FIELD CALIBRATION OF DUTCH CONE PENETROMETERS FOR LOUISIANA SOILS

Final Report

by

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ABSTRACT

Various sites that were penetrated by Louisiana's DOTD foundation boring crews with the mechanical cone penetrometer (Dutch Cone Penetrometer) and rotary drill rig (core borings) are discussed. A comparison of the resultant tests is given including stratigraphy determination, soil consistency, and ultimate capacity. Also some of the results of a corollary study of an electronic cone penetrometer (ECP) (Fugro Cone) performed in the same area are shown and compared.

Results of this study show that the mechanical cone penetration (MCP) test compares favorably (better than conventional lab test) with test piles driven in the vicinity, provided the foundation material is not too soft. Correlation between MCP and ECP is also given. In addition, these results correlate well with known geology.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
	Area	
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
	Volume (Capacity)	
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
	Mass	
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
	Mass per Volume	
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
	Temperature	
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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IMPLEMENTATION STATEMENT

Implementation of this project can be started as soon as the two recommendations for further study are complete. These recommendations are for the purpose of verifying procedures suggested herein. After confirmation, the use of the Dutch Cone Penetrometer, properly called the mechanical cone penetrometer (MCP), may provide monetary savings by eliminating laboratory testing since the MCP test for ultimate pile capacity prediction is an in-situ test. While this report does not address the slope stability or settlement problem as others have, the accuracy of the predictive process of ultimate pile capacity is surprising. Within certain limits explained herein, the verification need not be a formal research project but can be done along with routine testing presently in use by the Department.

INTRODUCTION

The Louisiana Department of Transportation and Development acquired a "Dutch" or Mechanical Cone Penetrometer (MCP) ostensibly for use for foundation investigation. At about this time, Louisiana State University (LSU) conducted an extensive investigation into the use of the "Fugro" or Electronic Cone Penetrometer (ECP) for foundation investigations (1, 2, 3, 4)*. This LSU research served as a catalyst to this project since the ECP data would become available. One intent of the ECP work was to correlate its results against the field and the standard lab tests and the conclusions that were reached from the latter two. It was decided that this would be an auspicious way to determine what the MCP test results would be, and how well they correlated to ECP results.

The MCP test is a sounding into the deeper foundation soils of interest. As the sounding takes place, measurements of the resistance offered to penetration of a conical tip of 60° and an area of 10 cm^2 are read from hydraulic gauges at the surface. The cone used in this study also has a "friction jacket" immediately above the cone which produces measurements (via the same gauges) of the friction/adhesion (F/A) which the surrounding medium offers to penetration. The gauges or load cells show the downward force required to overcome the penetration and F/A resistance, and these readings must be recorded by hand. For a more complete explanation of the device see Reference 5; however, a less extensive explanation will be given herein.

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*Underlined numbers in parentheses refer to the list of references.

PURPOSE AND SCOPE

The purpose of this study was to determine whether there is any correlation between the MCP and ECP test results, the MCP and the standard laboratory unconfined compression test, classification test, and the MCP and test piles. In reality, the last correlation is the most relevant; if one can predict ultimate pile capacity from MCP tests, then all other correlations become moot.

METHOD OF PROCEDURE

Equipment

The equipment that the Department used to accomplish the penetration should be discussed before any results are presented. The La. DOTD used a new Failing 1500 drill rig mounted on a new Ford (F-700) truck. It was found that a faulty hydraulic system such as found on some of the older models still serviceable for rotary drilling operations was not satisfactory for penetration. In addition, it was necessary to tie down the system in some manner to furnish the cone enough reaction to penetrate in medium to very stiff soils. One other adaptation was made to the penetrometer itself. The coupling furnished with the penetrometer kit to couple the cone and stems to a loading frame for extraction had to be modified slightly. Figures 1 and 2 show these modifications.

Sounding Sites

Three general locations were chosen for the mechanical cone penetrometer--soft soils near the coast and Lake Pontchartrain, the stiffer materials of the terrace in the lower portion of the state, and the very stiff soils of the mid and northern parts. All three general locations had been penetrated by the ECP, and the MCP soundings were done at the same sites.

Soft Soils

One site was chosen for correlation in the area near the coast. That area was in the town of Houma (see Figure 3) on State Project 855-03-14, Prospect Street Bridge. There were four different pile shapes to be checked, an 18-inch-square concrete, 12-inch-diameter steel, 14-inch-diameter steel, and a step taper pile, all of which are embedded to a depth of 95 feet. The stepped pile dimensions started at 14-3/8 inches diameter and stepped downward to a diameter

One of Tw[illegible] Augers to Serve As a Reacti[illegible]ation

Cone Penetrom[illegible]ition. Note Adapt[illegible] and Gauges, and "Tiedow[illegible] Background.

[illegible]

of 10-3/8 inches at one-inch steps. Each section was 16 feet long. The bottom step was 9-1/2 inches diameter and was 25 feet long. This and all piles' predicted ultimate loads will be discussed in the subsequent chapter.

The Stiffer Soils

Two sites in Baton Rouge (Figure 3) were investigated under an elevated section of I-110, State Project 450-33-56, Harding Boulevard-Badly Road. Here only one shape was to be investigated, a 14-inch-square concrete. The pile at Harding was embedded 45 feet and the other, at Badly Road, was embedded 43 feet.

Another location that is in an area where extremely soft material overlies the same geologic formation as is at the surface at Baton Rouge is the isthmus that lies between Lake Pontchartrain and Lake Maurepas about 30 miles northwest of New Orleans. The pile to be checked was 24-inch-square concrete, 65 feet long.

The Very Stiff Soils

Generally, the "very stiff soils" of central and northern Louisiana are silty, and sandy clays are of the Tertiary epoch, typically of the Eocene age. These soils, together with the Bentley and Williana (Pleistocene) range in age from 1 to 60 million years old. Consequently, these make up some of the firmer foundations in the state. The firm foundations proved to be impenetrable with the rig used by the Department.

Special Sounding

During the course of this study, the design section requested soundings in the Bonnet Carre Spillway west of New Orleans and south of Lake Pontchartrain (at LaPlace). There were a number

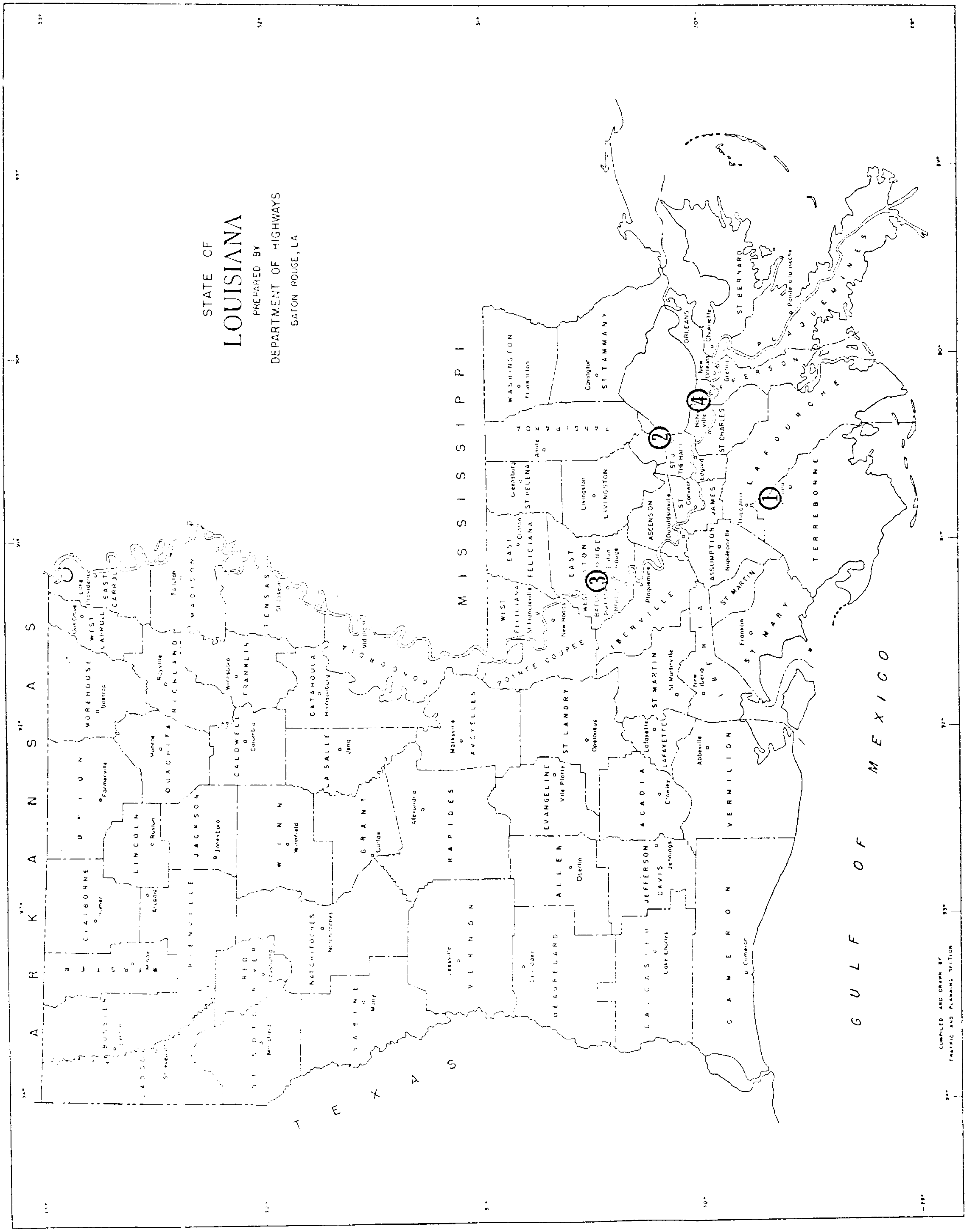

STATE OF
LOUISIANA
PREPARED BY
DEPARTMENT OF HIGHWAYS
BATON ROUGE, LA
ARKANSAS
MISSISSIPPI
TEXAS
GULF OF MEXICO
COMPILED AND DRAWN BY
TRAFFIC AND PLANNING SECTION
UNION
MOREHOUSE
WEST CARROLL
EAST CARROLL
CLAIBORNE
LINCOLN
OUACHITA
RICHLAND
MADISON
FRANKLIN
TENSAS
JACKSON
CALDWELL
CATAHOULA
CONCORDIA
LA SALLE
WINN
BIENVILLE
RED RIVER
NATCHITOCHES
GRANT
RAPIDES
AVOYELLES
SABINE
VERNON
BEAUREGARD
ALLEN
EVANGELINE
ST LANDRY
POINTE COUPEE
WEST FELICIANA
EAST FELICIANA
ST HELENA
WASHINGTON
ST TAMMANY
LIVINGSTON
EAST BATON ROUGE
WEST BATON ROUGE
IBERVILLE
ASCENSION
ST JAMES
ASSUMPTION
ST CHARLES
ORLEANS
ST BERNARD
PLAQUEMINES
JEFFERSON
LAFOURCHE
TERREBONNE
ST MARTIN
ST MARY
IBERIA
LAFAYETTE
ACADIA
VERMILION
JEFFERSON DAVIS
CALCASIEU
CAMERON
1
2
3
4

FIGURE 3

of pile shapes that the design section wished checked at three different sites. ECP soundings were also taken at the same sites. These piles are shown in Table 2 on page 23.

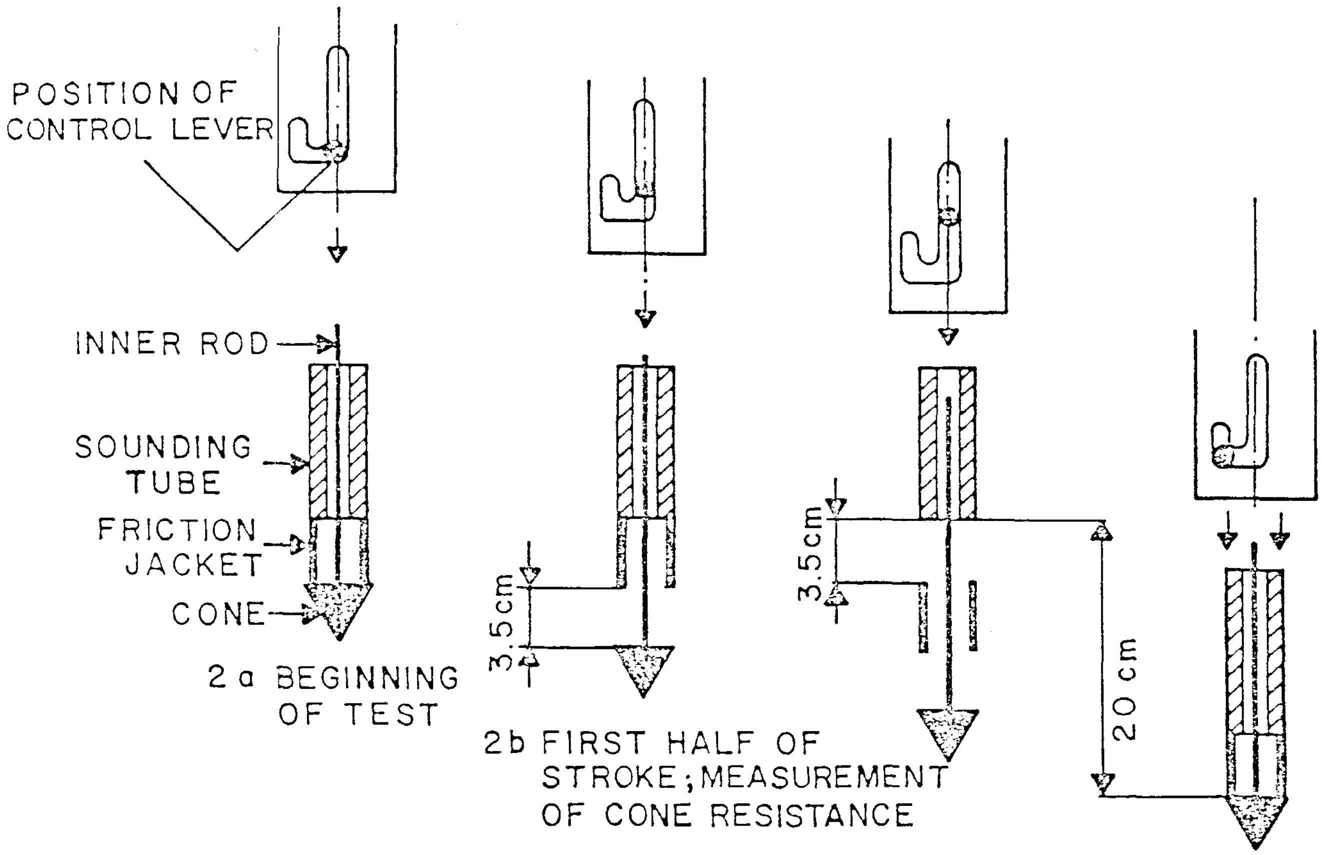
Procedures for Prediction

At the beginning, the procedures for prediction were those contained in "Guidelines for Cone Penetration Test - Performance and Design" prepared for the Federal Highway Administration by Dr. John H. Schmertmann (5) and Dr. Mehmet T. Tumay and M. Fakhroo (1). All calculations were done using a hand calculator. An example of these is shown in Appendix A. This is a rather complicated process which involves several hours for each pile. A computer program has now been developed by Dr. Tumay and his staff for use with the ECP. Since the ECP and the MCP measure the same properties when computing ultimate pile capacity, P_{ult}, i.e., resistance to penetration, q_c, and friction, f_s (the term used for friction/adhesion), that program is easily adaptable for MCP use and with minor modifications to the input mode.

The computations shown in Appendix A, Exhibit A-1, are explained as follows: As the cone is forced into the soil, the load cell feels an increase in pressure as shown by the dial gauge reading. This reading increases, hesitates momentarily, then continues to rise. When the end of the stroke is reached, indicated at the surface, the penetration is stopped. Dial readings are recorded at the moment of hesitation, written in the column headed C. At the end of the stroke F+C is recorded. The values in the column headed F are obtained by subtracting C from F+C (F+C-C). Since the load cell reads in kgf/cm^2, the area of the piston in the hydraulic load cell is 20 cm^2 and the area of the cone is 10 cm^2; therefore, q_c in kgf/cm^2 = 2 c. Similarly, the area of the friction cone is 150 cm^2 and $f_s = \frac{20}{150}$ F (see Figure 4). Friction ratio, $f_r = f_s/q_c \times 100$, is used only for the plot shown on the back of Exhibit A-1 along with q_c. The purpose of the plot is to

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



2c SECOND HALF OF STROKE; MEASUREMENT OF JACKET FRICTION + CONE RESISTANCE

2d ADVANCE TO NEXT DEPTH

CONE RESISTANCE: $25 \times 2 = 50$ 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

FIGURE 4

extend to the person doing the calculations the "picture" of the profile to work with. As a matter of fact, it is important to the Schmertmann calculations where the sands, clays or silts exist in relation to pile computations. That fact will be pointed out later.

Exhibit B-2 shows the actual Schmertmann/Tumay calculations of the ultimate pile capacity. There are two parts to the calculations. Part 1 is the calculation of end bearing and is strictly according to Schmertmann (5). Part 2 has two subparts. The first uses a penetrometer-to-pile friction ratio called α and is taken from (5) (Figure A-2). The second subpart uses the same ratio but is called "M-cone Method" and is symbolized by the letter m (1). As can be seen in Figure A-3, the M-cone Method was devised from Louisiana foundation soils, whereas the α Method is found in (5). Then too, Schmertmann divides the sounding into layers of sand and clay and uses different average values of $\bar{f}_s$ to produce different values of α for each. In the present example no such layering was evident, which is consistent with the geology of the area, so that $\bar{f}_s$ averaged for the entire length of the pile was used. The background of the computation is not fully explained in (5), but if one follows the procedure in "cookbook" fashion he will obtain good results.

A FORTRAN program modified from an unpublished program written by Tumay, et al., yields the same answer and is shown in the appendix. It takes the two dial readings recorded in the field and converts them into a plot of q_c versus depth, and f_r versus depth, so that the engineer can "see" the soil profile. The profile will take "getting used to" before the interpreter will understand it. The second part of the program gives the ultimate load at each depth increment, which is its big advantage. The design engineer merely has to know the design load and dimensions to determine the length. The program works as well with round piles as it does with square piles, and as well with steel as it does with concrete. It does not work with tapered or step tapered piles, although the program could be modified to work with step tapered piles. This program will be fully examined later in this report.

The output data is also shown as Exhibit B-6. According to Dr. Schmertmann (5), the friction of clays found from the friction sleeve should be reduced by 40 percent when computing pile friction. This procedure is disputable for the reason that there is no basis for the reduction. However, researchers decided to use the reduction anyway, and this is shown as Exhibit B-5. The determination of the soil type can be made from the output of Figures 1B and 2B. Noncohesive soils will display a low friction ratio, f_r, and, ideally, high penetration resistance, q_c. This may be interpreted from the plot or the printout. The input is 0.6 for cohesive soils and 1.0 for noncohesive.

By way of comparison, the ECP prints the q_c, f_s and f_r and gives a plot of the data on site in the field automatically, and that data is put into the computer in the office to yield the ultimate capacity.

DISCUSSION OF RESULTS

As was pointed out earlier, four general locations were penetrated with the Dutch cone as follows: the Baton Rouge area, Ruddock area (between Lake Maurepas and Lake Pontchartrain), Houma, and the Bonnet Carre Spillway. These locations are shown in Figure 3.

Representations of these soundings and the core holes are shown in Figures 5 through 11. On the outside edges of these figures are shown the values of cone resistance and friction ratio similar to those shown on the back sides of Exhibit 2. The two inner columns are: (1) a log analyzed from the sounding data, and (2) boring logs of the hole drilled at the site. The boring logs shown are a combination with visual observations--soil type and color plus notation of any structures found in the core sample--and laboratory/field tests--unconfined compression (q_c)/standard penetration test (N), though no standard penetration tests were performed in these borings--liquid limit (LL), and plasticity index (PI).

A number of tables and figures taken from (5) and others were used to determine the "Analysis of Dutch Cone Data." These figures and tables are shown in Appendix C, Figure C-1 and Tables C-1 and C-2. Generally, Figure C-1 shows that a soil layer with a higher q_c value and a particularly lower f_s value is a soil that is granular in nature, but these soils can display a rather low cone resistance if they are in a metastable condition. Further, soils with higher f_s and lower q_c values fall into the plastic range. Also by using the tables one can ascertain the consistency by simply computing N based on Table C-1 and going to Table C-2 to better determine the consistency.

Baton Rouge

Figures 5 and 6 depict the soundings and borings performed in the Baton Rouge location. The project name and number are shown on

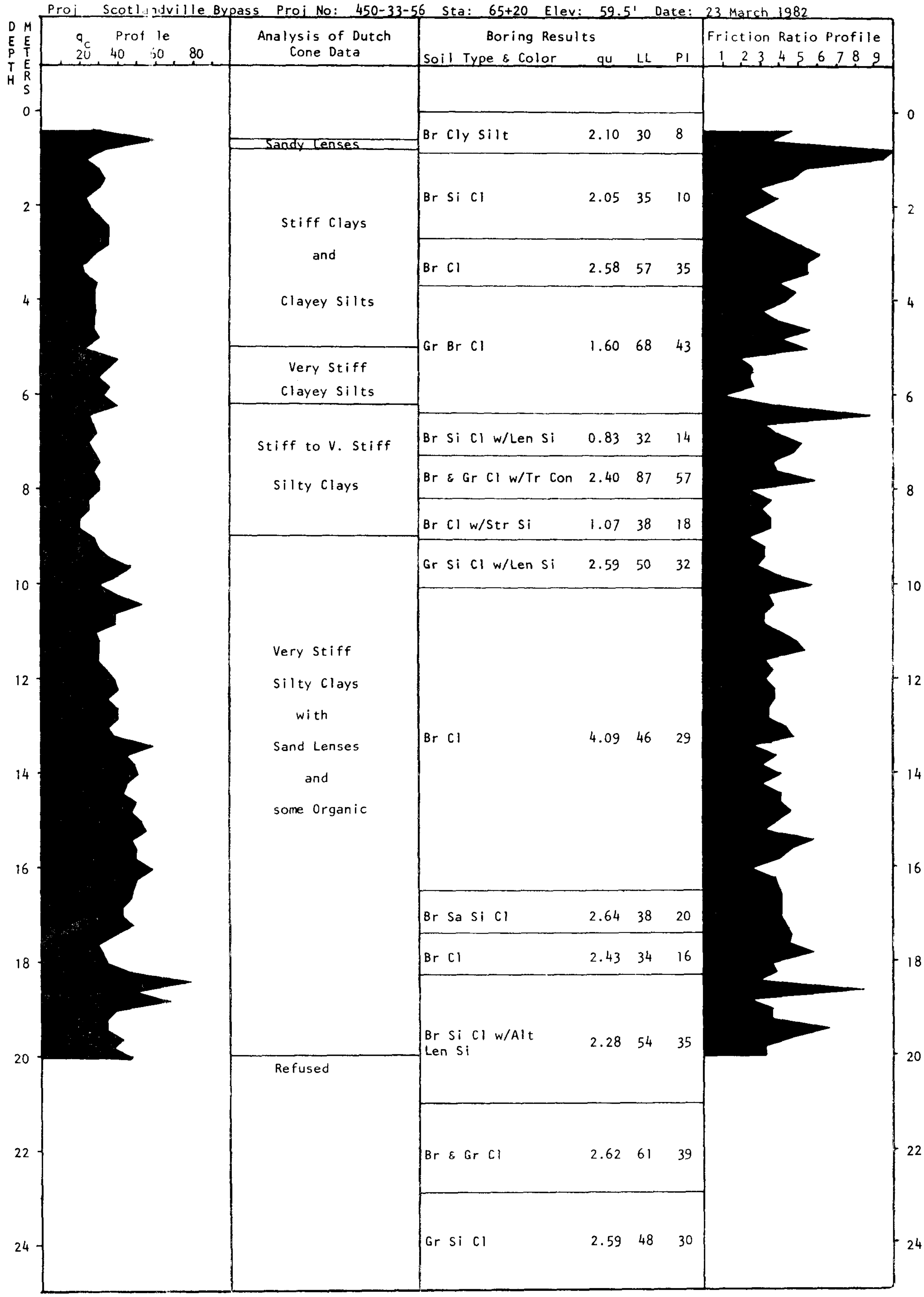
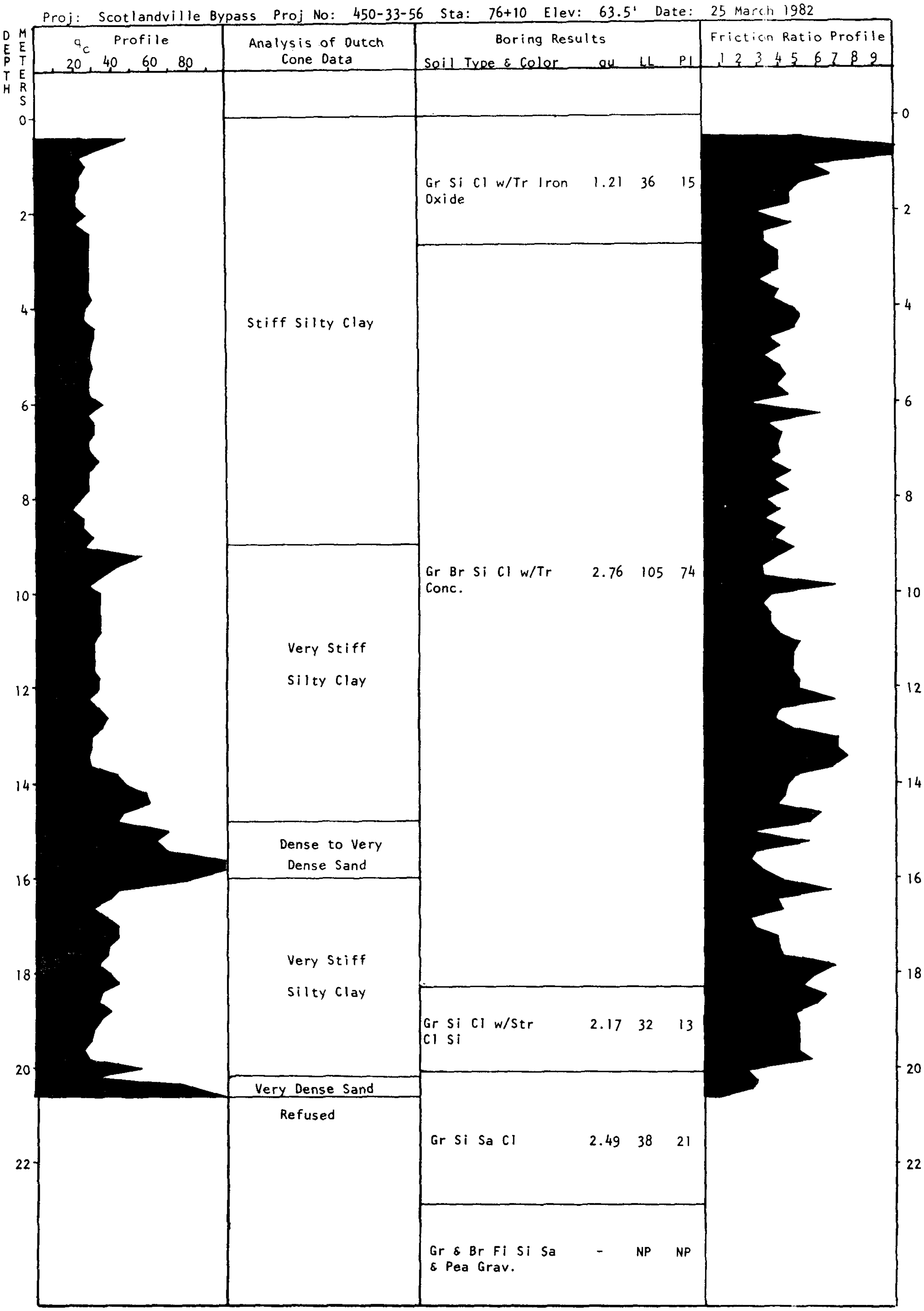

Proj Scotlandville Bypass Proj No: 450-33-56 Sta: 65+20 Elev: 59.5' Date: 23 March 1982
DEPTH METERS
q_c Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu LL PI
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
0
2
4
6
8
10
12
14
16
18
20
22
24
Sandy Lenses
Stiff Clays and Clayey Silts
Very Stiff Clayey Silts
Stiff to V. Stiff Silty Clays
Very Stiff Silty Clays with Sand Lenses and some Organic
Refused
Br Cly Silt 2.10 30 8
Br Si Cl 2.05 35 10
Br Cl 2.58 57 35
Gr Br Cl 1.60 68 43
Br Si Cl w/Len Si 0.83 32 14
Br & Gr Cl w/Tr Con 2.40 87 57
Br Cl w/Str Si 1.07 38 18
Gr Si Cl w/Len Si 2.59 50 32
Br Cl 4.09 46 29
Br Sa Si Cl 2.64 38 20
Br Cl 2.43 34 16
Br Si Cl w/Alt Len Si 2.28 54 35
Br & Gr Cl 2.62 61 39
Gr Si Cl 2.59 48 30

FIGURE 5



Proj: Scotlandville Bypass Proj No: 450-33-56 Sta: 76+10 Elev: 63.5' Date: 25 March 1982
DEPTH METERS
q_c Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu LL PI
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
Stiff Silty Clay
Very Stiff Silty Clay
Dense to Very Dense Sand
Very Stiff Silty Clay
Very Dense Sand
Refused
Gr Si Cl w/Tr Iron Oxide 1.21 36 15
Gr Br Si Cl w/Tr Conc. 2.76 105 74
Gr Si Cl w/Str Cl Si 2.17 32 13
Gr Si Sa Cl 2.49 38 21
Gr & Br Fi Si Sa & Pea Grav. - NP NP
0 2 4 6 8 10 12 14 16 18 20 22

FIGURE 6

the figures along with the elevation and station number of the sounding. As can be seen, the bore hole has more layers than the sounding, and in the case of Figure 6 there is evidence of a sand layer in the sounding that is not evident in the boring. Otherwise there seems to be a fair correlation between the two in spite of more layering in the boring log. The technicians who classify the materials for the boring log layering are influenced by a color change, by the feel of a core, and by a number of other things. Then too, the sounding and the boring are not in the exact same location; the two may be 25 to 50 feet apart. Furthermore, the techniques of sounding interpretations are far from perfect even though the sounding interpreter may not be influenced by appearance, feel, etc., of a core.

Ruddock

At the Ruddock location only one sounding is shown (Figure 7). Here is an example of marsh foundations. There are about 28 feet of very soft humus and loose silt with 1-1/2 to 2 feet of crust on top, if the marsh is dry. The Cajuns, inhabitants of French extraction, call this type of topography "trembling land." Beneath this "soup" there are Pleistocene clays and silts found at the surface at about the latitude of the north shore of Lake Pontchartrain and Baton Rouge. Here again some difference in classification is seen but the consistency is correlatable.

Houma

At this location, once again only one sounding and bore hole are shown (Figure 8). This is the type of foundation upon which the major part of New Orleans is situated. Four stringers of granular material which was deposited during "recent" time together with medium clays and silty clays can be seen here. These granular layers seen in the sounding correlate well with the sands in the boring log except that in the boring log they are deeper. This

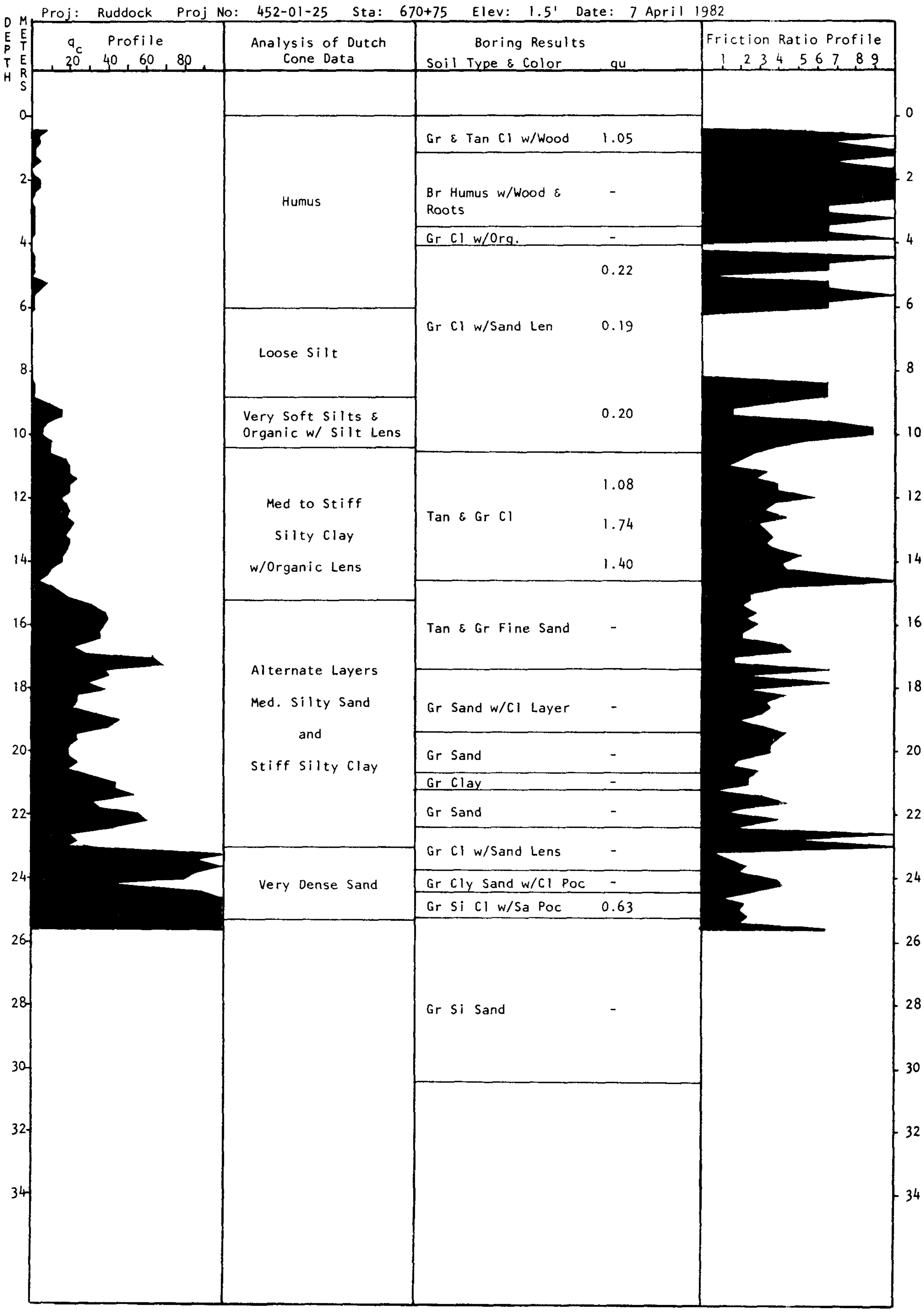

Proj: Ruddock Proj No: 452-01-25 Sta: 670+75 Elev: 1.5' Date: 7 April 1982
DEPTH METERS
q_c Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Humus
Loose Silt
Very Soft Silts & Organic w/ Silt Lens
Med to Stiff Silty Clay w/Organic Lens
Alternate Layers Med. Silty Sand and Stiff Silty Clay
Very Dense Sand
Gr & Tan Cl w/Wood 1.05
Br Humus w/Wood & Roots -
Gr Cl w/Org. -
0.22
Gr Cl w/Sand Len 0.19
0.20
1.08
Tan & Gr Cl 1.74
1.40
Tan & Gr Fine Sand -
Gr Sand w/Cl Layer -
Gr Sand -
Gr Clay -
Gr Sand -
Gr Cl w/Sand Lens -
Gr Cly Sand w/Cl Poc -
Gr Si Cl w/Sa Poc 0.63
Gr Si Sand -

FIGURE 7

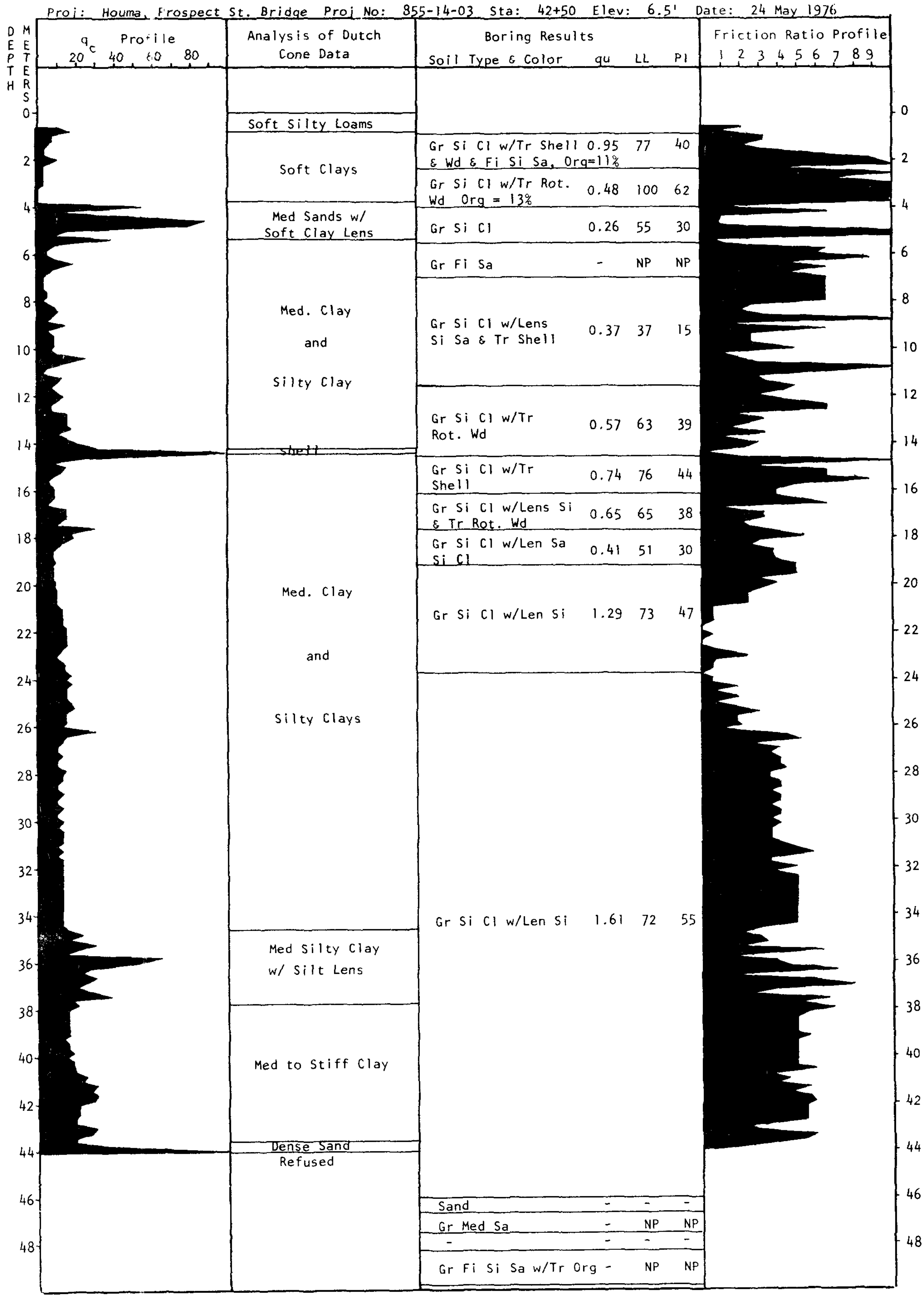

Proj: Houma, Prospect St. Bridge Proj No: 855-14-03 Sta: 42+50 Elev: 6.5' Date: 24 May 1976
DEPTH METERS
q_c Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu LL PI
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48
Soft Silty Loams
Soft Clays
Med Sands w/ Soft Clay Lens
Med. Clay and Silty Clay
Shell
Med. Clay and Silty Clays
Med Silty Clay w/ Silt Lens
Med to Stiff Clay
Dense Sand
Refused
Gr Si Cl w/Tr Shell & Wd & Fi Si Sa, Org=11% 0.95 77 40
Gr Si Cl w/Tr Rot. Wd Org = 13% 0.48 100 62
Gr Si Cl 0.26 55 30
Gr Fi Sa - NP NP
Gr Si Cl w/Lens Si Sa & Tr Shell 0.37 37 15
Gr Si Cl w/Tr Rot. Wd 0.57 63 39
Gr Si Cl w/Tr Shell 0.74 76 44
Gr Si Cl w/Lens Si & Tr Rot. Wd 0.65 65 38
Gr Si Cl w/Len Sa Si Cl 0.41 51 30
Gr Si Cl w/Len Si 1.29 73 47
Gr Si Cl w/Len Si 1.61 72 55
Sand - - -
Gr Med Sa - NP NP
- - - -
Gr Fi Si Sa w/Tr Org - NP NP

FIGURE 8

phenomenon is probably the result of the separation of the holes and the topography of the surface at the time of deposition.

Bonnet Carre Spillway

The reader will recall that this location was computed at the request of the Bridge Design Section. At present a second bridge is being added to carry the northbound traffic across the spillway. Figures 9, 10 and 11 depict the logs of borings and soundings at three locations. Here again the two penetrations, boring and sounding, seem to correlate reasonably well. What is more interesting, the three soundings tend to verify the recent geology of the area. According to Saucier (6) the top of the Pleistocene, generally at -50 feet at that latitude, is entrenched down to approximately -75 feet by a tributary to a major north-south trending valley in the Pleistocene. This tributary runs northeast-southwest across the spillway. The soundings indicate that the top of the Pleistocene is at approximately 16 meters (49.2 feet) at Stations 184+05 and 204+85 and 21 meters (68.9 feet) at Station 148+04. By the same token, gray-brown clays with traces of iron oxide nodules show up in the borings at approximately the same elevations which are common to the Pleistocene surface.

Above this surface there are two sand stringers seen in the soundings that appear more pronounced and widely separated in the westernmost penetration (Station 148+04) and are progressively closer together and less sandy in the more easterly holes. This is what one would expect when investigating an area of deposition around a channel such as this.

The intention of the preceding paragraphs is to show that the correlation of MCP results to the laboratory results are for the most part only fair to good. The MCP results present an excellent picture of the geologic history, particularly where that history is known. When it is not known, the MCP is an excellent tool for

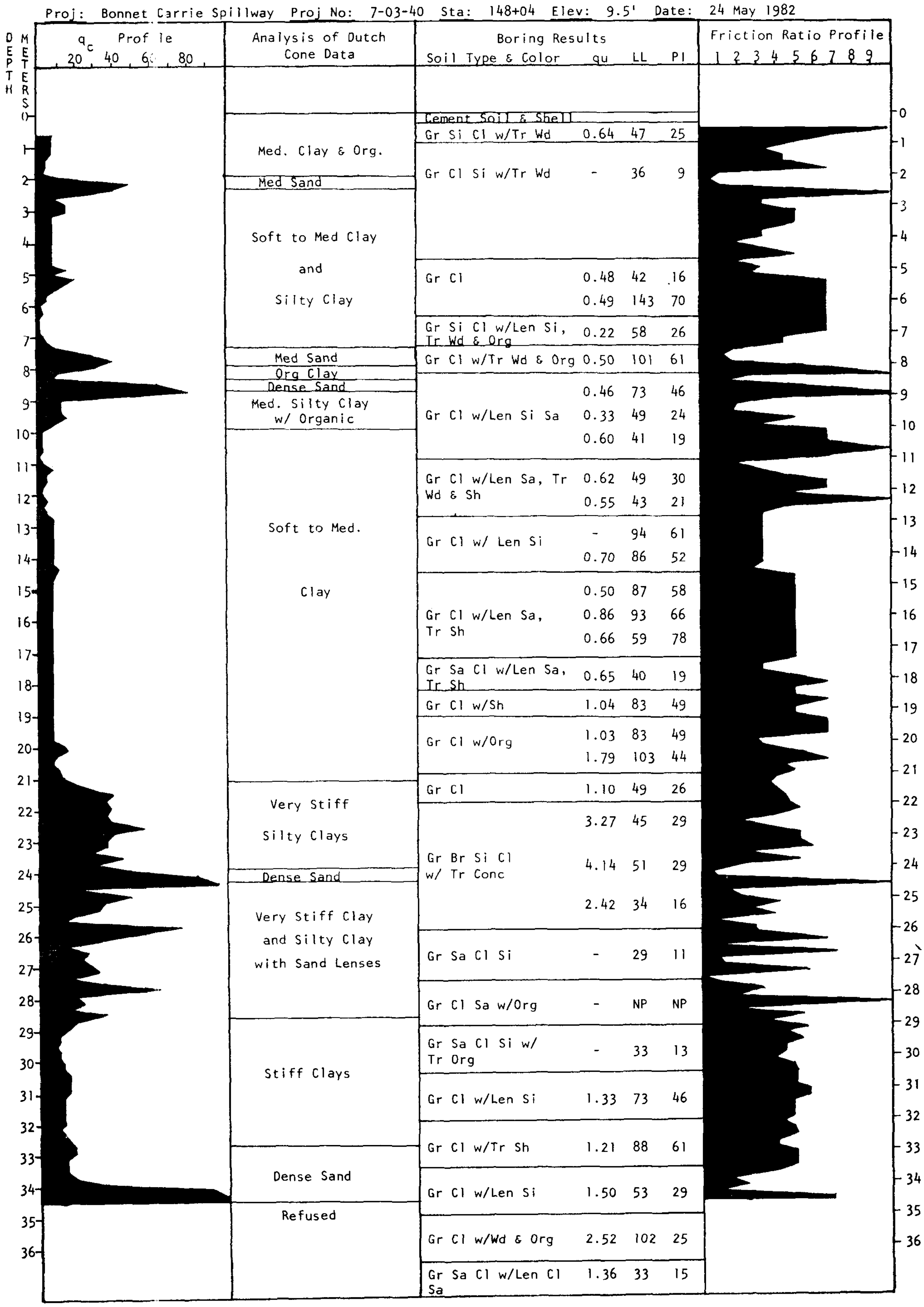

Proj: Bonnet Carrie Spillway Proj No: 7-03-40 Sta: 148+04 Elev: 9.5' Date: 24 May 1982
DEPTH METERS
qc Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu LL PI
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
Med. Clay & Org.
Med Sand
Soft to Med Clay and Silty Clay
Med Sand
Org Clay
Dense Sand
Med. Silty Clay w/ Organic
Soft to Med. Clay
Very Stiff Silty Clays
Dense Sand
Very Stiff Clay and Silty Clay with Sand Lenses
Stiff Clays
Dense Sand
Refused
Cement Soil & Shell
Gr Si Cl w/Tr Wd 0.64 47 25
Gr Cl Si w/Tr Wd - 36 9
Gr Cl 0.48 42 16
0.49 143 70
Gr Si Cl w/Len Si, Tr Wd & Org 0.22 58 26
Gr Cl w/Tr Wd & Org 0.50 101 61
0.46 73 46
Gr Cl w/Len Si Sa 0.33 49 24
0.60 41 19
Gr Cl w/Len Sa, Tr Wd & Sh 0.62 49 30
0.55 43 21
Gr Cl w/ Len Si - 94 61
0.70 86 52
0.50 87 58
Gr Cl w/Len Sa, Tr Sh 0.86 93 66
0.66 59 78
Gr Sa Cl w/Len Sa, Tr Sh 0.65 40 19
Gr Cl w/Sh 1.04 83 49
Gr Cl w/Org 1.03 83 49
1.79 103 44
Gr Cl 1.10 49 26
3.27 45 29
Gr Br Si Cl w/ Tr Conc 4.14 51 29
2.42 34 16
Gr Sa Cl Si - 29 11
Gr Cl Sa w/Org - NP NP
Gr Sa Cl Si w/ Tr Org - 33 13
Gr Cl w/Len Si 1.33 73 46
Gr Cl w/Tr Sh 1.21 88 61
Gr Cl w/Len Si 1.50 53 29
Gr Cl w/Wd & Org 2.52 102 25
Gr Sa Cl w/Len Cl Sa 1.36 33 15

FIGURE 9

Proj: Bonnet Carrie Spillway Proj No: 7-03-40 Sta: 184+05 Elev: 6.0' Date: 24 May 1982

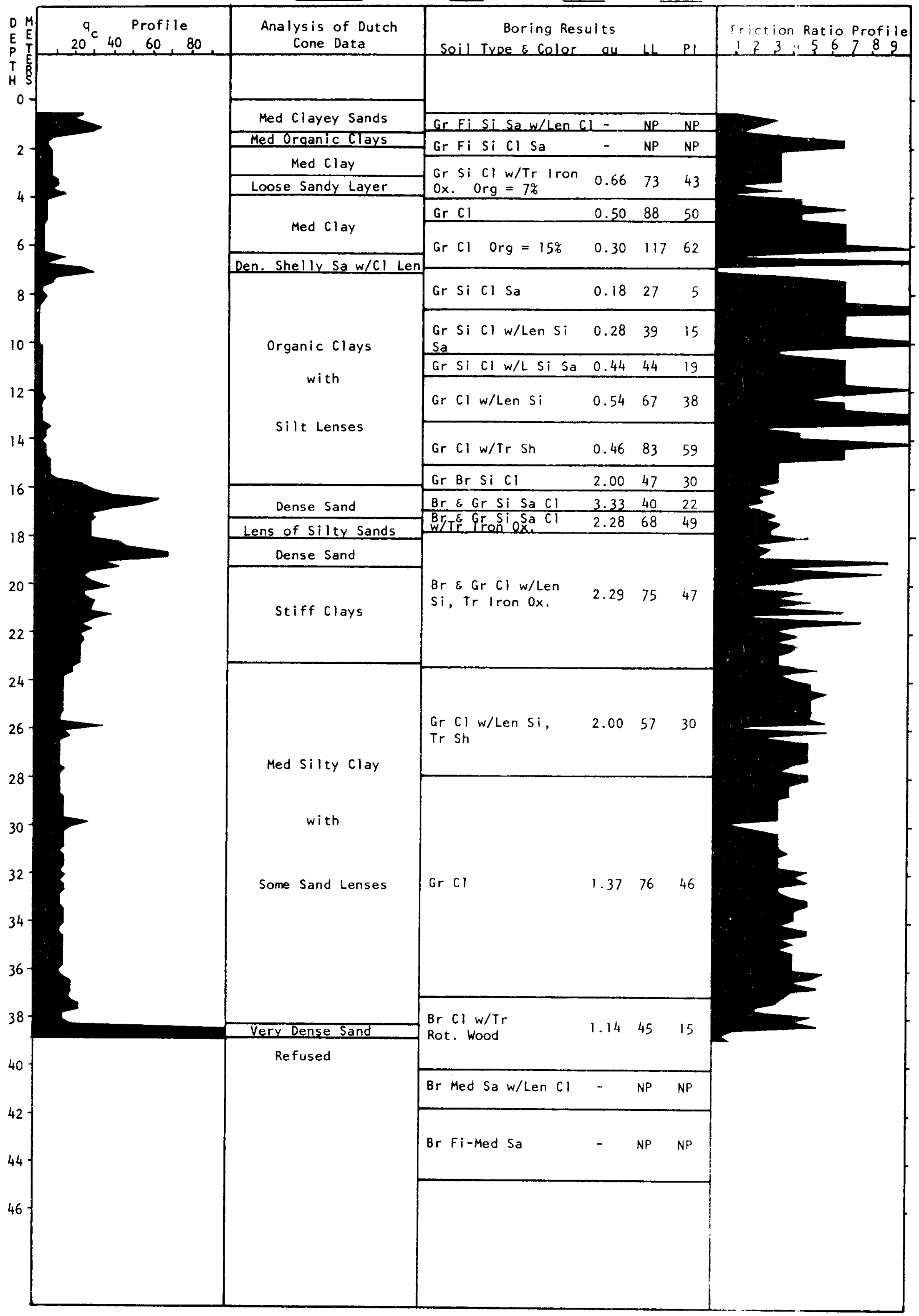


FIGURE 10

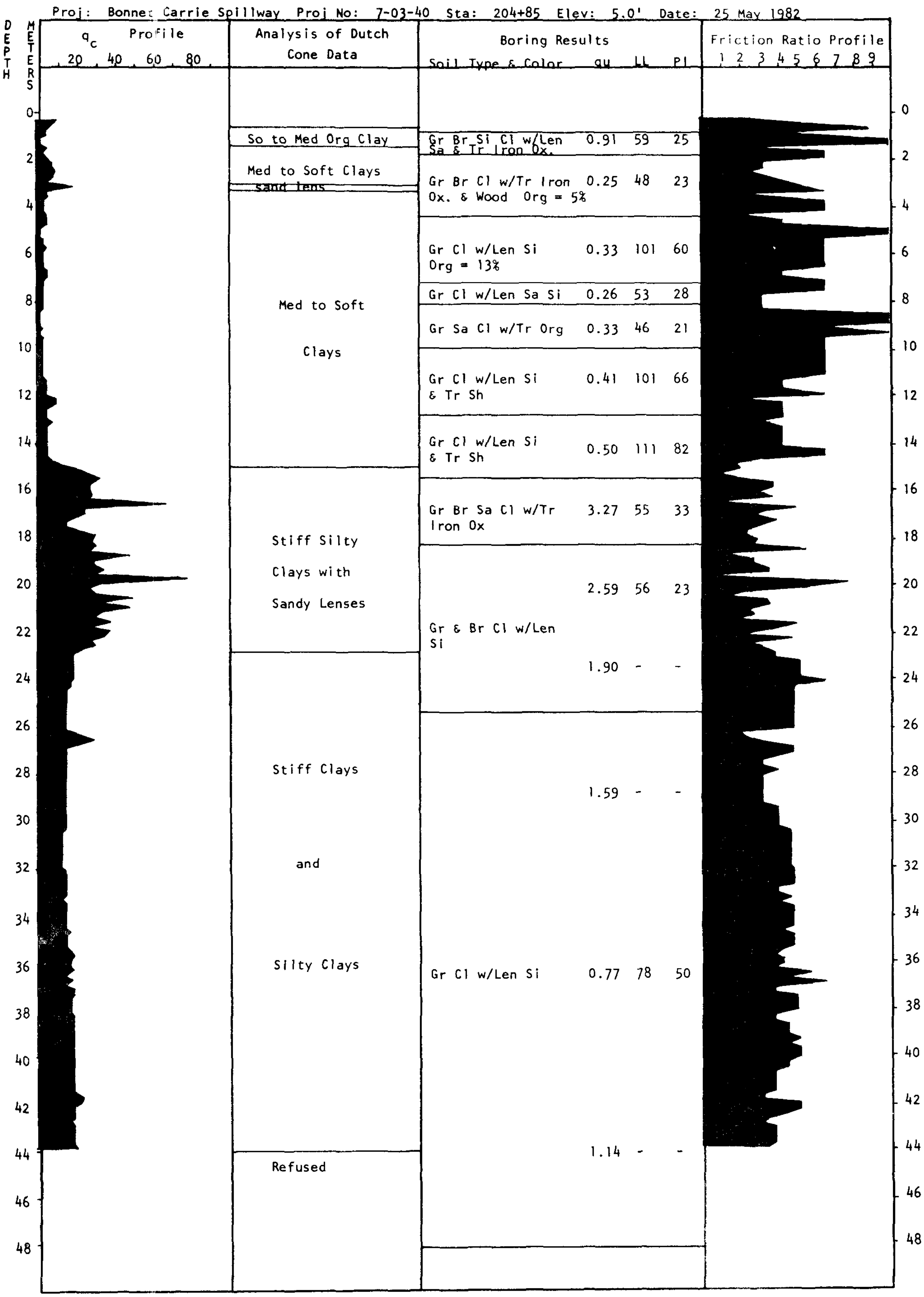

Proj: Bonnet Carrie Spillway Proj No: 7-03-40 Sta: 204+85 Elev: 5.0' Date: 25 May 1982
DEPTH METERS
q_c Profile
20 40 60 80
Analysis of Dutch Cone Data
Boring Results
Soil Type & Color qu LL PI
Friction Ratio Profile
1 2 3 4 5 6 7 8 9
So to Med Org Clay
Med to Soft Clays
Sand lens
Med to Soft Clays
Stiff Silty Clays with Sandy Lenses
Stiff Clays and Silty Clays
Refused
Gr Br Si Cl w/Len Sa & Tr Iron Ox. 0.91 59 25
Gr Br Cl w/Tr Iron Ox. & Wood Org = 5% 0.25 48 23
Gr Cl w/Len Si Org = 13% 0.33 101 60
Gr Cl w/Len Sa Si 0.26 53 28
Gr Sa Cl w/Tr Org 0.33 46 21
Gr Cl w/Len Si & Tr Sh 0.41 101 66
Gr Cl w/Len Si & Tr Sh 0.50 111 82
Gr Br Sa Cl w/Tr Iron Ox 3.27 55 33
Gr & Br Cl w/Len Si 2.59 56 23
1.90 - -
Gr Cl w/Len Si 0.77 78 50
1.59 - -
1.14 - -
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48

FIGURE 11

predicting pile capacity, as will be shown in the following pages, and will show when more information is needed at a fraction of the time it takes to sink a core hole and test the retrieval.

Test Pile Results Versus Penetrometer Results

Correlations of test pile ultimate load to the MCP predicted ultimate load at three of the locations, i.e., Baton Rouge (Scotlandville Bypass), Houma (Prospect Street Bridge) and Ruddock, are shown in Table 1. As can be seen, two of the three areas produced close results. The foundation soils at Houma were classified as medium to soft clays for a depth of 116.5 feet with the exception of two thin sand stringers (Figure 8). The higher of the two predictions was the α method, just the opposite of Baton Rouge and Ruddock. It is suspected that MCP soundings in soft foundations do not produce friction/adhesion results with sufficient accuracy to be read on the critical portion of either the α curve (Figure A-2) or the M curve (Figure A-3). For instance, if the average value for friction/adhesion (F) had been 2 instead of 3 kg/cm^2, a Q_{ult} of 221.2 tons would have been obtained instead of 187.4. (Actually $\overline{F}$ = 1.8375 would have produced 225 tons exactly.) It should be remembered that the F+C readings rapidly follow the C when they are in the neighborhood of 7 and 10 kg/cm^2 (Exhibit A-1). Hence the inaccuracy of the readings.

At Bonnet Carre Spillway the MCP pile capacity results completed as a part of this work and the pile capacity results from the ECP are available. Table 2 is a summary of the results from both cones, the test pile, plus the embedded length of the test pile, and the designed loads for each test pile. It will be seen that there were several piles of various dimensions and lengths being considered at the time of design.

By way of information, the correlation coefficient of the Dutch cone to the electronic cone is 0.9.

TABLE 1

CORRELATION OF TEST PILE AND MCP RESULTS

Test Pile Number	Location	Shape	Embedded Length (Feet)	Test Pile Ultimate Load (Tons)	Predicted Ultimate Load (M-Cone) (Tons)	Predicted Ultimate Load (α-Method) (Tons)
2A	Baton Rouge	14" Sq (C)	45	170	170.2	146.3
4A	Baton Rouge	14" Sq (C)	43	165	166.9	145.7
1	Houma	18" Sq (C)	95	225	187.4	203.4
2	Houma	12" Dia (S)	95	140	95.2	101.2
3	Houma	14" Dia (S)	95	160	112.2	119.1
4	Houma	Step Taper (S)	95	195	99.8	102.0
24-1	Ruddock	24" Sq (C)	65	250	256.7	219.4
30-1	Ruddock	30" Sq (C)	65	330	328.3	237.9

C: Concrete S: Steel

TABLE 2

SUMMARY OF PILE DATA - BONNET CARRE SPILLWAY

Sta. of Sounding	Sta. of Test Pile	Pile Dimen. (In.)	Design Embed. Length (Ft.)	Ultimate Capacity (Tons) Lab Test	ECP	MCP	Actual	Actual Length (Ft.)
			70	180	90	262		
		24 sq	80	228	331	270	257	83
			90	250	339	301		
148+04	148+00		98	340	386	424		
		30 sq	100	350	391	442		
			109	390	421	-		
		36 dia	105	340	397	-		
			114	350	-	-		
			68	180	228	242		
		24 sq	81	228	256	273		
			87	250	264	290	293	93
184+05	194+00		92	340	363	382		
		30 sq	94	350	370	398		
			102	390	399	420		
		36 dia	98	350	375	393		
			106	390	465	419		
			72	180	250	238		
		24 sq	85	248	280	269		
			91	250	294	295	322	95
204+85	205+00		95	340	401	392		
		30 sq	98	350	406	399		
			108	390	455	447		
		36 dia	105	350	434	415		
			108	390	491	470		

Figures 12, 13 and 14 are the results of MCP findings plotted against their corresponding depths shown as a solid line. The dashed line is drawn through the test pile plotted in the same manner parallel to the solid curve. Assuming that the two curves are parallel, i.e., that test piles of a length other than the one tested will develop similar ultimate loads as those found by the soundings, the "exact" depth of embedment necessary to support the ultimate load that the pile was designed to support could be determined. Unfortunately, however, this procedure was not thoroughly investigated in this research. Nevertheless, the procedure has merit, especially when it is combined with the computer program.

FIGURE 12

PREDICTED PILE LOAD VERSUS DEPTH
STATION NUMBER 148+04
ACTUAL = + / MECHANICAL CONE = *

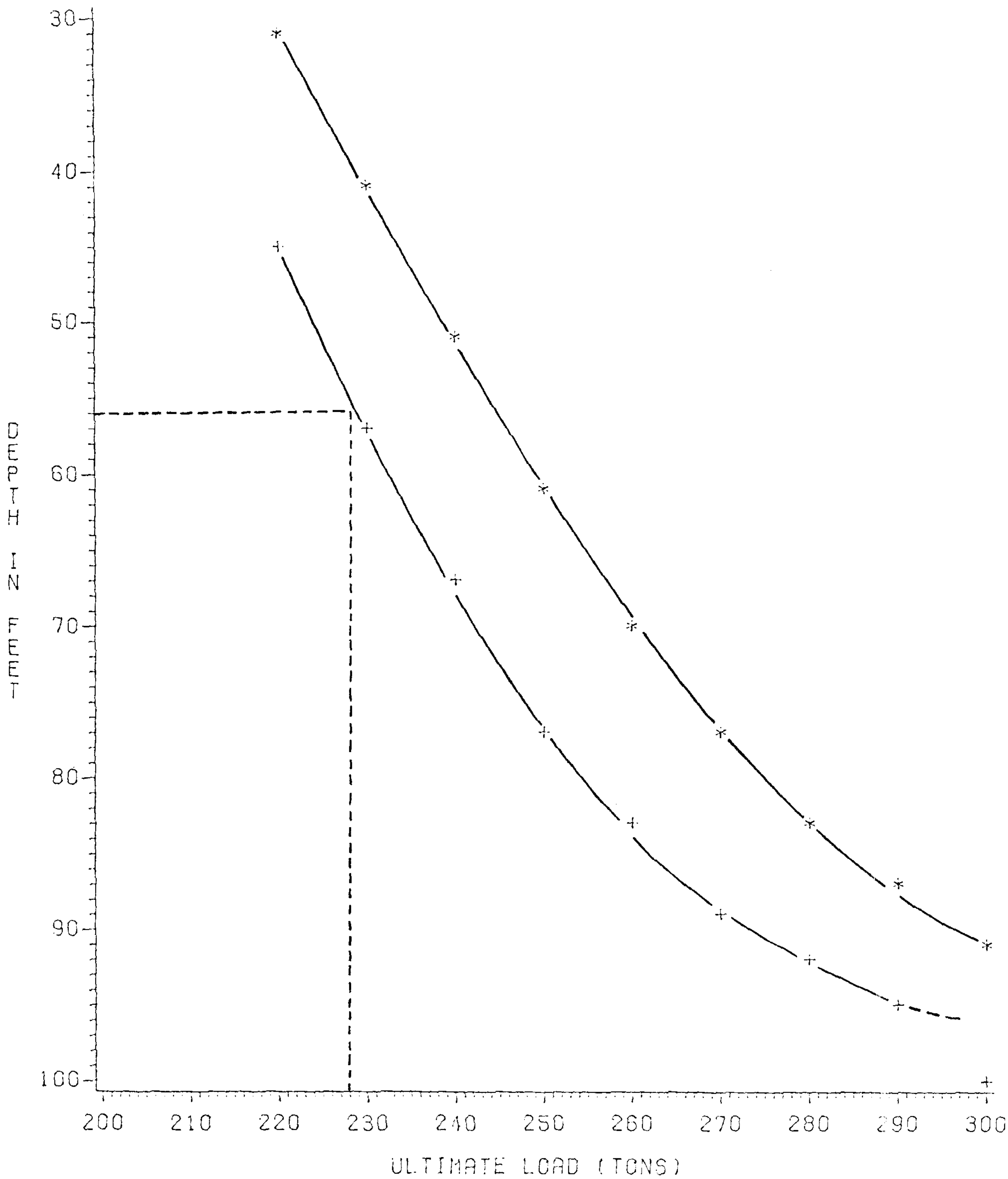


FIGURE 13

PREDICTED PILE LOAD VERSUS DEPTH
STATION NUMBER 184+06
ACTUAL = + / MECHANICAL CONE = *

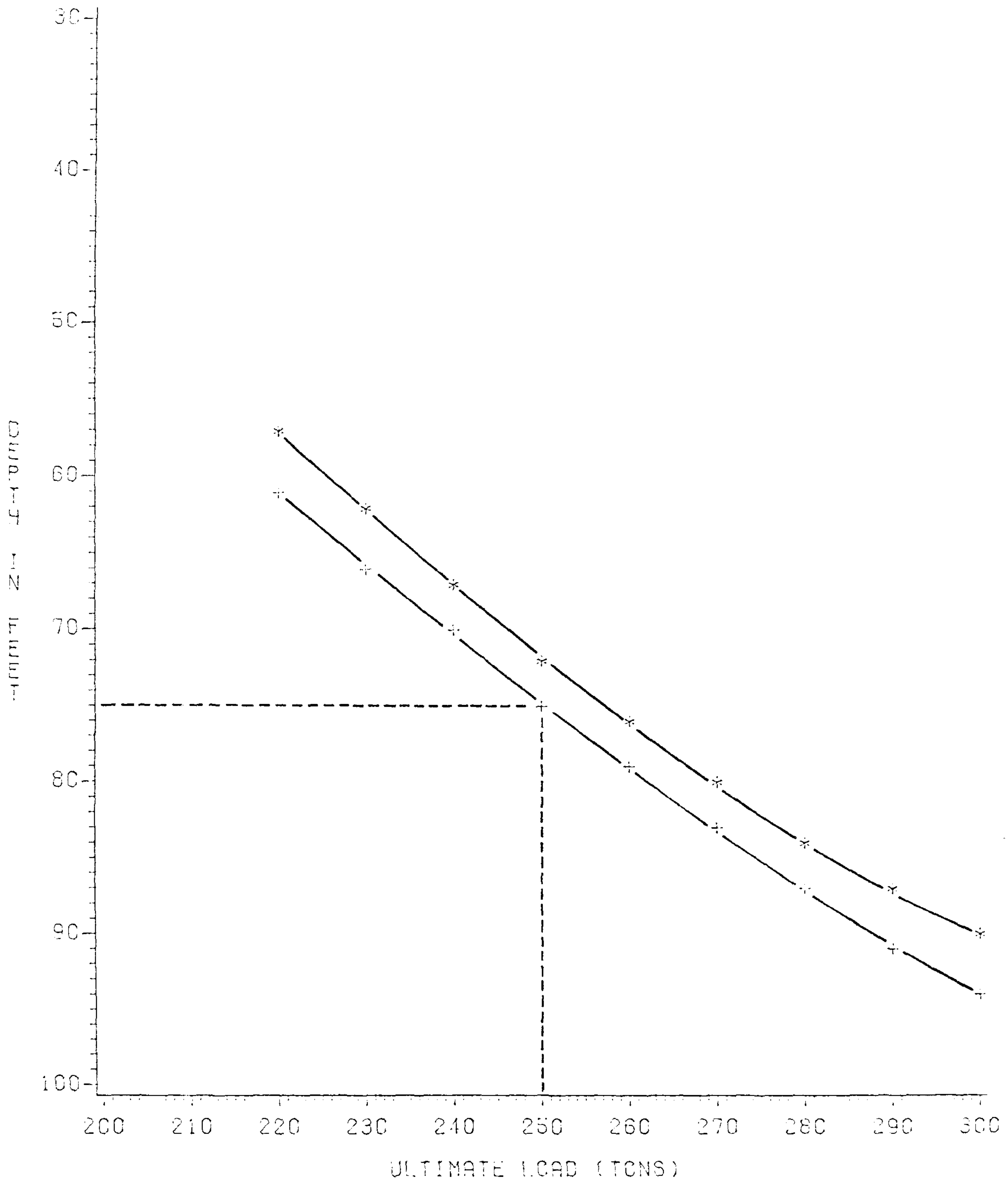
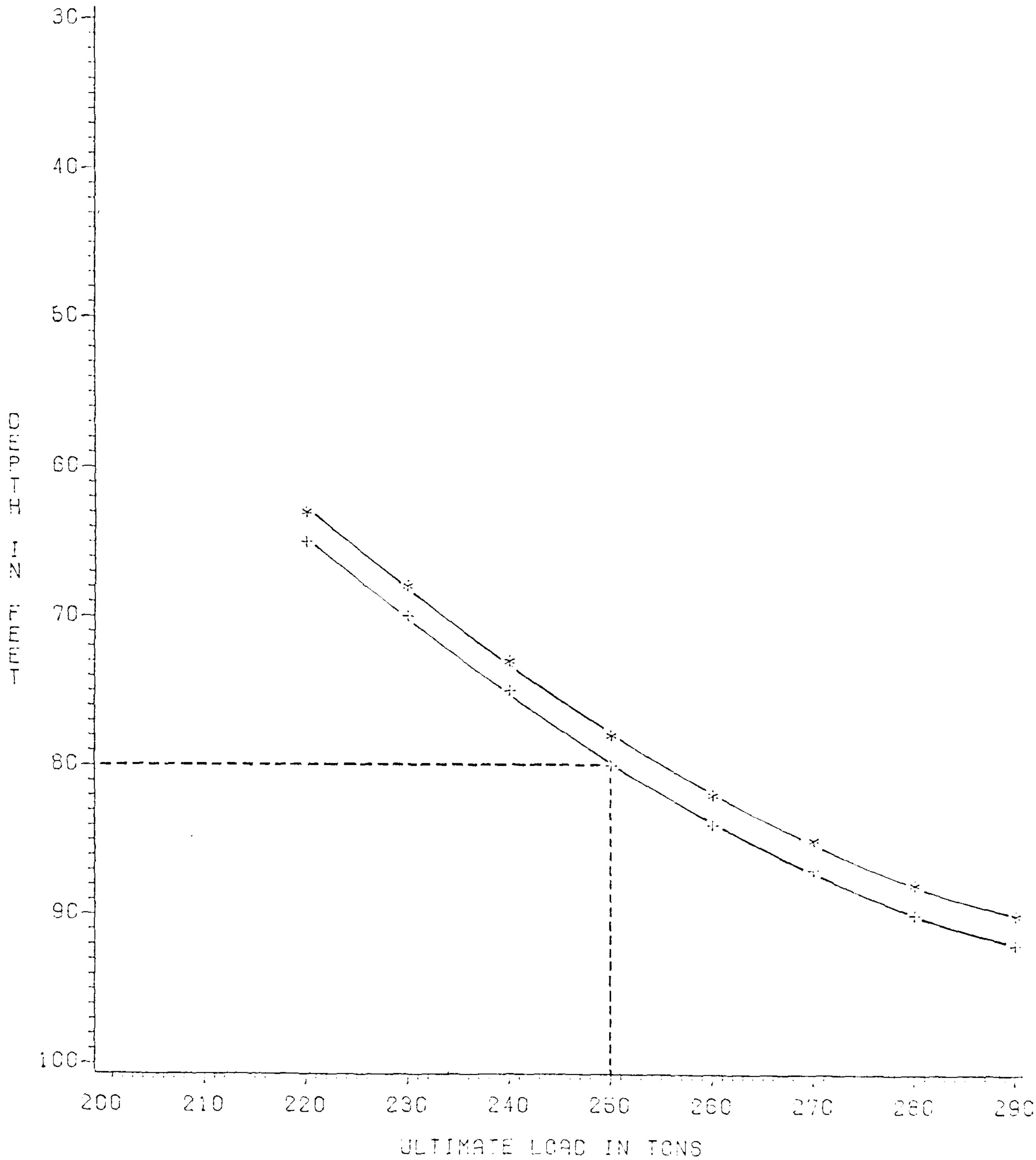


FIGURE 14

PREDICTED PILE LOAD VERSUS DEPTH
STATION NUMBER 204+85
ACTUAL = + / MECHANICAL CONE = *



CONCLUSIONS

From this study the following conclusions can be drawn:

1. The drill rig-mounted MCP seems to be a viable method of foundation exploration for every type soil except the firmer clays and sands. The Failings hydraulic system is insufficient for penetrating the very stiff clays and dense and very dense sands.

2. Soft and very soft clays and organics that produce F_s values that fall on the M-cone (Tumay's) and the α (Begemann's which appears in Reference 5) curves' most critical portions, and the inability to read the gauges accurately are the reasons implicated for the inaccuracy of the ultimate capacity predictions in this type of foundation material.

3. The laboratory versus MCP results regarding the soil type seem to provide a good relationship. The translocation of the layers defined by the lab test of the boring and MCP test of the sounding is probably due to the translocation of the two sites. Further, in the opinion of the writer, lab tests such as liquid limit and plasticity index are too precise and tend to confuse the layering. Sediments tend to grade into one another rather than having abrupt boundaries. Furthermore, the q_u and q_c tests performed on cores each have drawbacks created mostly by extricating a portion of the soil from its environment. Such differences are not realized in in-situ testing, especially when tests occur every 20 cm instead of 5, 10 or 20 feet.

4. The M-cone method developed by research done in Louisiana for ECP seems to work well when MCP tests are run on soils between the two extremes reiterated in conclusions 1 and 2 above. The

α method is not recommended for use in Louisiana. Soundings run in the Baton Rouge, Ruddock and Bonnet Carre areas all correlate well with the test pile data.

5. Correlation between the electronic and the mechanical cone results in the Bonnet Carre Spillway is 0.9 (R^2 = 0.901).

RECOMMENDATIONS

Two recommendations should be made concerning this subject. The first is that the program be tested in other locations around the state since the researchers were unable to test the suggested computer program on any but the one location. If the procedure by Schmertmann (5) is correct, and three out of four locations computed herein showed it to correlate with test piles using the M-cone adhesion factor, then the program should check. The expression $M = 10.0 - 9.5\,(1-e^{-9.0\,f_s})$, which is the regression equation for the M-curve developed by Tumay, needs further verification, however.

The second recommendation is that the suggested procedures of establishing the "exact" embedded length of the piles to be used in the structure be further investigated to see whether this procedure has merit. The first step would be to run the penetrometer test, establish the depth necessary to meet ultimate load of a test pile, and establish a curve similar to Figures 12 through 14. Then a test pile should be driven to the established depth and loaded to that point which is considered failure by the Department. If this point falls exactly on the established curve, then the exact depth is known and no further work need be done. If not, then the point should be plotted on the graph and a curve drawn parallel to the established curve from which the "exact" embedded length can be determined. A second test pile should be driven to the determined depth and loaded to ultimate load to test the idea. A safety factor of 2.0 is applied to the design load to obtain the desired ultimate test pile load. Therefore, the load at which test pile failure is achieved is not so critical that a few tons underrun will make that much difference.

These two recommendations could be accomplished at the same time in several locations. The first will be proven or disproven automatically if a goal is set to test the second. If these two recommendations prove functional, then it is further recommended that the Department use the mechanical cone penetrations in conjunction with conventional core borings to determine pile information. The mechanical cone soundings will be relatively inexpensive and save time since laboratory tests are unnecessary. With the suggested procedures, pile lengths will be shortened, or if lengthened the factor of safety will be more assured without driving another test pile.

LIST OF REFERENCES

1. Tumay, M. T. and Fakhroo, M., "Friction Pile Capacity Prediction in Soft Louisiana Soils Using Electric Quasi-Static Penetration Test," Interim Report No. 1, La. DOTD, La. Hwy. Resh., September 1981.

2. Tumay, M. T. and Yilmaz, R., "In-Situ Determination of Undrained Shear Strength of Louisiana Soil by Quasi-Static Cone Penetration Test," Interim Report No. 2, La. DOTD, La. Hwy. Resh., December 1981.

3. Tumay, M. T., Acar, Y. B., and Chan, S. K. A., "Analysis of Dissipation of Pore Pressure After Cone Penetration," Interim Report No. 3, La. DOTD, La. Hwy. Resh., June 1982.

4. Tumay, M. T. and Hajibakar, I., "In-Situ Determination of Compressibility of Louisiana Soils Using Piezo-Cone Penetration Test (PCPT)," Interim Report No. 4, La. DOTD, La. Hwy. Resh., 1982.

5. Federal Highway Administration, "Guidelines for Cone Penetration Tests - Performance and Design," prepared by Dr. Schmertmann, University of Florida, Report No. FHWA-TS-78-208, Wash., D.C., Implementation Div., February 1977.

6. U.S. Army, Waterways Experiment Station, Geology of the Mississippi River Deltaic Plain, Southeastern Louisiana, Technical Report No. 3-483, Vicksburg, Miss., Vol. 2, July 1958.

APPENDIX A

Col. {②③ Read Directly   Col. ④ = ③-② ⑤ = ②x2   Col ⑥ = ④x0.133 ⑦ = ⑥/⑤

DUTCH CONE PENETROMETER

FIELD DATA FORM

PROJECT: Scottlandville By Pass 450-33-50   DATE: 3-23-83

LOCATION: Sta 65+20 ℄ Med   TEST NO: 2

TESTED BY: Crochet   REMARKS:

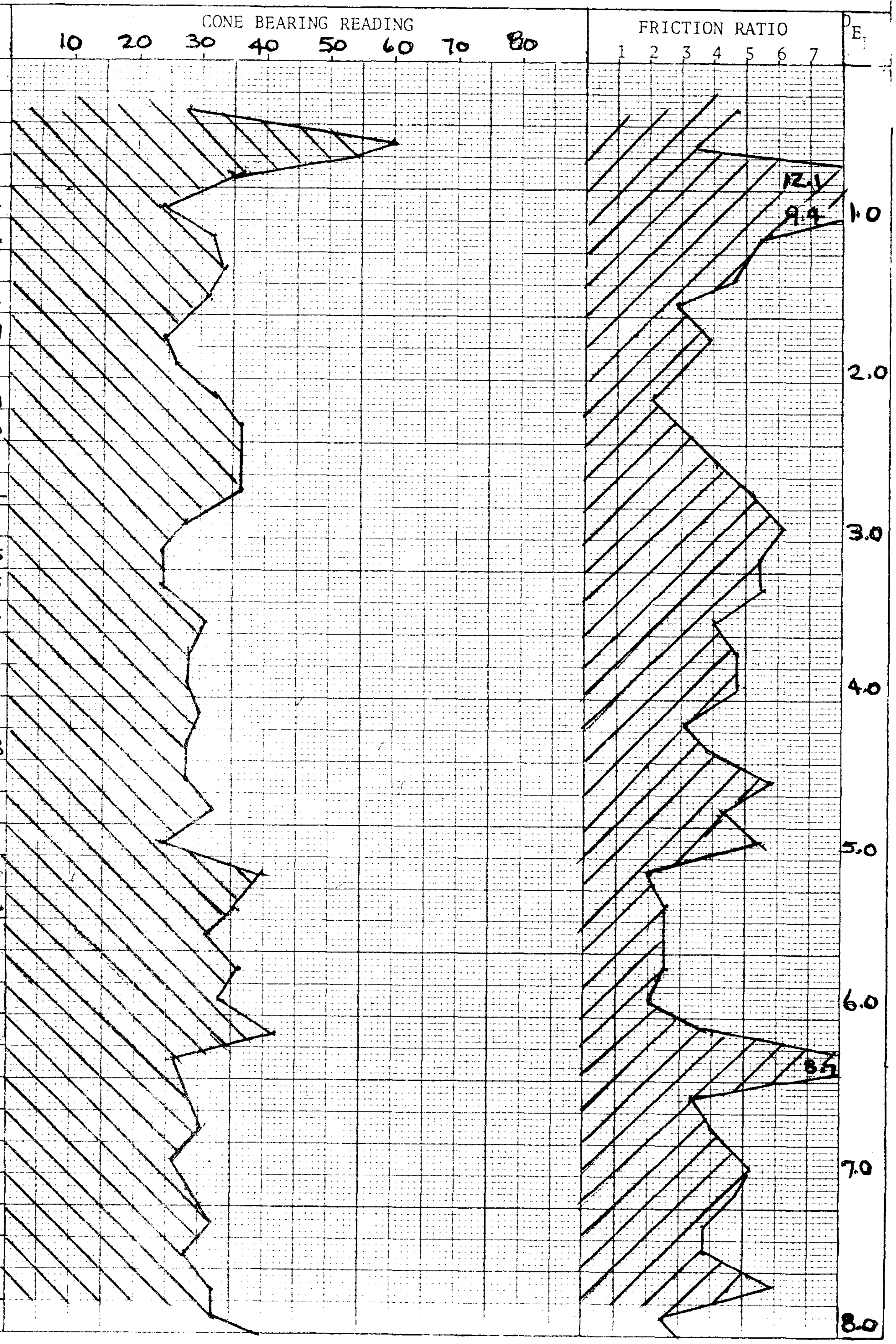
DEPTH	C ②	F+C ③	F ④	q_c ⑤	f_s ⑥	f_r ⑦
0.2	—	—	—	—	—	—
0.4	14	24	10	28	1.3	4.7
0.6	30	46	16	60	2.1	3.5
0.8	17	48	31	34	4.1	12.1
1.0	12	29	17	24	2.3	9.4
1.2	16	29	13	32	1.7	5.4
1.4	17	29	12	34	1.6	4.7
1.6	16	23	7	32	0.9	2.9
1.8	12	19	7	24	0.9	3.9
2.0	13	19	6	26	0.8	3.1
2.2	16	21	5	32	0.7	2.1
2.4	18	26	8	36	1.1	3.0
2.6	18	29	11	36	1.5	4.1
2.8	18	32	14	36	1.9	5.2
3.0	14	27	13	28	1.7	6.1
3.2	12	22	10	24	1.3	5.5
3.4	12	22	10	24	1.3	5.5
3.6	15	24	9	30	1.2	4.0
3.8	14	24	10	28	1.3	4.8
4.0	14	24	9	28	1.2	4.3

EXHIBIT A-1

DEPTH	C	F+C	F	q_c	f_s	f_r
4.2	15	22	7	30	0.9	3.1
4.4	14	22	8	28	1.1	3.8
4.6	14	26	12	28	1.6	5.7
4.8	16	26	10	32	1.3	4.2
5.0	12	22	10	24	1.3	5.5
5.2	20	26	6	40	0.8	2.0
5.4	18	25	7	36	0.9	2.6
5.6	16	22	6	32	0.8	2.5
5.8	18	25	7	36	0.9	2.6
6.0	17	22	5	34	0.7	2.0
6.2	21	27	6	42	0.8	4.0
6.4	13	30	17	26	2.3	8.7
6.6	14	21	7	28	0.9	3.3
6.8	15	24	9	30	1.2	4.0
7.0	13	23	10	26	1.3	5.1
7.2	14	24	10	28	1.3	4.8
7.4	16	25	9	32	1.2	3.7
7.6	14	22	8	28	1.1	3.8
7.8	16	30	14	32	1.9	5.8
8.0	16	22	6	32	0.8	2.5

C. P. T. PROFILE

q_c	f_s	f_r
—	—	—
28	1.3	4.7
60	2.1	3.5
34	4.1	12.1
24	2.3	9.4
32	1.7	5.4
34	1.6	4.7
32	0.9	2.9
24	0.9	3.9
26	0.8	3.1
32	0.7	2.1
36	1.1	3.0
36	1.5	4.1
36	1.9	5.2
28	1.7	6.1
24	1.3	5.5
24	1.3	5.5
30	1.2	4.0
28	1.3	4.8
28	1.2	4.3
30	0.9	3.1
28	1.1	3.8
28	1.6	5.7
32	1.3	4.2
24	1.3	5.5
40	0.8	2.0
36	0.9	2.6
32	0.8	2.5
36	0.9	2.5
34	0.7	2.0
42	0.8	4.0
26	2.3	8.7
28	0.9	3.3
30	1.2	4.0
26	1.3	5.1
28	1.3	4.8
32	1.2	3.7
28	1.1	3.8
32	1.9	5.8
32	0.8	2.5



DUTCH CONE PENETROMETER

FIELD DATA FORM

PROJECT: 450-33-50 DATE:

LOCATION: STA 65+20 TEST NO:

TESTED BY: REMARKS:

DEPTH	C	F+C	F	q_c	f_s	f_r
8.2	13	20	7	26	0.9	3.6
8.4	13	19	6	26	0.8	3.1
8.6	11	17	6	22	0.8	3.6
8.8	11	17	6	22	0.8	3.6
9.0	14	19	5	28	0.7	2.4
9.2	16	24	8	32	1.1	3.3
9.4	18	27	9	36	1.2	3.3
9.6	24	34	10	48	1.3	2.8
9.8	21	34	13	42	1.7	4.1
10.0	16	30	14	32	1.9	5.8
10.2	21	32	11	42	1.5	3.5
10.4	27	42	15	54	2.0	3.7
10.6	20	30	10	40	1.3	3.3
10.8	20	30	10	40	1.3	3.3
11.0	15	24	9	30	1.2	4.0
11.2	16	28	12	32	1.6	5.0
11.4	16	29	13	32	1.7	5.4
11.6	16	24	8	32	1.1	3.3
11.8	18	28	10	36	1.3	3.7
12.0	20	30	10	40	1.3	3.3

EXHIBIT A-1 (Cont)

DEPTH	C	F+C	F	q_c	f_s	f_r
12.2	21	33	12	42	1.6	3.8
12.4	18	28	10	36	1.3	3.7
12.6	21	32	11	42	1.5	3.5
12.8	21	32	11	42	1.5	3.5
13.0	18	30	12	36	1.6	4.4
13.2	19	30	11	38	1.5	4.8
13.4	30	42	12	60	1.6	2.7
13.6	23	36	13	46	1.7	3.8
13.8	25	37	12	50	1.6	3.2
14.0	26	42	16	52	2.1	4.1
14.2	23	34	11	46	1.5	3.2
14.4	22	36	14	44	1.9	4.2
14.6	26	42	16	52	2.1	4.1
14.8	24	41	17	48	2.3	4.7
15.0	27	43	16	54	2.1	3.8
15.2	28	42	14	56	1.9	3.3
15.4	24	45	21	48	2.8	5.8
15.6	26	44	18	52	2.4	4.6
15.8	26	42	16	52	2.1	4.1
16.0	30	42	12	60	1.6	2.7

C. P. T. PROFILE

q_c	f_s	f_r
26	0.9	3.6
26	0.8	3.1
22	0.8	3.6
22	0.8	3.6
28	0.7	2.4
32	1.1	3.3
36	1.2	3.3
48	1.3	2.8
42	1.7	4.1
32	1.9	5.8
42	1.5	3.5
54	2.0	3.7
40	1.3	3.3
40	1.3	3.3
30	1.2	4.0
32	1.6	5.0
32	1.7	5.4
32	1.1	3.3
36	1.3	3.7
40	1.3	3.3
42	1.6	3.8
36	1.3	3.7
42	1.5	3.5
42	1.5	3.5
36	1.6	4.4
38	1.5	4.8
60	1.6	2.7
46	1.7	3.8
50	1.6	3.2
52	2.1	4.1
46	1.5	3.2
44	1.9	4.2
52	2.1	4.1
48	2.3	4.7
54	2.1	3.8
56	1.9	3.3
48	2.8	5.8
52	2.4	4.6
52	2.1	4.1
60	1.6	2.7

DUTCH CONE PENETROMETER

FIELD DATA FORM

PROJECT: 450-33+50 DATE:

LOCATION: STA 65+20 TEST NO:

TESTED BY: REMARKS:

DEPTH	C	F+C	F	q_c	f_s	f_r
16.2	26	41	15	52	2.0	3.8
16.4	25	40	15	50	2.0	4.0
16.6	24	39	15	48	2.0	4.2
16.8	22	36	14	44	1.9	4.2
17.0	22	36	14	44	1.9	4.2
17.2	24	40	16	48	2.1	4.4
17.4	20	34	14	40	1.9	4.7
17.6	16	27	11	32	1.5	4.6
17.8	17	22	15	34	0.7	2.0
18.0	18	28	10	36	1.3	3.7
18.2	24	38	14	48	1.9	3.9
18.4	40	58	18	80	2.4	3.0
18.6	25	57	32	50	4.6	8.5
18.8	34	47	13	68	1.7	2.5
19.0	2[illegible]	31	11	40	1.5	3.7
19.2	18	28	10	36	1.3	3.7
19.4	18	36	18	36	2.4	6.7
19.6	22	34	16	44	2.1	4.8
19.8	20	30	10	40	1.3	3.3
20.0	24	46	12	40	1.6	3.3

EXHIBIT A-1 (Cont)

DEPTH	C	F+C	F	q_c	f_s	f_r

C. P. T. PROFILE

q_c	f_s	f_r
52	2.0	3.8
50	2.0	4.0
48	2.0	4.2
44	1.9	4.2
44	1.9	4.2
48	2.1	4.4
40	1.9	4.7
32	1.5	4.6
34	0.7	2.0
36	1.3	3.7
48	1.9	3.9
80	2.4	3.0
50	4.6	8.5
68	1.7	2.5
40	1.5	3.7
36	1.3	3.7
36	2.4	6.7
44	2.1	4.8
40	1.3	3.3
48	1.6	3.3

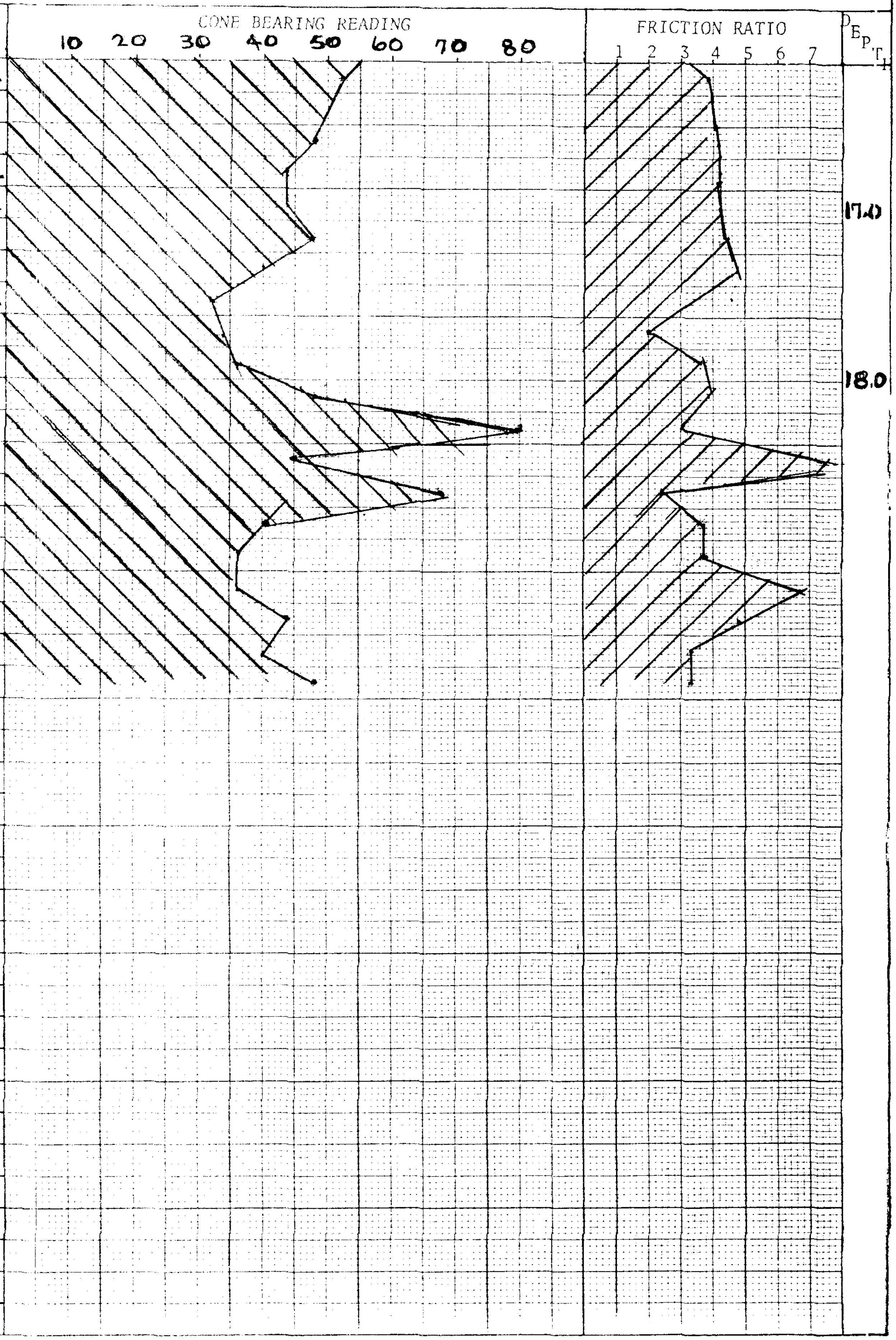


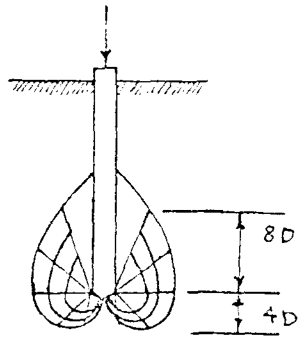
EXHIBIT A-2

BATON ROUGE I-110
SCOTLANDVILLE BYPASS
STATION 65+20 @ BADLEY ROAD

14" Sq - 0.36 M (B)
43' - 13.1 M (L)

Part 1

End Bearing



Theory of Pile Failure

$$Q_t = \frac{q_{c1}+q_{c2}}{2} \cdot A^2$$

$*q_{c1}$ = Least average q_c value 3.75 B under the pile tip in specified increments

$*q_{c2}$ = Average q_c 8 B above pile tip

A = Pile x-section area

0.7	0.25	13.3	1/4(23x2+36x2) = 29.5
1.0	0.36	13.5	1/6(23x2+36+28x2) = 29.0
1.5	0.53	13.6	1/6(23x2+36+28x2) = 29.0
2.0	0.71	13.8	1/8(23+36+28x2+30x3+23) = 28.5
2.5	0.89	14.0	1/10(23+36+28+30+2x31+30+2x28+23) = 28.8
3.0	1.07	14.2	1/12(23+36+28+30+31+6x28+23) = 28.2
3.5	1.24	14.3	1/14(23+36+28+30+31+28+7x26+23) = 27.2
3.75	1.33	14.4	Larger

q_{c1} = 27.2 kg/cm² or tons/ft²

q_{c2} = Average q_c 8B above tip

L-8B = 13.1-(8x0.36) = 10.2 m

q_{c2} = 1/15[23+(7x22)+(3x19)+(4x18)] = 23.6 kg/cm² or ton/ft²

$$Q_t = \left(\frac{27.2+25.4}{2}\right)\left(\frac{14}{12}\right)^2 = 34.5 \text{ tons}$$

---

*See Figure A-1 for an explanation of q_{c1} and q_{c2}.

Part 2

Skin Friction or Adhesion

$$Q_f = \alpha \, \overline{f}_s \, A_s$$

Where α = Penetrometer to pile friction ratio

$\overline{f}_s$ = Average f_s for pile length (L)

A_s = Surface area

$\overline{f}_s = 1.32 \text{ kg/cm}^2$

$\alpha_{1.32} = 0.42$

$A_s = \frac{14}{12}x43x4 = 200.67 \text{ ft}^2$

$Q_f = 0.42x1.32x200.67 = 111.2$

$Q_{ult} = 34.5+111.2 = 145.7$ tons

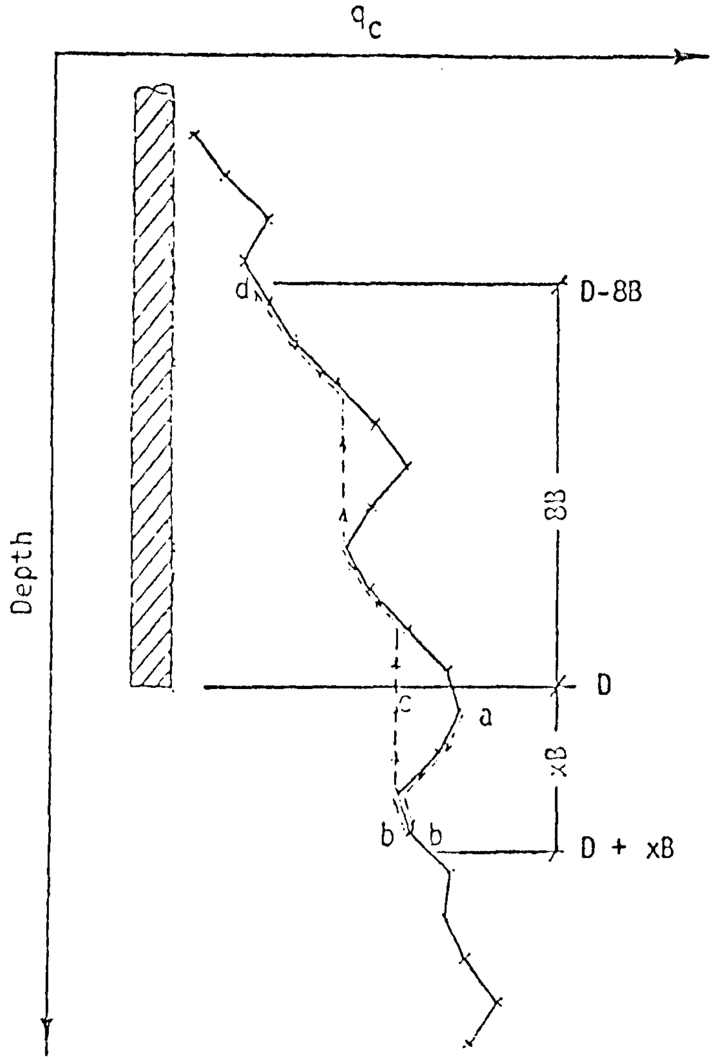
Using the M-Cone Method

$$Q_f = m \, \overline{f}_s \, A_s$$

$M_{1.32} = 0.5$

$Q_f = 0.5x1.32x200.67 = 132.4$

$Q_{ult} = 34.5+132.4 = 166.9$ tons



$$q_p = \frac{q_{c1} + q_{c2}}{2}$$

q_{c1} = Average q_c over a distance of xB below the pile tip (path a-b-c). Sum q_c values in both the downward (path a-b) and upward (path b-c) directions. Use actual q_c values along path a-b and the minimum path rule along path b-c. Compute q_{c1} for x-values from 0.7 to 3.75 and use the minimum q_{c1} value obtained.

q_{c2} = Average q_c over a distance of 8B above the pile tip (path c-d). Use the minimum path rule as for path b-c in the q_{c1} computations.

BEGEMANN PROCEDURE FOR PREDICTING PILE TIP CAPACITY

FIGURE A-1

FIGURE A-2

PENETROMETER CORRELATION
TO
PILE SIDE FRICTION
AFTER. SCHMERTANN (5)

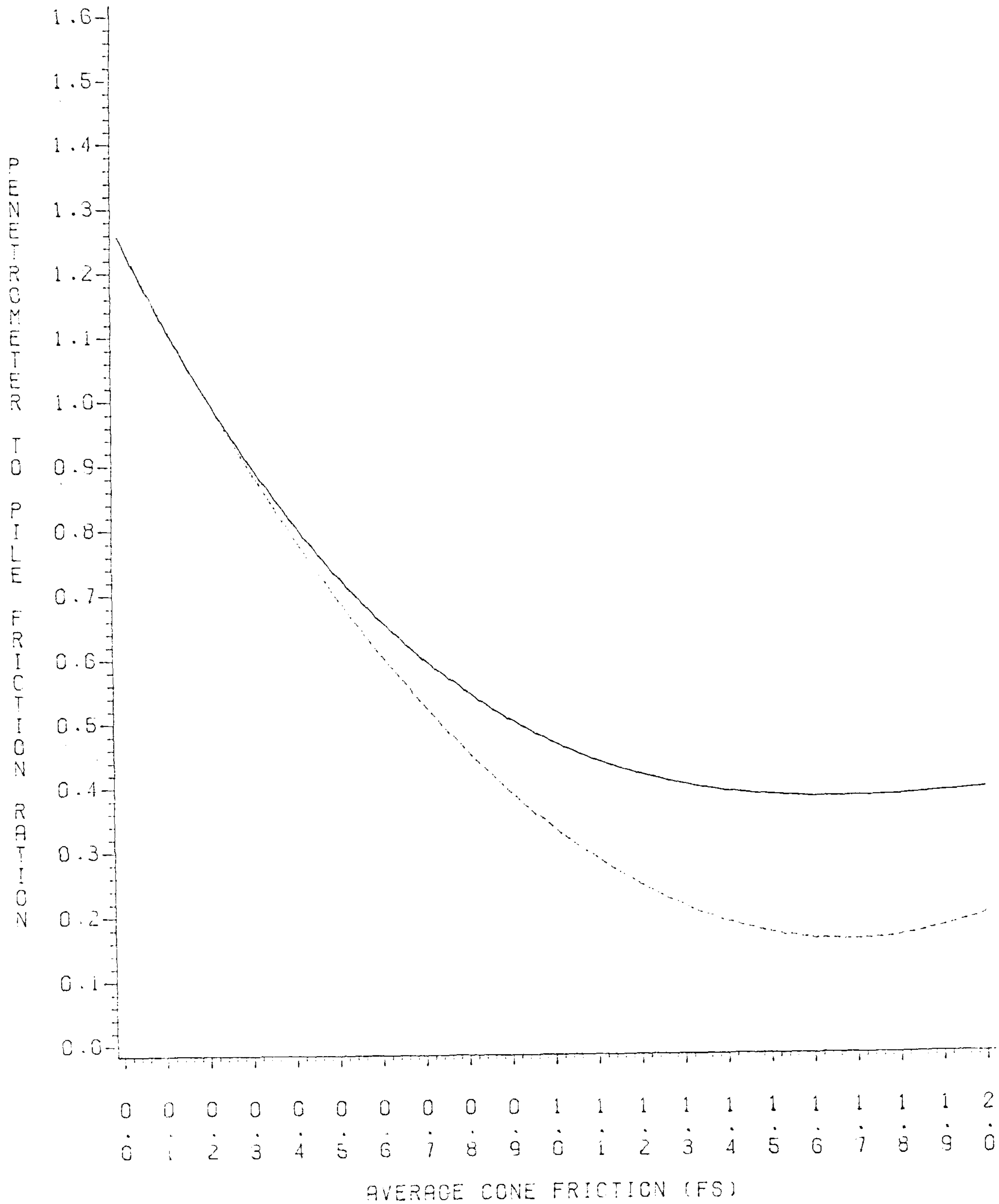
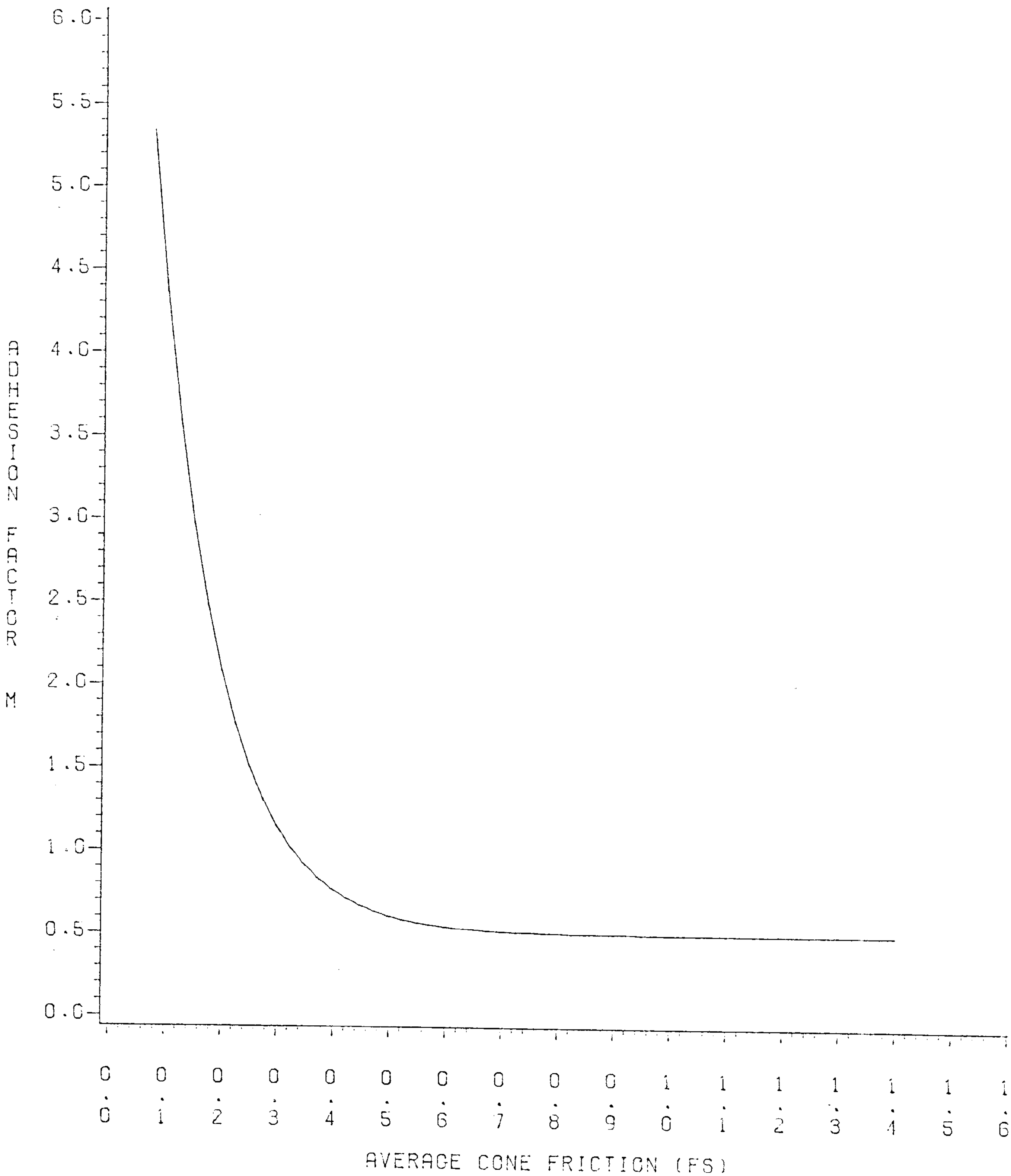


FIGURE A-3

PENETROMETER CORRELATION
TO
PILE SIDE FRICTION (CLAY)
AFTER: TUMAY & FAKHROO (1)



APPENDIX B

HOW TO USE THE PILE CAPACITY PROGRAMS

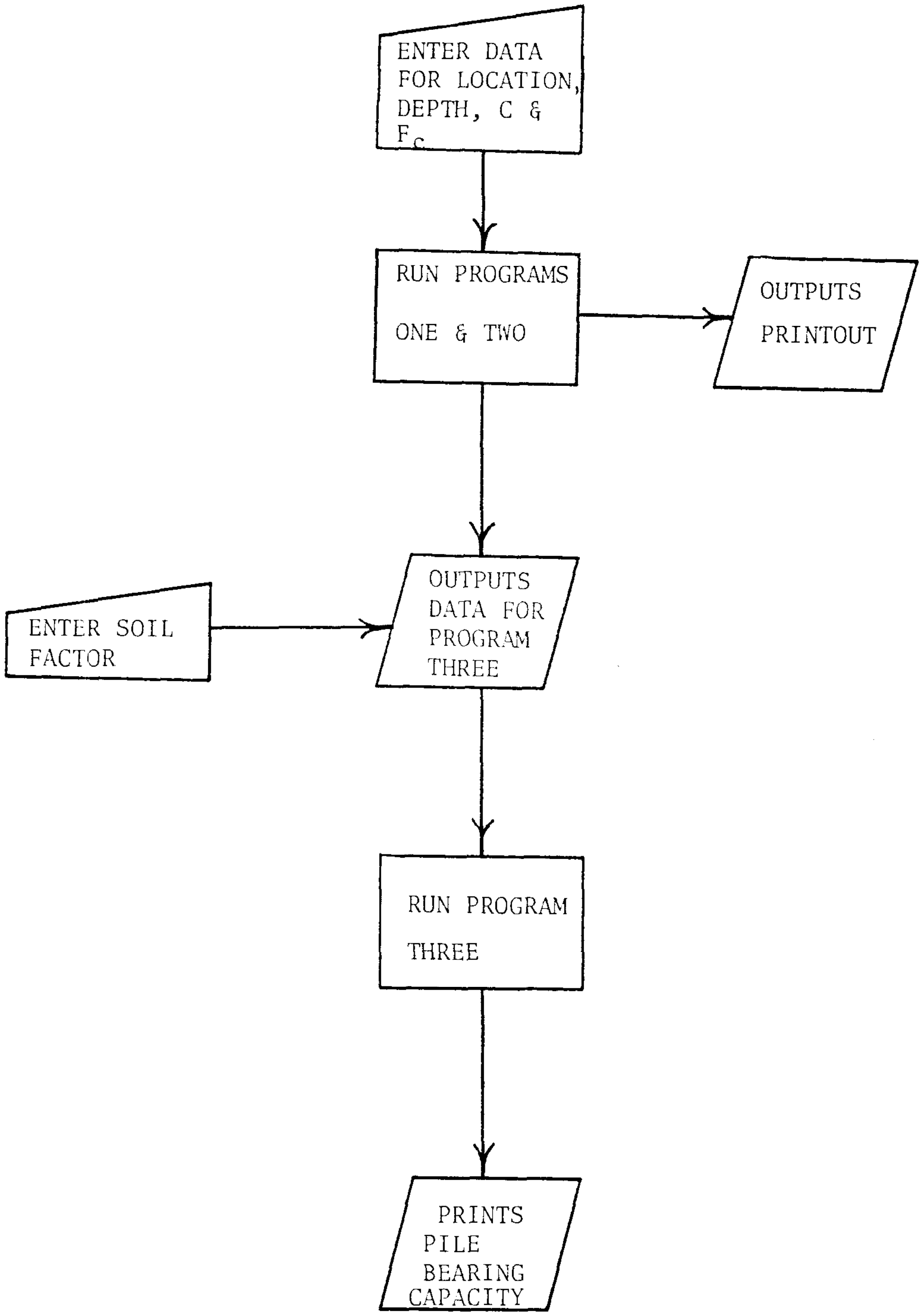
The pile capacity program is actually three programs. The first program calculates F, Q_c, F_s and FR; the second plots depth versus Q_c and depth versus FR; and the third and final program takes the information calculated by the first program and calculates the pile-bearing capacity of the test site.

The first step is to enter the information on the location and then the depth, C and F+C. An example of this is shown in the record layout. The next step is to run the first two programs. These two are set up to run simultaneously. Once finished, a printout will be generated as shown in Exhibit B-3. These programs also create the data file needed for program three. Before program three can be run, the soil factor must be entered (Exhibit B-5). Once the soil factor is entered, program three can be run. When program three is finished, a printout of the pile-bearing capacity is outputted.

The flowchart below indicates the way in which the programs work together.

Steps:

1. Enter location data, depth, C + (F+C).
2. Run programs one and two.
3. Enter soil factor.
4. Run program three.



FLOWCHART OF USE OF PILE CAPACITY PROGRAMS

RECORD LAYOUT FOR PILE CAPACITY PROGRAM ONE

FIRST CARD :

    $ENTRY

SECOND CARD :

    DESCRIPTION OF PILE

THIRD CARD :

    UNIT TIP CAPACITY LIMITING VALUE (999.9)
    UNIT PILE FRICTION LIMITING VALUE (9.99)

FOURTH CARD :

    PILE DIAMETER (99.99)
    PILE TIP AREA (9999.99)
    PILE PERIMETER (999.99)

FIFTH CARD :

    LOCATION OF PILE

SIXTH CARD :

    NUMBER OF POINTS OF INPUT (99)
    DEPTH AT WHICH RECORDING STARTS (999.99)

REST OF CARDS

    DEPTH (99.9)
    C (99)
    FC (99)

EXAMPLE OF LAYOUT

```
$ENTRY
14 INCH SQUARE PILE
100.0     0.75
40.13     1264.51     142.24
SCOTLANDVILLE BYPASS STA 65+20
   99 0.4
 0.4        14  24
 0.6        30  46
 0.8        17  48
```

```
PROJECT: D1901             MEMBER: PILEONE              DATE: 83/10/11
LIBRARY: TSO               LEVEL:  01.04                TIME: 14:09
TYPE:    CNTL              USERID: D1901                PAGE: 01 OF 01
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   1  OPTIONS NONOTES NONUMBER NODATE;
   1  DATA PR NT; INFILE FILE;
   1  IF _N_ = 1 THEN DO;
   1  INPUT @1 A $80.
   4     #2 @1 PILEDES $80.
   4     #3 @1 TIPLIM 5.1 @11 UPLIM 4.2
   4     #4 @1 PILEDIA 5.2 @11 TIPAREA 7.2 @22 PILEPER 6.2
   4     #5 @1 LOCATION $80.
   4     #6 @1 MISC $CHAR80.;
   1  END;
   1  INPUT @1 DH 4.1 @12 C 2. @16 FC 2.;
   1  DEPTH = DH*100;
   1  F     = FC - C;
   1  QC    = 2*C;
   1  FS    = F*(2/15);
   1  FR    = (FS/QC)*100;
   1  DATA _NULL_; SET PRINT;
   1  FILE PRINT NOTITLES HEADER=TOP;
   1  PUT @16 DEPTH 4.  @25 C 2. @32 FC 2. @38 F 2. @46 QC 2. @54 FS 3.1
   5      @61 FR    4.1; RETURN;
   1  TOP :
   1  IF _N_ EQ 1 THEN DO;
   1  PUT @1 'SOIL DATA FOR PILE LOCATED AT - ' //
   5      @1 LOCATION $80. //
   5      @1 29*'=' ' PILE SPECIFICATIONS ' 30*'=' /
   5      @1 'DIAMETER = ' PILEDIA 5.2 ' CMS' @24 '/'
   4     @27 'PERIMETER = ' PILEPER 6.2 ' CMS' @52 '/'
   4     @56 'TIP AREA = ' TIPAREA 7.2 ' SQ CMS' /
   5      @1 80*'=' / ; END;
   1  PUT @15 'DEPTH' /
   5      @15 '(CMS)' @24 '_C_' @31 'F+C' @38 '_F_' @45 '_QC_' @53 '_FS_'
   5      @61  '_FR_' / ; RETURN;
   1  DATA _NULL_; SET PRINT;
   1  FILE TSOFILE;
   1  IF _N_ EQ 1 THEN DO;
   1  PUT #1 @1 A $80.
   5      #2 @1 PILEDES $80.
   5      #3 @1 TIPLIM 5.1 @11 UPLIM 4.2
   5      #4 @1 PILEDIA 5.2 @11 TIPAREA 7.2 @22 PILEPER 6.2
   5      #5 @1 LOCATION $80.
   5      #6 @1 MISC $CHAR80.; END;
   1  PUT @ 1 DH 4.1 @ 7 F 2. '.' @12 QC 2. '.' @16 FR 4.1; RETURN;
```

EXHIBIT B-1

S.A.S. PROGRAM TO CONVERT FIELD DATA AND PLOT RESULTS

```
    PROJECT: D1901              MEMBER: PILETWO              DATE: 83/10/11
    LIBRARY: TSO                LEVEL:  01.00                TIME: 14:09
    TYPE:    CNTL               USERID: D1902                PAGE: 01 OF 01
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

  1   OPTIONS NONOTES NONUMBER NODATE;
  1   DATA PLOT; INFILE TSOFILE;
  1   IF _N_ = 1 THEN DO;
  1   INPUT @1 A $1.
  4      #2 @1 PILEDES $80.
  4      #3 @1 TIPLIM 5.1 @11 UPLIM 4.2
  4      #4 @1 PILEDIA 5.2 @11 TIPAREA 7.2 @22 PILEPER 6.2
  4      #5 @1 LOCATION $80.
  4      #6 @1 MISC $80.;
  1   END;
  1   INPUT @1 DH 4.1 @12 QC 3. @16 FR 4.1;
  1   DEPTH=DH*100;
  1   LABEL QC=QC OR FR
  7         DEPTH=DEPTH IN CENTIMETERS;
  1   PROC PLOT NOLEGEND; PLOT QC*DEPTH='Q' / VAXIS = 0 TO 90 BY 10;
  1   PROC PLOT NOLEGEND; PLOT FR*DEPTH='F' / VAXIS = 0 TO 20 BY 2;
  1   TITLE PLOT OF DUTCH CONE PENETROMETER;
  1   TITLE2 DEPTH VERSES QC -- SYMBOL = Q;
  1   TITLE3 DEPTH VERSES FR -- SYMBOL = F;
```

EXHIBIT B-1

S.A.S. PROGRAM (CONTINUED)

```
      PROJECT: D1901                MEMBER: PILEDATA                 DATE: 83/10/11
      LIBRARY: TSO                  LEVEL:   01.03                   TIME: 14:09
      TYPE:    CNTL                 USERID: D1901                    PAGE: 01 OF 02
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   1  $ENTRY
   1  14 INCH SQUARE PILE
   1  100.0      0.75
   1  40.13      1264.51     142.24
   1  SCOTLANDVILLE BYPASS STA 65+20
   4  DEPTH         C   F+C
   2   0.4         14   24
   2   0.6         30   46
   2   0.8         17   48
   2   1.0         12   29
   2   1.2         16   29
   2   1.4         17   29
   2   1.6         16   23
   2   1.8         12   19
   2   2.0         13   19
   2   2.2         16   21
   2   2.4         18   26
   2   2.6         18   29
   2   2.8         18   32
   2   3.0         14   27
   2   3.2         12   22
   2   3.4         12   22
   2   3.6         15   24
   2   3.8         14   24
   2   4.0         14   24
   2   4.2         15   22
   2   4.4         14   22
   2   4.6         14   26
   2   4.8         16   26
   2   5.0         12   22
   2   5.2         20   26
   2   5.4         18   25
   2   5.6         16   22
   2   5.8         18   25
   2   6.0         17   22
   2   6.2         21   27
   2   6.4         13   30
   2   6.6         14   21
   2   6.8         15   24
   2   7.0         13   23
   2   7.2         14   24
   2   7.4         16   25
   2   7.6         14   22
   2   7.8         16   30
   2   8.0         16   22
   2   8.2         13   20
   2   8.4         13   19
   2   8.6         11   17
   2   8.8         11   17
   2   9.0         14   19
   2   9.2         16   24
   2   9.4         18   27
   2   9.6         24   34
   2   9.8         21   34
   1  10.0         16   30
```

EXHIBIT B-2

EXAMPLE OF INPUT OF DATA

```
START
 COL   ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   1   10.2         21   32
   1   10.4         27   42
   1   10.6         20   30
   1   10.8         20   30
   1   11.0         15   24
   1   11.2         16   28
   1   11.4         16   29
   1   11.6         16   24
   1   11.8         18   28
   1   12.0         20   30
   1   12.2         21   33
   1   12.4         18   28
   1   12.6         21   32
   1   12.8         21   32
   1   13.0         18   30
   1   13.2         19   30
   1   13.4         30   42
   1   13.6         23   36
   1   13.8         25   37
   1   14.0         26   42
   1   14.2         23   34
   1   14.4         22   36
   1   14.6         26   42
   1   14.8         24   41
   1   15.0         27   43
   1   15.2         28   42
   1   15.4         24   45
   1   15.6         26   44
   1   15.8         26   42
   1   16.0         30   42
   1   16.2         26   41
   1   16.4         25   40
   1   16.6         24   39
   1   16.8         22   36
   1   17.0         22   36
   1   17.2         24   40
   1   17.4         20   34
   1   17.6         16   27
   1   17.8         17   22
   1   18.0         18   28
   1   18.2         24   38
   1   18.4         40   58
   1   18.6         25   57
   1   18.8         34   47
   1   19.0         20   31
   1   19.2         18   28
   1   19.4         18   36
   1   19.6         22   34
   1   19.8         20   30
   1   20.0         24   46
```

EXHIBIT B-2

INPUT (CONTINUED)

SOIL DATA FOR PILE LOCATED AT -

SCOTLANDVILLE BYPASS STA 65+20

============================ PILE SPECIFICATIONS ==============================
DIAMETER = 40.13 CMS / PERIMETER = 142.24 CMS / TIP AREA = 1264.51 SQ CMS
==

DEPTH (CMS)	_C_	F+C	_F_	_QC_	_FS_	_FR_
40	14	24	10	28	1.3	4.8
60	30	46	16	60	2.1	3.6
80	17	48	31	34	4.1	12.2
100	12	29	17	24	2.3	9.4
120	16	29	13	32	1.7	5.4
140	17	29	12	34	1.6	4.7
160	16	23	7	32	0.9	2.9
180	12	19	7	24	0.9	3.9
200	13	19	6	26	0.8	3.1
220	16	21	5	32	0.7	2.1
240	18	26	8	36	1.1	3.0
260	18	29	11	36	1.5	4.1
280	18	32	14	36	1.9	5.2
300	14	27	13	28	1.7	6.2
320	12	22	10	24	1.3	5.6
340	12	22	10	24	1.3	5.6
360	15	24	9	30	1.2	4.0
380	14	24	10	28	1.3	4.8
400	14	24	10	28	1.3	4.8
420	15	22	7	30	0.9	3.1
440	14	22	8	28	1.1	3.8
460	14	26	12	28	1.6	5.7
480	16	26	10	32	1.3	4.2
500	12	22	10	24	1.3	5.6
520	20	26	6	40	0.8	2.0
540	18	25	7	36	0.9	2.6
560	16	22	6	32	0.8	2.5
580	18	25	7	36	0.9	2.6
600	17	22	5	34	0.7	2.0
620	21	27	6	42	0.8	1.9
640	13	30	17	26	2.3	8.7
660	14	21	7	28	0.9	3.3
680	15	24	9	30	1.2	4.0
700	13	23	10	26	1.3	5.1
720	14	24	10	28	1.3	4.8
740	16	25	9	32	1.2	3.7
760	14	22	8	28	1.1	3.8
780	16	30	14	32	1.9	5.8
800	16	22	6	32	0.8	2.5
820	13	20	7	26	0.9	3.6
840	13	19	6	26	0.8	3.1
860	11	17	6	22	0.8	3.6
880	11	17	6	22	0.8	3.6
900	14	19	5	28	0.7	2.4
920	16	24	8	32	1.1	3.3
940	18	27	9	36	1.2	3.3
960	24	34	10	48	1.3	2.8
980	21	34	13	42	1.7	4.1
1000	16	30	14	32	1.9	5.8

EXHIBIT B-3

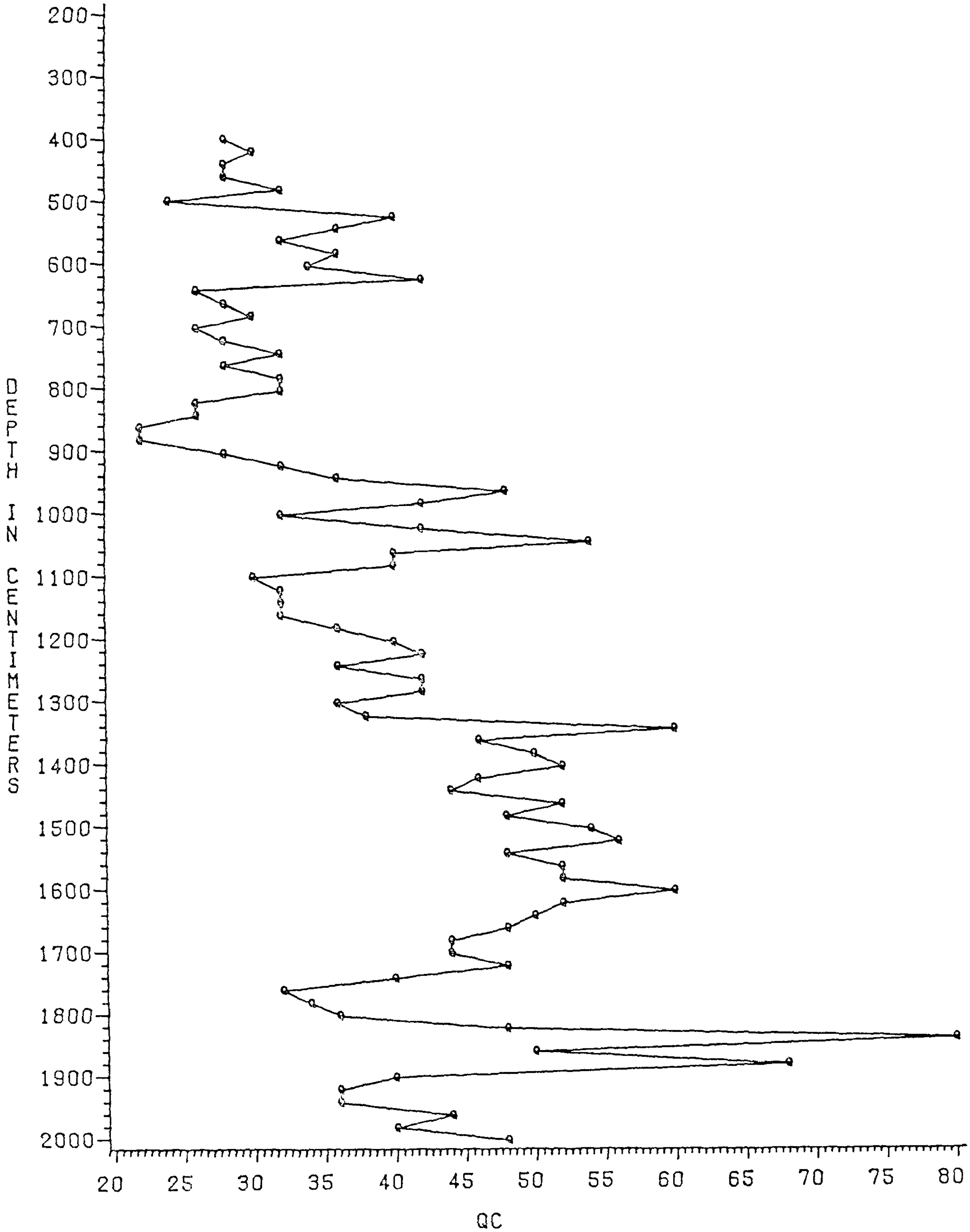
EXAMPLE OF STORED DATA

DEPTH (CMS)	_C_	F+C	_F_	_QC_	_FS_	_FR_
1020	21	32	11	42	1.5	3.5
1040	27	42	15	54	2.0	3.7
1060	20	30	10	40	1.3	3.3
1080	20	30	10	40	1.3	3.3
1100	15	24	9	30	1.2	4.0
1120	16	28	12	32	1.6	5.0
1140	16	29	13	32	1.7	5.4
1160	16	24	8	32	1.1	3.3
1180	18	28	10	36	1.3	3.7
1200	20	30	10	40	1.3	3.3
1220	21	33	12	42	1.6	3.8
1240	18	28	10	36	1.3	3.7
1260	21	32	11	42	1.5	3.5
1280	21	32	11	42	1.5	3.5
1300	18	30	12	36	1.6	4.4
1320	19	30	11	38	1.5	3.9
1340	30	42	12	60	1.6	2.7
1360	23	36	13	46	1.7	3.8
1380	25	37	12	50	1.6	3.2
1400	26	42	16	52	2.1	4.1
1420	23	34	11	46	1.5	3.2
1440	22	36	14	44	1.9	4.2
1460	26	42	16	52	2.1	4.1
1480	24	41	17	48	2.3	4.7
1500	27	43	16	54	2.1	4.0
1520	28	42	14	56	1.9	3.3
1540	24	45	21	48	2.8	5.8
1560	26	44	18	52	2.4	4.6
1580	26	42	16	52	2.1	4.1
1600	30	42	12	60	1.6	2.7
1620	26	41	15	52	2.0	3.8
1640	25	40	15	50	2.0	4.0
1660	24	39	15	48	2.0	4.2
1680	22	36	14	44	1.9	4.2
1700	22	36	14	44	1.9	4.2
1720	24	40	16	48	2.1	4.4
1740	20	34	14	40	1.9	4.7
1760	16	27	11	32	1.5	4.6
1780	17	22	5	34	0.7	2.0
1800	18	28	10	36	1.3	3.7
1820	24	38	14	48	1.9	3.9
1840	40	58	18	80	2.4	3.0
1860	25	57	32	50	4.3	8.5
1880	34	47	13	68	1.7	2.5
1900	20	31	11	40	1.5	3.7
1920	18	28	10	36	1.3	3.7
1940	18	36	18	36	2.4	6.7
1960	22	34	12	44	1.6	3.6
1980	20	30	10	40	1.3	3.3
2000	24	46	22	48	2.9	6.1

EXHIBIT B-3

STORED (CONTINUED)

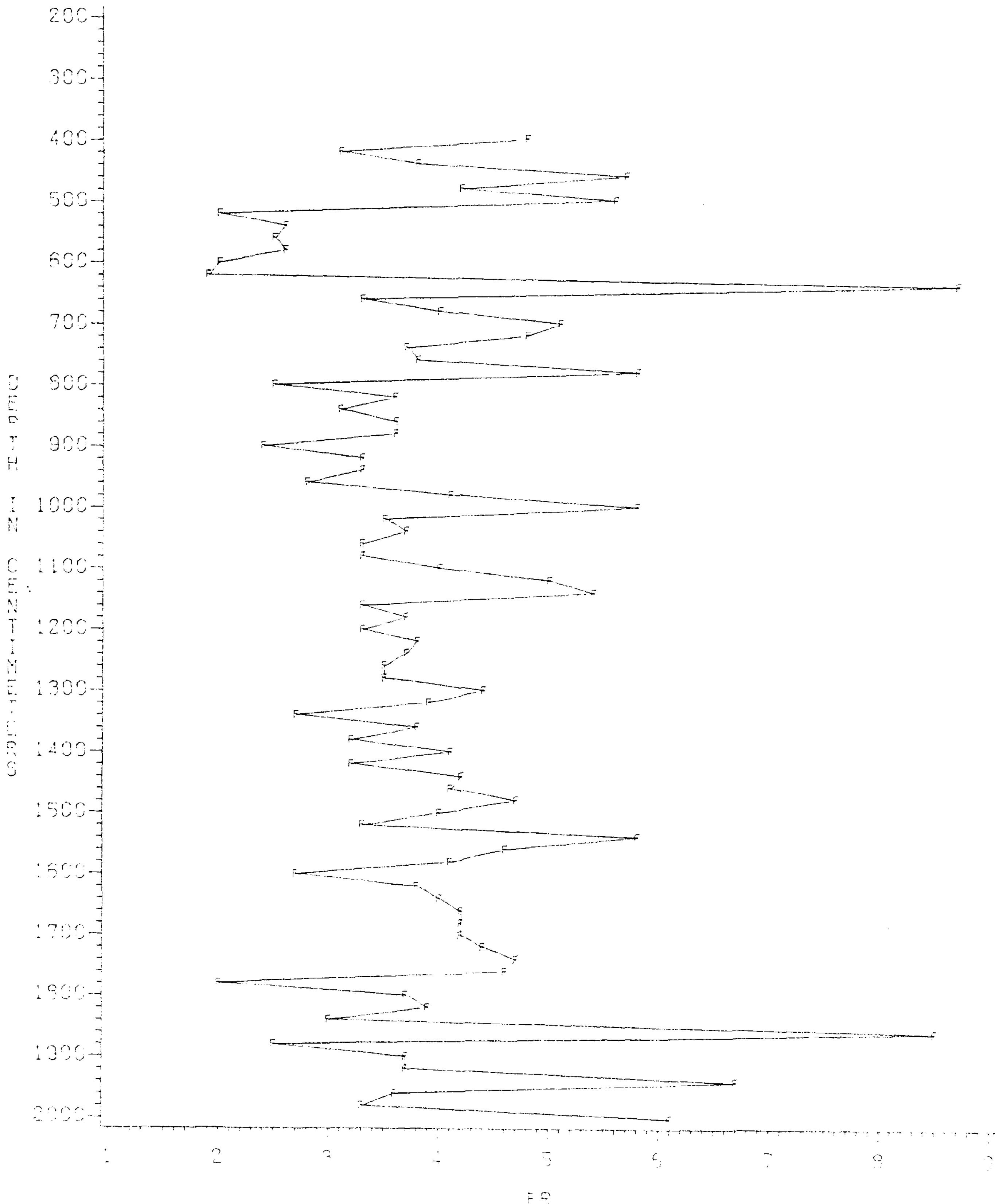
PLOT OF DUTCH CONE PENETROMETER



Example of Cone Resistance Plot

FIGURE B-1

PLOT OF DUTCH CONE PENETROMETER



Example of Friction Ratio Plot

FIGURE B-2

EXHIBIT B-4

PILE CAPACITY PROGRAM, FORTRAN (AFTER TUMAY)

```
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   1  $JOB
   7        DIMENSION FRI(1000),QC(1000),DE1(1000),RATIO(1000),FACTOR(1000),
   6       1IHED(18),DESPIL(18)
   1  C
   1  C     IHED= DESCRIPTION OF LOCATION
   1  C     DESPIL=DESCRIPTION OF PILE USED
   1  C     TIPLIM = UNIT TIP CAPACITY LIMITING VALUE (KG/SQCM)
   1  C     FRILIM = UNIT PILE FRICTION LIMITING VALUE (KG/SQCM)
   1  C     DIAM = DIAMETER OR EQUIVALENT DIAMETER OF PILE (CMS)
   1  C     AT = PILE TIP AREA (SQCM)
   1  C     P = PERIMETER OF PILE (CMS)
   1  C     NP1 = NUMBER OF POINTS OF INPUT
   1  C     STADEP IS THE DEPTH WHEN RECORDING STARTS (METERS)
   1  C     FACTOR = REDUCTION IN QC DUE TO SOIL TYPE (0.6 FOR CLAYS)
   1  C
   7        CHARACTER*4 TYPE
   7        DATA DE1/1000*0./
   7        READ(5,1006)DESPIL
   7        READ(5,1002)TIPLIM,FRILIM
   7        READ(5,1003)DIAM,AT,P
   2   1002 FORMAT(2F10.0)
   2   1003 FORMAT(3F10.0)
   7        READ(5,1006) IHED
   2   1006 FORMAT(18A4)
   7        WRITE(6,2001)IHED
   7        WRITE(6,2002)DIAM
   7        WRITE(6,2003)P
   7        WRITE(6,2004)AT
   7        WRITE(6,2005)DESPIL
   7        WRITE(6,2006)TIPLIM
   7        WRITE(6,2007)FRILIM
   7        READ(5,1000)NP1,STADEP
   2   1000 FORMAT(I5,F10.5)
   7        WRITE(6,2008)STADEP
   2   2001 FORMAT('1',1X,' PILE CAPACITY CALCULATION-',18A4)
   2   2002 FORMAT(/1X,'PILE DIAMETER FOR CALCULATIONS- ',F7.2,'(CMS)')
   2   2003 FORMAT(1X,'PILE PERIMETER- ',F7.3,' (CMS)')
   2   2004 FORMAT(1X,' AREA OF PILE TIP',F10.4,' (SQCM)')
   2   2005 FORMAT(1X,18A4)
   2   2006 FORMAT(' UNIT TIP CAPACITY LIMITING VALUE (KG/SQCM)- ',F7.3)
   2   2007 FORMAT(' UNIT PILE FRICTION LIMITING VALUE (KG/SQCM)- ',F7.3)
   2   2008 FORMAT(' SOUNDING STARTS AT',F5.1,' METER(S)')
   1  C
   1  C  READ AND STORE TEST DATA
   1  C
   7        M=NP1
   7        DO 101 I=1,M
   3    101 READ(5,2000,END=10000) DE1(I),FRI(I),QC(I),RATIO(I),FACTOR(I)
   2   2000 FORMAT(5F5.0)
   1  C
   1  C  PILE CAPACITY CALCULATION
   1  C
   1  10000 EIGD = 8.0*DIAM/100.0
   7        TWED = 12.0*DIAM/100.0
   7        DO 200 I=1,NP1
```

```
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

  7          IF(DE1(I)-EIGD-STADEP)200,390,390
  3      200 CONTINUE
  3      390 II=I
  7          DO 201 J=II,NP1
  7          IF(DE1(J)-TWED-STADEP)201,400,400
  3      201 CONTINUE
  3      400 KK=J
  1   C
  1   C  OUTPUT HEADING
  1   C
  7          WRITE(6,2101)
  7          WRITE(6,2102)
  7          WRITE(6,2103)
  7          WRITE(6,2104)
  2     2101 FORMAT(//,35X,'UNIT',19X,'UNIT',8X,'TIP')
  2     2102 FORMAT(11X,'AVER',8X,'TOTAL',7X,'PILE',5X,'FRICTIONAL',4X,
  6         1'TIP',7X,'BEARING',5X,'***ULTIMATE PILE CAPACITY***',5X,
  6         1'SOIL TYPE')
  2     2103 FORMAT(' DEPTH',3X,'FRICTION',4X,'FRICTION',4X,'FRICTION',
  6         14X,'CAPACITY',3X,'CAPACITY',3X,'CAPACITY')
  2     2104 FORMAT('  (CMS)',3X,'(KG/SQCM)',4X,'(KG/CM)',4X,
  6         1'(KG/SQCM)',5X,'(KG)',5X,'(KG/SQCM)',4X,'  (KG)',9X,
  6         2'(KG)',6X,'(TONS)',4X,'(KIPS)')
  1   C
  7          NP = NP1 - KK + 1
  1   C
  1   C   CAPACITY ITERATION
  7          DO 300 JJ=1,NP
  7          ISTART = JJ
  7          ISTOP  = JJ+II-1
  7          IDEPTH = DE1(ISTOP)*100
  7          F      = FACTOR(ISTOP)
  7          TAF = 0.0
  7          PFT = 0.0
  7          QBA = 0.0
  7          QS  = 0.0
  7          PF  = 0.0
  7          AF  = 0.0
  7          ISTA1 = ISTOP
  7          ISTO1 = JJ+KK-1
  1   C
  1   C  TOTAL FRICTION CALCULATION
  1   C
  7          DO 330 K=1,ISTOP
  7          DEEP   = (DE1(K+1)-DE1(K))*100.
  7          TEMP   = FRI(K)*(2.0/15.0)
  7          PFTEM  = TEMP*(10.0-9.5*(1.0-EXP(-9.0*TEMP)))
  7          IF (PFTEM.GT.FRILIM) PFTEMP = FRILIM
  7          TAFTEM = TEMP*DEEP
  7          TAF    = TAF + TAFTEM
  7          QSTEM  = P*DEEP*PFTEM
  7          QS     = QS + QSTEM
  7          AF     = AF + TEMP
  7          PF     = PF + PFTEM
  3      330 CONTINUE
```

EXHIBIT B-4

PILE CAPACITY (CONT)

```
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

  7          AF = AF/FLOAT(K)
  7          PF = PF/FLOAT(K)
  1   C
  1   C    TIP AVERAGE 4-D BELOW
  1   C
  7          DO 320 K=ISTA1,ISTO1
  7          QBA = QBA + QC(K)
  3     320 CONTINUE
  7          N=0
  7          DO 340 K=ISTA1,ISTO1
  7          LL=ISTO1-N
  7          IF(LL.LT.ISTA1) GOTO 341
  7          IF(LL.EQ.ISTO1) QBM=QC(LL)
  7          IF(LL.EQ.ISTO1) QBMIN=QC(LL)
  7          IF(LL.EQ.ISTO1) GOTO 345
  7          IF(QC(LL).GT.QBMIN)QBM=QBM+QBMIN
  7          IF(QC(LL).LE.QBMIN) QBM=QBM+QC(LL)
  7          IF(QC(LL).LE.QBMIN) QBMIN=QC(LL)
  3     345 N=N+1
  3     340 CONTINUE
  3     341 CONTINUE
  1   C
  1   C   TIP 8-D ABOVE
  7          N=0
  7          DO 310 K=ISTART,ISTOP
  7          LL=ISTOP-N
  7          IF(LL.LT.ISTART)GOTO 312
  7          IF(LL.EQ.ISTOP)QA=QBMIN
  7          IF(LL.EQ.ISTOP)QAMIN=QBMIN
  7          IF(LL.EQ.ISTOP)GO TO 311
  7          IF(QC(LL).GT.QAMIN) QA=QA+QAMIN
  7          IF(QC(LL).LE.QAMIN) QA=QA+QC(LL)
  7          IF(QC(LL).LE.QAMIN) QAMIN=QC(LL)
  3     311 N=N+1
  3     310 CONTINUE
  3     312 CONTINUE
  7          QA=QA/(ISTOP-ISTART+1)
  1   C
  1   C   VALUE FOR OUTPUT
  1   C
  7          QBA=QBA/(ISTO1-ISTA1+1)
  7          QBM=QBM/(ISTO1-ISTA1+1)
  7          QBT=(QBA+QBM)/2.0
  7          IF(F.EQ.0)F=0.6
  7          QN=F*(QBT+QA)/2.0
  7          IF(QN.GT.TIPLIM)QN=TIPLIM
  7          QT=AT*QN
  7          QU=QS+QT
  7          QUT=QU/908.0
  7          QUK=QUT*2.0
  7          IF(F.EQ.0.6)TYPE='CLAY'
  7          IF(F.EQ.1.0)TYPE='SAND'
  7          WRITE(6,9001)IDEPTH,AF,TAF,PF,QS,QN,QT,QU,QUT,QUK,TYPE
  2    9001 FORMAT(1X,I6,3X,F8.4,4X,F10.4,4X,F6.3,2X,3(2X,F9.1),3X,
  6         13(1X,F9.1),6X,A4)
```

EXHIBIT B-4

PILE CAPACITY (CONT)

```
PROJECT: D1901                    MEMBER: PILETRI                 DATE: 83/10/1
LIBRARY: TSO                      LEVEL:  01.37                   TIME: 14:09
TYPE:    CNTL                     USERID: D1901                   PAGE: 04 OF 04
START
 COL  ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   3    300 CONTINUE
   7        STOP
   7        END
   7        SUBROUTINE INIT(M,TOTAL)
   7        DIMENSION TOTAL(1000)
   7        DO 250 I=1,M
   7        TOTAL(I)=0.0
   3    250 CONTINUE
   7        RETURN
   7        END
```

EXHIBIT B-4

PILE CAPACITY (CONT)

```
     PROJECT: D1901                MEMBER: TESTDATA                 DATE: 83/10/11
     LIBRARY: TSO                  LEVEL:  01.00                    TIME: 14:10
     TYPE:    CNTL                 USERID: D1901                    PAGE: 01 OF 02
START
 COL ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

  1  $ENTRY
  1  14 INCH SQUARE PILE
  1  100.0     0.75
  1  40.13      1264.51     142.24
  1  SCOTLANDVILLE BYPASS STA 65+20
  4     99 0.4
  1  00.4  10.  28.  4.8  0.6
  1  00.6  16.  60.  3.6  0.6
  1  00.8  31.  34. 12.2  0.6
  1  11.0  17.  24.  9.4  0.6
  1  11.2  13.  32.  5.4  0.6
  1  11.4  12.  34.  4.7  0.6
  1  11.6   7.  32.  2.9  0.6
  1  11.8   7.  24.  3.9  0.6
  1  22.0   6.  26.  3.1  0.6
  1  22.2   5.  32.  2.1  0.6
  1  22.4   8.  36.  3.0  0.6
  1  22.6  11.  36.  4.1  0.6
  1  22.8  14.  36.  5.2  0.6
  1  33.0  13.  28.  6.2  0.6
  1  33.2  10.  24.  5.6  0.6
  1  33.4  10.  24.  5.6  0.6
  1  33.6   9.  30.  4.0  0.6
  1  33.8  10.  28.  4.8  0.6
  1  44.0  10.  28.  4.8  0.6
  1  44.2   7.  30.  3.1  0.6
  1  44.4   8.  28.  3.8  0.6
  1  44.6  12.  28.  5.7  0.6
  1  44.8  10.  32.  4.2  0.6
  1  55.0  10.  24.  5.6  0.6
  1  55.2   6.  40.  2.0  1.0
  1  55.4   7.  36.  2.6  1.0
  1  55.6   6.  32.  2.5  1.0
  1  55.8   7.  36.  2.6  1.0
  1  66.0   5.  34.  2.0  1.0
  1  66.2   6.  42.  1.9  1.0
  1  66.4  17.  26.  8.7  0.6
  1  66.6   7.  28.  3.3  0.6
  1  66.8   9.  30.  4.0  0.6
  1  77.0  10.  26.  5.1  0.6
  1  77.2  10.  28.  4.8  0.6
  1  77.4   9.  32.  3.7  0.6
  1  77.6   8.  28.  3.8  0.6
  1  77.8  14.  32.  5.8  0.6
  1  88.0   6.  32.  2.5  0.6
  1  88.2   7.  26.  3.6  0.6
  1  88.4   6.  26.  3.1  0.6
  1  88.6   6.  22.  3.6  0.6
  1  88.8   6.  22.  3.6  0.6
  1  99.0   5.  28.  2.4  0.6
  1  99.2   8.  32.  3.3  0.6
  1  99.4   9.  36.  3.3  0.6
  1  99.6  10.  48.  2.8  0.6
  1  99.8  13.  42.  4.1  0.6
  1  10.0  14.  32.  5.8  0.6
```

EXHIBIT B-5

EXAMPLE OF ADDED FACTOR (INPUT)

```
START
 COL   ----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

   1   10.2  11.  42.  3.5  0.6
   1   10.4  15.  54.  3.7  0.6
   1   10.6  10.  40.  3.3  0.6
   1   10.8  10.  40.  3.3  0.6
   1   11.0   9.  30.  4.0  0.6
   1   11.2  12.  32.  5.0  0.6
   1   11.4  13.  32.  5.4  0.6
   1   11.6   8.  32.  3.3  0.6
   1   11.8  10.  36.  3.7  0.6
   1   12.0  10.  40.  3.3  0.6
   1   12.2  12.  42.  3.8  0.6
   1   12.4  10.  36.  3.7  0.6
   1   12.6  11.  42.  3.5  0.6
   1   12.8  11.  42.  3.5  0.6
   1   13.0  12.  36.  4.4  0.6
   1   13.2  11.  38.  3.9  0.6
   1   13.4  12.  60.  2.7  0.6
   1   13.6  13.  46.  3.8  0.6
   1   13.8  12.  50.  3.2  0.6
   1   14.0  16.  52.  4.1  0.6
   1   14.2  11.  46.  3.2  0.6
   1   14.4  14.  44.  4.2  0.6
   1   14.6  16.  52.  4.1  0.6
   1   14.8  17.  48.  4.7  0.6
   1   15.0  16.  54.  4.0  0.6
   1   15.2  14.  56.  3.3  0.6
   1   15.4  21.  48.  5.8  0.6
   1   15.6  18.  52.  4.6  0.6
   1   15.8  16.  52.  4.1  0.6
   1   16.0  12.  60.  2.7  0.6
   1   16.2  15.  52.  3.8  0.6
   1   16.4  15.  50.  4.0  0.6
   1   16.6  15.  48.  4.2  0.6
   1   16.8  14.  44.  4.2  0.6
   1   17.0  14.  44.  4.2  0.6
   1   17.2  16.  48.  4.4  0.6
   1   17.4  14.  40.  4.7  0.6
   1   17.6  11.  32.  4.6  0.6
   1   17.8  15.  34.  2.0  0.6
   1   18.0  10.  36.  3.7  1.0
   1   18.2  14.  48.  3.9  1.0
   1   18.4  18.  80.  3.0  1.0
   1   18.6  32.  50.  8.5  1.0
   1   18.8  13.  68.  2.5  1.0
   1   19.0  11.  40.  3.7  1.0
   1   19.2  10.  36.  3.7  0.6
   1   19.4  18.  36.  6.7  0.6
   1   19.6  12.  44.  3.6  0.6
   1   19.8  10.  40.  3.3  0.6
   1   20.0  22.  48.  6.1  0.6
```

EXHIBIT B-5

ADDED FACTOR (CONTINUED)

PILE CAPACITY CALCULATION-SCOTLANDVILLE BYPASS STA 65+20

PILE DIAMETER FOR CALCULATIONS- 40.13(CMS)
PILE PERIMETER- 142.240 (CMS)
AREA OF PILE TIP 1264.5100 (SQCM)
14 INCH SQUARE PILE
UNIT TIP CAPACITY LIMITING VALUE (KG/SQCM)- 100.000
UNIT PILE FRICTION LIMITING VALUE (KG/SQCM)- 0.750
SOUNDING STARTS AT 0.4 METER(S)

EXHIBIT B-6

EXAMPLE OF OUTPUT OF FORTRAN PROGRAM

DEPTH (CMS)	AVER FRICTION (KG/SQCM)	TOTAL FRICTION (KG/CM)	UNIT PILE FRICTION (KG/SQCM)	FRICTIONAL CAPACITY (KG)	UNIT TIP CAPACITY (KG/SQCM)	TIP BEARING CAPACITY (KG)	***ULTIMATE PILE CAPACITY*** (KG)	(TONS)	(KIPS)	SOIL TYPE
380	1.4667	557.3315	0.735	39713.3	15.8	19937.1	59650.4	65.7	131.4	CLAY
400	1.4600	583.9980	0.731	41610.0	15.8	20021.4	61631.4	67.9	135.8	CLAY
419	1.4349	602.6646	0.719	42943.3	16.2	20442.9	63386.2	69.8	139.6	CLAY
439	1.4182	623.9978	0.710	44462.4	16.4	20695.8	65158.2	71.8	143.5	CLAY
460	1.4261	655.9976	0.714	46738.3	16.9	21370.2	68108.5	75.0	150.0	CLAY
480	1.4222	682.6641	0.712	48635.1	16.1	20316.4	68951.4	75.9	151.9	CLAY
500	1.4187	709.3306	0.711	50531.8	16.1	20316.4	70848.3	78.0	156.1	CLAY
519	1.3949	725.3303	0.699	51685.9	27.2	34352.5	86038.4	94.8	189.5	SAND
539	1.3778	743.9968	0.690	53019.1	26.7	33720.3	86739.4	95.5	191.1	SAND
560	1.3571	759.9966	0.680	54173.2	26.6	33579.7	87752.9	96.6	193.3	SAND
580	1.3425	778.6631	0.673	55506.4	26.8	33860.8	89367.1	98.4	196.8	SAND
600	1.3200	791.9963	0.662	56499.3	26.6	33579.7	90079.1	99.2	198.4	SAND
619	1.3032	807.9961	0.654	57653.4	26.7	33790.5	91443.9	100.7	201.4	SAND
639	1.3333	853.3296	0.669	60877.5	16.0	20232.1	81109.6	89.3	178.7	CLAY
660	1.3212	871.9961	0.663	62210.8	15.7	19894.9	82105.7	90.4	180.8	CLAY
680	1.3176	895.9958	0.661	63918.3	15.7	19894.9	83813.3	92.3	184.6	CLAY
700	1.3181	922.6624	0.661	65815.0	14.1	17829.6	83644.6	92.1	184.2	CLAY
719	1.3185	949.3289	0.661	67711.8	14.0	17745.3	85457.0	94.1	188.2	CLAY
739	1.3153	973.3289	0.660	69419.3	14.1	17871.7	87290.9	96.1	192.3	CLAY
760	1.3088	994.6621	0.656	70938.4	14.3	18082.5	89020.8	98.0	196.1	CLAY
780	1.3231	1031.9950	0.663	73593.5	14.7	18546.1	92139.6	101.5	203.0	CLAY
800	1.3100	1047.9950	0.657	74747.5	15.4	19431.3	94178.8	103.7	207.4	CLAY
819	1.3008	1066.6610	0.652	76080.7	15.8	19937.1	96017.8	105.7	211.5	CLAY
839	1.2889	1082.6610	0.646	77234.8	15.6	19768.5	97003.2	106.8	213.7	CLAY
860	1.2775	1098.6610	0.641	78388.8	16.2	20527.2	98915.9	108.9	217.9	CLAY
880	1.2667	1114.6610	0.635	79542.8	17.3	21876.0	101418.8	111.7	223.4	CLAY
900	1.2533	1127.9940	0.629	80535.6	17.7	22424.0	102959.6	113.4	226.8	CLAY
919	1.2493	1149.3270	0.627	82054.8	18.3	23140.5	105195.3	115.9	231.7	CLAY
939	1.2482	1173.3270	0.626	83762.3	17.5	22171.1	105933.3	116.7	233.3	CLAY
960	1.2500	1199.9940	0.627	85659.0	17.6	22297.5	107956.5	118.9	237.8	CLAY
980	1.2599	1234.6600	0.632	88124.4	17.5	22171.1	110295.5	121.5	242.9	CLAY
1000	1.2720	1271.9930	0.638	90779.6	17.5	22171.0	112950.6	124.4	248.8	CLAY
1019	1.2758	1301.3270	0.640	92865.8	17.8	22550.4	115416.2	127.1	254.2	CLAY
1039	1.2897	1341.3270	0.647	95710.6	18.1	22887.6	118598.1	130.6	261.2	CLAY
1060	1.2906	1367.9930	0.647	97607.3	18.2	23056.2	120663.5	132.9	265.8	CLAY
1080	1.2911	1394.6600	0.648	99504.1	18.2	23056.2	122560.3	135.0	270.0	CLAY
1100	1.2897	1418.6590	0.647	101211.6	18.6	23519.9	124731.4	137.4	274.7	CLAY
1119	1.2952	1450.6590	0.650	103487.4	19.2	24236.4	127723.8	140.7	281.3	CLAY
1139	1.3029	1485.3260	0.653	105952.9	19.3	24362.9	130315.7	143.5	287.0	CLAY
1160	1.2988	1506.6590	0.651	107472.0	19.6	24826.5	132298.5	145.7	291.4	CLAY
1180	1.2994	1533.3260	0.652	109368.8	20.8	26301.8	135670.5	149.4	298.8	CLAY
1200	1.3000	1559.9920	0.652	111265.5	21.1	26723.3	137988.8	152.0	303.9	CLAY
1219	1.3049	1591.9920	0.654	113541.3	21.8	27524.2	141065.4	155.4	310.7	CLAY
1239	1.3054	1618.6590	0.654	115438.1	22.4	28367.2	143805.2	158.4	316.8	CLAY
1260	1.3079	1647.9920	0.656	117524.3	22.7	28746.5	146270.8	161.1	322.2	CLAY

1280	1.3104	1677.3250	0.657	119610.6	22.8	28873.0	148483.5	163.5	327.1	CLAY
1300	1.3149	1709.3250	0.659	121886.4	23.4	29547.4	151433.7	166.8	333.6	CLAY
1319	1.3172	1738.6580	0.660	123972.6	23.8	30137.5	154110.1	169.7	339.4	CLAY
1339	1.3214	1770.6580	0.662	126248.4	24.6	31106.9	157355.3	173.3	346.6	CLAY
1360	1.3274	1805.3250	0.665	128713.9	25.0	31570.6	160284.4	176.5	353.0	CLAY
1380	1.3314	1837.3240	0.667	130989.7	25.1	31697.0	162686.7	179.2	358.3	CLAY
1400	1.3428	1879.9910	0.673	134024.1	25.5	32202.8	166226.9	183.1	366.1	CLAY
1419	1.3446	1909.3240	0.674	136110.4	25.8	32666.5	168776.9	185.9	371.8	CLAY
1439	1.3518	1946.6570	0.677	138765.5	26.6	33593.8	172359.3	189.8	379.6	CLAY
1460	1.3625	1989.3240	0.683	141799.9	27.0	34141.8	175941.7	193.8	387.5	CLAY
1480	1.3748	2034.6570	0.689	145024.0	27.1	34310.3	179334.3	197.5	395.0	CLAY
1500	1.3849	2077.3240	0.694	148058.4	27.2	34436.8	182495.2	201.0	402.0	CLAY
1519	1.3912	2114.6570	0.697	150713.6	26.5	33467.4	184180.9	202.8	405.7	CLAY
1539	1.4095	2170.6570	0.706	154696.3	26.4	33383.1	188079.3	207.1	414.3	CLAY
1560	1.4222	2218.6570	0.713	158110.0	26.6	33636.0	191745.9	211.2	422.3	CLAY
1580	1.4312	2261.3230	0.717	161144.4	25.0	31612.7	192757.1	212.3	424.6	CLAY
1600	1.4333	2293.3220	0.718	163420.3	21.4	27018.3	190438.6	209.7	419.5	CLAY
1619	1.4403	2333.3220	0.722	166265.0	21.0	26512.6	192777.5	212.3	424.6	CLAY
1639	1.4471	2373.3240	0.725	169109.9	20.8	26259.7	195369.6	215.2	430.3	CLAY
1660	1.4538	2413.3230	0.728	171954.7	21.0	26554.7	198509.4	218.6	437.2	CLAY
1680	1.4587	2450.6560	0.731	174609.8	22.3	28240.7	202850.4	223.4	446.8	CLAY
1700	1.4635	2487.9880	0.733	177264.8	22.2	28114.3	205379.1	226.2	452.4	CLAY
1719	1.4713	2530.6540	0.737	180299.2	23.2	29378.8	209677.9	230.9	461.8	CLAY
1739	1.4759	2567.9890	0.739	182954.4	22.3	28198.6	211152.9	232.5	465.1	CLAY
1760	1.4757	2597.3220	0.739	185040.6	22.0	27777.1	212817.6	234.4	468.8	CLAY
1780	1.4667	2610.6550	0.735	186033.5	22.1	27987.8	214021.3	235.7	471.4	CLAY
1800	1.4652	2637.3210	0.734	187930.2	37.6	47489.4	235419.5	259.3	518.5	SAND
1819	1.4696	2674.6540	0.736	190585.3	37.8	47770.3	238355.6	262.5	525.0	SAND
1839	1.4797	2722.6560	0.741	193999.2	38.2	48332.4	242331.5	266.9	533.8	SAND

CORE USAGE OBJECT CODE= 5968 BYTES,ARRAY AREA= 20144 BYTES,TOTAL AREA AVAILABLE= 403456 BYTES

DIAGNOSTICS NUMBER OF ERRORS= 0, NUMBER OF WARNINGS= 0, NUMBER OF EXTENSIONS= 0

COMPILE TIME= 0.29 SEC,EXECUTION TIME= 2.13 SEC, WATFIV - JUL 1973 V1L4 13.56.18 WEDNESDAY 2 NOV 83

EXHIBIT B-6

FORTRAN PROGRAM (CONTINUED)

APPENDIX C

TABLE C1

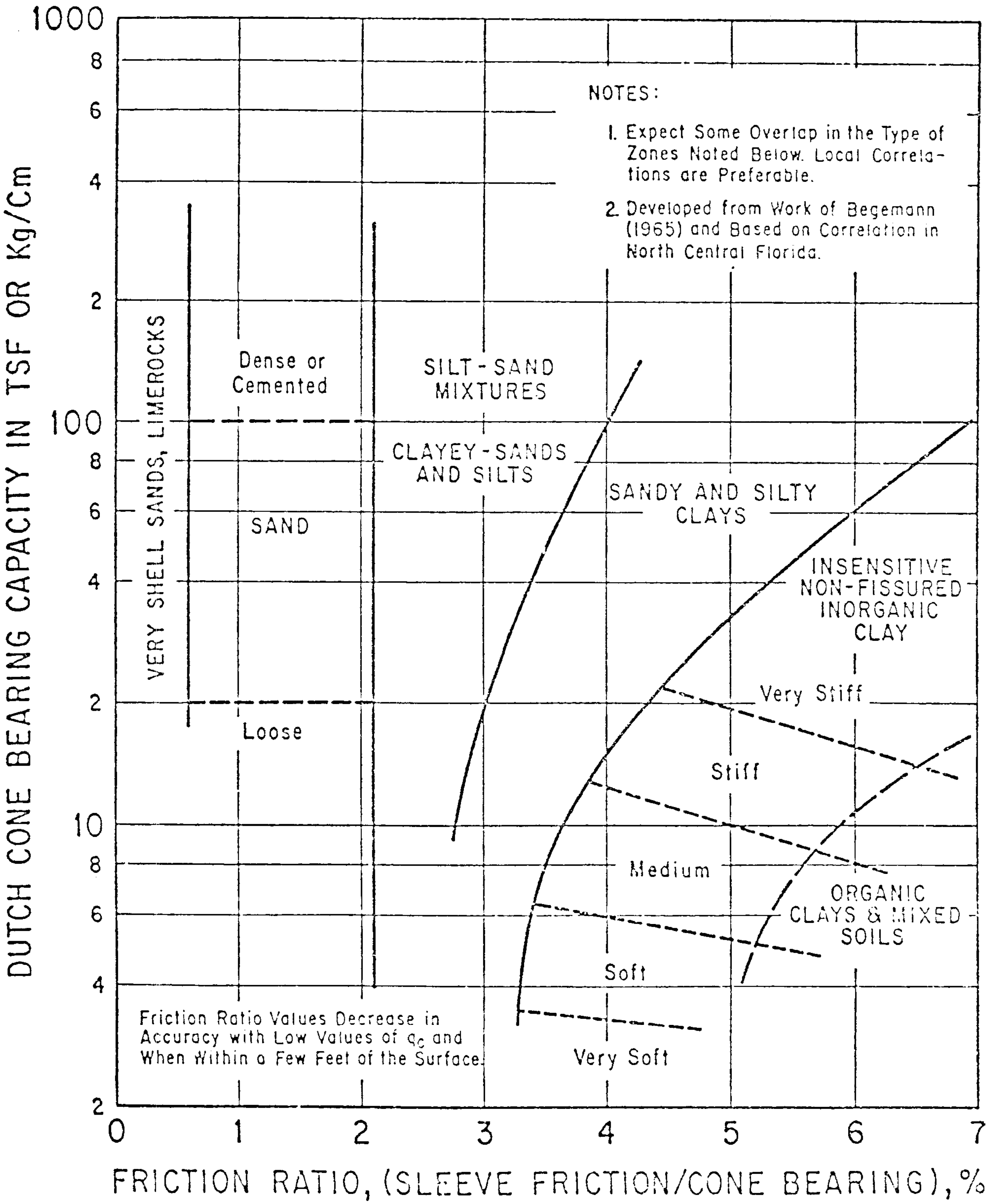
Typical q_c (kg/cm^2) / N(SPT blows/ft) Ratios

Type Soil	Fugro Tip	Delft Mechanical Tips
sand and gravel mixtures	8	6
sand	5	4
sandy soils	4	3
clay-silt-sand mixtures	2	2
insensitive clays	1	1½
sensitive clays	Ratios can get very high because N approaches 0	

(After Schmertmann (5))

TABLE C2

CORRELATION OF PENETRATION RESISTANCE AND SOIL PROPERTIES				
SOIL	DESIGNATION		Nº OF BLOWS "N"	"qu" UNCONFINED COMPRESSIVE STRENGTH TONS PER SQ.FT.
SAND & SILT	RELATIVE DENSITY	VERY LOOSE	LESS THAN 4	
		LOOSE	4 - 10	
		MEDIUM	10 - 30	
		DENSE	30 - 50	
		VERY DENSE	OVER 50	
CLAY	CONSISTENCY	VERY SOFT	LESS THAN 2	LESS THAN 0.25
		SOFT	2 - 4	0.25 - 0.50
		MEDIUM	4 - 8	0.50 - 1.00
		STIFF	8 - 15	1 - 2
		VERY STIFF	15 - 30	2 - 4
		HARD	OVER 30	OVER 4



GUIDE FOR ESTIMATING SOIL TYPE FROM DUTCH FRICTION-CONE RATIO (BEGEMANN MECHANICAL TIP)

(AFTER SCHMERTMANN, 1969) - unpublished

FIGURE C-1