United States Department of Agriculture
Soil Conservation Service
P.O. Box 2890
Washington, D.C.
20013

December 10, 1984

SOIL MECHANICS NOTE NO. 11
210-VI

SUBJECT: ENG - THE STATIC CONE PENETROMETER: THE EQUIPMENT AND USING THE DATA

Purpose. To distribute Soil Mechanics Note No. 11 (SMN-11)

Effective date. Effective when received.

The cone penetrometer is an effective tool for use in certain conditions and along with other methods and equipment for geotechnical investigations. The test data provide additional information upon which to base assumptions and make interpretations for preparing geologic reports, taking samples, making tests, and preparing designs. Where soil conditions do not permit taking adequate samples, the cone penetrometer may be the best alternative for obtaining information to judge engineering properties. Several states are using this equipment on a regular basis. Others may need to use it or include it in contracts for investigation work.

This soil mechanics note gives some detailed procedures for using the equipment and guidance on obtaining and using the data from cone penetrometer tests.

Filing instructions. File with other soil mechanics notes or guide material on geologic investigation equipment and methods.

Distribution. Initial distribution (shown on the reverse side) to each state and NTC is sufficient to provide a copy to each professional engineer and engineering geologist. Additional copies may be obtained from Central Supply by ordering SMN-11.

Gerald D. Seinwill

GERALD D. SEINWILL
Associate Deputy Chief
for Technology

DIST: See reverse

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

NO-ADS-4
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REMARKS

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U.S. Department of Agriculture
Soil Conservation Service
Engineering Division

SOIL MECHANICS NOTE NO. 11

THE STATIC CONE PENETROMETER:

THE EQUIPMENT AND USING THE DATA

June 1984

CONTENTS

<u>APPENDIX</u>

I. Purpose and Scope

A. The quasi-static cone penetrometer test (CPT) is a valuable tool when used in conjunction with other tools and procedures in making investigations for engineering structures. This notes describes the cone penetrometer equipment and explains in detail the procedures for making cone penetrometer tests. It also describes some procedures for and guidance in interpreting and using the test results. Uniformity in all aspects of cone penetrometer testing is desired.

B. This note is limited to the use of the static (or quasi-static) penetrometer which employs a hydraulic load cell and Bourdon-tube gages for observation of loads. Electric (or strain-gage) cones are being used by several organizations in the United States, and the data derived from their use is comparable to that from nonelectric equipment.

II. Introduction

Several penetrometers of various types were used in the Netherlands and Scandinavia beginning around 1900. A cone penetrometer using a sleeve or shield was patented in Holland in 1936. In 1946, the "Dutch" cone was manufactured by Goudsche Machinefabriek of Gouda, first as a 2,500 kg capacity apparatus. A few years later, this company began making penetration equipment of 10,000 kg and 20,000 kg capacity. One of the many advantages of static cone penetrometers is the ability to isolate, or remove, the unknown (but considerable) friction forces that develop on the push rods. In static penetrometer testing, only the resistance to the cone point and the friction sleeve (if used) is measured.

In the United States, most static penetration tests are made by adapting a drill rig and its hydraulic controls to push and retrieve the penetrometer. Self-contained trailer- and truck-mounted penetrometer rigs are also available.

Results of static penetration tests are now accurate enough that they can be used to make reliable estimates of settlement and undrained shear strength in areas where at least some knowledge about the engineering properties of the soil is available. With both static and dynamic testing available, it should not be necessary to rely entirely on testing samples that may be disturbed or may not even be retrievable.

Cone penetrometer equipment is currently used by SCS in Iowa, Kansas, and Nebraska. Several other penetrometers are being used in the Midwest by the Corps of Engineers and consulting engineering companies. The cone penetrometer was first used in Nebraska by SCS in May 1974.

This note was prepared by Robert J. Fredrickson, Civil Engineer, Soil Mechanics Laboratory, Lincoln, Nebraska.

III. Equipment

A. Description

1. A photograph of the CPT equipment with a descriptive caption is in the appendix.

2. The cone penetrometer equipment currently used by SCS is manufactured by Goudsche Machinefabriek B.V., Gouda, Holland. The general description of the equipment follows:

a. Cone.--Mantle cone, which gives only point resistance, and the friction sleeve cone, which gives point resistance and friction resistance on a steel-to-soil interface. The cone has a 60° point and a 36-mm diameter base. The projected area of the cone is 10 cm^2. The friction sleeve is 36 mm in diameter and has an area of 150 cm^2. Drawings of both cone and friction sleeve cone are in ASTM D 3441.

b. Sounding tubes.--An inner rod of 15-mm diameter which transmits downward thrust to the cone, and an outer tube (16 mm ID, 36 mm OD) which shields the test from definite, but unknown, friction resistance. The outer tube is also used to advance the cone for subsequent test readings and to retrieve the cone. Only the cone or cone plus friction sleeve are used in determining penetration resistance.

c. Load cell.--The load cell transmits the vertical thrust to a hydraulic oil-filled chamber, which activates the bourdon-tube gages. The gages (three are generally used) read direct hydraulic pressure in ranges of 0-16, 0-100, and 0-600 kgf/cm^2. The manufacturer is now making gages calibrated for the Newton unit of force.

d. Other support equipment includes cone-retrieval tools, vertical-increment staff rod and base, and maintenance hand tools.

e. Adapter(s)--Custom made to enable various drill rigs, using the rig hydraulic system, to perform the test and retrieve the cone.

B. Adaption to Drill Rigs

1. Adapter hardware.--Nearly all late-model hydraulic drill rigs can be adapted to use in performing CPT. The Mobile B 53 and CME 75 rigs will allow vertical thrust in line with the designed center of thrust; some older rigs require an offset shelf. For some rigs, an offset adapter has the advantage of not requiring any changes to the Kelly bar or auger rod. Drill rigs having a hydraulic piston travel of less than 1 meter can be used, but the time required for a test is much longer. A drawing of one rig adapter is in the appendix.

The manufacturer of the cone equipment offers a motor-driven, hydraulic-thrust, trailer-mounted rig that includes all of the penetrometer equipment. The cost of this complete package is about ten times that of cone equipment, which is the reason for adapting cone equipment to an already-owned drill rig.

2. Drill rig requirements and notes on conducting the test: The rig hydraulic controls should be such that speed and pressure can be accurately controlled. Controls on later model rigs usually have these features.

Rigs should have hydraulic leveling jacks which, in addition to providing a level drill platform, place the weight of the rig on the cone and the jacks instead of on the moveable tires and springs. The leveling jacks also provide more safety (rigs without jacks often roll off the leveling planks) and speed of operation. A penetration test can be performed to a depth of 15 to 20 m (50 to 65 ft) in less than an hour with a well-equipped rig and a proficient crew.

The downward thrust of most drill rigs is enough to cause cone point loads up to 150 to 200 kgf/cm^2. For comparison, most soft and wet soils will have point resistance (q_c) of 1 to 10 kgf/cm^2; dense CH till, 40 to 80 kgf/cm^2; low density sands, 20 to 50 kgf/cm^2; and higher density sands, 100 to 200 kgf/cm^2. The dense sands may have $q_c > 200$ kgf/cm^2, but the drill rig may start to lift off the leveling jacks at q_c of 150 to 200 kgf/cm^2. Anchors can be provided to give greater downward thrust, but are usually not needed for most soil conditions encountered in site investigations for low dams. On most drill rigs, upward pull is greater than the downward thrust; thus, cone retrieval is seldom difficult.

Cone equipment weighs about 600 lb and can be transported in a pickup truck having suitable boxes and racks for storage. Most drilling equipment includes a tool truck and the cone equipment can be stored and transported in this vehicle. The hydraulic load cell, with large glass-covered gages attached, needs a well-padded box for transport and storage. A custom-made metal case for the load cell is usually included with the purchase of the equipment.

C. Maintenance of Equipment

1. Cone tips.--At the end of the day, completely disassemble, wash, dry, and oil the cone. If CH soil is allowed to dry in and on a cone, the cone will be very difficult to take apart. Apply nondetergent oil (20W or 30W) with a pump-type oilcan. Store the necessary wrenches, socket head wrenches in metric sizes, and spare parts in a small toolbox.

After each test the cone should be washed and dried and the moving parts oiled. When used in very fine-grained soils, complete disassembly of the cone for cleaning may be required between tests.

2. Push tubes.--Clean the soil from the outside of the tubes as they are retrieved. Pulling the tubes through a hole in a piece of rubber tire will usually clean them sufficiently. The tubes will have to be washed during retrieval where some soils, notably the high plasticity clays, are encountered.

About once per week (more often if the tubes are not screwed tight by hand) clean and oil the inside of the tubes. Use a 115-cm-long (45 inches) shotgun type cleaning rod that has a slotted tip for holding rag patches and a T-handle. Clean with solvent, dry with rags or air pressure, and oil the tubes. Use a bristle brush, wire brush, and air pressure for cleaning threads.

3. Hydraulic Load Cell.--For new equipment, remove the filler and air bleed socket screws so that all water, oil, sludge, gummy substance, and steel filings can be removed. Use a small amount of solvent and air pressure for final cleaning.

The load cell has a free-floating piston and rubber O-ring seal. Push the piston down, using a hex wrench, until it clicks against the pressure rod. Fill the reservoir with winter grade hydraulic oil ("Magnus 150," Phillips Petroleum Co., or equal). Tip the load cell in several directions until all air has escaped from the bleeder hole. Do not use 20W or 30W in place of hydraulic oil; the gages will be sluggish in their return motion at temperatures of 25 °F or lower. The load cell and gages will function normally at -30 °F if the recommended hydraulic oil is used.

Before new equipment is used and at least annually thereafter, test the load cell and gages in a compression testing machine such as the Soil Mechanics Laboratory Riehle compression machine. A sketch of the testing setup is in the appendix.

To test the load cell after replacing the hydraulic oil, place a small load on the cell and loosen the double threaded union nuts (one at a time) until all of the air is bled through the small hole in the center of the nut. Tighten all union nuts and increase the load to 250 to 300 kgf/cm^2, then return to about zero load. Note the gage response and cutoff reading on the 0 to 16 and 0 to 100 kgf/cm^2 gages. Adjust the cutoff valve cup screw to give cutoff at 80 to 85 percent of maximum gage reading. Check the oil in the load cell reservoir. Push the free-floating piston downward each time the oil is checked. Test the gages on the laboratory compression machine for accuracy at this time, using the graph for conversion in the appendix.

Check for oil leaks when the load cell is loaded, and replace the "Usitring" gaskets, if necessary.

Do not unload the load cell so rapidly that the gage dial hands are wrapped around the zero stop pin. Such damage contributes to inaccurate readings.

Clean the inside of the lower end of the load cell with solvent and dry with air pressure, then oil with WD-40 or similar type oil. Leave a light film of oil on all metal parts to prevent rusting. In the presence of water, black (not reddish brown) oxide forms on the steel used for the load cell.

4. Spare Parts.--The manufacturer provides one extra gage of each load range, and one extra mantle cone and friction sleeve cone. Extra "Usitring" gaskets, cone points, one union nut, hydraulic oil, cone tip oil, and a pump-type oilcan are needed. Check extra gages for accuracy before performing field tests.

IV. Field Operations--Performing the CPT

A. Setting Up the Equipment.--Level the drill rig with nearly all the weight of the rig on the leveling jacks. On slopes, keep the vertical distance from the hydraulic load cell to the ground as small as possible to reduce the tendency of the push tubes to bow under load. Secure the load cell to the rig using the applicable adapter.

Assemble the friction sleeve cone as follows:

1. Turn the cone hand-tight against the shoulder of the 0.3-m push tube, which has an antifriction ring welded at about the middle.

2. Turn the assembly hand-tight to a 1-m push tube.

3. Hold this assembly under the load cell and set the cone tip about 10 cm into the soil. Adjust for plumb using a level and the drill rig adjustment.

4. Set the cone point at a depth of 40 cm.

5. Set the staff gage rod and adjust the pointer to allow for 1 m of travel. (The pointer is made from a spring clamp with a 15-inch long, 1/4-inch diameter rod welded to it.)

6. Set the drill rig hydraulic feed controls to give a downward rate of 1 to 2 cm/s (0.5 to 1.0 in/s). Sufficient time is needed for the notekeeper to observe and record two gage readings. The "jump" in the gage reading must be observed because:

a. The second reading is taken after movement of the friction sleeve of about 1 cm. The first gage reading is observed when the cone point has moved about 2 cm.

b. The gages indicate whether or not coarse sand or rocks are being forced aside.

B. Performing the Test.--Continue the CPT to refusal. On nearly all earthfill structures, it is necessary to know the lower boundary or limit of potential settlements. The CPT gives this total depth and also indicates the intervals between the ground surface and refusal where undisturbed samples may be obtained. The depth interval for which a sample is representative can also be determined from the CPT data.

The 0.3-m push tube with the antifriction ring allows the CPT to be performed to relatively great depths. Depths to refusal (on bedrock) of up to 21.2 m (69.5 ft) have been accomplished. If the antifriction ring tube is not used, the maximum depth reached depends on the weight of the drill rig, classification of soil, and soil moisture and is usually limited to about 6 to 13 m (20 to 43 ft).

Note any delays exceeding 10 min in the record. Drainage (pore pressure dissipation) due to load will occur in time, and the test data will be in error for a small interval of < 30 cm.

Erratic Readings.--When the cone point contacts a small rock in an otherwise uniform, fine-grained soil, the gage's reading will rise rapidly and drop as soon as the rock is pushed aside. The gage readings change much more slowly as the cone passes from a soft layer to one that is more dense or of different classification.

Some soils will give gage readings of < 0.5 kgf/cm^2 on the 0 to 16 kgf/cm^2 gage and little, if any, indication on the 0 to 100 kgf/cm^2 gage. Extremely low readings are not uncommon for the CPT and are seldom erratic. For extremely soft soils, the equipment manufacturer makes aluminum inner rods. Using lighter inner rods will provide more accurate gage readings.

Since a very small amount of oil usually escapes from the load cell, check the level of the oil often and add oil as needed. Low oil levels will give inaccurate gage readings which will be low. At the end of each working day, check the load cell oil level and bleed off any air.

A rock or tree root may cause the string of push tubes to deviate from the vertical. If deviation occurs at a shallow (1 to 3 m $\pm$) depth, the push tubes will continue to move laterally or in a vertical curve. When this occurs, retrieve the cone and start a new test.

If the gage dial hands vibrate so that readings are impossible, change the speed of the drill rig engine. Each rig and load cell has its own resonant frequency, and changing engine speed will usually correct this problem. The resonant frequency vibration problem is sometimes caused by an unbalanced drive shaft.

Retrieving the Equipment.--The hydraulic uplift of most rigs is the strongest and also the slowest method of retrieval. If a threaded adapter is made for the hoisting swivel, the cable winch can be used: it's use will reduce retrieval time to about one-half.

In soft, wet soils, the string of sounding tubes may tend to drop in the hole. A variety of one-way clamps are available to prevent the loss of equipment.

The tubes will have to be washed during retrieval for some soils, usually the high-plasticity clays. Use a nylon string or thin wire to cut the clay from the tube.

V. Plotting the Test Data

A. Reducing Field Notes.--The actual load on the cone or friction sleeve is in proportion to the areas involved in the measurement of the loads. The plunger (piston) in the load cell has an area of 20 cm^2; thus, the load on the cone point is twice the gage reading (20 cm^2 ÷ 10 cm^2 cone) plus the weight of the inner rods. If the first gage reading is G_1, the cone reading (q_c) is $2G_1 + 0.14n$ in units of kgf/cm^2 (n = number of sounding tubes). The friction sleeve resistance (f_s) is in the ratio of 20 cm^2 (plunger) ÷ 150 cm^2 (sleeve area), or $0.133\ (G_2 - G_1)$ where G_2 is the second gage reading. Friction ratio (FR) is the ratio of f_s to q_c expressed as a percentage. Obtain q_c from the previous reading, up 20 cm; then $FR = f_s \cdot 100/q_c$.

For speed and accuracy in reducing notes, use a printing calculator (such as a Monroe 1880). Enter values of "n" (number of push tubes), G_1, and G_2; the printout will list q_c, f_s, and FR. The paper tape output provides plotting speed and accuracy. Appendix C shows field data sheet that is adapted to computer reduction of field notes. Field data are also easily reduced and plotted using small personal computers having a plotter attachment.

B. Plotting the CPT Graph.--Use 4-cycle by 70 or 150 division semilog transparent paper. The 4-cycle by 70 measures 8 1/2 by 11 inches; the 4-cycle by 150, 11 by 16 1/2 inches. Plot the data as shown on the examples in the appendix.

The vertical scale is in metric units with the heavy lines at 1/2-inch intervals representing 1 meter. Each horizontal line then represents 20 cm, which is the depth interval for the friction sleeve-cone test data. The 8 1/2 by 11 inch paper provides space for CPT to 14 m (46 ft); 11 by 16 1/2 inch paper for CPT to 30 m (98 ft).

The two log cycles on the left side are used as the ordinate for q_c, cone point resistance, with units of 1 to 10 and 10 to 100 kgf/cm^2. The third log cycle is for f_s, friction sleeve, in units of 0.1 to 1.0 kgf/cm^2. The fourth log cycle is for FR, friction ratio, in units of 1 to 10 percent. Occasionally, some overlap will be needed, but the graphs will never cross each other. FR > 10 is usually not plotted.

Use the plotting method described above for all sites so that two or more graphs can be overlaid for comparison of q_c and f_s. This comparison allows rapid delineation of deposit boundaries. It also provides a basis for grouping soil deposits that may be expected to have similar engineering properties.

It is recommended that a log of a test hole, where available, be plotted to the same vertical scale as the CPT. Convert depths of soil layers from feet to meters using the constant 0.3048. Indicate the depth to the water table and depths to moisture changes and bedrock on the soil profile.

Maintain the original plot of the graphs in one notebook for each penetrometer. This simplifies comparison of soils in terms of q_c, f_s, and FR for an area. Attach copies of the CPT graph to each structure report or place them in each structure file.

VI. Field Use of CPT

A. Guide to Determining Stratigraphy.--Each site has a unique set of conditions requiring judgement in the selection and use of investigational tools. Generally, CPT data are better interpreted with a systematic coverage that includes the entire foundation area: this is particularly true for uniform soil deposits.

For foundations that are not uniform, as in alluvial deposits, the location of CPT will be based on data from previous test holes and CPT. One of the main advantages of CPT is the ability to provide a continuous record of the stratification of a soil deposit.

Make a log of the soil profile for each location where there is an indication of a change in the soil profile. The log should include a description of the changes in moisture, depth to the water table, and depth to bedrock.

B. Guide to Obtaining Samples.--When taking undisturbed samples, obtain at least one sample where q_c and f_s show definite intervals of different soils. Often, q_c and f_s vary considerably within one geologic formation. Take one or more samples to represent dry or moist soil layers.

When reliable undisturbed samples cannot be retrieved using the sampling tools on hand, explain the difficulty in the logs. Make two or more CPT in these soils to verify data and provide more information upon which to base judgements. For soils of SP and SM classification, the CPT should include one or more continuous penetration tests. The continuous CPT uses the mantle cone with readings obtained at 5 or 10 cm intervals. Describe, in the investigative reports, any difficulties in making field tests or obtaining representative samples.

The undrained shear strength of the in-place soils is generally related to the sleeve resistance by:

$$\tau_f = 0.8 \ f_s$$

Convert τ_f to units of psf by multiplying 0.8 f_s by 2048. For example, f_s of 0.3 kgf/cm^2 or 500 psf indicates sampling and testing may be needed if the structure size so dictates. Saturated fine-grained soils having f_s < 0.5 kgf/cm^2 are generally suspect concerning strength.

VII. Soil Mechanics Laboratory Use of CPT Data

A. Soil Classification.--Where possible, soil classifications are to be based on the appropriate laboratory test data or field identification procedure. As a basis for correlation, a reasonable classification of the soils can be made from the graph of q_c, f_s, and FR. Fine-grained saturated soils will generally have $q_c \leq 15$ kgf/cm^2, $f_s \leq 0.5$ kgf/cm^2, and FR of 2 to 6 (CL, ML, and CH). Some compact and dense soils of CH and MH classification may have q_c of 20 to 30 kgf/cm^2, f_s of 0.5 to 1.0 kgf/cm^2, and FR of 5 to 15. Sands will generally have q_c > 30 kgf/cm^2, f_s < 0.2 kgf/cm^2, and FR < 2. Loose sands may have q_c of 30 to 60 kgf/cm^2; moderately dense sands, q_c > 100 kgf/cm^2; and dense sands, $q_c \geq 200$ kgf/cm^2. Examples of interpretation of CPT graphs are given in appendix D.

B. Determining Soils to be Represented by Sample Testing.--One of the most important and beneficial uses of CPT data in the laboratory is to provide a basis for judging whether engineering property test data can be accurately extended to represent soils located some distance from the sampling location. For example, in the slope stability analysis, shear strength values determined using samples taken from the centerline of a structure are usually assumed to represent the foundation soils several hundred feet upstream and downstream. CPT data can be used in judging the extent of the area to which these data apply.

C. Consolidation Testing and Analysis.--Undisturbed samples are seldom obtained from the center of a particular layer of foundation soil. Data from CPT usually provides information for determining more precisely the upper and lower boundaries represented by one or more samples. Not always will soil of a given formation or age have uniform engineering properties.

Several cone tests (e.g., at the base of an abutment) will establish a reasonably accurate estimate of potential differential settlements which can then be confirmed by sampling and testing.

To compute horizontal strain associated with the design of principal spillway conduits (see Technical Release No. 18), the lower limit of settlement must be known. Cone penetrometer tests extended to bedrock or to refusal in sands, gravels, or stiff clays provide good information for determining this lower limit. The reliability of samples, often obtained with great difficulty and expense, can then be judged as to their potential use in settlement and strain analysis.

In areas where previous work has established a base of test results, analysis, and field measurements, settlement can be estimated using only CPT data if results of direct testing are not available. The general equation for consolidation of a layer as given by Sanglerat and others is:

$$\Delta = h \cdot \Delta p \cdot m_v \text{ or}$$

$$\Delta h = h \cdot \Delta p \cdot \frac{1}{\alpha . q_c}$$

where:

Δh = change in layer thickness, cm

h = layer thickness, cm

Δp = load; increase in vertical stress, kg/cm^2

α = variable coefficient based on the nature of the soil

q_c = cone point resistance, kgf/cm^2

$m_v = \frac{1}{\alpha . q_c}$; coefficient of mass volume change, cm^2/kg

Using settlement plate data supported by laboratory testing, a graph of q_c vs. α is computed for soils found in a given area:

$$\alpha = \frac{h \cdot \Delta p}{q_c \cdot \Delta h}$$

For fairly uniform soils and given adequate time, Δh from settlement plate records will be accurate for determining the α coefficient. Compute the increase in stress due to the embankment load Δp from field placement records. The graph will be less accurate where the basis for computation is only laboratory testing to determine Δh.

D. Shear Strength Comparisons:

1. Using the friction sleeve, Drnevich et al. (2) found that:

$$\tau_f = 0.80\ f_s$$

where:

τ_f = undrained shear strength, kgf/cm^2

f_s = friction sleeve resistance, kgf/cm^2; from static penetrometer of the Delft type.

The value of the constant 0.80 was determined from unconsolidated-undrained (UU) and consolidated-undrained (CU) tests on CL, ML, and MH soils from Kentucky. This value compares well with CPT and laboratory UU tests on soils from Iowa, Kansas, and Nebraska. For example, if $f_s \leq 0.3$ kgf/cm^2, $\tau_f \leq 0.24$ kg/cm^2 ≤ 490 lb/ft^2 (kg/cm^2 x 2048 = lb/ft^2). In relatively weak ML soils where f_s ≤ 0.3 kgf/cm^2, UU test results are 200 to 300 lb/ft^2.

2. From the cone point resistance, C_u (undrained shear strength) is in the range of $q_c/15$ to $q_c/18$. These values are for the Delft mantle cone in normally consolidated clays where $q_c < 20$ kgf/cm^2. (Note: Some authors use C_u, others use τ_f for undrained shear strength.)

For example, where $f_s \leq 0.3$ kgf/cm^2 and $q_c \leq 5$ kgf/cm^2: then τ_f = 5/18 x 2048 = 570 lb/ft^2.

3. Comparing q_c and f_s with results of laboratory shear testing will aid in establishing depths of foundation soils to use in the slope stability analysis.

VIII. Use of CPT Data in Design

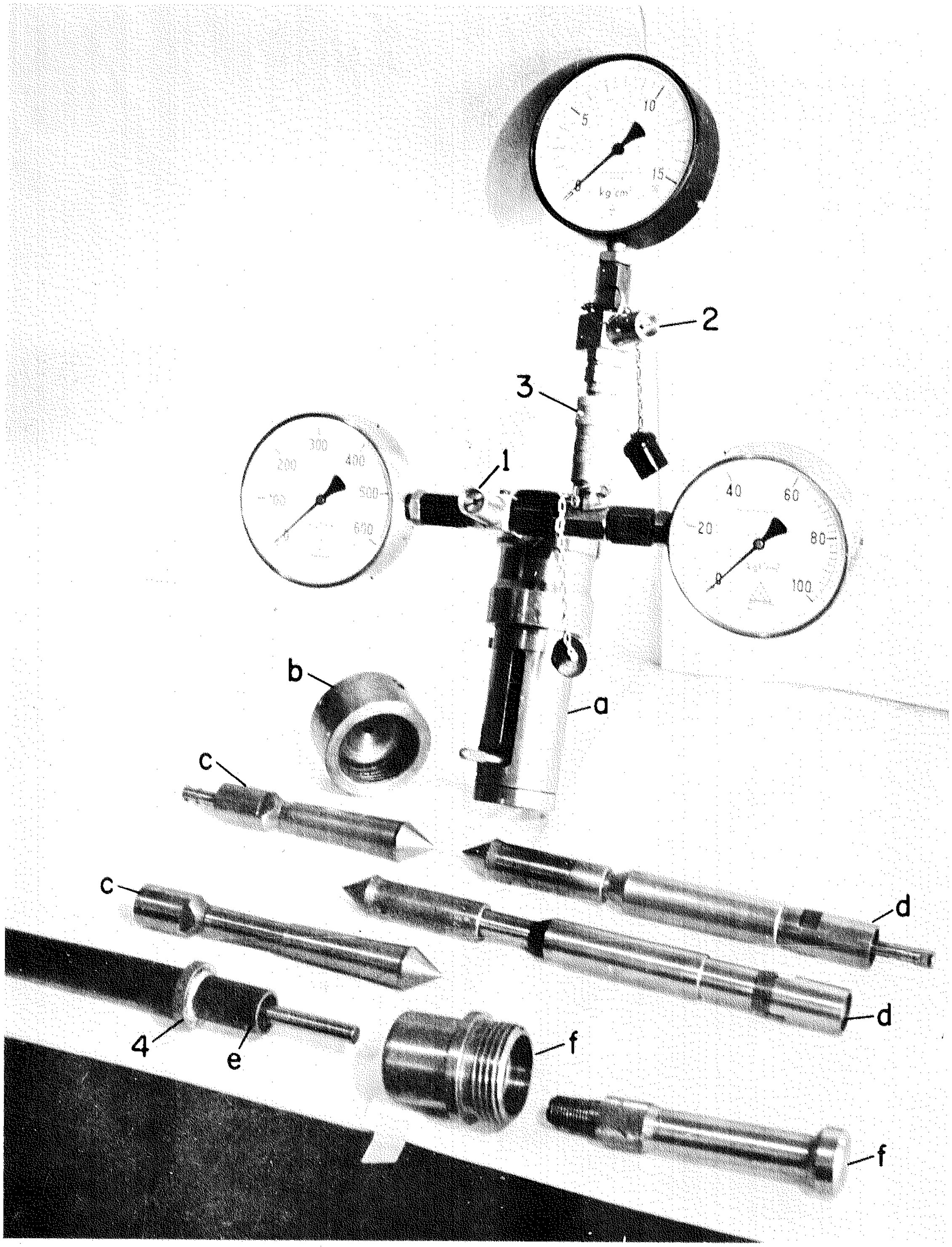
A. Foundation.--When determining the extent of excavation needed in fine-grained soils, compare results of representative laboratory consolidation and shear tests with CPT data. Tests on undisturbed samples usually represent a small volume of soil; in-place testing with the penetrometer allows the laboratory data to be applied to larger volumes of soil.

The CPT is a good tool for use during construction to determine if foundation excavation is completed and to locate soils of questionable properties not found in the predesign investigations. Construction specifications should allow the engineer to use CPT or other in-place tests.

B. Sectional Embankment or Preloading.--Where highly compressible soils extend to great depths, CPT can be used to determine settlement at various points. This information indicates that preloading the foundation soil or a sectional embankment is needed if settlements, differential settlements, and horizontal strain are problems. If preloading or a sectional embankment does not provide a solution to the problem, relocation of the structure may be required. Data from CPT will aid in locating soils of acceptable properties, if such soils exist in the area of consideration. Sampling and testing will then confirm the decision of structure location.

Data from CPT at locations of stilling basins and risers will confirm the results of tests on samples which are in many cases obtained only on the centerline of the structure.

C. Channels.--Channel projects usually involve stratified soils and encompass long reaches. Use of the friction sleeve cone is accurate enough to classify the soils vertically and horizontally so that sampling will be more representative and the investigation will also be faster and thus more economical.



CONE PENETROMETER EQUIPMENT: This equipment is manufactured by Goudsche Machinefabriek of Gouda, Holland. a. hydraulic load cell with bourdon-tube gages, 1. cutoff to protect the 0-100 kgf/cm² gage, 2. cutoff to protect the 0-15 gage, 3. quick-coupling to disconnect the 0-15 gage; b. cap for attaching load cell or pulling attachment (f) to the drill rig adapter; c. mantle cone, shown in closed and extended position; d. cone with Begemann friction sleeve, shown in closed and completely extended position; e. 30 cm long sounding tube with 15 mm inner rod and anti-friction (4) ring; f. pulling attachment for retrieving the sounding tubes. Not shown are the 1 m sounding tubes and the Depth Indicating Rod & Stand.

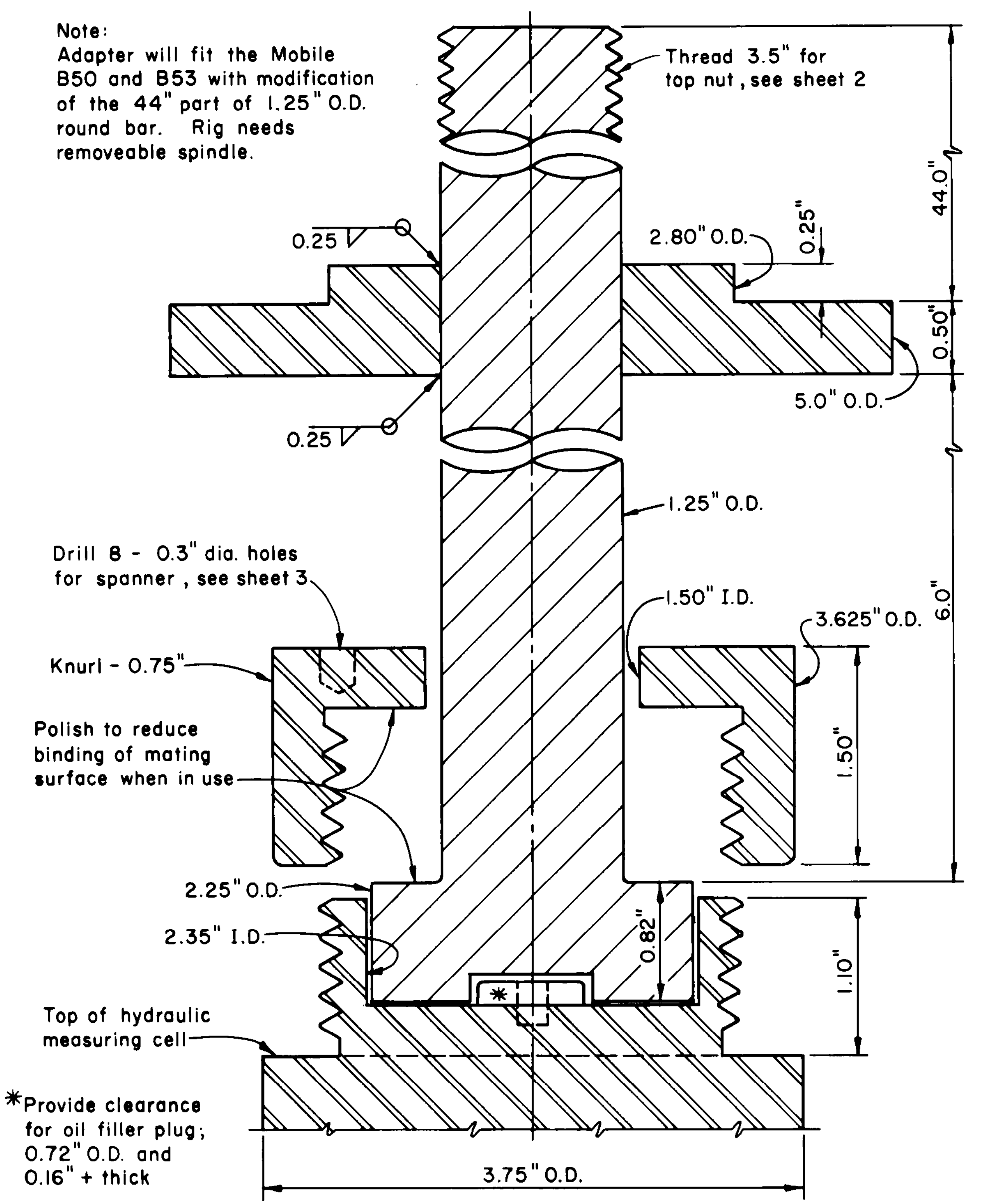
Drill Rig Adapters

1. The drawing shows the adapter to fit the CME-75; the adapter can also be used with the Mobile B-50 and B-53 when the 44-inch dimension (see upper corner of drawing) is modified. The Mobile rigs need a hollow spindle to use this adapter.

2. Drill rigs having less than 1 meter of downstroke are less desirable since the operation is much slower. If the drill rig has an automatic chuck, an adapter can be made similar to that shown on the bottom half of the drawing for the CME-75 adapter, No. 1; the upper end would have to adapt to the threads on the Kelley bar. Check the clearance from the drill rig cross-head to the back of the penetrometer gages; center of load cell to back of gages is 4½ inches minimum and can be extended using an additional union nut and properly threaded pipe nipple.

3. The CME-55 is readily adapted by fabricating a shelf bracket which attaches to the drill cross-head. This adapter leaves the auger spindle free for any needed drilling. The shelf bracket does not need to be removed between tests.

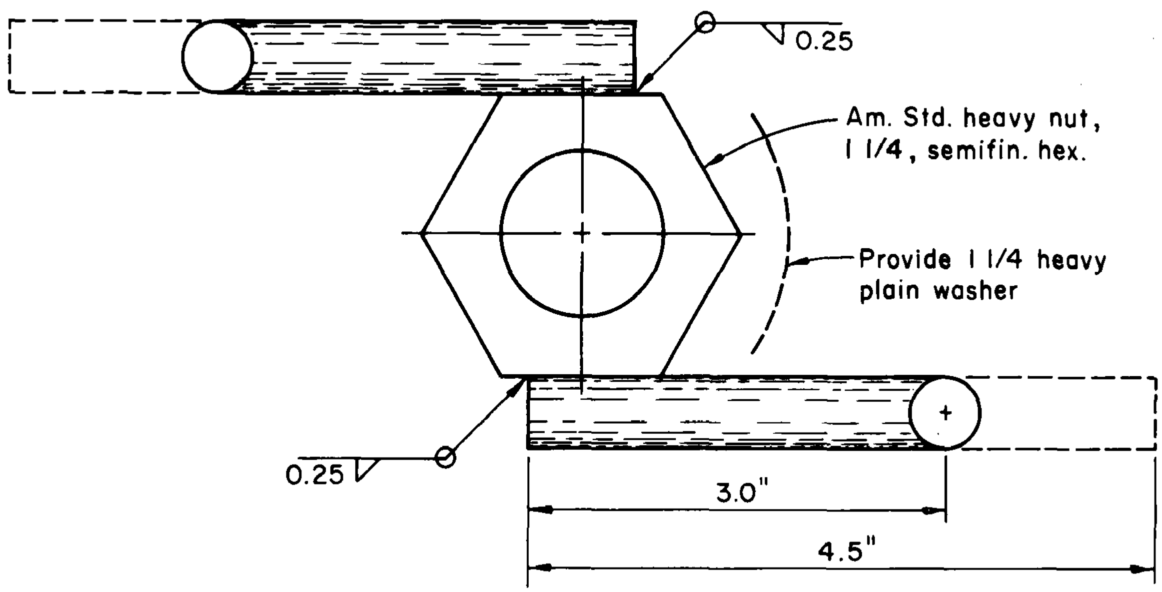
4. The CME-45 adapter is a short shaft with a cap similar to the lower end of the CME-75 adapter. A plate is welded to the shaft and then bolted to the upper half of the auger U-joint.



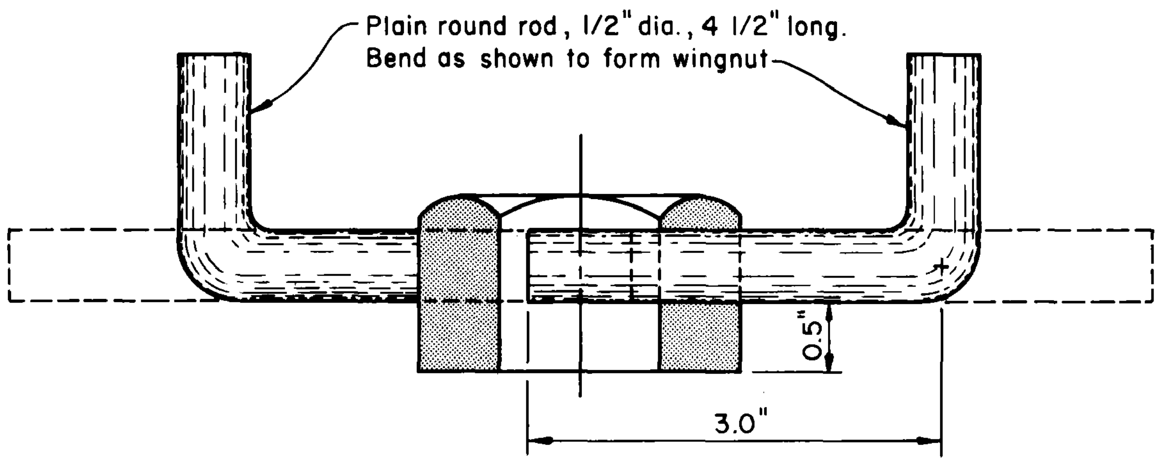
CONE PENETROMETER ADAPTER FOR CME 75 DRILL

Sheet 1 of 3

R.J.F.
4 - 77



PLAN

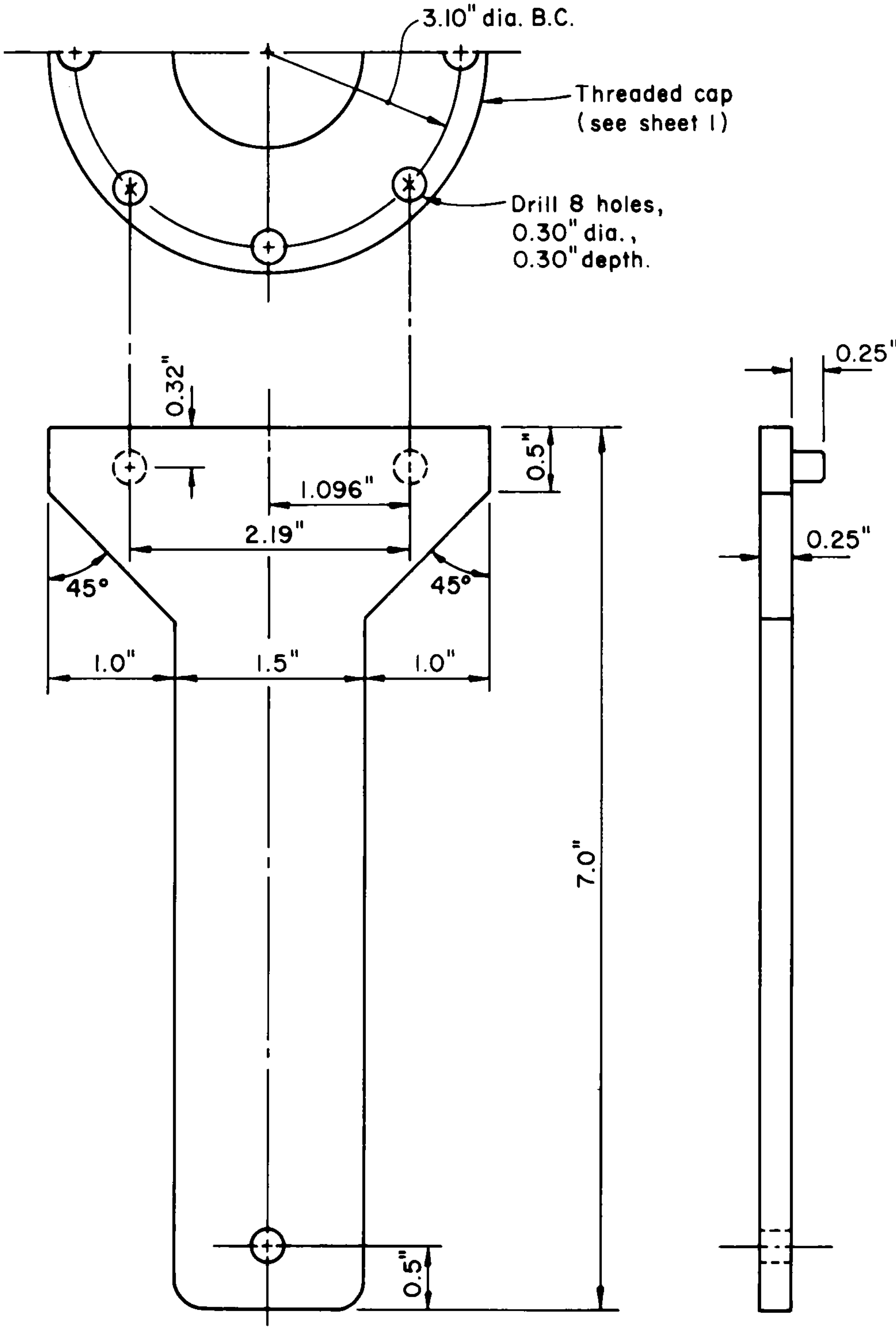


ELEVATION

CONE PENETROMETER ADAPTER
FOR CME 75 DRILL

Sheet 2 of 3

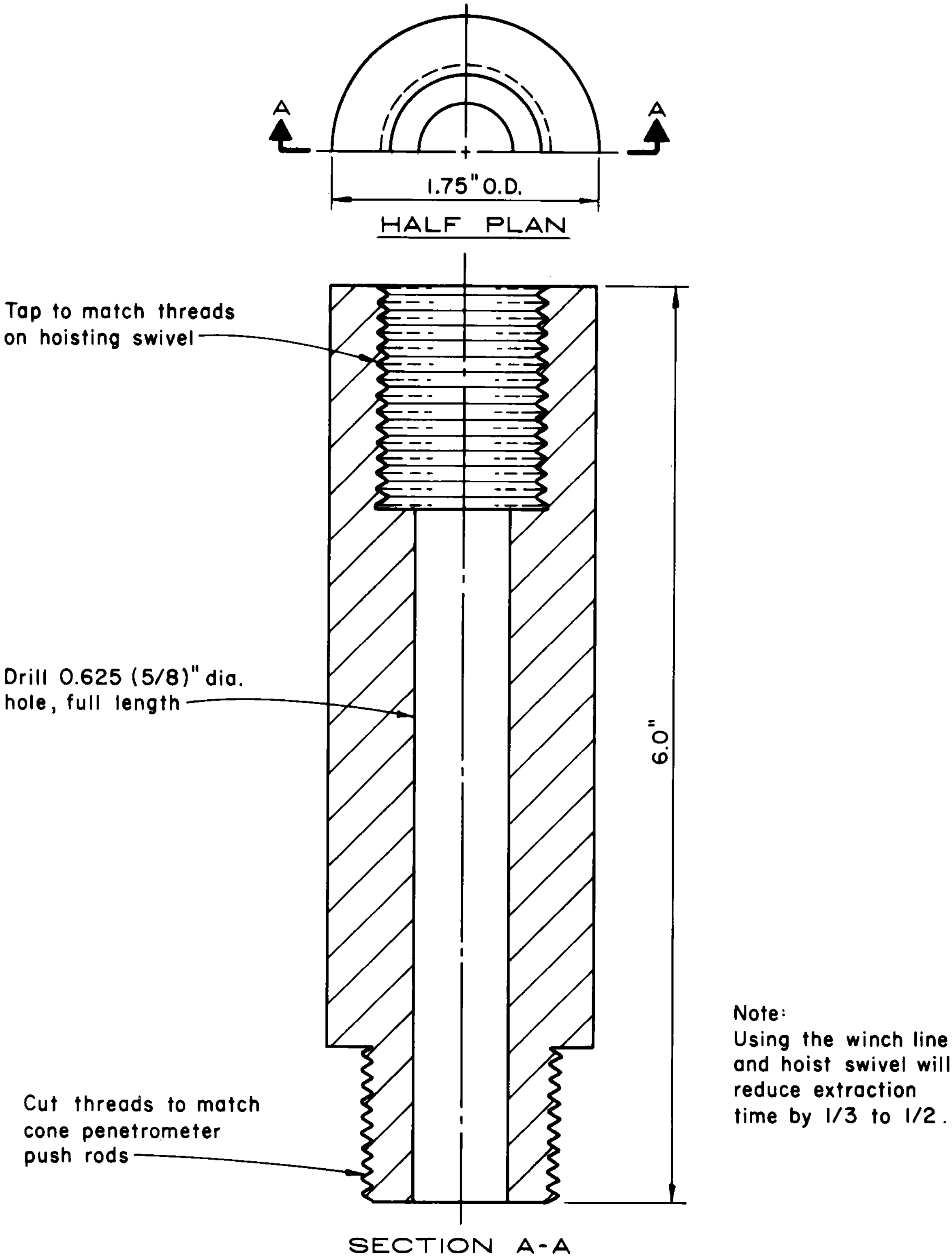
R.J.F.
4-77



SPANNER WRENCH
FOR CONE PENETROMETER

Sheet 3 of 3

R.J.F.
4-77



CONE PENETROMETER ADAPTER

Attachment to adapt cable hoist for push tube retrieval

R. J. F.
4-77

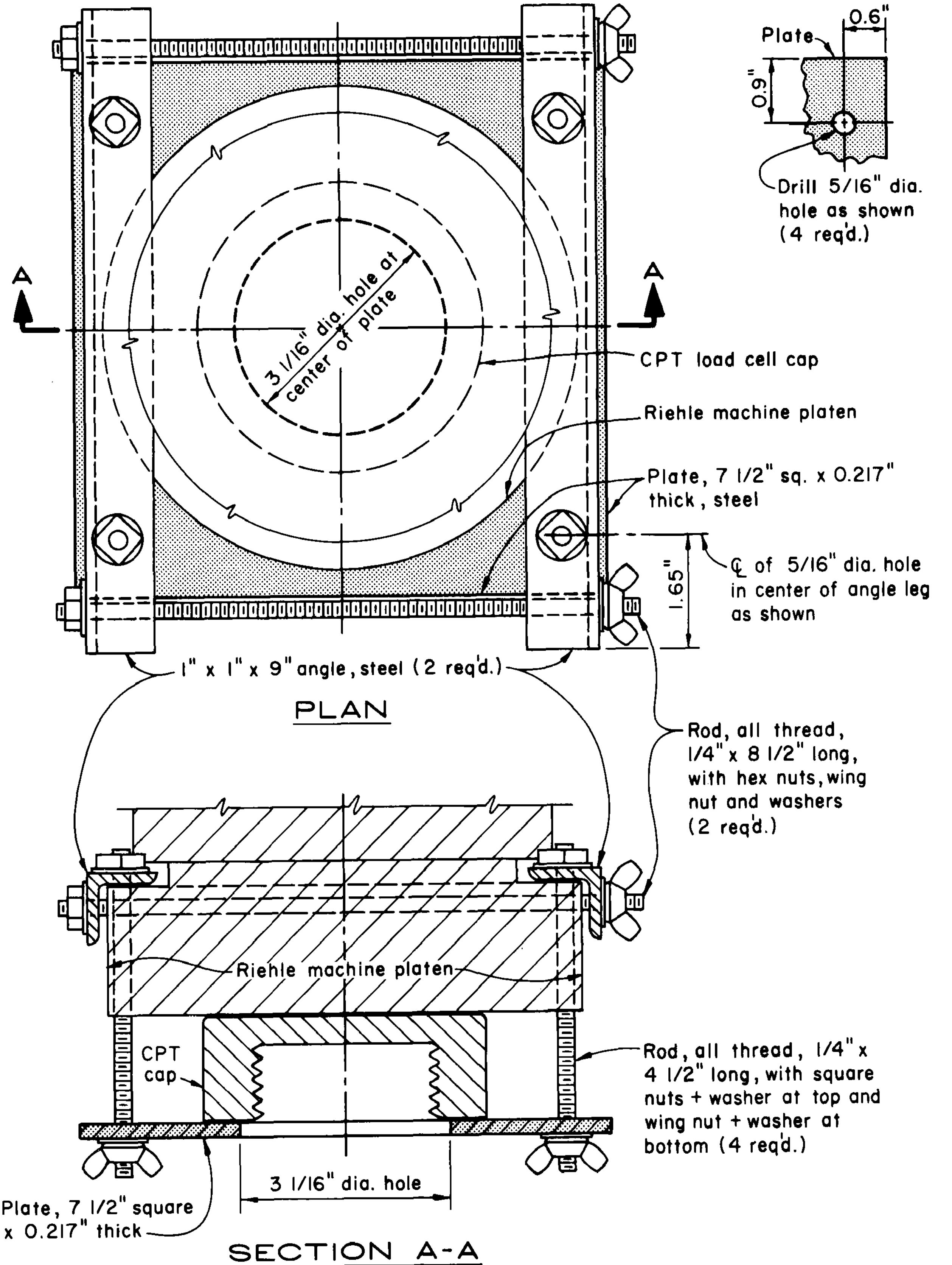
Adapter for Checking Load Cell Gages

The purpose of this adapater is to place the load cell in an upright position for testing the gages. The load cell is secured to the platen of the compression-testing machine and will not fall over and be damaged when the cross-head is raised. Without the adapter, the gages are usually checked with the load cell inverted. When checking three gages (0-15, 0-100, and 0-600 kgf/cm^2), the union nuts have to be loosened to place the load cell inverted; with the adapter, no union nuts are loosened.

Graph of Laboratory Compression Machine Gage vs. Cone Penetrometer Gages

When the accuracy of the penetrometer gages is checked, the 0-16 kgf/cm^2 gage should plot within 25 lb of the value shown on the graph. The values for the 0-100 kgf/cm^2 gage should plot within 100 lb of the value shown on the graph: the value at the upper and lower end of the gage travel may be less accurate, which is a reason for the overlap in penetrometer gage scales. The values for the 0-600 kgf/cm^2 gage should plot within 200 lbs of the value shown on the graph. When test data are nearly all recorded from the 0-16 kgf/cm^2 gage, a correction can be applied, if needed, before reducing the notes and plotting the penetration graphs of q_c, f_s, and FR. Corrections are seldom needed for the other two gages because the indicated soil properties are obtained from high values of resistance to penetration.

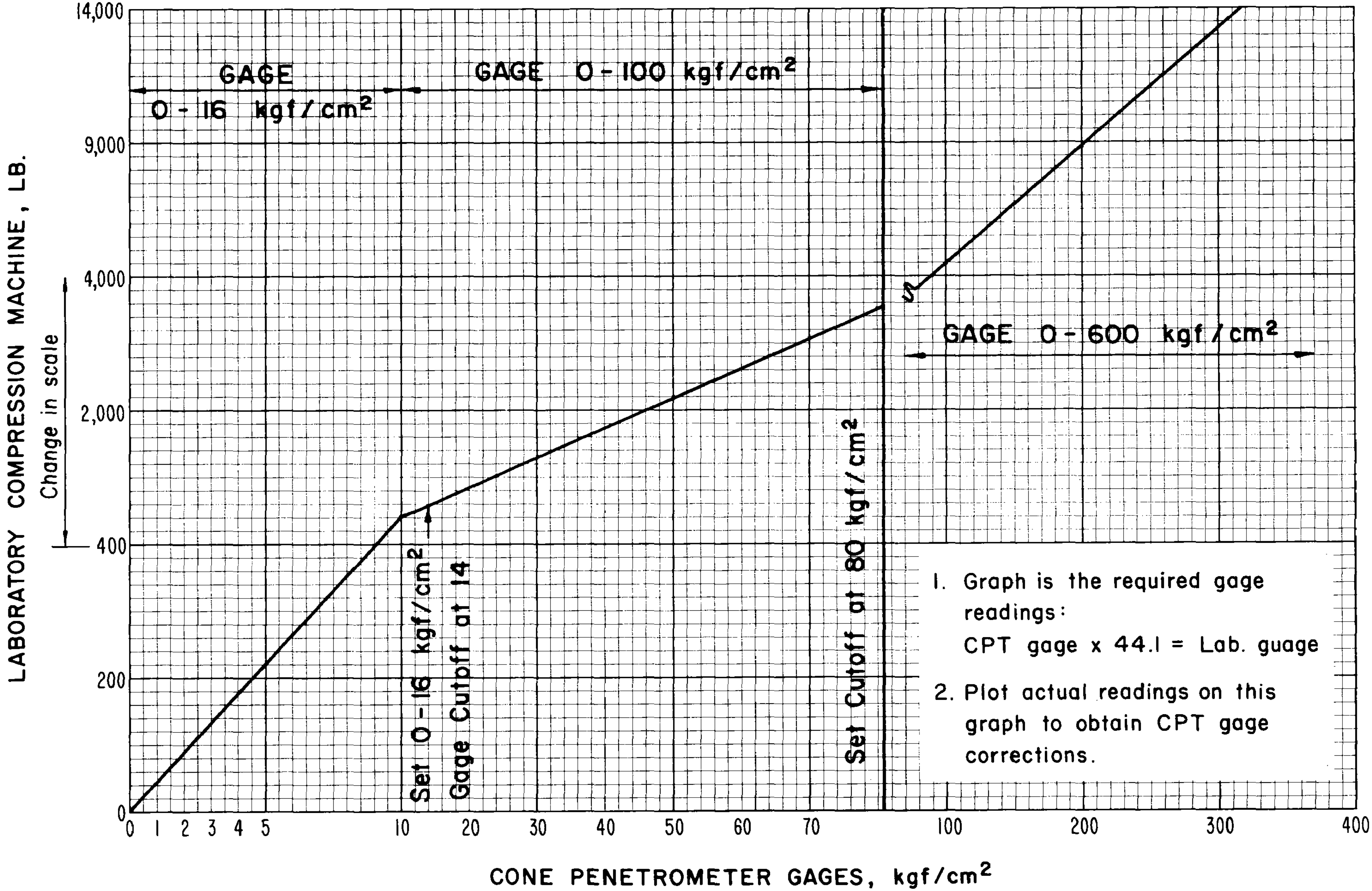
Excessive errors in the penetrometer gages are reasons for returning gages to the distributor/manufacturer. Errors in gage readings are sometimes caused by unloading the gages too rapidly during field testing.



CPT ADAPTER FOR CHECKING LOAD CELL GAGES

SCALE: 0.5" = 1.0"

R.J.F.
2-4-81


GAGE
0 - 16 kgf/cm²
GAGE 0 - 100 kgf/cm²
GAGE 0 - 600 kgf/cm²
Set 0 - 16 kgf/cm²
Gage Cutoff at 14
Set Cutoff at 80 kgf/cm²
Change in scale
LABORATORY COMPRESSION MACHINE, LB.
CONE PENETROMETER GAGES, kgf/cm²
14,000
9,000
4,000
2,000
400
200
0
0 1 2 3 4 5 10 20 30 40 50 60 70 100 200 300 400
1. Graph is the required gage readings:
CPT gage x 44.1 = Lab. guage
2. Plot actual readings on this graph to obtain CPT gage corrections.

3. Field Record Sheets

Examples of forms designed for recording gage readings and reducing notes are shown. When soft soil is being penetrated, be sure to record the number of sounding tubes in use. The weight of the 15 mm inner rods can be an appreciable part of the cone point record. Recording the number of inner rods is also the method used to maintain the record of depth of penetration.

Continuous sounding is generally used in sand where f_s is not significant. Although the form is set for the 10 cm intervals, the gages can be read at 5 cm if desired, and the records entered on the line.

When reducing notes, friction ratio (FR) is expressed as a percentage. FR = $f_s \times 100 \div q_c$; q_c is taken from the previous reading. The reason for taking q_c from 20 cm higher is apparent when the dimensions of the friction sleeve cone point are examined. When fully extended, the friction sleeve is located 21.5 to 34.8 cm above the cone point.

CONE PENETROMETER (FRICTION SLEEVE)

STATE		PROJECT		
BY	DATE	T.H. NO	OFFSET	STA.

DEPTH m	NO. OF RODS	GAGE READINGS 1	GAGE READINGS 2	DEPTH m	NO. OF RODS	GAGE READINGS 1	GAGE READINGS 2	DEPTH m	NO. OF RODS	GAGE READINGS 1	GAGE READINGS 2
0.0											
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
1.0				8.0				15.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
2.0				9.0				16.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
3.0				10.0				17.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
4.0				11.0				18.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
5.0				12.0				19.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
6.0				13.0				20.0			
.2				.2				.2			
.4				.4				.4			
.6				.6				.6			
.8				.8				.8			
7.0				14.0				21.0			

No. of Rods = number of sounding tubes; the inner rods (15 mm dia.) add 0.14 n kgf/cm^2 to the cone point.

This form was designed for reducing notes using a printing calculator; the CPT graph is plotted from the tape output.

CONE PENETROMETER FIELD LOG

T.H. NO. ______ STA. __________ DATE __________ LOCATION ________________ SITE ________

DEPTH		N	GAGE READING		ΔG	q_c	f_s	FRICTION RATIO	NOTES
Meters	Feet	Number of One Meter Rods	P1 Cone	P2 Cone Sleeve	P2 - P1	0.14N + 2P1	$0.133 \Delta G$	$\frac{f_s}{q_c} \times 100$ (qc from) (up 20 cm)	
0						0.14			
0.2									
0.4									
0.6									
0.8									
1.0	3.3								
1.2						0.28			
1.4									
1.6									
1.8									
2.0	6.6								
2.2						0.42			
2.4									
2.6									
2.8									
3.0	9.8								
3.2						0.56			
3.4									
3.6									
3.8									
4.0	13.1								
4.2						0.70			
4.4									
4.6									
4.8									
5.0	16.4								
5.2						0.84			
5.4									
5.6									
5.8									
6.0	19.7								
6.2						0.98			
6.4									
6.6									
6.8									
7.0	23.0								
7.2						1.12			
7.4									
7.6									
7.8									
8.0	26.2								

CONE PENETROMETER FIELD LOG

T.H. NO. ________ STA. __________ DATE __________ LOCATION __________________ SITE __________

DEPTH		N	GAGE READING		ΔG	q_c	f_s	FRICTION RATIO	NOTES
Meters	Feet	Number of One Meter Rods	P1 Cone	P2 Cone Sleeve	P2 - P1	0.14N + 2P1	$0.133 \Delta G$	$\frac{f_s}{q_c} \times 100$ (qc from) (up 20 cm)	
8.0									
8.2						1.26			
8.4									
8.6									
8.8									
9.0	29.5								
9.2						1.40			
9.4									
9.6									
9.8									
10.0	32.8								
10.2						1.54			
10.4									
10.6									
10.8									
11.0	36.1								
11.2						1.68			
11.4									
11.6									
11.8									
12.0	39.4								
12.2						1.82			
12.4									
12.6									
12.8									
13.0	42.7								
13.2						1.96			
13.4									
13.6									
13.8									
14.0	45.9								
14.2						2.10			
14.4									
14.6									
14.8									
15.0	49.2								
15.2						2.24			
15.4									
15.6									
15.8									
16.0	52.5								

CONE PENETROMETER FIELD LOG

T.H. NO. ______ STA. ________ DATE ________ LOCATION ______________ SITE ________

DEPTH		N	GAGE READING		ΔG	q_c	f_s	FRICTION RATIO	NOTES
Meters	Feet	Number of One Meter Rods	P1 Cone	P2 Cone Sleeve	P2 - P1	$0.14N + 2P1$	$0.133 \Delta G$	$\frac{f_s}{q_c} \times 100$ (qc from) (up 20 cm)	
16.0									
16.2						2.38			
16.4									
16.6									
16.8									
17.0	55.8								
17.2						2.52			
17.4									
17.6									
17.8									
18.0	59.1								
18.2						2.66			
18.4									
18.6									
18.8									
19.0	62.3								
19.2						2.80			
19.4									
19.6									
19.8									
20.0	65.6								
20.2						2.94			
20.4									
20.6									
20.8									
21.0	68.9								
21.2						3.08			
21.4									
21.6									
21.8									
22.0	72.2								
22.2						3.22			
22.4									
22.6									
22.8									
23.0	75.5								
23.2						3.36			
23.4									
23.6									
23.8									
24.0	78.7								

CONE PENETROMETER - CONTINUOUS SOUNDING

STATE		PROJECT		
BY	DATE	T.H. NO.	STA.	DIST.

DEPTH IN METERS	GAGE	qc, kgf/cm²	DEPTH IN METERS	GAGE	qc, kgf/cm²	DEPTH IN METERS	GAGE	qc, kgf/cm²
0								
0.1			3.1			6.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
1.0			4.0			7.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
2.0			5.0			8.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
3.0			6.0			9.0		

Gage, 0 - 15 kgf/cm² correction = ________ .

CONE PENETROMETER - CONTINUOUS SOUNDING

STATE			PROJECT		
BY	DATE		T.H. NO.	STA.	DIST.

DEPTH IN METERS	GAGE	qc, kgf/cm^2	DEPTH IN METERS	GAGE	qc, kgf/cm^2	DEPTH IN METERS	GAGE	qc, kgf/cm^2
9.0								
9.1			12.1			15.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
10.0			13.0			16.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
11.0			14.0			17.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
12.0			15.0			18.0		

Gage, 0 - 15 kgf/cm^2 correction = ________ .

CONE PENETROMETER - CONTINUOUS SOUNDING

STATE		PROJECT		
BY	DATE	T.H. NO.	STA.	DIST.

DEPTH IN METERS	GAGE	qc, kgf/cm^2	DEPTH IN METERS	GAGE	qc, kgf/cm^2	DEPTH IN METERS	GAGE	qc, kgf/cm^2
18.0								
18.1			21.1			24.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
19.0			22.0			25.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
20.0			23.0			26.0		
.1			.1			.1		
.2			.2			.2		
.3			.3			.3		
.4			.4			.4		
.5			.5			.5		
.6			.6			.6		
.7			.7			.7		
.8			.8			.8		
.9			.9			.9		
21.0			24.0			27.0		

Gage, 0 - 15 kgf/cm^2 correction = ________ .

4. Plotting Methods

There are several reasons for establishing a uniform method of plotting CPT graphs:

a. q_c, f_s, and FR are plotted on one shet for convenience in using the data.

b. q_c and f_s can be compared for two or three tests when plotted on semitransparent paper and to the same vertical and horizontal scales. This comparison is especially valuable when test data from one set of undisturbed samples taken in one test hole are being extrapolated vertically and in several horizontal directions.

c. The mixing of metric and British units of measure is eliminated. There is no need to use British units except for adding a depth scale after the graph is plotted (see examples).

d. Specifications for cone penetrometer testing to be included in site investigation contracts are uniform and the reported data are uniform.

e. Only two printed forms are needed for plotting graphs:

(1) 8½ x 11", 4 cycle x 70 divisions (Keuffel and Esser No. 66 6013, or similar), for plotting depths of 0 to 14 meters.

(2) 11" x 16½", 4 cycle x 150 divisions (Keuffel and Esser No. 47 6013, or similar), for plotting depths of 0 to 26 meters.

The plotted points are connected free hand with a fine felt-point pen (Pilot Razor Point or similar, black) to form the graphs for q_c, f_s, and FR.

Examples of Cone Penetration Tests

a. Iowa: Twin Ponies Watershed (near Council Bluffs)

A composite of several CPT graphs was drawn to show the similarity of the foundation soils on one side of the valley and the difference in the soils between the right and left sides of the valley, which are divided by a deep erosional channel.

Sta 1+45--right side of valley: CPT's were made on centerline, 100' downstream and 100' upstream. The soil above the water table (6.2 m) shows variable, but low q_c and f_s, indicating that density and in-place shear strength are low. The q_c and f_s increase between 8 and 14 meters, then become nearly constant to a depth of 19.6 m (64 ft).

The test on centerline was continued to near refusal in a layer of sand and gravel; possibly the test could have been continued to 23 or 24 m (about 77 ft). The samples shown as being obtained to a depth of 6.5 m (22 ft) represent the weakest and most compressible soil, but they would not give, upon testing, information as to total settlements or the lower limit for estimating settlement. CPT's were made right and left of Sta 1+45, which gives confidence in extrapolating test data from one set of samples from test hole 2 on centerline at Sta 1+45, right baseline.

Sta 2+08--left side of valley: The graphs show more variability, but generally higher q_c and f_s to a depth of 6.5 m (22 ft). Between 6.5 and 9 m (30 ft), q_c, f_s, and FR increase uniformly, both above and below the water table and in two soil formations. Below 9 m, q_c is generally constant except for thin sand and silt layers; these layers are apparent from the variability of f_s and FR. Test hole 7 was on centerline, 7b and 7c were 100' and 200' downstream and 301 was 95' upstream of Sta 2+08, left baseline. The undisturbed samples represent only the weaker and more compressible soils above the apparent water table. Note that the penetration test was carried to 21.6 m (71 ft) without encountering refusal or any definite increase in q_c or f_s with the increasing depth. The plotting method used here shows the value of being able to overlay graphs and compare the data.

b. Nebraska: Tekamah-Mud Creek Watershed (about 40 miles north of Omaha)

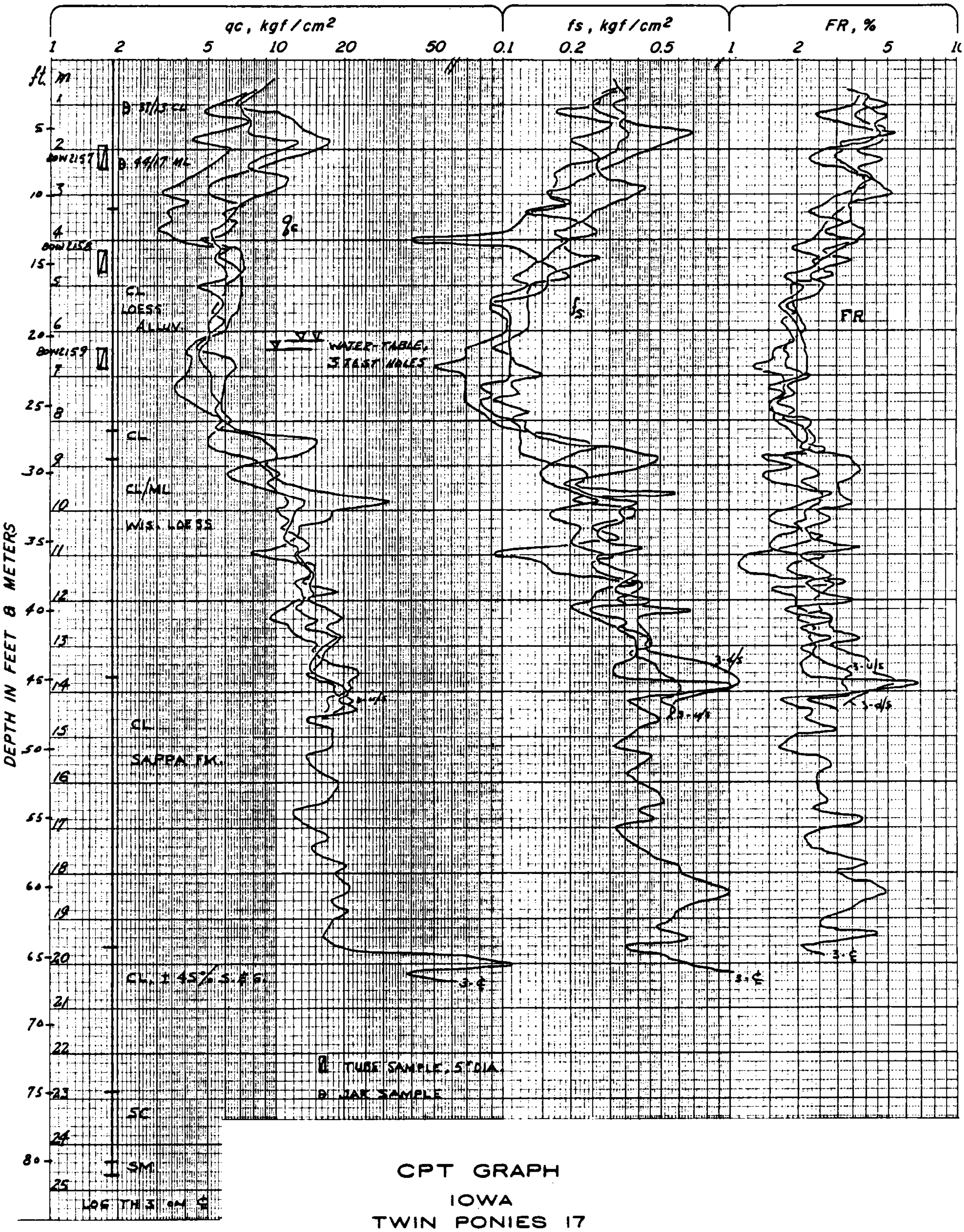
The increase in moisture as the test approaches the water table depth is readily apparent as q_c and f_s both decrease. q_c and f_s increase from 5 to 8.5 m; a strata of sand and silt is found from 8 to 10 m. The auger hole was discontinued at 10.7 m; the CPT shows a strong layer of CL or CH soil from about 11 to 15 m where q_c is 15-20 kgf/cm^2 and f_s > 0.5 kgf/cm^2. q_c and f_s both decrease until refusal at 21.2 m (69.5 ft). This structure was built between September 1979 and May 1980; settlement plates at Sta 16+00 and 18+00 show 3.6 and 3.7 ft of settlement from September 1979 to December 1980. Estimated settlement, based on CPT was 3.5 and 3.7 ft for 49 and 54 ft of embankment load. Shallow undisturbed samples were of little value for comparing settlement estimates.

c. Nebraska: Clear Creek Watershed (about 25 miles west of Omaha)

This graph shows the effect of moisture increase with depth; sand and silt strata between 3.5 and 5 meters; a low-density, weak layer at 3 to 4 m and at 6 m; weak layers at 11 and 15 meters; and sand strata at 14 meters. The graph for FR from 5 to 13 meters shows a nearly constant soil classification where q_c and f_s are changing, indicating changing density, in-place shear strength, and potential settlements.

d. Nebraska: South Fork Watershed (about 60 miles southeast of Lincoln)

Two CPT's were performed at Sta 23+50, one on the survey line and one 200' downstream. Both graphs indicate many weak, low-density layers divided by relatively thin layers of sand or sand-silt mixtures. One test was terminated in a sand-gravel layer just above the shale bedrock, the other in weathered shale. Six tube samples are shown on the log of the test hole; only two proved reliable in subsequent testing and analysis. These two CPT graphs were the basis for relocating this structure to more reliable foundation.

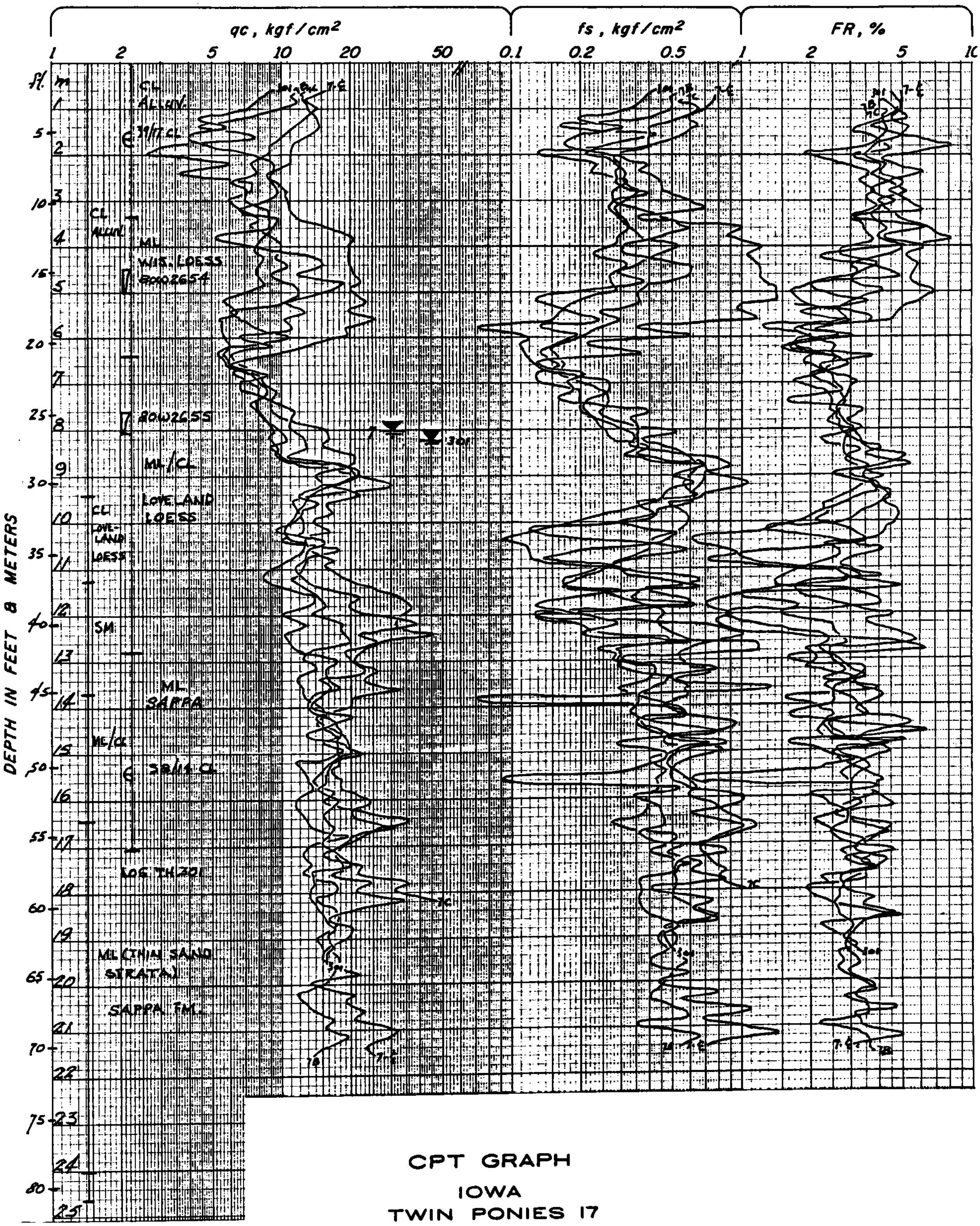


CPT GRAPH

IOWA
TWIN PONIES 17

COMPOSITE GRAPH FOR
STA. 1+45 RT. ℄

R.J.F. 1-81



CPT GRAPH

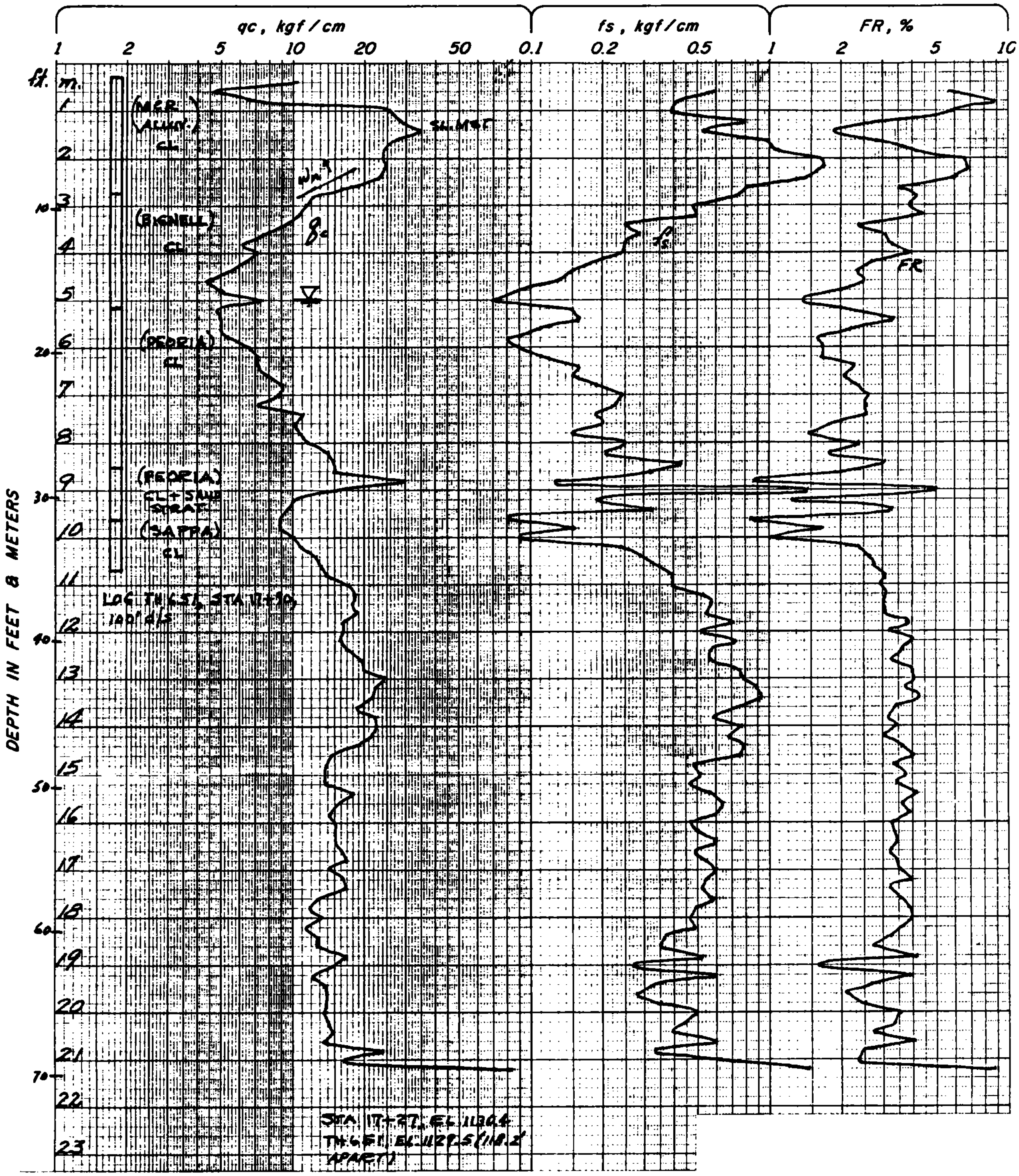
IOWA

TWIN PONIES 17

COMPOSITE GRAPH FOR

STA: 2+08 LT. ℄

R.J.F. 1-81



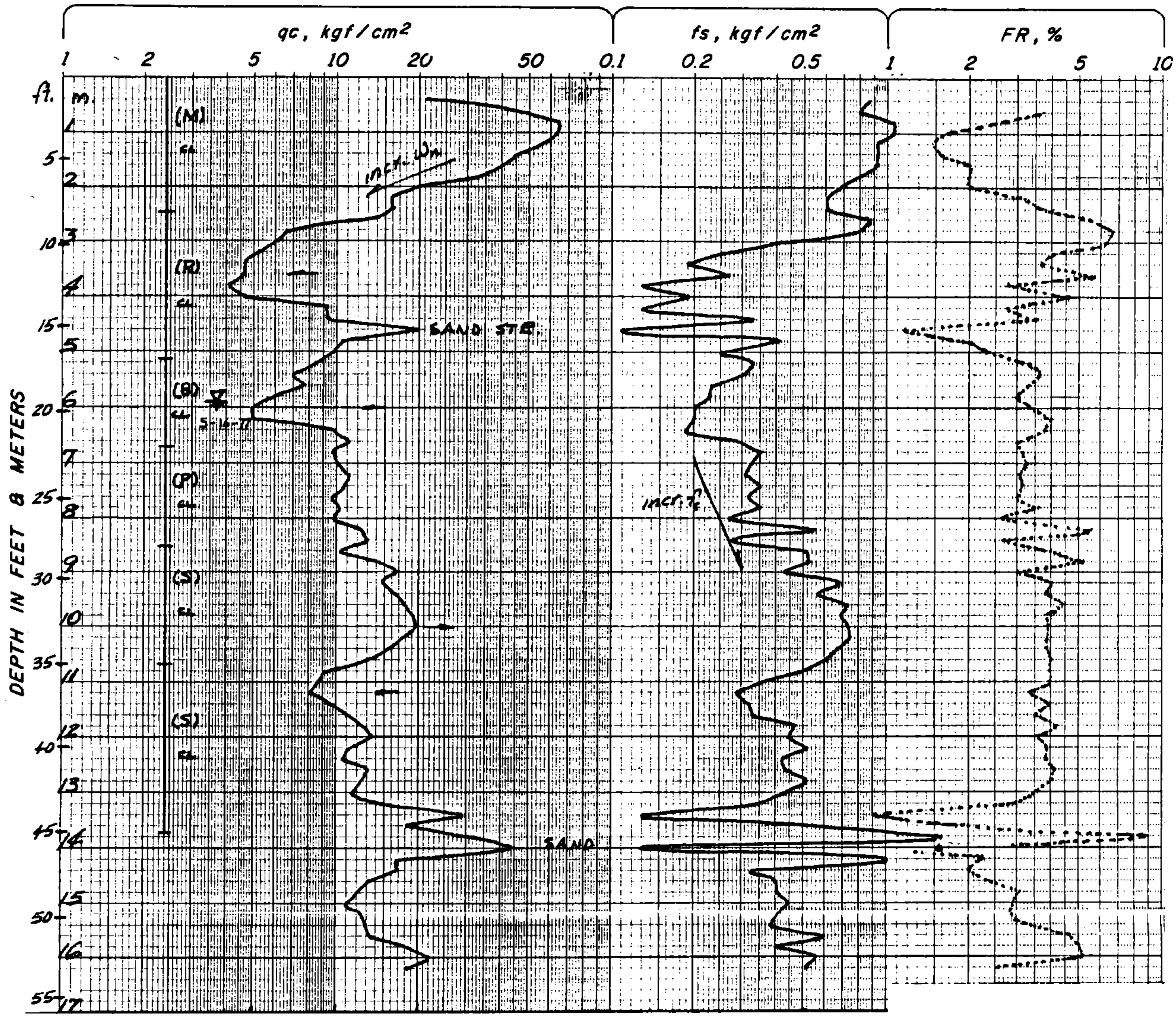
CPT GRAPH

NEBRASKA

TEKAMAH-MUD 5A

STA. 17+27 AT ℄, T.H. 651 (REP.)

R.J.F. 7-77

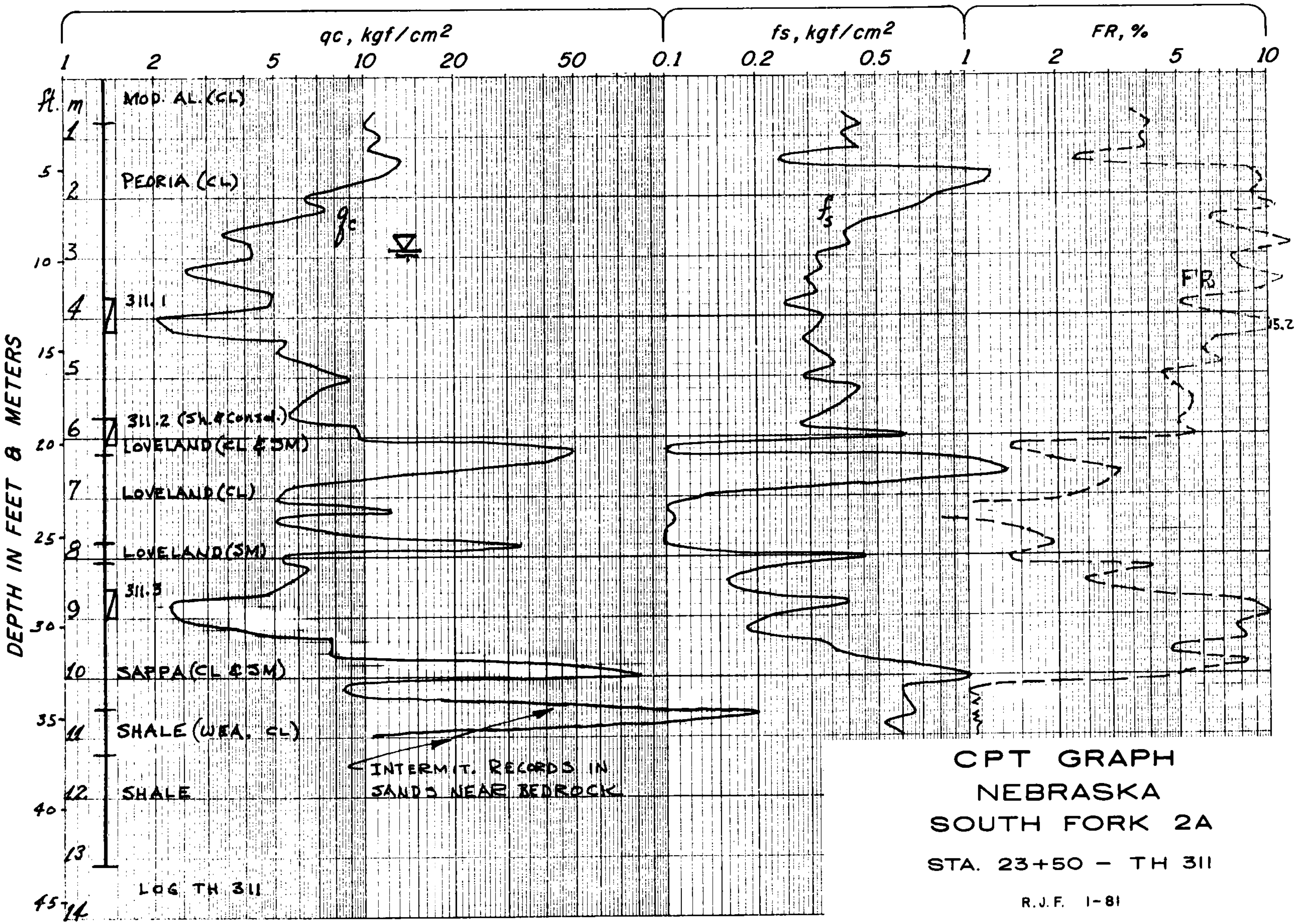


CPT GRAPH

NEBRASKA
CLEAR CREEK - 7A

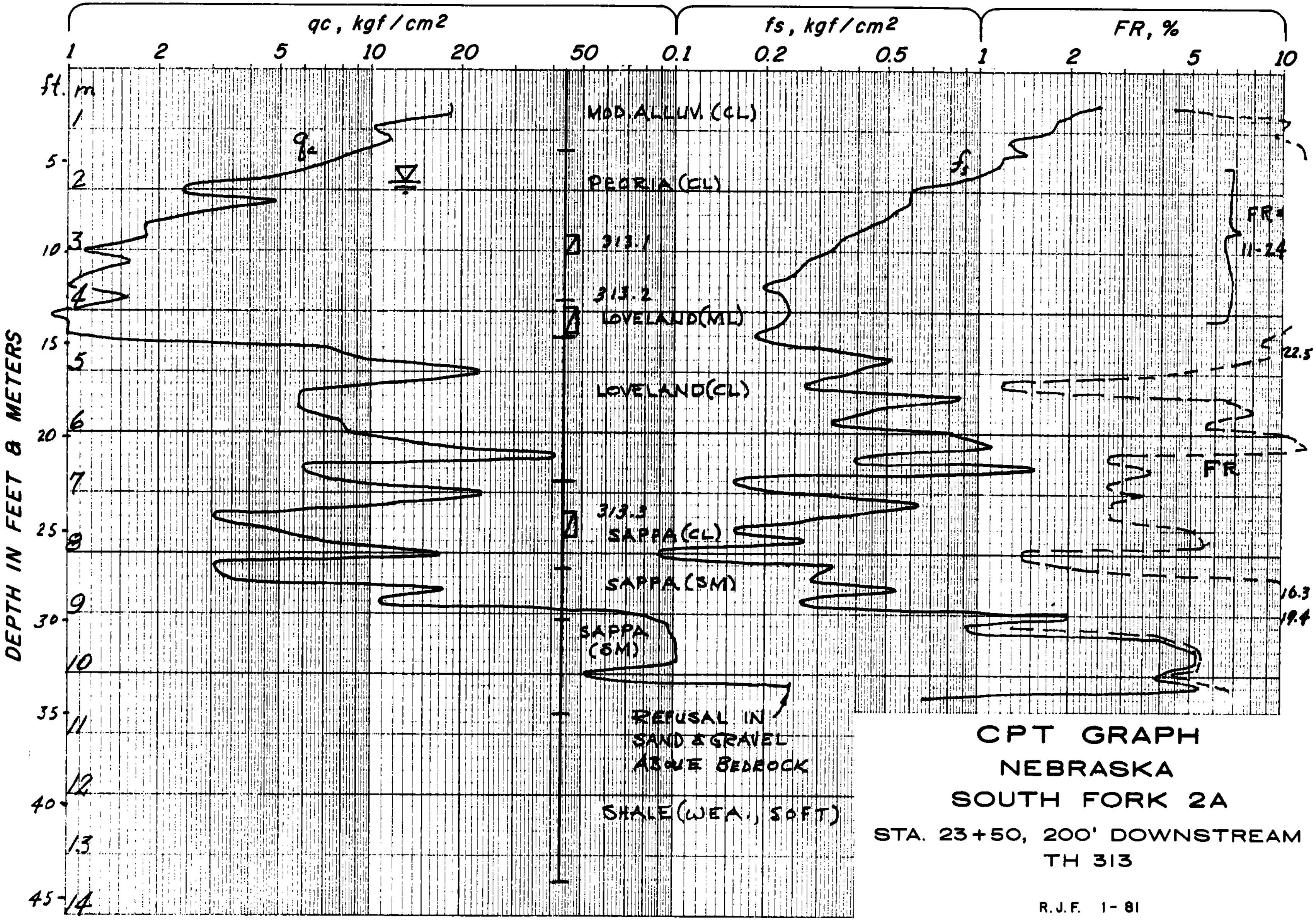
STA. 10+10 T.H. 78

R.J.F. 1 - 81



CPT GRAPH
NEBRASKA
SOUTH FORK 2A
STA. 23+50 – TH 311

R.J.F. 1-81



CPT GRAPH
NEBRASKA
SOUTH FORK 2A

STA. 23+50, 200' DOWNSTREAM
TH 313

R.J.F. 1-81

CONE PENETROMETER FIELD LOG

T.H. NO. 56 STA. 12+00 DATE 6-22-76 LOCATION Tekemah-Mud SITE 5A

DEPTH Meters	DEPTH Feet	N Number of One Meter Rods	GAGE READING P1 Cone	GAGE READING P2 Cone Sleeve	ΔG P2 - P1	q_c 0.14N+2P1	f_s 0.133ΔG	FRICTION RATIO $\frac{f_s}{q_c} \times 100$ (q_c from) (up 20 cm)	NOTES
0						0.14			
0.2									
0.4									
0.6									
0.8									
1.0	3.3	2	7.1	16.0	8.9	14.5	1.18	—	
						0.28			
1.2			9.5	20.0	10.5	19.3	1.40	9.66	
1.4			9.1	17.0	7.9	18.5	1.05	5.44	
1.6			6.2	12.7	6.5	12.7	0.86	4.67	
1.8			5.2	10.0	4.8	10.4	0.64	5.03	
2.0	6.6	3	4.4	7.3	2.9	9.2	0.39	3.71	
						0.42			
2.2			3.4	6.1	2.7	7.2	0.36	3.90	(R)
2.4			1.9	3.6	1.7	4.2	0.23	3.14	
2.6			2.4	3.7	1.3	5.2	0.17	4.12	
2.8			2.5	4.0	1.5	5.4	0.20	3.84	
3.0	9.8	4	2.2	3.8	1.6	5.0	0.21	3.94	
						0.56			
3.2			2.3	3.7	1.4	5.2	0.19	3.72	
3.4			2.2	3.7	1.5	5.0	0.20	3.84	
3.6			2.8	4.1	1.3	6.2	0.17	3.46	
3.8			2.8	4.1	1.3	6.2	0.17	2.79	B
4.0	13.1	5	2.5	3.8	1.3	5.7	0.17	2.79	
						0.70			
4.2			1.8	2.8	1.0	4.3	0.13	2.33	
4.4			1.6	2.5	0.9	3.9	0.12	2.78	
4.6			2.0	2.8	0.8	4.7	0.11	2.73	
4.8			2.1	2.8	0.7	4.9	0.09	1.98	
5.0	16.4	6	2.8	3.5	0.7	6.4	0.09	1.89	
						0.84			
5.2			5.0	6.0	1.0	9.4	0.13	2.08	Fast
5.4			3.8	5.7	1.9	8.4	0.25	3.41	
5.6			4.4	8.0	3.6	9.6	0.48	5.70	
5.8			2.2	3.6	1.4	5.2	0.19	1.94	
6.0	19.7	7	3.4	4.6	1.2	7.8	0.16	3.07	
						0.98			
6.2			2.3	4.5	2.2	5.6	0.29	3.75	(P)
6.4			1.9	3.2	1.3	4.8	0.17	3.09	
6.6			3.3	4.8	1.5	7.6	0.20	4.16	
6.8									
7.0	23.0								
7.2									
7.4									
7.6									
7.8									
8.8	26.2								

EXAMPLE -
FROM TEKEMAH - MUD, SITE 5A
STA. 12+00 - TEST HOLE 56
(FOR USE WITH NON-PRINTING CALCULATOR)

CONE PENETROMETER TEST (CPT); SPECIFICATION FOR INCLUSION IN SITE INVESTIGATION CONTRACTS

Cone Penetrometer Tests (CPT) using static or quasi-static equipment shall be performed in accordance with ASTM Designation D 3441-75T with the inclusion of the additions and requirements as given below.

Equipment providing reaction force for CPT shall be capable of at least 4000 kg (about 9000 lb) of downward force and an equal or sufficient upward force to retrieve the penetrometer. The stroke, or travel, distance shall be greater than 1 meter. Equipment controls shall be capable of providing constant downward speed of 1 to 2 cm/sec against varying soil resistance. Control adjustments and travel speed shall be checked before beginning a penetrometer test. The equipment shall have at least three hydraulic leveling jacks in working order. None of the equipment weight shall be allowed to rest upon the wheels of the equipment during penetration testing.

Penetrometer equipment shall be complete onsite and shall include the hydraulic load cell with three gages attached, measuring 0 to 600 kgf/cm^2, 0 to 100 kgf/cm^2, and 0 to 16 kgf/cm^2; at least twenty-five 1-meter push rods or tubes; one 30-cm-long push tube with an antifriction ring: two each of friction-sleeve cone and mantle cone: spare parts including (but not limited to) gages, hydraulic load cell oil, push rod extender for continuous cone penetration; and miscellaneous spare parts and necessary tools for maintenance. Hydraulic load cell oil shall be of such vicosity that gages function properly at air temperatures of -25 ^{o}F. Cone penetrometer equipment shall be made available for checking condition and maintenance at any time.

Penetrometer tips shall be cleaned and oiled before each test. The amount of disassembly needed to clean the tip is dependent on the classification of the soil being penetrated. Some clay soils will adhere to interior surfaces making complete disassembly, cleaning, and oiling of the tip necessary.

Push tubes shall be cleaned as they are retrieved after completing a test. The tube threads shall be cleaned to ensure a tight joint with only hand effort (no tools).

A maximum of 1.5 percent of the original penetrometer tip dimensions shall be allowed for wear.

CPT shall be performed using the friction cone penetrometer in fine-grained soil or in stratified fine- and coarse-grained soil. In coarse-grained soil, the cone penetrometer (mantle cone) shall be used in the continuous mode with load cell records obtained at 5-cm intervals. The antifriction ring section of push rod shall be mounted directly above the penetrometer tip and shall be used when penetrating fine-grained or stratified soils.

CPT shall be continued to refusal in either dense soils or bedrock. The reason for discontinuing a test shall be noted on the field log. Isolated rocks shall not be considered as refusal; the test location shall be moved 2-5 feet and the test started again from the ground surface. Deviations in alignment caused by isolated rocks or tree roots will require the test to be restarted from the ground surface.

CPT data, including cone resistance (q_c), friction sleeve resistance (f_s), and friction ratio (FR) shall be plotted in graph form. Undisturbed sampling locations shall be selected based on interpretation of this penetration data and on logs of nearby test holes.[1/] When undisturbed samples cannot be obtained with available tools, additional CPT shall be performed to delineate the three-dimensional boundaries of these soils and to provide data on in-place engineering properties.

Cone penetrometer test data shall be plotted on 4 log cycle x 70 division graph paper for depths to 14 m and on 4 log cycle x 150 division graph paper for depths exceeding 14 m. The first and second log cycles shall be reserved for the q_c graph (1 to 10, 10 to 100 kgf/cm^2); the third cycle shall be reserved for the f_s (0.1 to 1.0 kgf/cm^2); and the fourth cycle shall be reserved for FR (1 to 10 percent). The depth scale shall be plotted in the metric system with each graph division equal to 20 cm. The graph shall include the site name or number, location, related drill hole number, name of person who reduced the field notes and plotted the graph, and the date the graph was completed. The graph shall be accompanied by a copy of the field note record. No units of force or length shall be converted from metric to British units, either during the testing and recording or when reducing notes and plotting data.

The graphs shall be of such quality that copies suitable for inclusion in subsequent reports can readily be made on local copying machines.

[1/] Specify the person responsible for determining sampling needs.

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☆U.S. Government Printing Office : 1988 - 201-056/80215