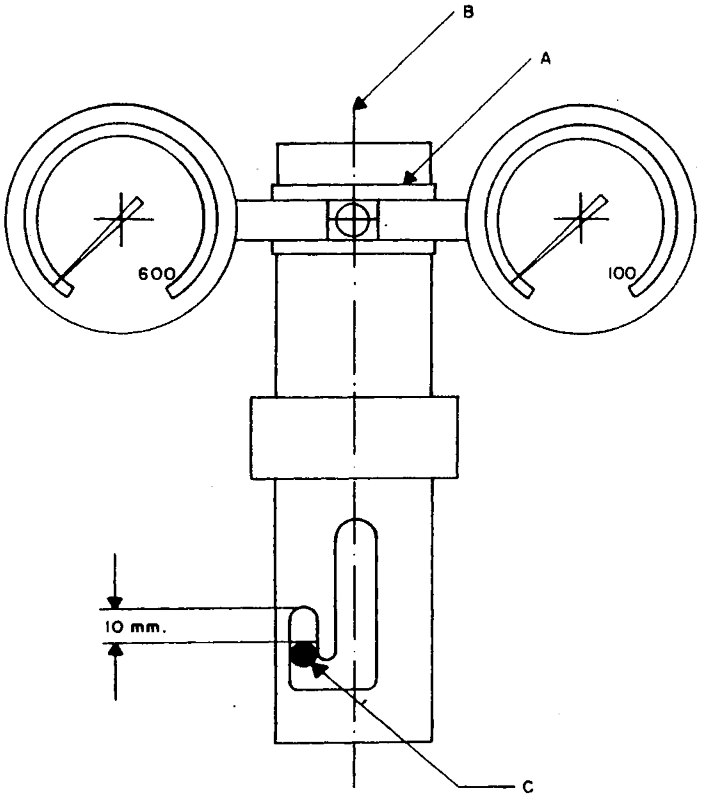
Oil is added to the cell by:

1. Release all pressure on the load cell.
2. Unscrew fill plug B (See Figure 10 or screw 3, Figure B3, Appendix B).
3. Push down the plunger, using the 3 mm pin provided (until it stops).

4. Open vent A to allow trapped air to escape.
5. Fill the cell with oil of grade ____________ through plug B.
6. Close vent A and plug B when the cell is full.

APPENDIX B

Detailed Diagrams and Parts Lists



OIL LEVEL CHECK

FIGURE 10

BY TWISTING THE ADJUSTING SCREW "7," THE MAX. PRESSURE ON THE RIGHT GAUGE IS REGULATED. (MAX. 80 kg/cm2)

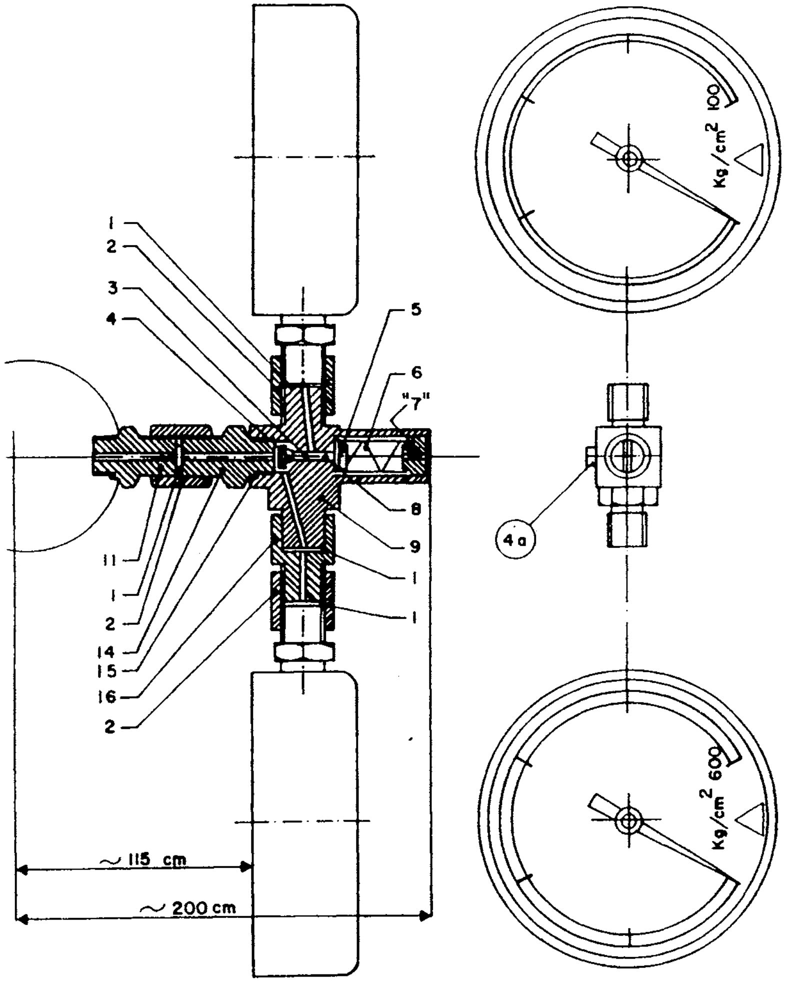


FIGURE B1

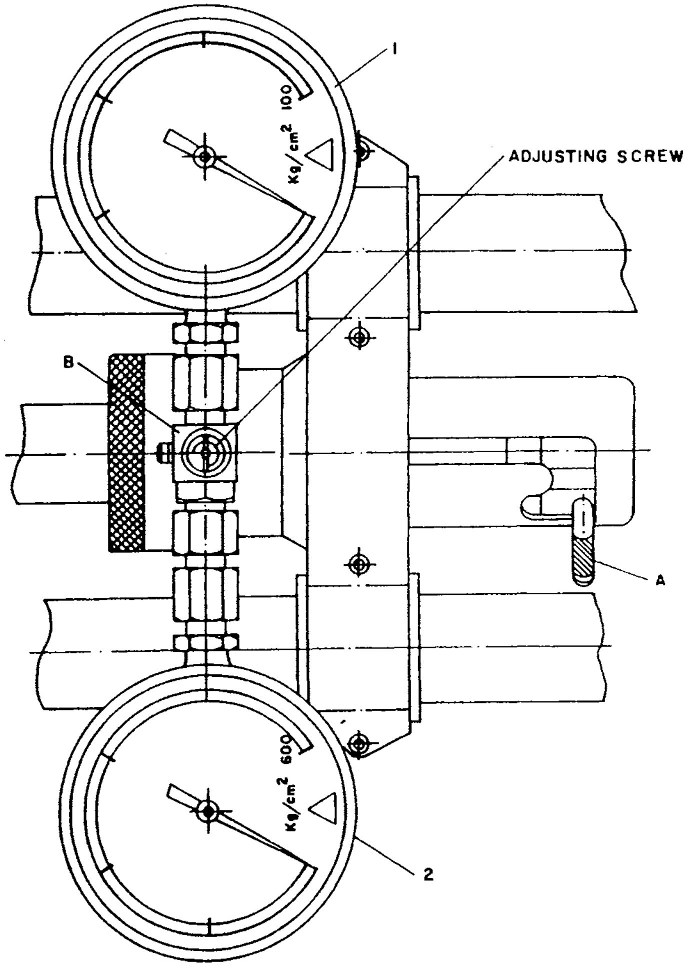
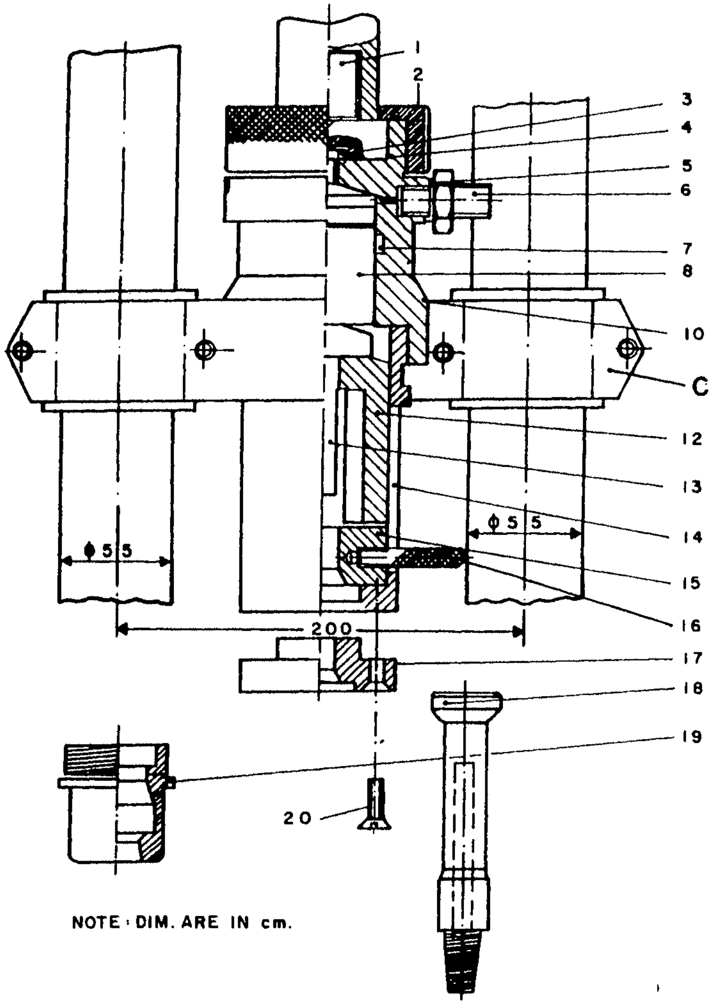


FIGURE B2



NOTE : DIM. ARE IN cm.

FIGURE B3

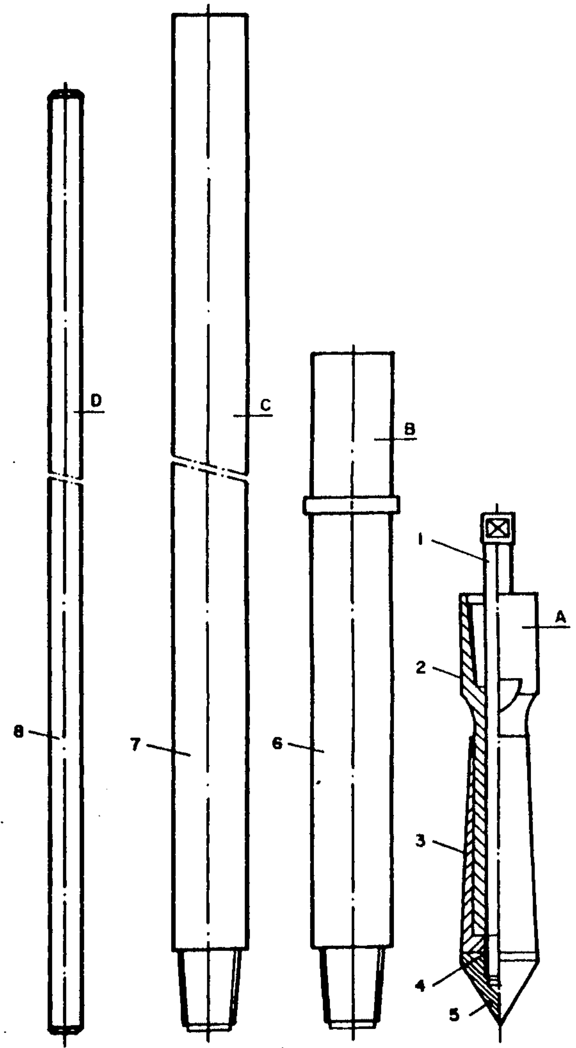
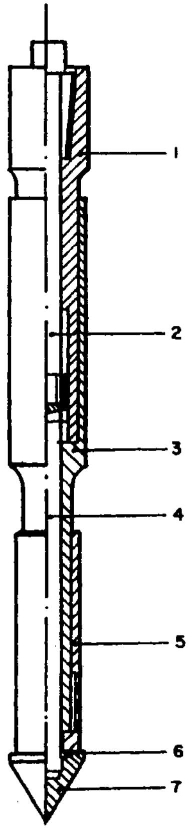


FIGURE B4



1. UNION SLEEVE
2. CONE ROD
3. FRICTION SLEEVE 150 cm^2
4. CONE ROD
5. CONE SLEEVE
6. RIM WASHER
7. CONE 10 cm^2

FIGURE
B5

APPENDIX C

Inner Rod Extensions

Instruction For Use of

Figures C1 and C2

Increasing cone resistance results in the shortening of the inner rods. To compensate for this shortening, 15 mm lengthening rods are added to the inner rods. To determine the number of lengthening rods which must be used, the force on the inner rods must be found. To determine the rod force it is necessary to obtain the gauge pressure readings for the cone (mantle cone) or cone plus friction jacket (friction jacket cone). These are the values recorded in columns 2 and 3, respectively on Figure 8. To convert the gauge pressure readings to tons:

$$\text{Rod force (tons)} = \frac{A \times 20}{1000}$$

A = Gauge pressure as defined above for the mantle cone or friction jacket cone, whichever is used (kg/cm^2)

To determine the added length of inner rod required, find the zone on Figure C1 or C2 where the intersect of the rod force (ton) and length of rod (m) falls. The figures are:

Mantle cone = See Figure C1

Friction jacket cone = See Figure C2

Figures are used as follows:

Area A - penetration is made without lengthening rod

Area B - penetration is made using one 15 mm piece of lengthening rod

Area C - penetration is made using two 15 mm pieces of lengthening rods

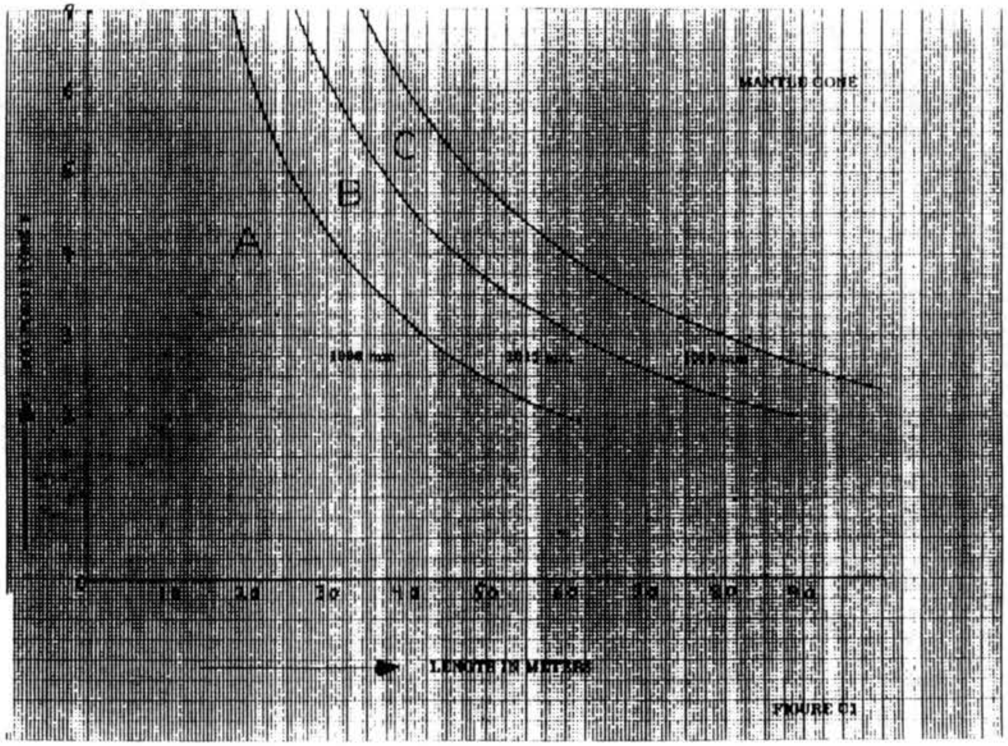

MANTLE CONE
A
B
C
1000 mm
2000 mm
0
10
20
30
40
50
60
70
80
90
2
3
4
5
6
7
LENGTH IN METERS

FIGURE C1

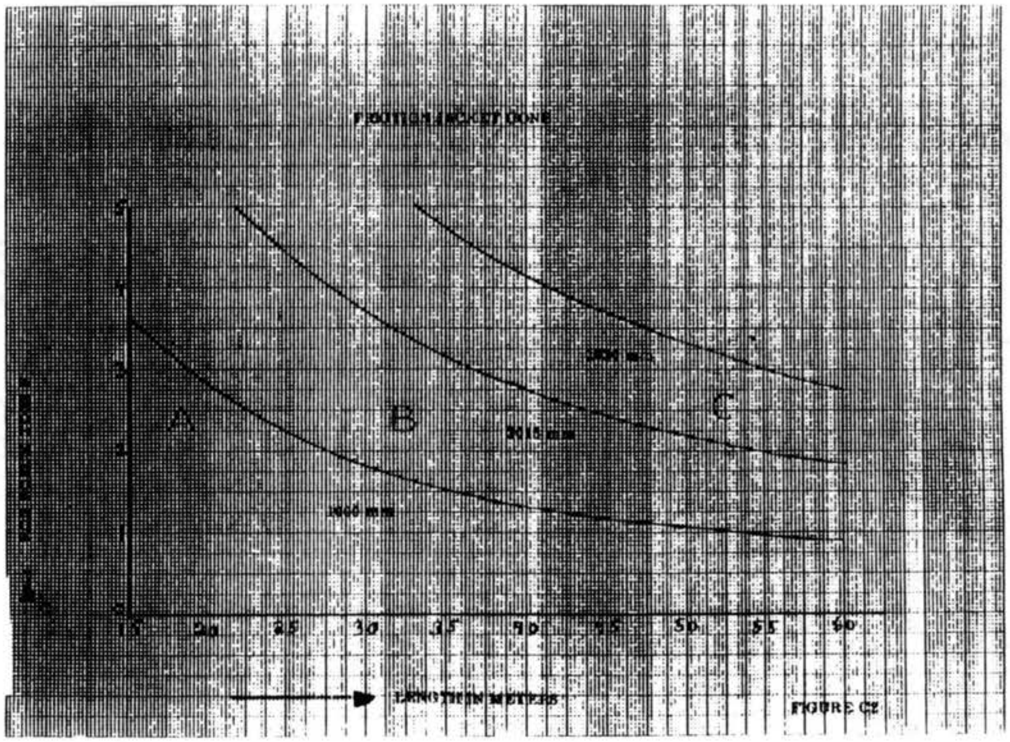

FRICTION JACKET CONE
0
1
2
3
4
5
15
20
25
30
35
40
45
50
55
60
A
B
C
1000 mm
2015 mm
2000 mm
LENGTH IN METERS

FIGURE C2

APPENDIX D

Technical Specifications

TECHNICAL SPECIFICATION - OPERATING AND MAINTENANCE INSTRUCTIONS

TECHNICAL SPECIFICATION:

Load cell with gauges

Area of the measuring plunger: 20 sq cm

Measuring range of the low pressure gauge 0 - 100 kgf/sq cm

Measuring range of the high pressure gauge 0 - 600 kgf/sq cm

The low pressure gauge is protected from overload by an automatic shut-off valve which begins operating at about 80 kgf/sq cm.

Readings on the low pressure gauge over 80 kgf/sq cm are therefore not exact.

Weight of the pressure sleeve: 1,65 kg

Weight of the pressure hammer + handle: 0-40 kg

If very accurate measurements are needed in soil with very low cone resistance, please contact us for information on aluminum push rods and/or more sensitive equipment.

Sounding gear

A) Jacket cone: max. admissible load 7.000 kgf

weight of jacket and rod: 0.4 kg

cone base area: 10 sq cm

apex angle: 60°

stroke: 70 mm

B) Friction jacket cone max. admissible load: 7.000 kgf

weight of friction mantle + rod: 0.8 kg

cone base area: 10 sq cm

apex angle: 60°

stroke of cone: 35 mm

stroke of cone plus mantle: 35 mm

total stroke: 70 mm

surface of friction jacket: 150 sq cm

C) **Friction reducing section tube**

D) **Sounding tubes:**

seamless: ø 36/16 mm x 1000 mm long

weight: 6.65 kg

E) **Inner rods:**

ø 15 mm x 1000 mm long

weight: 1.40 kg

Your spare parts order can be correctly carried out only if you quote all of the following references:

No. of the Machine
Page Number
Part Number

PARTS LIST

Fig. No.	Part No.	Denomination	
B1	1	Usitring	
	2	Union nut	
	3	Valve	
	4	O-ring	
	4a	Bolt	
	5	Spring cup	
	6	Spring	
	7	Spring cup bolt	
	8	O-ring	
	9	House	
	11	Union bolt	
	14	Union bolt	
	15	Ring	
	16	Bolt	
B2	1	Pressure	100 kgf/cm^2
	2	Pressure	600 kgf/cm^2
B3	1	Collar bolt	
	2	Union nuts	
	3	Sealing nipple	
	4	Usitring	
	5	Usitring	
	6	Union bolt	
	7	Cupper washer	
	8	Plunger	
	10	Plungercasing	
	12	Pressure sleeve	
	13	Pressure rod	
	14	Pressure casing	
	15	Pressure plate	
	16	Lever	
	17	Ring for continuous sounding	
	18	Tube extractor	
	19	Extractor head	
B4	1	Cone rod	
	2	Union sleeve	
	3	Cone sleeve	
	4	Spring washer	
	5	Cone (10 sq cm^2)	
	12	Friction reducing section tube	
	13	Sounding tube	
	14	Inner rod	

APPENDIX D

BORING LOGS AND PHYSICAL PROPERTY DATA

TABLE D1, WAGONER, BORING W1

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	1A	0.0-0.5	FAT CLAY	15.0	53	31	(100)	*98	96	89.2	CH	-0.226	
2	1B	0.5-1.0	" "	24.5	66	40		100	99	97.1	"	-0.038	
3	1C	1.0-1.7	" "	30.1	67	40		100	100	98.5	"	0.078	7/1.5
4	1D	1.7-2.4	" "	31.9	72	46		100	100	98.7	"	0.128	
5	1E	2.4-3.1	" "	33.8	73	45		100	100	98.8	"	0.129	3/3.0
6	1F	3.1-3.8	" "	31.8	71	44		100	99	97.7	"	0.109	
7	1G	3.8-4.1	" "	29.1	66	41		100	100	97.9	"	0.100	
8	1H	4.1-4.8	" "	28.1	58	35		100	99	96.9	"	0.146	
9	1I	4.8-5.5	" "	32.8	74	48		100	99	98.1	"	0.142	
10	1J	5.5-6.2	" "	30.9	75	49		100	99	98.1	"	0.100	4/6.0
11	1K	6.2-6.9	" "	29.6	69	45		100	99	99.0	"	0.124	
12	1L	6.9-7.6	" "	30.1	71	47		100	100	98.5	"	0.130	7/7.5
13	1M	7.6-8.3	" "	30.5	67	43		100	100	98.3	"	0.151	
14	1N	8.3-9.1	" "	29.5	68	44		100	99	97.9	"	0.125	6/9.0
15	1O	9.1-9.8	" "	30.9	66	42		100	99	98.1	"	0.164	
16	1P	9.08-10.5	" "	30.5	68	45		100	99	98.3	"	0.167	6/10.5
17	1Q	10.5-11.2	" "	35.4	65	42		100	99	98.3	"	0.295	
18	1R	11.2-11.9	" "	34.0	63	39		100	99	98.1	"	0.256	6/12.0
19	1S	11.9-12.6	" "	34.5	66	43		100	100	98.5	"	0.267	
20	1T	12.6-13.3	" "	38.4	64	41		100	100	98.3	"	0.376	6/13.5
21	1U	13.3-14.0	" "	35.8	64	42		100	99	98.5	"	0.329	
22	1V	14.0-14.3	" "	27.7	59	35		100	99	97.5	"	0.106	
23	1W	14.3-15.0	" "	25.5	61	38		100	99	97.3	"	0.066	7/15.0
24	1X	15.0-15.7	" "	27.4	62	39		100	99	97.7	"	0.113	
25	1Y	15.7-16.4	" "	26.0	63	39		100	99	98.5	"	0.051	5/16.5
26	1Z	16.4-17.1	" "	26.2	62	40		100	99	97.1	"	0.105	
27	1AA	17.1-17.8	" "	25.9	55	35		100	100	94.2	"	0.169	8/18.0
28	1BB	17.8-18.5	" "	24.8	55	34		100	100	96.3	"	0.112	
29	1CC	18.5-19.2	" "	25.7	62	38		100	99	97.6	"	0.045	
30	1DD	19.2-19.6	" "	30.7	52	31		100	100	91.3	"	0.313	9/19.5
31	1EE	19.6-20.3	LEAN CLAY	26.6	45	26		100	100	94.9	CL	0.292	
32	1FF	20.3-21.0	" "	24.1	40	21		100	100	89.0	"	0.243	8/21.0
33	1GG	21.0-21.7	" "	25.9	37	19		100	100	94.3	"	0.416	
34	1HH	21.7-22.4	LEAN CLAY WITH SAND	25.5	32	15		100	100	82.7	"	0.567	4/22.5
35	1II	22.4-22.7	" " " "	23.3	31	15		100	100	80.9	"	0.487	
36	1JJ	22.7-23.2	" " " "	26.7	28	11		100	100	74.0	"	0.882	
37	1KK	23.2-23.4	" " " "	25.4	24	8		100	100	73.7	"	1.175	
38	1LL	23.4-24.1	" " " "	22.4	29	12		100	100	79.1	"	0.450	3/24.0
39	1MM	24.1-24.7	" " " "	27.5	28	11		100	100	76.3	"	0.955	
40	1NN	24.7-25.4	" " " "	28.7	29	13		100	100	79.1	"	0.208	0/25.5
41	1OO	25.4-26.1	SANDY SILTY CLAY	27.2	23	6		100	100	67.5	CL-ML	1.700	
42	1PP	26.1-26.8	" " "	24.0	24	7		100	100	62.1	CL-ML	1.000	0/27.0
43	1QQ	26.8-27.5	LEAN CLAY WITH SAND	26.9	25	8		100	100	71.9	CL	1.238	
44	1RR	27.5-28.2	SANDY SILTY CLAY	27.0	23	5		100	100	65.0	CL-ML	1.800	7/28.5
45	1SS	28.2-28.9	" " "	25.4	23	5		100	100	60.0	CL-ML	1.400	
46	1TT	28.9-29.7	POORLY GRADED SAND	23.5	NP	NP	(99)	*99	95	11.6	SP-SM	.	9/30.0
47			WITH SILT						.	.		.	
48	1UU	29.7-30.4	" " " "	22.2	NP	NP	(99)	*98	96	8.3	"	.	
49	1VV	30.4-31.1	" " " "	23.4	NP	NP	(99)	*97	92	10.4	"	.	
50	1WW	31.1-31.6	SILTY SAND	14.8	NP	NP		100	99	12.5	SM	.	14/31.5
51	1XX	31.6-31.9	" "	16.4	NP	NP	(91)	*88	83	12.1	"	.	
52	11VV	31.9-33.0	SITLY SAND WITH		NP	NP	(74)	*67	60	12.4	SM	.	13/33.0
53			GRAVEL						.	.		.	
54	11W	33.0-34.5	" " " "		NP	NP	(50)	*38	32	14.9	"	.	7/34.5

TABLE D1, WAGONER, BORING W1 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	11X	34.5-35.0	SILTY SAND		NP	NP		100	95	12.3	"	.	
56	11XX	35.0-36.5	SILTY SAND WITH		NP	NP	(57)	*46	37	13.6	"	.	11/36.5
57			GRAVEL						.	.		.	
58	11ZZ	36.5-37.2	LEAN CLAY WITH SAND		38	12		100	95	82.4	CL	.	
59			(SHALE)						.	.		.	

TABLE D2, WAGONER, BORING W2

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	2A	0.0-0.4	FAT CLAY	14.7	53	31	(97)	*96	94	89.9	CH	-0.235	
2	2B	0.4-1.0	" "	29.3	70	44		100	100	99.4	"	0.075	
3	2C	1.0-1.6	" "	33.5	70	42		100	100	98.5	"	0.131	7/1.5
4	2D	1.6-2.3	" "	33.3	72	46		100	100	98.9	"	0.159	
5	2E	2.3-3.0	" "	30.4	68	44		100	100	98.1	"	0.145	4/3.0
6	2F	30.-3.7	" "	31.5	71	47		100	99	96.8	"	0.160	
7	2G	3.7-4.2	" "	31.8	80	54		100	100	98.5	"	0.107	4/4.5
8	2H	4.2-4.9	" "	31.3	75	50		100	100	98.5	"	0.126	
9	2I	4.9-5.6	" "	29.8	66	43		100	99	98.3	"	0.158	
10	2J	5.6-6.3	" "	25.4	59	39		100	99	97.2	"	0.138	4/6.0
11	2K	6.3-6.9	" "	24.5	58	38		100	99	97.9	"	0.118	
12	2L	6.9-7.5	" "	25.7	60	38		100	99	96.9	"	0.097	5/7.5
13	2M	7.5-8.2	" "	27.6	65	43	(99)	*98	97	95.6	"	0.130	
14	2N	8.2-8.9	" "	27.3	62	39		100	99	97.4	"	0.110	7/9.0
15	2O	8.9-9.2	" "	30.0	66	42	(99)	*97	95	93.3	"	0.143	
16	2P	9.2-9.7	" "	26.2	61	40		100	99	97.3	"	0.130	
17	2Q	9.7-10.4	" "	25.4	55	34		100	99	97.7	"	0.129	6/10.5
18	2R	10.4-11.1	" "	26.8	63	41		100	100	99.0	"	0.117	
19	2S	11.1-11.8	" "	26.6	63	41		100	100	98.3	"	0.112	7/12.0
20	2T	11.8-12.5	" "	26.6	64	41		100	99	98.1	"	0.088	
21	2U	12.5-13.2	" "	26.7	63	40		100	100	98.7	"	0.093	8/13.5
22	2V	13.2-13.9	" "	26.9	65	43		100	100	98.3	"	0.114	
23	2W	13.9-14.6	" "	26.1	64	44		100	100	97.8	"	0.139	
24	2X	14.6-15.0	" "	24.0	53	32		100	100	98.3	"	0.094	8/15.0
25	2Y	15.0-15.7	" "	24.4	55	33		100	100	98.5	"	0.073	
26	2Z	15.7-16.4	" "	24.5	56	37		100	100	97.5	"	0.149	8/16.5
27	2AA	16.4-17.1	" "	23.5	54	34		100	99	96.8	"	0.103	
28	2BB	17.1-17.8	" "	22.6	52	33	(100)	*98	96	92.2	"	0.109	11/18.0
29	2CC	17.8-18.5	" "	23.1	51	32	(99)	*99	99	92.2	"	0.128	
30	2DD	18.5-19.2	LEAN CLAY	22.1	47	29		100	99	95.9	CL	0.141	12/19.5
31	2EE	19.2-19.9	" "	21.0	43	23		100	100	90.1	"	0.043	
32	2FF	19.9-20.2	" "	20.5	36	17		100	100	86.9	"	0.088	
33	2GG	20.2-20.9	" "	19.7	40	21		100	100	87.9	"	0.033	10/21.0
34	2HH	20.9-21.6	" "	22.5	38	20		100	100	93.0	"	0.225	
35	2II	21.6-22.3	" "	23.0	37	19		100	100	92.4	"	0.263	
36	2JJ	22.3-23.0	" "	22.5	34	16		100	100	85.5	"	0.281	4/22.5
37	2KK	23.0-23.7	LEAN CLAY WITH SAND	25.7	33	16		100	100	81.7	"	0.544	
38	2LL	23.7-24.0	LEAN CLAY	23.4	33	16		100	100	91.9	"	0.400	3/24.0
39	2MM	24.0-24.1	" "	21.9	26	11		100	100	83.8	"	0.627	
40	2NN	24.1-24.5	" "	22.5	36	18		100	100	85.4	"	0.250	
41	2OO	24.5-25.0	LEAN CLAY WITH SAND	22.7	26	11		100	100	81.2	"	0.700	
42	2PP	25.0-25.4	" " " "	23.8	27	11		100	100	81.2	"	0.709	
43	2QQ	25.4-25.5	SANDY LEAN CLAY	27.2	21	7		100	100	62.6	"	1.886	1/25.5
44	2RR	25.5-26.2	LEAN CLAY	28.7	30	13		100	100	87.6	"	0.900	
45	2SS	26.2-26.8	" "	30.1	27	10		100	100	92.9	"	1.310	
46	2TT	26.8-26.9	SILTY SAND	28.2	NP	NP		100	100	47.2	SM	.	
47	2UU	26.9-27.6	SANDY SILTY CLAY	29.1	24	6		100	100	60.0	CL-ML	1.850	2/27.3
48	2VV	27.6-28.0	" " "	29.6	26	7		100	100	64.2	"	1.514	
49	2WW	28.0-28.7	SILTY CLAYEY SAND	24.7	22	5		100	100	45.6	SC-SM	1.540	6/28.8
50	2XX	28.7-29.0	SILTY SAND	29.0	NP	NP		100	100	44.2	SM	.	
51	2YY	29.0-29.7	SANDY SILTY CLAY	25.1	23	6		100	100	59.6	CL-ML	1.350	
52	2ZZ	29.7-30.1	SILTY SAND	26.2	NP	NP		100	100	28.0	SM	.	5/30.3
53	22U	30.1-31.8	SILTY SAND WITH		NP	NP	(58)	*47	38	13.1	"	.	16/31.8
54			GRAVEL						.	.		.	

TABLE D2, WAGONER, BORING W2 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	22V	31.8-32.3	SILTY SAND WITH GRAVEL		NP	NP	(57)	*44	34	22.8	"	.	
56	22VV	32.3-33.3	POORLY GRADED SAND		NP	NP	(60)	*48	35	1.9	SP-SM	.	17/33.3
57			WITH GRAVEL						.	.		.	
58	22W	33.3-34.0	SILTY SAND WITH		NP	NP	(63)	*52	41	14.3	SM	.	
59			GRAVEL						.	.		.	
60	22WW	34.0-34.8	CLAYEY SAND WITH		19	7	(77)	*68	57	21.3	SC	.	17/34.8
61			GRAVEL						.	.		.	
62	22X	34.8-35.5	" " " "		28	10	(B2)	*75	68	40.7	"	.	
63	22XX	35.5-36.3	LEAN CLAY (SHALE)		40	15		100	98	87.2	CL	.	32/36.3

TABLE D3, WAGONER, BORING W3

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	3A	0.0-0.3	FAT CLAY	15.7	52	27		100	100	95.9	CH	-0.344	
2	3B	0.3-0.8	" "	24.8	59	33		100	100	97.7	"	-0.036	
3	3C	0.8-1.5	" "	29.5	61	36		100	100	97.9	"	0.125	8/1.5
4	3D	1.5-2.2	" "	30.0	60	36		100	100	97.7	"	0.167	
5	3E	2.2-2.9	" "	30.1	62	37		100	100	97.9	"	0.165	6/3.0
6	3F	2.9-3.6	LEAN CLAY	27.0	47	26		100	98	95.1	CL	0.231	
7	3G	3.6-4.0	" "	25.2	42	22		100	97	94.1	"	0.236	
8	3H	4.0-4.7	FAT CLAY	26.4	51	31		100	100	95.3	CH	0.206	7/4.5
9	3I	4.7-5.4	" "	25.2	54	34		100	99	96.9	"	0.153	
10	3J	5.4-6.1	" "	25.8	59	39		100	99	97.3	"	0.149	7/6.0
11	3K	6.1-6.8	" "	25.8	56	35		100	99	97.1	"	0.137	
12	3L	6.8-7.5	" "	27.2	56	35		100	99	97.3	"	0.177	9/7.5
13	3M	7.5-8.2	" "	28.4	58	36		100	99	97.7	"	0.192	
14	3N	8.2-8.9	" "	26.0	56	35		100	99	97.3	"	0.143	8/9.0
15	3O	8.9-9.2	" "	26.5	57	35		100	99	96.9	"	0.129	
16	3P	9.2-9.9	" "	26.7	62	39		100	100	97.7	"	0.095	
17	3Q	9.9-10.6	" "	26.2	62	38		100	99	97.7	"	0.058	7/10.5
18	3R	10.6-11.3	" "	25.3	62	40		100	100	98.8	"	0.083	
19	3S	11.3-12.0	" "	25.3	60	38		100	99	97.7	"	0.087	9/12.0
20	3T	12.0-12.7	" "	24.9	60	38		100	100	97.9	"	0.076	
21	3U	12.7-13.4	" "	25.2	62	39		100	100	97.9	"	0.056	9/13.5
22	3V	13.4-14.1	" "	24.7	65	42		100	100	97.9	"	0.040	
23	3W	14.1-14.3	" "	24.6	59	37		100	100	97.7	"	0.070	
24	3X	14.3-15.0	" "	24.8	59	37		100	99	97.1	"	0.076	9/15.0
25	3Y	15.0-15.7	" "	25.5	59	37		100	99	97.1	"	0.089	
26	3Z	15.7-16.4	" "	24.1	58	37		100	99	96.7	"	0.084	10/16.5
27	3AA	16.4-17.1	" "	24.4	57	36	(99)	*99	98	94.6	"	0.094	
28	3BB	17.1-17.8	" "	24.0	54	33		100	100	96.5	"	0.091	11/18.0
29	3CC	17.8-18.5	" "	23.2	50	30		100	99	91.9	"	0.107	
30	3DD	18.5-19.2	LEAN CLAY	23.0	49	28		100	99	88.8	CL	0.071	
31	3EE	19.2-19.5	LEAN CLAY WITH SAND	19.7	40	22		100	100	82.3	"	0.077	11/19.5
32	3FF	19.5-20.2	" " " "	21.2	36	19		100	99	79.7	"	0.221	
33	3GG	20.2-20.9	" " " "	20.1	34	17		100	100	79.7	"	0.182	8/21.0
34	3HH	20.9-21.6	SANDY LEAN CLAY	22.1	27	11		100	100	70.1	"	0.555	
35	3II	21.6-22.3	LEAN CLAY WITH SAND	23.1	28	12		100	100	78.8	"	0.592	4/22.5
36	3JJ	22.3-23.0	" " " "	24.8	28	11		100	100	75.1	"	0.709	
37	3KK	23.0-23.4	" " " "	22.2	28	11		100	100	78.0	"	0.473	
38	3LL	23.4-23.8	" " " "	22.4	2B	13		100	100	78.3	"	0.569	
39	3MM	23.8-24.0	" " " "	22.9	30	13		100	100	82.3	"	0.454	3/24.0
40	3NN	24.0-24.5	SANDY LEAN CLAY	23.2	25	9		100	100	67.0	"	0.800	
41	3OO	24.5-25.3	SILT WITH SAND	32.7	NP	NP		100	100	79.4	ML	.	2/25.5
42	3PP	25.3-25.8	SANDY SILTY CLAY	24.5	23	7		100	100	61.0	CL-ML	1.214	
43	3QQ	25.8-26.2	SILTY SAND	31.6	NP	NP		100	100	32.5	SM	.	
44	3RR	26.2-27.0	SANDY LEAN CLAY	29.7	25	8		100	100	69.4	CL	1.588	3/27.0
45	3SS	27.0-27.4	SANDY SILTY CLAY	25.7	20	4		100	100	49.4	CL-ML	2.425	
46	3TT	27.4-28.1	SILTY SAND	24.4	NP	NP		100	100	40.6	SM	.	
47	3UU	28.1-28.7	" "	24.6	NP	NP		100	100	31.8	"	.	2/28.5
48	3VV	28.7-29.1	" "	24.4	NP	NP	(80)	*89	89	27.6	"	.	
49	3WW	29.1-29.8	POORLY GRADED SAND	22.4	NP	NP		100	100	10.2	SP-SM	.	3/30.0
50			WITH SILT						.	.		.	
51	3XX	29.8-30.5	" " " "	20.6	NP	NP		100	97	6.6	"	.	
52	3YY	30.5-31.2	" " " "	20.1	NP	NP		100	95	5.6	"	.	
53	3ZZ	31.2-31.5	SILTY SAND	19.6	NP	NP	(99)	*98	91	18.8	SM	.	13/31.5
54	3-1	31.5-31.9	" "	16.2	NP	NP	(96)	*91	80	18.6	"	.	

TABLE D3, WAGONER, BORING W3 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	3-2	31.9-32.4	SILTY SAND	14.6	NP	NP	(95)	*93	78	25.8	"	.	
56	3-3	32.4-32.9	" "	14.3	NP	NP	(58)	*50	46	16.4	"	.	20/33.0
57	3-4	32.9-33.5	POORLY GRADED GRAVEL	12.5	NP	NP	(53)	*46	37	9.8	GP-GM	.	
58			WITH SILT AND SAND						.	.		.	
59	33WW	33.5-34.5	SILT WITH GRAVEL		NP	NP	(62)	*53	42	16.3	SM	.	20/34.5
60	33X	34.5-35.4	CLAYEY SAND WITH		25	9	(71)	*61	50	25.8	SC	.	
61			WITH GRAVEL						.	.		.	
62	33XX	35.4-36.0	CLAYEY SAND		42	17	(95)	*93	71	38.4	"	.	25/36.0
63	33Y	36.0-36.8	LEAN CLAY WITH SAND		35	13	(95)	*94	84	71.7	CL	.	
64			(SHALE)						.	.		.	

TABLE D4, WAGONER, BORING W4

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	4A	0.0-0.3	FAT CLAY	19.3	67	43		100	99	97.9	CH	-0.109	
2	4B	0.3-0.7	" "	23.1	62	37		100	100	98.3	"	-0.051	
3	4C	0.7-1.4	" "	32.7	67	41		100	100	97.7	"	0.163	4/1.5
4	4D	1.4-2.1	ELASTIC SILT	30.5	66	30		100	100	97.7	MH	-0.183	
5	4E	2.1-2.8	FAT CLAY	27.1	58	36		100	99	96.4	CH	0.142	4/3.0
6	4F	2.8-3.5	" "	29.5	63	41		100	99	97.0	"	0.183	
7	4G	3.5-4.2	" "	29.5	66	46		100	99	97.1	"	0.206	
8	4H	4.2-4.7	" "	28.1	60	38		100	99	97.7	"	0.161	4/4.5
9	4I	4.7-5.1	" "	27.3	62	41		100	99	97.5	"	0.154	
10	4J	5.1-5.5	" "	27.6	62	40		100	99	97.1	"	0.140	
11	4K	5.5-6.2	" "	29.4	64	41		100	100	98.7	"	0.156	5/6.0
12	4L	6.2-6.9	" "	29.7	67	44		100	99	98.1	"	0.152	
13	4M	6.9-7.6	" "	25.9	65	42		100	99	97.3	"	0.069	5/7.5
14	4N	7.6-8.3	" "	27.5	68	46		100	98	96.9	"	0.120	
15	4O	8.3-9.0	" "	26.9	63	41		100	99	97.7	"	0.120	7/9.0
16	4P	9.0-9.7	" "	26.8	61	38		100	98	96.8	"	0.100	
17	4Q	9.7-10.0	" "	26.1	61	40		100	99	97.7	"	0.128	
18	4R	10.0-10.7	" "	26.6	58	38		100	99	96.8	"	0.174	8/10.5
19	4S	10.7-11.4	" "	26.6	62	40		100	99	98.5	"	0.115	
20	4T	11.4-12.1	" "	26.3	62	40		100	100	98.3	"	0.108	7/12.0
21	4U	12.1-12.8	" "	25.7	61	39		100	100	98.3	"	0.095	
22	4V	12.8-13.5	" "	26.4	62	40		100	99	97.9	"	0.110	8/13.5
23	4W	13.5-13.9	" "	26.0	61	39		100	99	96.6	"	0.103	
24	4X	13.9-14.6	" "	24.8	59	36		100	99	97.9	"	0.050	
25	4Y	14.6-15.2	" "	25.6	57	35		100	99	95.8	"	0.103	8/15.0
26	4Z	15.2-15.9	" "	27.1	59	37		100	98	94.9	"	0.138	
27	4AA	15.9-16.6	" "	27.4	56	33		100	98	95.3	"	0.133	3/16.5
28	4BB	16.6-17.3	" "	27.9	55	33		100	99	96.4	"	0.179	
29	4CC	17.3-17.6	" "	26.7	56	35		100	99	96.9	"	0.163	
30	4DD	17.6-18.3	" "	25.2	56	34	(99)	*99	98	95.1	"	0.094	10/18.0
31	4EE	18.3-19.0	FAT CLAY WITH SAND	23.6	50	30		100	100	84.4	"	0.120	
32	4FF	19.0-19.7	FAT CLAY	23.1	53	31		100	98	93.9	"	0.035	8/19.5
33	4GG	19.7-20.1	" "	24.5	58	35		100	99	96.6	"	0.043	
34	4HH	20.1-20.5	LEAN CLAY	22.7	46	28	(99)	*99	97	87.3	CL	0.168	
35	4II	20.5-21.2	" "	23.0	43	24		100	98	85.1	"	0.167	4/21.0
36	4JJ	21.2-21.9	" "	29.0	45	25		100	99	90.7	"	0.360	
37	4KK	21.9-22.6	" "	29.4	45	27		100	100	91.5	"	0.422	2/22.2
38	4LL	22.6-23.3	" "	26.7	43	25		100	100	90.9	"	0.348	
39	4MM	23.3-24.0	" "	27.7	42	23		100	100	90.1	"	0.378	2/24.0
40	4NN	24.0-24.5	LEAN CLAY WITH SAND	23.2	30	13		100	100	82.5	"	0.477	
41	4OO	24.5-25.1	" " " "	24.3	26	10		100	100	80.6	"	0.830	
42	4PP	25.1-25.8	" " " "	29.7	25	8		100	100	81.2	"	1.588	1/25.5
43	4QQ	25.8-26.2	LEAN CLAY	31.0	27	10		100	100	98.3	"	1.400	
44	4RR	26.2-26.5	LEAN CLAY WITH SAND3	.9	28	10		100	100	84.8	"	1.290	
45	4SS	26.5-26.7	" " " "	29.5	28	10		100	100	71.2	"	1.150	
46	4TT	26.7-27.1	SILTY CLAY	27.1	22	4		100	100	88.1	CL-ML	2.275	3/27.0
47	4UU	27.1-27.5	SANDY SILT	25.8	20	3		100	100	57.4	ML	2.933	
48	4VV	27.5-28.2	SILTY SAND	21.6	NP	NP		100	100	31.1	SM	.	9/28.5
49	4WW	28.2-28.9	" "	23.3	NP	NP		100	100	39.5	"	.	
50	4XX	28.9-29.6	" "	21.8	NP	NP		100	100	17.8	"	.	
51	4YY	29.6-30.0	" "	23.3	NP	NP		100	99	15.4	"	.	49/30.0
52	4ZZ	30.0-30.4	" "	23.5	NP	NP	(99)	*97	93	18.8	"	.	
53	44G	30.4-31.2	SILTY SAND WITH		NP	NP	(50)	*40	29	13.6	"	.	
54			GRAVEL						.	.		.	

TABLE D4, WAGONER, BORING W4 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	44GG	31.2-32.0	SILTY SAND WITH GRAVEL		NP	NP	(51)	*41	30	13.7	"	.	45/32.0
56	44H	32.0-32.8	" " " "		NP	NP	(76)	*66	52	17.4	"	.	
57	44HH	32.8-33.5	" " " "		NP	NP	(64)	*57	44	16.5	"	.	19/33.5
58	44I	33.5-34.0	" " " "		NP	NP	(69)	*58	44	10.6	"	.	
59	44II	34.0-35.0	" " " "		16	2	(82)	*71	54	19.1	"	.	20/35.0
60	44J	35.0-35.4	CLAYEY SAND		35	14	(81)	*76	63	39.6	SC	.	
61	44JJ	35.4-36.5	LEAN CLAY WITH SAND		36	11		100	94	72.2	CL	.	
62			(SHALE)						.	.		.	

TABLE D5, WAGONER, BORING W5

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	5A	0.0-0.4	FAT CLAY	17.6	57	32		100	99	97.5	CH	-0.231	
2	5B	0.4-1.1	" "	31.6	64	37		100	99	97.5	"	0.124	
3	5C	1.1-1.8	" "	30.7	63	40		100	99	97.1	"	0.193	8/1.5
4	5D	1.8-2.5	" "	23.9	54	33		100	98	95.7	"	0.088	
5	5E	2.5-2.9	" "	25.4	57	35		100	98	96.4	"	0.097	5/3.0
6	5F	2.9-3.6	" "	27.8	60	39		100	99	97.5	"	0.174	
7	5G	3.6-4.3	" "	26.7	60	38		100	99	97.7	"	0.124	5/4.5
8	5H	4.3-5.0	" "	25.8	57	36		100	98	96.4	"	0.133	
9	5I	5.0-5.7	" "	27.3	63	41		100	99	97.5	"	0.129	7/6.0
10	5J	5.7-6.4	" "	27.1	68	46		100	100	98.3	"	0.111	
11	5K	6.4-6.9	" "	26.8	57	38		100	99	90.3	"	0.205	
12	5L	6.9-7.6	" "	27.7	64	42		100	99	97.3	"	0.136	6/7.5
13	5M	7.6-8.1	" "	27.6	65	38		100	99	98.3	"	0.016	
14	5N	8.1-8.8	" "	27.1	63	40		100	98	97.0	"	0.103	7/9.0
15	5O	8.8-9.5	" "	26.8	67	42		100	99	98.3	"	0.043	
16	5P	9.5-10.2	" "	27.4	63	40		100	99	98.3	"	0.110	
17	5Q	10.2-10.9	" "	26.7	66	43		100	99	98.5	"	0.086	6/10.5
18	5R	10.9-11.6	" "	26.5	66	44		100	100	98.7	"	0.102	
19	5S	11.6-12.1	" "	26.3	64	41		100	100	98.7	"	0.080	7/12.0
20	5T	12.1-12.7	" "	26.8	66	43		100	100	98.7	"	0.088	
21	5U	12.7-13.3	" "	26.4	63	41		100	98	98.1	"	0.107	8/13.5
22	5V	13.3-13.9	" "	27.0	62	39		100	99	97.3	"	0.102	
23	5W	13.9-14.5	" "	26.2	56	33		100	98	94.8	"	0.097	
24	5X	14.5-15.1	" "	26.0	55	32		100	98	95.2	"	0.094	9/15.0
25	5Y	15.1-15.7	" "	26.7	56	33		100	98	95.8	"	0.112	
26	5Z	15.7-16.4	" "	25.2	55	33		100	98	96.0	"	0.097	10/16.5
27	5AA	16.4-17.1	" "	23.7	53	30		100	99	96.7	"	0.023	
28	5BB	17.1-17.8	" "	24.4	54	31		100	99	96.3	"	0.045	12/18.0
29	5CC	17.8-18.5	" "	24.6	54	32		100	99	93.2	"	0.081	
30	5DD	18.5-19.1	LEAN CLAY	25.5	49	29	(99)	*99	97	90.2	CL	0.190	
31	5EE	19.1-19.6	" "	23.7	42	24	(99)	*99	98	86.9	"	0.238	13/19.5
32	5FF	19.6-20.1	" "	25.9	40	22		100	99	86.4	"	0.359	
33	5GG	20.1-20.6	LEAN CLAY WITH SAND	23.9	38	19	(99)	*99	97	81.8	"	0.258	
34	5HH	20.6-21.3	" " " "	22.5	35	17	(99)	*99	98	81.8	"	0.265	7/21.0
35	5II	21.3-22.0	LEAN CLAY	25.9	35	16		100	99	93.8	"	0.431	
36	5JJ	22.0-22.6	LEAN CLAY WITH SAND	26.4	38	19		100	100	73.3	"	0.389	5/22.5
37	5KK	22.6-23.0	" " " "	22.6	31	13		100	100	72.4	"	0.354	
38	5LL	23.0-23.3	SANDY LEAN CLAY	22.4	25	7		100	100	68.4	"	0.629	
39	5MM	23.3-23.7	LEAN CLAY WITH SAND	25.1	28	11		100	100	77.5	"	0.736	
40	5NN	23.7-24.1	" " " "	27.3	28	11	(97)	*97	97	73.7	"	0.936	3/24.0
41	5OO	24.1-24.5	SANDY SILT	26.5	19	2		100	100	47.3	ML	4.750	
42	5PP	24.5-25.1	SILTY CLAY WITH SAND	25.6	25	7		100	100	74.1	CL-ML	1.086	
43	5QQ	25.1-25.4	SANDY SILTY CLAY	28.0	23	5	(96)	*96	96	59.0	"	2.000	1/25.5
44	5RR	25.4-25.9	SANDY LEAN CLAY	26.1	26	9		100	100	70.9	CL	1.011	
45	5SS	55.9-26.5	SANDY SILT	27.4	21	2		100	100	60.1	ML	4.200	
46	5TT	26.5-27.0	SILTY SAND	25.1	NP	NP		100	98	24.2	SM	.	3/27.0
47	5UU	27.0-27.6	SANDY SILTY CLAY	21.8	23	6		100	100	58.7	CL-ML	0.800	
48	5VV	27.6-28.1	POORLY GRADED SAND	21.9	NP	NP		100	99	7.2	SP-SM	.	7/28.5
49			WITH SILT						.	.		.	
50	55SS	28.1-29.0	SILTY SAND		NP	NP		100	99	26.5	SM	.	
51	55T	29.0-29.5	CLAYEY SAND		20	8	(92)	*91	88	39.7	SC	.	
52	55TT	29.5-30.3	SILTY SAND		NP	NP	(99)	*97	85	18.7	SM	.	8/30.5
53	55U	30.3-31.5	" "		NP	NP	(97)	*94	86	16.4	"	.	
54	55UU	31.5-32.0	" "		NP	NP	(74)	*67	61	14.1	"	.	20/32.0

TABLE D5, WAGONER, BORING W5 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	55W	32.0-33.5	SILTY SAND WITH		NP	NP	(56)	*50	42	14.0	"	.	6/33.5
56			GRAVEL						.	.		.	
57	55Y	33.5-35.0	" " " "		NP	NP	(53)	*45	32	13.0	"	.	3/35.0
58	55X	35.0-35.6	CLAYEY SAND WITH		26	8	(62)	*54	42	21.2	SC	.	
59			GRAVEL						.	.		.	
60	55XX	35.6-35.9	LEAN CLAY (SHALE)		50	22		100	98	94.0	CL	.	

TABLE D6, WAGONER, BORING W6

OBS	SAMPLEND	DEPTH	LOG	W	LL	PI	ND4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	6A	0.0-0.4	FAT CLAY	20.8	61	38		100	99	96.3	CH	-0.058	
2	6B	0.4-1.1	" "	29.1	66	37		100	100	98.9	"	0.003	
3	6C	11.1-1.8	" "	34.8	65	36		100	100	99.4	"	0.161	12/1.5
4	6D	1.8-2.5	" "	32.9	67	41		100	100	98.9	"	0.168	
5	6E	2.5-3.2	" "	31.8	72	48		100	100	98.7	"	0.163	3/3.0
6	6F	3.2-3.9	" "	25.9	61	40		100	100	97.3	"	0.123	
7	6G	3.9-4.4	" "	25.4	59	39		100	98	96.3	"	0.138	7/4.5
8	6H	4.4-4.8	" "	25.9	56	45		100	99	97.7	"	0.131	
9	6I	4.8-5.5	" "	25.6	60	39		100	99	97.1	"	0.118	
10	6J	5.5-6.2	" "	27.3	60	40		100	99	97.5	"	0.183	8/6.0
11	6K	6.2-6.9	" "	25.0	63	42		100	99	97.9	"	0.095	
12	6L	6.9-7.6	" "	25.9	66	45		100	99	97.7	"	0.109	7/7.5
13	6M	7.6-8.3	" "	25.8	60	39		100	99	97.3	"	0.123	
14	6N	8.3-8.9	" "	26.0	61	40		100	99	96.6	"	0.125	7/9.0
15	6O	8.9-9.5	" "	27.3	66	44		100	99	97.4	"	0.120	
16	6P	9.5-10.2	" "	27.7	65	43		100	99	97.9	"	0.133	
17	6Q	10.2-10.9	" "	28.7	69	46		100	100	98.5	"	0.119	7/10.5
18	6R	10.9-11.6	" "	25.8	58	39		100	100	98.3	"	0.174	
19	6S	11.6-12.3	" "	25.7	66	44		100	99	98.3	"	0.084	7/12.0
20	6T	12.3-13.0	" "	26.9	59	39		100	100	98.5	"	0.177	
21	6U	13.0-13.7	" "	28.8	61	39		100	100	98.3	"	0.174	7/13.5
22	6V	13.7-14.2	" "	33.8	62	41		100	100	99.2	"	0.215	
23	6W	14.2-14.7	" "	28.8	61	40		100	100	98.7	"	0.195	7/15.0
24	6X	14.7-15.4	LEAN CLAY	26.8	33	16		100	100	98.5	CL	0.613	
25	6Y	15.4-16.1	FAT CLAY	25.9	59	37		100	100	99.2	CH	0.105	
26	6Z	16.1-16.8	" "	25.1	58	38		100	100	98.0	"	0.134	7/16.5
27	6AA	16.8-17.5	" "	25.2	59	33		100	100	96.9	"	-0.024	
28	6BB	17.5-18.2	" "	24.9	56	36		100	99	96.5	"	0.136	8/18.0
29	6CC	18.2-18.9	" "	24.0	56	36		100	99	96.3	"	0.111	
30	6DD	18.9-19.5	" "	23.1	52	33		100	99	94.8	"	0.124	6/19.5
31	6EE	19.5-20.2	LEAN CLAY	22.4	49	30		100	99	90.7	CL	0.113	
32	6FF	20.2-20.9	" "	26.6	44	26		100	99	86.6	"	0.100	13/21.0
33	6GG	20.9-21.6	" "	22.1	43	25		100	100	91.0	"	0.164	
34	6HH	21.6-22.3	" "	22.3	40	22		100	100	89.1	"	0.195	
35	6II	22.3-22.7	LEAN CLAY WITH SAND	22.3	34	16		100	100	84.0	"	0.269	8/22.5
36	6JJ	22.7-23.3	" " " "	25.5	38	19		100	100	77.4	"	0.342	
37	6KK	23.3-23.8	" " " "	22.1	31	15		100	100	84.5	"	0.407	
38	6LL	23.8-24.1	SANDY LEAN CLAY	24.3	23	8		100	100	57.1	"	1.163	5/24.0
39	6MM	24.1-24.8	SILTY SAND	22.5	NP	NP		100	100	19.7	SM	.	
40	6NN	24.8-25.5	SANDY SILT	23.9	NP	NP		100	100	50.2	ML	.	3/25.5
41	6OO	25.5-26.2	SANDY LEAN CLAY	25.5	25	9		100	100	68.6	CL	1.056	
42	6PP	26.2-26.4	FAT CLAY WITH SAND	22.9	61	41		100	100	84.1	CH	0.071	
43	6QQ	26.4-26.7	LEAN CLAY WITH SAND	29.0	26	9		100	100	80.6	CL	1.333	
44	6RR	26.7-27.1	LEAN CLAY	28.5	30	13		100	100	94.7	"	0.885	2/27.0
45	6SS	27.1-27.6	SANDY SILT	24.4	NP	NP		100	100	63.5	ML	.	
46	6TT	27.6-28.1	LEAN CLAY WITH SAND	25.6	25	8		100	100	70.9	CL	1.075	
47	6UU	28.1-28.6	SANDY SILT	24.3	NP	NP		100	100	60.7	ML	.	
48	6VV	28.6-29.0	LEAN CLAY	21.4	26	7		100	100	85.5	CL	0.343	3/28.9
49	66T	29.0-29.5	SILTY SAND		NP	NP		100	100	21.1	SM	.	
50	66TT	29.5-30.4	" "		NP	NP		100	100	35.6	"	.	3/30.4
51	66U	30.4-31.2	" "		NP	NP	(100)	*98	96	32.1	"	.	
52	66UU	31.2-31.9	" "		NP	NP	(59)	*47	40	14.9	"	.	56/31.9
53	66V	31.9-23.6	" "		NP	NP	(66)	*51	38	13.5	"	.	
54	66VV	32.6-33.4	SILTY CLAYEY		23	4	(70)	*58	48	25.9	SC-SM	.	24/33.4

TABLE D6, WAGONER, BORING W6 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	66W	33.4-34.9	SILTY SAND WITH		NP	NP	(70)	*63	49	17.9	SM	.	19/34.9
56			GRAVEL						.	.		.	
57	66X	34.9-35.5	SILTY CLAYEY SAND		19	5	(79)	*71	57	19.0	SC-SM	.	
58			WITH GRAVEL						.	.		.	
59	66XX	35.5-36.4	SANDY LEAN CLAY WITH		31	21	(91)	*86	86	67.4	CL	.	13/36.4
60			GRAVEL						.	.		.	
61	66Y	36.4-36.8	SILTY SAND WITH		NP	NP	(75)	*62	58	42.7	SM	.	
62			GRAVEL						.	.		.	
63	66YY	36.8-37.2	LEAN CLAY (SHALE)		34	10		100	98	88.1	CL	.	
64	66YYY	37.2-37.9	CLAYEY SAND (SANDY		33	13	(92)	*90	87	48.5	SC	.	
65			SHALE)						.	.		.	

WATER LEVEL AT 24 HOURS: 2.6 FEET

TABLE D7, TULSA, BORING T1

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	16A	D.0-0.2	LEAN CLAY WITH SAND	24.1	34	18		100	98	81.2	CL	0.44	
2	16AA	20.-0.8	LEAN CLAY	19.2	37	21		100	100	88.9	"	0.14	
3	16AAA	0.8-1.5	" "	15.5	31	11		100	100	91.1	"	-0.25	6/1.5
4	16B	1.5-2.2	" "	17.6	39	20		100	100	97.8	"	-0.05	
5	16BB	2.2-3.0	" "	18.9	37	18		100	100	97.5	"	0.00	6/3.0
6	16C	30.-3.6	FAT CLAY	26.2	51	28		100	100	96.0	CH	0.11	
7	16CC	3.6-4.5	" "	24.1	56	35		100	100	96.9	"	0.09	8/4.5
8	16D	4.5-5.2	" "	26.7	54	33		100	99	94.7	"	0.18	
9	16DD	5.2-6.0	" "	23.8	50	30		100	99	91.8	"	0.13	7/6.0
10	16E	6.0-6.8	" "	22.4	51	34		100	98	93.8	"	0.15	
11	16EE	6.8-7.5	" "	23.2	52	32		100	100	95.0	"	0.09	9/7.5
12	16F	7.5-8.3	" "	24.7	50	33		100	100	95.4	"	0.24	
13	16FF	8.3-9.0	" "	22.2	52	34		100	100	93.9	"	0.12	109.0
14	16G	9.0-9.7	" "	24.3	50	33		100	99	95.5	"	0.21	
15	16GG	9.7-10.5	" "	25.0	58	39		100	100	96.5	"	0.15	10/10.5
16	16H	10.5-11.1	" "	23.9	51	32	(97)	*97	96	91.9	"	0.16	
17	16HH	11.1-12.0	" "	22.8	50	32		100	99	93.4	"	0.16	10/12.0
18	16I	12.0-12.8	LEAN CLAY	23.2	47	30		100	99	92.1	CL	0.20	
19	16II	12.8-13.5	" "	22.3	45	27		100	99	92.2	"	0.15	1013.5
20	16J	13.5-14.3	" "	19.3	39	23		100	99	89.0	"	0.13	
21	16JJ	14.3-15.0	LEAN CLAY WITH SAND	19.1	41	25		100	99	83.7	"	0.12	9/15.0
22	16K	15.0-15.7	LEAN CLAY	19.7	43	27		100	100	89.4	"	0.15	
23	16KK	15.7-16.5	" "	21.5	46	28		100	100	89.9	"	0.14	10/16.5
24	16L	16.5-17.4	LEAN CLAY WITH SAND	19.4	40	24		100	100	79.5	"	0.13	
25	16LL	17.4-18.0	" " " "	19.2	33	19		100	100	71.6	"	0.26	9/18.0
26	16M	18.0-18.8	" " " "	18.7	38	23		100	97	79.7	"	0.17	
27	16MM	18.8-19.5	" " " "	18.6	38	20		100	99	84.5	"	0.05	10/19.5
28	16N	19.5-20.3	" " " "	19.1	37	21		100	100	84.0	"	0.14	
29	16NN	20.3-21.0	" " " "	23.3	37	21		100	99	82.3	"	0.33	9/21.0
30	16O	21.0-21.9	" " " "	19.2	35	21		100	99	83.6	"	0.24	
31	16OO	21.9-22.5	LEAN CLAY	19.7	37	21		100	99	85.3	"	0.19	8/22.5
32	16P	22.5-23.2	" "	21.3	40	24		100	99	87.2	"	0.31	
33	16PP	23.2-24.0	" "	20.3	39	23		100	99	87.8	"	0.17	9/24.0
34	16Q	24.0-24.8	" "	21.5	42	26		100	99	89.8	"	0.23	
35	16QQ	24.8-25.5	" "	20.1	40	23		100	99	86.8	"	0.13	11/25.5
36	16R	25.5-26.3	LEAN CLAY WITH SAND	19.7	35	20		100	100	84.7	"	0.25	
37	16RR	26.3-27.0	LEAN CLAY	23.0	37	20		100	100	90.7	"	0.30	8/27.0
38	16S	27.0-27.6	" "	22.7	37	21		100	99	89.8	"	0.33	
39	16SS	27.6-28.5	" "	22.2	35	19		100	99	89.3	"	0.32	7/28.5
40	16T	28.5-29.2	" "	21.0	37	20		100	99	91.6	"	0.20	
41	16TT	29.2-30.0	" "	22.3	35	19		100	99	87.0	"	0.32	9/30.0
42	16U	30.0-30.8	" "	22.6	44	28		100	100	87.2	"	0.25	
43	16UU	30.8-31.5	" "	22.2	35	19		100	99	89.8	"	0.32	7/31.5
44	16V	31.5-32.3	LEAN CLAY WITH SAND	21.6	31	16		100	100	78.3	"	0.44	
45	16VV	32.3-33.0	" " " "	22.6	32	16		100	100	78.0	"	0.44	6/33.0
46	16W	33.0-33.5	SANDY LEAN CLAY	21.7	26	12		100	100	63.0	"	0.67	
47	16WW	33.5-33.9	" " "	20.9	23	9		100	100	50.4	"	0.89	
48	16WWW	33.9-34.5	" " "	20.9	28	13		100	100	65.9	"	0.46	6/34.5
49	16X	34.5-35.0	" " "	23.1	28	13		100	100	69.9	"	0.62	
50	16XX	35.0-36.0	" " "	24.4	26	5		100	100	65.1	"	1.40	4/36.0
51	16Y	36.0-36.8	" " "	23.9	25	11		100	100	60.2	"	0.91	
52	16YY	36.8-37.5	LEAN CLAY WITH SAND	27.0	32	16		100	100	74.2	"	0.69	0/37.5
53	16Z	37.5-38.3	" " " "	29.5	33	17		100	100	78.8	"	0.82	
54	16ZZ	38.3-39.0	" " " "	29.9	34	17		100	100	82.0	"	0.76	0/39.0

TABLE D7, TULSA, BORING T1 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
55	16-1	39.0-39.7	" " " "	29.8	29	13		100	100	77.1	"	1.08	
56	16-11	39.7-40.5	SANDY LEAN CLAY	25.1	24	10		100	100	63.5	"	1.10	0/40.5
57	16-2	40.5-41.3	SILTY CLAYEY SAND	28.0	20	5		100	100	43.9	SC-SM	2.60	
58	16-22	41.3-42.1	" " "	23.3	19	6		100	100	38.5	"	1.67	
59	16-22	42.1-42.6	" " "	25.5	19	5		100	100	40.7	"	2.40	0/42.6
60	16-3	42.6-43.4	SANDY LEAN CLAY	26.8	26	11		100	100	58.7	CL	1.09	
61	16-33	43.4-44.1	" " "	29.5	26	11		100	100	61.2	"	1.36	1/44.1
62	16-4	44.1-44.6	SILTY SAND	25.3	19	3		100	100	36.3	SM	3.00	
63	16-44	44.6-45.1	SANDY LEAN CLAY	31.0	36	16		100	98	69.4	CL	0.74	
64	16-44	45.1-45.6	SILTY SAND	21.2	17	1		100	86	29.2	SM	5.00	6/45.6
65	16-5	45.6-46.4	" "	19.6	20	2		100	80	32.4	"	1.00	
66	16-55	46.4-47.1	SILTY SAND WITH	19.0	20	2P	(80)	*69	60	27.2	"	0.50	13/47.1
67			GRAVEL						.	.		.	
68	16-6	47.1-47.7	SILTY CLAYEY SAND	17.4	21	5	(82)	*65	57	31.2	SC-SM	0.20	
69			WITH GRAVEL						.	.		.	
70	16-66	47.7-48.6	LEAN CLAY	12.1	29	11		100	99	94.8	CL	-0.55	99/48.6

TABLE D8, TULSA, BORING T2

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH'
1	17A	0.0-0.5	LEAN CLAY	9.7	40	23	(99)	*98	96	87.2	CL	.	
2	17AA	0.5-0.7	CLAYEY GRAVEL	3.2	39	21	(35)	*28	27	26.5	GC	.	
3	17AAA	0.7-1.2	LEAN CLAY	12.0	38	20		100	97	87.8	CL	.	
4	17-4A	1.2-1.5	LEAN CLAY WITH SAND	15.1	32	14		100	98	75.0	"	.	17/1.5
5	17B	1.5-2.4	" " " "	18.4	33	16	(93)	*92	90	71.6	"	.	
6	17BB	2.4-3.0	LEAN CLAY	28.8	41	23		100	99	93.6	"	.	10/3.0
7	17C	3.0-3.7	" "	24.4	49	29		100	99	96.3	"	.	
8	17CC	3.7-4.5	FAT CLAY	31.2	54	33		100	99	97.5	CH	.	3/4.5
9	17D	4.5-5.2	" "	25.1	53	34		100	99	95.4	"	.	
10	17DD	5.2-6.0	" "	28.7	52	34		100	98	94.4	"	.	6/6.0
11	17E	6.0-6.7	" "	22.0	53	36		100	99	94.8	"	.	
12	17EE	6.7-7.5	" "	28.7	54	36		100	99	93.8	"	.	7/7.5
13	17F	7.5-8.2	" "	22.8	52	35		100	99	95.2	"	.	
14	17FF	8.2-9.0	" "	27.2	51	33		100	98	93.0	"	.	7/9.0
15	17G	9.0-9.7	LEAN CLAY	20.7	49	22		100	99	94.8	CL	.	
16	17GG	9.7-10.5	FAT CLAY	32.8	53	34		100	99	94.6	CH	.	7/10.5
17	17H	10.5-11.2	" "	23.1	54	35		100	99	95.0	"	.	
18	17HH	11.2-12.0	" "	24.2	56	38		100	99	96.5	"	.	7/12.0
19	17I	12.0-12.7	" "	22.5	53	35		100	99	96.5	"	.	
20	17II	12.7-13.5	" "	21.0	50	32		100	99	97.7	"	.	8/13.5
21	17J	13.5-14.2	LEAN CLAY	21.7	44	26		100	99	93.7	CL	.	
22	17JJ	14.2-15.0	" "	24.6	45	28		100	99	92.8	"	.	10/15.0
23	17K	15.0-15.7	" "	17.8	48	31		100	99	90.8	"	.	
24	17KK	15.7-16.5	" "	22.8	48	30		100	100	91.6	"	.	14/16.5
25	17L	16.5-17.2	" "	19.7	46	29		100	100	88.7	"	.	
26	17LL	17.2-18.0	LEAN CLAY WITH SAND	18.5	35	20		100	100	73.9	"	.	9/18.0
27	17M	18.0-18.7	" " " "	18.6	37	18		100	100	75.5	"	.	
28	17MM	18.7-19.5	" " " "	18.9	37	22		100	100	80.3	"	.	7/19.5
29	17N	19.5-20.2	" " " "	18.7	39	23		100	100	84.5	"	.	
30	17NN	20.2-21.0	" " " "	25.3	36	19		100	99	82.3	"	.	7/21.0
31	17O	21.0-21.7	LEAN CLAY	20.3	37	21		100	99	85.5	"	.	
32	17OO	21.7-22.5	LEAN CLAY WITH SAND	18.0	34	18		100	100	80.0	"	.	7/22.5
33	17P	22.5-23.2	LEAN CLAY	21.1	38	23		100	100	86.7	"	.	
34	17PP	23.2-24.0	" "	20.7	38	24		100	100	87.6	"	.	5/24.0
35	17Q	24.0-24.7	" "	21.8	39	22		100	99	84.8	"	.	
36	17QQ	24.7-25.5	" "	27.0	38	20		100	99	86.2	"	.	7/25.5
37	17R	25.5-26.2	" "	20.9	36	18		100	99	86.9	"	.	
38	17RR	26.2-27.0	LEAN CLAY WITH SAND	31.5	34	18		100	99	82.4	"	.	5/27.0

WATER LEVEL AT 24 HOURS: 12.7 FEET

TABLE D9, COLLINSVILLE, BORING C1

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	1A	0.0-0.5	FAT CLAY	16.4	60	34		100	100	96.3	CH	.	
2	1AA	0.5-1.1	" "	16.3	50	28		100	100	93.9	"	.	
3	1AAA	1.1-1.5	" "	36.1	56	32		100	100	95.0	"	.	14/1.5
4	1B	1.5-2.2	" "	23.0	50	29	(99)	*99	99	88.1	"	.	
5	1BB	2.2-3.0	" "	36.4	57	36		100	100	88.1	"	.	4/3.0
6	1C	3.0-3.7	FAT CLAY WITH SAND	23.6	61	42	(100)	*99	98	82.7	"	.	
7	1CC	3.7-4.5	" " " "	30.5	57	39		100	99	80.4	"	.	5/4.5
8	1D	4.5-5.2	SANDY LEAN CLAY	18.7	42	26		100	99	63.0	CL	.	
9	1DD	5.2-6.0	" " "	24.9	34	20		100	100	55.2	"	.	7/6.0
10	1E	6.0-6.7	" " "	17.5	32	18		100	100	53.2	"	.	
11	1EE	6.7-7.0	CLAYEY SAND	18.5	24	9		100	100	49.4	SC	.	
12	1EEE	7.0-7.5	" "		23	8	(100)	*99	99	45.2	"	.	3/7.5
13	1F	7.5-8.0	" "		24	9	(92)	*88	86	43.5	"	.	
14	1FF	8.0-8.5	SILTY CLAYEY SAND		22	7	(93)	*90	89	37.2	SC-SM	.	
15	1FFF	8.5-9.0	CLAYEY SAND		23	8	(88)	*84	80	37.1	SC	.	5/9.0
16	1G	9.0-9.6	SILTY CLAYEY SAND		22	7	(72)	*65	60	29.6	SC-SM	.	
17			WITH GRAVEL						.	.		.	
18	1GG	9.6-10.3	SILTY SAND WITH		21	2	(74)	*69	61	27.6	SM	.	
19			GRAVEL						.	.		.	
20	1GGG	10.3-10.5	SILTY CLAYEY SAND		21	5	(91)	*79	69	33.4	SC-SM	.	23/10.5
21	1H	10.5-10.7	" " "		22	5	(65)	*63	60	43.0	"	.	
22	1HH	10.7-11.4	LEAN CLAY		38	16		100	96	87.7	CL	.	
23	1HHH	11.4-11.6	LEAN CLAY (WEATHERED		33	14		100	95	70.5	"	.	10, 20,10
24			SHALE)						.	.		.	R 3 3/16"

WATER TABLE AT 24 HOURS: 7.3 FEET

TABLE D10, COLLINSVILLE, BORING C2

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	2A	0.0-0.7	LEAN CLAY	14.0	47	24		100	100	97.1	CL	.	
2	2AA	0.7-1.5	" "	29.8	49	25		100	100	97.1	"	.	8/1.5
3	2B	1.5-2.2	" "	18.5	45	24		100	100	97.7	"	.	
4	2BB	2.2-3.0	" "	33.9	45	26		100	100	96.1	"	.	11/3.0
5	2C	3.0-3.9	" "	11.0	31	12		100	100	90.6	"	.	
6	2CC	3.9-4.5	" "	27.3	32	14		100	100	92.4	"	.	13/4.5
7	2D	4.5-5.0	" "	19.7	33	16		100	100	87.2	"	.	
8	5DD	5.0-5.2	" "	15.6	43	24		100	100	96.0	"	.	
9	20DD	5.2-6.0	" "	34.6	38	18		100	99	95.9	"	.	10/6.0
10	2E	6.0-6.7	" "	18.6	44	25		100	99	94.6	"	.	
11	2EE	6.7-7.5	" "	27.5	47	27		100	99	94.4	"	.	10/7.5
12	2F	7.5-8.2	FAT CLAY	25.1	53	32		100	99	94.5	CH	.	
13	2FF	8.2-9.0	" "	38.4	51	32		100	99	93.9	"	.	10/9.0
14	2G	9.0-9.7	GRAVELLY FAT CLAY	29.2	58	38	(78)	*59	58	56.1	"	.	
15			WITH SAND						.	.		.	
16	2GG	9.7-10.5	FAT CLAY	32.6	54	35		100	99	94.9	"	.	9/10.5
17	2H	10.5-11.2	" "	22.9	52	33		100	99	95.6	"	.	
18	2HH	11.2-12.0	LEAN CLAY	32.0	41	24		100	98	95.4	CL	.	9/10.5
19	2I	12.0-12.7	" "	23.8	42	24		100	99	94.8	"	.	
20	2II	12.7-13.5	" "	31.9	38	24		100	99	94.6	"	.	4/13.5
21	2J	13.5-14.2	" "	27.7	36	19		100	100	93.8	"	.	
22	2JJ	14.2-15.0	" "	31.9	38	20		100	99	95.4	"	.	3/15.0
23	2K	15.0-15.7	" "	24.9	34	16		100	100	94.0	"	.	
24	2KK	15.7-16.5	" "	32.4	34	16		100	99	92.8	"	.	0/16.5
25	2L	16.5-17.2	" "	26.0	35	16		100	100	96.7	"	.	
26	2LL	17.2-18.0	" "	33.6	41	23		100	100	96.2	"	.	0/18.0
27	2M	18.0-18.7	" "	40.2	42	24		100	100	97.7	"	.	
28	2MM	18.7-19.1	" "	28.9	41	24		100	100	95.9	"	.	
29	2MMM	19.1-19.5	" "	28.6	31	13		100	99	89.9	"	.	0/19.5
30	2N	19.5-20.2	" "	25.9	30	12		100	100	91.0	"	.	
31	2NN	20.2-21.0	" "	27.9	28	10		100	100	91.8	"	.	1/21.0
32	2O	21.0-21.7	" "	26.6	30	11	(99)	*93	92	87.3	"	.	
33	2OO	21.7-22.5	" "	28.9	29	10		100	100	92.2	"	.	1/22.5
34	2P	22.5-23.2	LEAN CLAY WITH SAND	28.5	27	10		100	100	78.1	"	.	
35	2PP	23.2-24.0	LEAN CLAY	28.0	28	11		100	99	88.1	"	.	0/24.0
36	2Q	24.0-24.8	LEAN CLAY WITH SAND	25.5	26	9		100	100	77.1	"	.	
37	2QQ	24.8-25.5	" " " "	29.5	29	13		100	100	80.5	"	.	1/25.5
38	2R	25.5-26.1	" " " "	32.9	28	12		100	100	74.4	"	.	
39	2RR	26.1-26.4	" " " "	27.6	27	11		100	100	78.9	"	.	
40	2RRR	26.4-27.0	LEAN CLAY	30.6	32	15		100	100	91.8	"	.	0/27.0
41	2S	27.0-27.7	LEAN CLAY WITH SAND	31.8	28	11		100	100	79.4	"	.	
42	2SS	27.7-28.5	" " " "	30.9	28	10		100	100	77.9	"	.	0/28.5
43	2T	28.5-29.2	SANDY LEAN CLAY	25.3	25	8		100	100	68.4	"	.	
44	2TT	29.2-30.0	LEAN CLAY WITH SAND	32.2	26	9		100	100	73.8	"	.	1/30.0
45	2U	30.0-30.7	" " " "	30.1	29	11		100	99	82.4	"	.	
46	2UU	30.7-31.5	" " " "	39.9	28	9		100	100	78.0	"	.	0/31.5
47	2V	31.5-32.2	SANDY LEAN CLAY	26.4	26	10		100	98	62.0	"	.	
48	2VV	32.2-33.0	LEAN CLAY WITH SAND	32.9	26	11		100	100	71.9	"	.	0/33.0
49	2W	33.0-33.6	" " " "	29.4	28	12		100	100	75.8	"	.	
50	2WW	33.6-33.9	SILTY SAND	29.1	NP	NP		100	99	27.7	SM	.	
51	2WWW	33.9-34.4	" "	29.2	NP	NP		100	99	29.6	"	.	
52	2WWWW	34.4-34.9	SANDY LEAN CLAY	28.6	25	10		100	100	66.9	CL	.	2/34.9
53	2X	34.9-35.7	SILTY CLAYEY SAND	21.6	20	4	(96)	*88	85	41.2	SC-SM	.	
54	2XX	35.7-36.4	CLAYEY SAND	18.4	25	8	(87)	*73	68	45.8	SC	.	3/36.4

TABLE D10, COLLINSVILLE, BORING C2 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH'
55	2Y	36.4-37.2	SANDY LEAN CLAY	23.8	26	9	(100)	*99	97	66.9	CL	.	
56	2YY	37.2-37.9	LEAN CLAY WITH SAND	22.6	29	12		100	99	71.5	"	.	3/37.9
57	2Z	37.9-38.5	SANDY LEAN CLAY	21.4	28	10	(97)	*94	92	64.7	"	.	
58	2ZZ	38.5-39.2	SANDY SILTY CLAY	22.4	22	6		100	100	56.5	CL-ML	.	
59	2ZZZ	39.2-40.0	" " "	24.0	24	7		100	92	66.9	"	.	4/40.0
60	2-1	40.0-40.3	" " "	24.4	22	5		100	100	57.1	"	.	
61	2-11	40.8-41.5	SILTY SAND	26.2	NP	NP		100	100	36.3	SM	.	9/41.5
62	2-2	41.5-42.1	SANDY SILT	22.1	19	3		100	99	52.0	ML	.	
63	2-22	42.1-42.5	SILTY SAND	20.4	NP	NP		100	99	35.2	SM	.	
64	2-222	42.5-43.0	SILTY SAND WITH	12.8	NP	NP	(76)	*66	62	18.4	"	.	35/43.0
65			GRAVEL						.	.		.	
66	2-3	43.0-43.7	" " " "	13.4	NP	NP	(68)	*54	38	19.4	"	.	
67	2-33	43.7-44.5	" " " "	13.0	NP	NP	(85)	*81	65	24.1	"	.	74/44.5
68	2-4	44.5-45.3	SILTY GRAVEL WITH	14.6	NP	NP	(53)	*40	36	22.1	GM	.	
69			SAND						.	.		.	
70	2-44	45.3-46.0	SILTY SAND	15.9	NP	NP	(60)	*45	39	17.9	SM	.	27/46.0
71	2-5	46.0-46.4	" "	13.0	NP	NP	(65)	*51	38	29.1	"	.	
72	2-55	46.4-47.5	LEAN CLAY (SHALE)	15.7	31	9		100	96	89.9	CL	.	42/47.5
73	2-6	47.5-48.2	" " (")	10.5	32	12	(100)	*99	96	88.9	"	.	5, 38, 50
74									.	.		.	R 2 1/8"

LOCATION: N.W. 1/4, N.E. 1/4, N.E. 1/4, SEC 15, T 22 N,R 14 E
ROGERS COUNTY

WATER LEVEL AT 24 HOURS: 17.8 FEET

TABLE D11, BIXBY, BORING B1

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH'
1	5A	0.0-0.8	LEAN CLAY		28	8		100	100	87.4	CL	.	
2	5AA	0.8-1.5	SANDY LEAN CLAY		32	16		100	100	61.8	"	.	6/1.5
3	5B	1.5-2.1	LEAN CLAY WITH SAND		26	9		100	100	73.4	"	.	
4	5BB	2.1-3.0	SILTY CLAY WITH SAND		23	5		100	100	79.3	CL-ML	.	2/3.0
5	5C	3.0-3.6	SANDY SILT		22	2		100	100	68.0	ML	.	
6	5CC	3.6-4.5	SANDY SILTY CLAY		23	4		100	100	67.9	CL-ML	.	2/4.5
7	5D	4.5-4.8	SILTY CLAY WITH SAND		23	5		100	100	81.0	"	.	
8	5DD	4.8-5.5	LEAN CLAY WITH SAND		30	14		100	100	80.2	CL	.	
9	5DDD	5.5-6.0	" " " "		32	15		100	100	77.1	"	.	0/6.0
10	5E	6.0-6.6	SANDY LEAN CLAY		31	15		100	100	61.8	"	.	
11	5EE	6.6-7.4	LEAN CLAY WITH SAND		30	15		100	100	74.0	"	.	0/7.5
12	5F	7.4-8.3	SANDY LEAN CLAY		28	13		100	100	65.8	"	.	
13	5FF	8.3-9.0	" " "		28	14		100	100	63.2	"	.	3/9.0
14	5G	9.0-9.7	" " "		29	14		100	100	61.8	"	.	
15	5GG	9.7-10.4	" " "		27	13		100	99	56.1	"	.	4/10.5
16	5H	10.4-11.1	" " "		28	13		100	100	59.9	"	.	
17	5HH	11.1-12.0	" " "		27	12		100	100	60.1	"	.	5/12.0
18	5I	12.0-12.8	" " "		28	13		100	99	60.1	"	.	
19	5II	12.8-13.5	" " "		29	13		100	100	65.8	"	.	0/13.5
20	5J	13.5-14.2	LEAN CLAY WITH SAND		29	13		100	100	70.6	"	.	
21	5JJ	14.2-15.0	" " " "		31	15		100	100	77.8	"	.	0/15.0
22	5K	15.0-15.8	" " " "		30	15		100	100	70.2	"	.	
23	5KK	15.8-16.5	" " " "		35	20		100	98	76.9	"	.	0/16.5
24	5L	16.5-17.2	SANDY LEAN CLAY		30	15		100	100	64.9	"	.	
25	5LL	17.2-18.0	SILTY CLAYEY SAND		22	4		100	100	45.3	SC-SM	.	5/18.0
26	5M	18.0-18.8	SANDY LEAN CLAY		27	12		100	100	56.9	CL	.	
27	5MM	18.8-19.5	" " "		24	10		100	98	57.5	"	.	3/19.5
28	5N	19.5-20.1	" " "		37	21		100	96	68.8	"	.	
29	5NN	20.1-20.4	LEAN CLAY		46	26	(100)	*99	96	86.5	"	.	
30	5NNN	20.4-20.8	LEAN CLAY WITH SAND		40	19	(99)	*96	91	76.2	"	.	
31	5NNNN	20.8-21.0	SANDY LEAN CLAY		42	23		100	100	68.2	"	.	9/21.0
32			(WEATHERED SHALE)						.	.		.	
33	5O	21.0-21.4	" " " (" ")		35	16		100	99	94.3	"	.	50R1 1/4"

LOCATION: N.W. 1/4, S.W. 1/4, S.E. 1/4, SEC 9, T 17 N,R 13 E
TULSA COUNTY

WATER LEVEL AT 24 HOURS: 14.1 FEET

TABLE D12, ROLAND, BORING R1

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH
1	3A	5.7-6.1	FAT CLAY	50.8	81	51		100	100	99.6	CH	0.41	
2	3AA	6.1-6.8	" "	50.6	77	53		100	100	99.4	"	0.50	
3	3AAA	6.8-7.2	" "	41.3	75	51		100	100	99.8	"	0.34	0/7.2
4	3B	7.2-7.9	" "	48.0	87	59		100	100	98.5	"	0.34	
5	3BB	7.9-8.7	" "	42.5	82	54		100	100	99.6	"	0.27	2/8.7
6	3C	8.7-9.2	" "	41.6	81	54		100	100	98.7	"	0.27	
7	3CC	9.2-9.7	" "	42.5	87	59		100	100	99.6	"	0.25	
8	3CCC	9.7-10.2	" "	43.7	73	46		100	100	99.8	"	0.36	3/10.2
9	3D	10.2-10.7	" "	47.1	96	63		100	100	99.6	"	0.22	
10	3DD	10.7-11.2	" "	43.3	98	63		100	100	99.8	"	0.13	
11	3DDD	11.2-11.7	" "	45.4	91	60		100	100	99.4	"	0.24	3/11.7
12	3E	11.7-12.2	" "	49.0	100	75		100	100	99.6	"	0.32	
13	3EE	12.2-12.7	" "	38.8	87	55		100	100	99.6	"	0.12	
14	3EEE	12.7-13.2	" "	37.8	92	58		100	100	99.6	"	0.07	3/13.2
15	3F	13.2-13.7	" "	39.6	88	59		100	100	99.8	"	0.18	
16	3FF	13.7-14.2	" "	39.3	83	53		100	100	99.6	"	0.18	
17	3FFF	14.2-14.7	" "	40.7	90	59		100	100	99.6	"	0.16	3/14.7
18	3G	14.7-15.4	" "	45.1	87	56		100	100	99.3	"	0.69	
19	3GG	15.4-16.2	" "	42.1	86	54		100	99	98.7	"	0.23	4/16.2
20	3H	16.2-16.7	" "	39.8	93	64		100	100	99.6	"	0.17	
21	3HH	16.7-17.2	" "	40.0	91	63		100	100	99.6	"	0.19	
22	3HHH	17.2-17.7	" "	43.4	98	70		100	100	99.3	"	0.22	3/17.7
23	3I	17.7-17.9	" "	43.9	89	62		100	100	99.1	"	0.27	
24	3II	17.9-18.7	" "	43.3	77	48		100	100	99.3	"	0.30	
25	3III	18.7-19.2	" "	44.2	72	44		100	100	97.0	"	0.37	4/19.2
26	3J	19.2-19.7	" "	35.7	72	47		100	99	95.0	"	0.23	
27	3JJ	19.7-20.2	" "	40.3	79	50		100	100	99.3	"	0.23	
28	3JJJ	20.2-20.7	" "	40.1	83	56		100	100	99.6	"	0.23	3/20.7
29	3K	20.7-21.2	" "	38.8	82	53		100	99	98.7	"	0.18	
30	3KK	21.2-21.7	" "	38.4	90	63	(100)	*99	99	98.6	"	0.18	
31	3KKK	21.7-22.2	" "	42.2	84	56		100	100	99.3	"	0.25	3/22.2
32	3L	22.2-22.7	" "	38.6	91	62		100	100	91.1	"	0.15	
33	3LL	22.7-23.2	" "	36.5	84	73		100	99	98.9	"	0.35	
34	3LLL	23.2-23.7	" "	40.6	91	63		100	100	99.8	"	0.20	4/23.7
35	3M	23.7-24.2	" "	41.6	93	66		100	100	99.7	"	0.22	
36	3MM	24.2-24.7	" "	41.5	92	63		100	100	99.6	"	0.20	
37	3MMM	24.7-25.2	" "	43.3	92	65		100	100	98.8	"	0.25	5/25.2
38	3N	25.2-25.7	" "	45.9	98	68		100	100	100.0	"	0.23	
39	3NN	25.7-26.2	" "	38.3	91	62		100	100	99.8	"	0.15	
40	3NNN	26.2-26.7	" "	45.3	94	64		100	100	100.0	"	0.24	5/26.7
41	3O	26.7-27.2	" "	44.0	92	63		100	100	100.0	"	0.24	
42	3OO	27.2-27.7	" "	38.9	86	59		100	100	100.0	"	0.20	
43	3OOO	27.7-28.2	" "	47.6	92	62		100	100	99.9	"	0.28	4/28.2
44	3P	28.2-28.7	" "	47.4	89	61		100	100	99.8	"	0.32	
45	3PP	28.7-29.2	" "	58.9	96	66		100	100	99.8	"	0.44	
46	3PPP	29.2-29.7	" "	59.7	100	66		100	100	99.8	"	0.39	3/29.7
47	3Q	29.7-30.2	" "	62.8	90	59		100	100	100.0	"	0.54	
48	3QQ	30.2-30.7	" "	59.7	84	56		100	100	99.7	"	0.57	
49	3QQQ	30.7-31.2	" "	62.4	85	57		100	100	99.8	"	0.60	
50	3QQQQ	31.2-31.7	" "	64.6	86	58		100	100	100.0	"	0.63	0/31.7
51	3R	31.7-32.2	" "	66.7	82	54	(100)	*93	93	92.5	"	0.72	
52	3RR	32.2-32.7	" "	52.3	54	36		100	100	94.7	"	0.95	
53	3RRR	32.7-33.2	" "	31.2	55	36		100	100	97.9	"	0.34	1/33.2
54	3S	33.2-33.9	" "	26.0	54	37	(100)	*98	96	92.7	"	0.24	

TABLE D12, ROLAND, BORING R1 (CONTINUED)

OBS	SAMPLENO	DEPTH	LOG	W	LL	PI	NO4	NO10	NO40	NO200	USC	LI	N/DEPTH'
55	3SS	33.9-34.7	LEAN CLAY	39.2	48	30		100	100	98.1	CL	0.71	4/34.7
56	3T	34.7-35.4	" "	24.2	49	30		100	100	97.7	"	0.17	
57	3TT	35.4-36.2	FAT CLAY	27.7	51	33	(100)	*97	95	89.6	CH	0.29	4/36.2
58	3U	36.2-36.7	" "	32.2	50	30		100	100	96.4	"	0.41	
59	3UU	36.7-37.2	LEAN CLAY	25.3	44	27		100	97	90.2	CL	0.31	
60	3UUU	37.2-37.7	FAT CLAY	51.5	70	46		100	100	99.0	CH	0.60	5/37.7
61	3V	37.7-39.2	POORLY GRADED SAND		NP	NP	(100)	*95	15	9.4	SP-SM	.	1/39.2
62			WITH SILT						.	.		.	

LOCATION: S.E. 1/4, S.W. 1/4, S.E. 1/4, SEC 19, T 11 N, R 27 E AND
S.W. 1/4, S.E. 1/4, S.E. 1/4, SEC 19, T 11 N, R 27 E
SEQUOYAH COUNTY

WATER LEVEL AT 24 HOURS: 6.3 FEET

APPENDIX E

CPT DATA

TABLE E1, WAGONER, BORING W1

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	7	FAT CLAY	CH	2300	73.3	3.1870
2	7	FAT CLAY	CH	4000	126.7	3.1675
3	7	FAT CLAY	CH	4800	213.3	4.4437
4	7	FAT CLAY	CH	4000	193.3	4.8325
5	7	FAT CLAY	CH	3800	220.0	5.7895
6	7	FAT CLAY	CH	3500	260.0	7.4286
7	7	FAT CLAY	CH	3400	213.3	6.2735
8	7	FAT CLAY	CH	3300	266.7	8.0818
9	7	FAT CLAY	CH	3700	286.7	7.7486
10	7	FAT CLAY	CH	3800	306.7	8.0711
11	7	FAT CLAY	CH	3100	273.3	8.8161
12	7	FAT CLAY	CH	3100	266.7	8.6032
13	7	FAT CLAY	CH	3000	326.7	10.8900
14	7	FAT CLAY	CH	3100	260.0	8.3871
15	7	FAT CLAY	CH	2900	273.3	9.4241
16	7	FAT CLAY	CH	2300	253.3	11.0130
17	7	FAT CLAY	CH	2200	233.3	10.6045
18	7	FAT CLAY	CH	2100	180.0	8.5714
19	7	FAT CLAY	CH	2400	160.0	6.6667
20	7	FAT CLAY	CH	2200	126.7	5.7591
21	7	FAT CLAY	CH	2100	140.0	6.6667
22	7	FAT CLAY	CH	2400	146.7	6.1125
23	7	FAT CLAY	CH	2300	140.0	6.0870
24	7	FAT CLAY	CH	2100	146.7	6.9857
25	7	FAT CLAY	CH	1900	140.0	7.3684
26	7	FAT CLAY	CH	1700	146.7	8.6294
27	7	FAT CLAY	CH	1700	146.7	8.6294
28	7	FAT CLAY	CH	1800	106.7	5.9278
29	7	FAT CLAY	CH	1600	40.0	2.5000
30	7	FAT CLAY	CH	1900	40.0	2.1053
31	7	FAT CLAY	CH	1900	40.0	2.1053
32	7	FAT CLAY	CH	1900	53.3	2.8053
33	7	FAT CLAY	CH	1900	60.0	3.1579
34	7	FAT CLAY	CH	1900	73.3	3.8579
35	7	FAT CLAY	CH	1900	66.7	3.5105
36	7	FAT CLAY	CH	1900	66.7	3.5105
37	7	FAT CLAY	CH	2100	80.0	3.8095
38	7	FAT CLAY	CH	2000	93.3	4.6650
39	7	FAT CLAY	CH	2000	73.3	3.6650
40	7	FAT CLAY	CH	1900	73.3	3.8579
41	7	FAT CLAY	CH	2200	60.0	2.7273
42	7	FAT CLAY	CH	2200	73.3	3.3318
43	7	FAT CLAY	CH	2100	60.0	2.8571
44	7	FAT CLAY	CH	2100	60.0	2.8571
45	7	FAT CLAY	CH	2000	60.0	3.0000
46	7	FAT CLAY	CH	2100	60.0	2.8571
47	7	FAT CLAY	CH	2000	40.0	2.0000
48	7	FAT CLAY	CH	2100	60.0	2.8571
49	7	FAT CLAY	CH	2100	46.7	2.2238
50	7	FAT CLAY	CH	2000	53.3	2.6650
51	7	FAT CLAY	CH	2100	60.0	2.8571
52	7	FAT CLAY	CH	2100	66.7	3.1762
53	7	FAT CLAY	CH	2100	93.3	4.4429
54	7	FAT CLAY	CH	2100	73.3	3.4905

TABLE E1, WAGONER, BORING W1 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	7	FAT CLAY	CH	2400	80.0	3.33333
56	7	FAT CLAY	CH	2700	53.3	1.97407
57	7	FAT CLAY	CH	2500	53.3	2.13200
58	7	FAT CLAY	CH	2300	53.3	2.31739
59	7	FAT CLAY	CH	2400	66.7	2.77917
60	7	LEAN CLAY	CL	2400	80.0	3.33333
61	7	LEAN CLAY	CL	2400	53.3	2.22083
62	7	LEAN CLAY	CL	2400	66.7	2.77917
63	7	LEAN CLAY	CL	2700	66.7	2.47037
64	7	LEAN CLAY	CL	2100	60.0	2.85714
65	7	LEAN CLAY	CL	1800	73.3	4.07222
66	7	LEAN CLAY	CL	1500	40.0	2.66667
67	7	LEAN CLAY W/SAND	CL	1300	40.0	3.07692
68	7	LEAN CLAY W/SAND	CL	1400	46.7	3.33571
69	7	LEAN CLAY W/SAND	CL	1800	40.0	2.22222
70	7	LEAN CLAY W/SAND	CL	1300	26.7	2.05385
71	7	LEAN CLAY W/SAND	CL	1200	20.0	1.66667
72	7	LEAN CLAY W/SAND	CL	1500	33.3	2.22000
73	7	LEAN CLAY W/SAND	CL	1500	40.0	2.66667
74	7	LEAN CLAY W/SAND	CL	1600	53.3	3.33125
75	7	LEAN CLAY W/SAND	CL	1900	26.7	1.40526
76	7	LEAN CLAY W/SAND	CL	2300	20.0	0.86957
77	7	LEAN CLAY W/SAND	CL	1700	26.7	1.57059
78	7	SANDY SILTY CLAY	CL-ML	1700	40.0	2.35294
79	7	SANDY SILTY CLAY	CL-ML	1800	60.0	3.33333
80	7	SANDY SILTY CLAY	CL-ML	1400	0.0	0.00000
81	7	SANDY SILTY CLAY	CL-ML	3200	153.3	4.79062
82	7	LEAN CLAY W/SAND	CL	1900	80.0	4.21053
83	7	LEAN CLAY W/SAND	CL	1700	13.3	0.78235
84	7	SANDY SILTY CLAY	CL-ML	3100	73.3	2.36452
85	7	SANDY SILTY CLAY	CL-ML	4500	126.7	2.81556
86	7	SANDY SILTY CLAY	CL-ML	4300	113.3	2.63488
87	7	SANDY SILTY CLAY	CL-ML	4000	66.7	1.66750
88	7	SANDY SILTY CLAY	CL-ML	6000	340.0	5.66667
89	7	SILTY SAND	SM	18000	500.0	2.77778
90	7	SILTY SAND	SM	18000	466.7	2.59278
91	7	SILTY SAND	SM	18000	366.7	2.03722

TABLE E2, WAGONER, BORING W2

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	8	FAT CLAY	CH	1600	26.7	1.66875
2	8	FAT CLAY	CH	1800	106.7	5.92778
3	8	FAT CLAY	CH	1600	126.7	7.91875
4	8	FAT CLAY	CH	1200	93.3	7.77500
5	8	FAT CLAY	CH	1100	93.3	8.48182
6	8	FAT CLAY	CH	1000	73.3	7.33000
7	8	FAT CLAY	CH	1100	60.0	5.45455
8	8	FAT CLAY	CH	1400	53.3	3.80714
9	8	FAT CLAY	CH	1400	46.7	3.33571
10	8	FAT CLAY	CH	1300	53.3	4.10000
11	8	FAT CLAY	CH	1300	60.0	4.61538
12	8	FAT CLAY	CH	1000	46.7	4.67000
13	8	FAT CLAY	CH	1100	26.7	2.42727
14	8	FAT CLAY	CH	1100	40.0	3.63636
15	8	FAT CLAY	CH	1400	20.0	1.42857
16	8	FAT CLAY	CH	1400	40.0	2.85714
17	8	FAT CLAY	CH	1500	40.0	2.66667
18	8	FAT CLAY	CH	1500	46.7	3.11333
19	8	FAT CLAY	CH	1400	53.3	3.80714
20	8	FAT CLAY	CH	1500	53.3	3.55333
21	8	FAT CLAY	CH	1400	60.0	4.28571
22	8	FAT CLAY	CH	1600	60.0	3.75000
23	8	FAT CLAY	CH	1600	46.7	2.91875
24	8	FAT CLAY	CH	1600	40.0	2.50000
25	8	FAT CLAY	CH	1800	60.0	3.33333
26	8	FAT CLAY	CH	1700	46.7	2.74706
27	8	FAT CLAY	CH	1800	60.0	3.33333
28	8	FAT CLAY	CH	1900	60.0	3.15789
29	8	FAT CLAY	CH	1800	66.7	3.70556
30	8	FAT CLAY	CH	1800	73.3	4.07222
31	8	FAT CLAY	CH	1800	73.3	4.07222
32	8	FAT CLAY	CH	1900	66.7	3.51053
33	8	FAT CLAY	CH	1900	60.0	3.15789
34	8	FAT CLAY	CH	2000	66.7	3.33500
35	8	FAT CLAY	CH	2100	66.7	3.17619
36	8	FAT CLAY	CH	2000	60.0	3.00000
37	8	FAT CLAY	CH	2200	66.7	3.03182
38	8	FAT CLAY	CH	2300	66.7	2.90000
39	8	FAT CLAY	CH	2200	53.3	2.42273
40	8	FAT CLAY	CH	2300	60.0	2.60870
41	8	FAT CLAY	CH	2200	66.7	3.03182
42	8	FAT CLAY	CH	2000	53.3	2.66500
43	8	FAT CLAY	CH	1900	60.0	3.15789
44	8	FAT CLAY	CH	2000	53.3	2.66500
45	8	FAT CLAY	CH	1900	66.7	3.51053
46	8	FAT CLAY	CH	2000	46.7	2.33500
47	8	FAT CLAY	CH	1900	60.0	3.15789
48	8	FAT CLAY	CH	2100	66.7	3.17619
49	8	FAT CLAY	CH	2000	60.0	3.00000
50	8	FAT CLAY	CH	2000	53.3	2.66500
51	8	FAT CLAY	CH	2100	66.7	3.17619
52	8	FAT CLAY	CH	2200	100.0	4.54545
53	8	FAT CLAY	CH	2100	86.7	4.12857
54	8	FAT CLAY	CH	2200	93.3	4.24091

TABLE E2, WAGONER, BORING W2 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	8	FAT CLAY	CH	2800	93.3	3.3321
56	8	FAT CLAY	CH	2800	53.3	1.9036
57	8	LEAN CLAY	CL	2800	66.7	2.3821
58	8	LEAN CLAY	CL	2300	60.0	2.6087
59	8	LEAN CLAY	CL	1500	33.3	2.2200
60	8	LEAN CLAY	CL	2200	40.0	1.8182
61	8	LEAN CLAY	CL	2400	40.0	1.6667
62	8	LEAN CLAY	CL	1900	60.0	3.1579
63	8	LEAN CLAY	CL	1700	26.7	1.5706
64	8	LEAN CLAY	CL	1300	33.3	2.5615
65	8	LEAN CLAY	CL	1500	33.3	2.2200
66	8	LEAN CLAY	CL	1700	33.3	1.9588
67	8	LEAN CLAY	CL	2000	46.7	2.3350
68	8	LEAN CLAY	CL	1900	33.3	1.7526
69	8	LEAN CLAY	CL	1700	53.3	3.1353
70	8	LEAN CLAY	CL	1600	86.7	5.4187
71	8	LEAN CLAY W/SAND	CL	1100	26.7	2.4273
72	8	LEAN CLAY W/SAND	CL	1100	120.0	10.9091
73	8	LEAN CLAY	CL	2200	40.0	1.8182
74	8	LEAN CLAY	CL	1000	13.3	1.3300
75	8	LEAN CLAY W/SAND	CL	900	80.0	8.8889
76	8	LEAN CLAY W/SAND	CL	1800	46.7	2.5944
77	8	LEAN CLAY W/SAND	CL	1100	0.0	0.0000
78	8	SANDY LEAN CLAY	CL	3100	73.3	2.3645
79	8	LEAN CLAY	CL	2800	66.7	2.3821
80	8	LEAN CLAY	CL	1700	320.0	18.8235
81	8	LEAN CLAY	CL	2500	293.3	11.7320
82	8	SILTY SAND	SM	2000	146.7	7.3350
83	8	SANDY SILTY CLAY	CL-ML	2100	266.7	12.7000
84	8	SANDY SILTY CLAY	CL-ML	3000	226.7	7.5567
85	8	SANDY SILTY CLAY	CL-ML	3200	20.0	0.6250
86	8	SILTY CLAY SAND	SC-SM	5800	166.7	2.8741
87	8	SILTY CLAY SAND	SC-SM	5700	166.7	2.9246
88	8	SILTY SAND	SM	3200	440.0	13.7500
89	8	SANDY SILT CLAY	CL-ML	6000	466.7	7.7783
90	8	SANDY SILT CLAY	CL-ML	10400	0.0	0.0000
91	8	SILTY SAND	SM	18000	300.0	1.6667
92	8	SILTY SAND W/GRAVE	SM	23000	106.7	0.4639
93	8	SILTY SAND W/GRAVE	SM	12500	373.3	2.9864
94	8	SILTY SAND W/GRAVE	SM	14400	186.7	1.2965
95	8	SILTY SAND W/GRAVE	SM	10400	466.7	4.4875
96	8	SILTY SAND W/GRAVE	SM	8200	200.0	2.4390
97	8	SILTY SAND W/GRAVE	SM	16000	266.7	1.6669
98	8	SILTY SAND W/GRAVE	SM	19000	400.0	2.1053
99	8	SILTYSANDW/GRAVEL	SM	20000	266.7	1.3335
100	8	SILTYSANDW/GRAVEL	SM	15000	333.3	2.2220
101	8	CLAYEYSANDW/GRAVEL	SC	17000	533.3	3.1371
102	8	CLAYEYSANDW/GRAVEL	SC	15000	600.0	4.0000
103	8	CLAYEYSANDW/GRAVEL	SC	7000	306.7	4.3814
104	8	CLAYEYSANDW/GRAVEL	SC	18000	1066.7	5.9261
105	8	CLAYEYSANDW/GRAVEL	SC	10400	800.0	7.6923

TABLE E3, WAGONER, BORING W3

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	9	FAT CLAY	CH	2000	106.7	5.33500
2	9	FAT CLAY	CH	2400	146.7	6.11250
3	9	FAT CLAY	CH	2200	120.0	5.45455
4	9	FAT CLAY	CH	2200	166.7	7.57727
5	9	FAT CLAY	CH	2700	166.7	6.17407
6	9	FAT CLAY	CH	2300	160.0	6.95652
7	9	FAT CLAY	CH	2500	140.0	5.60000
8	9	FAT CLAY	CH	2800	146.7	5.23929
9	9	LEAN CLAY	CL	3100	180.0	5.80645
10	9	LEAN CLAY	CL	2900	173.3	5.97586
11	9	LEAN CLAY	CL	2600	160.0	6.15385
12	9	LEAN CLAY	CL	2300	146.7	6.37826
13	9	FAT CLAY	CH	2000	166.7	8.33500
14	9	FAT CLAY	CH	2000	40.0	2.00000
15	9	FAT CLAY	CH	1800	140.0	7.77778
16	9	FAT CLAY	CH	3800	133.3	3.50789
17	9	FAT CLAY	CH	1800	126.7	7.03889
18	9	FAT CLAY	CH	1700	120.0	7.05882
19	9	FAT CLAY	CH	1600	93.3	5.83125
20	9	FAT CLAY	CH	1500	86.7	5.78000
21	9	FAT CLAY	CH	1700	73.3	4.31176
22	9	FAT CLAY	CH	1700	73.3	4.31176
23	9	FAT CLAY	CH	1700	80.0	4.70588
24	9	FAT CLAY	CH	1800	80.0	4.44444
25	9	FAT CLAY	CH	1700	60.0	3.52941
26	9	FAT CLAY	CH	1600	53.3	3.33125
27	9	FAT CLAY	CH	1600	60.0	3.75000
28	9	FAT CLAY	CH	1700	86.7	5.10000
29	9	FAT CLAY	CH	1600	93.3	5.83125
30	9	FAT CLAY	CH	1800	86.7	4.81667
31	9	FAT CLAY	CH	1900	60.0	3.15789
32	9	FAT CLAY	CH	2000	46.7	2.33500
33	9	FAT CLAY	CH	2300	60.0	2.60870
34	9	FAT CLAY	CH	2300	53.3	2.31739
35	9	FAT CLAY	CH	2100	53.3	2.53810
36	9	FAT CLAY	CH	2400	60.0	2.50000
37	9	FAT CLAY	CH	2500	66.7	2.66800
38	9	FAT CLAY	CH	2500	86.7	3.46800
39	9	FAT CLAY	CH	2500	66.7	2.66800
40	9	FAT CLAY	CH	2200	66.7	3.03182
41	9	FAT CLAY	CH	2200	66.7	3.03182
42	9	FAT CLAY	CH	2100	60.0	2.85714
43	9	FAT CLAY	CH	2000	80.0	4.00000
44	9	FAT CLAY	CH	2200	60.0	2.72727
45	9	FAT CLAY	CH	2300	66.7	2.90000
46	9	FAT CLAY	CH	2500	80.0	3.20000
47	9	FAT CLAY	CH	2500	73.3	2.93200
48	9	FAT CLAY	CH	2300	53.3	2.31739
49	9	FAT CLAY	CH	2300	60.0	2.60870
50	9	FAT CLAY	CH	2500	66.7	2.66800
51	9	FAT CLAY	CH	2200	80.0	3.63636
52	9	FAT CLAY	CH	2000	60.0	3.00000
53	9	FAT CLAY	CH	2200	86.7	3.94091
54	9	FAT CLAY	CH	2900	160.0	5.51724

TABLE E3, WAGONER, BORING E3 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	9	FAT CLAY	CH	3000	80.0	2.66667
56	9	FAT CLAY	CH	3500	86.7	2.47714
57	9	LEAN CLAY	CL	3300	86.7	2.62727
58	9	LEAN CLAY	CL	3500	86.7	2.47714
59	9	LEAN CLAY W/SAND	CL	3100	66.7	2.15161
60	9	LEAN CLAY W/SAND	CL	2800	66.7	2.38214
61	9	LEAN CLAY W/SAND	CL	2300	33.3	1.44783
62	9	LEAN CLAY W/SAND	CL	2100	53.3	2.53810
63	9	LEAN CLAY W/SAND	CL	2000	60.0	3.00000
64	9	SANDY LEAN CLAY	CL	1600	33.3	2.08125
65	9	SANDY LEAN CLAY	CL	1500	33.3	2.22000
66	9	LEAN CLAY W/SAND	CL	1600	40.0	2.50000
67	9	LEAN CLAY W/SAND	CL	2000	40.0	2.00000
68	9	LEAN CLAY W/SAND	CL	2200	53.3	2.42273
69	9	LEAN CLAY W/SAND	CL	1900	33.3	1.75263
70	9	LEAN CLAY W/SAND	CL	1800	100.0	5.55556
71	9	LEAN CLAY W/SAND	CL	2000	0.0	0.00000
72	9	LEAN CLAY W/SAND	CL	2400	80.0	3.33333
73	9	LEAN CLAY W/SAND	CL	2400	26.7	1.11250
74	9	SANDY LEAN CLAY	CL	1200	113.3	9.44167
75	9	SILT	ML	2500	120.0	4.80000
76	9	SILT	ML	2300	46.7	2.03043
77	9	SILT	ML	1900	46.7	2.45789
78	9	SANDY SILTY CLAY	CL-ML	2600	160.0	6.15385
79	9	SILTY SAND	SM	3800	120.0	3.15789
80	9	SILTY SAND	SM	3900	106.7	2.73590
81	9	SANDY LEAN CLAY	CL	4200	120.0	2.85714
82	9	SANDY LEAN CLAY	CL	4300	66.7	1.55116
83	9	SANDY SILTY CLAY	CL-ML	4200	133.3	3.17381
84	9	SILTY SAND	SM	2500	66.7	2.66800
85	9	SILTY SAND	SM	3500	133.3	3.80857
86	9	SILTY SAND	SM	4400	206.7	4.69773
87	9	SILTY SAND	SM	4100	280.0	6.82927
88	9	SILTY SAND	SM	8000	106.7	1.33375

TABLE E4, WAGONER, BORING W4

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	14	FAT CLAY	CH	1000	0.0	0.0000
2	14	FAT CLAY	CH	2500	66.7	2.6680
3	14	FAT CLAY	CH	3000	133.3	4.4433
4	14	FAT CLAY	CH	2200	113.3	5.1500
5	14	FAT CLAY	CH	2000	133.3	6.6650
6	14	FAT CLAY	CH	2000	120.0	6.0000
7	14	FAT CLAY	CH	2200	120.0	5.4545
8	14	FAT CLAY	CH	2200	146.7	6.6682
9	14	FAT CLAY	CH	2300	140.0	6.0870
10	14	FAT CLAY	CH	2400	146.7	6.1125
11	14	FAT CLAY	CH	2500	160.0	6.4000
12	14	FAT CLAY	CH	2600	133.3	5.1269
13	14	FAT CLAY	CH	2400	133.3	5.5542
14	14	FAT CLAY	CH	2400	153.3	6.3875
15	14	FAT CLAY	CH	2000	146.7	7.3350
16	14	FAT CLAY	CH	1600	193.3	12.0812
17	14	FAT CLAY	CH	1400	120.0	8.5714
18	14	FAT CLAY	CH	1600	100.0	6.2500
19	14	FAT CLAY	CH	1400	106.7	7.6214
20	14	FAT CLAY	CH	1300	86.7	6.6692
21	14	FAT CLAY	CH	1400	106.7	7.6214
22	14	FAT CLAY	CH	1600	93.3	5.8312
23	14	FAT CLAY	CH	1600	100.0	6.2500
24	14	FAT CLAY	CH	1600	106.7	6.6687
25	14	FAT CLAY	CH	1600	113.3	7.0812
26	14	FAT CLAY	CH	1800	120.0	6.6667
27	14	FAT CLAY	CH	1700	106.7	6.2765
28	14	FAT CLAY	CH	1800	113.3	6.2944
29	14	FAT CLAY	CH	1800	100.0	5.5556
30	14	FAT CLAY	CH	1700	113.3	6.6647
31	14	FAT CLAY	CH	1900	113.3	5.9632
32	14	FAT CLAY	CH	1800	93.3	5.1833
33	14	FAT CLAY	CH	1800	93.3	5.1833
34	14	FAT CLAY	CH	1700	100.0	5.8824
35	14	FAT CLAY	CH	2000	100.0	5.0000
36	14	FAT CLAY	CH	2000	113.3	5.6650
37	14	FAT CLAY	CH	2100	100.0	4.7619
38	14	FAT CLAY	CH	1800	113.3	6.2944
39	14	FAT CLAY	CH	1800	100.0	5.5556
40	14	FAT CLAY	CH	2000	106.7	5.3350
41	14	FAT CLAY	CH	2100	113.3	5.3952
42	14	FAT CLAY	CH	2000	106.7	5.3350
43	14	FAT CLAY	CH	2100	106.7	5.0810
44	14	FAT CLAY	CH	2000	100.0	5.0000
45	14	FAT CLAY	CH	2000	80.0	4.0000
46	14	FAT CLAY	CH	2000	106.7	5.3350
47	14	FAT CLAY	CH	2000	100.0	5.0000
48	14	FAT CLAY	CH	2000	100.0	5.0000
49	14	FAT CLAY	CH	2200	120.0	5.4545
50	14	FAT CLAY	CH	2300	106.7	4.6391
51	14	FAT CLAY	CH	2400	120.0	5.0000
52	14	FAT CLAY	CH	2600	133.3	5.1269
53	14	FAT CLAY	CH	2600	113.3	4.3577
54	14	FAT CLAY W/SAND	CH	2600	106.7	4.1038

TABLE E4, WAGONER, BORING W4 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	14	FAT CLAY W/SAND	CH	2600	93.3	3.5885
56	14	FAT CLAY	CH	2500	106.7	4.2680
57	14	FAT CLAY	CH	2400	80.0	3.3333
58	14	FAT CLAY	CH	2000	86.7	4.3350
59	14	LEAN CLAY	CL	1900	66.7	3.5105
60	14	LEAN CLAY	CL	1800	53.3	2.9611
61	14	LEAN CLAY	CL	1800	60.0	3.3333
62	14	LEAN CLAY	CL	1600	60.0	3.7500
63	14	LEAN CLAY	CL	1600	46.7	2.9187
64	14	LEAN CLAY	CL	1900	66.7	3.5105
65	14	LEAN CLAY	CL	2000	60.0	3.0000
66	14	LEAN CLAY	CL	1600	40.0	2.5000
67	14	LEAN CLAY	CL	1600	40.0	2.5000
68	14	LEAN CLAY	CL	1400	40.0	2.8571
69	14	LEAN CLAY	CL	1200	13.3	1.1083
70	14	LEAN CLAY	CL	800	26.7	3.3375
71	14	LEAN CLAY W/SAND	CL	1200	13.3	1.1083
72	14	LEAN CLAY W/SAND	CL	1000	80.0	8.0000
73	14	LEAN CLAY W/SAND	CL	1000	13.3	1.3300
74	14	LEAN CLAY W/SAND	CL	1000	26.7	2.6700
75	14	LEAN CLAY W/SAND	CL	1200	133.3	11.1083
76	14	LEAN CLAY W/SAND	CL	1800	53.3	2.9611
77	14	LEAN CLAY	CL	1200	26.7	2.2250
78	14	LEAN CLAY W/SAND	CL	1600	40.0	2.5000
79	14	LEAN CLAY W/SAND	CL	3200	93.3	2.9156
80	14	SILTY CLAY	CL-ML	3000	93.3	3.1100
81	14	SANDY SILT	ML	3800	120.0	3.1579
82	14	SILTY SAND	SM	4200	106.7	2.5405
83	14	SILTY SAND	SM	4800	360.0	7.5000
84	14	SILTY SAND	SM	6600	800.0	12.1212
85	14	SILTY SAND	SM	7800	1066.7	13.6756
86	14	SILTY SAND	SM	18000	1333.3	7.4072
87	14	SILTY SAND	SM	24000	666.7	2.7779

TABLE E5, WAGONER, BORING W5

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	10	FAT CLAY	CH	2900	120.0	4.13793
2	10	FAT CLAY	CH	2200	126.7	5.75909
3	10	FAT CLAY	CH	2100	93.3	4.44286
4	10	FAT CLAY	CH	2100	160.0	7.61905
5	10	FAT CLAY	CH	1800	106.7	5.92778
6	10	FAT CLAY	CH	1600	120.0	7.50000
7	10	FAT CLAY	CH	1600	86.7	5.41875
8	10	FAT CLAY	CH	1600	93.3	5.83125
9	10	FAT CLAY	CH	1600	86.7	5.41875
10	10	FAT CLAY	CH	1600	86.7	5.41875
11	10	FAT CLAY	CH	1500	80.0	5.33333
12	10	FAT CLAY	CH	1700	106.7	6.27647
13	10	FAT CLAY	CH	1800	86.7	4.81667
14	10	FAT CLAY	CH	1700	80.0	4.70588
15	10	FAT CLAY	CH	1600	73.3	4.58125
16	10	FAT CLAY	CH	1600	66.7	4.16875
17	10	FAT CLAY	CH	1800	86.7	4.81667
18	10	FAT CLAY	CH	1900	86.7	4.56316
19	10	FAT CLAY	CH	1800	80.0	4.44444
20	10	FAT CLAY	CH	1900	80.0	4.21053
21	10	FAT CLAY	CH	1900	73.3	3.85789
22	10	FAT CLAY	CH	2000	60.0	3.00000
23	10	FAT CLAY	CH	2000	53.3	2.66500
24	10	FAT CLAY	CH	2200	66.7	3.03182
25	10	FAT CLAY	CH	2100	66.7	3.17619
26	10	FAT CLAY	CH	2100	66.7	3.17619
27	10	FAT CLAY	CH	2100	86.7	4.12857
28	10	FAT CLAY	CH	2200	86.7	3.94091
29	10	FAT CLAY	CH	2000	66.7	3.33500
30	10	FAT CLAY	CH	2000	80.0	4.00000
31	10	FAT CLAY	CH	2200	80.0	3.63636
32	10	FAT CLAY	CH	2000	53.3	2.66500
33	10	FAT CLAY	CH	2000	80.0	4.00000
34	10	FAT CLAY	CH	2400	86.7	3.61250
35	10	FAT CLAY	CH	2400	86.7	3.61250
36	10	FAT CLAY	CH	2500	80.0	3.20000
37	10	FAT CLAY	CH	2400	53.3	2.22083
38	10	FAT CLAY	CH	2600	46.7	1.79615
39	10	FAT CLAY	CH	2600	53.3	2.05000
40	10	FAT CLAY	CH	2700	53.3	1.97407
41	10	FAT CLAY	CH	2700	53.3	1.97407
42	10	FAT CLAY	CH	2400	46.7	1.94583
43	10	FAT CLAY	CH	2400	46.7	1.94583
44	10	FAT CLAY	CH	2500	46.7	1.86800
45	10	FAT CLAY	CH	2400	46.7	1.94583
46	10	FAT CLAY	CH	2400	53.3	2.22083
47	10	FAT CLAY	CH	2400	93.3	3.88750
48	10	FAT CLAY	CH	2400	66.7	2.77917
49	10	FAT CLAY	CH	2400	53.3	2.22083
50	10	FAT CLAY	CH	3200	46.7	1.45937
51	10	FAT CLAY	CH	3200	60.0	1.87500
52	10	FAT CLAY	CH	3200	53.3	1.66562
53	10	FAT CLAY	CH	3100	60.0	1.93548
54	10	FAT CLAY	CH	3200	33.3	1.04062

TABLE E5, WAGONER, BORING W5 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	10	FAT CLAY	CH	3200	80.0	2.50000
56	10	LEAN CLAY	CL	3100	60.0	1.93548
57	10	LEAN CLAY	CL	2600	60.0	2.30769
58	10	LEAN CLAY	CL	2500	80.0	3.20000
59	10	LEAN CLAY	CL	2300	73.3	3.18696
60	10	LEAN CLAY	CL	2000	46.7	2.33500
61	10	LEAN CLAY W/SAND	CL	2100	53.3	2.53810
62	10	LEAN CLAY W/SAND	CL	1800	53.3	2.96111
63	10	LEAN CLAY W/SAND	CL	1700	60.0	3.52941
64	10	LEAN CLAY W/SAND	CL	1700	33.3	1.95882
65	10	LEAN CLAY	CL	1800	46.7	2.59444
66	10	LEAN CLAY	CL	2200	40.0	1.81818
67	10	LEAN CLAY W/SAND	CL	1700	60.0	3.52941
68	10	LEAN CLAY W/SAND	CL	1400	0.0	0.00000
69	10	LEAN CLAY W/SAND	CL	1500	26.7	1.78000
70	10	SANDY LEAN CLAY	CL	2000	13.3	0.66500
71	10	LEAN CLAY W/SAND	CL	1200	80.0	6.66667
72	10	LEAN CLAY W/SAND	CL	1400	0.0	0.00000
73	10	SANDY SILT	ML	1000	0.0	0.00000
74	10	SANDY SILT	ML	2400	53.3	2.22083
75	10	SILTY CLAY W/SAND	CL-ML	2500	13.3	0.53200
76	10	SILTY CLAY W/SAND	CL-ML	2400	26.7	1.11250
77	10	SANDY SILTY CLAY	CL-ML	2300	20.0	0.86957
78	10	SANDY LEAN CLAY	CL	1800	133.3	7.40556
79	10	SANDY SILT	ML	2100	160.0	7.61905
80	10	SANDY SILT	ML	1800	173.3	9.62778
81	10	SILTY SAND	SM	6400	146.7	2.29219
82	10	SANDY SILTY CLAY	CL-ML	6600	226.7	3.43485
83	10	SANDY SILTY CLAY	CL-ML	8200	240.0	2.92683

TABLE E6, WAGONER, BORING W6

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	15	FAT CLAY	CH	600	0.0	0.00000
2	15	FAT CLAY	CH	1600	0.0	0.00000
3	15	FAT CLAY	CH	1700	53.3	3.13529
4	15	FAT CLAY	CH	1400	53.3	3.80714
5	15	FAT CLAY	CH	1200	80.0	6.66667
6	15	FAT CLAY	CH	1200	80.0	6.66667
7	15	FAT CLAY	CH	1000	26.7	2.67000
8	15	FAT CLAY	CH	1200	93.3	7.77500
9	15	FAT CLAY	CH	1200	66.7	5.55833
10	15	FAT CLAY	CH	1600	93.3	5.83125
11	15	FAT CLAY	CH	1800	100.0	5.55556
12	15	FAT CLAY	CH	1400	80.0	5.71429
13	15	FAT CLAY	CH	1500	86.7	5.78000
14	15	FAT CLAY	CH	1600	93.3	5.83125
15	15	FAT CLAY	CH	1600	93.3	5.83125
16	15	FAT CLAY	CH	1600	80.0	5.00000
17	15	FAT CLAY	CH	1600	86.7	5.41875
18	15	FAT CLAY	CH	1600	80.0	5.00000
19	15	FAT CLAY	CH	1600	93.3	5.83125
20	15	FAT CLAY	CH	1400	80.0	5.71429
21	15	FAT CLAY	CH	1400	86.7	6.19286
22	15	FAT CLAY	CH	1600	80.0	5.00000
23	15	FAT CLAY	CH	1600	100.0	6.25000
24	15	FAT CLAY	CH	1800	93.3	5.18333
25	15	FAT CLAY	CH	1600	100.0	6.25000
26	15	FAT CLAY	CH	1800	86.7	4.81667
27	15	FAT CLAY	CH	1600	93.3	5.83125
28	15	FAT CLAY	CH	1600	80.0	5.00000
29	15	FAT CLAY	CH	1600	80.0	5.00000
30	15	FAT CLAY	CH	1700	93.3	5.48824
31	15	FAT CLAY	CH	1700	93.3	5.48824
32	15	FAT CLAY	CH	1600	106.7	6.66875
33	15	FAT CLAY	CH	1600	106.7	6.66875
34	15	FAT CLAY	CH	1600	113.3	7.08125
35	15	FAT CLAY	CH	2000	113.3	5.66500
36	15	FAT CLAY	CH	2100	106.7	5.08095
37	15	FAT CLAY	CH	2200	113.3	5.15000
38	15	FAT CLAY	CH	2200	106.7	4.85000
39	15	FAT CLAY	CH	2000	106.7	5.33500
40	15	FAT CLAY	CH	2000	106.7	5.33500
41	15	FAT CLAY	CH	2000	106.7	5.33500
42	15	FAT CLAY	CH	2000	106.7	5.33500
43	15	FAT CLAY	CH	2200	113.3	5.15000
44	15	FAT CLAY	CH	2200	133.3	6.05909
45	15	FAT CLAY	CH	2300	126.7	5.50870
46	15	LEAN CLAY	CL	2200	106.7	4.85000
47	15	LEAN CLAY	CL	2300	126.7	5.50870
48	15	FAT CLAY	CH	2400	126.7	5.27917
49	15	FAT CLAY	CH	2300	106.7	4.63913
50	15	FAT CLAY	CH	2400	133.3	5.55417
51	15	FAT CLAY	CH	2400	113.3	4.72083
52	15	FAT CLAY	CH	2200	106.7	4.85000
53	15	FAT CLAY	CH	2300	133.3	5.79565
54	15	FAT CLAY	CH	2500	126.7	5.06800

TABLE E6, WAGONER, BORING W6 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	15	FAT CLAY	CH	2200	126.7	5.75909
56	15	FAT CLAY	CH	2600	120.0	4.61538
57	15	FAT CLAY	CH	2600	146.7	5.64231
58	15	FAT CLAY	CH	2800	106.7	3.81071
59	15	FAT CLAY	CH	3000	106.7	3.55667
60	15	LEAN CLAY	CL	3200	120.0	3.75000
61	15	LEAN CLAY	CL	3200	106.7	3.33437
62	15	LEAN CLAY	CL	2800	100.0	3.57143
63	15	LEAN CLAY	CL	2900	106.7	3.67931
64	15	LEAN CLAY	CL	2900	46.7	1.61034
65	15	LEAN CLAY	CL	2400	80.0	3.33333
66	15	LEAN CLAY	CL	2300	53.3	2.31739
67	15	LEAN CLAY	CL	1800	80.0	4.44444
68	15	LEAN CLAY	CL	2000	53.3	2.66500
69	15	LEAN CLAY W/SAND	CL	2400	93.3	3.88750
70	15	LEAN CLAY W/SAND	CL	2400	53.3	2.22083
71	15	LEAN CLAY W/SAND	CL	2100	60.0	2.85714
72	15	LEAN CLAY W/SAND	CL	2400	40.0	1.66667
73	15	LEAN CLAY W/SAND	CL	2000	60.0	3.00000
74	15	SANDY LEAN CLAY	CL	1800	40.0	2.22222
75	15	SILTY SAND	SM	1500	53.3	3.55333
76	15	SILTY SAND	SM	1200	80.0	6.66667
77	15	SANDY SILT	ML	1600	26.7	1.66875
78	15	SANDY SILT	ML	1600	40.0	2.50000
79	15	SANDY LEAN CLAY	CL	2000	26.7	1.33500
80	15	SANDY LEAN CLAY	CL	1600	0.0	0.00000
81	15	FAT CLAY W/SAND	CH	3800	40.0	1.05263
82	15	LEAN CLAY W/SAND	CL	2600	120.0	4.61538
83	15	LEAN CLAY	CL	2600	0.0	0.00000
84	15	SANDY SILT	ML	2400	120.0	5.00000
85	15	LEAN CLAY W/SAND	CL	3800	26.7	0.70263
86	15	LEAN CLAY W/SAND	CL	6400	146.7	2.29219
87	15	SANDY SILT	ML	6200	160.0	2.58065
88	15	LEAN CLAY	CL	5000	186.7	3.73400
89	15	LEAN CLAY	CL	4300	126.7	2.94651

TABLE E7, TULSA, BORING T1

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	3	LEAN CLAY	CL	1800	13.3	0.73889
2	3	LEAN CLAY	CL	2200	44.4	2.01818
3	3	LEAN CLAY	CL	1900	66.7	3.51053
4	3	LEAN CLAY	CL	1600	73.3	4.58125
5	3	LEAN CLAY	CL	1200	66.7	5.55833
6	3	LEAN CLAY	CL	900	40.0	4.44444
7	3	LEAN CLAY	CL	800	6.7	0.83750
8	3	LEAN CLAY	CL	1400	13.3	0.95000
9	3	FAT CLAY	CH	1800	53.3	2.96111
10	3	FAT CLAY	CH	1800	66.7	3.70556
11	3	FAT CLAY	CH	1600	66.7	4.16875
12	3	FAT CLAY	CH	1800	100.0	5.55556
13	3	FAT CLAY	CH	1800	93.3	5.18333
14	3	FAT CLAY	CH	1900	106.7	5.61579
15	3	FAT CLAY	CH	2800	133.3	4.76071
16	3	FAT CLAY	CH	2800	133.3	4.76071
17	3	FAT CLAY	CH	2800	140.0	5.00000
18	3	FAT CLAY	CH	2400	133.3	5.55417
19	3	FAT CLAY	CH	2200	100.0	4.54545
20	3	FAT CLAY	CH	2200	100.0	4.54545
21	3	FAT CLAY	CH	2400	93.3	3.88750
22	3	FAT CLAY	CH	2200	80.0	3.63636
23	3	FAT CLAY	CH	2200	86.7	3.94091
24	3	FAT CLAY	CH	2300	86.7	3.76957
25	3	FAT CLAY	CH	2400	93.3	3.88750
26	3	FAT CLAY	CH	2400	86.7	3.61250
27	3	FAT CLAY	CH	2400	73.3	3.05417
28	3	FAT CLAY	CH	2200	80.0	3.63636
29	3	FAT CLAY	CH	2500	93.3	3.73200
30	3	FAT CLAY	CH	2600	86.7	3.33462
31	3	FAT CLAY	CH	2500	93.3	3.73200
32	3	FAT CLAY	CH	2600	86.7	3.33462
33	3	FAT CLAY	CH	2500	86.7	3.46800
34	3	FAT CLAY	CH	2600	93.3	3.58846
35	3	FAT CLAY	CH	2500	86.7	3.46800
36	3	FAT CLAY	CH	2400	93.3	3.88750
37	3	LEAN CLAY	CL	2200	73.3	3.33182
38	3	LEAN CLAY	CL	2000	93.3	4.66500
39	3	LEAN CLAY	CL	1700	60.0	3.52941
40	3	LEAN CLAY	CL	2000	60.0	3.00000
41	3	LEAN CLAY	CL	1900	66.7	3.51053
42	3	LEAN CLAY	CL	1900	73.3	3.85789
43	3	LEAN CLAY	CL	2200	93.3	4.24091
44	3	LEAN CLAY W/SAND	CL	2000	100.0	5.00000
45	3	LEAN CLAY W/SAND	CL	2000	66.7	3.33500
46	3	LEAN CLAY	CL	1900	93.3	4.91053
47	3	LEAN CLAY	CL	1800	53.3	2.96111
48	3	LEAN CLAY	CL	1800	46.7	2.59444
49	3	LEAN CLAY	CL	1800	53.3	2.96111
50	3	LEAN CLAY	CL	1800	60.0	3.33333
51	3	LEAN CLAY W/SAND	CL	1600	66.7	4.16875
52	3	LEAN CLAY W/SAND	CL	1600	80.0	5.00000
53	3	LEAN CLAY W/SAND	CL	2400	86.7	3.61250
54	3	LEAN CLAY W/SAND	CL	2600	93.3	3.58846

TABLE E7, TULSA, BORING T1 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	3	LEAN CLAY W/SAND	CL	2500	73.3	2.93200
56	3	LEAN CLAY W/SAND	CL	2500	73.3	2.93200
57	3	LEAN CLAY W/SAND	CL	2800	73.3	2.61786
58	3	LEAN CLAY W/SAND	CL	2800	80.0	2.85714
59	3	LEAN CLAY W/SAND	CL	2800	73.3	2.61786
60	3	LEAN CLAY W/SAND	CL	2800	80.0	2.85714
61	3	LEAN CLAY W/SAND	CL	2800	80.0	2.85714
62	3	LEAN CLAY W/SAND	CL	2400	73.3	3.05417
63	3	LEAN CLAY W/SAND	CL	2300	73.3	3.18696
64	3	LEAN CLAY W/SAND	CL	2400	73.3	3.05417
65	3	LEAN CLAY W/SAND	CL	2500	73.3	2.93200
66	3	LEAN CLAY W/SAND	CL	2400	53.3	2.22083
67	3	LEAN CLAY	CL	2300	53.3	2.31739
68	3	LEAN CLAY	CL	2200	73.3	3.33182
69	3	LEAN CLAY	CL	2200	66.7	3.03182
70	3	LEAN CLAY	CL	2200	73.3	3.33182
71	3	LEAN CLAY	CL	2500	33.3	1.33200
72	3	LEAN CLAY	CL	2800	80.0	2.85714
73	3	LEAN CLAY	CL	3800	80.0	2.10526
74	3	LEAN CLAY	CL	2800	100.0	3.57143
75	3	LEAN CLAY	CL	2800	93.3	3.33214
76	3	LEAN CLAY	CL	2200	93.3	4.24091
77	3	LEAN CLAY	CL	2000	80.0	4.00000
78	3	LEAN CLAY W/SAND	CL	2000	80.0	4.00000
79	3	LEAN CLAY W/SAND	CL	2200	80.0	3.63636
80	3	LEAN CLAY	CL	2400	73.3	3.05417
81	3	LEAN CLAY	CL	2400	80.0	3.33333
82	3	LEAN CLAY	CL	2400	80.0	3.33333
83	3	LEAN CLAY	CL	2200	73.3	3.33182
84	3	LEAN CLAY	CL	2200	60.0	2.72727
85	3	LEAN CLAY	CL	2200	86.7	3.94091
86	3	LEAN CLAY	CL	1900	73.3	3.85789
87	3	LEAN CLAY	CL	2100	80.0	3.80952
88	3	LEAN CLAY	CL	2400	86.7	3.61250
89	3	LEAN CLAY	CL	2200	86.7	3.94091
90	3	LEAN CLAY	CL	2200	93.3	4.24091
91	3	LEAN CLAY	CL	2200	66.7	3.03182
92	3	LEAN CLAY	CL	2000	53.3	2.66500
93	3	LEAN CLAY	CL	1900	26.7	1.40526
94	3	LEAN CLAY	CL	2000	46.7	2.33500
95	3	LEAN CLAY	CL	1900	40.0	2.10526
96	3	LEAN CLAY W/SAND	CL	1800	40.0	2.22222
97	3	LEAN CLAY W/SAND	CL	1800	46.7	2.59444
98	3	LEAN CLAY W/SAND	CL	1800	73.3	4.07222
99	3	LEAN CLAY W/SAND	CL	1800	40.0	2.22222
100	3	LEAN CLAY W/SAND	CL	1900	26.7	1.40526
101	3	SANDY LEAN CLAY	CL	1900	53.3	2.80526
102	3	SANDY LEAN CLAY	CL	1800	26.7	1.48333
103	3	SANDY LEAN CLAY	CL	1400	26.7	1.90714
104	3	SANDY LEAN CLAY	CL	1500	26.7	1.78000
105	3	SANDY LEAN CLAY	CL	1800	40.0	2.22222
106	3	SANDY LEAN CLAY	CL	1700	60.0	3.52941
107	3	SANDY LEAN CLAY	CL	1400	46.7	3.33571
108	3	SANDY LEAN CLAY	CL	1000	53.3	5.33000

TABLE E7, TULSA, BORING T7 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
109	3	SANDY LEAN CLAY	CL	1100	53.3	4.8455
110	3	SANDY LEAN CLAY	CL	1000	46.7	4.6700
111	3	SANDY LEAN CLAY	CL	1000	46.7	4.6700
112	3	LEAN CLAY W/SAND	CL	1000	53.3	5.3300
113	3	LEAN CLAY W/SAND	CL	1000	46.7	4.6700
114	3	LEAN CLAY W/SAND	CL	1000	46.7	4.6700
115	3	LEAN CLAY W/SAND	CL	1000	40.0	4.0000
116	3	LEAN CLAY W/SAND	CL	800	33.3	4.1625
117	3	LEAN CLAY W/SAND	CL	700	20.0	2.8571
118	3	LEAN CLAY W/SAND	CL	600	53.3	8.8833
119	3	LEAN CLAY W/SAND	CL	600	13.3	2.2167
120	3	LEAN CLAY W/SAND	CL	1000	13.3	1.3300
121	3	SANDY LEAN CLAY	CL	2400	80.0	3.3333
122	3	SANDY LEAN CLAY	CL	1000	33.3	3.3300
123	3	SANDY LEAN CLAY	CL	1800	26.7	1.4833
124	3	SILTY, CLAYEY SAND	SC-SM	1000	66.7	6.6700
125	3	SILTY, CLAYEY SAND	SC-SM	1400	26.7	1.9071
126	3	SILTY, CLAYEY SAND	SC-SM	1800	20.0	1.1111
127	3	SILTY, CLAYEY SAND	SC-SM	2000	53.3	2.6650
128	3	SILTY, CLAYEY SAND	SC-SM	1900	60.0	3.1579
129	3	SILTY, CLAYEY SAND	SC-SM	1000	53.3	5.3300
130	3	SANDY LEAN CLAY	CL	900	40.0	4.4444
131	3	SANDY LEAN CLAY	CL	1000	40.0	4.0000
132	3	SANDY LEAN CLAY	CL	1200	26.7	2.2250
133	3	SANDY LEAN CLAY	CL	900	66.7	7.4111
134	3	SANDY LEAN CLAY	CL	1400	26.7	1.9071
135	3	SILTY SAND	SM	4800	66.7	1.3896
136	3	SANDY LEAN CLAY	CL	6000	93.3	1.5550
137	3	SANDY LEAN CLAY	CL	5000	13.3	0.2660
138	3	SILTY SAND	SM	8400	106.7	1.2702
139	3	SILTY SAND	SM	7000	120.0	1.7143
140	3	SILTY SAND	SM	6400	240.0	3.7500
141	3	SILTY SAND	SM	8400	106.7	1.2702
142	3	SILTY SAND W/GRAVE	SM	10400	200.0	1.9231
143	3	SILTY SAN W/GRAVEL	SM	4800	533.3	11.1104

TABLE E8, TULSA, BORING T2

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	17	LEAN CLAY	CL	2600	153.3	5.89615
2	17	LEAN CLAY	CL	2400	133.3	5.55417
3	17	LEAN CLAY	CL	1800	133.3	7.40556
4	17	LEAN CLAY	CL	1800	86.7	4.81667
5	17	FAT CLAY	CH	1800	106.7	5.92778
6	17	FAT CLAY	CH	1700	106.7	6.27647
7	17	FAT CLAY	CH	1400	106.7	7.62143
8	17	FAT CLAY	CH	1600	100.0	6.25000
9	17	FAT CLAY	CH	1600	93.3	5.83125
10	17	FAT CLAY	CH	1700	106.7	6.27647
11	17	FAT CLAY	CH	1700	106.7	6.27647
12	17	FAT CLAY	CH	1600	93.3	5.83125
13	17	FAT CLAY	CH	1600	80.0	5.00000
14	17	FAT CLAY	CH	1800	86.7	4.81667
15	17	FAT CLAY	CH	1800	86.7	4.81667
16	17	FAT CLAY	CH	1800	106.7	5.92778
17	17	FAT CLAY	CH	1800	106.7	5.92778
18	17	FAT CLAY	CH	1800	80.0	4.44444
19	17	FAT CLAY	CH	2000	66.7	3.33500
20	17	FAT CLAY	CH	2200	80.0	3.63636
21	17	LEAN CLAY	CL	2200	66.7	3.03182
22	17	LEAN CLAY	CL	2200	60.0	2.72727
23	17	FAT CLAY	CH	2400	86.7	3.61250
24	17	FAT CLAY	CH	2400	80.0	3.33333
25	17	FAT CLAY	CH	2300	80.0	3.47826
26	17	FAT CLAY	CH	2400	80.0	3.33333
27	17	FAT CLAY	CH	2600	80.0	3.07692
28	17	FAT CLAY	CH	2600	80.0	3.07692
29	17	FAT CLAY	CH	2500	80.0	3.20000
30	17	FAT CLAY	CH	2400	80.0	3.33333
31	17	FAT CLAY	CH	2600	73.3	2.81923
32	17	FAT CLAY	CH	2800	66.7	2.38214
33	17	FAT CLAY	CH	2800	66.7	2.38214
34	17	FAT CLAY	CH	2600	66.7	2.56538
35	17	LEAN CLAY	CL	2500	80.0	3.20000
36	17	LEAN CLAY	CL	2400	73.3	3.05417
37	17	LEAN CLAY	CL	2500	66.7	2.66800
38	17	LEAN CLAY	CL	3100	126.7	4.08710
39	17	LEAN CLAY	CL	3200	120.0	3.75000
40	17	LEAN CLAY	CL	3100	133.3	4.30000
41	17	LEAN CLAY	CL	2800	86.7	3.09643
42	17	LEAN CLAY	CL	2300	93.3	4.05652
43	17	LEAN CLAY	CL	2900	106.7	3.67931
44	17	LEAN CLAY	CL	2800	106.7	3.81071
45	17	LEAN CLAY	CL	2600	106.7	4.10385
46	17	LEAN CLAY W/SAND	CL	2600	93.3	3.58846
47	17	LEAN CLAY W/SAND	CL	2300	86.7	3.76957
48	17	LEAN CLAY W/SAND	CL	2400	73.3	3.05417
49	17	LEAN CLAY W/SAND	CL	2500	93.3	3.73200
50	17	LEAN CLAY W/SAND	CL	2100	100.0	4.76190
51	17	LEAN CLAY W/SAND	CL	2400	86.7	3.61250
52	17	LEAN CLAY W/SAND	CL	2300	93.3	4.05652
53	17	LEAN CLAY W/SAND	CL	2400	86.7	3.61250
54	17	LEAN CLAY W/SAND	CL	2400	80.0	3.33333

TABLE E8, TULSA, BORING T2 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	17	LEAN CLAY W/SAND	CL	2400	106.7	4.44583
56	17	LEAN CLAY W/SAND	CL	2200	106.7	4.85000
57	17	LEAN CLAY	CL	2000	106.7	5.33500
58	17	LEAN CLAY	CL	2000	93.3	4.66500
59	17	LEAN CLAY	CL	2200	73.3	3.33182
60	17	LEAN CLAY W/SAND	CL	2200	93.3	4.24091
61	17	LEAN CLAY W/SAND	CL	2300	120.0	5.21739
62	17	LEAN CLAY	CL	2200	93.3	4.24091
63	17	LEAN CLAY	CL	2200	106.7	4.85000
64	17	LEAN CLAY	CL	2800	86.7	3.09643
65	17	LEAN CLAY	CL	3000	106.7	3.55667
66	17	LEAN CLAY	CL	3300	106.7	3.23333
67	17	LEAN CLAY	CL	3100	100.0	3.22581
68	17	LEAN CLAY	CL	3200	100.0	3.12500
69	17	LEAN CLAY	CL	3200	93.3	2.91562
70	17	LEAN CLAY	CL	3300	106.7	3.23333
71	17	LEAN CLAY	CL	3200	106.7	3.33437
72	17	LEAN CLAY	CL	2400	66.7	2.77917
73	17	LEAN CLAY W/SAND	CL	2200	80.0	3.63636
74	17	LEAN CLAY W/SAND	CL	2200	66.7	3.03182
75	17	LEAN CLAY W/SAND	CL	2000	53.3	2.66500

TABLE E9, COLLINSVILLE, BORING C1

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	18	FAT CLAY	CH	800	0.0	0.0000
2	18	FAT CLAY	CH	2000	53.3	2.6650
3	18	FAT CLAY	CH	3000	66.7	2.2233
4	18	FAT CLAY	CH	3800	66.7	1.7553
5	18	FAT CLAY	CH	4400	53.3	1.2114
6	18	FAT CLAY	CH	3600	86.7	2.4083
7	18	FAT CLAY	CH	2400	120.0	5.0000
8	18	FAT CLAY	CH	1600	133.3	8.3312
9	18	FAT CLAY	CH	1900	26.7	1.4053
10	18	FAT CLAY W/SAND	CH	1200	53.3	4.4417
11	18	FAT CLAY W/SAND	CH	1200	53.3	4.4417
12	18	FAT CLAY W/SAND	CH	1500	66.7	4.4467
13	18	FAT CLAY W/SAND	CH	1700	100.0	5.8824
14	18	FAT CLAY W/SAND	CH	2000	133.3	6.6650
15	18	SANDY LEAN CLAY	CL	2200	120.0	5.4545
16	18	SANDY LEAN CLAY	CL	2100	106.7	5.0810
17	18	SANDY LEAN CLAY	CL	2000	106.7	5.3350
18	18	SANDY LEAN CLAY	CL	2000	86.7	4.3350
19	18	SANDY LEAN CLAY	CL	2200	80.0	3.6364
20	18	SANDY LEAN CLAY	CL	2500	86.7	3.4680
21	18	SANDY LEAN CLAY	CL	3200	86.7	2.7094
22	18	CLAYEY SAND	SC	3800	73.3	1.9289
23	18	CLAYEY SAND	SC	4000	106.7	2.6675
24	18	CLAYEY SAND	SC	4400	86.7	1.9705
25	18	CLAYEY SAND	SC	4000	133.3	3.3325
26	18	SILTY, CLAYEY SAND	SC-SM	6200	386.7	6.2371
27	18	CLAYEY SAND	SC	12400	213.3	1.7202
28	18	CLAYEY SAND	SC	13800	413.3	2.9949
29	18	SILTY, CLAYEY SAND	SC-SM	18000	266.7	1.4817
30	18	SILTY, CLAYEY SAND	SC-SM	15600	160.0	1.0256
31	18	SILTY SAND	SM	14000	533.3	3.8093
32	18	SILTY SAND	SM	12400	1306.7	10.5379

TABLE E10, COLLINSVILLE, BORING C2

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	19	LEAN CLAY	CL	2200	160.0	7.27273
2	19	LEAN CLAY	CL	4800	80.0	1.66667
3	19	LEAN CLAY	CL	2400	53.3	2.22083
4	19	LEAN CLAY	CL	4800	53.3	1.11042
5	19	LEAN CLAY	CL	5400	86.7	1.60556
6	19	LEAN CLAY	CL	5600	133.3	2.38036
7	19	LEAN CLAY	CL	5500	120.0	2.18182
8	19	LEAN CLAY	CL	5900	133.3	2.25932
9	19	LEAN CLAY	CL	5800	153.3	2.64310
10	19	LEAN CLAY	CL	5800	146.7	2.52931
11	19	LEAN CLAY	CL	6400	253.3	3.95781
12	19	LEAN CLAY	CL	6600	220.0	3.33333
13	19	LEAN CLAY	CL	7800	186.7	2.39359
14	19	LEAN CLAY	CL	7400	180.0	2.43243
15	19	LEAN CLAY	CL	8400	146.7	1.74643
16	19	LEAN CLAY	CL	8200	206.7	2.52073
17	19	LEAN CLAY	CL	7400	173.3	2.34189
18	19	LEAN CLAY	CL	5700	126.7	2.22281
19	19	LEAN CLAY	CL	5400	120.0	2.22222
20	19	LEAN CLAY	CL	4800	153.3	3.19375
21	19	LEAN CLAY	CL	3600	146.7	4.07500
22	19	LEAN CLAY	CL	3200	173.3	5.41562
23	19	LEAN CLAY	CL	3000	173.3	5.77667
24	19	FAT CLAY	CH	2600	173.3	6.66538
25	19	FAT CLAY	CH	2600	180.0	6.92308
26	19	FAT CLAY	CH	2000	173.3	8.66500
27	19	FAT CLAY	CH	2000	133.3	6.66500
28	19	FAT CLAY	CH	2100	113.3	5.39524
29	19	FAT CLAY	CH	2300	93.3	4.05652
30	19	FAT CLAY	CH	2400	80.0	3.33333
31	19	FAT CLAY	CH	2400	80.0	3.33333
32	19	FAT CLAY	CH	2200	80.0	3.63636
33	19	FAT CLAY	CH	2200	60.0	2.72727
34	19	FAT CLAY	CH	2400	60.0	2.50000
35	19	LEAN CLAY	CL	2500	60.0	2.40000
36	19	LEAN CLAY	CL	2200	46.7	2.12273
37	19	LEAN CLAY	CL	1900	46.7	2.45789
38	19	LEAN CLAY	CL	1700	46.7	2.74706
39	19	LEAN CLAY	CL	1700	40.0	2.35294
40	19	LEAN CLAY	CL	1500	33.3	2.22000
41	19	LEAN CLAY	CL	1500	26.7	1.78000
42	19	LEAN CLAY	CL	1600	26.7	1.66875
43	19	LEAN CLAY	CL	1400	26.7	1.90714
44	19	LEAN CLAY	CL	1400	33.3	2.37857
45	19	LEAN CLAY	CL	1400	26.7	1.90714
46	19	LEAN CLAY	CL	1300	26.7	2.05385
47	19	LEAN CLAY	CL	1200	26.7	2.22500
48	19	LEAN CLAY	CL	1200	26.7	2.22500
49	19	LEAN CLAY	CL	1200	20.0	1.66667
50	19	LEAN CLAY	CL	1100	26.7	2.42727
51	19	LEAN CLAY	CL	1200	26.7	2.22500
52	19	LEAN CLAY	CL	1200	26.7	2.22500
53	19	LEAN CLAY	CL	1200	26.7	2.22500
54	19	LEAN CLAY	CL	1200	33.3	2.77500

TABLE E10, COLLINSVILLE, BORING C2 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	19	LEAN CLAY	CL	1400	20.0	1.42857
56	19	LEAN CLAY	CL	1600	40.0	2.50000
57	19	LEAN CLAY	CL	1500	40.0	2.66667
58	19	LEAN CLAY	CL	1000	26.7	2.67000
59	19	LEAN CLAY	CL	900	26.7	2.96667
60	19	LEAN CLAY	CL	800	20.0	2.50000
61	19	LEAN CLAY	CL	800	26.7	3.33750
62	19	LEAN CLAY	CL	800	26.7	3.33750
63	19	LEAN CLAY	CL	800	26.7	3.33750
64	19	LEAN CLAY	CL	800	20.0	2.50000
65	19	LEAN CLAY	CL	800	26.7	3.33750
66	19	LEAN CLAY	CL	900	13.3	1.47778
67	19	LEAN CLAY	CL	800	26.7	3.33750
68	19	LEAN CLAY	CL	800	13.3	1.66250
69	19	LEAN CLAY	CL	800	20.0	2.50000
70	19	LEAN CLAY W/SAND	CL	800	0.0	0.00000
71	19	LEAN CLAY W/SAND	CL	800	20.0	2.50000
72	19	LEAN CLAY	CL	1000	13.3	1.33000
73	19	LEAN CLAY	CL	900	13.3	1.47778
74	19	LEAN CLAY W/SAND	CL	1100	33.3	3.02727
75	19	LEAN CLAY W/SAND	CL	1000	33.3	3.33000
76	19	LEAN CLAY W/SAND	CL	1200	33.3	2.77500
77	19	LEAN CLAY W/SAND	CL	1300	40.0	3.07692
78	19	LEAN CLAY W/SAND	CL	1300	40.0	3.07692
79	19	LEAN CLAY W/SAND	CL	1200	40.0	3.33333
80	19	LEAN CLAY W/SAND	CL	1200	26.7	2.22500
81	19	LEAN CLAY W/SAND	CL	1200	40.0	3.33333
82	19	LEAN CLAY	CL	1000	26.7	2.67000
83	19	LEAN CLAY	CL	1000	20.0	2.00000
84	19	LEAN CLAY W/SAND	CL	800	26.7	3.33750
85	19	LEAN CLAY W/SAND	CL	1200	33.3	2.77500
86	19	LEAN CLAY W/SAND	CL	1000	26.7	2.67000
87	19	LEAN CLAY W/SAND	CL	1200	60.0	5.00000
88	19	SANDY LEAN CLAY	CL	1400	13.3	0.95000
89	19	SANDY LEAN CLAY	CL	900	6.7	0.74444
90	19	LEAN CLAY W/SAND	CL	1200	26.7	2.22500
91	19	LEAN CLAY W/SAND	CL	1700	6.7	0.39412
92	19	LEAN CLAY W/SAND	CL	1000	20.0	2.00000
93	19	LEAN CLAY W/SAND	CL	1500	13.3	0.88667
94	19	LEAN CLAY W/SAND	CL	900	20.0	2.22222
95	19	LEAN CLAY W/SAND	CL	1200	26.7	2.22500
96	19	LEAN CLAY W/SAND	CL	1000	33.3	3.33000
97	19	SANDY LEAN CLAY	CL	800	0.0	0.00000
98	19	SANDY LEAN CLAY	CL	1600	40.0	2.50000
99	19	LEAN CLAY W/SAND	CL	1600	40.0	2.50000
100	19	LEAN CLAY W/SAND	CL	1000	20.0	2.00000
101	19	LEAN CLAY W/SAND	CL	1200	26.7	2.22500
102	19	LEAN CLAY W/SAND	CL	1000	26.7	2.67000
103	19	LEAN CLAY W/SAND	CL	800	26.7	3.33750
104	19	SILTY SAND	SM	900	26.7	2.96667
105	19	SILTY SAND	SM	1600	26.7	1.66875
106	19	SANDY LEAN CLAY	CL	4000	40.0	1.00000
107	19	SANDY LEAN CLAY	CL	6000	186.7	3.11167
108	19	SILTY, CLAYEY SAND	SC-SM	7800	0.0	0.00000

TABLE E10, COLLINSVILLE, BORING C2 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
109	19	SILTY, CLAYEY SAND	SC-SM	3600	60.0	1.66667
110	19	CLAYEY SAND	SC	5200	33.3	0.64038
111	19	CLAYEY SAND	SC	1600	6.7	0.41875
112	19	SANDY LEAN CLAY	CL	1800	0.0	0.00000
113	19	SANDY LEAN CLAY	CL	2000	0.0	0.00000
114	19	SANDY LEAN CLAY	CL	2200	40.0	1.81818
115	19	LEAN CLAY W/SAND	CL	2600	20.0	0.76923
116	19	LEAN CLAY W/SAND	CL	2000	40.0	2.00000
117	19	SANDY LEAN CLAY	CL	2000	40.0	2.00000
118	19	SANDY LEAN CLAY	CL	1800	160.0	8.88889
119	19	SANDY SILTY CLAY	CL-ML	2200	53.3	2.42273
120	19	SANDY SILTY CLAY	CL-ML	3600	0.0	0.00000
121	19	SANDY SILTY CLAY	CL-ML	5200	26.7	0.51346
122	19	SANDY SILTY CLAY	CL-ML	8200	226.7	2.76463
123	19	SANDY SILTY CLAY	CL-ML	4400	0.0	0.00000

TABLE E11, BIXBY, BORING B1

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	16	LEAN CLAY	CL	1800	0.0	0.0000
2	16	LEAN CLAY	CL	6800	40.0	0.5882
3	16	LEAN CLAY	CL	7000	66.7	0.9529
4	16	SANDY LEAN CLAY	CL	6600	66.7	1.0106
5	16	SANDY LEAN CLAY	CL	6000	66.7	1.1117
6	16	LEAN CLAY W/SAND	CL	5200	60.0	1.1538
7	16	LEAN CLAY W/SAND	CL	4800	60.0	1.2500
8	16	SILTY CLAY W/ SAND	CL-ML	4600	66.7	1.4500
9	16	SILTY CLAY W/SAND	CL-ML	3900	40.0	1.0256
10	16	SILTY CLAY W/SAND	CL-ML	3600	60.0	1.6667
11	16	SANDY SILT	ML	3800	46.7	1.2289
12	16	SANDY SILT	ML	2800	46.7	1.6679
13	16	SILTYCLAY W/SAND	CL-ML	2600	46.7	1.7962
14	16	SILTY CLAY W/SAND	CL-ML	2000	66.7	3.3350
15	16	SILTYCLAY W/SAND	CL-ML	1600	73.3	4.5812
16	16	LEAN CLAY W/SAND	CL	1200	26.7	2.2250
17	16	LEAN CLAY W/SAND	CL	1200	6.7	0.5583
18	16	LEAN CLAY W/SAND	CL	1400	80.0	5.7143
19	16	LEAN CLAY W/SAND	CL	1600	86.7	5.4187
20	16	SANDY LEAN CLAY	CL	400	46.7	11.6750
21	16	SANDY LEAN CLAY	CL	400	53.3	13.3250
22	16	LEAN CLAY W/SAND	CL	1200	53.3	4.4417
23	16	LEAN CLAY W/SAND	CL	1200	40.0	3.3333
24	16	SANDY LEAN CLAY	CL	1600	60.0	3.7500
25	16	SANDY LEAN CLAY	CL	1800	73.3	4.0722
26	16	SANDY LEAN CLAY	CL	1800	60.0	3.3333
27	16	SANDY LEAN CLAY	CL	2100	73.3	3.4905
28	16	SANDY LEAN CLAY	CL	2200	66.7	3.0318
29	16	SANDY LEAN CLAY	CL	2000	73.3	3.6650
30	16	SANDY LEAN CLAY	CL	2000	66.7	3.3350
31	16	SANDY LEAN CLAY	CL	1900	66.7	3.5105
32	16	SANDY LEAN CLAY	CL	2100	73.3	3.4905
33	16	SANDY LEAN CLAY	CL	2000	66.7	3.3350
34	16	SANDY LEAN CLAY	CL	2000	60.0	3.0000
35	16	SANDY LEAN CLAY	CL	1800	46.7	2.5944
36	16	SANDY LEAN CLAY	CL	1500	40.0	2.6667
37	16	SANDY LEAN CLAY	CL	1300	40.0	3.0769
38	16	SANDY LEAN CLAY	CL	1000	33.3	3.3300
39	16	SANDY LEAN CLAY	CL	1000	40.0	4.0000
40	16	SANDY LEAN CLAY	CL	1000	26.7	2.6700
41	16	SANDY LEAN CLAY	CL	1000	33.3	3.3300
42	16	SANDY LEAN CLAY	CL	1200	33.3	2.7750
43	16	LEAN CLAY W/SAND	CL	1200	33.3	2.7750
44	16	LEAN CLAY W/SAND	CL	1300	26.7	2.0538
45	16	LEAN CLAY W/SAND	CL	1200	26.7	2.2250
46	16	LEAN CLAY W/SAND	CL	1200	26.7	2.2250
47	16	LEAN CLAY W/SAND	CL	1000	46.7	4.6700
48	16	LEAN CLAY W/SAND	CL	1000	66.7	6.6700
49	16	LEAN CLAY W/SAND	CL	900	13.3	1.4778
50	16	LEAN CLAY W/SAND	CL	1200	40.0	3.3333
51	16	LEAN CLAY W/SAND	CL	1500	53.3	3.5533
52	16	SANDY LEAN CLAY	CL	1100	33.3	3.0273
53	16	SANDY LEAN CLAY	CL	1500	53.3	3.5533
54	16	SANDY SILTY CLAY	CL-ML	1700	40.0	2.3529

TABLE E11, BIXBY, BORING B1 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	16	SANDY SILTY CLAY	CL-ML	1500	80.0	5.333
56	16	SANDY LEAN CLAY	CL	1400	33.3	2.379
57	16	SANDY LEAN CLAY	CL	1600	46.7	2.919
58	16	SANDY LEAN CLAY	CL	1900	33.3	1.753
59	16	SANDY LEAN CLAY	CL	1700	80.0	4.706
60	16	SANDY LEAN CLAY	CL	1800	213.3	11.850
61	16	SANDY LEAN CLAY	CL	1600	266.7	16.669
62	16	SANDY LEAN CLAY	CL	3200	133.3	4.166
63	16	LEAN CLAY	CL	1400	1733.3	123.807

TABLE E12, ROLAND, BORING R1

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
1	2	FAT CLAY	CH	1000	53.3	5.3300
2	2	FAT CLAY	CH	600	20.0	3.3333
3	2	FAT CLAY	CH	800	66.7	8.3375
4	2	FAT CLAY	CH	1100	86.7	7.8818
5	2	FAT CLAY	CH	600	26.7	4.4500
6	2	FAT CLAY	CH	1500	53.3	3.5533
7	2	FAT CLAY	CH	800	40.0	5.0000
8	2	FAT CLAY	CH	200	33.3	16.6500
9	2	FAT CLAY	CH	600	26.7	4.4500
10	2	FAT CLAY	CH	500	46.7	9.3400
11	2	FAT CLAY	CH	800	40.0	5.0000
12	2	FAT CLAY	CH	800	53.3	6.6625
13	2	FAT CLAY	CH	1000	46.7	4.6700
14	2	FAT CLAY	CH	1000	46.7	4.6700
15	2	FAT CLAY	CH	1200	33.3	2.7750
16	2	FAT CLAY	CH	1200	40.0	3.3333
17	2	FAT CLAY	CH	1500	53.3	3.5533
18	2	FAT CLAY	CH	1400	53.3	3.8071
19	2	FAT CLAY	CH	1500	40.0	2.6667
20	2	FAT CLAY	CH	1500	53.3	3.5533
21	2	FAT CLAY	CH	1800	53.3	2.9611
22	2	FAT CLAY	CH	1600	53.3	3.3312
23	2	FAT CLAY	CH	1600	60.0	3.7500
24	2	FAT CLAY	CH	1600	53.3	3.3312
25	2	FAT CLAY	CH	1600	46.7	2.9187
26	2	FAT CLAY	CH	1600	46.7	2.9187
27	2	FAT CLAY	CH	1800	53.3	2.9611
28	2	FAT CLAY	CH	1700	60.0	3.5294
29	2	FAT CLAY	CH	1800	66.7	3.7056
30	2	FAT CLAY	CH	1700	66.7	3.9235
31	2	FAT CLAY	CH	1800	60.0	3.3333
32	2	FAT CLAY	CH	1800	53.3	2.9611
33	2	FAT CLAY	CH	1600	120.0	7.5000
34	2	FAT CLAY	CH	1800	80.0	4.4444
35	2	FAT CLAY	CH	1000	80.0	8.0000
36	2	FAT CLAY	CH	1800	93.3	5.1833
37	2	FAT CLAY	CH	1800	86.7	4.8167
38	2	FAT CLAY	CH	1800	93.3	5.1833
39	2	FAT CLAY	CH	1900	93.3	4.9105
40	2	FAT CLAY	CH	1800	46.7	2.5944
41	2	FAT CLAY	CH	1900	53.3	2.8053
42	2	FAT CLAY	CH	1800	66.7	3.7056
43	2	FAT CLAY	CH	1800	73.3	4.0722
44	2	FAT CLAY	CH	1900	46.7	2.4579
45	2	FAT CLAY	CH	1800	53.3	2.9611
46	2	FAT CLAY	CH	1900	46.7	2.4579
47	2	FAT CLAY	CH	1900	66.7	3.5105
48	2	FAT CLAY	CH	2000	66.7	3.3350
49	2	FAT CLAY	CH	1900	60.0	3.1579
50	2	FAT CLAY	CH	2000	66.7	3.3350
51	2	FAT CLAY	CH	2400	60.0	2.5000
52	2	FAT CLAY	CH	2400	106.7	4.4458
53	2	FAT CLAY	CH	2400	80.0	3.3333
54	2	FAT CLAY	CH	2200	66.7	3.0318

TABLE E12, ROLAND, BORING R1 (CONTINUED)

OBS	LOCATION	SOIL TYPE	USC	CR	LF	FR
55	2	FAT CLAY	CH	2400	93.3	3.8875
56	2	FAT CLAY	CH	2500	93.3	3.7320
57	2	FAT CLAY	CH	2200	66.7	3.0318
58	2	FAT CLAY	CH	2200	80.0	3.6364
59	2	FAT CLAY	CH	2300	80.0	3.4783
60	2	FAT CLAY	CH	2400	73.3	3.0542
61	2	FAT CLAY	CH	2400	100.0	4.1667
62	2	FAT CLAY	CH	2200	80.0	3.6364
63	2	FAT CLAY	CH	1900	93.3	4.9105
64	2	FAT CLAY	CH	2000	66.7	3.3350
65	2	FAT CLAY	CH	1900	66.7	3.5105
66	2	FAT CLAY	CH	1800	40.0	2.2222
67	2	FAT CLAY	CH	1800	40.0	2.2222
68	2	FAT CLAY	CH	1400	53.3	3.8071
69	2	FAT CLAY	CH	1200	40.0	3.3333
70	2	FAT CLAY	CH	1000	40.0	4.0000
71	2	FAT CLAY	CH	1000	46.7	4.6700
72	2	FAT CLAY	CH	1000	53.3	5.3300
73	2	FAT CLAY	CH	800	60.0	7.5000
74	2	FAT CLAY	CH	800	40.0	5.0000
75	2	FAT CLAY	CH	600	53.3	8.8833
76	2	FAT CLAY	CH	600	60.0	10.0000
77	2	FAT CLAY	CH	600	53.3	8.8833
78	2	FAT CLAY	CH	600	66.7	11.1167
79	2	FAT CLAY	CH	800	53.3	6.6625
80	2	FAT CLAY	CH	800	53.3	6.6625
81	2	FAT CLAY	CH	1000	173.3	17.3300
82	2	FAT CLAY	CH	1000	26.7	2.6700
83	2	FAT CLAY	CH	2400	153.3	6.3875
84	2	FAT CLAY	CH	3800	126.7	3.3342
85	2	FAT CLAY	CH	3600	106.7	2.9639
86	2	FAT CLAY	CH	6600	160.0	2.4242
87	2	FAT CLAY	CH	7200	186.7	2.5931
88	2	LEAN CLAY	CL	7000	160.0	2.2857
89	2	LEAN CLAY	CL	8000	293.3	3.6662
90	2	LEAN CLAY	CL	10000	466.7	4.6670
91	2	LEAN CLAY	CL	11400	200.0	1.7544

APPENDIX F

COMPARATIVE CPT DATA

Table F-1

CPT 11 Wagner

Depth		① C (N×1000)	② F+C (N×1000)	③ F (N×1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm²) ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
.43		2.3	3.4	1.0	230	6.67	2.90
.76		2.9	3.6	1.5	290	10.00	3.45
1.08		3.0	4.0	2.1	300	14.00	4.67
1.41		3.2	4.7	1.9	320	12.67	3.96
1.74		3.3	5.4	2.8	330	18.67	5.66
2.07		4.7	6.6	3.8	470	25.33	5.39
2.40		3.8	6.6	3.1	380	20.67	5.44
2.76		3.5	7.3	3.1	350	20.67	5.91
3.03		3.7	6.8	3.1	370	20.67	5.59
3.38		3.7	6.8	3.1	370	20.67	5.59
3.71		3.4	6.5	3.3	340	22.00	6.47
4.04		3.3	6.4	3.2	330	21.33	6.46
4.37		2.8	6.1	3.2	280	21.33	7.62
4.69		2.9	6.1	3.1	290	20.67	7.13
5.02		2.8	6.0	2.9	280	19.33	6.90
5.35		2.5	5.6	2.8	250	18.67	7.47
5.68		2.3	5.2	2.6	230	17.33	7.53
6.01		2.0	4.8	1.5	200	10.00	5.00
6.33		1.9	4.5	1.5	190	10.00	5.26
6.66		1.8	3.3	1.3	180	8.67	4.82
1.99		1.6	3.1	1.1	160	7.33	4.58
7.32		1.5	2.8	1.2	150	8.00	5.33
7.65		1.5	2.6	1.3	150	8.67	5.78
7.97		1.6	2.8	1.3	160	8.67	5.42
8.30		1.7	3.0	1.1	170	7.33	4.31
8.63		1.9	3.2	1.2	190	8.00	4.21
8.96		1.9	3.0	1.1	190	7.33	3.86
9.29		1.8	3.0	1.2	180	8.00	4.44
9.61		1.8	2.9	1.2	180	8.00	4.44
9.94		1.8	3.0	1.2	180	8.00	4.44
10.27		1.9	3.1	1.5	190	10.00	5.26
10.60		1.8	3.0	1.5	180	10.00	5.56
10.93		1.8	3.3	1.5	180	10.00	5.56
11.25		2.2	3.7	1.9	220	12.67	5.76
11.58		2.1	3.6	1.8	210	12.00	5.71
11.71		2.1	4.0	2.0	210	13.33	6.35
12.24		2.4	4.2	2.0	240	13.33	5.55
12.57		2.3	4.3	2.0	230	13.33	5.80
12.90		2.3	4.3	2.0	230	13.33	5.80
13.22		2.5	4.5	2.0	250	13.33	5.33
13.55		2.3	4.3	2.1	230	13.33	5.80
13.88		2.4	4.4	1.7	240	14.00	5.83
14.21		2.2	4.3	1.8	220	11.33	5.15

Table F-1 Cont.'

Depth		① C	② F·C	③ F	④ CR	⑤ LF	Friction Ratio
ft.	m.	(N×1000)	(N×1000)	(N×1000) ② − ①	(N/cm²) ① ÷ 10 × 1000	(N/cm²) ③ ÷ 150 × 1000	⑤ ÷ ④ × 100
14.54		2.6	4.3	1.5	260	12.00	4.62
14.86		2.5	4.3	1.8	250	10.00	4.00
15.19		2.4	3.9	1.5	240	12.00	5.00
15.52		2.1	3.9	1.8	210	10.00	4.76
15.85		2.2	3.7	1.9	220	12.00	5.45
16.18		2.0	3.8	2.0	200	12.67	6.34
16.50		2.4	4.3	1.8	240	13.33	5.55
16.83		2.5	4.5	1.7	250	12.00	4.80
17.16		3.0	4.8	2.2	300	11.33	3.78
17.49		3.2	4.7	2.9	320	14.67	4.58
17.82		3.0	5.2	2.5	300	19.33	6.44
18.14		2.8	5.7	2.7	280	16.67	5.95
18.47		2.6	5.1	2.2	260	18.00	6.92
18.80		2.5	5.2	2.0	250	14.67	5.87
19.13		3.0	5.2	1.5	300	13.33	4.43
19.46		2.8	4.8	1.8	280	10.00	3.57
19.78		2.8	4.3	1.7	280	12.00	4.29
20.11		2.0	3.8	1.3	200	11.33	5.67
20.44		1.9	3.6	0.8	190	8.67	4.56
20.67		1.7	3.0	0.9	170	5.33	3.14
21.10		1.7	2.5	0.9	170	6.00	3.53
21.43		1.4	2.3	1.0	140	6.00	4.29
21.75		1.5	2.4	0.7	150	6.67	4.43
22.08		2.0	3.0	1.2	200	4.67	2.34
22.41		2.5	3.2	1.3	250	8.00	3.20
22.74		2.5	3.7	1.0	250	8.67	3.47
23.07		2.0	3.3	0.8	200	6.67	3.34
23.39		2.3	3.3	0.3	230	5.33	2.32
23.72		1.7	2.5	0.8	170	2.00	1.18
24.05		1.7	2.0	1.0	170	5.33	3.14
24.38		1.0	1.8	0.8	100	6.67	6.67
24.71		.8	1.8	0.6	80	5.33	6.66
25.03		2.8	3.6	0.2	280	4.00	1.43
25.36		1.8	2.4	0.9	180	1.33	.74
25.69		2.1	2.3	1.9	210	6.00	2.86
26.02		2.4	3.3	2.0	240	12.67	5.28
26.35		2.1	4.0	4.1	210	13.33	6.35
26.67		2.2	4.2	6.0	220	27.33	12.42
27.00		1.7	5.8	4.6	170	40.00	2353
27.33		1.2	7.2	5.6	120	30.67	25.56
27.66		2.8	7.4	7.1	280	37.33	13.32
27.99		2.3	7.9	5.6	230	47.33	20.58
28.32		2.4	5.5	3.1	240	37.33	15.55

Table F-1 Cont.'

Depth		① C (N÷1000)	② F+C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
28.64		5.2	10.8	6.1	520	20.67	3.98
28.97		10.1	13.2	5.0	1010	40.67	4.03
29.30		11.9	18.0	6.0	1190	33.33	2.80
29.63		20.0	25.0	4.4	2000	40.00	2.00
29.96		16.0	22.0	6.9	1600	29.33	1.83
30.28		13.1	17.5	19.0	1310	4600	3.51
30.61		13.1	20.0	28.0	1310	126.67	9.67
30.94		29.0	48.0		2900	186.67	6.44
31.27		34.0	62.0		3400		

Table F-2

Depth		① C	② F • C	③ F	④ CR	⑤ LF	Friction
ft.	m.	(N•1000)	(N•1000)	(N•1000) ② - ①	(N/cm²) ① ÷ 10 • 1000	(N/cm² ③ ÷ 150 • 1000	Ratio ⑤ ÷ ④ • 100
0.15		1.0		0.2	100	1.33	1.33
0.48		1.8		1.2	180	8.00	4.44
0.81		1.8	2.0	1.6	180	10.67	5.93
1.13		1.6	2.8	1.6	160	10.67	6.67
1.46		1.6	3.2	1.8	160	12.00	7.50
1.79		1.6	3.2	1.7	160	11.33	7.08
2.12		1.4	3.2	1.6	140	10.67	7.62
2.45		1.4	3.1	0.8	140	5.33	3.81
2.77		1.2	2.8	0.5	120	3.33	2.78
3.10		1.6	2.4	0.4	160	2.67	1.67
3.43		1.2	1.7	0.6	120	4.00	3.33
3.76		1.2	1.6	0.6	120	4.00	3.33
4.09		1.2	1.8	0.5	120	3.33	2.78
4.42		1.2	1.8	0.6	120	4.00	3.33
4.74		1.3	1.8	0.6	130	4.00	3.08
5.07		1.4	2.0	0.8	140	5.33	3.81
5.40		1.4	2.0	0.8	140	5.33	3.81
5.73		1.4	2.2	0.8	140	5.33	3.81
6.06		1.4	2.2	0.8	140	5.33	3.81
6.38		1.4	2.2	0.8	140	5.33	3.81
6.71		1.5	2.3	0.8	150	5.33	3.55
7.04		1.5	2.3	0.8	150	5.33	3.55
7.37		1.5	2.3	0.8	150	5.33	3.55
7.70		1.5	2.3	0.8	150	5.33	3.55
8.02		1.3	2.1	0.7	130	4.67	3.59
8.35		1.5	2.3	0.8	150	5.33	3.55
8.68		1.4	2.1	0.9	140	6.00	4.29
9.01		1.3	2.1	0.7	130	4.67	3.59
9.34		1.5	2.4	0.9	150	6.00	4.00
9.66		1.8	2.5	0.8	180	5.33	2.96
9.99		1.6	2.5	0.8	160	5.33	3.33
10.32		1.6	2.4	0.9	160	6.00	3.75
10.65		1.6	2.4	0.8	160	5.33	3.33
10.98		1.7	2.6	1.0	170	6.67	3.92
11.30		1.9	2.7	0.9	190	6.00	3.16
11.63		2.0	3.0	0.9	200	6.00	3.00
11.96		2.0	2.9	1.0	200	6.67	3.34
12.29		1.9	2.8	1.0	190	6.67	3.51
12.62		1.8	2.8	0.9	180	6.00	3.33
12.94		1.8	2.8	0.8	180	5.33	2.96
13.27		1.9	2.8	0.9	190	6.00	3.16
13.60		2.0	2.8	0.8	200	5.33	2.67
13.93		2.0	2.9	0.8	200	5.33	2.67

Table F-2 Cont.'

Depth		① C (N×1000)	② F·C (N×1000)	③ F (N×1000) ② - ①	④ CR (N/cm²) ① ÷ 10 × 1000	⑤ LF (N/cm² ③ ÷ 150 × 1000	Friction Ratio ⑤ ÷ ④ × 100
ft.	m.						
14.26		2.1	3.1	1.0	210	6.67	3.18
14.59		2.1	3.2	1.1	210	7.33	3.49
14.91		2.1	[illegible]	1.1	210	7.33	3.49
15.24		2.0	3.1	1.1	200	7.33	3.67
15.57		2.0	3.1	1.1	200	7.33	3.67
15.90		2.0	3.1	1.1	200	7.33	3.67
16.23		2.1	3.2	1.3	210	8.67	4.13
16.56		2.1	3.2	1.6	210	10.67	5.08
16.88		1.8	3.1	1.3	180	8.67	4.82
17.21		2.2	3.8	1.3	220	8.67	3.94
17.54		2.3	3.6	1.0	230	6.67	2.90
17.87		2.4	3.7	1.8	240	12.00	5.00
18.20		2.2	3.2	1.3	220	8.67	3.94
18.52		2.0	3.8	1.9	200	12.67	6.34
18.85		2.0	3.3	1.3	200	8.67	4.34
19.18		2.0	3.9	1.1	200	7.33	3.67
19.51		3.1	4.4	1.1	310	7.33	2.36
19.84		2.7	3.8	1.0	270	6.67	2.47
20.16		2.6	3.7	.7	260	4.67	1.80
20.49		2.4	3.4	1.1	240	7.33	3.05
20.82		2.4	3.1	1.2	240	8.00	3.33
21.15		2.2	3.3	.8	220	5.33	2.42
21.48		2.2	3.4	1.1	220	7.33	3.33
21.80		1.9	2.7	.4	190	2.67	1.41
22.13		2.0	3.1	1.0	200	6.67	3.34
22.46		2.7	3.1	1.0	270	6.67	2.47
22.79		2.2	3.2	.2	220	1.33	0.61
23.11		2.4	3.4	1.0	240	6.67	2.78
23.44		1.9	3.1	.9	190	6.00	3.16
23.77		2.0	3.0	.8	200	5.33	2.67
24.10		1.9	2.8	.8	190	5.33	2.81
24.43		1.5	2.3	.4	150	2.67	1.78
24.76		1.4	2.2	1.8	140	12.00	8.57
25.08		1.2	1.6	.8	120	5.33	4.44
25.41		2.0	3.8	.8	200	5.33	2.67
25.74		2.6	3.8	1.0	260	6.67	2.57
26.07		3.4	4.2	.1	340	.67	0.20
26.40		4.0	5.0	1.9	400	12.67	3.17
26.73		3.5	3.6	1.2	350	8.00	2.29
27.05		4.5	6.4	4.8	450	32.00	7.11
27.38		3.2	4.4	.6	320	4.00	1.25
27.71		3.2	2.0	1.4	320	7.33	2.92
28.04		7.0	7.6	1.9	700	12.67	1.81

Table F-2 Cont.

Depth		① C (N÷1000)	② F+C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
28.37		5.2	6.6	3.6	520	24.00	4.62
28.69		6.1	8.0	16.0	610	106.67	17.87
29.02		5.8	9.4	11.0	580	73.33	12.64
29.34		18.0	34.0	5.0	1800	33.33	1.85
29.68		34.0	45.0		3400		
30.01		40.0	45.0		4000		

Table F-3

CPT 113 Wagoner

Depth		① C (N÷1000)	② F+C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm²) ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
.55		.6		.4	60	2.67	4.45
.88		1.8		1.1	180	7.33	4.07
1.21		1.8	2.2	1.5	180	10.00	5.56
1.53		1.7	2.8	1.6	170	10.67	6.28
1.86		1.8	3.3	1.6	180	10.67	5.93
2.19		1.8	3.4	1.4	180	9.33	5.18
2.52		1.8	3.4	1.2	180	8.00	4.44
2.85		1.7	3.1	1.1	170	7.33	4.31
3.17		1.6	2.8	.9	160	6.00	3.75
3.50		1.2	2.3	1.2	120	8.00	6.67
3.83		1.2	2.1	1.0	120	[illegible]	5.56
4.16		1.4	2.6	.7	140	4.67	3.34
4.49		1.2	2.2	.7	120	4.67	3.89
4.82		1.1	1.8	.8	110	5.33	4.85
5.14		1.2	1.9	.8	120	5.33	4.44
5.47		1.3	2.1	.9	130	6.00	4.62
5.80		1.5	2.3	.8	150	5.33	3.55
6.13		1.5	2.4	.5	150	3.33	6.66
6.46		1.5	2.3	.9	150	6.00	4.00
6.78		1.5	2.0	[illegible]	150	4.67	3.11
7.11		1.4	2.3	.8	140	5.33	3.81
7.44		1.3	2.0	1.2	130	8.00	[illegible]
7.77		1.3	2.1	.8	130	5.33	4.10
8.10		1.3	2.5	[illegible]	130	5.33	4.10
8.42		1.6	2.4	.7	160	[illegible]	2.92
8.75		1.6	2.4	.8	160	5.33	3.33
9.08		1.8	2.5	1.2	180	8.00	4.44
9.41		1.8	2.6	1.2	180	8.00	4.44
9.74		1.8	3.0	1.2	180	8.00	4.44
10.06		1.9	3.1	1.1	190	7.33	3.86
10.39		1.8	3.0	1.6	180	10.67	[illegible]
10.72		2.0	3.1	1.6	200	10.67	5.34
11.05		2.0	3.6	1.6	200	10.67	5.34
11.38		2.0	3.6	1.7	200	11.33	5.67
11.71		2.0	3.6	2.1	200	14.00	7.00
12.03		1.9	3.6	2.0	190	13.33	7.02
12.36		1.9	4.0	2.0	190	13.33	7.02
12.69		2.1	4.1	2.0	210	13.33	6.35
13.02		2.1	4.1	1.9	210	12.67	6.03
13.35		2.0	4.0	2.0	200	13.33	6.67
13.67		2.0	3.9	1.7	200	11.33	5.67
14.00		2.0	4.0	1.8	200	12.00	6.00
14.33		2.3	4.0	1.6	230	10.67	4.64

Table F-3 Cont.

Depth		① C (N÷1000)	② F+C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm²) ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
14.66		2.3	4.1	1.6	230	10.67	4.64
14.99		2.2	3.8	1.6	220	10.67	4.64
15.31		2.1	3.7	1.7	210	11.33	5.40
15.64		2.0	3.6	1.8	200	1200	6.00
15.97		1.9	3.6	1.7	190	11.33	5.96
16.30		2.3	4.1	1.7	230	11.33	4.93
16.63		2.6	4.3	1.9	260	12.67	4.87
16.96		2.8	4.5	2.1	280	14.00	5.00
17.28		2.8	4.7	1.4	280	9.33	3.33
17.61		2.7	4.8	1.2	270	8.00	2.96
17.94		3.0	5.4	1.3	300	8.67	2.89
18.27		3.0	5.2	2.1	300	14.00	4.67
18.60		2.9	5.2	2.1	290	14.00	4.83
18.92		2.8	4.9	1.5	280	10.00	3.57
19.25		2.7	4.8	1.2	270	8.00	2.96
19.58		2.7	4.2	1.3	270	8.67	3.21
19.91		2.5	3.7	1.3	250	8.67	3.47
20.24		1.8	3.1	1.2	180	8.00	4.44
20.56		1.4	2.7	.8	140	5.33	3.81
20.89		1.0	2.6	.4	[illegible]	[illegible]	[illegible]
21.22		1.5	2.3	1.1	150	7.33	4.89
21.55		1.5	2.4	.5	[illegible]	[illegible]	2.22
21.88		1.6	2.7	.5	[illegible]	[illegible]	2.08
22.20		2.3	2.8	.9	[illegible]	[illegible]	2.61
22.53		1.9	2.4	.7	[illegible]	[illegible]	2.46
22.86		1.9	2.8	.7	[illegible]	[illegible]	2.46
23.19		1.6	2.3	1.0	[illegible]	[illegible]	4.17
23.52		1.3	2.0	.3	130	2.00	1.54
23.85		1.8	2.8	.4	180	2.67	1.48
24.17		1.6	1.9	.5	160	3.33	2.08
24.50		1.1	1.5	.5	110	3.33	3.03
24.83		1.4	1.8	.7	140	4.67	3.34
25.16		1.9	2.4	.7	190	4.67	2.46
25.49		2.0	2.7	2.4	200	16.00	8.00
25.81		1.7	2.4	.4	170	2.67	1.57
26.14		2.4	4.8	1.0	240	6.67	2.78
26.47		3.8	4.2	1.5	380	10.00	2.63
26.80		3.4	4.4	1.4	340	9.33	2.74
27.13		3.8	5.3	3.7	380	24.67	6.49
27.45		3.8	5.2	2.2	380	14.67	3.86
27.78		4.3	8.0	6.6	430	44.00	10.23
28.11		10.2	12.4	4.0	1020	26.67	2.61
28.44		12.4	19.0	2.0	1240	13.33	1.08

Table F-3 Cont.

Depth		① C	② F + C	③ F	④ CR	⑤ LF	Friction Ratio
ft.	m.	(N×1000)	(N×1000)	(N×1000) ② - ①	(N/cm²) ① ÷ 10 × 1000	(N/cm² ③ ÷ 150 × 1000	⑤ ÷ ④ × 100
28.77		28.0	32.0	2.0	2800	13.33	0.48
29.09		29.0	31.0	6.0	2900	40.00	1.38
29.42		31.0	33.0	1.0	3100	6.67	0.22
29.75		16.0	22.0	6.8	1600	45.33	2.83
30.08		12.0	13.0	5.8	1200	38.67	3.22
30.41		6.0	12.8	9.8	600	65.33	10.89
30.74		5.0	10.8	2.2	500	14.67	2.93
31.06		10.2	20.0	3.8	1020	25.33	2.48
31.39		12.4	14.6	3.4	1240	22.67	1.83
31.72		8.4	12.2	2.4	840	16.00	1.90
32.05		10.8	14.2	6.6	1080	44.00	4.07
32.38		10.4	12.8	13.0	1040	86.67	8.33
32.70		12.4	19.0	13.0	1240	86.67	6.99
33.03		28.0	41.0		2800		
33.36		28.0	41.0		2800		

Table F-4

CPT 12 Wagoner

Depth		①	②	③	④	⑤	
ft.	m.	C (N÷1000)	F+C (N÷1000)	F (N÷1000) ②-①	CR (N/cm²) ①÷10×1000	LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
.63		2.0	2.0	0.2	200	1.33	0.67
.93		1.8	1.8	0.9	180	6.00	3.33
1.28		1.6	1.8	0.9	160	6.00	3.75
1.61		1.0	1.9	0.8	100	5.33	5.33
1.94		1.0	1.9	0.8	100	5.33	5.33
2.27		1.0	1.8	0.7	100	4.67	4.67
2.60		1.0	1.8	0.7	100	4.67	4.67
2.92		1.2	1.9	1.0	120	6.67	5.56
3.25		1.1	1.8	1.2	110	8.00	7.27
3.58		1.2	2.2	1.3	120	8.67	7.23
3.91		1.2	2.4	1.1	120	7.33	6.11
4.24		1.4	2.7	1.0	140	6.67	4.84
4.57		1.2	2.3	0.8	120	5.33	4.44
4.89		1.2	2.2	1.0	120	6.67	5.56
5.22		1.3	2.1	0.9	130	6.00	4.62
5.55		1.4	2.4	1.2	140	8.00	5.71
5.88		1.4	2.3	1.0	140	6.67	4.76
6.21		1.6	2.8	1.4	160	9.33	5.83
6.53		1.7	2.7	1.4	170	9.33	5.49
6.86		1.5	2.9	1.3	150	8.67	[illegible]
7.19		1.5	2.9	1.4	150	9.33	6.22
7.52		1.7	3.0	1.2	170	8.00	4.71
7.82		1.7	3.1	1.2	170	8.00	4.71
8.17		1.8	3.0	1.3	180	8.67	4.82
8.50		1.8	3.0	1.7	180	11.33	6.29
8.83		1.7	3.0	1.8	170	12.00	7.06
9.16		1.7	3.6	1.7	190	11.33	5.96
9.49		2.1	3.9	1.7	210	11.33	5.40
9.81		2.1	3.8	1.8	210	12.00	5.71
10.14		2.1	3.8	1.7	210	11.33	5.40
10.47		2.0	3.8	1.8	200	12.00	6.00
10.80		2.0	3.7	1.5	200	10.00	5.00
11.13		2.0	3.8	1.6	200	10.67	5.34
11.45		2.2	3.7	1.7	220	11.33	5.15
11.78		2.2	3.8	1.8	220	12.00	5.45
12.11		2.2	3.9	1.9	220	12.67	5.76
12.44		2.2	4.0	1.9	220	12.67	5.76
12.77		2.1	4.0	2.1	210	14.00	5.71
13.10		2.1	4.0	2.0	210	13.33	6.34
13.42		2.2	4.3	2.0	220	13.33	6.06
13.75		2.3	4.3	1.8	230	12.00	5.22
14.08		2.4	4.4	2.0	240	13.33	5.55
14.41		2.5	4.3	1.6	250	10.67	4.27

Table F-4 Cont.'

Depth		① C	② F + C	③ F	④ CR	⑤ LF	Friction Ratio
ft.	m.	(N÷1000)	(N÷1000)	(N÷1000) ②-①	(N/cm²) ①÷10×1000	(N/cm²) ③÷150×1000	⑤÷④×100
14.74		2.4	4.4	1.9	240	12.67	5.28
15.06		2.3	3.9	2.0	230	13.33	5.80
15.39		2.5	4.4	1.8	250	12.00	4.80
15.72		2.5	4.5	2.1	250	14.00	5.60
16.05		2.5	4.3	2.2	250	14.67	5.87
16.38		2.5	4.6	2.3	250	15.33	6.13
16.70		2.4	4.6	2.5	240	16.67	6.95
17.03		2.5	4.8	2.2	250	14.67	5.87
17.36		2.5	5.0	2.8	250	18.67	7.47
17.69		[illegible]	5.0	2.7	280	18.00	6.42
18.02		[illegible]	5.6	2.1	280	14.00	5.00
18.34		[illegible]	5.7	3.1	300	20.67	6.89
18.67		3.1	5.2	1.9	310	12.67	4.09
19.00		3.3	6.4	2.0	330	13.33	4.04
19.33		2.9	4.8	1.4	290	9.33	3.22
19.66		3.0	5.0	1.7	300	11.33	3.78
19.98		2.9	4.3	1.7	290	11.33	3.91
20.31		2.4	4.1	1.5	240	10.00	4.17
20.64		2.4	4.1	1.2	240	8.00	3.33
20.97		2.4	3.9	1.2	240	8.00	3.33
21.30		2.4	3.6	1.1	240	7.33	3.05
21.63		2.4	3.6	1.1	240	7.33	3.05
21.95		2.8	3.9	0.8	280	5.33	1.90
22.28		2.5	3.6	1.0	250	6.67	2.67
22.61		2.2	3.0	0.8	220	5.33	2.42
22.94		[illegible]	2.8	0.6	180	4.00	2.22
23.27		1.9	2.7	0.7	190	4.67	2.46
23.59		1.8	2.4	0.7	180	4.67	2.59
23.92		1.6	2.3	0.3	160	2.00	1.25
24.25		1.6	2.3	1.5	160	10.00	6.25
24.58		2.0	2.3	0.9	200	6.00	3.00
24.91		1.9	3.4	1.9	190	12.67	6.67
25.23		2.3	3.2	1.6	230	10.67	4.64
25.56		2.2	4.1	2.4	220	16.00	7.27
25.87		2.4	4.0	0.8	240	5.33	2.22
26.22		2.0	4.4	0.6	200	4.00	2.00
26.55		4.0	4.8	2.0	400	13.33	3.33
26.87		4.0	4.6	2.9	400	19.33	4.83
27.20		2.4	4.4	4.4	240	29.33	12.22
27.53		2.4	5.3	4.3	240	28.67	11.95
27.86		2.4	6.8	2.4	240	16.00	6.67
28.19		2.4	6.7	1.8	240	12.00	5.00
28.52		2.4	4.8	29.0	240	193.33	80.55

Table F-4 Cont.'

Depth		① C (N×1000)	② F + C (N×1000)	③ F (N×1000) ② - ①	④ CR (N/cm²) ① ÷ 10 × 1000	⑤ LF (N/cm² ③ ÷ 150 × 1000	Friction Ratio ⑤ ÷ ④ × 100
ft.	m.						
28.84		5.2	7.0	26.0	520	173.33	33.33
29.17		8.0	37.0	29.0	800	193.33	24.17
29.50		38.0	64.0		3800		
29.83		40.0	69.0		4000		

Table F-5

CPT 14- Wagener

Depth		① C (N×1000)	② F+C (N×1000)	③ F (N×1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
.33		1.9	2.0	0.8	190	5.33	2.81
.86		2.3	2.4	2.0	230	13.33	5.80
1.18		2.0	2.8	2.1	200	14.00	7.00
1.51		1.7	3.7	2.4	170	16.00	9.41
1.84		1.7	3.8	2.3	170	15.33	9.02
2.17		1.5	3.9	2.3	150	15.33	10.22
2.50		1.4	3.7	2.1	140	14.00	10.06
2.82		1.2	3.5	1.7	120	11.33	9.44
3.15		1.2	3.3	1.7	120	11.33	9.44
3.48		1.3	3.0	1.6	[illegible]	10.67	8.21
3.81		1.3	3.0	[illegible]	130	12.00	9.23
4.14		1.3	2.9	1.7	130	11.33	8.72
4.47		1.3	3.1	1.8	[illegible]	12.00	9.23
4.79		1.7	3.4	1.8	170	12.00	7.06
5.12		1.6	3.4	1.6	160	10.67	6.67
5.45		1.5	3.3	1.4	150	9.33	6.22
5.78		1.5	3.1	1.4	[illegible]	9.33	6.22
6.11		1.6	3.0	1.2	160	8.00	5.00
6.43		1.6	3.0	1.1	160	7.33	4.58
[illegible]		[illegible]	[illegible]	1.0	[illegible]	[illegible]	[illegible]
7.09		1.2	2.3	0.6	120	4.00	3.33
7.42		1.4	2.4	0.7	140	4.67	3.34
7.75		1.7	2.3	0.7	170	4.67	2.75
8.07		1.7	2.4	0.8	[illegible]	5.33	3.14
8.40		1.8	2.5	1.2	[illegible]	8.00	4.44
8.73		1.8	2.6	1.1	[illegible]	7.33	4.07
9.06		1.8	3.0	1.1	[illegible]	7.33	4.07
9.39		1.9	3.0	1.0	[illegible]	6.67	3.51
9.71		1.8	2.9	0.8	180	5.33	2.96
10.04		2.0	3.0	0.7	[illegible]	4.67	2.34
10.37		2.1	2.9	0.8	210	5.33	2.54
10.70		2.1	2.8	0.7	210	4.67	2.22
11.03		2.0	2.8	0.9	[illegible]	6.00	3.00
11.35		2.2	2.9	0.7	[illegible]	4.67	[illegible]
11.68		2.0	2.9	0.7	200	4.67	2.34
12.01		2.2	2.9	0.6	[illegible]	4.00	1.82
12.34		2.1	2.8	0.7	[illegible]	4.67	2.22
12.67		2.1	2.7	0.6	[illegible]	4.00	1.90
13.00		2.1	2.8	0.5	[illegible]	3.33	1.59
13.32		2.2	2.8	0.7	[illegible]	4.67	2.12
13.65		2.1	2.6	0.6	[illegible]	4.00	1.90
13.98		2.0	2.7	0.8	200	5.33	2.67
14.31		2.3	2.9	0.8	230	5.33	2.32

Table F-5 Cont.'

Depth		① C (N÷1000)	② F + C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm²) ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
14.64		2.2	3.0	0.7	220	4.67	2.12
14.96		2.2	3.0	0.6	220	4.00	1.82
15.29		2.2	2.9	0.7	220	4.67	2.12
15.62		2.4	3.0	0.6	240	4.00	1.67
15.95		2.3	3.0	0.7	230	4.67	2.03
16.28		2.5	3.1	0.6	250	4.00	1.60
16.60		2.3	3.0	1.1	230	7.33	3.19
16.93		2.4	3.0	0.9	240	[illegible]	2.50
17.26		2.7	3.8	0.9	270	[illegible]	2.22
17.59		2.8	3.7	0.8	280	[illegible]	1.90
[illegible]		2.9	3.8	1.2	290	[illegible]	2.76
18.24		3.0	3.8	1.0	300	[illegible]	2.22
18.57		3.1	4.3	1.2	[illegible]	[illegible]	2.58
18.90		3.0	4.0	1.0	[illegible]	[illegible]	2.22
19.23		2.6	3.8	1.2	[illegible]	[illegible]	3.08
19.56		2.5	3.5	0.6	[illegible]	[illegible]	1.60
19.88		2.3	3.5	1.4	[illegible]	9.33	4.06
20.21		2.2	2.8	0.7	[illegible]	4.67	2.12
20.54		1.6	3.0	0.5	[illegible]	3.33	2.08
20.87		1.3	2.0	[illegible]	[illegible]	[illegible]	2.05
21.20		1.2	1.7	[illegible]	[illegible]	4.00	3.33
21.55		1.0	1.4	[illegible]	[illegible]	3.33	3.33
21.85		1.0	1.6	0.3	[illegible]	2.00	2.00
22.18		1.9	2.4	[illegible]	[illegible]	6.67	3.51
22.51		1.5	1.8	[illegible]	[illegible]	5.33	3.55
22.84		1.3	2.3	[illegible]	[illegible]	2.00	1.54
23.17		1.5	2.3	0.2	[illegible]	1.33	0.89
23.55		1.7	2.0	[illegible]	[illegible]	13.33	7.84
23.82		1.5	1.7	[illegible]	[illegible]	0.00	0.00
24.15		1.3	4.1	[illegible]	[illegible]	2.67	2.05
24.48		1.8	1.8	[illegible]	[illegible]	4.00	2.22
44.81		2.1	2.5	[illegible]	[illegible]	5.33	2.54
25.13		3.1	3.7	[illegible]	[illegible]	4.00	1.29
25.46		3.2	[illegible]	[illegible]	[illegible]	4.00	1.25
25.79		2.9	3.5	[illegible]	[illegible]	[illegible]	2.07
26.12		2.0	2.6	[illegible]	[illegible]	5.33	1.67
26.45		1.6	2.3	[illegible]	[illegible]	[illegible]	3.33
26.77		2.4	2.9	[illegible]	[illegible]	3.33	1.39
27.10		2.5	3.3	[illegible]	[illegible]	5.33	2.13
27.43		1.6	2.1	3.8	[illegible]	25.33	15.83
27.76		2.8	3.6	0.0	[illegible]	0.00	0.00
28.09		2.4	6.2	3.1	[illegible]	20.67	[illegible]
28.42		6.8	6.8	1.3	[illegible]	8.67	1.28

Table F-5 Cont.'

Depth		① C (N×1000)	② F+C (N×1000)	③ F (N×1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
28.74		6.0	9.1	3.2	600	21.33	3.56
29.07		4.7	6.0	3.9	470	26.00	5.53
29.40		2.4	5.6	3.7	240	24.67	10.28
29.73		7.1	11.0	0.7	710	4.67	0.66
30.06		7.9	11.6	25.0	790	166.67	21.10
30.38		7.9	8.6	26.0	790	173.33	21.94
30.71		18.0	43.0		1800		
31.04		22.0	48.0		2200		

Table F-6

CPT 15 Wagoner

Depth		①	②	③	④	⑤	
ft.	m.	C (N×1000)	F+C (N×1000)	F (N×1000) ②-①	CR (N/cm²) ①÷10×1000	LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
.63		2.4	2.4	1.2	240	8.00	3.33
.96		3.0	3.5	1.6	300	10.67	3.56
1.28		2.7	3.9	1.6	270	10.67	3.95
1.61		2.4	4.0	1.5	240	10.00	4.17
1.94		2.2	3.8	1.5	220	10.00	4.55
2.27		2.1	3.6	1.5	210	10.00	4.76
2.60		2.1	3.4	1.8	210	12.00	5.71
2.92		2.0	3.5	2.1	200	14.00	7.00
3.25		2.0	3.8	1.8	200	12.00	6.00
3.58		2.1	4.2	2.1	210	14.00	6.67
3.91		2.1	3.9	2.0	210	13.33	6.35
4.24		[illegible]	3.9	2.0	180	13.33	7.41
4.57		1.7	3.7	1.7	170	11.33	6.66
4.89		1.6	3.6	0.2	160	1.33	0.83
5.22		1.7	3.4	1.4	170	9.33	5.49
5.55		2.9	3.1	1.4	290	9.33	3.22
5.88		1.5	2.9	1.4	150	9.33	6.22
6.21		1.5	2.9	1.3	150	8.67	5.78
6.53		1.4	2.8	1.2	140	8.00	5.71
6.86		1.5	2.8	1.4	150	9.33	6.22
7.19		1.6	2.8	1.1	160	7.33	4.58
7.52		1.6	3.0	1.4	160	9.33	5.83
7.82		1.8	2.9	1.3	180	8.67	4.82
8.17		1.5	2.9	1.3	150	8.67	5.78
8.50		1.8	3.1	1.3	180	8.67	4.82
8.83		1.9	3.2	1.5	190	10.00	5.26
9.16		1.9	3.2	1.3	190	8.67	4.56
9.49		2.0	3.5	1.5	200	10.00	5.00
9.81		1.8	3.1	1.5	180	10.00	5.56
10.14		1.9	3.4	1.5	190	10.00	5.26
10.47		1.8	3.3	1.5	180	10.00	5.56
10.80		1.7	3.2	1.5	170	10.00	5.88
11.13		1.6	3.1	1.6	160	10.67	6.67
11.45		1.4	2.9	1.3	140	8.67	6.19
11.78		1.8	3.4	1.2	180	8.00	4.44
12.11		2.2	3.5	0.6	220	4.00	1.82
12.44		2.1	3.3	1.5	210	10.00	4.76
12.77		1.6	2.2	0.8	160	5.33	3.33
13.10		2.4	3.9	1.7	240	11.33	4.72
13.42		1.5	2.3	1.9	150	12.67	8.45
13.75		2.2	3.9	1.5	220	10.00	4.55
14.08		2.0	3.9	1.5	200	10.00	5.00
14.41		2.3	3.8	1.4	230	9.33	4.06

Table F-6 Cont.'

Depth		① C (N÷1000)	② F+C (N÷1000)	③ F (N÷1000) ②-①	④ CR (N/cm²) ①÷10÷1000	⑤ LF (N/cm² ③÷150÷1000	Friction Ratio ⑤÷④×100
ft.	m.						
14.74		2.3	3.8	1.5	230	10.00	4.35
15.06		2.4	3.8	1.5	240	10.00	4.17
15.39		2.3	3.8	1.3	230	8.67	3.77
15.72		2.4	3.9	1.5	240	10.00	4.17
16.05		2.3	3.6	1.4	230	9.33	4.06
16.38		2.3	3.8	1.3	230	8.67	3.77
16.70		2.4	3.8	1.5	240	10.00	4.17
17.03		2.4	3.7	1.7	240	11.33	4.72
17.36		2.5	4.0	1.7	250	11.33	4.53
17.69		2.5	4.2	1.5	250	10.00	4.00
18.02		2.7	[illegible]	1.8	270	12.00	4.44
18.34		3.0	[illegible]	2.0	300	13.33	4.44
18.67		3.0	4.8	1.4	300	9.33	3.11
19.00		3.0	5.0	1.3	300	8.67	2.89
19.33		2.9	4.3	1.0	290	6.67	2.30
19.66		2.4	3.7	1.0	240	6.67	2.78
19.98		2.0	3.0	0.8	200	5.33	2.67
20.31		1.6	2.6	1.6	[illegible]	10.67	6.67
20.64		1.7	2.5	0.8	170	5.33	3.14
20.97		1.3	2.9	1.3	130	8.67	6.67
21.30		1.9	2.7	0.4	190	2.67	1.41
21.63		1.8	3.1	1.0	180	6.67	3.71
21.95		3.8	4.2	1.5	380	10.00	2.63
22.28		1.9	2.8	0.9	190	6.00	3.16
22.61		2.4	[illegible]	[illegible]	240	5.33	2.22
22.94		2.0	[illegible]	2.4	200	16.00	8.00
23.27		1.3	2.1	0.9	130	6.00	4.62
23.59		1.9	4.3	1.1	190	7.33	3.86
23.92		3.5	4.4	1.7	350	11.33	3.24
24.25		3.2	4.3	0.8	320	5.33	1.67
24.58		3.5	5.2	0.5	350	3.33	0.95
24.91		3.7	4.5	1.6	370	10.67	2.88
25.23		2.8	3.3	2.0	280	13.33	4.75
25.56		1.9	3.5	0.4	190	2.67	1.41
25.89		2.0	4.0	0.8	200	5.33	2.67
26.22		2.8	3.2	0.4	280	2.67	0.95
26.55		4.2	5.0	0.6	420	4.00	0.95
26.87		4.4	4.8	1.6	440	10.67	2.43
27.20		3.2	3.8	0.9	320	6.00	1.88
27.53		3.5	5.1	0.3	350	2.00	0.57
27.86		3.6	4.5	1.5	360	10.00	2.78
28.19		4.4	4.7	3.5	440	23.33	5.30
28.52		6.4	7.9	8.0	640	53.33	8.33

Table F-6 Cont.'

Depth		① C (N×1000)	② F + C (N×1000)	③ F (N×1000) ② - ①	④ CR (N/cm²) ① ÷ 10 × 1000	⑤ LF (N/cm² ③ ÷ 150 × 1000	Friction Ratio ⑤ ÷ ④ × 100
ft.	m.						
28.84		8.5	12.0	20.0	850	133.33	15.69
29.17		17.0	25.0		1700		
29.50		34.0	54.0		3400		

Table F-7

CPT 17 Wagoner

Depth		① C (N×1000)	② F + C (N×1000)	③ F (N×1000) ② - ①	④ CR (N/cm²) ① ÷ 10 × 1000	⑤ LF (N/cm²) ③ ÷ 150 × 1000	Friction Ratio ⑤ ÷ ④ × 100
ft.	m.						
0.53		2.8	2.8	1.6	280	10.67	3.81
0.86		3.9	4.0	2.3	390	15.33	3.93
1.18		3.0	4.6	1.7	300	11.33	3.78
1.51		2.7	5.0	1.7	270	11.33	4.20
1.84		2.8	4.5	1.9	280	12.67	4.52
2.17		2.5	4.2	2.0	250	13.33	5.33
2.50		2.4	4.3	2.0	240	13.33	5.56
2.82		2.5	4.5	1.5	250	10.00	4.00
3.15		3.0	5.0	1.5	300	10.00	3.33
3.48		3.2	4.7	[illegible]	320	12.67	3.96
3.81		2.9	4.4	2.2	290	14.67	5.06
4.14		2.3	4.2	1.7	230	11.33	4.93
4.47		2.1	4.3	2.0	210	13.33	6.35
4.79		2.1	3.8	2.2	210	14.67	6.98
5.12		2.0	4.0	2.0	200	13.33	6.67
5.45		1.8	4.0	2.1	180	14.00	7.78
5.78		1.8	3.8	1.9	180	12.67	7.04
6.11		1.7	3.8	1.8	170	12.00	7.06
6.43		1.8	3.7	1.9	180	12.67	7.04
6.76		1.8	3.6	1.6	180	10.67	5.93
7.09		1.9	3.8	1.6	190	10.67	5.61
7.42		1.9	3.5	1.3	190	8.67	4.56
7.75		1.8	3.4	1.4	180	9.33	5.19
8.07		1.6	2.9	0.9	160	6.00	3.75
8.40		1.8	3.2	1.4	180	9.33	5.19
8.73		2.1	3.0	1.5	210	10.00	4.76
9.06		1.8	3.2	1.6	180	10.67	5.93
9.39		1.9	3.4	1.6	190	10.67	5.61
9.71		2.0	3.6	1.7	200	11.33	5.67
10.04		2.0	3.6	1.6	200	10.67	5.33
10.37		1.9	3.6	1.7	190	11.33	5.96
10.70		2.0	3.6	1.6	200	10.67	5.33
11.03		1.9	3.6	1.7	190	11.33	5.96
11.35		2.0	3.6	1.4	200	9.33	4.67
11.68		2.0	3.7	1.6	200	10.67	5.33
12.01		2.2	3.6	1.6	220	10.67	4.85
12.34		2.2	3.8	1.5	220	10.00	4.55
12.67		2.3	3.9	1.8	230	12.00	5.22
13.00		2.3	3.8	2.2	230	14.67	6.38
13.32		2.1	3.9	1.5	210	10.00	4.76
13.65		2.2	4.4	1.7	220	11.33	5.15
13.98		2.3	3.8	1.8	230	12.00	5.22
14.31		2.2	3.9	1.8	220	12.00	5.45

Table F-7 Cont.'

Depth		① C	② F•C	③ F	④ CR	⑤ LF	Friction Ratio
ft.	m.	(N•1000)	(N•1000)	(N•1000) ②-①	(N/cm²) ①÷10×1000	(N/cm² ③÷150×1000	⑤÷④×100
14.64		2.5	4.3	2.2	250	14.67	5.87
14.96		2.5	4.3	2.2	250	14.67	5.87
15.29		2.4	4.6	2.4	240	16.00	6.67
15.62		2.4	4.6	2.3	240	15.33	6.39
15.95		2.4	4.8	2.1	240	14.00	5.83
16.28		2.5	4.8	1.9	250	12.67	5.07
16.60		2.6	4.7	2.0	260	13.33	5.13
16.93		2.6	4.5	1.8	260	12.00	4.62
17.26		2.4	4.4	1.4	240	9.33	3.89
17.59		2.8	4.6	1.9	280	12.67	4.52
17.92		2.8	4.2	1.8	280	12.00	4.29
18.24		2.6	4.5	1.6	260	10.67	4.10
18.57		2.7	4.5	1.4	270	9.33	3.46
18.90		2.5	4.1	1.6	250	10.67	4.27
19.23		2.5	3.9	1.2	250	8.00	3.20
19.56		2.3	3.9	1.1	230	7.33	3.19
19.88		2.3	3.5	1.0	230	6.67	2.90
20.21		2.1	3.2	0.9	210	6.00	2.86
20.54		2.0	3.0	0.9	200	6.00	3.00
20.87		1.9	2.8	0.8	190	5.33	2.81
21.20		1.6	2.5	0.6	160	4.00	2.50
21.53		1.5	2.3	1.1	150	7.33	4.89
21.85		1.6	2.2	0.5	160	3.33	2.08
22.18		1.3	2.4	0.2	130	1.33	1.03
22.51		2.0	2.5	0.8	200	5.33	2.67
22.84		1.8	2.0	0.4	180	2.67	1.48
23.17		1.6	2.4	2.2	160	14.67	9.17
23.49		1.6	2.0	1.4	160	9.33	5.83
23.82		0.8	3.0	0.3	80	2.00	2.50
24.15		0.6	2.0	0.6	60	4.00	6.67
24.48		1.0	1.3	1.3	100	8.67	8.67
24.81		0.8	1.4	0.5	80	3.33	4.17
25.13		1.6	2.9	0.5	160	3.33	2.08
25.46		2.2	2.7	1.0	220	6.67	3.03
25.79		1.8	2.3	0.3	180	2.00	1.11
26.12		1.5	2.5	1.3	150	8.67	5.78
26.45		3.4	3.7	0.4	340	2.67	0.78
26.77		2.3	3.6	1.8	230	12.00	5.22
27.10		3.0	3.4	1.7	300	11.33	3.78
27.43		5.2	7.0	0.9	520	6.00	1.15
27.76		6.5	8.2	3.2	650	21.33	3.28
28.09		7.6	8.5	3.2	760	21.33	2.81
28.42		10.0	13.2	1.6	1000	10.67	1.07

Table F-7 Cont.'

Depth		① C (N×1000)	② F+C (N×1000)	③ F (N×1000) ②-①	④ CR (N/cm²) ①÷10×1000	⑤ LF (N/cm² ③÷150×1000	Friction Ratio ⑤÷④×100
ft.	m.						
28.74		9.2	12.4	3.7	920	24.67	2.68
29.07		10.8	12.4	2.0	1080	13.33	1.23
29.40		8.4	12.1	5.0	840	33.33	3.97
29.73		8.4	10.4	3.0	840	20.00	2.38
30.06		6.2	11.2	1.0	620	6.67	1.08
30.38		18.0	21.0	6.2	1800	41.33	2.30
30.71		15.0	16.0	5.0	1500	33.33	2.22
31.04		9.0	15.2	2.7	900	18.00	2.00
31.37		13.0	18.0	4.5	1300	30.00	2.31
31.70		15.3	18.0	3.2	1530	21.33	1.39
32.02		12.5	17.0	5.9	1250	39.33	3.15
32.35		10.8	14.0	2.4	1080	16.00	1.48
32.68		8.1	14.0	2.0	810	13.33	1.65
33.01		8.4	10.8	2.4	840	16.00	1.90
33.34		7.6	9.6	1.8	760	12.00	1.58
33.66		5.0	7.4	4.0	500	26.67	5.33
33.99		6.8	8.6	4.0	680	26.67	3.92
34.32		8.0	12.0	0.8	800	5.33	0.67
34.65		11.0	15.0	1.9	1100	12.67	1.15
34.98		6.8	7.6	7.9	680	52.67	7.75
35.30		6.4	8.3	4.9	640	32.67	5.10
35.63		6.1	14.0	7.6	610	50.67	8.31
35.96		6.7	11.6	6.0	670	40.00	5.97
36.29		2.8	10.4	4.0	280	26.67	9.52
36.62		20	28		2000		
36.95		34	38		3400		

APPENDIX G

CONE RESISTANCE COMPARISON BETWEEN DUTCH MANTLE AND FRICTION SLEEVE MECHANICAL CONES

Table *G-1*

Comparison of Mantle Cone to Friction Cone

Wagoner County- Mantle Cone No. 106
Friction Cone No. 107
Boring No. 2

Depth (ft)	Unified Classification	qc Mantle (N/cm2)	qc Friction (N/cm2)	qc (M)/ /qc (F)
0.05	CH	100	120	0.8333
1.03	"	250	240	1.0417
2.02	"	130	130	1.0000
3.00	"	170	100	1.7000
3.99	"	150	110	1.3636
4.97	"	130	100	1.3000
5.96	"	110	120	0.9167
6.94	"	110	120	0.9167
7.92	"	150	130	1.1538
8.91	"	160	150	1.0667
8.89	"	200	170	1.1765
10.88	"	200	200	1.0000
11.86	"	210	220	0.9545
12.84	"	240	230	1.0435
13.83	"	260	200	1.3000
14.81	"	230	200	1.1500
15.80	"	180	210	0.8571
16.78	"	270	190	1.4211
17.77	"	310	180	1.7222
18.75	CL	350	240	1.4583
19.74	"	280	300	0.9333
20.72	"	220	260	0.8462
21.70	"	160	160	1.0000
22.69	"	240	200	1.2000
23.67	"	260	200	1.3000
24.66	"	120	140	0.8571

Table G-2

Comparison of Mantle Cone to Friction Cone

Wagoner County- Mantle Cone No. 108
Friction Cone No. 109
Boring No. 4

Depth (ft)	Unified Classification	qc Mantle (N/cm2)	qc Friction (N/cm2)	qc (M)/ /qc (F)
0.10	CH	140	100	1.4000
1.08	CH	230	220	1.0455
2.07	MH	240	180	1.3333
3.05	CH	220	220	1.0000
4.04	"	260	240	1.0833
5.02	"	220	240	0.9167
6.00	"	140	160	0.8750
6.99	"	160	140	1.1429
7.97	"	150	160	0.9375
8.96	"	180	160	1.1250
9.94	"	180	180	1.0000
10.93	"	220	190	1.1579
11.91	"	230	170	1.3529
12.90	"	240	210	1.1429
13.88	"	240	200	1.2000
14.86	"	210	210	1.0000
15.85	"	240	200	1.2000
16.83	"	290	220	1.3182
17.82	"	270	260	1.0385
18.80	CL	250	260	0.9615
19.79	"	200	200	1.0000
20.77	"	160	180	0.8889
21.75	"	190	190	1.0000
22.74	"	140	160	0.8750
23.72	"	120	80	1.5000
24.71	"	190	100	1.9000
25.69	"	170	180	0.9444
26.68	"	320	320	1.0000

Table G-3

Comparison of Mantle Cone to Friction Cone

Tulsa County- US75 & Harvard Mantle Cone
US75 & Harvard Friction Cone
US75 & Harvard Boring No. 16

Depth (ft)	Unified Classification	qc Mantle (N/cm2)	qc Friction (N/cm2)	qc (M)/ /qc (F)
0.05	CL	190	220	0.8636
1.03	"	980	260	3.7692
2.02	"	320	180	1.7778
3.00	CH	180	240	0.7500
3.99	"	180	180	1.0000
4.97	"	180	160	1.1250
5.96	"	210	170	1.2353
6.94	"	210	180	1.1667
7.92	"	180	180	1.0000
8.91	"	250	220	1.1364
8.89	"	260	240	1.0833
10.88	"	270	240	1.1250
11.86	"	310	250	1.2400
12.84	CL	260	280	0.9286
13.83	"	210	250	0.8400
14.81	"	280	310	0.9032
15.80	"	330	280	1.1786
16.78	"	300	280	1.0714
17.77	"	290	230	1.2609
18.75	"	280	210	1.3333
19.74	"	250	240	1.0417
20.72	"	210	220	0.9545
21.70	"	290	220	1.3182
22.69	"	310	220	1.4091
23.67	"	330	300	1.1000
24.66	"	360	320	1.1250
25.64	"	340	320	1.0625
26.63	"	240	220	1.0909
27.61	"	260	280	0.9286
28.59	"	320	200	1.6000
29.58	"	310	210	1.4762
30.56	"	280	240	1.1667
31.55	"	260	220	1.1818
32.53	"	280	230	1.2174
33.52	"	250	230	1.0870
34.50	"	240	260	0.9231
35.48	"	180	160	1.1250
36.47	"	200	150	1.3333
37.45	"	140	100	1.4000
38.44	"	140	110	1.2727
39.42	"	140	110	1.2727
40.41	"	90	100	0.9000

APPENDIX H

CONE RESISTANCE COMPARISON BETWEEN FRICTION SLEEVE MECHANICAL CONE AND ELECTRICAL CONE

Table II-1

Comparison of Friction Cone to Electric Cone

Wagoner County- Friction Cone No. 10
Electric Cone No. 207
Boring No. 1

Depth (ft)	Unified Classification	qc Friction (N/cm2)	qc Electric (N/cm2)	qc (F)/ /qc (E)
0.33	CH	280	170	1.6471
1.31	"	400	140	2.8571
2.30	"	340	90	3.7778
3.28	"	380	140	2.7143
4.27	"	300	170	1.7647
5.25	"	230	160	1.4375
6.23	"	240	120	2.0000
7.22	"	240	120	2.0000
8.20	"	400	120	3.3333
9.19	"	180	130	1.3846
10.17	"	190	110	1.7273
11.15	"	190	100	1.9000
12.14	"	210	80	2.6250
13.12	"	190	110	1.7273
14.11	"	210	100	2.1000
15.09	"	210	130	1.6154
16.08	"	210	120	1.7500
17.06	"	210	170	1.2353
18.04	"	240	210	1.1429
19.03	"	230	210	1.0952
20.01	CL	240	160	1.5000
21.00	"	210	130	1.6154
21.98	"	130	100	1.3000
22.97	"	130	90	1.4444
23.95	"	150	90	1.6667
24.93	"	230	100	2.3000

Table II-2

Comparison of Friction Cone to Electric Cone

Wagoner County- Friction Cone No. 13
Electric Cone No. 201
Boring No. 2

Depth (ft)	Unified Classification	qc Friction (N/cm2)	qc Electric (N/cm2)	qc (F)/ /qc (E)
0.33	CH	160	130	1.2308
1.31	"	120	100	1.2000
2.30	"	110	100	1.1000
3.28	"	130	110	1.1818
4.27	"	110	80	1.3750
5.25	"	140	80	1.7500
6.23	"	140	90	1.5556
7.22	"	160	90	1.7778
8.20	"	180	90	2.0000
9.19	"	190	110	1.7273
10.17	"	180	110	1.6364
11.15	"	200	130	1.5385
12.14	"	220	90	2.4444
13.12	"	230	130	1.7692
14.11	"	190	120	1.5833
15.09	"	200	120	1.6667
16.08	"	200	140	1.4286
17.06	"	220	160	1.3750
18.04	"	280	140	2.0000
19.03	CL	230	270	0.8519
20.01	"	240	240	1.0000
21.00	"	130	160	0.8125
21.98	"	200	120	1.6667
22.97	"	160	270	0.5926
23.95	"	220	170	1.2941
24.93	"	180	80	2.2500
25.92	"	280	240	1.1667

Table *H-3*

Comparison of Friction Cone to Electric Cone

Wagoner County- Friction Cone No. 16
Electric Cone No. 202
Boring No. 3

Depth (ft)	Unified Classification	qc Friction (N/cm2)	qc Electric (N/cm2)	qc (F)/ /qc (E)
0.33	CH	200	130	1.5385
1.31	"	220	110	2.0000
2.30	"	250	150	1.6667
3.28	CL	290	180	1.6111
4.27	CH	200	170	1.1765
5.25	"	380	120	3.1667
6.23	"	160	120	1.3333
7.22	"	170	140	1.2143
8.20	"	170	150	1.1333
9.19	"	170	140	1.2143
10.17	"	190	140	1.3571
11.15	"	230	160	1.4375
12.14	"	250	180	1.3889
13.12	"	220	160	1.3750
14.11	"	200	170	1.1765
15.09	"	250	170	1.4706
16.08	"	230	180	1.2778
17.06	"	200	180	1.1111
18.04	"	300	220	1.3636
19.03	CL	350	230	1.5217
20.01	"	230	190	1.2105
21.00	"	160	140	1.1429
21.98	"	200	140	1.4286
22.97	"	180	160	1.1250
23.95	"	240	160	1.5000

Table II-4

Comparison of Friction Cone to Electric Cone

Tulsa County- US75 & Harvard Friction Cone
US75 & Harvard Electric Cone
US75 & Harvard Boring No. 16

Depth (ft)	Unified Classification	qc Friction (N/cm2)	qc Electric (N/cm2)	qc (F)/ /qc (E)
0.05	CL	220	220	1.0000
1.03	"	260	850	0.3059
2.02	"	180	550	0.3273
3.00	CH	240	190	1.2632
3.99	"	180	130	1.3846
4.97	"	160	130	1.2308
5.96	"	170	150	1.1333
6.94	"	180	160	1.1250
7.92	"	180	160	1.1250
8.91	"	220	170	1.2941
8.89	"	240	160	1.5000
10.88	"	240	170	1.4118
11.86	"	250	140	1.7857
12.84	CL	280	130	2.1538
13.83	"	250	110	2.2727
14.81	"	310	130	2.3846
15.80	"	280	200	1.4000
16.78	"	280	220	1.2727
17.77	"	230	200	1.1500
18.75	"	210	200	1.0500
19.74	"	240	200	1.2000
20.72	"	220	180	1.2222
21.70	"	220	180	1.2222
22.69	"	220	170	1.2941
23.67	"	300	180	1.6667
24.66	"	320	200	1.6000
25.64	"	320	220	1.4545
26.63	"	220	190	1.1579
27.61	"	280	180	1.5556
28.59	"	200	190	1.0526
29.58	"	210	190	1.1053
30.56	"	240	190	1.2632
31.55	"	220	190	1.1579
32.53	"	230	170	1.3529
33.52	"	230	170	1.3529
34.50	"	260	180	1.4444
35.48	"	160	180	0.8889
36.47	"	150	170	0.8824
37.45	"	100	120	0.8333
38.44	"	110	100	1.1000
39.42	"	110	100	1.1000
40.41	"	100	110	0.9091

VITA

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