

The Miniature Electrical Cone Penetrometer and Data
Acquisition System

by

Terese Marie Kwiatkowski

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APPROVED:

G. Wayne Clough, Chairman

J. Michael Duncan

T. Kuppusamy

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(ABSTRACT)

The static cone penetrometer is an in-situ testing tool which was originally developed to derive information on soil type and soil strength. More recently, it has found application in liquefaction assessment. Typical cone penetrometers are heavy duty devices which are operated with the assistance of a drill rig. However, this capacity is not necessary in the case of field studies of liquefaction, since liquefaction usually occurs at relatively shallow depths. This thesis is directed to the goal of the development of a miniature, lightweight cone penetrometer which can be used in earthquake reconnaissance studies related to liquefaction problems.

The research for this thesis involved four principal objectives:

1. Development of procedures to automatically acquire and process measurements from a miniature electrical cone;

2. Develop and perform tests in a model soil-filled bin to calibrate the cone;
3. Evaluate the utility and accuracy of the cone results as a means to assess conventional soil properties; and,
4. Conduct a preliminary evaluation of the cone results in the context of recently developed methods to predict liquefaction potential.

The work in regard to the first objective involved assembling and writing software for a microcomputer based data acquisition system. Successful implementation of this system allowed data from the tests to be rapidly processed and displayed. Calibration tests with the cone were carried out in a four foot high model bin which was filled ten times with sand formed to variety of densities. The sand used is Monterey No. 0/30, a standard material with well known behavioral characteristics under static and dynamic loading.

The test results showed the cone to produce consistent data, and to be able to readily distinguish the varying density configurations of the sand. Using the results in conventional methods for converting cone data into soil parameters yielded values which were consistent with those expected. Liquefaction potential predictions were less satisfying, although not unreasonable. Further research is needed in this area both

to check the reliability of the prediction procedures and the ability to achieve the desired objectives.

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1.0 INTRODUCTION

After several decades of growing popularity in Europe, the cone penetrometer is finding greater acceptance in the United States. The cone penetrometer allows rapid and economical in-situ soil testing, by indirectly determining soil type and key soil parameters such as density, strength, and stiffness. More recently, researchers have suggested that the cone is well-suited for evaluating liquefaction potential in sands. This particular application is important since the possibility of liquefaction is an issue of great economic impact and of significance to human safety. Further, it is important to research especially for earthquake hazard mitigation. Proper evaluation of the soil conditions at a site where liquefaction has occurred following an earthquake is essential, and the cone penetrometer can be a very useful tool in this regard.

This thesis is directed towards the possibility of developing a lightweight, portable miniature electrical cone system which could be used in the following modes:

1. Subsurface reconnaissance in earthquake zones where large-scale or complex equipment is not available;
2. A tool for broadening an investigation where full-scale exploration is too expensive; and

3. A demonstration device for classes and short courses devoted to in-situ testing.

The thrust of this effort is to establish the basic requirements of the equipment, implement important supporting elements, and to carry out preliminary trials to evaluate its utility. Specific efforts include:

1. Preliminary calibration testing of the first generation electrical cone penetrometer;
2. Developing an automated data acquisition system; and
3. Evaluating the cone as a tool to predict soil parameters and liquefaction potential.

The calibration of the cone was performed using a four-foot-high by two-foot-square soil filled bin. A standard sand, Monterey No. 0/30, was used as the test medium since data concerning its behavior and liquefaction response are well established.

The first step in accomplishing the research tasks was to develop a microcomputer based automated data acquisition system. To evaluate the data collection system, a simplified soil box was designed and constructed. The results of performing several cone penetrometer calibration tests in this box led to a need for methods to interpret the test data.

This thesis is divided into five chapters. Chapter 2 presents background information concerning cone penetrometers and interpretations for basic soil parameters and liquefaction potential. Chapter 3 describes the design of the first generation miniature electrical cone and compares it to the full-size Earth Technology cone, from which the basis for the miniature design was derived. Further, this section describes operation of the cone. Chapter 4 outlines the automated data acquisition system and the experimental calibration scheme developed by the writer. Procedures are presented which describe how to use the data acquisition system with sample output. Also, the soil test bin and procedures for filling it with sand are provided. Chapter 5 presents typical test results from insertion of the miniature electrical cone and compares them with that from a miniature mechanical cone. In addition, the data are examined for obtaining basic soil parameters and predicting liquefaction potential. Finally, Chapter 6 concludes and summarizes the thesis work.

In addition to the main body of the thesis, four appendices are provided. The first gives a detailed user's guide for operating the ISAAC/Apple II automated data acquisition system. The second appendix lists the programs and plots from which the cone and the position transducer are calibrated. The third appendix presents a summary of some of the factors influencing the cone data. Finally, the fourth appendix contains detailed miniature electrical cone test results from homogeneous samples.

2.0 BACKGROUND

This chapter describes the origin and operation of cone penetrometers. To set the stage for interpreting the test data from the miniature cone, the theories for deriving soil parameters assessing liquefaction potential are also reviewed. Moreover, information is provided relative to cone calibrating systems.

2.1 HISTORY OF CONE PENETROMETERS

Because nature has provided no assurances of site quality, the design engineer must plan a site investigation that will identify subsoil conditions. In ancient times, builders simply drove poles into the soil to locate firm strata. They identified changes in underground conditions by recognizing the differences in the resistances felt when driving the poles. Today, this principle is used in a more sophisticated approach. Currently, there are static and dynamic cone penetrometers which yield measurements that can be correlated to soil parameters useful for design. Most commonly, cone penetrometers are used to obtain information on soil type and soil strength as a basis for pile capacity, to estimate compressibility and in-situ density of cohesionless soils, to estimate the settlements of footings on sand and to characterize trafficability over unpaved soils. More recently, cone penetrometers have found application in defining the potential of a soil for liquefaction during an earthquake.

2.2 STATIC VERSUS DYNAMIC PENETROMETERS

The static cone penetrometer test (CPT) was developed in the late 1800s in Holland and Belgium. The static test consists of pushing a conical point attached to a slender rod into the soil. In North America, the dynamic penetration procedure known as the Standard Penetration Test (SPT) is more common than the static cone test. In this case a standard sized sampler is driven a specified distance into the ground by a hammer. However, the static CPT is becoming more popular in North America (Campanella and Robertson, 1983; Seed et al., 1983).

There are two types of static penetrometers: (1) a movable cone-tip static penetrometer in which an inner rod forces the cone located below a static sleeve downward into the soil; and, (2) a fixed cone-tip penetrometer in which both the sleeve and the cone tip are forced into the soil together (Sanglerat, 1972). The movable cone-tips operate mechanically and give discontinuous readings since the cone is advanced telescopically ahead of its drill rod. The fixed cone-tip usually measures resistance electrically and can give continuous readings since the cone is advanced continuously with interruptions occurring only when another drill rod is added. Both types of cones are pictured in figure 2.1. The mechanical penetrometers are simple to use and the cost for replacement is relatively low. The quality of test data is operator dependent. The most common testing error is due to the friction between the drive rods and the inner push rods which are required for advancing the tip.

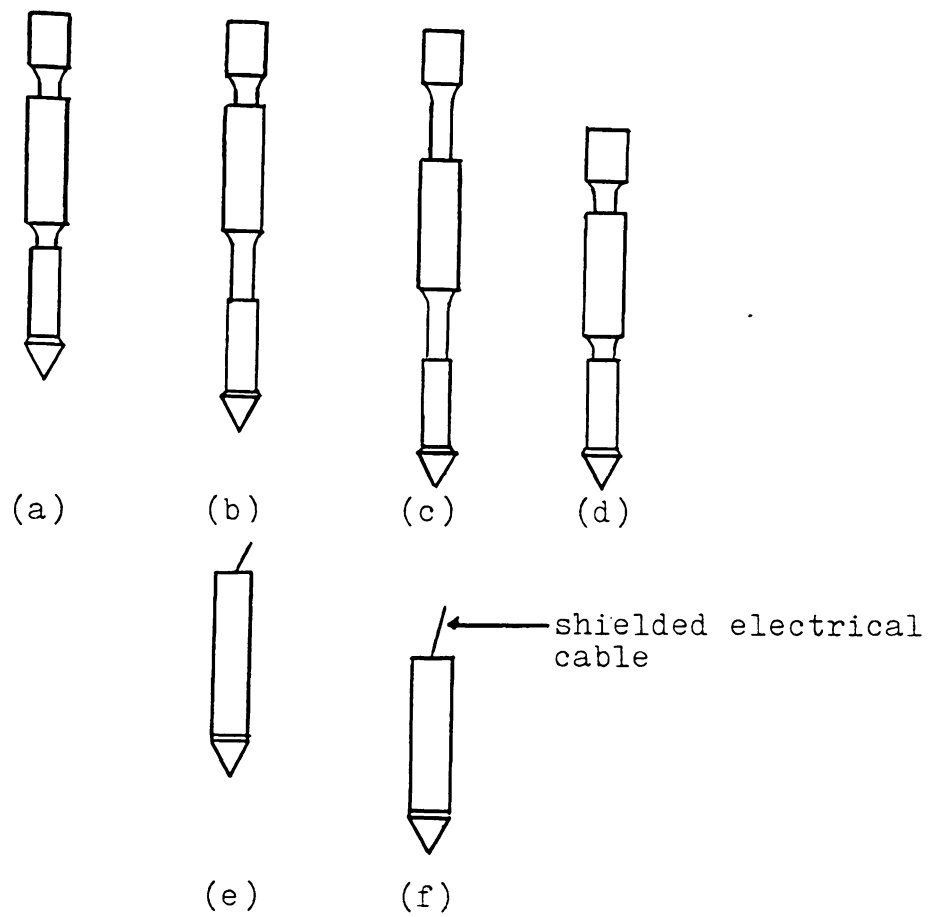


Figure 2.1: Schematics of Mechanical Cone Operation (a-d) versus Electrical Cone Operation (e-f)

In comparison to mechanical cones, electrical cones are more accurate and consistent than the mechanical types. The quality and repeatability of the test data provide for continuous tip resistance and friction sleeve readings with depth as exemplified in figure 2.2.

2.3 CONE OPERATION

In the field cone penetrometers are advanced into the soil by pushing with a hydraulic jacking system attached to a drill rig. Reaction against the downward thrust is provided by the weight of the drill rig. In addition, screw anchors can be used to supply additional reaction force. The engine of the truck supplies the power to operate the drill rig.

The standard rate for advancing a cone is 2 cm/sec (0.8 in/sec). As the cone is driven, the cone resistance and the local sleeve friction are measured. The electrical penetrometer measures these with strain gages. Additional sensors such as inclinometers, pore pressure transducers, temperature gages and chemical sensors can also be adapted for special purposes.

2.4 DATA ACQUISITION

A data acquisition system is needed to record and monitor electrical cone testing. In some applications, simple strip chart recorders or strain indicators are used. More sophisticated systems employ microcom-

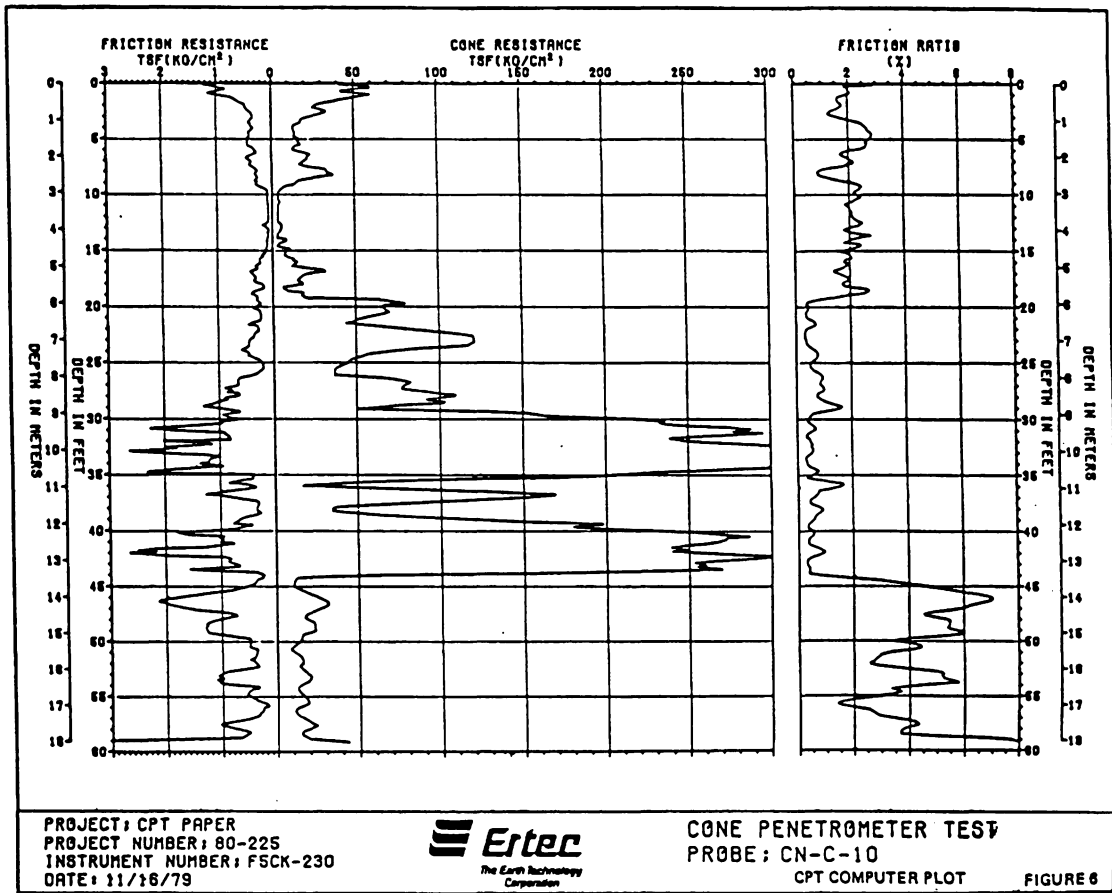


Figure 2.2: Typical Electrical Cone Penetrometer Test Data

puter based techniques. The data can be plotted, and in some cases, processed.

2.5 THEORY, CORRELATIONS AND INTERPRETATIONS WITH ENGINEERING PARAMETERS

The following sections present the empirical relationships which provide a means for interpreting static cone penetrometer test data, especially as applied to evaluating liquefaction potential. The design of the miniature electric cone penetrometer is primarily intended for testing the type of soils susceptible to liquefaction. Since the clayey soils do not liquefy, the miniature cone will be used in liquefiable soils such as sands and silty sands.

2.6 WHAT IS LIQUEFACTION ?

There are several factors which act together to determine whether or not liquefaction will occur at a site. In general, liquefaction occurs under large amplitude, dynamic ground movements applied to saturated sands. Since the term "liquefaction" was originated in 1925 by Terzaghi, its definition has been subjected to several interpretations. The official definition proposed by The Committee on Soil Dynamics of the Geotechnical Engineering Division, of the American Society of Civil Engineering, 1980, is, "the transformation from a solid state to a liquid state as a consequence of increased pore pressures and reduced effective stress". Basically, this occurs as the excess pore pressures approach the total confining stress; hence the effective confining stress is es-

entially zero. This condition can cause a loose sand to flow like a liquid.

2.7 BASIC CONCEPTS OF CONE RESISTANCE

Understanding the cone penetrometer and developing correlations for it require both theoretical and empirical procedures. There are two theoretical approaches used to interpret cone resistance: (1) classical bearing capacity theory, and (2) cavity expansion theory. Bearing capacity theories assume a slip surface shear failure as the cone is driven into the soil. Cavity expansion theory (Vesic, 1975) involves calculating the work required to expand a cylindrical or spherical cavity around the cone as it is driven into the soil. Cavity expansion theory is not as popular as the bearing capacity theories because, although it can generate a reasonable solution, it cannot account for penetrometer geometry. At the same time, the bearing capacity theory is not totally adequate either since it is only valid for incompressible materials. Durgunoglu and Mitchell (1975) have concluded, however, that the bearing capacity approach closely estimates cone resistance provided that shape factors are applied in the calculations.

2.7.1 Alternate Assumptions for Failure Mechanisms

There are a number of proposed mechanisms of failure for static cone penetration into soil. For incompressible soils and a simple footing element Terzaghi (1943) used an approach which assumes a log spiral slip

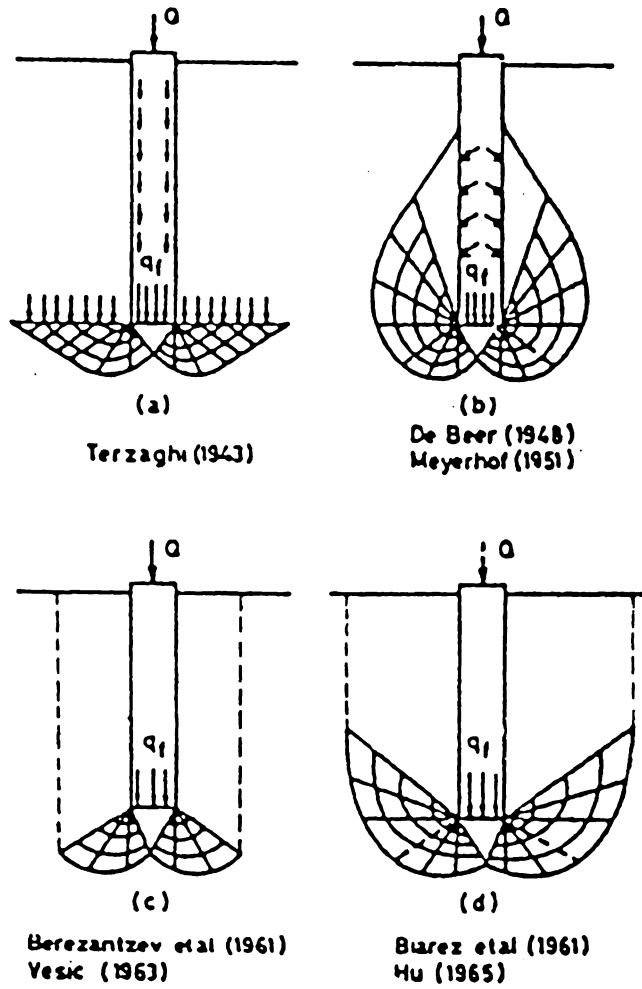


Figure 2.3: Assumed Failure Mechanisms

surface ending at the base level of the penetrating foundation element. This theory neglects the effect of the shear strength of the soils above the base level. De Beer (1948) and Meyerhof (1951) extended Terzaghi's basic theory to include slip surfaces which curve back to the shaft of the bearing element (in this case, the penetrometer). Vesic (1963) and Berezantzev et al. (1961) later suggested an alternative radial slip surface which ends prior to reaching the base level of the penetrometer. In yet another approach, Biarez et al. (1961) and Hu (1965) assumed a radial slip surface which reaches a vertical tangency. A final alternative, proposed by Vesic (1972), involved a failure surface described by the expansion of a cylindrical or spherical cavity. Each of these mechanisms, excluding cavity expansion, is illustrated in figure 2.3.

2.8 PREDICTION OF CONE RESISTANCE

The theories used in calculating cone resistance assume one of the alternative failure surfaces previously described. Since these are based on plane strain conditions, the equations for a cone must include shape factors for circular foundations. Using the failure mechanism suggested by Biarez and Hu, Durgunoglu and Mitchell (1975) proposed the following expression for the evaluation of cone resistance in sand:

$$q_c = \rho g B N_{\gamma q} \xi_{\gamma q}$$

where: ρ = soil mass density

g = acceleration of gravity

B = width of penetrometer tip

$N_{\gamma q}$ = bearing capacity factor based on soil
 friction angle, (ϕ); friction angle
 between soil and penetrometer, (δ/ϕ);
 lateral earth pressure coefficient,
 (K_o); and the relative depth of the
 penetrometer, (D/B).

$\xi_{\gamma q}$ = shape factor for circular foundations

This approach has found acceptance by the geotechnical profession. An
 alternative approach by Vesic (1977) assumes an expanding cylindrical
 cavity and the equation is given as:

$$q_c = p_u^c \lambda [1 + \tan(\pi/4 + \phi_s/2) \tan\phi_s] \exp(\pi/2 - \phi_s)$$

where:

p_u^c = ultimate pressure of the expanding
 cylindrical cavity in an elasto-
 plastic infinite medium

λ = empirical shape factor = $1 + \tan(\phi)$

ϕ_s = secant angle of friction related to
 the average effective stress at
 failure in the plastic zone

$$\phi_s = \arctan(\tau_f/\sigma_f)_{ave}$$

A third approach was presented by Schmertmann (1978) and is based on an
 empirical correlation between relative density and vertical effective
 stress.

$$D_r(\%) = (100/2.91) \ln(q_c / 12.31 p_o^{0.71})$$

rewrite to solve for q_c :

$$q_c = 12.31 p_o^{0.71} e^{0.291 D_r}$$

2.9 SAND STRENGTH FROM MEASURED CONE PENETRATION RESISTANCE

The theories for evaluating the drained shear strength of sands from measured cone resistance data derive from bearing capacity theory, cavity expansion theory or correlations from field or laboratory calibration testing. Table 2.1 presents the available methods. Associated charts for this purpose are given in figures 2.4-2.7.

2.10 CORRELATION OF CPT WITH RELATIVE DENSITY

Numerous correlations have been developed for cone resistance with parameters such as relative density (Villet and Mitchell, 1981; Veismanis, 1974; Baldi et al., 1981). It is generally concluded that there is no universal or single relationship between relative density and cone resistance, since cone resistance is affected by soil compressibility, soil stress history, and cone geometry. Each of these factors and others will be reviewed subsequently. An inspection of cone resistance-relative density-vertical stress correlations reveals that the

Table 2.1: Summary of the Available Methods for Predicting Friction Angle

THEORY BY	CONCEPT OR THEORY	EQUATIONS OR CORRELATIONS	LIMITATIONS AND ASSUMPTIONS	REFERENCES
DeBeer (1974)	Bearing Capacity	$q_c/p_o = f(\phi, \phi'')$ q_c = cone resistance p_o = effective overburden pressure ϕ = angle of internal friction ϕ'' = apparent angle of internal friction	-incompressible material	Sanglerat, (1972)
Meyerhof (1961)	Bearing Capacity	correlates ϕ to bearing capacity factor N_q	-valid for $\alpha = 30^\circ$ and $f/\phi = 0.5$	Mitchell and Lunne (1978)
Meyerhof (1974)	Bearing Capacity	correlates ϕ to values of q_c based on testing in France and Germany (See figure 2.2)	-use the maximum value for q_c (Max. q_c occurs at the critical depth or where q_c shows little or no increase). Not all sands show a critical depth.	Mitchell and Lunne (1978)
Durgunoglu & Mitchell (1975)	Bearing Capacity	$q_c = \gamma_s * B * N_{1q} * \xi_{1q}$ an alternate plot is shown in figure 2.3	-valid for sand -is really a correlation where ϕ varies with depth -cone shape factors N_{1q} and ξ_{1q} are a $f(\phi)$	Baldi et al. (1975) Mitchell and Lunne (1978) Durgunoglu & Mitchell (1975)
Janbu (1974)	the shear strength of sand vs. depth is a linear relation	$\tau_f = (a + \sigma) \tan \phi$ a = attraction σ' = effective normal stress	- q_c vs. depth must be a linear relationship -valid for testing in Norway -typically over estimates ϕ	ESOPT Vol. 2.2 (1974)
Vesic, Al-Awkati (1963)	Cavity Expansion	$p_u = q * F_q$ p_u = limiting pressure required to expand a cavity in a cohesionless material q = mean normal stress F_q = a factor which is a $f(\phi, \text{soil rigidity})$	-only theory which accounts for compressibility of sand!!! -difficult to determine soil rigidity (requires special lab tests on undisturbed samples)	Mitchell and Lunne (1978)
Trofimenkov (1974)	correlation based on overburden pressure and q_c	See figure 2.4	-valid for overburden 1 kg/sq.cm.	Mitchell and Lunne (1978)
Schmertmann (1975)	estimate ϕ indirectly from Dr	Step 1: obtain Dr based on q_c and γ' Step 2: obtain ϕ from Dr See figures 2.5 a & b	-method is purely empirical -valid for n.c., uncemented, SP sands -need to estimate K_o if soil is o.c.	Mitchell and Lunne (1978) Schmertmann (1978)

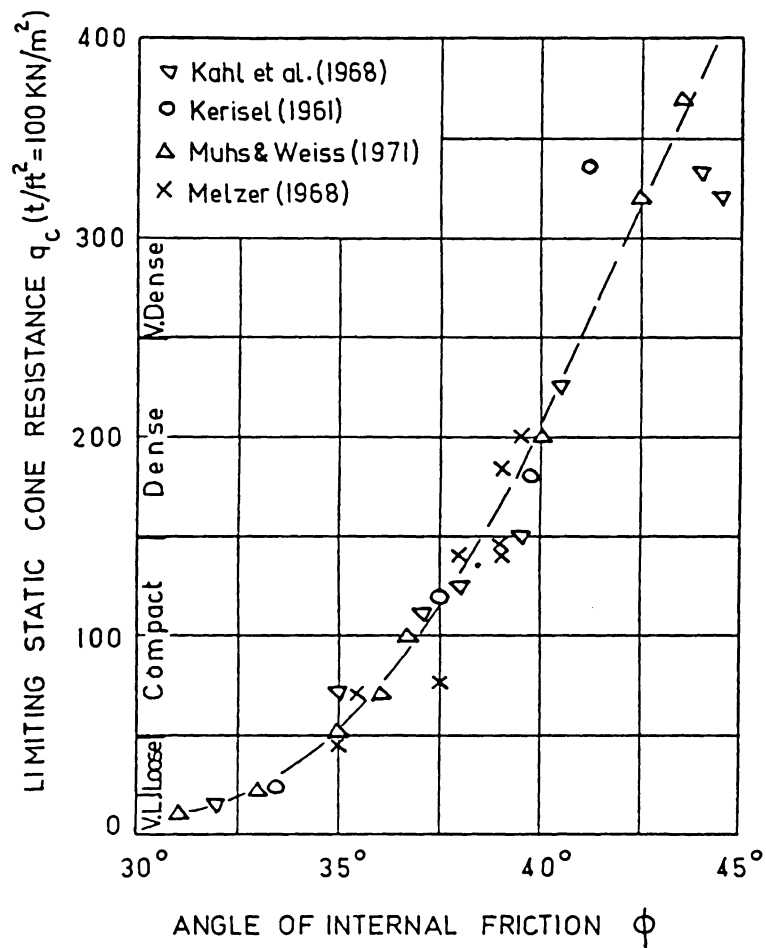


Figure 2.4: Approximate Relationship between Static Cone Resistance and Angle of Internal Friction of Sand (after Meyerhof, 1974)

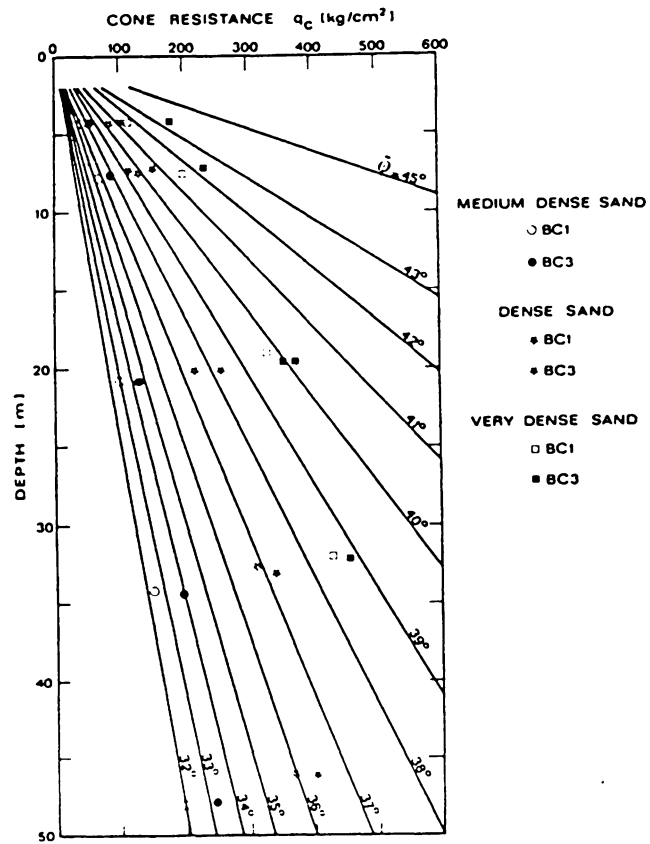


Figure 2.5: Cone Resistance versus Depth as a Function of Angle of Internal Friction of Sand (after Durgunoglu & Mitchell, 1975)

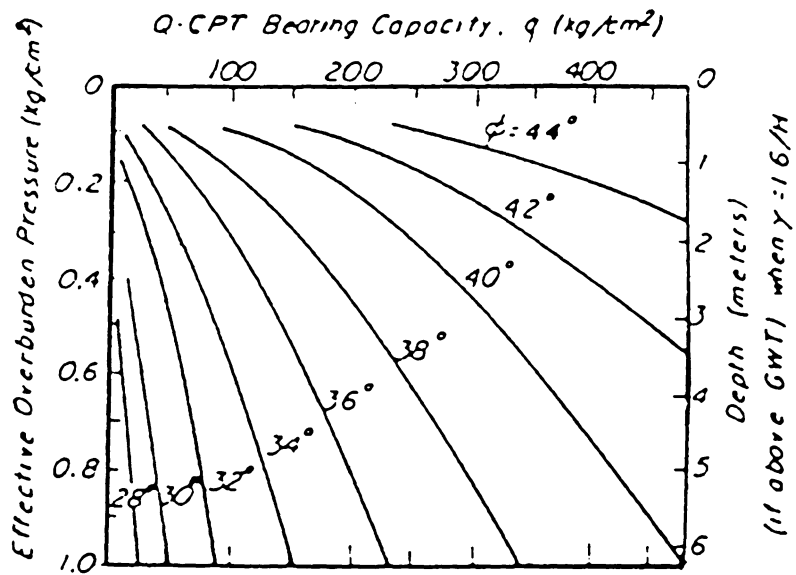
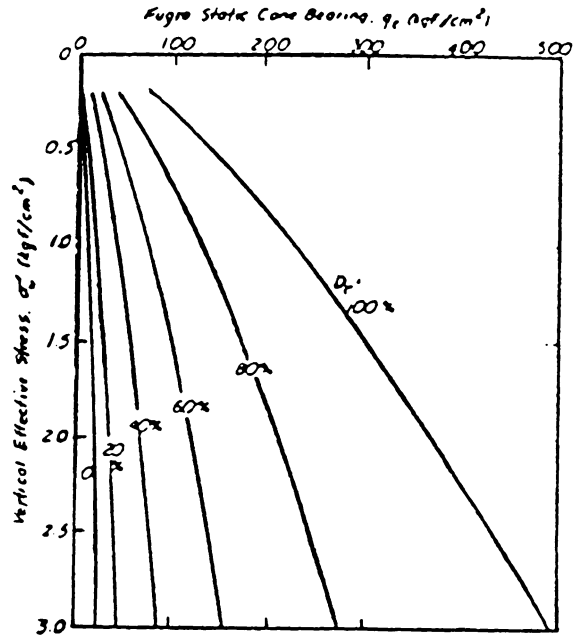
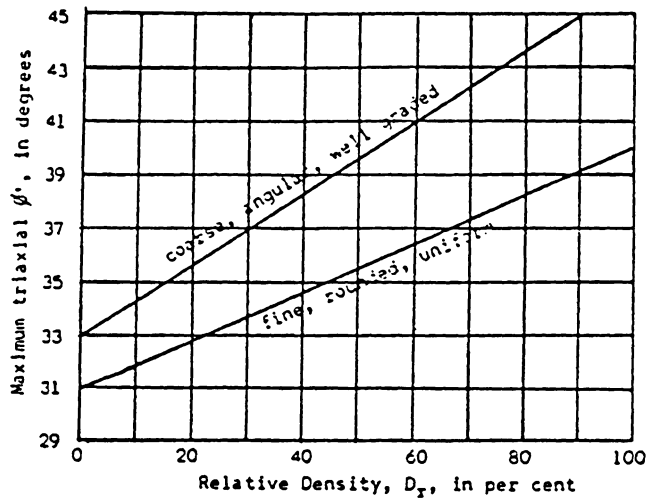


Figure 2.6: Cone Resistance versus Soil Friction Angle Correlation According to Trofimenkov (1974)



(a)



(b)

Figure 2.7: (a) Cone Resistance versus Relative Density Correlation
 (b) Approximate Correlation to Obtain Friction Angle from Relative Density (after Schmertmann, 1975)

Table 2.2: Correlations for Vertical Stress, Relative Density and Tip Resistance

CORRELATION	REFERENCE	FIGURE OR EQUATION	LIMITATIONS AND COMMENTS
q_c vs. σ'_v as a $f(D_r)$	Schmertmann (1976) Baldi et al. (1982) Villet and Mitchell (1981)	Figure 2.8 shows the importance of sand compressibility	-the differences in the correlations for a highly compressible sand, a medium compressible sand and a low compressible (Monterey) sand are due to the differences in the sand behavior -differences could also be due to different cone geometries and chamber sizes
q_c vs. σ'_v and q_c vs. σ'_h as a $f(D_r)$	Baldi et al. (1982)	See figure 2.9	-use σ'_v correlation for NC sands, ($K_o = 0.45$) -use σ'_h correlation for OC sands -the plot is never linear; whereas, others claim that q_c vs. σ'_v is linear until grain crushing occurs -plot is valid for uncemented, unaged quartz sands
q_c vs. σ'_v	Baligh (1976)	—	-from expanding cavity theory (Vesic, 1972), q_c is a non-linear function. A decrease in ϕ with depth and an increase in soil rigidity results in a non-linear relationship
q_c vs. σ'_v	Veismanis (1975)	See figure 2.10	-for a sand at a particular density q_c is a linear function of σ'_v up to a q_c that causes extensive grain crushing
q_c vs. σ'_v	Schmertmann (1978) Holden (1976)	—	- q_c is a linear function of σ'_v up to a resistance value where grain crushing occurs
q_c vs. σ'_v as a $f(\phi)$	Robertson and Campanella (1982)	See figure 2.11	-plot is valid for uncemented, unaged, quartz sands

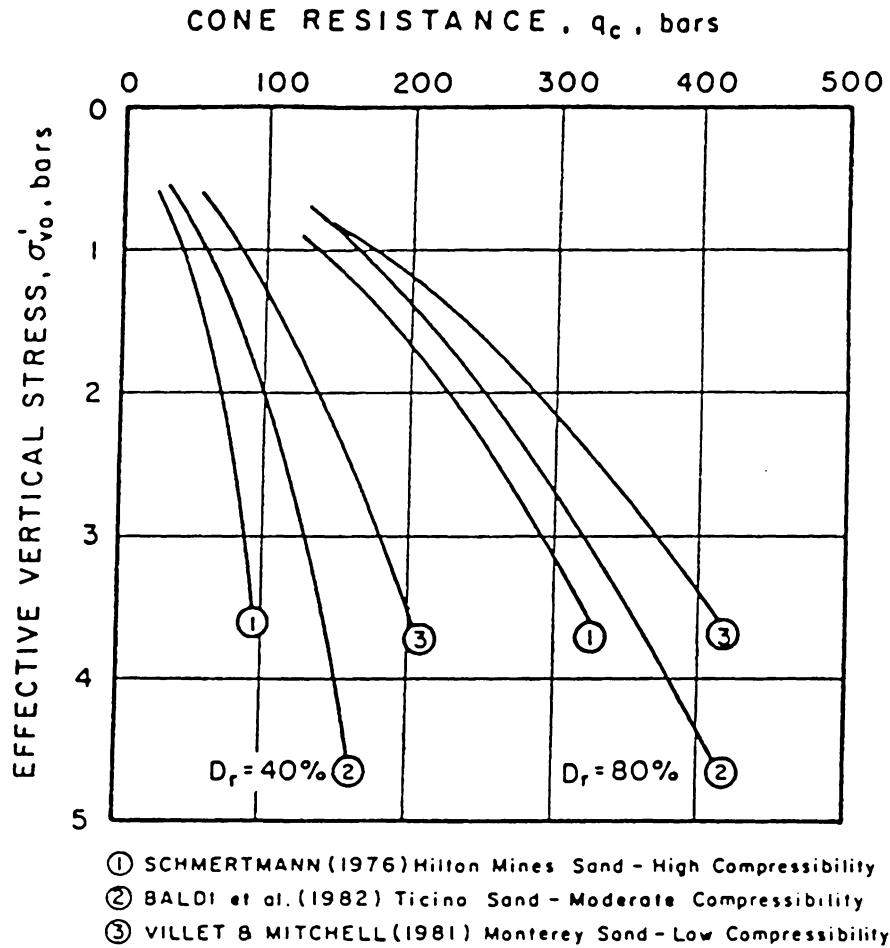


Figure 2.8: Comparison of Different Relative Density Relationships

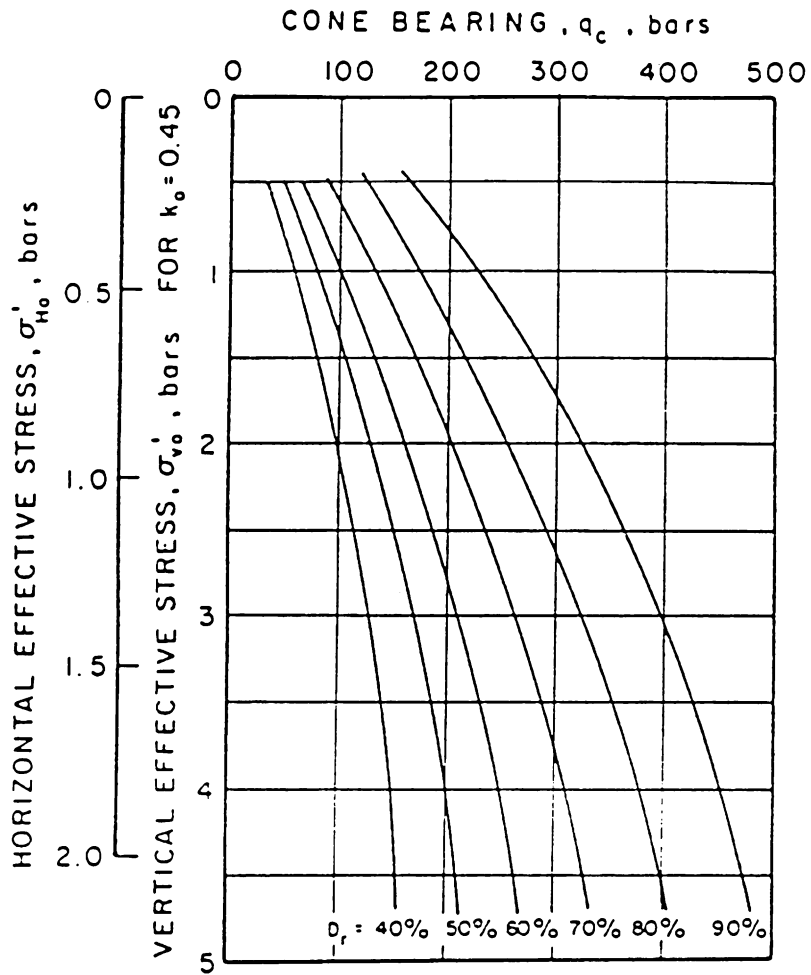


Figure 2.9: Proposed Correlation Between Cone Bearing and Friction Angle for Uncemented, Quartz Sands (Campanella and Robertson, 1983)

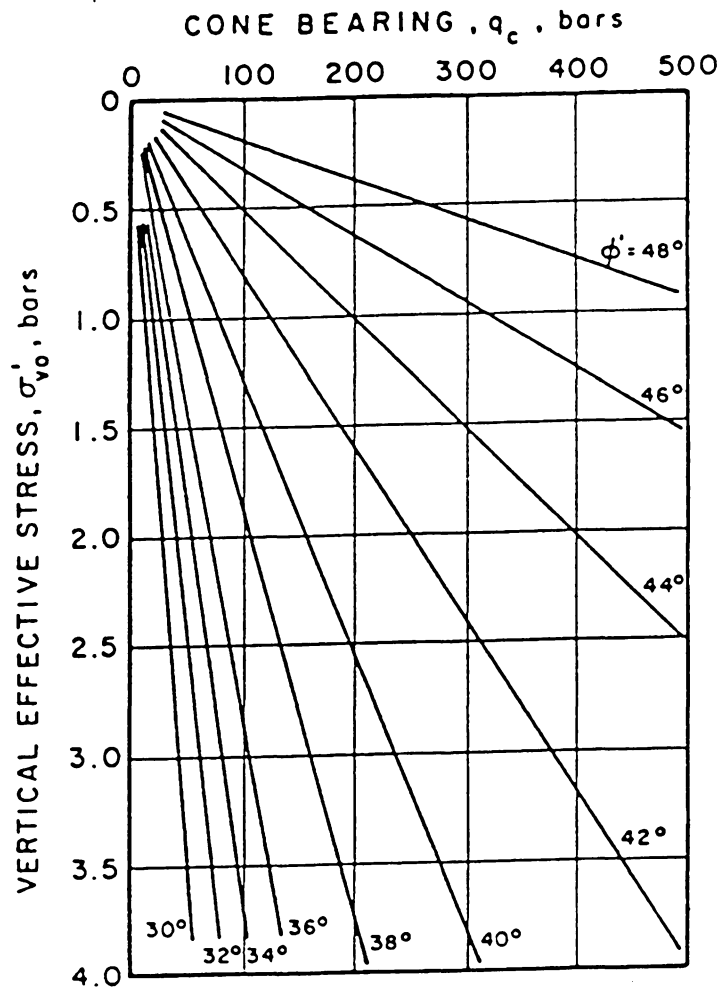


Figure 2.10: Relative Density Relationship for Uncemented and Unaged Quartz Sands - A Non-Linear Relationship (from Baldi et al., 1982)

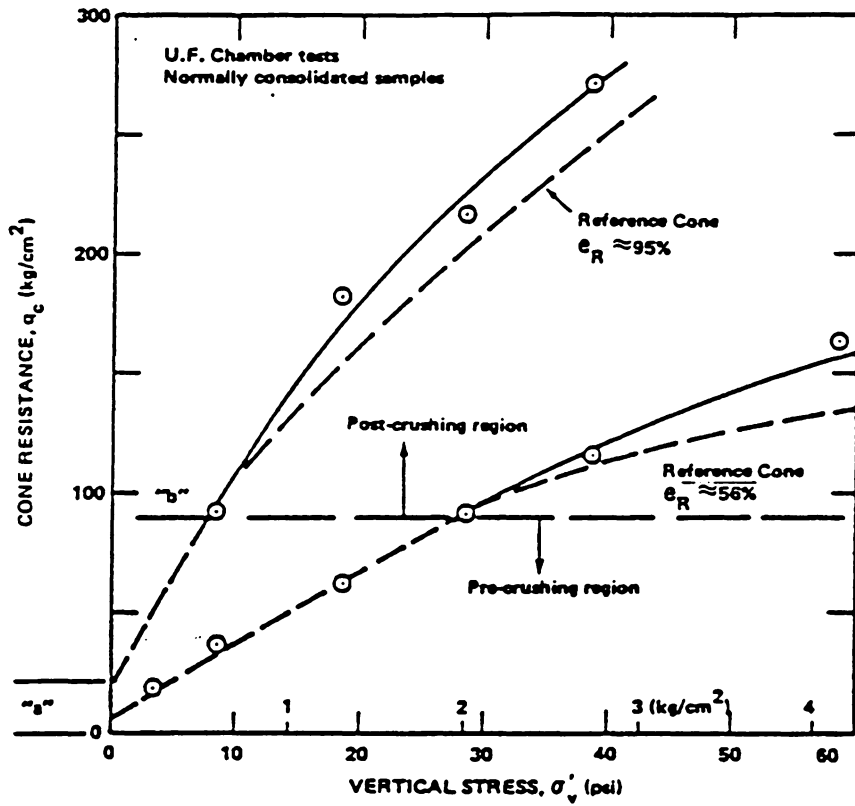


Figure 2.11: Vertical Stress versus Cone Resistance - A Linear Relationship (from Veismanis, 1975)

2.11 LIQUEFACTION CORRELATIONS

In general, the correlations of in situ test data to liquefaction potential are limited. The SPT is the most common in-situ test in North America and therefore most liquefaction correlations use SPT data. The CPT is gaining in popularity, however, and there are several new methods for relating the CPT data to liquefaction resistance. All are empirical and should be verified in the field whenever possible. The methods are as follows:

1. Schmertmann (1978): Schmertmann does not propose a method for predicting liquefaction in sands; however, his correlations for converting SPT N values to CPT resistance values provide a basis for some recent liquefaction relationships (ie. Seed, 1983). The correlation between SPT and CPT data is expressed by the ratio q_c / N . Schmertmann confirmed Meyerhof's relationship (1956) for q_c / N equal to 4 in sands. In addition, he suggested that the ratio decreases with increasing cohesiveness and thus presented q_c / N ratios for different soil types. Typically, the ratios represent an average since the energy delivered to the drive rod during a SPT test is subject to variations. q_c and N are correlated by:

$$q_c = 4 \text{ to } 5 N \quad (\text{for clean sands, } D_{50} > 0.25 \text{ mm})$$

$$q_c = 3.5 \text{ to } 4.5 N \quad (\text{for silty sands, } D_{50} < 0.15 \text{ mm})$$

2. Zhou (1980): Zhou developed a liquefaction correlation between earthquake shaking intensity causing liquefaction with cone

penetrometer resistance in sands. The method is not very practical because the correlation is based on data from a "non-standard" cone (16 sq.cm. tip, 100 sq.cm. friction sleeve).

3. Douglas et al. (1981): Douglas et al. used the approach of converting CPT data to equivalent SPT N values. The relationship at each study site was established by actually obtaining both CPT and SPT data. The equivalent SPT N values from the CPT results are then used in available liquefaction resistance correlations.

4. Seed et al. (1971-SPT, 1983-CPT): Most of the liquefaction work by Seed is based on the relationship between field values of cyclic stress ratio τ_l / σ_v (where: τ_l = the average horizontal shear stress induced by an earthquake; and σ_v = the initial effective overburden pressure on the soil layer involved), and the relative density of the sand (where D_r is determined using the Gibbs and Holtz (1957) method of estimating D_r from standard penetration test N values). Using extensive field data obtained from several 7-1/2 magnitude earthquake sites, Seed (1983) published a plot showing a boundary line or zone separating the sites which have and have not liquefied following the earthquake (figure 2.12). The boundary is expressed in terms of dynamic cone penetrometer resistance values corresponding to an overburden pressure of 1 tsf by using relationships similar to Schmertmann's:

$$q_c = 4 \text{ to } 5 \text{ N} \quad (\text{for clean sands})$$

$$q_c = 3.5 \text{ to } 4.5 \text{ N} \quad (\text{for silty sands})$$

$$\text{where: } q_{c1} = q_c * C_N$$

$$N_1 = N * C_N$$

C_N can be read from the curve in figure 2.13(a) and is a factor that modifies q_c and N to 1 tsf. The resulting plots relating cyclic stress ratio causing liquefaction with cone resistance values are as shown in figure 2.14.

5. Campanella and Robertson (1983): Campanella and Robertson proposed three alternative methods for predicting liquefaction resistance in sands using cone resistance data. All the methods are based on the Seed (1971) liquefaction prediction idea of using in-situ test data normalized to 1 tsf overburden pressure. The idea involves normalizing cone penetration tip resistance to an overburden stress level of 1 kg/sq.cm. (1 tsf) using the equation:

$$Q_C = q_c * C_Q$$

C_Q is a correction factor which is read from the chart in figure 2.13(b). C_Q varies in a manner similar to Seed's correction factor C_N for blow count data. Both correction factors vary with depth for sand at a constant relative density. With the correction applied, the three alternative liquefaction evaluations proceed as follows:

Method One: This method first considers static cone penetration data correlated with relative density by Baldi et al. (1982) and uses the Christian and Swiger (1975) correlation of field cyclic stress data with relative density, (figure 2.15). Combining these two correlations, Campanella and Robertson derived a correlation between

liquefaction resistance and cone penetration resistance for sand as a function of relative density, (figure 2.16).

Method Two: Based on a number of field and laboratory studies, this procedure converts SPT N values to CPT tip resistance values. The relationship is a function of mean grain size (D_{50}) and is expressed by the ratio q_c / N . A summary of numerous q_c / N relationships is shown in figure 2.17 which shows an increasing q_c / N ratio with increasing grain size with the most data scatter at high ratio values due to gravel-sized particles. In addition, in comparison to the relationships plotted in the figure, Schmertmann's ratios for q_c / N are slightly lower.

The q_c / N ratio is shown to vary with SPT hammer type, also. Kovacs (1982), Schmertmann (1976) and others have studied the amount of efficient energy delivered to the drill rods by the hammer. This energy varies between 20 and 90% of the theoretical maximum 4200 inch-lbs. Schmertmann suggests using 55% as the norm (corresponding to two turns of the rope around the cathead). An examination of Seed's SPT data reveals that the energy efficiency lies in the range of 50 to 60 percent. Therefore, Campanella and Robertson concluded that the following correlations initially proposed by Schmertmann (1978) and later on adopted by Seed et al. (1983), are considered valid.

$$q_c / N = 4.5 \text{ to } 5.0 \quad (\text{for clean sands})$$

$$q_c / N = 4.0 \quad (\text{for silty sands})$$

Using the above ratios for clean and silty sands, the normalized Q_c and N values are calculated. These values are then used in the Seed (1983) CPT liquefaction correlations.

Method Three: The alternative is based on the two previous methods. Campanella and Robertson indicated that correlations based on relative density (method one) tended to underestimate liquefaction resistance since the correlation neglects aging, cementation, and stress history of the soil. These factors tend to increase liquefaction resistance. The correlation based on the q_c / N ratio (method two) includes aging, cementation, and stress history; however, the values for q_c / N may be more representative of high energy SPT hammers. As a result, several data points for sites that had liquefied fell in the non-liquefied zone in the Seed liquefaction correlation. Therefore, Campanella and Robertson proposed a curve falling just between the curves obtained by method one and two. The suggested curve (figure 2.18) is based on an earthquake of magnitude 7 1/2 or for a lab sample at 10% double amplitude shear strain in 15 cycles and is valid only for clean sands ($D_{50} > 0.25$ mm).

In order to incorporate the silty sands which are also susceptible to liquefaction, Campanella and Robertson proposed an additional liquefaction resistance curve. The additional curve for $D_{50} < 0.15$ mm is derived from a soil classification chart which identifies soil type based on cone resistance and a relation for cyclic stress ratio with mean grain size as proposed by Iwasaki et al. (1978). Figure 2.19 is the correlation between liquefaction resistance and

cone resistance for both clean sands and silty sands. To evaluate the proposed cone penetration liquefaction assessment curve in figure 2.19, Campanella and Robertson collected data from sites in Canada, Japan, China, and the United States and plotted it as shown in figure 2.20. For comparison purposes the same data was plotted on Seed's (1983) CPT correlation. The plots in figures 2.21(a) and (b) indicate that the Seed method yields slightly unconservative values for predicting liquefaction.

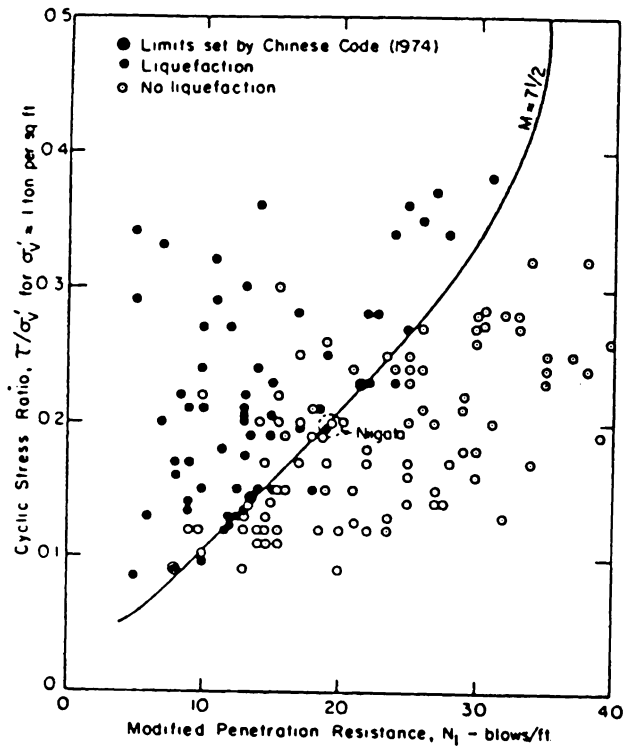
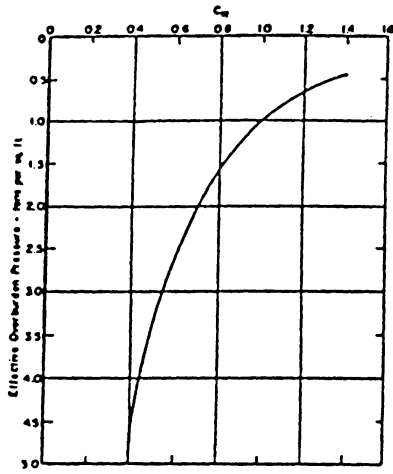
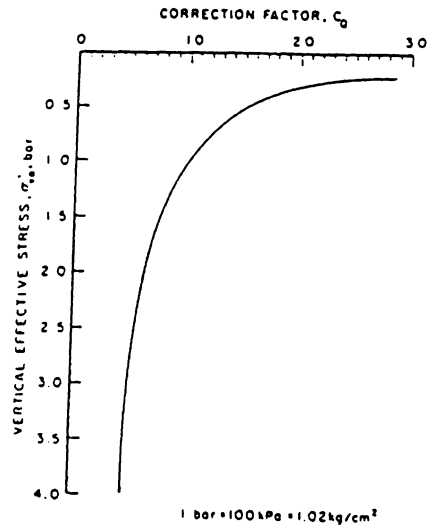


Figure 2.12: Correlation Between Field Liquefaction Behavior of Sands ($D_{50} > 0.25$ mm) Under Level Ground Conditions and Standard Penetration Resistance (after Seed et al., 1983)



(a)



(b)

Figure 2.13: (a) Curve for determining correction factor C_N (after Seed et al., 1983); (b) Curve for determining correction factor C_Q (after Campanella and Robertson, 1983).

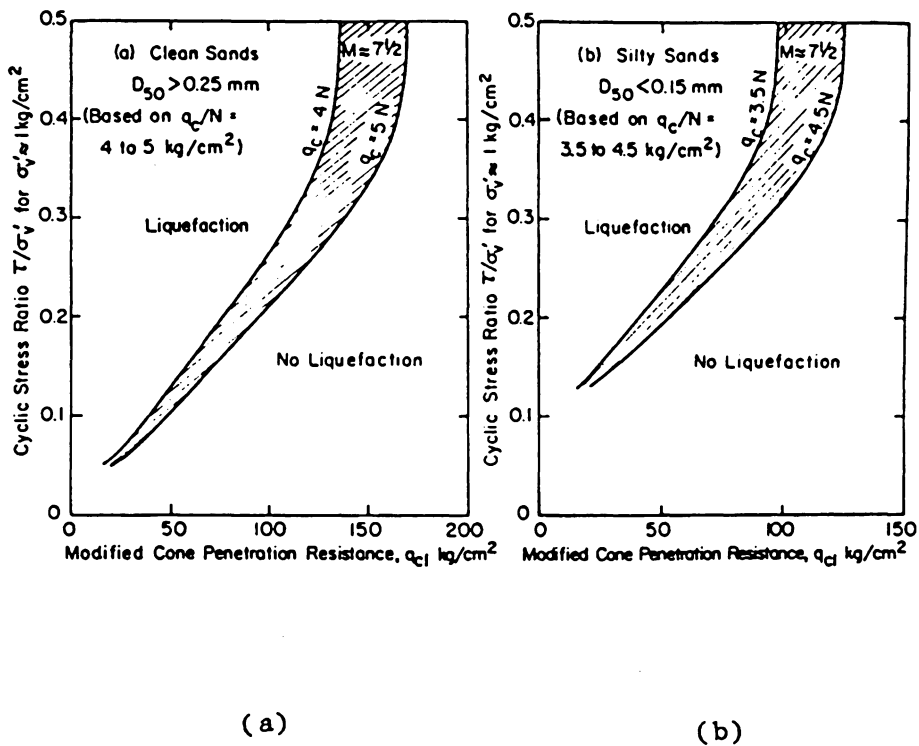
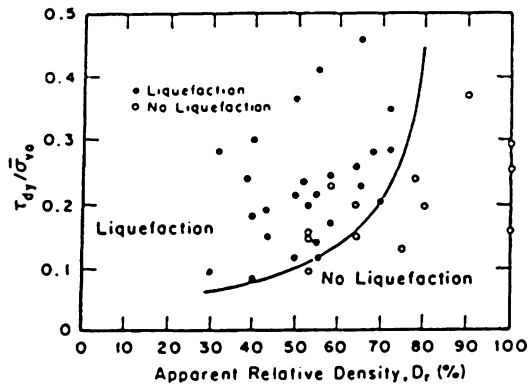
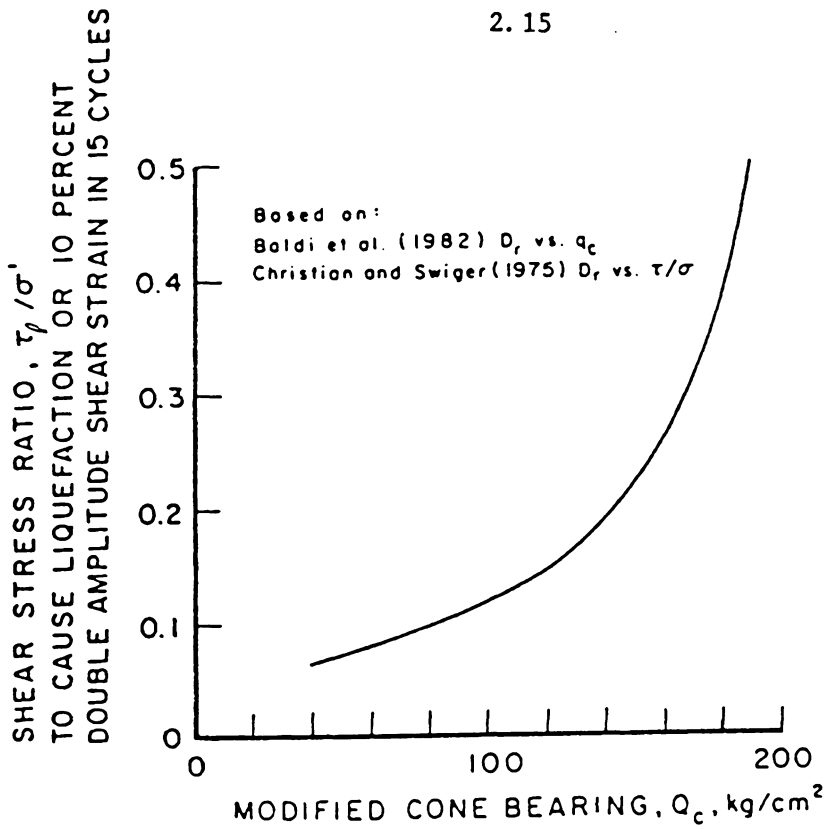


Figure 2.14: Proposed Correlation Between Liquefaction Resistance of (a) Clean Sands and (b) Silty Sands for Level Ground Conditions and Cone Penetration Resistance (after Seed et al., 1983)



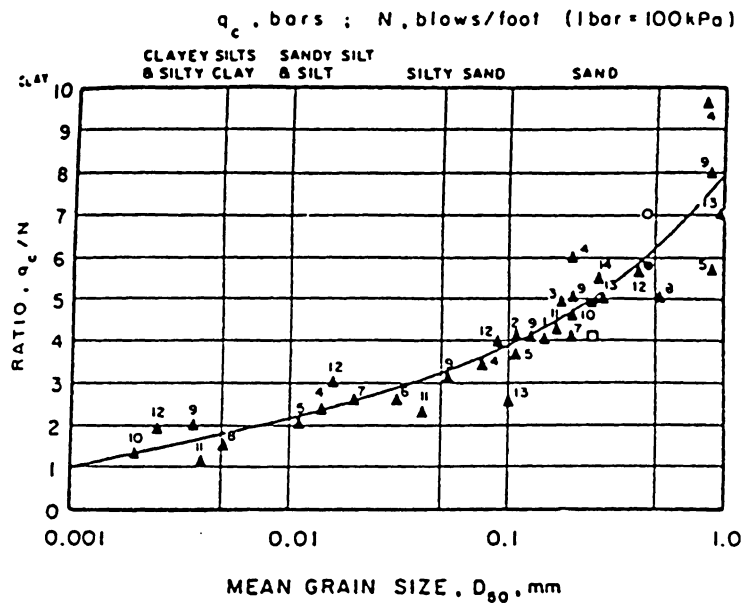
Based on Data by Christian and Swiger, 1975

2. 15



2. 16

Figure 2.15 and 2.16: Correlation Between Liquefaction Resistance and Cone Penetration Resistance for Sands Based on a Relative Density Correlation



- | | |
|------------------------------|----------------------------------|
| 1. Meyerhof (1956) | 8. Campanella et al. (1979) |
| 2. Meigh and Nixon (1961) | 9. Nixon (1982) |
| 3. Rodin (1961) | 10. Kruizinga (1982) |
| 4. De Alencar Valloso (1959) | 11. Douglas (1982) |
| 5. Schmertmann (1970) | 12. Muromachi & Kobayashi (1982) |
| 6. Sutherland (1974) | 13. Goel (1982) |
| 7. Thornburn (1970) | 14. Ishihara and Koga (1981) |

- | | |
|---|--|
| TILBURY ISLAND SITE {
□ SPT N_c , $ER_1 = 47\%$
■ SPT N_c , $ER_1 = 55\%$ | } UBC SITE, McDonalds Farm
○ SPT N_c , $ER_1 = 65\%$
● SPT N_c , $ER_1 = 55\%$ |
|---|--|

Figure 2.17: Variation of q_c / N Ratio with Mean Grain Size (after Robertson, Campanella, & Wightman, 1982)

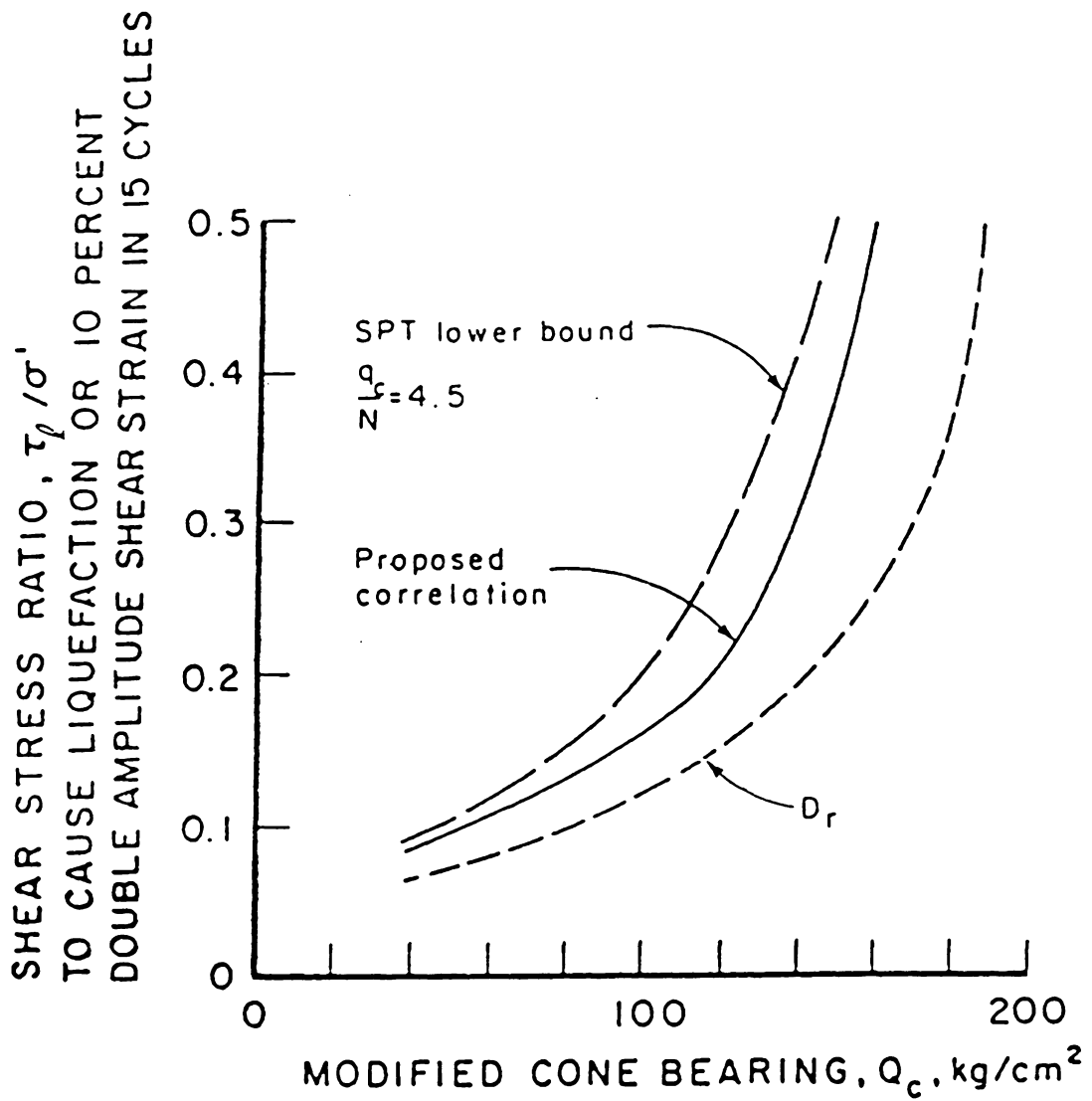


Figure 2.18: Summary of the Three Methods for Liquefaction Resistance and Cone Penetration Resistance in Sands (after Campanella and Robertson, 1983)

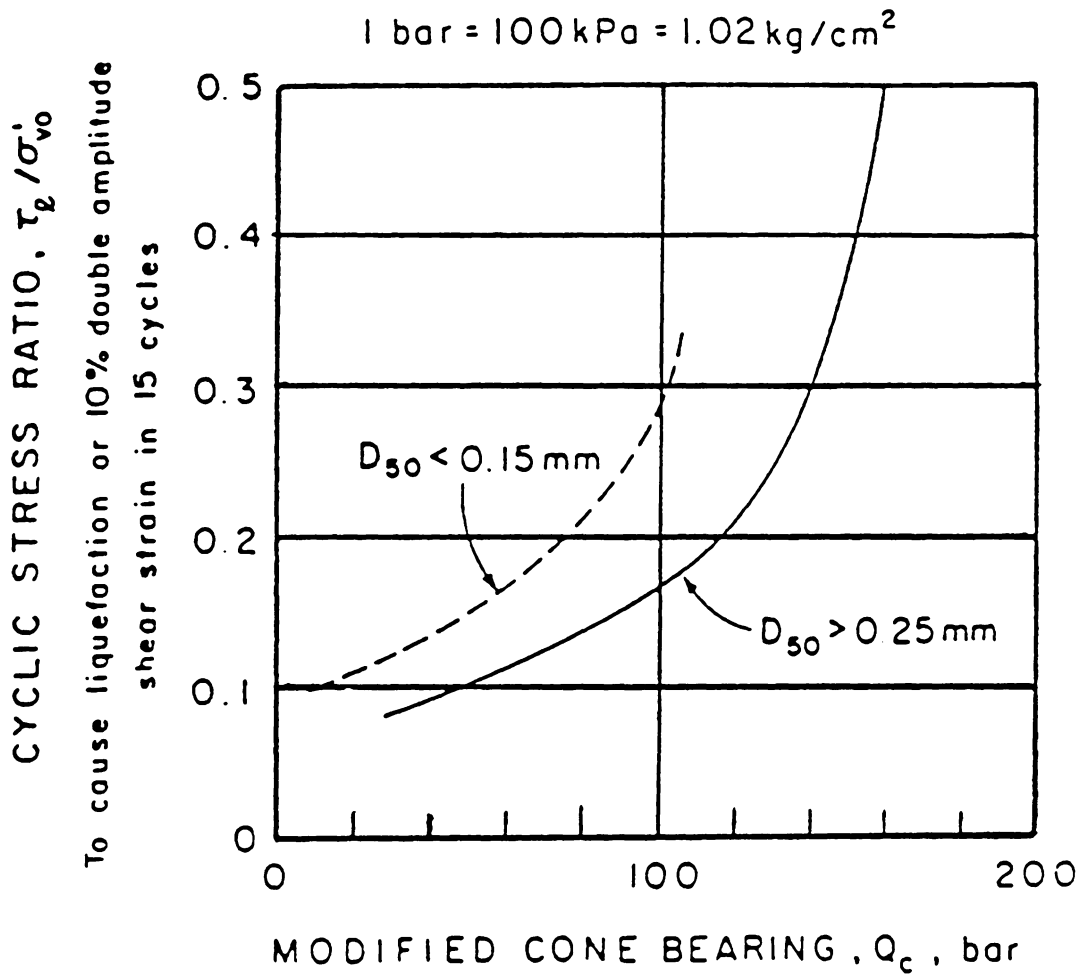


Figure 2.19: Robertson and Campanella (1983) Correlation Between Liquefaction Resistance Under Level Ground Conditions and Cone Penetration Resistance for Sands and Silty Sands

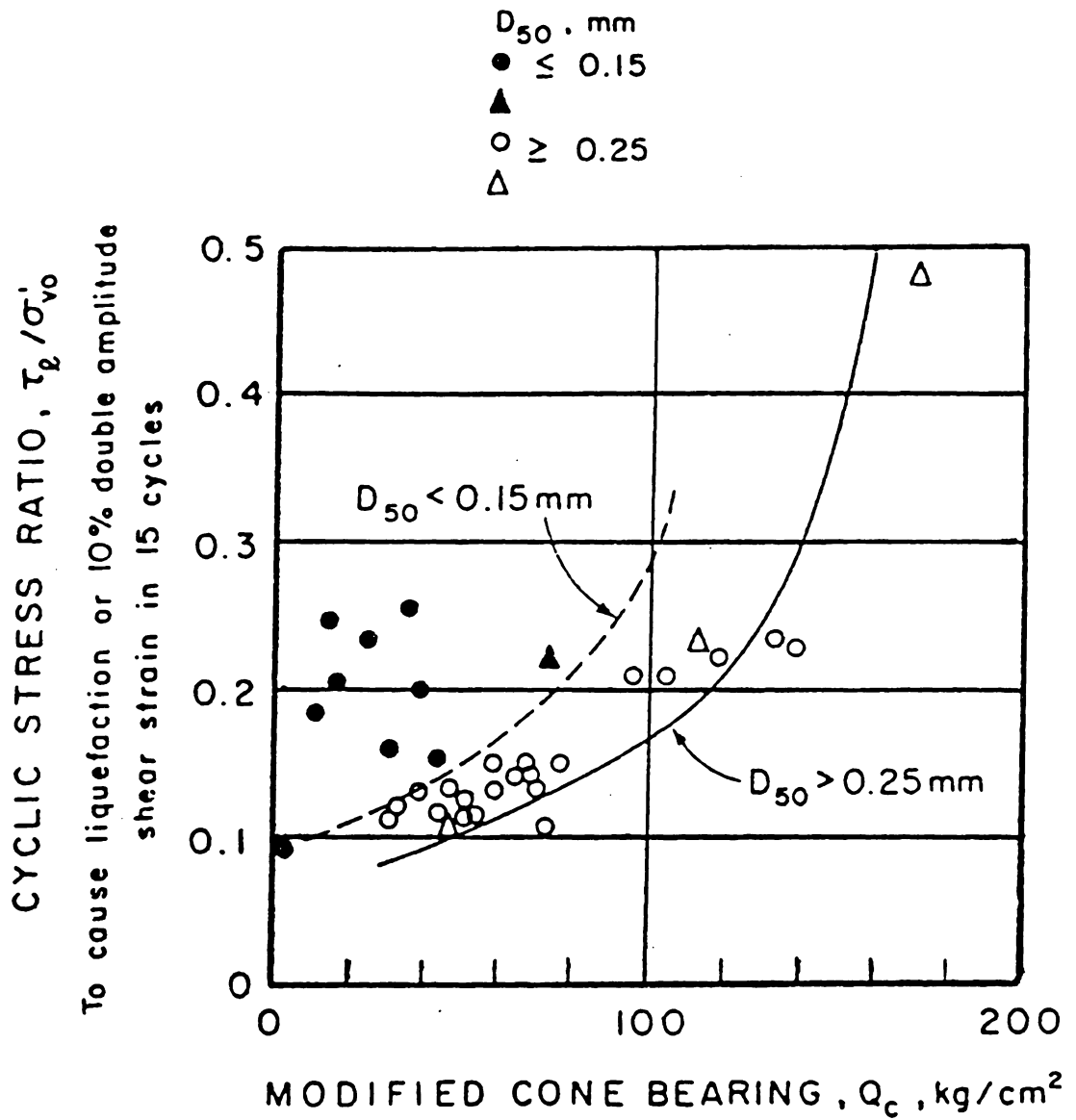


Figure 2.20: Comparison of Field Data from Liquefied Sites with the Campanella and Robertson (1983) proposed CPT Correlation

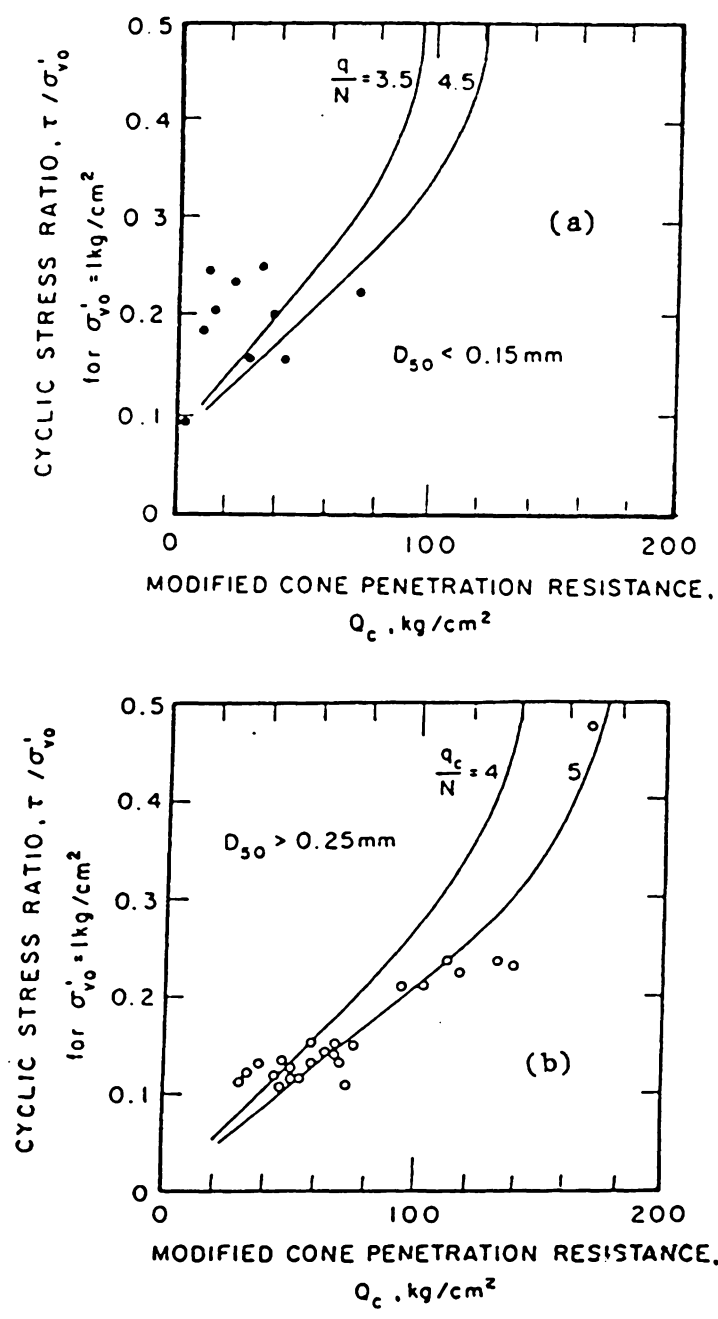


Figure 2.21: Comparison of Campanella and Robertson (1983) Data to the Seed et al. (1983) Liquefaction Correlation for (a) clean sands and (b) silty sands

3.0 THE MINIATURE ELECTRICAL CONE - BASIS FOR DESIGN

3.1 MINIATURE STATIC CONE PENETROMETERS

Several miniature or small-scale cone penetrometers have been developed. Table 3.1 summarizes information for examples of small-scale cones. The table indicates that most available small-scale cones are limited to measuring point resistance and are expected to penetrate only below the immediate subsurface level. Those for use at depth require a drill rig or a substantial insertion system. Thus, a small-scale cone which can measure both tip and sleeve friction and can be transported and operated without a drill rig is not available. Such a device would provide an efficient tool for liquefaction assessment, particularly at remote sites or sites in developing countries.

3.2 DEVELOPMENT OF A MINIATURE ELECTRICAL CONE FOR THIS STUDY

The first generation miniature electric cone designed at Virginia Tech is geometrically similar to the existing Fugro cone originally developed in the Netherlands and currently manufactured in the United States by Earth Technology Company in California. As per ASTM Standard D3441, a 60 degree apex angle cone tip is used. The dimensions for the miniature cone are governed by the minimum amount of surface space required for mounting the cone tip and friction sleeve strain gages, and by the ne-

Table 3.1: Summary of Available Small-Scale Cones (after Clough and Rude, 1983)

Item	Reference	Description	Specifications	Applications
Geostick from Soil Test Inc.	Soil Test catalog	Combination of a long handled geologist's soft rock hammer, surface cone penetrometer and soil	Overall length 34 in (864 mm) cone capacity 69.5 to 5560 psi (479 to 38300 kN/m ²) weight: 2.5 lbs (11.1 kN)	Approximate evaluation of character of soils to shallow depths. sampler
"Barensten" penetrometer from Hogentogler and Co., Inc.	Hogentogler catalog	Handheld; pressure limited to efforts of two men. Kit includes 6-3.3 ft (1 m) rods	Penetration measured by pressure gages 0-227.5 psi (0.16 MN/m ²) weight: 120 lbs (534.6N)	Small earth dams, rods; simple construction
Hand operated penetrometer from Hogentogler Co., Inc.	Hogentogler catalog	Hand operated drilling mechanism with two speed transmission. Reaction frame held down by screw augers	Hydraulic load cells used for specific cone resistance up to 3555 psi (24.5 kN/m ²) maximum load 2.75 tons (27.5 kN) weight: 209 lbs (912 kN)	General site investigation in soft soils
Drilling conversion kit from Hogentogler Co., Inc.	Hogentogler catalog	Kit contains two jacket cones, two friction sleeve cones, 25 3.3 ft (1 m) rods, hydraulic load cells	ASTM D 3441-75T	Coarse to gravely sands and clays
U.S. Army cone penetrometer	U.S. Army TM 5-330 (26)	Small diameter cone, inserted by manual pressure	Cone: 30°, 0.5 in ² (322.6 mm ²) base area shaft: 19 in (483 mm) long; 5/8" (15.9 mm) diameter; weight: 19 lbs (84 kN)	Trafficability studies

Table 3.1 (cont.)

Item	Reference	Description	Specifications	Applications
Swedish weight penetrometer from Borros A.S., Solna, Sweden	Borros catalog	Sounding rods gradually loaded with weights until a screw shaped cone just penetrates the soil. When maximum weight of 100 kg does not cause penetration, the screw is rotated and the penetration is recorded for each 25 half turns. Operated by hand or light motor	Weight: 88 lbs (392 kN)	
Static Penetrometer from Borros A.S.	Borros catalog	Hand operated crank drill driver. Transistorized recorded system. Point resistance measured by strain gages inside cone, temperature compensated	Maximum resistance 5688 (3.93x10 ⁴ kN/m ²) weight with 98 ft (30 m) of drill rods: 661 lbs (12944 kN)	soft soils
Static Penetrometer for measurement of local friction and point resistance from Borros A.S.	Borros catalog	Crank drill driving device with a maximum force of 8830 lbs (39.3 kN)	Cone: 60; 10 cm ² cross section Friction sleeve: area 150 cm ² located immediately above cone. Weight: assumed to be equal to item above	

Table 3.1 (cont.)

Item	Reference	Description	Specifications	Applications
Light static dynamic penetrometer from Borros A.S.	Borros catalog	Uses Swedish weight method for a force less than 165 lbs (734 N). Uses 22 lb (98 N) weight falling 1.64 ft (0.5 m) for more resistant layers	Swedish screwpoint	Loose-dense soils depths: 33-49 ft (10-15 m)
Suitcase penetrometer	Gardner and Nathan (8)	Electric cone which is attached to a drill rod of a conventional auger drilling rig. Has no friction sleeve. Point recordings from strain gages. Data logger used to record data	Weight: 40 lbs (178 N) (does not include rods) 500-10,000 lb (2.2 - 44.5 kN) load cells	Can be used anywhere a normal cone would be applicable. Requires a drill rig
Static Penetration Testing on the Moon	Mitchell and Houston (13)	Self recording penetrometer gives continuous force versus penetration depth. A bearing plate rested on lunar surface during operation. The device had three penetrating cones, each with a 30° apexangle. The device is hand-operated	Weight: 5.07 lbs (22.5 N); Area of Cone: 0.2 in ² (1.29 cm ²) 0.5 in ² (3.22 cm ²) 1.0 in ² (6.45 cm ²). Maximum depth of penetration: 30 in (76 cm) Maximum force: 24.9 lbs (111 N) for Apollo 15 and 48.3 lbs (215 N) for Apollo 16	Shallow depth testing of lunar surfaces

cessity of providing a sufficiently sized wireway for a shielded coaxial cable.

Compared to the Earth Technology cone, the first generation miniature electrical cone designed by Rude (1983) reduced the base area of the tip from 10 sq.cm. to 3.42 sq.cm. (0.53 sq.in.) by decreasing the base diameter from 1.4 inches to 0.825 inches. In addition, the friction sleeve area was reduced from 150 sq.cm. to 54.32 sq.in. (8.42 sq.in.). A diagram comparing the standard cone with the miniature electrical cone is shown in figure 3.1.

The miniature cone design includes strain gages for measuring tip resistance and local friction along the sleeve; however, the design lacks rubber o-ring seals or some type of method for preventing sand from entering the cone housing. This shortcoming resulted in erratic friction readings. Fortunately, in this research, tip resistance data are of greatest concern.

The cone armature is machined from 304 stainless steel, the tip from SAE1020 mild steel, and the friction sleeve from aluminum. Together with a 36 inch, 0.625 inch diameter, SAE1020 steel drive rod, the cone is strong enough to resist buckling under loads of less than 2 tons.

The typical maximum load capacity of the Earth Technology cone is 5000 kg (approximately 11000 lb.); whereas the load capacity for the miniature cone is 4000 lb.. It is important to note that this load ca-

capacity does not impose limitations on the use of the cone since the purpose of the cone is for testing in liquefiable sites which typically consist of low density and therefore low resistance sands.

Most miniature cones are intended for use at only shallow penetration depths. The expected maximum penetration depth for the lightweight, portable miniature cone is 40 feet, which is approximately the maximum depth at which liquefaction occurs. Soils which are difficult to penetrate must be augered or drilled to provide passage for the lightweight cone.

3.3 SCALE EFFECTS IN CONES

Little information is available concerning the scale effects of cone penetrometers. Schmertmann (1978) performed cone penetrometer tests with 5 sq.cm. to 40 sq.cm. base area cones and reported no change in the values for point resistance. However, he found that when cone testing in layered soil, the smaller the cone diameter the more sensitive the tip is to variations with depth. Sanglerat (1972) performed tests with different sized cones and also reported that the size of testing equipment did not effect the cone resistance values. Muromachi (1967) performed cone tests in clays in Japan using cones with small diameters (no dimensions given) to 20 sq.cm. base area cones, and reported a slight decrease in point resistance for an increase in cone width.

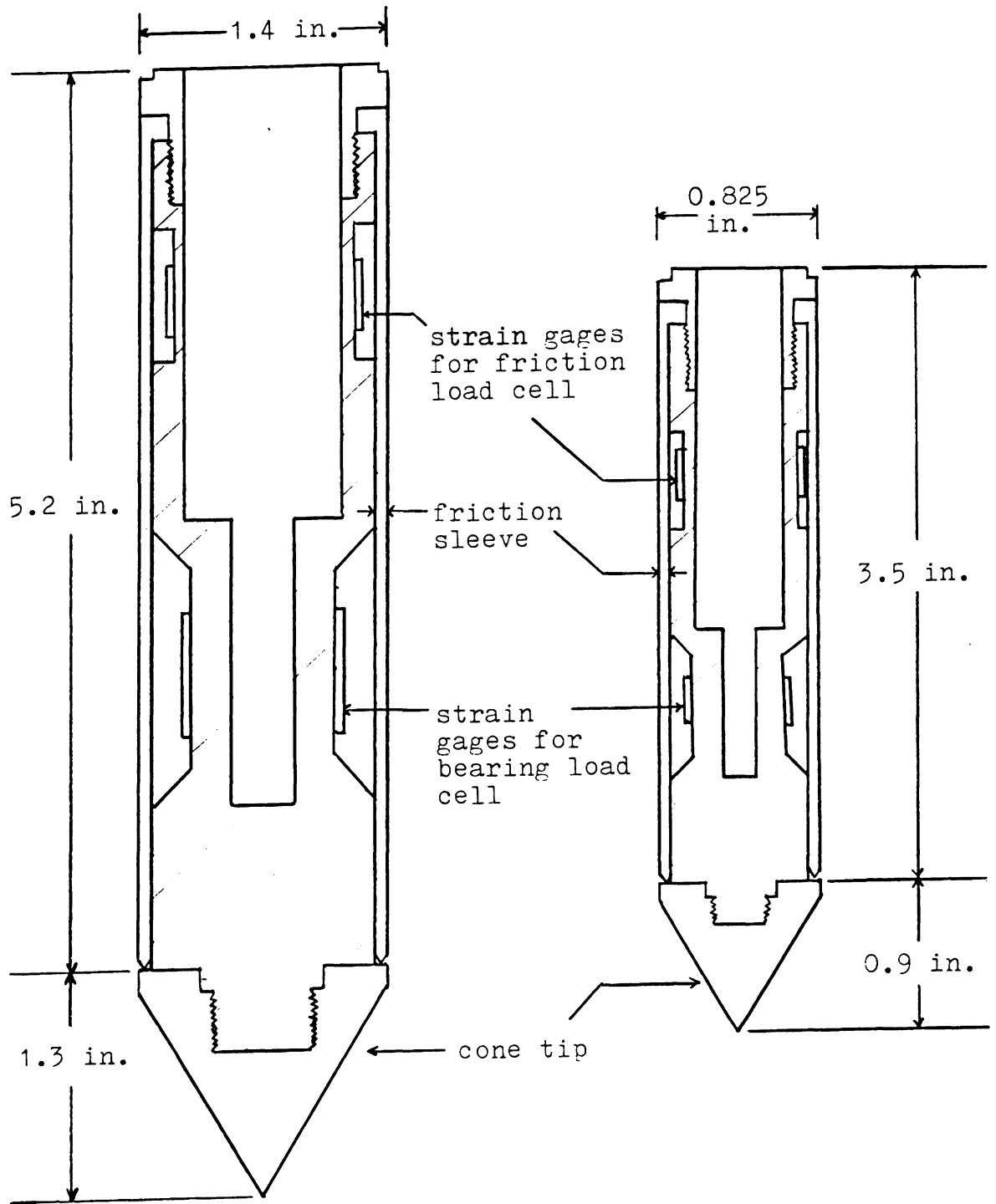


Figure 3.1: Comparison of the first generation miniature electrical cone with a standard electrical cone.

Shields (1981) presented a good explanation for the effects he observed from varying cone size. In an ideal (ie. isotropic, homogeneous, uniform) soil, the diameter of the tip has a negligible influence on the point resistance. The exception occurs only if the soil grains are large in comparison to the tip; then a small cone in a gravelly soil would show a higher resistance value than a larger cone in the same gravel. The particle size relative to the cone diameter can cause a higher resistance since the cone must displace the larger particles as rigid units. Similarly, the resistance curve for a cone with a larger tip diameter is smoother than for a smaller tip since the values reflect more of an average resistance. Thus, to date, evidence shows that the effect of cone size on cone resistance is small or negligible. The scale effects will be studied in greater detail next year upon completion of the Virginia Tech calibration chamber by comparing the test results using a 15 sq. cm. cone, a standard 10 sq. cm. Earth Technology cone, and a new (second generation) 3.5 sq. cm. miniature cone.

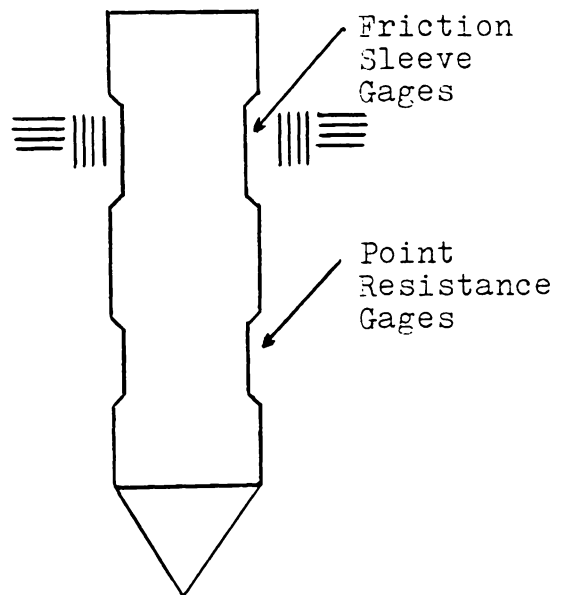
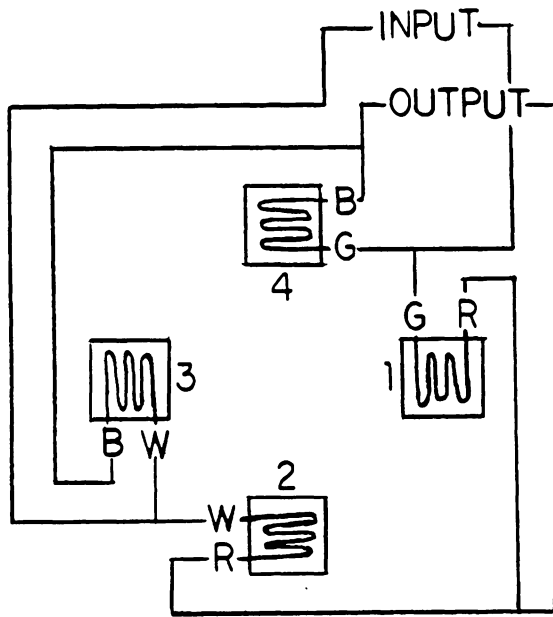
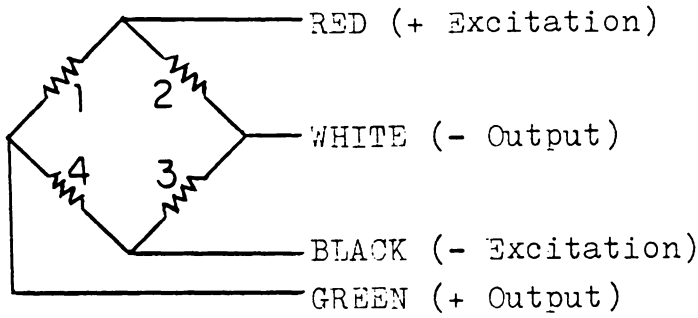
3.4 STRAIN GAGING FOR THE MINIATURE ELECTRICAL CONE

The purpose of an electrical cone penetrometer is to provide continuous data measurements as the cone penetrates the soil. The information is transmitted to the ground surface from cone tip and friction sleeve strain gages.

The strain gages serve as transducers to convert loads induced on the point and along the friction sleeve into electrical signals. Both

the tip and the friction sleeve strain gages are four-arm wheatstone bridge strain gages as shown in the schematics in figure 3.2(a). The strain gages are mounted in milled slots positioned on the outer surface of the cone armature in directions parallel and perpendicular to the point. See figure 3.2(b). Proper strain gage placement minimizes measurement errors caused by bending stresses that occur when the point is not advanced perfectly perpendicular to the soil (Rude, 1984). Also, careful gage placement, as well as skilled machining, reduces the chance of cutting any gage leads. A cut lead results in complete electrical discontinuity. The leads from the strain gages are ported to the inside of the cone armature, through a cable guide channel, then through the drill rods; and connected to the data collection system and a power supply. A 10-volt DC power supply is used to provide the required strain gage excitation.

In addition to the tip and friction sleeve strain gages, a position transducer is monitored. This linear potentiometer is used to measure the depth of the cone. The circuitry is simpler than the wheatstone bridge configuration. The transducer, which shares the same power supply as the cone, operates by means of a spring-tensioned wire cable fastened to the drill rod. As the wire is pulled away from the transducer housing, a voltage output is generated which is an analog to the cone position. The voltage is recorded and converted to units of inches.



(a) A typical four-arm wheatstone bridge strain gage.

(b) Strain gage placement is parallel and perpendicular to the point.

Figure 3.2: Four arm wheatstone bridge strain gages serve as load cells to convert loads on the point and along the friction sleeve into electrical signals.

3.5 CALIBRATION

Before conducting any cone penetrometer tests, the cone tip and friction sleeve gages and the position transducer were calibrated. To obtain the proportionality constants for converting millivolt signals into pound forces, a tension calibration test was performed. The calibration test is performed with the cone hanging from a load frame. A plate used for supporting load weights is welded to one end of a rod and the other end is threaded into the cone where the cone point is usually placed. This set-up is shown diagrammatically in figure 3.3. The cone is put into tension by incrementally loading and then incrementally unloading the weight rod. A data acquisition system records the electrical strain gage signals. The plot of the load versus change in millivolt output signals was found to be linear. It is interesting to note that although a cone penetrometer is subjected to compression during operation, a tension calibration test was performed. It was assumed that the response of the strain gages was independent of the direction of the applied force. In addition, the tension test included unloading as well as loading. Thus, a decrease in tension on the cone was assumed analogous to compression. This assumption is based on the linearity of the plot obtained from the strain gage load cell measurements.

The position transducer is calibrated by increasing or decreasing the length of the cable wire by equal increments. The voltages are recorded and the voltage change per inch is calculated. The calibration

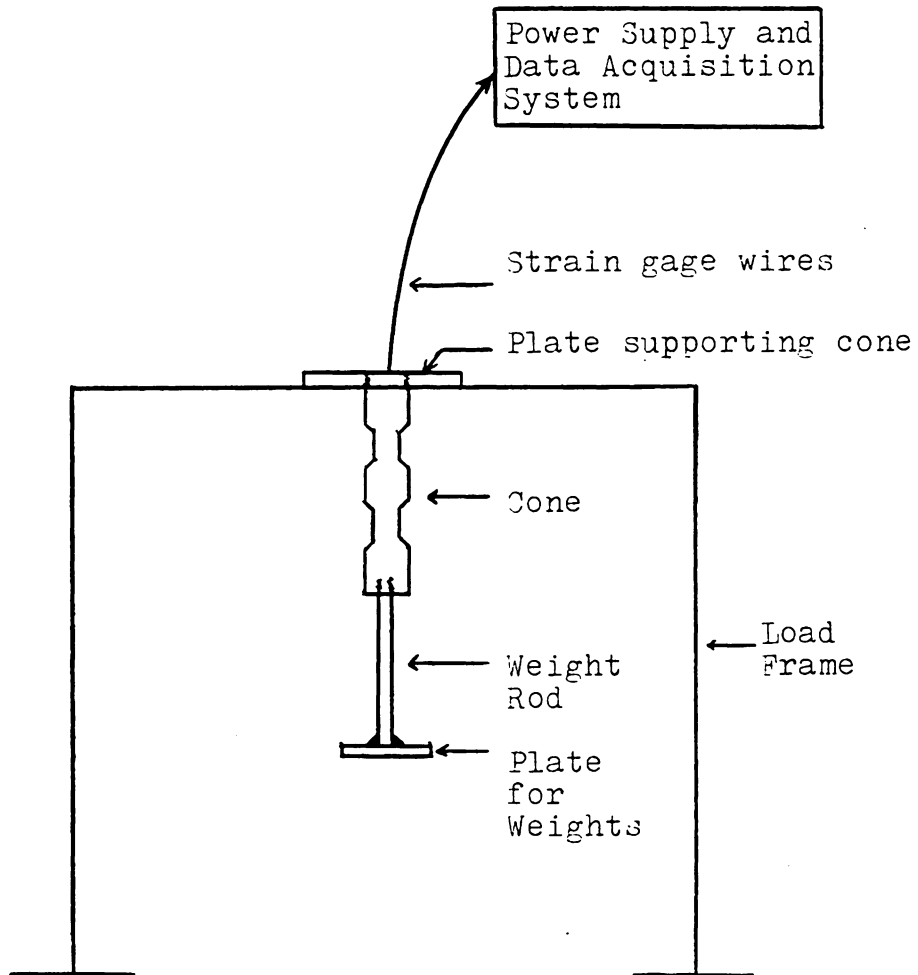


Figure 3.3: Simplified Diagram of Tension Calibration Set-Up

data and curves for the cone and the position transducer are found in Appendix 2.

4.0 THE DATA ACQUISITION SYSTEM AND THE EXPERIMENTAL CALIBRATION SCHEME

A system is required for collecting data from the miniature electrical cone penetrometer tests. Typically, data are recorded on a strip chart and collected through a microcomputer containing analog-to-digital conversion units. The system developed for the miniature electrical cone penetrometer consists of an Apple II Plus microcomputer and ISAAC analog to digital conversion devices. This equipment combination was dictated by its availability in the geotechnical laboratory at Virginia Tech.

4.1 DATA ACQUISITION

The ISAAC based data acquisition system is capable of sampling and recording 32 channels of data. The system developed for this thesis work required monitoring only 3 channels of output signals: the cone tip load cell, the friction sleeve load cell, and the position transducer.

When the cone testing began in the simplified soil box there was no position transducer; therefore, the data collection system sampled only 2 channels of data - the cone tip and the friction sleeve. However, one of the key plots obtained from a cone penetrometer test is resistance versus depth. Thus, the depth was calculated based on rate and time. This was accomplished by timing the crane used as the insertion device and by timing the computer for number of seconds per reading. There was one basic program used to collect data; however, there are several ver-

sions of it. Depending on the program, the program timing varies from 0.53 seconds/reading to 0.83 seconds/reading. The rate of the crane is a constant 1.7 inches/second. From these figures, the number of inches per reading is calculated. A summation loop in the data reduction part of the program generates the depth for each reading.

When the position transducer was adopted, the programs were modified to read three channels of data. In the interest of comparing transducer values to computer generated depth values, the calculations for depth were not deleted.

The actual cone test penetrates to a depth of 35 inches in approximately 18 seconds. Depending on the program, 20 to 35 test readings are obtained in each test, or about one reading for approximately every inch. The readings are collected by an averaging command. For each sensor, four readings are taken, summed, and then averaged to represent the one value for that reading. The sequence for sampling is cone tip, depth and then friction sleeve. This order attempts to allow each sensor reading to represent a value at the same approximate depth.

Once the data are collected, the program controlling the data acquisition then performs data reduction and calculations. The data acquisition process is as follows:

- Phase 1: Data Logging
- Phase 2: Data Reduction
- Phase 3: Reading and Printing Data

Phase 4: Operator Data Evaluation

Phase 5: Obtaining plots from mainframe computer

The data acquisition system, diagrammed in flowchart form in figure 4.1, is described as follows. Phase 1 of the system monitors point resistance and friction load cell output in millivolts during penetration. The signals are transmitted from the strain gage load cells through wire leads which are connected to a 10 volt DC power supply and into two channels of the ISAAC 12 bit analog-to-digital converter manufactured by Cyborg, Inc.. The ISAAC unit requires peripheral devices which receive the signals from the load cells. Since these signals are of millivolt magnitude, they must be amplified before they are read into the ISAAC 91A mainboard. Thus, the ISAAC I-140 device (a peripheral device of the 91A) receives the millivolt signals. In turn, the ISAAC I-130 (also a peripheral device of the 91A) translates the signals into the memory of the Apple II minicomputer. In addition to tip and friction data, the depth signals measured by the position transducer are taken directly into channel 1 on the 91A mainboard. The peripheral devices are not needed unless the signals are of millivolt magnitude. In Phase 2, the Apple II places the data into its 48K memory and, as programmed, reduces the data into various parameters. At the end of testing (when the penetrometer is driven to the desired test depth) the Apple II creates a file by placing the data into a text file on a floppy disk. This ends Phase 2. Phase 3 prints a hard copy of the file for the user. In Phase 4, the user examines the test data and interprets the validity of the data based on testing procedures and observations. And finally, if the data are rea-

sonable, it is sent to the university mainframe computer and a plot can be generated.

A more detailed explanation of the ISAAC system and the Apple II is provided in Appendix 1 in the form of a user's guide. The user's guide contains key programming commands, a diagram for wiring the system together, and the various programs written for the cone penetrometer data acquisition system.

4.2 THE EXPERIMENTAL CALIBRATION SCHEME

The automated data acquisition system previously described was developed for use with a full-scale calibration chamber which is now under fabrication. A simplified box was designed and constructed for this study for the preliminary calibration of the miniature electrical cone. The components of the operating system are detailed below.

4.2.1 The Sand

The sand used in the cone penetrometer testing program is a granular, uniform, sub-angular to sub-rounded clean Monterey No. 0/30 sand. The sand is a washed, sieved and air-dried fine beach sand with a mean particle diameter of 0.45 mm and a specific gravity of 2.65. It is designated as an SP sand by the Unified Classification System, has a minimum void ratio of 0.803, a maximum void ratio of 0.563, maximum dry unit

THE FIVE PHASE DATA ACQUISITION SYSTEM

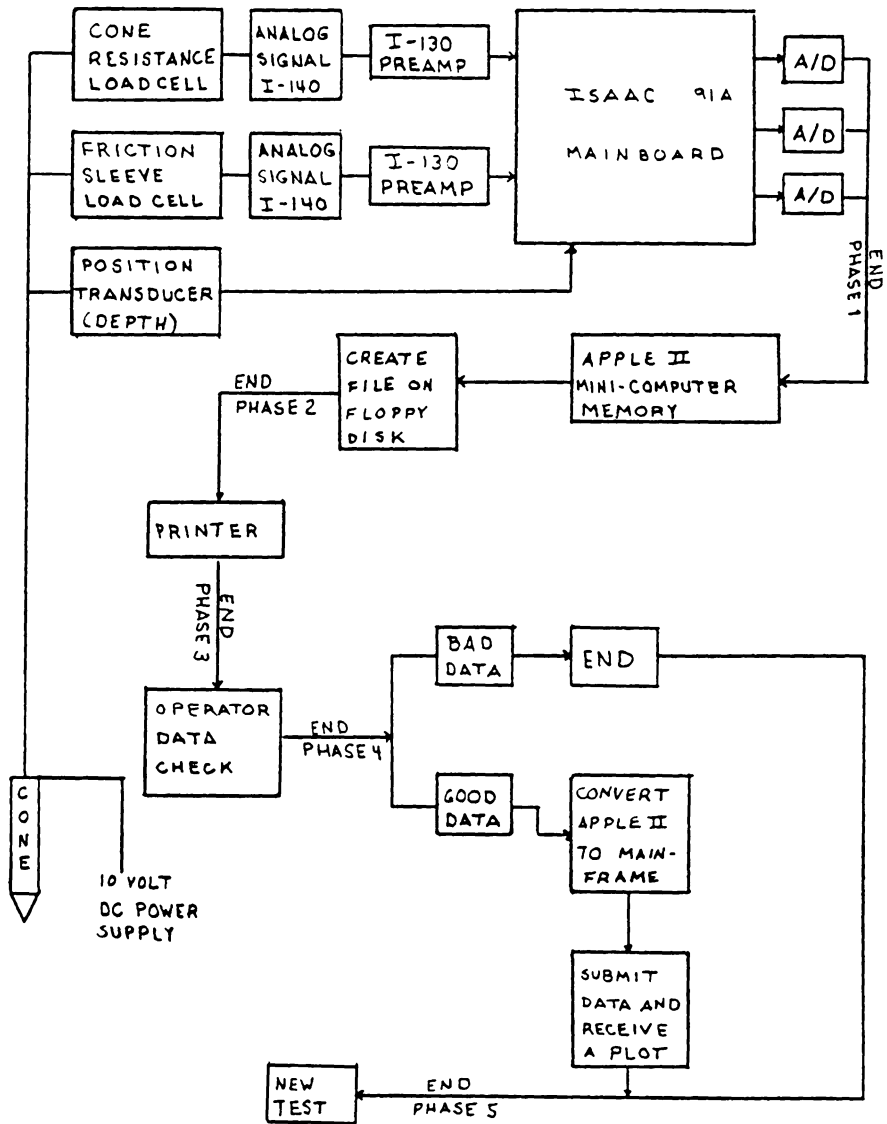


Figure 4.1

weight equal to 105.8 pcf, and minimum dry unit weight equal to 91.7 pcf. This sand was selected for use in this work because data on its behavior and, particularly, data on its liquefaction response are available.

4.2.2 Simplified Soil Box

The 2 foot x 2 foot x 4 foot high soil box used in this research was a simple open container which consisted of plexiglass panels connected by plastic welds. This type of chamber imposes a boundary condition of zero lateral strain on the sample (Parkin and Lunne, 1982). Based on available information, the boundaries should have negligible influence on the tip resistance of the cone. This is verified in the test program.

In order to facilitate several tests per box, the box was mounted on v-groove casters and located on an angle iron track. This allowed the box to be rolled under the test frame to provide for several penetrations per filling.

Three vertically aligned holes were cut into one side of the box to simplify emptying the box. Flanges were attached by screws, and PVC spouts, consisting of commercially available four inch diameter pre-threaded plumbing, were v-knotched at the bottom to remove a section of threads and, thus, make the threads self-cleaning. The plugs were faced with plastic spacers that restored the inner box contours when replaced. This "port hole" modification allowed the sand to simply pour out, and eliminated manually shovelling out the box or overstressing the

load frame by lifting the box, or driving in a fork lift truck to lift and empty the full box.

4.2.3 The Loading Frame

The loading frame was the same frame used by Rahardjo (1983) for calibrating miniature mechanical cone penetrometers. As designed, the frame provides a reaction point for a jacking system and carries a hoist used for sand filling. Unfortunately, the frame was constructed from treated pine lumber and over the course of less than one year, the frame warped considerably. Before proceeding with any electrical cone testing, all reinforcing members of the frame were replaced with angle iron sections, the columns were placed into compression by jacking them with screw supports against the ceiling, and the base of the frame expanded by approximately three inches to permit at least one direction of box movement.

4.2.4 The Insertion System

Due to the limited amount of headroom in the testing laboratory, any formal type of jacking system for cone penetration was not possible. Thus, a simple constant-rate one-ton capacity crane was hooked onto an eye-bolt tapped into a 225 pound steel weight. (The required force for driving the miniature electrical cone penetrometer was determined by examining the forces applied to the miniature mechanical cone to drive the cone to a depth of 36 inches. A force less than 200 pounds is adequate.)

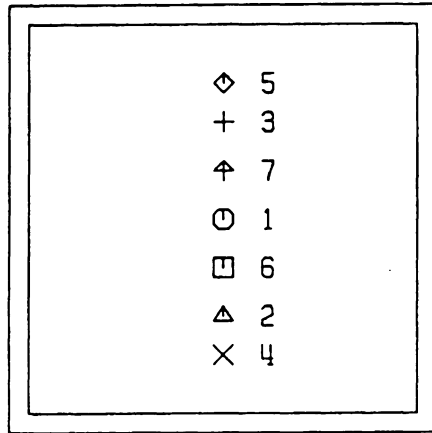
A double-ended bolt was tapped into the steel dead weight which could screw into the weight and into an adapter piece threaded into the drive rod of the cone. This type of insertion system provided enough force to drive the cone 35 inches at a relatively constant rate of penetration.

4.2.5 The Rod Guide Template

A 2 inch x 6 inch board cut to the width of the box served as a rod guide template. The board had a number of holes in it to allow for multiple cone tests and to help guide the cone as it penetrated the sand. In addition, the holes were numbered to provide consistency for comparing tests performed in different density samples. Each number is represented by a symbol which corresponds to a symbol in the FORTRAN programs written to plot the test results. (Refer to figure 4.2).

4.3 SAMPLE PREPARATION

The main objective of any sample preparation technique is to produce a uniform, homogeneous sample. One of the most common methods of preparing a model sample for calibrating in situ equipment is by a pluviation technique which involves dropping air-dry sand by gravity. In its simplest form, the sand is deposited through a hose or nozzle which is maintained at a uniform distance above the sand surface. The orifice is moved in concentric patterns until the sample is formed (Marcuson et al., 1976). More sophisticated schemes utilize mechanical devices to control



(PLAN VIEW OF TEST BOX)

SYMBOL	TEST NUMBER	DESCRIPTION
○	1	11.25 IN. FROM BOTTOM
△	2	5.5 IN. FROM BOTTOM
+	3	5.5 IN. FROM TOP
X	4	3.5 IN. FROM BOTTOM
◇	5	3.5 IN. FROM TOP
X	6	8 IN. FROM BOTTOM
□	7	8 IN. FROM TOP

Figure 4.2: Number and Order for Performing Cone Penetrometer Tests

drop height, and rain the sand from a supply which is as large as the specimen. Factors affecting the density obtained in any pluviation technique are drop height and orifice diameter.

It is known that drop height affects sample density; however, for heights greater than 20 inches, the variation is small. For consistency, drop height was maintained at 20 inches. Therefore, the relative density varied only with hole diameter.

Due to limitations imposed by the frame construction and by the low laboratory ceiling height, conventional rainers and spreaders could not be used in this research. Instead, laboratory samples were prepared by raining sand from a 10-quart bucket.

The 10 quart utility bucket had a small hole cut into the bottom into which a plastic 2-liter soda bottle top (0.85 inch diameter) was placed. The bottle top, in turn, held fabricated aluminum nozzles used to vary the hole diameter. Hole diameter was adjusted simply by fitting varying hole diameter pieces machined from aluminum into the bottle top. An aluminum bar was turned in a lathe so that the outer diameter of the piece fit into the bottle top, and the inner diameter was drilled and bored as required for each nozzle, and thus could be any diameter. The top of each nozzle piece had a lip to prevent it from being forced out of the bucket by the weight of the sand.

Table 4.1 presents densities obtained in the test bin samples with various nozzle diameters. As expected from past experience, the results, with only one exception, reveal that the bigger the orifice diameter, the looser the sample density. The one exception in the trend of density with hole size is the case for the lowest density sample. Although the pluviation hole size in this instance was the next to largest, the lowest density apparently resulted. The reasons for this are not totally clear, but are possibly related to surface finish inside the nozzle, or experimental scatter or error.

4.4 SAMPLE PREPARATION PROCEDURE

1. Clean and empty test box. Fit plugs into port holes of box.
2. Balance and zero scale.
3. Weigh rainer bucket used to fill test box. Weigh filling bucket use to fill rainer bucket.
4. Fill bucket with sand, weigh, dump the sand in a large (32 quart) trash barrel.
5. Continue step (4) until trash barrel is full.
6. Take full trash barrel to the test box.

Table 4.1: Results of Preparing a Sample Varying the Orifice Diameter in the Pluviation Device

Pluviation Orifice Diameter (in.)	Relative Density (%)	Void Ratio	Unit Weight (pcf)
0.675	17	0.762	93.8
0.85	22	0.751	94.4
0.57	32	0.727	95.7
0.46	49	0.685	98.1
0.46	52	0.678	98.6
0.41	62	0.654	100

7. Adjust drop height of rainer bucket (20 inches above sand bed) and use a No. 3 or 4 rubber stopper to cap hole in rainer bucket.
8. Fill rainer bucket with sand, pull out rubber stopper, evenly rain sand in a horizontal plane.
9. When sand stops raining (does not mean rainer bucket is empty), replace rubber stopper, go to step (8). When trash barrel is empty go to step (4). A full test box takes approximately 3 1/2 to 4 full trash barrels of sand.
10. When the test box is full (approx. 40 inches), measure the all-around height (take a minimum of 16 measurements).
11. Calculate total sample weight.
12. Calculate sample unit weight and relative density using phase diagrams:

(A) Unit Weight:

$$\gamma_s = \text{Weight of Sample (W)} / \text{Volume of Sample (V)}$$

$$\begin{aligned} W &= \text{wt. filler buckets} + \text{sand} \\ &- \text{wt. filler buckets} \\ &= \text{wt. sand} \end{aligned}$$

(if any sand remains in rainer, subtract it out of total weight)

Volume = sample height * model box dimensions

= measured height (step 10) * 22.5 in. * 22.5 in.

(B) Determine Void Ratio, e :

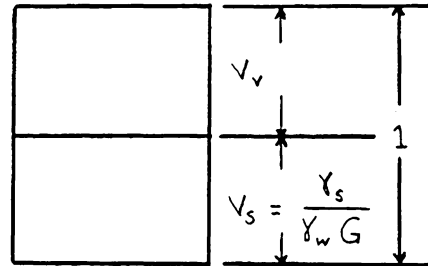
γ_s from (A)

$\gamma_w = 62.4$ pcf

$G = 2.65$

$V_v = 1 - V_s$

$e = V_v / V_s$



(C) Determine Relative Density, D_r :

$$D_r(\%) = \left(\frac{e_{\max} - e}{e_{\max} - e_{\min}} \right) * 100$$

4.5 MINIATURE ELECTRICAL CONE PENETROMETER TEST PROCEDURE

1. Choose sample density, prepare sample.
2. Place template on sand bed.
3. Raise steel dead weight with crane.
4. Attach drive rod adapter to weight.

5. Assemble cone, screw cone into drive rod, screw drive rod into adapter.
6. Connect cone and position transducer wires to the data acquisition system and to the power supply.
7. Lower cone through the template and into the sand.
8. Load data acquisition program into the Apple II.
9. Begin 5-phase data acquisition procedure.

4.5.1 Example Test Run

(This example test records the point resistance and depth.)

Type LOAD ISAACPT

Type RUN

Computer asks for number of load levels. Type 5 (or as many as desired). Keep running this program until voltage values have stabilized. Record these initial tip resistance millivolt values and depth volt values.

Type LOAD PTCALCS

Type RUN

Computer asks:

Number of test readings: 35

(Record this number)

Text filename: ANY NAME NEVER USED PREVIOUSLY

(It is best to use a name which is representative of the particular test. For example, SERIES152 represents test 1 in a homogeneous 52% relative density sample.)

Choose Option: 1 - to collect data and create a file
2 - if data are collected, option 2 reads the data file and prints it out at the request of the user.

Assume 1 was typed. The program continues:

Date: MONTH-DAY-YEAR

Computer asks for calibration factors and constants.

Area of Cone (sq. in.): 0.55

Cone load cell calibration factor (lb/mvolt): 107

Initial Tip Voltage (millivolts): (the value recorded from ISSACPT program) ~ 14.95

Position Transducer Calibration Factor (lb/mvolt): 7.69

Initial Depth Voltage (volts): (the value recorded from ISAACPT program)

Computer asks for calculation constants. Calculations are for generating depth, vertical stress, and dimensionless plotting parameters q_c/B and D/B .

Rate of Penetration (in/sec): 1.7

Diameter of Cone (inches): 0.825

Unit Weight (pcf): (as calculated in sample preparation procedure)

Computer generated depth factor (inches/reading): 0.91 (This factor varies with different programs. Okay for PTCALCS.)

Type "B" to start data acquisition: B

Press RETURN (Pressing the return key actually starts the data collection. At the end of the test, the computer automatically places data into a text file on the disk.)

END OF PHASES 1 AND 2

BEGIN PHASE 3

Type LOAD PTCALCS

Type RUN

Computer asks:

Number of Readings: 35 (same as in phase 1; this is why the value was previously recorded)

Text Filename: SAME AS IN PHASE 1

Option: 2

The computer reads the file. The red light on the disk drive will turn on and small white bars will flash on the monitor. When the file is read, the computer asks:

"Do you want a copy of data now?"

Type "Y" or "N"

Type N and no data are obtained and the program ends.

Type Y and the computer reminds the user to turn the printer on.

Turn on the printer.

Type C

END OF PHASE 3 - BEGIN PHASE 4

User receives a hardcopy of data. Examine the data. Do they appear valid?

END OF PHASE 4 - BEGIN PHASE 5

If the data are not reasonable, do not send it to mainframe. If the data seem valid send it to mainframe from the Apple II. This is accomplished through a Hayes modem which converts the Apple II into a terminal. Proceed as follows:

Insert VISITERM disk into the disk drive

Type IN#6

Press ESC SHIFT 1 simultaneously (for options screen)

Plug phone jack into modem

Type C

Type D

Type 7311

Type RS

Type VM1 (computer says welcome)

Type LOGON USERID

Type PASSWORD

Computer says "R". To send the file, place the disk with the data file on it into the disk drive.

Type RDTAPHP fn ft fm MARK REPLACE and press RETURN

Computer says nonsense.

Press ESC SHIFT 1 simultaneously (now in options mode)

Type F

Press space bar until PROTOCOL is highlighted

Press from NONE to EOB-ACK

Press space bar back to FILENAME

Press ESC and type fn and press RETURN

Type S

When END OF FILE is reached, type T

Press ESC SHIFT ? and press RETURN

LOGOFF

All the data from the sent text file are now in the user's mainframe account in separate DATA files. Several FORTRAN plotting programs were written to plot the data. (These programs are commented throughout and do not require further explanation. However, a brief explanation preceeding each program listing is provided in the User's Guide in appendix 1.) Before any of the programs can work, the DATA files must be edited.

4.5.2 Editing DATA Files and Receiving a Plot

When the text files are sent to the mainframe, the entire contents of the file are sent. The data required for the plot programs from the original file are cone resistance and depth. Therefore, to edit these files delete the initial input values (ie. date, calibration constants, etc.), delete the voltage values, delete the calculated parameters and save the cone resistance values.

The editing is easiest to understand by example. Figure 4.3 is an example of data collected using ASUMCALCS and the editing required for obtaining a plot. The example file is test 1 from the 17% relative den-

sity sample. Files SERIES217, SERIES317, SERIES417, and SERIES517 are edited similarly. The only number that precedes cone resistance and depth for these files is the number of points to plot. In addition, since SERIES517 is the last file the JCL symbols:

```
/*  
//
```

must be placed into columns one and two at the bottom of the file which tells the plotter "end of data". Note that when editing a text file the data placed into the file must be typed as specified by format statements 800 and 810 in each of the FORTRAN programs.

Every DATA file for every FORTRAN program must be edited to look like the previous example. The raw data files will appear slightly different than the one shown when using data from BASIC programs other than ASUMCALCS. The simplest file to edit is a file obtained using PTCALCS since the depth values are already in the right place. The only differences among the programs are: in LAYER FORTRAN, three values of relative density must be typed at the beginning of file 1; and, in COMPARE FORTRAN, six values of relative density (or the number of relative densities used in the comparison plot) must also be typed at the beginning of file 1.

Once the data files are edited they are submitted to the plotter. This is accomplished by using the MULTSUB command which submits the FORTRAN program and the DATA files to the plotter. For example:

Type MULTSUB and press RETURN

<u>RAW DATA FILE:</u> (File is SERIES117)		<u>EDITED DATA FILE:</u>	
DATE	12-1-84	Delete. Replace with value of relative density of samples, number of curves to plot, and number of data points on curve one.	17.0
⋮	⋮		5
CONSTANTS	CONSTANTS		22
⋮	⋮		
VOLTAGE VALUES FOR TIP AND FRICTION SLEEVE	.09624997 .03160160	Save cone resistances, type in depth where friction sleeve values are, and delete friction ratio.	18.724
⋮	⋮		5.14
CONE RESISTANCE SLEEVE FRICTION FRICTION RATIO	18.724994 .24320256 1.2988125 23.474639		23.474
⋮	⋮		6.5
⋮	⋮	Delete.	
READING NUMBER	0		
DEPTH	5.14 1 6.5		
⋮	⋮		
CALCULATED PARAMETERS	6.2323030 398.98627 42.105167		
⋮	⋮		
END OF FILE		END OF FILE	

Figure 4.3: Example for Editing a DATA File

Computer asks for files separately. The first one typed is the FORTRAN program.

Type OWNPLOT FORTRAN and press RETURN

SERIES117 DATA RETURN

SERIES217 DATA RETURN

SERIES317 DATA RETURN

SERIES417 DATA RETURN

SERIES517 DATA RETURN

Computer writes linked to MVS1.... and other messages.

If there are no FORTRAN errors, then the user can pick up the plot. There are two ways to check if the program worked. Both involve the BROWSE command. After the computer runs the program, the output is sent to the user's readerlist. Receive the output and browse it. The top of the output is computer JCL code. The code should list the code COND CODE 0000 three times. Usually, if there is an error, one of the codes will read COND CODE 0008 or COND CODE 0016. In addition, the code may say PLOT STEP NOT EXECUTED DUE TO CONDITION CODES. To find the error browse to the bottom of the file where the errors are listed. The messages are usually vague and the computer center manuals are not very helpful. Some user advice is to edit carefully, watch for errors in typing, make sure the data is input in the proper format, and have adequately dimensioned arrays.

END OF PHASE 5

4.6 COMMENT ON THE TEST PROCEDURE

Generally, phase 1 was repeated for the 5 tests performed on a sample. All the data was printed, sent to the mainframe, edited and plotted together.

5.0 DISCUSSION OF RESULTS

5.1 CONE RESISTANCE VERSUS DEPTH

This chapter examines data obtained in the calibration testing of the miniature cone. The test program is described in table 5.1; it involved the preparation of ten soil samples in the test bin and performing 60 individual cone penetration tests. The most important data are reviewed in the text of this chapter. Additional details are discussed regarding equipment design, testing procedure, and soil type, in Appendix 3.

5.1.1 Homogeneous Samples

Results of cone penetrometer tip resistances are plotted versus depth in figure 5.1 for the sample with a relative density of 52%. (Note that the error margin in calculating relative density based on scale accuracy is + or - 2%). Basic trends in this figure are typical of those from all of the tests with homogeneous samples (see data plots in appendix 4).

Seven penetration tests were performed in the sample with a relative density of 52%. Locations of the penetrations are given in figure 4.1 (chapter 4). Of course, it is expected that the data for the first penetration are the most reliable, because this test is located in the middle

Table 5.1: Summary of Miniature Electrical Cone Testing Program

SAMPLE NUMBER	TYPE OF SAMPLE	RELATIVE DENSITY (%)	NO. TESTS IN SAMPLE	COMMENT
1	uniform	17	5	
2	uniform	22	5	
3	uniform	32	7	
4	uniform	49	7	
5	uniform	52	7	
6	uniform	62	5	
7	layered	top = 49 bot = 5	7	top = 20" bot = 21"
8	layered	top = 28	5	top = 20.1" bot = 21.5"
9	layered	top = 35 mid = 43 bot = 24	5	top = 13.1" mid = 7.1" bot = 21.3"
10	layered	top = 64 mid = 21 bot = 30	7	top = 14" mid = 11.3" bot = 15.5"
<p>TOTAL NUMBER OF SAMPLES PREPARED = 10</p> <p>TOTAL NUMBER OF TESTS PERFORMED = 60</p>				

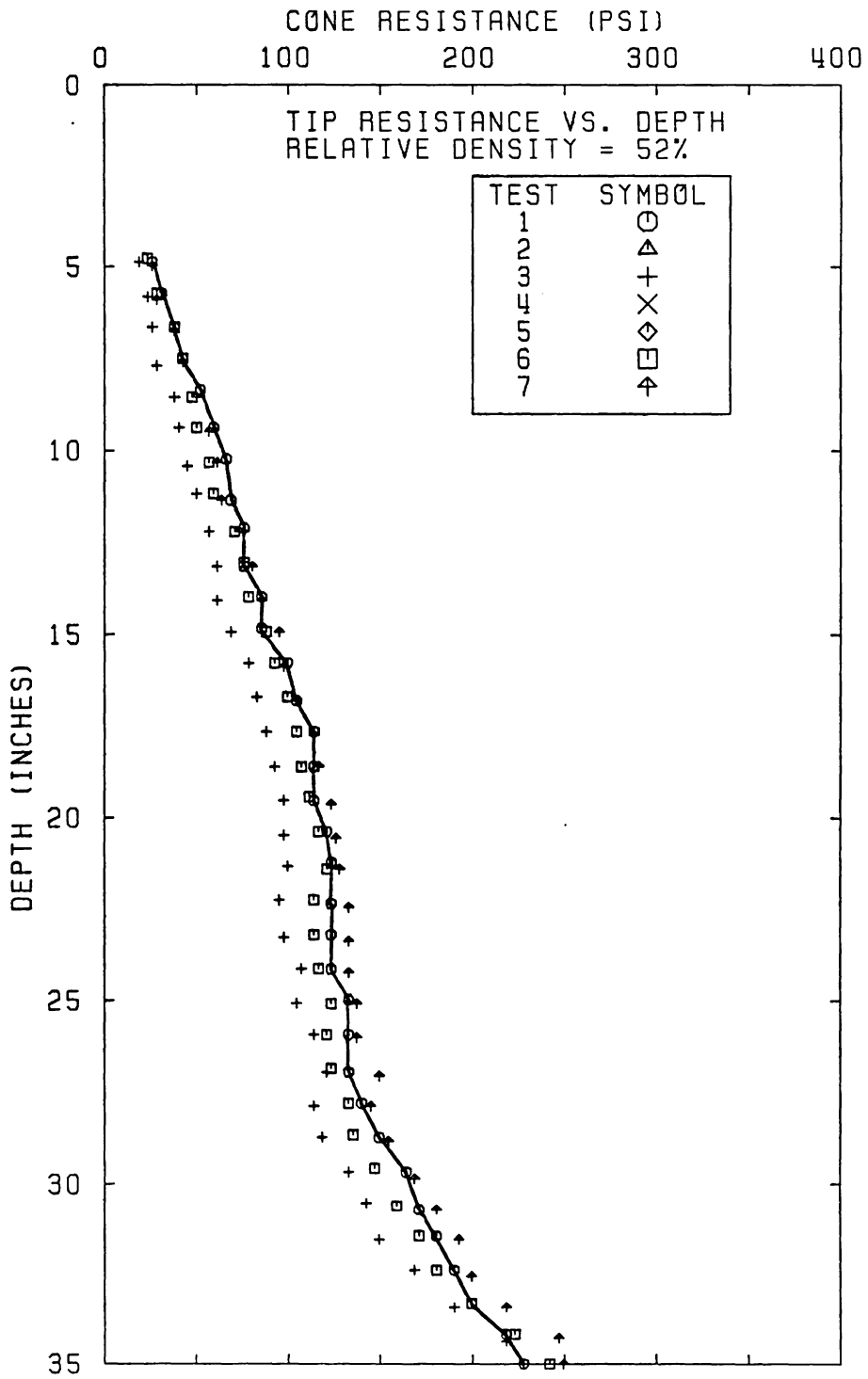


Figure 5.1: Typical Tip Resistance versus Depth Plot for a Homogeneous Test Sample

of the bin, the position farthest from the boundaries, and no other disturbance has occurred from a previous test. Interestingly, the first penetration yields very nearly the highest resistance values of all the tests. This was a common finding to all of the other samples. When comparing the relative magnitudes of the other penetrations, no other particular trends stand out. In other words, the magnitude of the resistances do not seem to relate to distance from the boundaries or number of the penetration. The relative lack of influence of the boundaries on the results is somewhat surprising since theoretical models would suggest that the tests closest to the walls could be affected. One hypothesis for the lack of effect of the side boundaries is that the confining pressures are so small in the test bin, they exert little influence on the boundaries, even when a cone penetrates and increases them.

Although there are some differences between the test results for the different penetrations, two points stand out:

- 1.) The differences between test results are not large; and,
- 2.) The trend of cone resistance values with depth for the seven tests is very consistent, even as to small changes in the slope of the resistance curves.

The last point is important because it speaks for reliability in the data. It is observed for all of the samples tested.

All of the cone resistance values for the 52% relative density sample (figure 5.1) increase gradually with depth to about 29 inches whereupon a more rapid increase occurs. This response near the bottom of the bin

was pronounced only in the denser specimens. It apparently reflects the influence of the bottom boundary, which is probably more significant in denser sands because of their tendency to expand during shear.

A summary plot for all of the first penetration tests in the homogeneous samples is presented in figure 5.2. Each test shows a similar basic trend with differences primarily reflecting the fact that the higher density samples create higher resistances. The result for the 49% relative density is the only test completely out of sequence; since the resistance values appear more representative of a significantly higher relative density sample, given that they fall above those for the 52 and 62% samples for the entire depth.

Table 5.2 provides a numerical comparison of the data in figure 5.2 at five inch depth intervals. It is again evident that the 49% sample is irregular. In addition, the test results for the 62% sample are somewhat erratic. For a depth to 20 inches, the values for the 62% sample are lower than the 52% sample. Below this depth the reverse is true, following the expected trend.

The penetration data show that the rate of increase of penetration resistance with depth tends to decrease below about 15 inches. No dramatic changes in resistance patterns occur thereafter except as noted in the case of the denser samples near the bottom of the bin. The decrease in rate of resistance to penetration below 15 inches is probably related to the "critical" depth concept described in a number of previous studies.

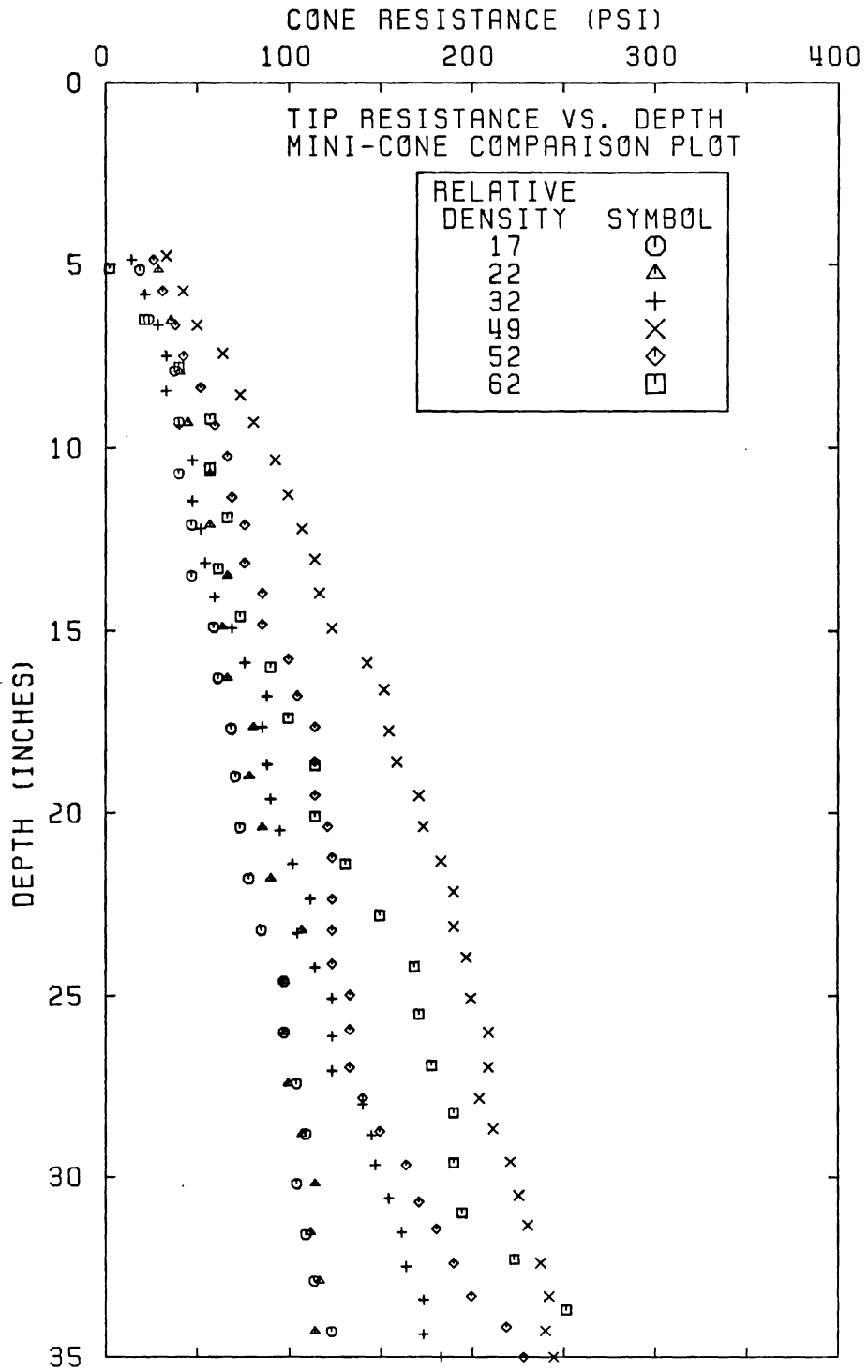


Figure 5.2: Summary Plot for all First Penetration Tests in the Homogeneous Samples

Table 5.2: Numerical Values for Tip Resistance (psi) with Depth

Dr (%)	depth = 5 in.	10	15	20	25	30	35
17	19	40	59	73	97	109	123
22	28	51	64	83	97	113	133
32	14	46	71	94	123	152	183
49	33	90	133	173	199	224	245
52	26	65	93	119	133	169	228
62	21	57	86	114	170	192	252

Schmertmann (1978) observed that during testing tip resistance and sleeve friction increase rapidly for a depth of 8 cone diameters (d), then more slowly. Schmertmann describes this depth as a transition zone from failure by shear to penetration by compression, grain crushing, and cavity expansion. Sanglerat (1972) indicates that when the soil is homogeneous the values of point resistance become constant at an embedment depth of 8-10 d . Vesic (1964) used cone data to predict pile behavior and noted a linear increase in resistance to d/B (where: d = depth of penetrometer, and B = base diameter of penetrometer) equal to 15, after which the rate of increase decreases until an ultimate value is reached. The measured resistances from tests conducted in a calibration chamber by Baldi et al. (1981) using loose to dense relative density samples showed a development of constant resistance at about a depth of 30 inches, or for their standard cone, a d/B ratio of 21.

An examination of the resistance versus depth curves in figure 5.2 indicates no clear definition of critical depth. It may be argued that the critical depth is around 15 inches since at this point the resistance curves of a number of the tests exhibit a lessening of the rate of increase of cone resistance. The 15 inch depth is about 15 times the cone diameter, or around twice the critical depth according to Schmertmann's results, but in line with the Vesic concept.

5.1.2 Miniature Electrical Cone Data vs. Miniature Mechanical Cone Data

Figures 5.3 and 5.4 present a comparison of miniature mechanical cone data obtained by Rahardjo (1983) to the miniature electrical cone data for loose and medium dense sands respectively. Rahardjo (1983) performed tests in the same bin used herein. Most of his techniques were also similar to this research, with the major difference occurring in the insertion procedure. Rather than jacking or mechanically driving the cones to depth, in a controlled fashion, the cones were manually inserted and the applied forces were read from a proving ring located at the top of the drive rod. The mechanical tests employed two different sized cones, one cone with a 0.625 inch tip diameter and the second with a 0.825 inch tip diameter. The 0.825 inch diameter cone had a reduced sleeve and rod diameter behind the tip while the smaller one had a drive shaft the same size as the tip. All the tests for this thesis were performed with a 0.825 inch tip diameter electrical cone.

According to theory (Schmertmann, 1978), the tip resistance for the mechanical cones in loose sands is expected to show greater resistance due to increased friction along the cone mantle behind the tip; whereas, in denser sands the tip resistance for the electrical cones is slightly greater.

The electrical cone resistance data is similar in trend to the mechanical cone data for both the loose and medium relative density samples. In the loose sample, all three of the cones yielded penetration resist-

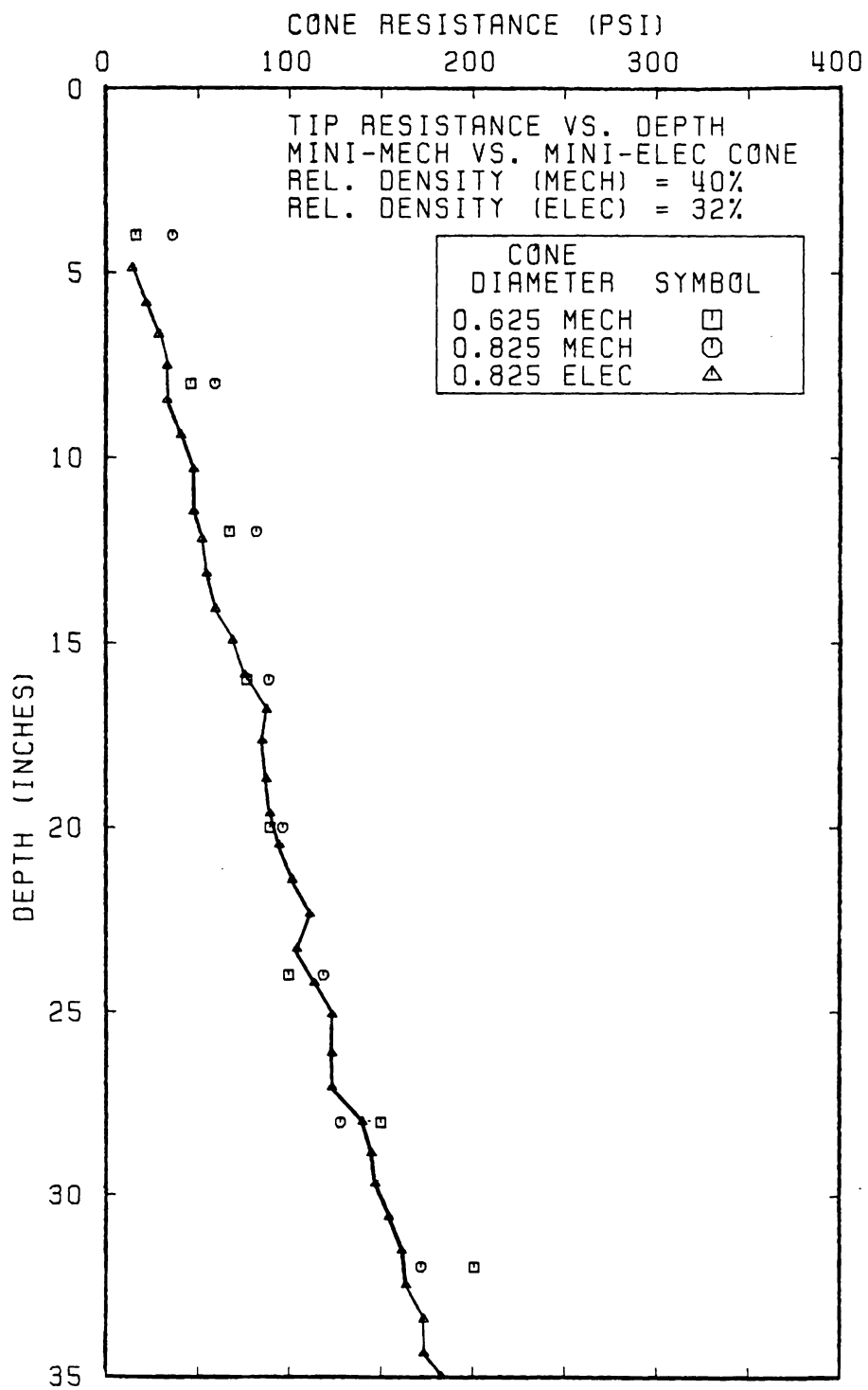


Figure 5.3: Miniature Mechanical versus Miniature Electrical Cone Resistance Data for a Loose-Medium Density Sample

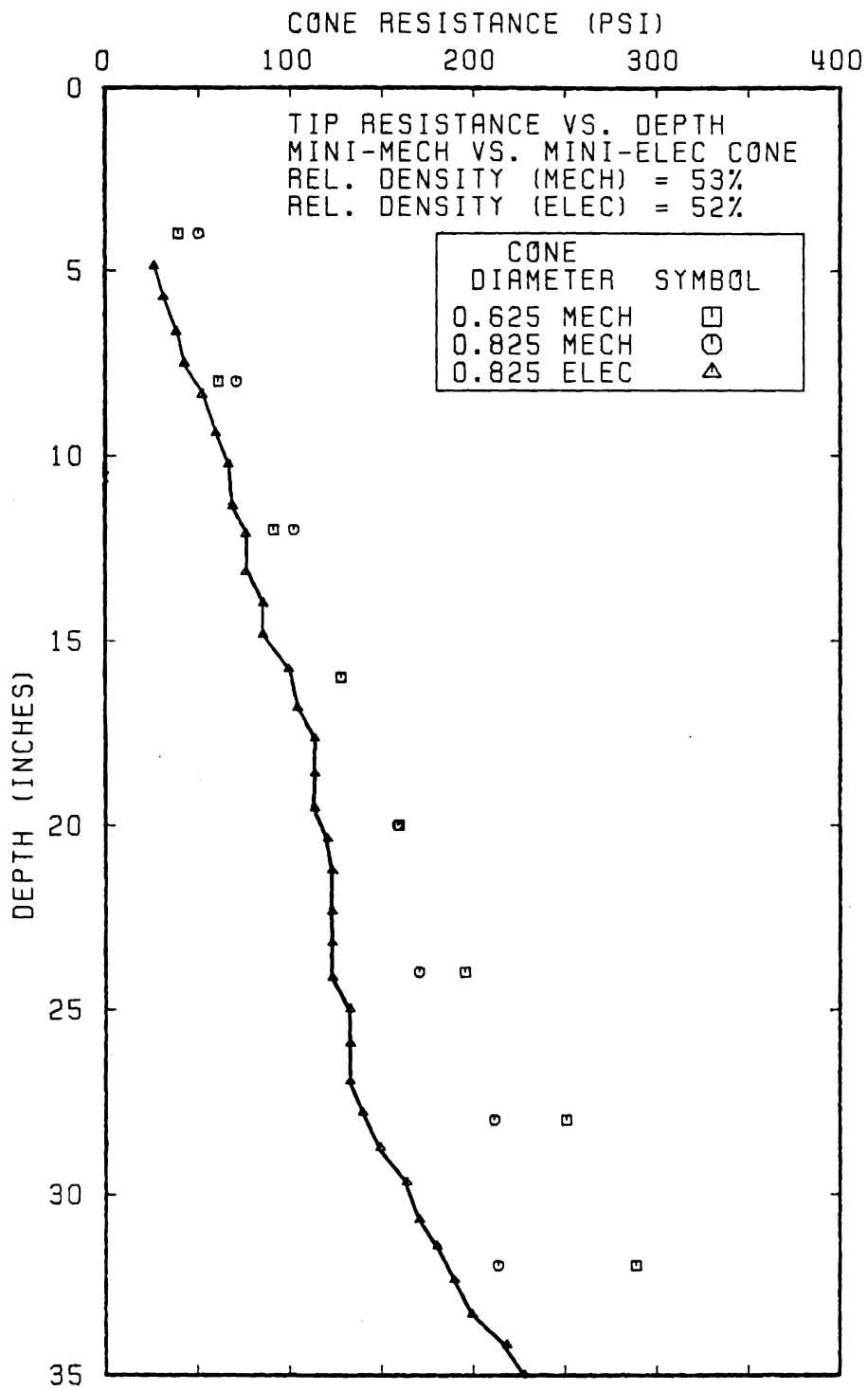


Figure 5.4: Miniature Mechanical versus Miniature Electrical Cone Resistance Data for a Medium Density Sample

ances which are also are very consistent in magnitude. In the medium density sample, the two mechanical cones are similar in both trend and magnitude, but the electrical cone data is lower than that for both mechanical cones. The greatest difference in the data exists at depths below 20 inches. The reason for the differences are not clear, although it may reflect possible nonhomogenities in the samples or the fact that Rahardjo (1983) was not able to control his cone penetrometer as well as in the present test procedure.

5.2 LAYERED TESTS

Approximately 20 tests were performed in four, layered sand samples to examine the sensitivity of the miniature electrical cone with respect to changes in sample density. The layered test results are plotted in figures 5.5-5.8. According to Sanglerat (1972), an abrupt change between two layers could only be detected with a cone of zero diameter. Schmertmann (1978) also demonstrated that the smaller the cone diameter, the more sensitive the tip is to variations with depth. Assuming a two-layered soil, both researchers agree that a penetration depth of $8d$ before and beyond the boundary layer interface is required for the tip resistance to stabilize. For loose soils, where the friction angle is less than 34 degrees, Sanglerat found the cone to be sensitive to the layer at penetration depths of 3 to $4d$ before encountering the interface. Schmertmann (1978) proposed that, in a two-layer soil sample, the cone tip resistances in the top layer are affected by the bottom layer at an

approximate penetration depth of 5 to 10d before the boundary interface. After passing across the boundary interface, an additional 5 to 10d is required for the tip resistances to stabilize. In general, 15d of cone penetration is required in sands to reach full resistance within a layer. Of course, it may be possible for the cone resistances to increase or decrease in a layer but the values may never reach full resistance if the layer is not 15d thick.

Figures 5.5-5.8 display the layered test results performed in this research. For comparison purposes, the closest relative densities from the homogeneous tests are also plotted. For the first case, ($D_r = 49\%/5\%$), in the depths where the cone readings do not appear to be influenced by the layering effect, the nonhomogeneous test readings are reasonably consistent with those from the respective homogeneous test sample. Interestingly, in the layered sample, the cone resistances begin decreasing at approximately 5d before the boundary interface between the top dense layer and bottom loose layer and continue decreasing for at least 5d after it. At 5d below the interface the readings resume their trend similarity to the homogeneous sample. This result is consistent with the findings of Schmertmann (1978).

Figure 5.6 presents the data for a sample with loose over very loose sand ($D_r = 28\%/18\%$). In the figure, the top 28% relative density layer is compared to the 32% homogeneous test and the bottom 18% relative density layer to the 17% homogeneous test. In depths not near the boundary there is good agreement for the data of the respective relative densities.

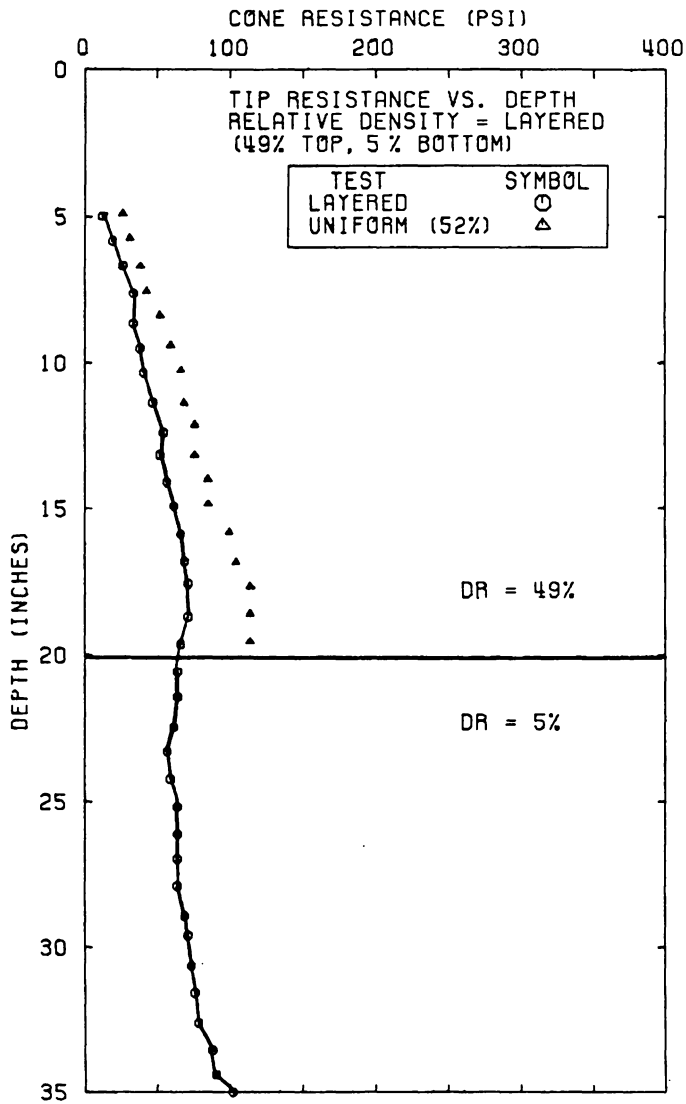


Figure 5.5: A Medium-Very Loose Layered Test

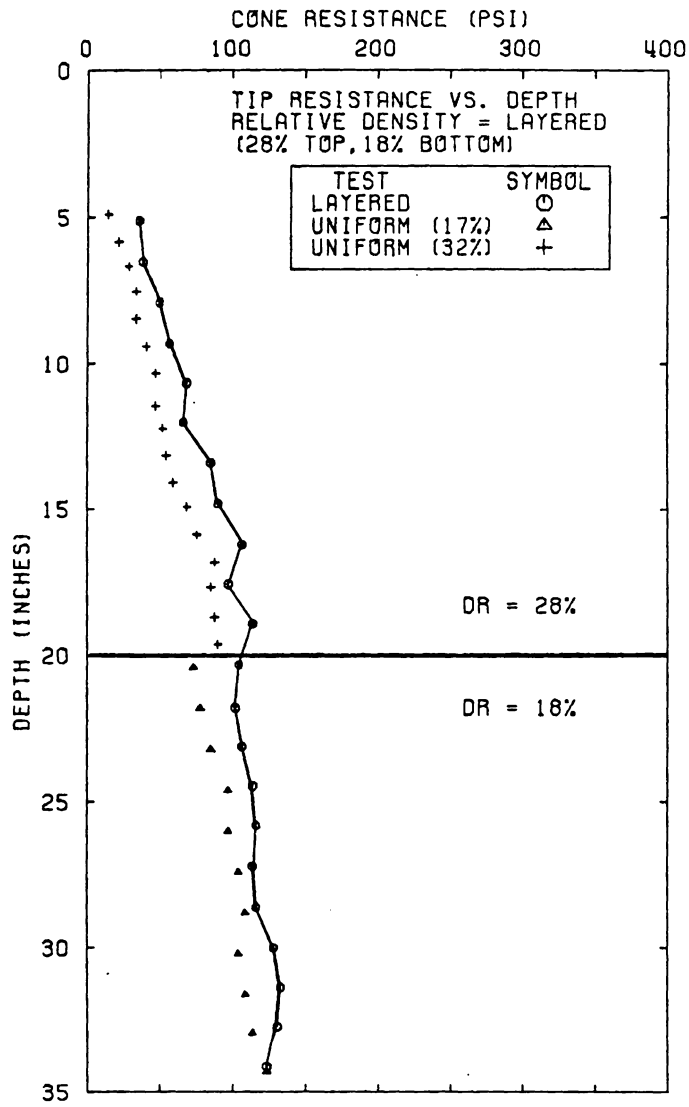


Figure 5.6: A Loose-Very Loose Layered Test

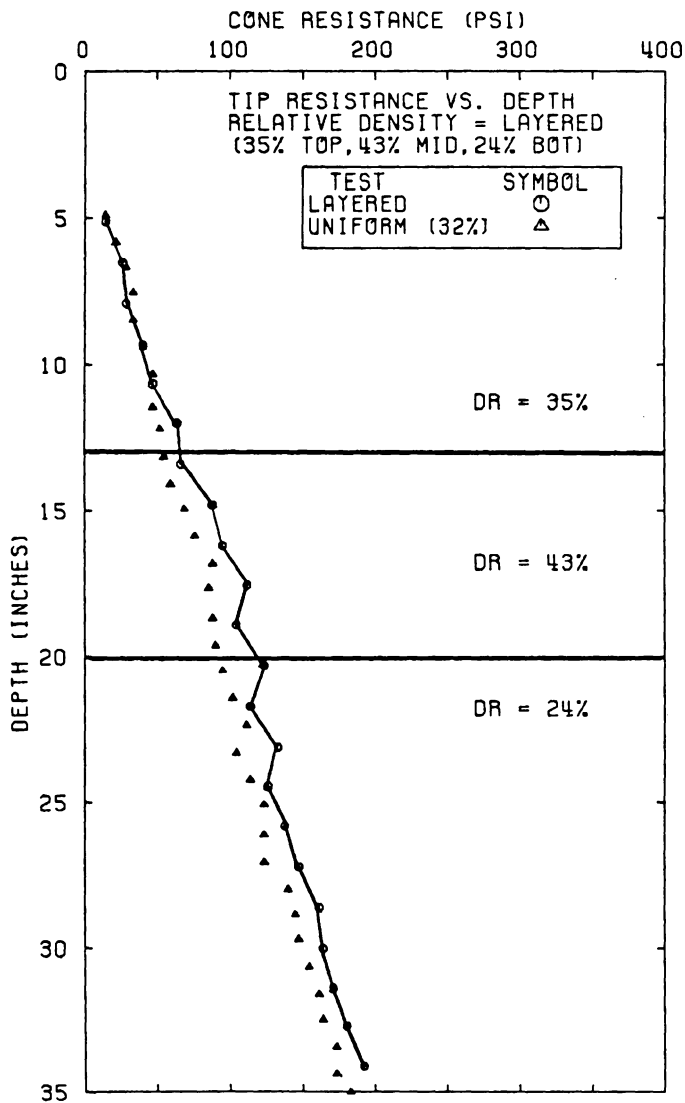


Figure 5.7: A Loose-Medium-Loose Layered Test

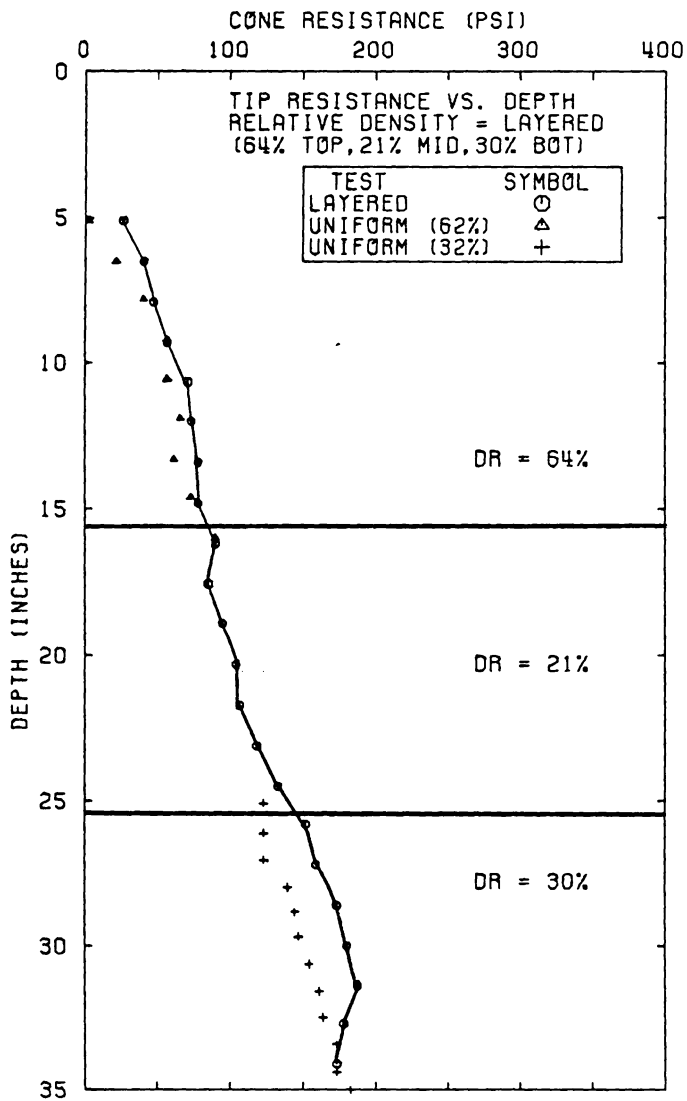


Figure 5.8: A Dense-Loose-Medium Layered Test

The 28% top layer resistances begin decreasing at slightly less than 5d before the medium-loose interface. For a depth of 5d beyond the interface, the resistances decrease, reflecting the very loose layer. At approximately 8d below the interface the resistances reach a steady agreement with those of the homogeneous 17% sample. These results are consistent with the data of both Schmertmann (1978) and Sanglerat (1972).

Figure 5.7 presents data for a loose-medium-loose test ($D_r = 35\%/43\%/24\%$). The homogeneous 32% relative density test data was plotted for comparison since the densities in the nonhomogeneous sample are all reasonably close to 32%. The resistance values for the 35% layer and 32% homogeneous sample are approximately equal to a depth of about 10 inches. At less than 5d above the top interface, the layered resistances increase in magnitude more rapidly than the homogeneous sample as a result of the 43% middle layer. The data do not fully stabilize in this intermediate layer presumably since it is not thick enough. The thickness is only about 10d, a value less than the 15d required to stabilize, according to Schmertmann. After the cone passed the bottom interface the resistance values decreased, and at 5d below the interface, the resistances begin to match up with the 32% homogeneous sample again. This is consistent with the expected response.

Figure 5.8 presents the results of a dense-loose-medium test ($D_r = 64\%/21\%/30\%$). For comparison, the data for the homogeneous 62% and 22% samples are plotted with the layered results. The 64% layered resistances match up to the 62% homogeneous test. It was expected that the 64% values

would decrease at a distance less than or equal to $5d$ before encountering the top dense to loose interface but, the values did not decrease until the cone had crossed the interface. However, at approximately $3d$ beyond the top interface the 21% layered resistances came close to the 22% homogeneous resistances. At $3d$ above the bottom loose to dense interface the layered resistances show a more rapid increase than the homogeneous 22%. Within $5d$ into the bottom 30% layer, the values tend to stabilize.

A qualitative review of the four layered test results demonstrates that the miniature electrical cone successfully identified variations within the layered soil, and, in most instances, the homogeneous density comparisons were similar in trend to the layered densities where no boundary effects were felt. Also, the distances at which the cone sensed the presence of the layers was generally consistent with the findings of other investigations.

5.3 EMPIRICAL CORRELATIONS FOR BASIC PARAMETERS

5.3.1 Soil Friction Angle

Table 2.1 of the background chapter (chapter two) summarized the available methods for predicting the soil friction angle. Following these methods, table 5.3 contains the results of calculating the soil friction angle using the cone resistance values of this test program.

Table 5.3: Predicting the Friction Angle

THEORY	RELATIVE DENSITY						REFERENCE
	17	22	32	49	52	62	
Trofimenkov (1974)	32.5	33	33.5	33.5	33.5	33.5	Figure 2.4 (q_c vs. σ'_v)
Meyerhof (1974)	30.5	30.5	31.3	32.2	31.8	32	Figure 2.2 (q_c vs. ϕ)
Schmertmann (1975)	33.5	34	34.5	36.5	35	36	Step 1: Evaluate D_r from figure 2.5a Step 2: Obtain ϕ from figure 2.5b
Durgunoglu & Mitchell (1975)	36	37	38	39	38	38.5	Figure 2.3 (q_c vs. depth as a function of ϕ)
De Beer (1974)	26	26	27.3	29	28	28.2	Sanglerat, 1972
Meyerhof (1961)	34	35	35.8	38	36.2	37.3	Mitchell and Lunne, 1978

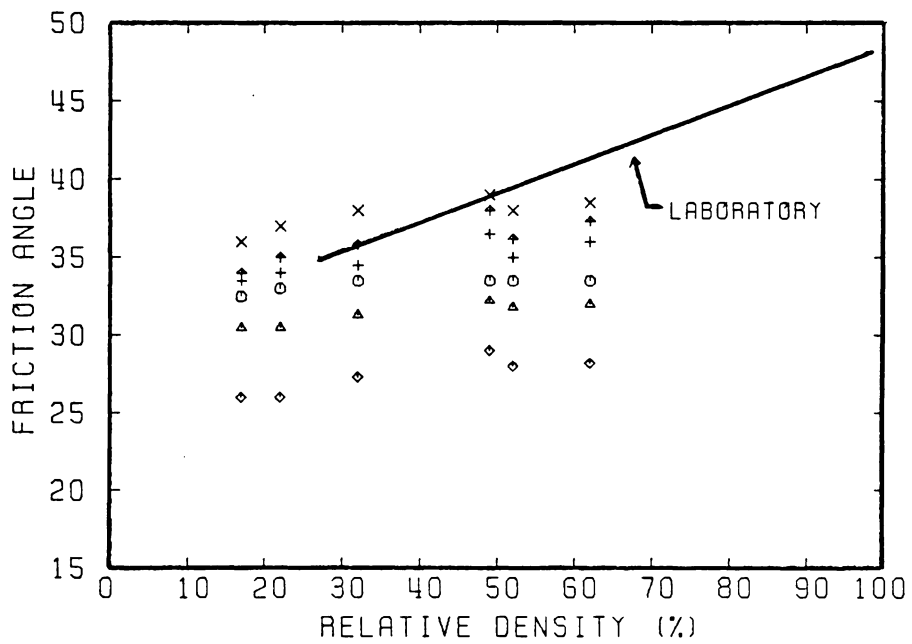
The methods of De Beer, Trofimenkov, and Meyerhof are the simplest to use since only cone resistance and overburden pressure need to be known. All three methods yield friction angle values, lower than those of the other approaches.

The friction angles for Monterey No. 0/30 sand were experimentally determined for various relative densities from a series of cylindrical tests performed by Ladd (1980). The values of the friction angles obtained in these tests were normalized and interpolated to a confining pressure equal to that in the open soil bin to provide a basis for comparing the predictions by various theories. From figure 5.9, the closest prediction to the actual is by the approach of Durgunoglu and Mitchell (1975). Mitchell and Lunne (1975) recommend using the methods of Meyerhof or Schmertmann and caution that each theory is subject to some limitation.

5.4 PREDICTING CONE RESISTANCE

5.4.1 The Method of Schmertmann

It is difficult to predict cone resistances since there are many factors influencing the CPT data (Appendix 3). The Schmertmann method for predicting cone resistance is based on a relationship with vertical effective stress and relative density. Table 5.4 summarizes the values of resistance predicted by the Schmertmann equation (1978) versus the measured laboratory results from the miniature electrical cone penetrometer. The comparison is shown in figure 5.10.



- TRÖFIMENKOV
- △ MEYERHÖF (74)
- + SCHMERTMANN
- × DURGUNOGLU AND MITCHELL
- ◇ DE BEER
- ⊕ MEYERHÖF (61)

Figure 5.9: Comparison of Friction Angles Computed by Different Theories

Table 5.4: Schmertmann's Prediction for Tip Resistance

DEPTH	$\gamma = 91.7$ Dr = 0%		$\gamma = 95.2$ Dr = 25%		$\gamma = 98.8$ Dr = 50%		$\gamma = 102.3$ Dr = 75%		$\gamma = 105.8$ Dr = 100%	
	p_o (psi)	q_c (psi)	p_o	q_c	p_o	q_c	p_o	q_c	p_o	q_c
5	0.265	3.27	0.267	10.2	0.286	21.7	0.296	46	0.306	97.5
10	0.531	7.85	0.551	16.7	0.571	35.5	0.592	75.2	0.612	160
15	0.796	10.5	0.827	22.3	0.857	47.3	0.888	100.3	0.918	213
20	1.06	12.8	1.10	27.3	1.14	58	1.18	123.1	1.22	261
25	1.33	15	1.38	32	1.43	67.9	1.48	144.2	1.53	306
30	1.59	17.1	1.65	36	1.71	77.3	1.78	164.1	1.84	348
35	1.86	19.1	1.93	40.6	2.	86.3	2.07	183.1	2.14	388
<p>Above resistance values predicted by: $q_c = 12.31p_o^{0.71}e^{0.0291(Dr)}$ Resistances below are laboratory measured.</p>										
	$\gamma = 93.8$ Dr = 17%		$\gamma = 98.6$ Dr = 52%							
5	0.271	18.7	0.285	28						
10	0.543	40	0.571	66						
15	0.814	60	0.856	85						
20	1.09	73	1.14	121						
25	1.36	97	1.43	133						
30	1.63	106	1.71	164						
35	1.9	123	2.	228						

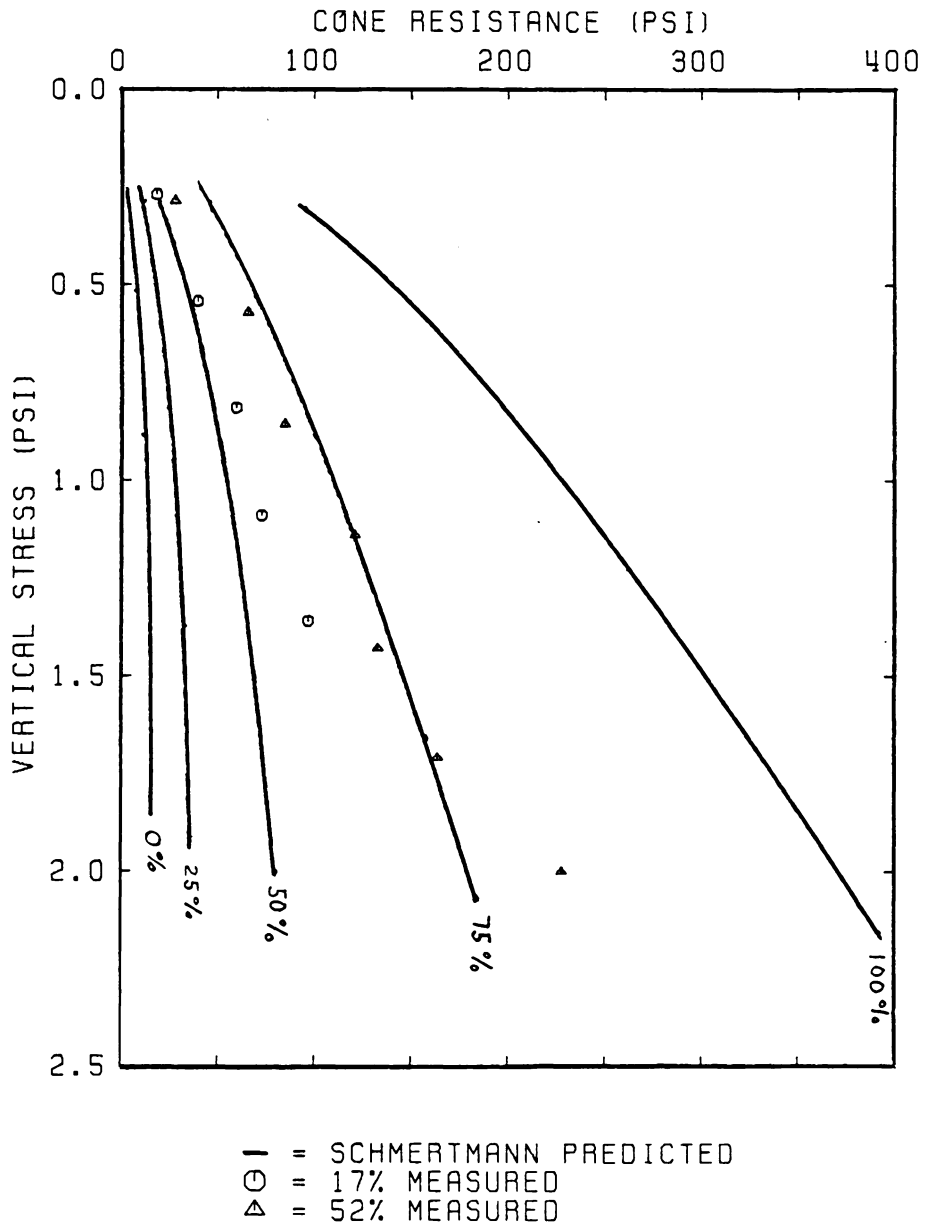


Figure 5.10: A Comparison Between Relative Density Curves Determined in this Study and those Predicted by the Schmertmann (1978) Equation

The trend expected for the plot in figure 5.10 varies among researchers. Baldi et al. (1981) and others observed that the vertical stress-relative density-tip resistance relationship is never linear. However, this behavior is not consistent with Schmertmann (1978), Veismanis (1974) and others who report that a linear relationship for vertical stress-relative density-tip resistance exists until grain crushing occurs.

An examination of figure 5.10 shows that the values for tip resistance especially for low density samples, obtained from the miniature electrical cone are higher than Schmertmann's predicted values. There are several possible reasons for this. In some cases, a chamber with a smaller diameter ratio, R_d (where: $R_d = \text{chamber diameter}/\text{cone diameter}$), could result in lower tip resistances (Parkin, 1977). Schmertmann worked with a diameter ratio equal to 20; whereas, the diameter ratio for the soil box used in this research is 27. However, the only conclusive and valid result for explaining the differences for the vertical stress-relative density-tip resistance relationship is due to the variations among soil types. There is no universal relationship that can consider every soil type. Therefore, the only common trend is that the tip resistance increases with increasing vertical stress. It is interesting to note that the measured values do not plot linearly.

5.5 LIQUEFACTION POTENTIAL PREDICTION

One of the purposes of this investigation was to use the data as a means of checking the existing liquefaction correlations. As described in chapter two, Seed and Idriss (1983) and Campanella and Robertson (1983) proposed empirically based correlations to evaluate cone penetrometer test data for field liquefaction assessment. Both methods deal with level ground conditions at the field site and provide for differences between clean sands ($D_{50} > 0.25$ mm), and for silty sands ($D_{50} < 0.15$ mm).

The liquefaction response of the Monterey 0/30 sand used as the test medium in this study has been defined through triaxial testing (Rad and Clough, 1982). The liquefaction resistance curve is shown in figure 5.11, where the stress ratio causing liquefaction is plotted against the relative density. Stress ratio is defined in laboratory triaxial tests as $\Delta\sigma_1 / 2\sigma_3$. To relate this to field conditions, it must be modified to a τ / σ_{vo} ratio. Seed and Idriss (1971) suggested a parameter C_r which is multiplied times $\Delta\sigma_1 / 2\sigma_3$ to get τ / σ_v . Using C_r , the resulting relationship between τ / σ_v and relative density is shown in figure 5.11 as a solid curve. This relationship allows a liquefaction resistance to be defined for any relative density.

To utilize either the Seed and Idriss (1983) or Campanella and Robertson (1983) method for liquefaction potential evaluation, the values of cone resistance must be modified by correction factors. Both Seed and Idriss and Campanella and Robertson present similar shaped curves for

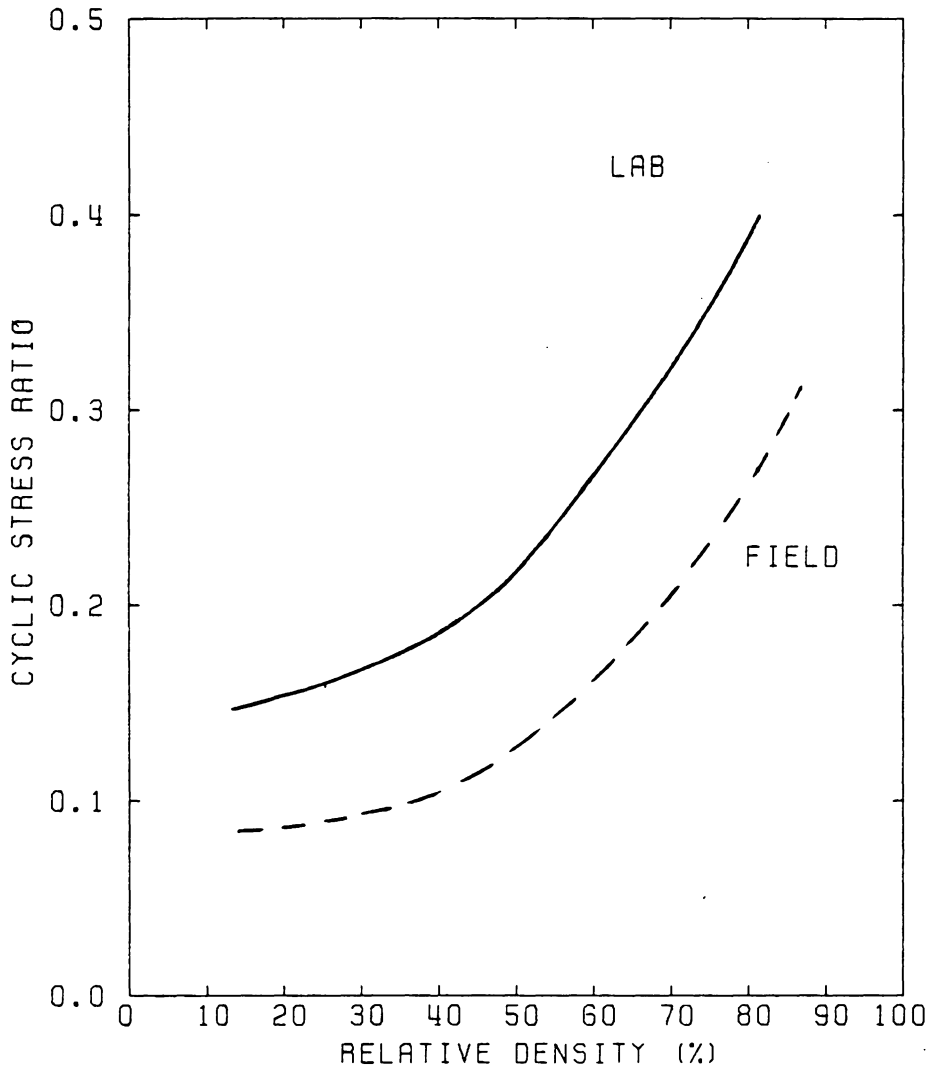


Figure 5.11: Cyclic Stress Ratios to Cause Liquefaction or 10 Percent Double Amplitude Shear Strain in 15 Cycles (Data is valid for Monterey sand, from Rad and Clough, 1982)

obtaining these factors; however, the actual values are significantly different. The results in table 5.5 basically define a correlation between the corrected cone readings and the shear stress ratio at which liquefaction occurs. This defines a boundary between the cases of liquefiable and non-liquefiable soils, and the data may be used to check corresponding boundaries established by Seed and Idriss and Campanella and Robertson which are based on field data only. In figures 5.12 and 5.13 the results from this investigation are superimposed on those of the Seed and Idriss and Campanella and Robertson, respectively. The data of this work only covers a very small range at the lower end of the plots because the confining pressures in the soil bin are low.

In terms of absolute values, the miniature cone data agree better with the Campanella and Robertson diagram than the Seed and Idriss version. In addition, as described in chapter two, Campanella and Robertson concluded that the Seed and Idriss method often yielded unconservative estimates for predicting liquefaction. This is evidenced in figure 5.12 since the laboratory cone data corrected by Campanella and Robertson plots lower than the Seed and Idriss corrected data. However, in both figures, the trend of the miniature cone data shows a sharper increase of the boundary curve with confining pressure than the field data. Basically, this means that, in some cases, the two field based procedures would predict the soil to be liquefiable, while the laboratory data suggests the soil cannot be liquefied.

Since the data for the preceding liquefaction correlations are field based, the existing confining pressures associated with the cone resistances are relatively high in comparison to those in the open model soil bin. The plot in figure 5.14 serves to demonstrate that the trend for the unmodified cone resistance values obtained under small confining pressures versus cyclic stress ratio are similar to the field based correlations. This may indicate that at low confining pressures the increase in tip resistance with shear stress ratio is actually sharper than indicated in figures 5.12 and 5.13. With more testing conducted under low confining pressures, it may be possible to define the low range of these existing correlations.

Because of the limited data base, it is not possible to draw definitive conclusions about the findings concerning liquefaction potential. It does appear that the subject needs additional research. Future testing in the calibration chamber which is presently under construction at Virginia Tech should help clarify the issues since larger confining pressures can be applied to the soil sample. This will allow results to be developed over the entire range of the liquefaction charts.

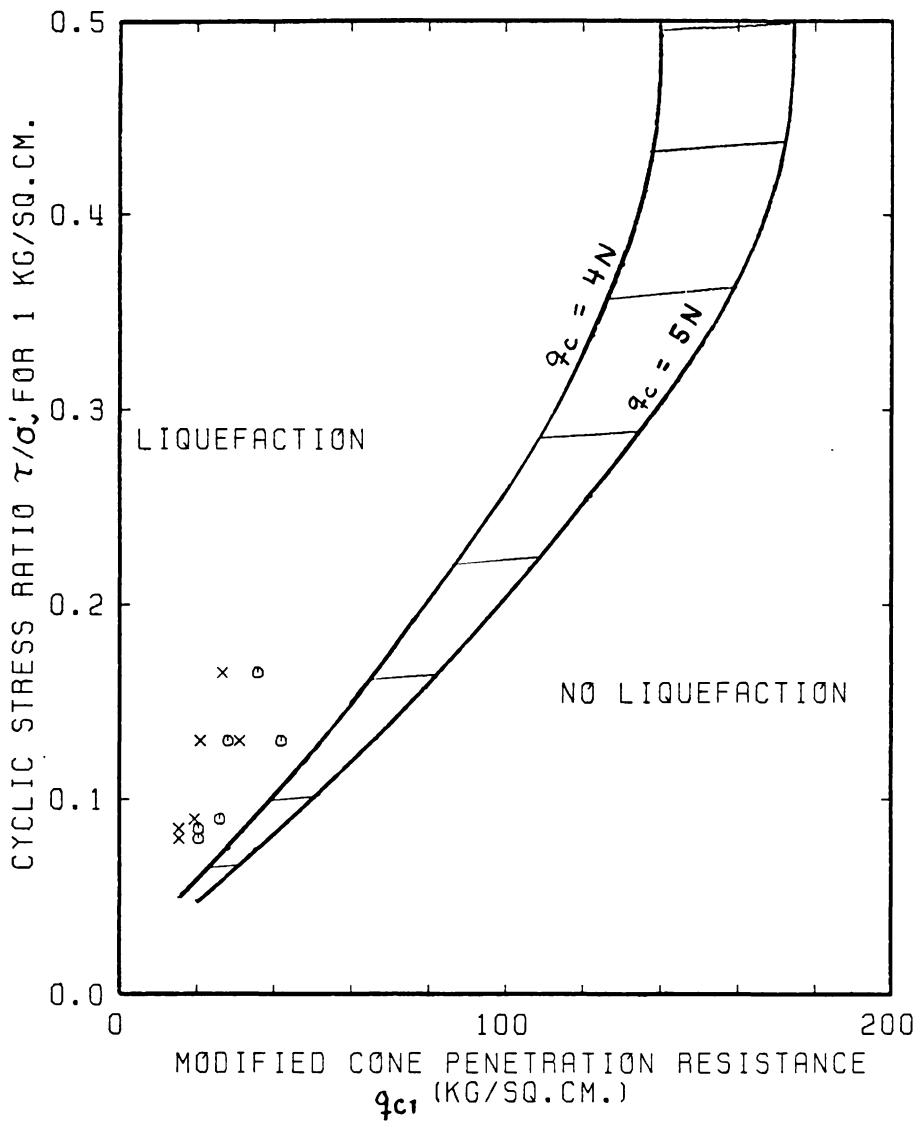
Table 5.5: (a) Modified Tip Resistance (after Seed and Idriss, 1983) and (b) Modified Tip Resistance (after Campanella and Robertson, 1983)

RELATIVE DENSITY (%)	TIP RESISTANCE (KG/SQ. CM.)	C_N	MODIFIED TIP RESISTANCE (KG/SQ. CM.)	τ_x / σ'_{vo}	CR
17	6.8	2.26	15.4	0.08	0.55
22	6.8	2.26	15.4	0.085	0.55
32	8.7	2.25	19.6	0.09	0.55
49	14	2.24	31.3	0.13	0.57
52	9.4	2.23	21	0.13	0.58
62	12	2.23	26.7	0.165	0.60

(a)

RELATIVE DENSITY (%)	TIP RESISTANCE (KG/SQ. CM.)	C_N	MODIFIED TIP RESISTANCE (KG/SQ. CM.)	τ_x / σ'_{vo}	CR
17	6.8	3	20.4	0.08	0.55
22	6.8	3	20.4	0.085	0.55
32	8.7	3	26.1	0.09	0.55
49	14.	3	42	0.13	0.57
52	9.4	3	28.2	0.13	0.58
62	12	3	36	0.165	0.60

(b)



CRITICAL BOUNDARIES SEPARATING LIQUEFIABLE FROM NON-LIQUEFIABLE CONDITIONS. PLOT IS VALID FOR CLEAN SANDS ($D_{50} > 0.25$ MM) AND IS BASED ON $q_c/N = 4$ TO 5

- | | |
|---|---|
| X | = SEED CORRECTED MEASURED TIP RESISTANCES |
| o | = CAMPANELLA & ROBERTSON CORRECTED MEASURED TIP RESISTANCES |

Figure 5.12: Proposed Correlation Between Liquefaction Resistance of Sands for Level Ground Conditions and Cone Penetration Resistance (after Seed et al., 1983)

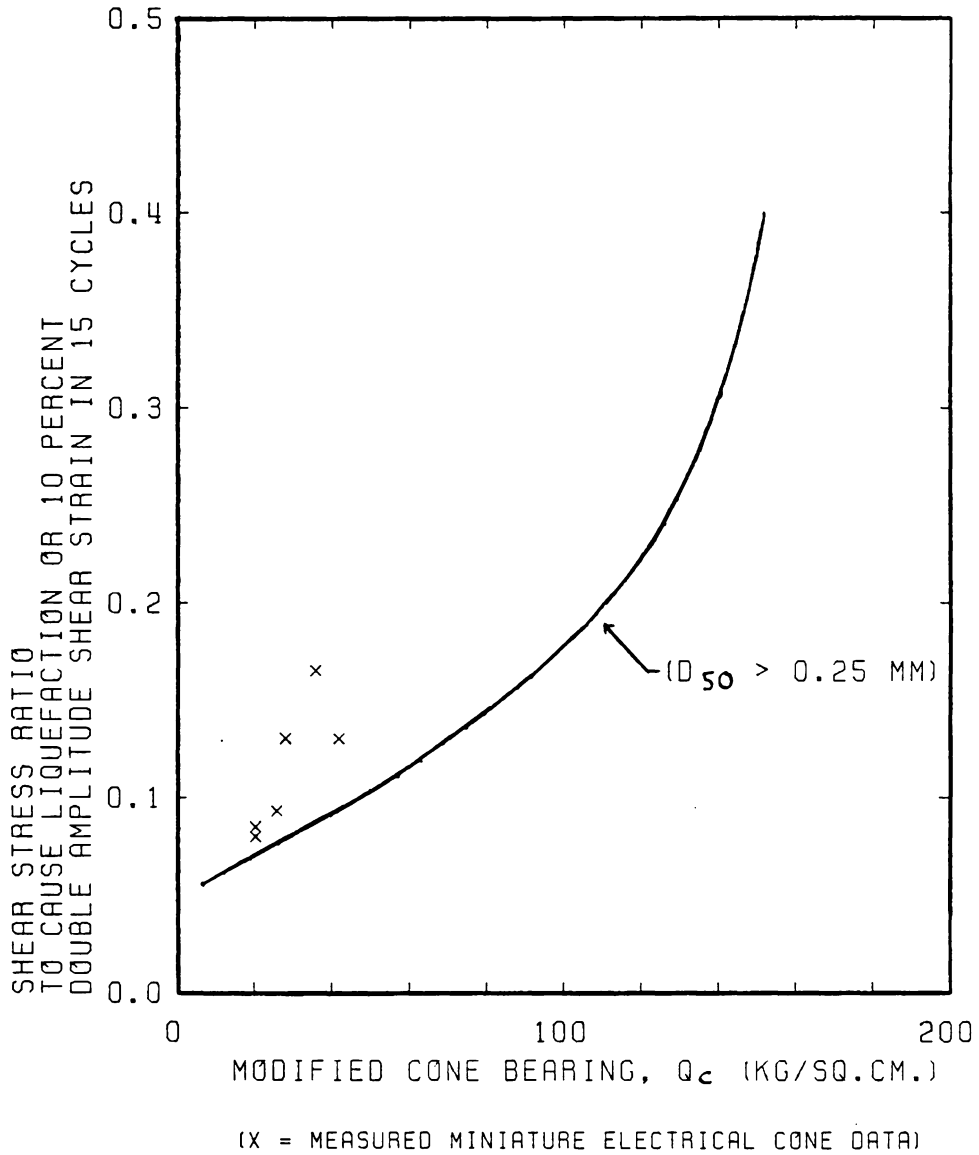


Figure 5.13: Proposed Correlation Between Liquefaction Resistance and Cone Penetration Resistance in Sands (after Campanella and Robertson, 1983)

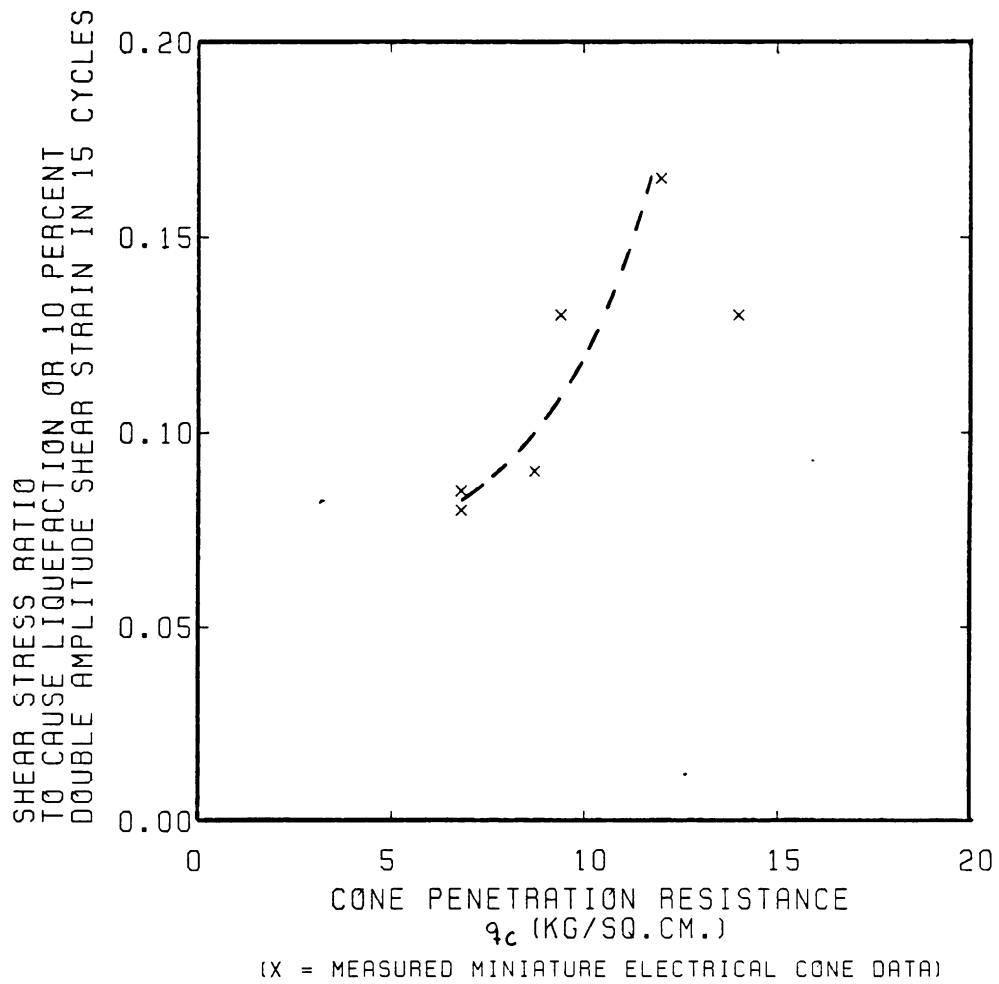


Figure 5.14: Results for Measured Miniature Cone Penetration Resistance and Liquefaction Resistance

6.0 SUMMARY AND CONCLUSIONS

The most widely used static cone penetrometer is the Dutch cone which is designed to operate from a drill rig and penetrate to great depths. Typically, the end bearing and sleeve friction are measured during penetration to provide data on soil engineering parameters useful for foundation and earth structure design. Most recently, the cone penetrometer has been used for liquefaction potential assessment. This thesis is directed toward the development of a miniature electrical cone penetrometer which can be employed for earthquake reconnaissance studies related to liquefaction. The basis for the miniature cone design stems from the need for studying earthquake zones where large scale equipment is not readily available; providing an economical and safe means for subsurface exploration; and, providing a demonstration device for short courses on in-situ testing.

The research involved performing a series of laboratory calibration tests in dry sand samples using a first-generation miniature electrical cone designed and machined at Virginia Tech. In order to conduct the test program, it was necessary to achieve a number of objectives.

1. Develop a system to automatically collect, process and plot the signals measured from the miniature electrical cone;

2. Develop an experimental scheme for performing cone calibration tests;
3. Evaluate the measured data in regard to the determination of conventional soil parameters; and,
4. Correlate the measured data to recently developed methods for predicting liquefaction.

Each of these objectives was successfully resolved. In the first case, an Apple II Plus microcomputer was combined with ISAAC analog-to-digital signal conversion devices to collect test data. Applesoft BASIC programs were written to read in two channels of millivolt magnitude signals for the cone tip and friction sleeve and one channel of volt magnitude signals for a position transducer used for monitoring the cone depth. The signals are read continuously with depth by the ISAAC and are stored in the 48K memory of the Apple II. At the end of penetration, the program stops collecting the electrical signals and begins processing them. Finally, a scheme was developed to display specific sets of data such as for plot comparisons between tests performed in a single sample or between tests conducted in various samples.

The experimental calibrations were performed in an open 2 foot square by 4 foot tall bin filled with Monterey sand No. 0/30 as the test medium. Monterey sand No. 0/30 was selected for calibrating the cone because data concerning its behavior and its liquefaction response are available. Dry

sand samples of uniform and layered relative densities were created using a pluviation technique.

The results from the cone tests were compared to previously obtained miniature mechanical cone data, as well as to other existing resistance relationships. In addition, the results were applied to available methods for predicting soil properties such as for obtaining the angle of internal friction. Finally, test data were used in evaluation of recently developed correlations for predicting liquefaction potential.

The actual testing program consisted of more than 60 cone calibration tests in 10 samples which included 36 uniform and 24 layered tests. The results of this program are listed below:

1. The data plots of the miniature electrical cone penetrometer tests are typical of standard cone resistance versus depth plots;
2. Tests performed per sample reveal repeatability of the resistance data;
3. A comparison of tests for all samples show similar trends for resistances versus depth;
4. The data from the miniature electrical tests are relatively consistent with previously performed miniature mechanical tests;

5. Increasing the sample density increases the magnitude of the resistance;
6. The miniature electrical cone is able to sense variations of relative density within the soil samples as evidenced in the samples with layered densities;
7. The values for friction angle established from laboratory triaxial testing provide the basis for evaluating friction angle values calculated from measured tip resistances;
8. The measured resistance data plots on the low end of the available liquefaction correlations due to small vertical stresses developed in the model soil bin; and,
9. The available field-based liquefaction correlations suggest that the general magnitude of the measured miniature cone data are similar but the trend increases more sharply.

The results of testing in both the uniform and layered samples lead to the following conclusions:

1. The developed data acquisition system fulfilled the requirements for this thesis. Thus, the system can be used for further investigations; including, schemes requiring several data channels.

2. The open model soil bin provided more of a qualitative than quantitative means for evaluating the utility of the miniature electrical cone because of the low confining pressures.
3. A miniature electrical cone yields data consistent with standard electrical cone data.
4. The miniature cone is sensitive to variations in relative density within a soil and is possibly more sensitive than a standard cone because of its smaller size.
5. Additional research encompassing a greater stress range is required to evaluate the trend and magnitude of test data in regard to existing liquefaction correlations.

The test results serve to demonstrate that the miniature electrical cone is comparable to the standard electrical cone and should therefore provide a useful tool for investigating soil. Further research is warranted using a more sophisticated soil chamber and an improved cone design to establish the utility of the cone as a means for predicting liquefaction.

APPENDIX A: THE DATA ACQUISITION SYSTEM

Contents of the ISAAC/Apple II User's Guide

THE DATA ACQUISITION SYSTEM

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APPENDIX: Calibration Factors and Constants for the Miniature
Electrical Cone Penetrometer (Generation 1)

APPENDIX A. THE DATA ACQUISITION SYSTEM

A.1 HARDWARE

The data acquisition system developed for the miniature electrical cone penetrometer consists of the following equipment:

- ISAAC 91A 12-bit analog to digital conversion board
- ISAAC I-130 Preamp Interface
- ISAAC I-140 Preamp System
- Apple II Plus microcomputer (48K memory)
- Single disk drive
- Screen monitor
- Floppy disks
- Epsom FX-80 dot matrix printer
- University mainframe computer system

The ISAAC system is a high performance data acquisition system which is compatible with the Apple II minicomputer. The principal components of ISAAC hardware are the 91A mainboard, the ISAAC/Apple Interface card, and the input/output (I/O) distribution panel. Plugging the ISAAC/Apple Interface card into a peripheral or expansion slot of the Apple II provides the communication and power link between the ISAAC and the Apple, thereby enabling the Apple to collect voltage signals.

A.1.1.1 The ISAAC 91A

The ISAAC 91A is a unit which receives signals from an outside source. It has the capability to input and output analog or binary signals via a number of different channels. The input and output signals range in value from -5 to +5 volts. The actual I/O connections are made to the 91A distribution panel which consists of a series of screw terminals on the green distribution board.

The application of the ISAAC system to the miniature electrical cone penetrometer concerns collecting analog signals. The strain gage load cell signals from the cone are millivolts; whereas, the associated position transducer signals are volts. Since the position transducer outputs signals in volt units, it is wired directly into the distribution panel of the 91A. However, since the cone outputs signals in millivolt units additional ISAAC hardware is required.

A.1.1.2 The I-130 Preamp Interface and the I-140 Preamp System

The ISAAC system contains a number of devices which are incorporated into the 91A through expansion slots. The devices utilized for the cone are the I-130 Preamp Interface and the Preamp System.

The I-130 interface module is an input/output device designed by Cyborg, Inc. primarily to operate with the I-140. The intended use of the I-130 is to provide channel selection logic and 12-bit analog to digital conversion for the I-140 Preamp System. The I-140 Preamp is the "front end" for the I-130. The I-140 amplifies the signals not large enough for direct measurement by the 91A. The signals supplied or input by the I-140 range from ± 5 millivolts to ± 100 millivolts.

The I-130 is a card inserted into an expansion slot of the 91A, whereas, the I-140 system consists of a single housing. Systems installed in a housing draw their power through the I-130. With several I-140 cards connected to each other, the system may provide up to 64 channels of input. The cone research currently uses two channels of one four-channel I-140 housing for receiving millivolt signals from the tip resistance strain gage load cell and from the friction sleeve strain gage load cell. Future research will involve more sophisticated calibration chamber equipment which will require more data collection capability than the three channels presently recorded.

A.1.2 System Assembly

This section will describe how to connect the data acquisition together and how to wire the cone and the depth transducer into the ISAAC data acquisition system. In addition to the data acquisition components, the user must obtain one 10-volt DC power supply and one pair of electrical leads with alligator clips.

The connections required for the data acquisition system in figure A.1 are described below. Starting with the Apple II, the ISAAC/Apple interface card is placed into peripheral slot 6, the disk drive control card into slot 7, the Hayes micromodem card into slot 4, and the Epsom printer control card into slot 2 or any other vacant peripheral slots. Finally, the I-130 pin-ended cable is connected to the I-140 housing and the I-130 card is inserted into expansion slot 1 of the 91A.

Figures A.2 through A.4 show how to wire the cone penetrometer and the position transducer into the ISAAC system. First consider the position transducer. Four wire leads encased in shielded cable housing connect to the position transducer through a standard military style multi-prong connector. At the opposite end of the housing are red, black, green, and white lead wires. Red is for positive excitation and black is for negative excitation. The black and red wires are wired into the power supply. The green wire is common with the black and it transfers negative signal. The white wire is for positive signal. Referring to figure A.2, which pictures only the analog portion of the 91A distribution

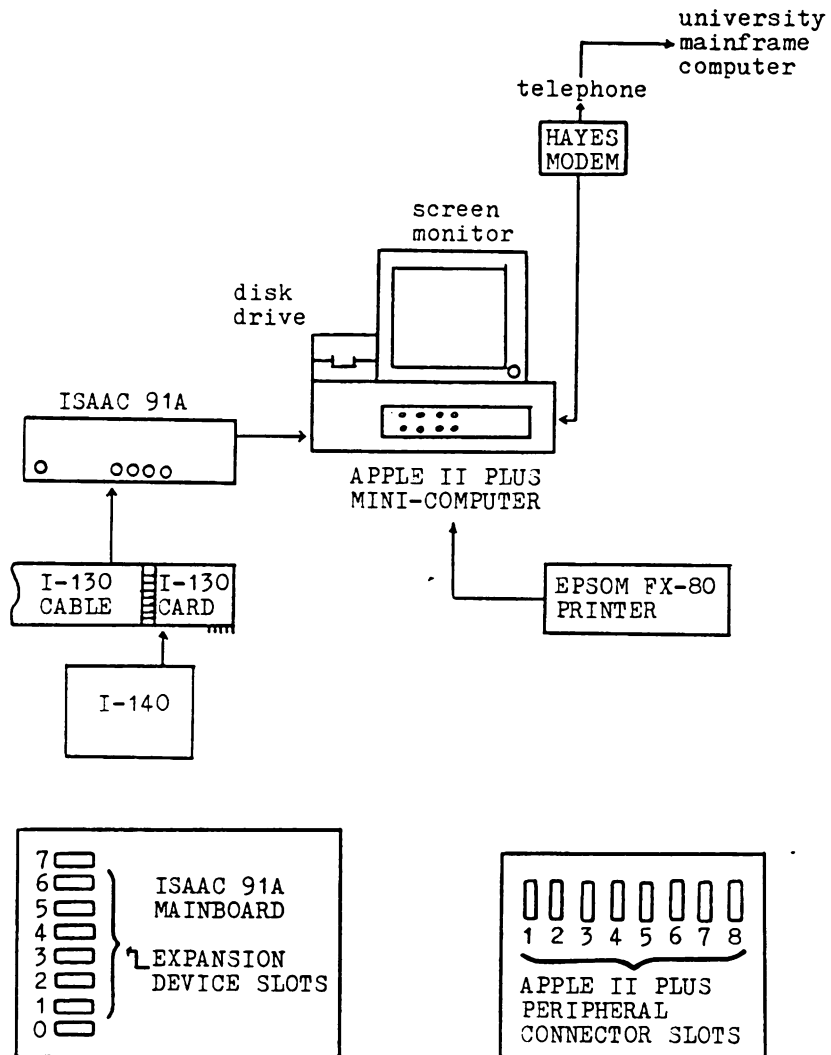


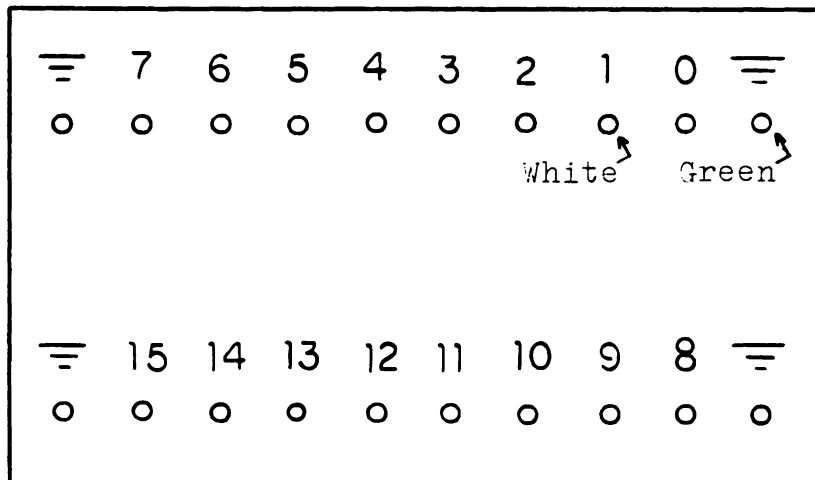
Figure A.1: The Data Acquisition System

panel, the green wire is plugged into the ground screw terminal (to the right of channel zero). Since the program is written to read in from ISAAC channel 1, the white wire is plugged into screw terminal 1.

The wiring of the cone penetrometer consists of two four-arm wheatstone bridge strain gages. Since one gage requires four wires and there are two gages, collectively there are eight wires leading out of the cone. The cone outputs millivolt signals; therefore the signal leads are plugged into the I-140 housing as pictured in figure A.3. (Notice the positions of the dip switch control settings.) In this case, the green wires represent positive signal and the white wires negative. The tip resistance gage is designated as channel 0 and the friction sleeve gage as channel 1. Also notice in figure A.3 that each channel is represented by four pins or screw terminals. The green, positive wires are plugged into screw terminal 1 and the white, negative wires are plugged into screw terminal 4. The negative signal wires are always referenced to analog ground. The red and black excitation wires are wired with the red and black from the position transducer since the power for the entire system is supplied by one 10-volt DC power supply. The entire wiring scheme is shown in figure A.4.

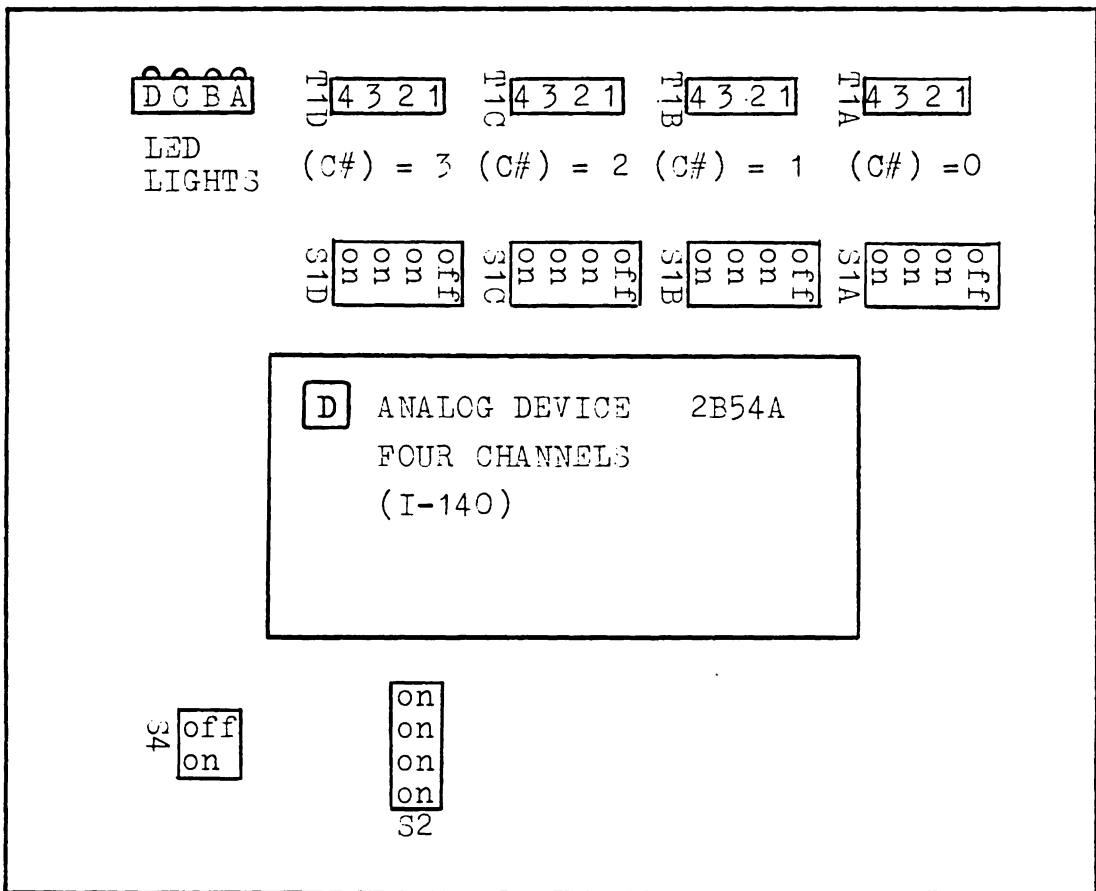
A.1.3 How The System Works - System Interaction

The system interaction is best addressed by following the previously described data acquisition process, illustrated in flowchart form. For convenient reference, the flowchart is repeated in figure A.5. Figure



numbers = channel numbers
 o = screw terminals

Figure A.2: ISAAC 91A Distribution Board (The A/D Conversion Portion)



T1 boxes = pins or terminals

S1 boxes = dip switches

Note: The LED lights monitor channel selection activity.

Figure A.3: The I-140 ISAAC Peripheral Device

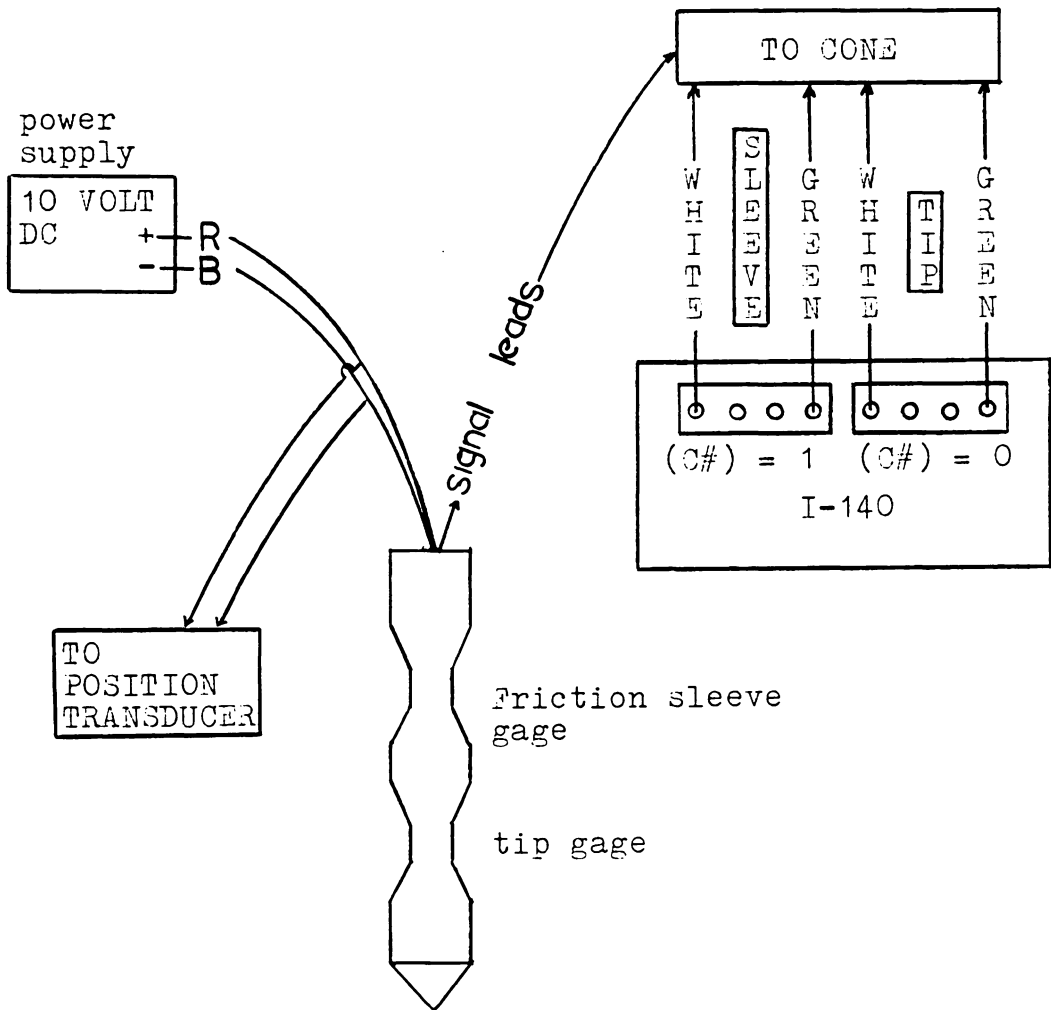


Figure A.4: Wiring Scheme for Miniature Electrical Cone Testing

A.5 clearly indicates how the data acquisition equipment interacts with the exception of the Hayes microcoupler. The purpose of the microcoupler or modem is to provide the link, via telephone line, to the mainframe computer. The link occurs in phase 5. If the data from cone testing is valid, the user converts the Apple II into a terminal to send the data, which is stored on a floppy disk in a text file, to the university mainframe computer. The data is edited within the user's account and then submitted following a FORTRAN plotting program to obtain a plot.

A.2 SOFTWARE

Attention is now directed toward the software. The example procedure for operating the data acquisition system described in the thesis body is sufficient for performing cone penetrometer tests. However, the procedure did not detail why the system works; that is the purpose of this appendix. This is to provide a starting point for modifying the existing programs or writing new ones without having to extensively research the ISAAC and Apple II manuals.

A.2.1 Disk Operating System (DOS)

The programs controlling data acquisition and the collected data are stored in files on floppy disks. The following section describes how data is placed on and obtained from the disks.

THE FIVE PHASE DATA ACQUISITION SYSTEM

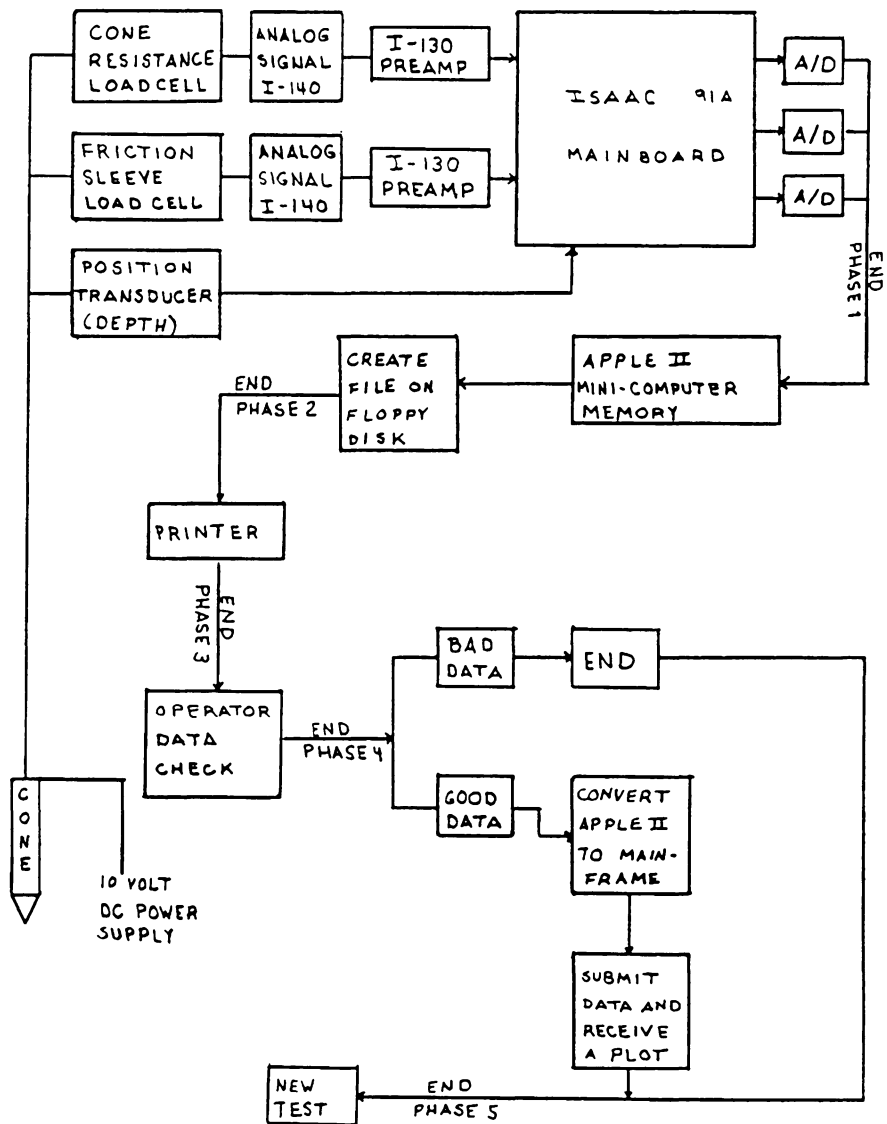


Figure A.5

A.2.1.1 Booting the System

For each programming session at the Apple II, the following steps are performed:

1. Place the SYSTEM MASTER disk (or a previously initialized disk) into the disk drive and close the drive door.
2. Turn on the Apple II power (back of unit on the left).
3. Turn on the screen monitor.

Note: If the power is already on, proceed with step (1), type PR#6, and press RETURN.

After following these steps, the disk drive will engage and a red light indicator will turn on. Caution: never remove a disk from the drive when the red "in use" light is on as this could permanently damage the disk and destroy all the information on it. When the red disk drive light goes out and the monitor comes back with a blinking box cursor, then the disk operating system (DOS) commands are successfully stored in the computer memory. This procedure is called "booting" the system.

Similarly, the Labsoft Master disk must be booted to enable the Apple II to access the ISAAC system. To boot Labsoft:

1. Place the Labsoft Master disk into the disk drive
2. Type PR/#6 and press RETURN.

When the red indicator light goes out and the monitor comes back with the Labsoft logo and a blinking prompt signal, then the Labsoft extension language is installed in the Apple II memory.

The ISAAC/Labsoft/Apple system is now ready for use. When beginning a new session, it does not matter which disk is booted first. The most efficient method is to boot the system with Labsoft and then to work with a disk previously initialized with Applesoft BASIC. Also, if the power of the system is shut down for any reason then the system must be booted again since Labsoft is stored in temporary memory.

A.2.1.2 How to Initialize a New Disk

Every time a new disk is used, it must be initialized. The procedure of initializing is performed once per disk and it is the only time the INIT command is used. The procedure is described below. First, boot the system with the Applesoft BASIC System Master disk. Remove the System Master disk and replace a new blank disk into the drive. Type NEW, press RETURN, and then type any simple "greeting" program. For example,

```
5  REM GREETING PROGRAM
10 PRINT "HELLO"
15 END
```

Then type INIT HELLO and press return. The red "in use" light will come on. For the 30 seconds that the light is on the computer is transferring numerical information onto the disk to enable the computer to later find file storage locations on that disk. In addition, the process allows the disk to automatically boot Applesoft BASIC into the computer memory such that the Applesoft master disk is not needed. When the light goes out, the disk is initialized.

It is important to note that if the INIT command is typed while a disk with existing files on it is in the disk drive, and RETURN is pressed, then all the information stored on that disk will be destroyed.

A.2.2 How Files are Organized on the Disk

The Apple II computer stores programs or data on the floppy disk in four different types of files. The first type contains Applesoft BASIC program files, marked "A". The second type are Integer BASIC program files, marked "I". The third type holds binary information, marked "B". And, the fourth file is a text file, marked "T".

Two types of files of concern in the miniature electrical cone penetrometer research are the Applesoft BASIC, (A), file and the text, (T), file. The A files are the working programs which tell the ISAAC and the Apple to collect data and perform calculations. The T files store the data collected by the A files. T files do not contain computer commands.

A.2.3 How to Look at the Files on a Disk

Assuming the system is booted, type CATALOG. The disk drive will come on and then a listing of all the files on that disk will appear on the screen monitor. Each line contains a single letter which identifies the file type as A, B, I, or T; a three digit number indicating the file size; and the file name. Typing CATALOG lists the files in the order in which they were created.

A.2.3.1 How to Access an Applesoft File

Applesoft BASIC, A, files are programs. For consistency, A files will be referred to as the programs. To look at any program listed in the catalog, type LOAD PROGRAM FILE NAME. The red "in use" light will go on as the computer searches the disk for that program. Once the program is loaded it can be RUN which causes immediate program execution or it can be looked at by typing LIST. The user may look at only part of the program by typing LIST 100,150, for example, which lists only lines 100 through 150 in the program. If any of the lines are changed, added or deleted to modify the program, then the command SAVE will replace the new information in the program and save it.

A.2.3.2 How to Access a Text File

The commands, LOAD, LIST, RUN, and SAVE, used to manipulate A files are not applicable to text files. Any attempt to use them results in an

error message. Text files must utilize DOS commands from within a program. Thus, a separate program is required to access a text file.

The program written to store information on a disk in a TEXT file or to retrieve information from the disk in a TEXT file uses the keys CONTROL and D pressed simultaneously. CONTROL-D tells the computer to access the disk rather than the screen. There are various methods to inform the computer that CONTROL-D is going to be used. The easiest method is to write the following equation at the beginning of a program:

$$D\$ = \text{CHR}\$(4)$$

The statement equates the string variable D\$ to CONTROL-D. CHR\$(4) is the code that the Apple II reads as CONTROL-D. To explain in minor detail, ASCII is the code used by the Apple and most other microcomputers. It sets a hexadecimal or a decimal value to all characters typed by the keyboard. The decimal value for control "D" is 4. In addition, since typing control and D at the same time on the keyboard results in non-printable characters, Applesoft BASIC has reserved the characters "CHR\$" to display the non-printing characters. Thus, whenever the program sees a statement followed by D\$ the disk rather than the screen will be accessed. In addition to D\$, the text files primarily use four DOS commands: OPEN, CLOSE, READ, and WRITE. The WRITE command adds information to an existing file or creates a new file. READ is used to see or read the information contained in the TEXT file. Before a file is written or read, it must first be opened with the OPEN command. After working with the file the CLOSE command closes that file as well as any other file that is open.

In an OPEN-WRITE-CLOSE sequence, the data or information written in the text file is preceded by a PRINT command. This sequence puts the data onto the disk. The OPEN-READ-CLOSE sequence reads back what was written on the disk. The command INPUT brings a copy of the information in the text file into the computer and stores it in a memory location labeled by a variable. Thus, for every PRINT statement following WRITE there should be an INPUT statement following READ. For example, consider the following sample program.

```
20 D$ = CHR$(4) REM DOS CONTROL-D
40 PRINTD$;"OPEN CONE DATA FILE"
60 PRINTD$;"WRITE CONE DATA FILE"
80 PRINT "THIS IS A SAMPLE DATA FILE"
100 PRINTD$;"CLOSE CONE DATA FILE"
120 PRINTD$;"OPEN CONE DATA FILE"
140 PRINTD$;"READ CONE DATA FILE"
160 INPUT SP$
180 PRINTD$;"CLOSE CONE DATA FILE"
200 PRINT SP$
```

Line 20 sets the string variable D\$ equal to the ASCII value for CONTROL-D. The colon symbol allows more than one BASIC command to be written on one line. REM is a non-executable statement meaning remark in BASIC. Line 40 begins with PRINTD\$ which tells the computer to access the disk. A file named CONE DATA FILE is opened if it already exists; otherwise it is created. Line 60 tells the computer to add information to the file, CONE DATA FILE, with a WRITE command. Line 80 tells the computer what to write in the text file. Line 100 closes CONE DATA FILE.

To read back what was written, line 120 reopens CONE DATA FILE. Line 140 is the same as line 60 only in this case CONE DATA FILE is read. Line 160 is the first (and in this case, the only) input statement in the READ sequence corresponding to the first (and only) print statement in the WRITE sequence. Note that SP\$ is the string variable placed into the computer memory and represents the phrase "This is a sample data file". Line 180 closes the file. If this program were RUN, the result of line 200 would cause the statement "THIS IS A SAMPLE DATA FILE" to appear on the screen.

In sum, there are four types of Apple files. The two applicable for the cone penetrometer are the Applesoft BASIC (A) file and the TEXT (T) file. A files are straightforward and easy to access. Text files are more complicated and are accessed only through a program. For an in depth explanation concerning TEXT files, refer to "Apple Files", by David Miller (1982).

A.3 COMMANDS TO FACILITATE DATA ACQUISITION AND CONTROL I/O OPERATIONS

The Apple II is a versatile computer with a 48K memory, an efficient disk operating system and a BASIC programming language. The Apple II, however, was not originally designed as an effective data acquisition system. Thus, the ISAAC analog to digital conversion components manufactured by Cyborg, Inc. were developed to complement the Apple and enable

data collection. This meant that the Apple II had to install an additional set of commands into its memory. The commands for the ISAAC data acquisition are recognized by an ampersand symbol (&). In a program, when Applesoft reads the ampersand the computer jumps to a certain memory location. Assuming the Labsoft Master disk is booted, the Apple controls the ISAAC through a language called Labsoft. Booting the Labsoft Master disk places the Labsoft commands into the ROM or temporary memory of the Apple.

Before examining the programs written for the data acquisition system, a review of some critical and commonly used Applesoft BASIC commands as well as some structural and syntactic requirements for Labsoft are initially presented.

A.3.1.1 Applesoft BASIC Commands

The following is a list of frequently used commands. It is not worthwhile to define all commands since documents of this nature are readily available. One of the best references is the "Applesoft Programming Reference Manual".

CATALOG provides a list of every program or file stored on a particular disk

LIST lists every line in a particular file. Type LIST and press return. Use Control-S and the key "S" to stop and start the listing

- or list only part of the program. (ie: LIST 5,10 lists only lines 5 through 10)
- LOAD** puts a program stored on a disk into the computer memory. (ie: Type LOAD FILE NAME)
- NEW** clears the computer memory of any previous programs so that a new program can be created.
- REM** a non-executable statement. Stands for remark and represents a common statement used to aid the programmer.
- RUN** executes the program.
- SAVE** save places a new or existing file onto the disk.

A.3.1.2 Labsoft Commands and Parameters

One of the differences between a line of Applesoft code and Labsoft code is that a Labsoft command is followed by one or more parenthetical expressions. The Labsoft commands control input/output operations. The function of parameters within the parenthesis are dependent on the command which precedes them. The parameters and commands defined below are utilized in the cone penetrometer data acquisition system. More detailed explanations and further applications are provided in the "ISAAC User's

Guide" and the "Labsoft Reference Manual" written by Cyborg to accompany the ISAAC system.

Labsoft Parameters

{C#} specifies a channel number of an ISAAC I/O device (ie: (C#)=0)

{D#} device number. Specifies to ISAAC which expansion slot in the 91A the peripheral device is installed in.

{FU} specifies a function in equation form which is evaluated in terms of raw I/O values. The (FU) parameter when combined with Applesoft's define function command, DEF FN, outputs the values as + or - voltages. This will be explained in a later section.

{RT} sampling rate at which I/O commands are executed
(milliseconds-per-execution)

{SW} number of I/O sweeps of samples to be taken in a matrix operation.

{TV} the integer or target variable into which input values are stored.

Labsoft Commands

& AIN,(TV) reads an analog signal and stores the value in the variable
(TV)

& ASUM,(TV) reads an analog signal and sums it with the current value of
(TV)

& BEEP beeps ISAAC's internal speaker for 0.1 seconds

& PAUSE pauses program execution for a user specified number of seconds and tenths of seconds

A.3.2 Sample Data Acquisition Program

The miniature electrical cone penetrometer data acquisition program collects analog signals. The following example program demonstrated how the Labsoft commands and parameters are combined to collect these signals. The program is a simple program written to read in only one channel of signals.

```
10 REM SIMPLE AIN
20 DEF FN VOLTS(X) = ABS(X/20.48-100)
30 & AIN,(TV)=Q,(C#)=0,(D#)=1,(FU)=FNVOLTS(RAW%)
40 PRINT Q:"VOLTS"
50 GOTO 30
```

LINE TRANSLATION

- 10 Remark. A non-executable statement reminding the user that this is a simple program for ISAAC to read in analog signals. Using Labsoft's (FU) parameter and Applesoft's DEF FN command, the equation for FU represents the linear translation of the computer's digital values to + or - analog values. (Refer to the next section)

- 20 Using Labsoft's (FU) parameter and Applesoft's DEF FN command, the equation for FU represents the linear translation of the computer's digital values to + or - analog values. (Refer to the next section.)

- 30 Line 30 accomplishes several tasks:
 1. Reads in an analog value from an ISAAC expansion device which is connected into expansion slot number 1 on the 91A mainboard. The incoming analog value is read from channel number 0.

 2. Stores the value in target variable Q.

 3. Provides for the value to be displayed as a + or - voltage. (RAW%) is a reserved Labsoft variable and represents the raw input voltage value collected by an input command.

- 40 Line 40 prints the value of Q.

A.3.3 Interpreting I/O Signals

The ISAAC system is designed with the option of receiving or outputting either binary (digital) signals or analog signals. The only signals the ISAAC understands are digital signals which are represented by an integer number. Therefore, any incoming analog signals are converted to digital. The ISAAC 91A mainboard can act as an analog-to-digital converter and a digital-to-analog converter. Both converters are 12 bit boards with a range of -5 to +5 volts. A 12 bit system has digital numbers ranging from 0 to 4095. The conversion from digital to analog is a linear relationship. In equation form:

$$\begin{aligned}\text{Voltage Analog Value} &= f(\text{digital value}) \\ &= \text{digital value}/20.48 - 100\end{aligned}$$

In the normal + or - 5 volt configuration, a digital value of 0 sets the output of the ISAAC D/A converter to -5 volts, a digital value of 2048 sets the output to 0 volts, and a digital value of 4095 sets the output to +4.997 volts.

A.4 PROGRAMS CONTROLLING DATA ACQUISITION

The following section describes the programs written for electrical cone penetrometer data acquisition. The section begins with the filename and a short description for each Apple II BASIC program, as well as for each mainframe FORTRAN program. Next, a list of variables and a de-

scription for the execution of the BASIC programs is presented. Finally, a list of variables and a description of the execution of the FORTRAN plot routines is included.

List of Programs

Applesoft BASIC Programs:

1. ISAAC - takes rapid readings from two channels of the I-140
2. ISAACPT - takes rapid readings from one channel of the I-140 and one channel of the 91A distribution board
3. ASUMCALCS - program records cone resistance and friction sleeve millivolt readings with the I-140. Also, calculates a computer generated depth, a friction ratio, vertical stress and dimensionless parameters for relative depth, D/B , and tip resistance, q_c/B .
4. PTCALCS - program records cone resistance from the I-140 and depth from the position transducer taken in by the 91A. Calculations are the same as in (3) with the exception of friction ratio.
5. ASUMLAYERS - program records cone resistance and friction sleeve values with the I-140. Calculates a computer generated depth only.

6. MINI - calibration program for the miniature electrical cone. Reads two channels from the I-140.
7. PTCAL - calibration program for the position transducer. Reads one channel of the 91A distribution board.
8. FUGRO - calibrates cone resistance of a standard electrical cone from one channel of the I-140.

Mainframe FORTRAN Plot Programs:

1. OWNPLOT FORTRAN - plots the test results obtained from one homogeneous sample.
2. LAYER FORTRAN - plots the test results obtained from a three layered sample. Also, for a two-layer sample the program is modified to 2LAYER FORTRAN.
3. COMPARE FORTRAN - comparison plot. Plots all test 1 (or the designated representative test) values from each homogeneous sample.
4. FUGRO FORTRAN - compares standard cone to miniature cone test data.

A.4.1 Constants, Variables and Arrays in the Applesoft BASIC Programs

(Note that the calibration programs appear in appendix 2)

Arrays

TEST(I,N) = two-dimensional array specifying channel number and number of readings per channel

TEST(0,J) = channel number 0 in the I-140, representing cone tip millivolt readings

TEST(1,J) = channel number 1 in the I-140, representing friction sleeve millivolt readings

TEST(0,J) = channel number 0 on the 91A distribution board, representing position transducer volt readings

CNDEP(N) = computer generated depth of penetration
= DEP + CNDEP(J-1) where: CNDEP(0) = DEP + 3.95

CR(N) = cone point resistance (psi)
= (TEST(0,J) - ICVOLT) * CLC/AC

TRANS(N) = depth of penetration from the position transducer (in.)
= (TEST(0,J) - IPVOLT) * PTC

FS(N) = sleeve friction (psi)
= (TEST(1,J) - FIVOLT) * FLC/AF

FR(N) = friction ratio (%)
= (FS(N)/CR(N)) * 100

VS(N) = vertical stress (psf)
= GAMMA * TRANS(N)/12.

XDM(N) = dimensionless resistance factor (q / B)
= (CR(J)/GAMMA * B) * 1728

YDM(N) = relative depth
= TRANS(J)/B

Constants and Variables

A5‡ = prompt variable to begin testing

AC = area of cone (sq. in.)

AF = area of friction sleeve (sq. in.)

B = diameter of cone (inches)

CLC = cone load cell calibration factor (lb/millivolt)

C\$ = prompt variable to start printer

DEP = number of inches per computer reading (in./reading)

D\$ = DOS Control-D character

FIVOLT = initial friction sleeve voltage reading (millivolts)

FLC = friction sleeve load cell calibration factor (lb/millivolt)

FLNAM\$ = data file name specified by user. Each data file must have a unique name.

GAMMA = unit weight of sand sample (pcf)

ICVOLT = initial tip resistance voltage reading (millivolts)

IPVOLT = initial depth transducer voltage reading (volts)

J,I = counter variables

N = number of readings per test

OPT = prompt variable. Type 1 to run program, type 2 to print text file.

PR = rate of cone penetration (in./sec)

PTC = position transducer calibration factor (in./volt)

TD\$ = date of test

YES\$ = prompt variable. Type Y for yes, print the data; type N for no and the program ends.

A.4.2 Execution of the Applesoft BASIC Data Acquisition Programs

A.4.2.1 Programs ISAAC and ISAACPT

The purpose of the program ISAAC is to obtain rapid voltage readings from the cone tip and the friction sleeve strain gages on the miniature electrical cone penetrometer. Since both gages do not begin voltage readings at zero under no load, the initial voltage values must be determined prior to cone testing. Similarly, program ISAACPT obtains initial voltage readings for the cone tip strain gage and the position transducer.

For both programs, the only input required is to type RUN; type N, the number of desired readings; and press RETURN. Line 4 dimensions an array informing the computer to provide sufficient memory space for storing two channels containing N data values each. Line 10 defines a function calculated for every value read; it converts the computer's

digital value (a number in the range of 0 to 4095) to an analog value (millivolts).

The millivolt analog values are read in (& AIN) from channel 0 ((C#) = 0) of the I-140. The I-140 is connected to the I-130 and the I-130 is plugged into expansion slot number 1 of the 91A, ((D#) = 1). The voltage value is stored in variable Q. The loop in lines 20, 40, and 50 is a dummy loop. At the time this research was performed, the I-140 unit would not switch channels properly unless the same channel was programmed to read twice. The second reading is the desired reading. Thus, the loop tells the computer to read a channel, then it sets that reading to zero and tells the computer to read the channel again. The program records the valid voltage reading in variable Q, places Q into the array TEST(0,J), and proceeds to the next channel. Only the I-140 device is read this way.

Line 70 is where ISAAC and ISAACPT begin to differ. Lines 70 to 110 in ISAAC are the same as lines 20 to 60. Lines 70 to 110 in ISAACPT represent a direct depth voltage reading from channel 1 of the 91A. Since the units are volts, a new conversion function is defined in line 80. Line 120 prints all the recorded voltage values on the screen.

These programs provide the initial voltage values required for the data acquisition programs: PTCALCS, ASUMCALCS, and ASUMLAYERS. To begin testing, the cone is inserted through the rod guide template until only the drive rod is showing above the template. This is the time to LOAD ISAAC (or ISAACPT), RUN the program, and observe the voltages. Once the

readings stabilize, they are recorded into a notebook. Programs ISAAC and ISAACPT are listed in figures A.6 and A.7.

A.4.2.2 Programs ASUMCALCS, ASUMLAYERS, and PTCALCS

Each of the data acquisition programs are similar. ASUMCALCS and ASUMLAYERS both read two data channels for the cone tip resistance and sleeve friction. Program PTCALCS is a modified version of ASUMCALCS which incorporates reading a channel for a position transducer. Since the friction values recorded when PTCALCS was written were erratic, the friction sleeve channel was eliminated. However, each of the three programs follow the same format and are explained below.

The first line in each program is line 100 which prints a simple title on the screen monitor. Lines 101-110 dimension all the arrays in the programs. Notice that for the two-dimensional array the number of data collecting channels appears to be one. However, because the internal counters of the computer start at zero, the two-dimensional array TEST(1,N) actually samples two channels of data. Similarly, N, the number of samples, represents N-1 samples. For example, in the two-dimensional array (1,35) two channels actually read in 36 samples each.

In line 120, D\$ defines control character "D" to enable DOS (disk operating system) command execution. The name of the file accessed by control-D is the one selected in line 130. As suggested previously, a filename representative of the test is easiest to remember. For example,

```

3 INPUT "NUMBER OF READINGS: ";N
4 DIM TEST(2,N)
5 FOR J = 0 TO N - 1
10 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
20 I = 0
30 & AIN, (TV) = 0, (D#) = 1, (C#) = 0, (FU) = FN VOLTS(RAW%)
40 I = I + 1
50 IF I < 2 THEN GOTO 30
60 TEST(0,J) = 0
70 I = 0
80 & AIN, (TV) = 0, (D#) = 1, (C#) = 1, (FU) = FN VOLTS(RAW%)
90 I = I + 1
100 IF I < 2 THEN GOTO 80
110 TEST(1,J) = 0
120 PRINT TEST(0,J),TEST(1,J)
130 NEXT J

```

Figure A.6: BASIC Program ISAAC

```

3 INPUT "NUMBER OF READINGS: ";N
4 DIM TEST(2,N)
5 FOR J = 0 TO N - 1
10 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
20 I = 0
30 & AIN, (TV) = 0, (D#) = 1, (C#) = 0, (FU) = FN VOLTS(RAW%)
40 I = I + 1
50 IF I < 2 THEN GOTO 30
60 TEST(0,J) = 0
70 DEF FN VOLTS(X) = ABS (X / 81.88 - 25)
80 & AIN, (TV) = 0, (C#) = 1, (FU) = FN VOLTS(RAW%)
110 TEST(1,J) = 0
120 PRINT TEST(0,J),TEST(1,J)
130 NEXT J

```

Figure A.7: BASIC Program ISAACPT

the file named SERIES152 interprets as test 1 in a homogeneous 52% relative density sample.

Lines 150-200 are those instructing the computer to either collect data and create a disk file or read data from an existing file and print it.

Line 206 requests the current date. The corresponding input specifies month-day-year.

Lines 210-281 are computer prompted statements. Each line prompts the user to input calibration factors and constants and calculation constants. The calibration factors and constants include: cone tip area, cone tip calibration factor, initial cone tip voltage (the recorded value from ISAAC or ISAACPT), friction sleeve area, friction sleeve calibration factor, initial friction sleeve voltage (the recorded value from ISAAC), and the position transducer calibration factor and initial voltage (the recorded value from ISAACPT). The calculation constants include: the rate of penetration of the insertion system, the cone diameter, the unit weight of the sand sample, and the sampling rate (the number of inches of depth per computer reading). In line 281, type "B" and press RETURN to begin data collection.

Lines 1000-1500 instruct the ISAAC system to read in analog values. All three programs are the same from lines 1000-1070. These lines differ slightly from the ISAAC program. Line 1005 defines the function for

converting the digital computer value to the analog millivolt value. Lines 1020, 1040, 1059, and 1060 are the dummy loop lines required for proper channel switching. In line 1030, & ASUM is the same as & AIN except that after the analog value is read it is summed with the current value of Q. Channel number 0 of the I-140 is read four times, (SW) = 4, at a rate of 32.2 milliseconds per sample, (RT) = 32.2. This rate provides for a set of channel readings at approximately every inch of penetration depth. The analog value stored in Q equals the sum of the four readings. Line 1065 averages the four readings. Thus, in line 1070, the voltage value of the tip resistance placed into the sampling array, TEST(0,J), represents the average tip resistance at a particular depth. In ASUMCALCS and ASUMLAYERS the same channel reading procedure as in in lines 1000-1070 is repeated in lines 1080-1130 only for channel 1 of the I-140. In lines 1080-1130 of PTCALCS, channel number 1 of the 91A distribution board reads the position transducer voltage. As in ISAACPT, the analog values of the position transducer are read in directly with no summing command.

To reference all the voltage values to zero, lines 1135 and 1136 subtract the previously recorded initial voltage values from ISAAC (or ISAACPT) from each successive voltage reading.

When the requested number of data values are read and zeroed, lines 1500-1550 calculate the cone resistance, the local sleeve friction, and a friction ratio. In PTCALCS, lines 1500-1550 calculate the cone resistance and the depth of penetration.

Lines 1560-1600 generate cone penetrometer depth. Line 1570 defines the initial cone depth in equation form where 3.75 represents the initial penetration depth and DEP represents a computer constant. The value of DEP is figured by timing the program with a stopwatch to determine the number of inches of penetration covered for each computer channel reading. The calculations for generating depth by computer are included in PTCALCS to provide a comparison between the computer generated depth and the transducer depth. The comparison revealed that the first reading in ASUMCALCS and ASUMLAYERS is underestimated by 0.2 inches. Therefore, the initial computer generated depth equation in PTCALCS was adjusted accordingly.

Lines 1600-1650 in ASUMCALCS and PTCALCS calculate some common plotting parameters including: vertical stress, relative depth, and a dimensionless resistance factor (q_c / B).

Lines 2000-3000 create a data file on the floppy disk using the filename designated earlier in the program. Lines 2010 to 2030 open the file twice. Line 2010 opens the file; line 2020 deletes the file in case there is another existing file with the same name; and line 2030 opens the file again. If the delete statement were omitted, and, if there were an existing file with the same filename, an open statement would open the existing file and write over it. This typically results in a confused and jumbled data file. Therefore, to secure one clean logical file, the file is opened, deleted, and opened. This procedure should be taken as

a caution to the user since valuable data could be lost by using the same filename twice.

Assume in line 200 that option 2, (read the file sequence), was selected, then the program skips the previously described lines and proceeds to line 3000. Lines 3000-3200 open an existing file and read the file. The read process takes the data file from the floppy disk and inputs the file from the floppy disk and inputs the file into the computer memory. In line 3200 the user opts to end the program or to access the printer to obtain a hard copy of the data file. Lines 3270-3290 activate the printer and lines 3300-3550 tell the printer what and how to print the data file. The program ends in line 5000.

The three programs ASUMCALCS, ASUMLAYERS, and PTCALCS are listed in figures A.8-A.10.

Programs MINI, FUGRO, and PTCAL are calibration programs written to calibrate the first-generation miniature electrical cone, the standard 10 sq. cm. cone, and the position transducer, respectively. The BASIC and the Labsoft commands do not differ from the previously discussed programs. The execution of the calibration programs is described in the calibration appendix (Appendix 2).

```

JLOAD ASUMCALCS
JLIST

100 PRINT "DATA ACQUISITION FOR CONE PENETROMETER"
101 REM DIM MUST COME BEFORE FIRST EXECUTABLE STATEMENT
102 INPUT "NUMBER OF TEST READINGS = ";N
103 DIM TEST(1,N)
104 DIM CR(N): DIM FS(N)
105 DIM FR(N)
106 DIM VS(N): DIM YDM(N): DIM XDM(N)
107 DIM CNDEF(N)
110 REM DISK FILE PROCEDURES
120 D# = CHR$(4): REM DOS CONTROL-D
130 INPUT "TEXT FILENAME?";FLNAM#
140 HOME : VTAB 5
150 PRINT "THIS PROGRAM WORKS WITH TWO OPTIONS"
160 PRINT "OPTION 1: CREATE THE FILE AND WRITE DATA ON DISK"
170 PRINT "OPTION 2: READ DATA ON DISK AND HAVE PRINTER"
180 PRINT "PRINT DATA"
190 INPUT "TYPE '1' OR '2': ";OPT
200 IF OPT = 2 THEN GOTO 3000
205 HOME : VTAB 5
206 INPUT "DATE OF TEST: ";TD#
207 PRINT
210 PRINT "CALIBRATION FACTORS AND CONSTANTS"
220 PRINT : INPUT "AREA OF CONE(SQ.IN.): ";AC
230 INPUT "AREA OF FRICTION SLEEVE(SQ.IN.): ";AF
240 INPUT "CONE LOAD CELL CALIB FACTOR(LB/MVOLT): ";CLC
241 INPUT "INITIAL VOLTAGE, MV = ";ICVOLT
250 INPUT "FRICT SLEEVE CALIB FACTOR(LB/MVOLT): ";FLC
251 INPUT "INITIAL VOLTAGE, MV = ";FIVOLT
252 PRINT : PRINT "CALCULATION CONSTANTS"
260 INPUT "RATE OF PENETRATION,(IN/SEC): ";FR
265 INPUT "DIAM OF CONE (IN.): ";B
270 INPUT "UNIT WEIGHT (PCF): ";GAMMA
275 INPUT "COMPUTER IN./READING: ";DEF
281 INPUT "TYPE 'B' TO BEGIN TEST: ";A5#
282 IF A5# = "B" THEN GOTO 290
290 FOR J = 0 TO N - 1
300 HOME : PRINT "READING NUMBER = ";J
1000 REM ISAAC READS VOLTAGES
1005 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
1020 I = 0
1030 & ASUM,(TV) = Q,(RT) = 32.2,(SW) = 4,(D#) = 1,(C#) = 0,(FU) =
FN VOLTS(RAWZ)
1040 I = I + 1
1059 IF I < 2 THEN Q = 0
1060 IF I < 2 THEN GOTO 1030
1065 D = Q / 4
1070 TEST(Q,J) = D
1080 I = 0
1090 & ASUM,(TV) = Q,(RT) = 32.2,(SW) = 4,(D#) = 1,(C#) = 1,(FU) =
FN VOLTS(RAWZ)
1100 I = I + 1
1119 IF I < 2 THEN Q = 0
1120 IF I < 2 THEN GOTO 1090
1125 D = Q / 4
1130 TEST(1,J) = D

```

Figure A.8: BASIC Program ASUMCALCS

```

1135 TEST(0,J) = ABS (TEST(0,J) - ICVOLT)
1136 TEST(1,J) = ABS (TEST(1,J) - FIVOLT)
1140 PRINT TEST(0,J),TEST(1,J)
1145 NEXT J
1500 REM CONE CALCULATIONS
1505 FOR J = 0 TO N - 1
1510 CR(J) = TEST(0,J) * CLC / AC
1520 FS(J) = TEST(1,J) * FLC / AF
1525 FR(J) = (FS(J) / CR(J)) * 100
1530 PRINT "CONE RESIST (LB) = ";CR(J)
1540 PRINT "FRICT SLEEVE (LB) = ";FS(J)
1545 PRINT "FRICTION RATIO (%) = ";FR(J)
1550 NEXT J
1560 REM PLOTTING PARAMETERS
1570 CNDEP(0) = DEP + 3.75
1580 FOR J = 1 TO N - 1
1590 CNDEP(J) = DEP + CNDEP(J - 1)
1595 NEXT J
1600 REM VERTICAL STRESS
1605 FOR J = 0 TO N - 1
1610 VS(J) = GAMMA * CNDEP(J) / 12.
1620 REM DURGUNGLO & MITCHELL DIMENSIONLESS
1630 YDM(J) = CNDEP(J) / B
1640 XDM(J) = (CR(J) / (GAMMA * B)) * 1728.
1650 NEXT J
2000 REM OPTION 1: CREATE FILE
2010 PRINT D$;"OPEN ";FLNAM$
2020 PRINT D$;"DELETE ";FLNAM$
2030 PRINT D$;"OPEN ";FLNAM$
2040 PRINT D$;"WRITE ";FLNAM$
2045 PRINT TD$
2050 PRINT AC
2060 PRINT AF
2070 PRINT CLC
2080 PRINT ICVOLT
2090 PRINT FLC
2100 PRINT FIVOLT
2105 PRINT FR
2106 PRINT B
2107 PRINT GAMMA
2108 PRINT DEP
2110 PRINT N
2120 FOR I = 0 TO N - 1
2130 PRINT I
2140 PRINT TEST(0,I)
2150 PRINT TEST(1,I)
2160 NEXT I
2170 FOR I = 0 TO N - 1
2180 PRINT CR(I)
2190 PRINT FS(I)
2195 PRINT FR(I)
2200 NEXT I
2201 PRINT CNDEP(0)
2202 FOR I = 1 TO N - 1
2203 PRINT CNDEP(I)
2204 NEXT I
2205 FOR I = 0 TO N - 1
2206 PRINT YDM(I)
2207 PRINT XDM(I)
2208 PRINT VS(I)

```

Figure A. 8(cont.)


```

2209 NEXT I
2210 PRINT D#;"CLOSE ";FLNAM#
2220 GOTO 5000
3000 REM OPTION 2: READ DATA FILE
3010 PRINT D#;"OPEN ";FLNAM#
3020 PRINT D#;"READ ";FLNAM#
3025 INPUT TD#
3030 INPUT AC
3040 INPUT AF
3050 INPUT CLC
3060 INPUT ICVOLT
3070 INPUT FLC
3080 INPUT FIVOLT
3085 INPUT PR
3086 INPUT B
3087 INPUT GAMMA
3088 INPUT DEF
3090 INPUT N
3100 FOR I = 0 TO N - 1
3110 INPUT I
3120 INPUT TEST(0,I)
3130 INPUT TEST(1,I)
3140 NEXT I
3150 FOR I = 0 TO N - 1
3160 INPUT CR(I)
3170 INPUT FS(I)
3175 INPUT FR(I)
3180 NEXT I
3181 INPUT CNDEP(0)
3182 FOR I = 1 TO N - 1
3183 INPUT CNDEP(I)
3184 NEXT I
3185 FOR I = 0 TO N - 1
3186 INPUT YDM(I)
3187 INPUT XDM(I)
3188 INPUT VS(I)
3189 NEXT I
3190 PRINT D#;"CLOSE ";FLNAM#
3200 PRINT "DO YOU WANT A COPY OF DATA NOW?"
3210 INPUT "TYPE 'Y' OR 'N' ";YES#
3220 IF YES# = "N" THEN GOTO 5000
3230 REM PRINT ROUTINE
3240 PRINT "TURN PRINTER POWER ON"
3250 INPUT "TYPE 'C' TO CONTINUE: ";C#
3260 IF C# = "C" THEN GOTO 3270
3270 PRINT CHR# (4);"PR#1"
3280 PRINT CHR# (9);"80N"
3290 PRINT CHR# (9);"6L"
3300 PRINT "DATA ACQUISITION FOR STATIC MINI-ELECTRIC CONE PENETR
OMETER"
3301 PRINT "(GENERATION 1)"
3305 PRINT : PRINT "TEXT FILENAME: ";FLNAM#
3306 PRINT : PRINT "DATE OF TEST: ";TD#
3310 PRINT : PRINT "CALIBRATION FACTORS AND CONSTANTS"
3320 PRINT "AREA OF CONE (SQ.IN.) = ";AC
3330 PRINT "AREA OF FRICTION SLEEVE (SQ.IN) = ";AF
3340 PRINT "CONE LOAD CELL CALIB FACTOR (LB/MVOLT) = ";CLC
3350 PRINT "INITIAL CONE CELL VOLTAGE, MV = ";ICVOLT
3360 PRINT "FRICTION SLEEVE CALIB FACTOR (LB/MVOLT) = ";FLC
3370 PRINT "INITIAL FRICTION SLEEVE VOLTAGE, MV = ";FIVOLT

```

Figure A. 8(cont.)

```

3371 PRINT : PRINT "CALCULATION CONSTANTS"
3375 PRINT "RATE OF PENETRATION (IN/SEC) = ";FR
3376 PRINT "UNIT WEIGHT OF SAND (PCF) = ";GAMMA
3377 PRINT "COMPUTER IN./READING = ";DEP
3380 PRINT "NUMBER OF TEST READINGS = ";N
3390 PRINT : PRINT "INITIAL DATA VALUES"
3400 PRINT "LOAD CELL, MV = ";TEST(0,0)
3410 PRINT "FRICTION SLEEVE, MV = ";TEST(1,0)
3411 PRINT "DEPTH OF CONE (INCHES) = ";CNDEF(0)
3420 PRINT : PRINT "VOLTAGE DATA"
3430 PRINT SPC( 5)"CONE LOAD CELL" SPC( 8)"FRICTION SLEEVE"
3440 PRINT SPC( 8)"MVOLTS" SPC( 18)"MVOLTS"
3450 FOR I = 0 TO N - 1
3460 PRINT TAB( 2)I TAB( 6)TEST(0,I) TAB( 15)TEST(1,I)
3470 NEXT I
3480 PRINT : PRINT "CALCULATED DATA"
3490 PRINT SPC( 5)"CONE RESISTANCE" SPC( 8)"FRICTION SLEEVE" SPC(
8)"FRICTION RATIO"
3500 PRINT SPC( 8)"LBS/SQ. IN." SPC( 12)"LBS/SQ. IN." SPC( 17)"(%"
"
3510 FOR I = 0 TO N - 1
3520 PRINT TAB( 2)I TAB( 6)CR(I) TAB( 14)FS(I) TAB( 15)FR(I)
3530 NEXT I
3531 PRINT
3532 PRINT SPC( 5)"TEST READING" SPC( 3)"DEPTH"
3533 FOR I = 0 TO N - 1
3534 PRINT TAB( 10)I TAB( 10)CNDEF(I)
3535 NEXT I
3536 PRINT SPC( 15)"D/B" SPC( 16)"XDM" SPC( 14)"VERT STRESS"
3537 FOR I = 0 TO N - 1
3538 PRINT TAB( 2)I TAB( 10)YDM(I) TAB( 10)XDM(I) TAB( 10)VS(I)
3539 NEXT I
3540 PRINT "END OF FILE"
3550 PRINT CHR$( 4);"PR#0"
5000 END

```

Figure A. 8(cont.)

```

JLOAD ASUMLAYERS
JLIST

100 PRINT "DATA ACQUISITION FOR CONE PENETROMETER"
101 REM DIM MUST COME BEFORE FIRST EXECUTABLE STATEMENT
102 INPUT "NUMBER OF TEST READINGS = ";N
103 DIM TEST(1,N)
104 DIM CR(N): DIM FS(N)
105 DIM FR(N)
107 DIM CNDEP(N)
110 REM DISK FILE PROCEDURES
120 D# = CHR$(4): REM DOS CONTROL-D
130 INPUT "TEXT FILENAME?";FLNAM#
140 HOME : VTAB 5
150 PRINT "THIS PROGRAM WORKS WITH TWO OPTIONS"
160 PRINT "OPTION 1: CREATE THE FILE AND WRITE DATA ON DISK"
170 PRINT "OPTION 2: READ DATA ON DISK AND HAVE PRINTER"
180 PRINT "PRINT DATA"
190 INPUT "TYPE '1' OR '2': ";OPT
200 IF OPT = 2 THEN GOTO 3000
205 HOME : VTAB 5
206 INPUT "DATE OF TEST: ";TD#
207 PRINT
210 PRINT "CALIBRATION FACTORS AND CONSTANTS"
220 PRINT : INPUT "AREA OF CONE(SQ.IN.): ";AC
230 INPUT "AREA OF FRICTION SLEEVE(SQ.IN.): ";AF
240 INPUT "CONE LOAD CELL CALIB FACTOR(LB/MVOLT): ";CLC
241 INPUT "INITIAL VOLTAGE, MV = ";ICVOLT
250 INPUT "FRICT SLEEVE CALIB FACTOR(LB/MVOLT): ";FLC
251 INPUT "INITIAL VOLTAGE, MV = ";FIVOLT
252 PRINT : PRINT "CALCULATION CONSTANTS"
260 INPUT "RATE OF PENETRATION,(IN/SEC): ";PR
265 INPUT "DIAM OF CONE (IN.): ";B
275 INPUT "COMPUTER IN./READING: ";DEP
281 INPUT "TYPE 'B' TO BEGIN TEST: ";A5#
282 IF A5# = "B" THEN GOTO 290
290 FOR J = 0 TO N - 1
300 HOME : PRINT "READING NUMBER = ";J
1000 REM ISAAC READS VOLTAGES
1005 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
1020 I = 0
1030 & ASUM, (TV) = 0, (RT) = 32.2, (SW) = 4, (D#) = 1, (C#) = 0, (FU) =
  FN VOLTS(RAW%)
1040 I = I + 1
1059 IF I < 2 THEN Q = 0
1060 IF I < 2 THEN GOTO 1030
1065 D = Q / 4
1070 TEST(0,J) = D
1080 I = 0
1090 & ASUM, (TV) = 0, (RT) = 32.2, (SW) = 4, (D#) = 1, (C#) = 1, (FU) =
  FN VOLTS(RAW%)
1100 I = I + 1
1119 IF I < 2 THEN Q = 0
1120 IF I < 2 THEN GOTO 1090
1125 D = Q / 4
1130 TEST(1,J) = D
1135 TEST(0,J) = ABS (TEST(0,J) - ICVOLT)
1136 TEST(1,J) = ABS (TEST(1,J) - FIVOLT)

```

Figure A.9: BASIC Program ASUMLAYERS

```

1140 PRINT TEST(0,J),TEST(1,J)
1145 NEXT J
1500 REM CONE CALCULATIONS
1505 FOR J = 0 TO N - 1
1510 CR(J) = TEST(0,J) * CLC / AC
1520 FS(J) = TEST(1,J) * FLC / AF
1525 FR(J) = (FS(J) / CR(J)) * 100
1530 PRINT "CONE RESIST (LB) = ";CR(J)
1540 PRINT "FRICT SLEEVE (LB) = ";FS(J)
1545 PRINT "FRICTION RATIO (%) = ";FR(J)
1550 NEXT J
1560 REM PLOTTING PARAMETERS
1570 CNDEP(0) = DEP + 3.75
1580 FOR J = 1 TO N - 1
1590 CNDEP(J) = DEP + CNDEP(J - 1)
1595 NEXT J
1600 REM VERTICAL STRESS
2000 REM OPTION 1: CREATE FILE
2010 PRINT D$;"OPEN ";FLNAM$
2020 PRINT D$;"DELETE ";FLNAM$
2030 PRINT D$;"OPEN ";FLNAM$
2040 PRINT D$;"WRITE ";FLNAM$
2045 PRINT TD$
2050 PRINT AC
2060 PRINT AF
2070 PRINT CLC
2080 PRINT ICVOLT
2090 PRINT FLC
2100 PRINT FIVOLT
2105 PRINT PR
2106 PRINT B
2108 PRINT DEP
2110 PRINT N
2120 FOR I = 0 TO N - 1
2130 PRINT I
2140 PRINT TEST(0,I)
2150 PRINT TEST(1,I)
2160 NEXT I
2170 FOR I = 0 TO N - 1
2180 PRINT CR(I)
2190 PRINT FS(I)
2195 PRINT FR(I)
2200 NEXT I
2201 PRINT CNDEP(0)
2202 FOR I = 1 TO N - 1
2203 PRINT CNDEP(I)
2204 NEXT I
2210 PRINT D$;"CLOSE ";FLNAM$
2220 GOTO 5000
3000 REM OPTION 2: READ DATA FILE
3010 PRINT D$;"OPEN ";FLNAM$
3020 PRINT D$;"READ ";FLNAM$
3025 INPUT TD$
3030 INPUT AC
3040 INPUT AF
3050 INPUT CLC
3060 INPUT ICVOLT
3070 INPUT FLC
3080 INPUT FIVOLT
3085 INPUT PR

```

Figure A.9(cont.)

```

3086 INPUT B
3088 INPUT DEF
3090 INPUT N
3100 FOR I = 0 TO N - 1
3110 INPUT I
3120 INPUT TEST(0,I)
3130 INPUT TEST(1,I)
3140 NEXT I
3150 FOR I = 0 TO N - 1
3160 INPUT CR(I)
3170 INPUT FS(I)
3175 INPUT FR(I)
3180 NEXT I
3181 INPUT CNDEP(0)
3182 FOR I = 1 TO N - 1
3183 INPUT CNDEP(I)
3184 NEXT I
3190 PRINT D$;"CLOSE ";FLNAM$
3200 PRINT "DO YOU WANT A COPY OF DATA NOW?"
3210 INPUT "TYPE 'Y' OR 'N' ";YES$
3220 IF YES$ = "N" THEN GOTO 5000
3230 REM PRINT ROUTINE
3240 PRINT "TURN PRINTER POWER ON"
3250 INPUT "TYPE 'C' TO CONTINUE: ";C$
3260 IF C$ = "C" THEN GOTO 3270
3270 PRINT CHR$(4);"PR#1"
3280 PRINT CHR$(9);"80N"
3290 PRINT CHR$(9);"6L"
3300 PRINT "DATA ACQUISITION FOR STATIC MINI-ELECTRIC CONE PENETR
OMETER"
3301 PRINT "(GENERATION 1)"
3305 PRINT : PRINT "TEXT FILENAME: ";FLNAM$
3306 PRINT : PRINT "DATE OF TEST: ";TD$
3310 PRINT : PRINT "CALIBRATION FACTORS AND CONSTANTS"
3320 PRINT "AREA OF CONE (SQ.IN.) = ";AC
3330 PRINT "AREA OF FRICTION SLEEVE (SQ.IN) = ";AF
3340 PRINT "CONE LOAD CELL CALIB FACTOR (LB/MVOLT) = ";CLC
3350 PRINT "INITIAL CONE CELL VOLTAGE, MV = ";ICVOLT
3360 PRINT "FRICTION SLEEVE CALIB FACTOR (LB/MVOLT) = ";FLC
3370 PRINT "INITIAL FRICTION SLEEVE VOLTAGE, MV = ";FIVOLT
3371 PRINT : PRINT "CALCULATION CONSTANTS"

```

Figure A.9(cont.)

```

3375 PRINT "RATE OF PENETRATION (IN/SEC) = ";PR
3377 PRINT "COMPUTER IN./READING = ";DEP
3380 PRINT "NUMBER OF TEST READINGS = ";N
3390 PRINT : PRINT "INITIAL DATA VALUES"
3400 PRINT "LOAD CELL, MV = ";TEST(0,0)
3410 PRINT "FRICTION SLEEVE, MV = ";TEST(1,0)
3411 PRINT "DEPTH OF CONE (INCHES) = ";CNDEP(0)
3420 PRINT : PRINT "VOLTAGE DATA"
3430 PRINT SPC( 5)"CONE LOAD CELL" SPC( 8)"FRICTION SLEEVE"
3440 PRINT SPC( 8)"MVOLTS" SPC( 18)"MVOLTS"
3450 FOR I = 0 TO N - 1
3460 PRINT TAB( 2)I TAB( 6)TEST(0,I) TAB( 15)TEST(1,I)
3470 NEXT I
3480 PRINT : PRINT "CALCULATED DATA"
3490 PRINT SPC( 5)"CONE RESISTANCE" SPC( 8)"FRICTION SLEEVE" SPC(
8)"FRICTION RATIO"
3500 PRINT SPC( 8)"LBS/SQ.IN." SPC( 12)"LBS/SQ.IN." SPC( 17)"(%)
"
3510 FOR I = 0 TO N - 1
3520 PRINT TAB( 2)I TAB( 6)CR(I) TAB( 14)FS(I) TAB( 15)FR(I)
3530 NEXT I
3531 PRINT
3532 PRINT SPC( 5)"TEST READING" SPC( 3)"DEPTH"
3533 FOR I = 0 TO N - 1
3534 PRINT TAB( 10)I TAB( 10)CNDEP(I)
3535 NEXT I
3540 PRINT "END OF FILE"
3550 PRINT CHR$( 4);"PR#0"
5000 END

```

Figure A.9(cont.)

```

100 PRINT "DATA ACQUISITION FOR CONE PENETROMETER"
101 REM DIM MUST COME BEFORE FIRST EXECUTABLE STATEMENT
102 INPUT "NUMBER OF TEST READINGS = ";N
103 DIM TEST(1,N)
104 DIM CR(N)
105 DIM TRANS(N)
106 DIM VS(N): DIM YDM(N): DIM XDM(N)
107 DIM CNDEP(N)
110 REM DISK FILE PROCEDURES
120 D$ = CHR$(4): REM DOS CONTROL-D
130 INPUT "TEXT FILENAME?";FLNAM$
140 HOME : VTAB 5
150 PRINT "THIS PROGRAM WORKS WITH TWO OPTIONS"
160 PRINT "OPTION 1: CREATE THE FILE AND WRITE DATA ON DISK"
170 PRINT "OPTION 2: READ DATA ON DISK AND HAVE PRINTER"
180 PRINT "PRINT DATA"
190 INPUT "TYPE '1' OR '2': ";OPT
200 IF OPT = 2 THEN GOTO 3000
205 HOME : VTAB 5
206 INPUT "DATE OF TEST: ";TD$
207 PRINT
210 PRINT "CALIBRATION FACTORS AND CONSTANTS"
220 PRINT : INPUT "AREA OF CONE(SQ.IN.): ";AC
240 INPUT "CONE LOAD CELL CALIB FACTOR(LB/MVOLT): ";CLC
241 INPUT "INITIAL VOLTAGE, MV = ";ICVOLT
250 INPUT "POSITION X-DUCER CALIBRATION FACTOR = ";PTC
251 INPUT "INITIAL DEPTH VOLTAGE,(VOLTS) = ";IPVOLT
252 PRINT : PRINT "CALCULATION CONSTANTS"
260 INPUT "RATE OF PENETRATION,(IN/SEC): ";PR
265 INPUT "DIAM OF CONE (IN.): ";B
270 INPUT "UNIT WEIGHT (PCF): ";GAMMA
275 INPUT "COMPUTER IN./READING: ";DEP
281 INPUT "TYPE 'B' TO BEGIN TEST: ";A5$
282 IF A5$ = "B" THEN GOTO 290
290 FOR J = 0 TO N - 1
300 HOME : PRINT "READING NUMBER = ";J
1000 REM ISAAC READS VOLTAGES
1005 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
1020 I = 0
1030 & ASUM, (TV) = Q, (RT) = 32.2, (SW) = 4, (D#) = 1, (C#) = 0, (FU) =
  FN VOLTS(RAWZ)
1040 I = I + 1
1059 IF I < 2 THEN Q = 0
1060 IF I < 2 THEN GOTO 1030
1065 D = Q / 4
1070 TEST(0,J) = D
1080 DEF FN VOLTS(X) = ABS (X / 81.88 - 25)
1090 & AIN, (TV) = Q, (C#) = 1, (FU) = FN VOLTS(RAWZ)
1130 TEST(1,J) = Q
1135 TEST(0,J) = ABS (TEST(0,J) - ICVOLT)
1136 TEST(1,J) = ABS (TEST(1,J) - IPVOLT)
1140 PRINT TEST(0,J),TEST(1,J)
1145 NEXT J
1500 REM CONE CALCULATIONS
1505 FOR J = 0 TO N - 1

```

Figure A.10: BASIC Program PTCALCS

```

1510 CR(J) = TEST(0,J) * CLC / AC
1520 TRANS(J) = (TEST(1,J) * PTC) + 3.75
1530 PRINT "CONE RESIST (LB) = ";CR(J)
1540 PRINT "DEPTH OF CONE (IN) = ";TRANS(J)
1550 NEXT J
1560 REM PLOTTING PARAMETERS
1570 CNDEP(0) = DEP + 3.97
1580 FOR J = 1 TO N - 1
1590 CNDEP(J) = DEP + CNDEP(J - 1)
1595 NEXT J
1600 REM VERTICAL STRESS
1605 FOR J = 0 TO N - 1
1610 VS(J) = GAMMA * TRANS(J) / 12.
1620 REM DURGUNGL0 & MITCHELL DIMENSIONLESS
1630 YDM(J) = TRANS(J) / B
1640 XDM(J) = (CR(J) / (GAMMA * B)) * 1728.
1650 NEXT J
2000 REM OPTION 1: CREATE FILE
2010 PRINT D#;"OPEN ";FLNAM#
2020 PRINT D#;"DELETE ";FLNAM#
2030 PRINT D#;"OPEN ";FLNAM#
2040 PRINT D#;"WRITE ";FLNAM#
2045 PRINT TD#
2050 PRINT AC
2070 PRINT CLC
2080 PRINT ICVOLT
2090 PRINT PTC
2100 PRINT IPVOLT
2105 PRINT PR
2106 PRINT B
2107 PRINT GAMMA
2108 PRINT DEP
2110 PRINT N
2120 FOR I = 0 TO N - 1
2130 PRINT I
2140 PRINT TEST(0,I)
2150 PRINT TEST(1,I)
2160 NEXT I
2170 FOR I = 0 TO N - 1
2180 PRINT CR(I)
2190 PRINT TRANS(I)
2200 NEXT I
2201 PRINT CNDEP(0)
2202 FOR I = 1 TO N - 1
2203 PRINT CNDEP(I)
2204 NEXT I
2205 FOR I = 0 TO N - 1
2206 PRINT YDM(I)
2207 PRINT XDM(I)
2208 PRINT VS(I)
2209 NEXT I
2210 PRINT D#;"CLOSE ";FLNAM#
2220 GOTO 5000
3000 REM OPTION 2: READ DATA FILE
3010 PRINT D#;"OPEN ";FLNAM#
3020 PRINT D#;"READ ";FLNAM#
3025 INPUT TD#
3030 INPUT AC
3050 INPUT CLC
3060 INPUT ICVOLT

```

Figure A. 10(cont.)


```

3070 INPUT PTC
3080 INPUT IPVOLT
3085 INPUT PR
3086 INPUT B
3087 INPUT GAMMA
3088 INPUT DEP
3090 INPUT N
3100 FOR I = 0 TO N - 1
3110 INPUT I
3120 INPUT TEST(0,I)
3130 INPUT TEST(1,I)
3140 NEXT I
3150 FOR I = 0 TO N - 1
3160 INPUT CR(I)
3170 INPUT TRANS(I)
3180 NEXT I
3181 INPUT CNDEF(0)
3182 FOR I = 1 TO N - 1
3183 INPUT CNDEF(I)
3184 NEXT I
3185 FOR I = 0 TO N - 1
3186 INPUT YDM(I)
3187 INPUT XDM(I)
3188 INPUT VS(I)
3189 NEXT I
3190 PRINT D$;"CLOSE ";FLNAM$
3200 PRINT "DO YOU WANT A COPY OF DATA NOW?"
3210 INPUT "TYPE 'Y' OR 'N' ";YES$
3220 IF YES$ = "N" THEN GOTO 5000
3230 REM PRINT ROUTINE
3240 PRINT "TURN PRINTER POWER ON"
3250 INPUT "TYPE 'C' TO CONTINUE: ";C$
3260 IF C$ = "C" THEN GOTO 3270
3270 PRINT CHR$(4);"PR#1"
3280 PRINT CHR$(9);"80N"
3290 PRINT CHR$(9);"6L"
3300 PRINT "DATA ACQUISITION FOR STATIC MINI-ELECTRIC CONE PENETR
OMETER"
3301 PRINT "(GENERATION 1)"
3305 PRINT : PRINT "TEXT FILENAME: ";FLNAM$
3306 PRINT : PRINT "DATE OF TEST: ";TD$
3310 PRINT : PRINT "CALIBRATION FACTORS AND CONSTANTS"
3320 PRINT "AREA OF CONE (SQ.IN.) = ";AC
3340 PRINT "CONE LOAD CELL CALIB FACTOR (LB/MVOLT) = ";CLC
3350 PRINT "INITIAL CONE CELL VOLTAGE, MV = ";ICVOLT
3360 PRINT "POSITION X-DUCER CALIBRATION FACTOR (IN/VOLT) = ";PTC

3370 PRINT "INITIAL TRANSDUCER VOLTAGE, VOLTS = ";IPVOLT
3371 PRINT : PRINT "CALCULATION CONSTANTS"
3375 PRINT "RATE OF PENETRATION (IN/SEC) = ";PR
3376 PRINT "UNIT WEIGHT OF SAND (PCF) = ";GAMMA
3377 PRINT "COMPUTER IN./READING = ";DEF

```

Figure A. 10(cont.)

```

3380 PRINT "NUMBER OF TEST READINGS = ";N
3390 PRINT : PRINT "INITIAL DATA VALUES"
3400 PRINT "LOAD CELL, MV = ";TEST(0,0)
3410 PRINT "DEPTH OF CONE (VOLTS) = ";TEST(1,0)
3420 PRINT : PRINT "VOLTAGE DATA"
3430 PRINT SPC( 5)"CONE LOAD CELL" SPC( 8)"POSITION TRANSDUCER"
3440 PRINT SPC( 8)"MVOLTS" SPC( 18)"VOLTS"
3450 FOR I = 0 TO N - 1
3460 PRINT TAB( 2)I TAB( 6)TEST(0,I) TAB( 15)TEST(1,I)
3470 NEXT I
3480 PRINT : PRINT "CALCULATED DATA"
3490 PRINT SPC( 5)"CONE RESISTANCE" SPC( 8)"DEPTH OF CONE"
3500 PRINT SPC( 8)"LBS/SQ.IN." SPC( 14)"INCHES"
3510 FOR I = 0 TO N - 1
3520 PRINT TAB( 2)I TAB( 6)CR(I) TAB( 14)TRANS(I)
3530 NEXT I
3531 PRINT
3532 PRINT SPC( 5)"TEST READING" SPC( 3)"DEPTH"
3533 FOR I = 0 TO N - 1
3534 PRINT TAB( 10)I TAB( 10)CNDEP(I)
3535 NEXT I
3536 PRINT SPC( 15)"D/B" SPC( 16)"XDM" SPC( 14)"VERT STRESS"
3537 FOR I = 0 TO N - 1
3538 PRINT TAB( 2)I TAB( 10)YDM(I) TAB( 10)XDM(I) TAB( 10)VS(I)
3539 NEXT I
3540 PRINT "END OF FILE"
3550 PRINT CHR$( 4);"PR#0"
5000 END

```

Figure A. 10(cont.)

A.4.3 Arrays and Variables for the FORTRAN Plotting Programs

CR(I,J) = the array representing the tip resistance data from one complete test series on a sample where: I represents the total number of data points and J represents the number of individual tests to plot.

TRANS(I,J) = array representing the depth values which correspond to the values in CR(I,J).

N(J) = the number of data points or number of pairs of (CR,TRANS) to plot for one test.

DR = the relative density of a sand sample
For layered tests:
DRT = relative density of the top layer
DRM = relative density of the middle layer
DRB = relative density of the bottom layer

NC = the number of curves to plot (typically 5)

Note: For clarity, a series represents five (or seven) cone tests performed in one sample. One test means one test from that series. Each test is plotted on its own curve using different symbols. Therefore, one series is represented by five (or seven) curves each with a different symbol.

A.4.4 Execution of the FORTRAN Plotting Programs

Programs: OWNPLOT FORTRAN, COMPARE FORTRAN, LAYER FORTRAN, 2LAYER FORTRAN, and FUGRO FORTRAN

OWNPLOT FORTRAN plots the results from testing the miniature electrical cone in homogeneous sand samples. The plotting commands are standard plotting commands as defined in Document number GR01 - Versatec and CALCOMP User's Guide. The guide is obtained from the computer center by issuing the command: DOCS GR01 from a CMS account. The program OWNPLOT is commented throughout and is therefore self-explanatory. However, one section to approach with caution is labeled "Each curve is plotted with a different symbol". For example, test 1 is represented by symbol 1, test 2 by symbol 2, test 3 by symbol 3, test 4 by symbol 4, test 5 by symbol 5, test 6 by symbol 0, and test 7 by symbol 6. In the program, for J equals 1 to 3, the corresponding symbols are 1 to 3. However, the fourth data set is from test number 6, therefore, the corresponding symbol is 0.

The remaining FORTRAN programs are modified versions of OWNPLOT. COMPARE compares test 1 values which are the designated results most representative of each homogeneous sample. LAYER (and 2LAYER) is the same as OWNPLOT except the test results from each 3-layered (or 2-layered) sample are plotted. Finally, FUGRO is for a plot comparing miniature electrical to standard 10 sq. cm. electrical cone penetrometer test data. Each of the FORTRAN programs are listed in figures A.11-A.15.

```

//B000038 JOB 306D3,TKWIAT
/*PRIORITY STANDARD
/*JOBPARM LINES=1,CARDS=100
//STEP1 EXEC FORTXCGV
//FORT.SYSIN DD *
C
C ** PROGRAM TITLE: OWNPLOT FORTRAN **
C ** THIS PROGRAM PLOTS THE MINIATURE ELECTRICAL CONE **
C ** PENETROMETER TESTS FOR ONE HOMOGENEOUS SAMPLE **
C
C * DIMENSION DATA VARIABLES *
C
      DIMENSION CR(175,7),TRANS(175,7),N(175)
      READ(5,800)DR
      READ(5,810)NC
      DO 200 J=1,NC
        READ(5,810)N(J)
        NJ=N(J)
        DO 190 I=1,NJ
          READ(5,800)CR(I,J)
          READ(5,800)TRANS(I,J)
          CR(I,J)=CR(I,J)/100.
          TRANS(I,J)=-TRANS(I,J)/5.
190      CONTINUE
200      CONTINUE
C
C * DRAW THE PLOT BORDERS *
C
      CALL PLOTS(0.,0.,50)
      CALL PLOT(3.,9.25,-3)
      CALL PLOT(4.,0.,-2)
      CALL PLOT(0.,-7.00,-2)
      CALL PLOT(-4.,0.,-2)
      CALL PLOT(0.,7.00,-2)
C
C * DRAW X-AXIS TICK MARKS *
C
      DO 100 I=1,7
        CALL PLOT(-5,0.,-3)
        CALL PLOT(0.,-05,2)
        CALL PLOT(0.,-7.,3)
        CALL PLOT(0.,-6.95,2)
100      CONTINUE
      CALL PLOT(-3.5,0.,-3)
C
C * DRAW Y-AXIS TICK MARKS *
C
      DO 110 I=1,6
        CALL PLOT(0.,-1.,-3)
        CALL PLOT(0.05,0.,2)
        CALL PLOT(4.,0.,3)
        CALL PLOT(3.95,0.,2)
110      CONTINUE
      CALL PLOT(0.,6.,-3)
C
C * EACH CURVE IS PLOTTED WITH A DIFFERENT SYMBOL *
C
      DO 150 J=1,NC
        IF(J.EQ.1)NSY=1
        IF(J.EQ.2)NSY=2
        IF(J.EQ.3)NSY=3
        IF(J.EQ.4)NSY=0
        IF(J.EQ.5)NSY=6
        NJ=N(J)
C
C * PLOT THE DATA POINTS *
C
      DO 140 I=1,NJ
        CALL SYMBOL(CR(I,J),TRANS(I,J),.05,
          $ NSY,0.,-1)
140      CONTINUE
150      CONTINUE

```

Figure A.11: FORTRAN Program OWNPLOT

```

C
C * LABEL Y-AXIS SCALE *
C
CALL PLOT(0, -.05, -3)
CALL SYMBOL(-.3, 0, .1, 2H 0, 0, .2)
CALL SYMBOL(-.3, -1, .1, 2H 5, 0, .2)
CALL SYMBOL(-.3, -2, .1, 2H 10, 0, .2)
CALL SYMBOL(-.3, -3, .1, 2H 15, 0, .2)
CALL SYMBOL(-.3, -4, .1, 2H 20, 0, .2)
CALL SYMBOL(-.3, -5, .1, 2H 25, 0, .2)
CALL SYMBOL(-.3, -6, .1, 2H 30, 0, .2)
CALL SYMBOL(-.3, -7, .1, 2H 35, 0, .2)
CALL PLOT(0, -.05, -3)
CALL SYMBOL(-.40, -4.5, .1, 14HDEPTH (INCHES), 90, .14)
C
C * LABEL X-AXIS SCALE *
C
CALL SYMBOL(-.05, .1, .1,
$42H0      100      200      300      400, 0, .42)
CALL SYMBOL(1, .3, .1, 2HINCOME RESISTANCE (PSI), 0, .21)
C
C * GIVE THE PLOT A TITLE *
C
CALL SYMBOL(1, -.25, .1, 24HTIP RESISTANCE VS. DEPTH,
$0, .24)
CALL SYMBOL(1, -.40, .1, 22HRELATIVE DENSITY = %, 0, .22)
CALL NUMBER(2.9, -.40, .1, DR, 0, -1)
C
C * GIVE THE PLOT A LEGEND *
C
CALL PLOT(2, 0, -.50, -3)
CALL SYMBOL(.95, -.25, .1, 1, 0, -1)
CALL SYMBOL(.95, -.40, .1, 2, 0, -1)
CALL SYMBOL(.95, -.55, .1, 3, 0, -1)
CALL SYMBOL(.95, -.70, .1, 4, 0, -1)
CALL SYMBOL(.95, -.85, .1, 5, 0, -1)
CALL SYMBOL(.95, -1.00, .1, 0, 0, -1)
CALL SYMBOL(.95, -1.15, .1, 6, 0, -1)
CALL SYMBOL(.1, -.15, .1,
$12HTEST SYMBOL, 0, .12)
CALL SYMBOL(.25, -.3, .1, 1H1, 0, .1)
CALL SYMBOL(.25, -.45, .1, 1H2, 0, .1)
CALL SYMBOL(.25, -.6, .1, 1H3, 0, .1)
CALL SYMBOL(.25, -.75, .1, 1H4, 0, .1)
CALL SYMBOL(.25, -.9, .1, 1H5, 0, .1)
CALL SYMBOL(.25, -1.05, .1, 1H6, 0, .1)
CALL SYMBOL(.25, -1.2, .1, 1H7, 0, .1)
CALL PLOT(0, .0, -3)
C
C * DRAW BORDERS AROUND THE LEGEND *
C
CALL PLOT(1, 4, 0, -2)
CALL PLOT(0, -1, 3, -2)
CALL PLOT(-1, 4, 0, -2)
CALL PLOT(0, 1, 3, -2)
CALL PLOT(12, -1, 5, 999)
C
800 FORMAT(F20.10)
810 FORMAT(I3)
STOP
END
/*
//GO.SYSIN DD *

```

Figure A. 11(cont.)

```

//8000038 JOB 306D3,TKWIAT
/*PRIORITY STANDARD
/*JOBPARM LINES=1,CARDS=100
//STEP1 EXEC FORTXCGV
//FORT.SYSIN DD *
C
C *** COMPARISON PLOT PROGRAM (MINI-CONE ONLY) ***
C
      DIMENSION CR(175,7),TRANS(175,7),N(175),DR(7)
      DO 10 J=1,6
      READ(5,800)DR(J)
10    CONTINUE
      READ(5,810)NC
      DO 200 J=1,NC
      READ(5,810)N(J)
      NJ=N(J)
      DO 190 I=1,NJ
      READ(5,800)CR(I,J)
      READ(5,800)TRANS(I,J)
      CR(I,J)=CR(I,J)/100.
      TRANS(I,J)=-TRANS(I,J)/5.
190   CONTINUE
200   CONTINUE
      CALL PLOTS(0.,0.,50)
      CALL PLOT(3.,9.25,-3)
      CALL PLOT(4.,0.,-2)
      CALL PLOT(0.,-7.00,-2)
      CALL PLOT(-4.,0.,-2)
      CALL PLOT(0.,7.00,-2)
      DO 100 I=1,7
      CALL PLOT(.5,0.,-3)
      CALL PLOT(0.,-.05,2)
      CALL PLOT(0.,-7.,3)
      CALL PLOT(0.,-6.95,2)
100   CONTINUE
      CALL PLOT(-3.5,0.,-3)
      DO 110 I=1,6
      CALL PLOT(0.,-1.,-3)
      CALL PLOT(.05,0.,2)
      CALL PLOT(4.,0.,3)
      CALL PLOT(3.95,0.,2)
110   CONTINUE
      CALL PLOT(0.,6.,-3)
      DO 150 J=1,NC
      IF(J.EQ.1)NSY=1
      IF(J.EQ.2)NSY=2
      IF(J.EQ.3)NSY=3
      IF(J.EQ.4)NSY=4
      IF(J.EQ.5)NSY=5
      IF(J.EQ.6)NSY=0
      IF(J.EQ.7)NSY=6
C
      NJ=N(J)
      DO 140 I=1,NJ
      CALL SYMBOL(CR(I,J),TRANS(I,J),.05,
      NSY,0.,-1)
      $

```

Figure A.12: FORTRAN Program COMPARE

```

140 CONTINUE
150 CONTINUE
CALL PLOT(0.,-.05,-3)
CALL SYMBOL(-.3,0.,.1,2H 0,0.,2)
CALL SYMBOL(-.3,-1.,.1,2H 5,0.,2)
CALL SYMBOL(-.3,-2.,.1,2H10,0.,2)
CALL SYMBOL(-.3,-3.,.1,2H15,0.,2)
CALL SYMBOL(-.3,-4.,.1,2H20,0.,2)
CALL SYMBOL(-.3,-5.,.1,2H25,0.,2)
CALL SYMBOL(-.3,-6.,.1,2H30,0.,2)
CALL SYMBOL(-.3,-7.,.1,2H35,0.,2)
CALL PLOT(0.,.05,-3)
CALL SYMBOL(-.40,+4.5,.1,14HDEPTH (INCHES),90.,14)
CALL SYMBOL(-.05,.1,.1,
$42H0 100 200 300 400,0.,42)
CALL SYMBOL(1.,.3,.1,21HCONE RESISTANCE (PSI),0.,21)
CALL SYMBOL(1.,-.25,.1,24HTIP RESISTANCE VS. DEPTH,
$0.,24)
CALL SYMBOL(1.,-.40,.1,
$25HMINI-CONE COMPARISON PLOT,0.,25)
CALL PLOT(1.7,-.50,-3)
C ** LEGEND PLOT **
CALL SYMBOL(1.30,-.4,.1,1,0.,-1)
CALL SYMBOL(1.30,-.55,.1,2,0.,-1)
CALL SYMBOL(1.30,-.7,.1,3,0.,-1)
CALL SYMBOL(1.30,-.85,.1,4,0.,-1)
CALL SYMBOL(1.30,-1.,.1,5,0.,-1)
CALL SYMBOL(1.30,-1.15,.1,6,0.,-1)
C CALL SYMBOL(1.30,-1.3,.1,6,0.,-1)
CALL SYMBOL(.1,-.15,.1,8HRELATIVE,0.,8)
CALL SYMBOL(.15,-.3,.1,15HDENSITY SYMBOL,0.,15)
CALL NUMBER(40,-.45,.1,DR(1),0.,-1)
CALL NUMBER(40,-.60,.1,DR(2),0.,-1)
CALL NUMBER(40,-.75,.1,DR(3),0.,-1)
CALL NUMBER(40,-.90,.1,DR(4),0.,-1)
CALL NUMBER(40,-1.05,.1,DR(5),0.,-1)
CALL NUMBER(40,-1.20,.1,DR(6),0.,-1)
C CALL NUMBER(40,-1.35,.1,DR(7),0.,-1)
CALL PLOT(0.,.0.,-3)
CALL PLOT(1.7,0.,-2)
CALL PLOT(0.,-1.30,-2)
CALL PLOT(-1.7,0.,-2)
CALL PLOT(0.,1.30,-2)
CALL PLOT(12.,-1.5,999)
800 FORMAT(F20.10)
810 FORMAT(I3)
-C999 CONTINUE
STOP
END
/*
//GO.SYSIN DD *

```

Figure A.12(cont.)


```

//B000038 JOB 306D3,TKWIAT
/*PRIORITY STANDARD
/*JOBPARM LINES=1,CARDS=100
//STEPI EXEC FTGICGV
//FORT.SYSIN DD *
C
C ** PROGRAM TITLE: LAYER FORTRAN **
C ** THIS PROGRAM PLOTS THE TEST RESULTS FROM THE MINIATURE **
C ** ELECTRICAL CONE PENETROMETER FOR LAYERED SAMPLES **
C
C DIMENSION CR(175,5),TRANS(175,5),N(175)
C
C * READ IN TOP LAYER RELATIVE DENSITY, MIDDLE, AND BOTTOM *
C
READ(5,800)DRT
READ(5,800)DRM
READ(5,800)DRB
READ(5,810)NC
DO 200 J=1,NC
READ(5,810)N(J)
NJ=N(J)
DO 190 I=1,NJ
READ(5,800)CR(I,J)
READ(5,800)TRANS(I,J)
CR(I,J)=CR(I,J)/100.
TRANS(I,J)=-TRANS(I,J)/5.
190 CONTINUE
200 CONTINUE
CALL PLOTS(0.,0.,50)
C *# DRAW CONE PLOT BORDERS *#
CALL PLOT(3.,9.25,-3)
CALL PLOT(4.,0.,-2)
CALL PLOT(0.,-7.00,-2)
CALL PLOT(-4.,0.,-2)
CALL PLOT(0.,7.00,-2)
C * DRAW X-AXIS TICK MARKS *
DO 100 I=1,7
CALL PLOT(.5,0.,-3)
CALL PLOT(0.,-.05,2)
CALL PLOT(0.,-.7.,3)
CALL PLOT(0.,-6.95,2)
100 CONTINUE
CALL PLOT(-3.5,0.,-3)
C * DRAW Y-AXIS TICK MARKS *
DO 110 I=1,6
CALL PLOT(0.,-1.,-3)
CALL PLOT(.05,0.,2)
CALL PLOT(4.,0.,3)
CALL PLOT(3.95,0.,2)
110 CONTINUE
CALL PLOT(0.,6.,-3)
C * MATCH SYMBOL TO CURVE *
DO 150 J=1,NC
IF(J.EQ.1)NSY=1
IF(J.EQ.2)NSY=2
IF(J.EQ.3)NSY=3
IF(J.EQ.4)NSY=4
IF(J.EQ.5)NSY=5
C * PLOT THE DATA *
NJ=N(J)
DO 140 I=1,NJ
CALL SYMBOL(CR(I,J),TRANS(I,J),.05,
NSY,0.,-1)
140 CONTINUE
150 CONTINUE

```

Figure A.13: FORTRAN Program LAYER

```

C * LABEL THE Y-AXIS *
  CALL PLOT(0.,-.05,-3)
  CALL SYMBOL(-.3,0.,.1,2H 0.0.,2)
  CALL SYMBOL(-.3,-1.,.1,2H 5.0.,2)
  CALL SYMBOL(-.3,-2.,.1,2H10.0.,2)
  CALL SYMBOL(-.3,-3.,.1,2H15.0.,2)
  CALL SYMBOL(-.3,-4.,.1,2H20.0.,2)
  CALL SYMBOL(-.3,-5.,.1,2H25.0.,2)
  CALL SYMBOL(-.3,-6.,.1,2H30.0.,2)
  CALL SYMBOL(-.3,-7.,.1,2H35.0.,2)
  CALL PLOT(0.,.05,-3)
  CALL SYMBOL(-.40,-4.5,.1,14HDEPTH (INCHES),90.,14)
C * LABEL THE X-AXIS *
  CALL SYMBOL(-.05,.1,.1,
$42H0      100      200      300      400,0.,42)
  CALL SYMBOL(1.,.3,.1,21HCONE RESISTANCE (PSI),0.,21)
C * GIVE THE PLOT A TITLE *
  CALL SYMBOL(1.,-.25,.1,24HTIP RESISTANCE VS. DEPTH,
$0.,24)
  CALL SYMBOL(1.,-.40,.1,26HRELATIVE DENSITY = LAYERED,0.,26)
  CALL SYMBOL(1.,-.55,.1,
$25H( % TOP, % MID, % BOT),0.,25)
  CALL NUMBER(1.1,-.55,.1,DRT,0.,-1)
  CALL NUMBER(1.9,-.55,.1,DRM,0.,-1)
  CALL NUMBER(2.7,-.55,.1,DRB,0.,-1)
  CALL PLOT(2.0,-.65,-3)
C ** LEGEND PLOT **
  CALL SYMBOL(.95,-.25,.1,1.0.,-1)
  CALL SYMBOL(.95,-.40,.1,2.0.,-1)
  CALL SYMBOL(.95,-.55,.1,3.0.,-1)
  CALL SYMBOL(.95,-.70,.1,4.0.,-1)
  CALL SYMBOL(.95,-.85,.1,5.0.,-1)
  CALL SYMBOL(.95,-1.00,.1,0.0.,-1)
  CALL SYMBOL(.95,-1.15,.1,6.0.,-1)
  CALL SYMBOL(.1,-.15,.1,
$12HTEST SYMBOL,0.,12)
  CALL SYMBOL(.25,-.3,.1,0.1H1,0.,1)
  CALL SYMBOL(.25,-.45,.1,1H2,0.,1)
  CALL SYMBOL(.25,-.6,.1,1H3,0.,1)
  CALL SYMBOL(.25,-.75,.1,1H4,0.,1)
  CALL SYMBOL(.25,-.9,.1,1H5,0.,1)
  CALL SYMBOL(.25,-1.05,.1,1H6,0.,1)
  CALL SYMBOL(.25,-1.2,.1,1H7,0.,1)
  CALL PLOT(0.,0.,-3)
  CALL PLOT(1.4,0.,-2)
  CALL PLOT(0.,-1.3,-2)
  CALL PLOT(-1.4,0.,-2)
  CALL PLOT(0.,1.3,-2)
  CALL PLOT(12.,-1.5,999)
800 FORMAT(F20.10)
810 FORMAT(I3)
  STOP
  END
/*
//GO.SYSIN      DD *

```

Figure A. 13(cont.)

```

//B000038 JOB 306D3,TKHIAT
/*PRIORITY STANDARD
/*JOBPARM LINES=1,CARDS=100
//STEP1 EXEC FTG1CGV
//FORT.SYSIN DD *
C
C ** PROGRAM: 2LAYER FORTRAN **
C
      DIMENSION CR(175,5),TRANS(175,5),N(175)
      READ(5,800)DRT
      READ(5,800)DRB
      READ(5,810)NC
      DO 200 J=1,NC
        READ(5,810)N(J)
        NJ=N(J)
        DO 190 I=1,NJ
          READ(5,800)CR(I,J)
          READ(5,800)TRANS(I,J)
          CR(I,J)=CR(I,J)/100.
          TRANS(I,J)=-TRANS(I,J)/5.
190      CONTINUE
200      CONTINUE
      CALL PLOTS(0.,0.,50)
      CALL PLOT(3.,9.25,-3)
      CALL PLOT(4.,0.,-2)
      CALL PLOT(0.,-7.00,-2)
      CALL PLOT(-4.,0.,-2)
      CALL PLOT(0.,7.00,-2)
      DO 100 I=1,7
        CALL PLOT(.5,0.,-3)
        CALL PLOT(0.,-.05,2)
        CALL PLOT(0.,-7.,3)
        CALL PLOT(0.,-6.95,2)
100      CONTINUE
      CALL PLOT(-3.5,0.,-3)
      DO 110 I=1,6
        CALL PLOT(0.,-1.,-3)
        CALL PLOT(.05,0.,2)
        CALL PLOT(4.,0.,3)
        CALL PLOT(3.95,0.,2)
110      CONTINUE
      CALL PLOT(0.,6.,-3)
C ** THIS IS FOR THE 2-LAYER TEST **
      DO 150 J=1,NC
        IF(J.EQ.1)NSY=2
        IF(J.EQ.2)NSY=3
        IF(J.EQ.3)NSY=0
        IF(J.EQ.4)NSY=6
        NJ=N(J)
        DO 140 I=1,NJ
          CALL SYMBOL(CR(I,J),TRANS(I,J),.05,
140          $ NSY,0.,-1)
150      CONTINUE
      CALL PLOT(0.,-.05,-3)

```

Figure A.14: FORTRAN Program 2LAYER

```

CALL SYMBOL(-.3,0.,.1,2H 0,0.,.2)
CALL SYMBOL(-.3,-1.,.1,2H 5,0.,.2)
CALL SYMBOL(-.3,-2.,.1,2H10,0.,.2)
CALL SYMBOL(-.3,-3.,.1,2H15,0.,.2)
CALL SYMBOL(-.3,-4.,.1,2H20,0.,.2)
CALL SYMBOL(-.3,-5.,.1,2H25,0.,.2)
CALL SYMBOL(-.3,-6.,.1,2H30,0.,.2)
CALL SYMBOL(-.3,-7.,.1,2H35,0.,.2)
CALL PLOT(0.,.05,-3)
CALL SYMBOL(-.40,-4.5,.1,14HDEPTH (INCHES),90.,.14)
CALL SYMBOL(-.05,.1,.1,
$Q2H0      100      200      300      400,0.,.42)
CALL SYMBOL(1.,.3,.1,21HCONE RESISTANCE (PSI),0.,.21)
CALL SYMBOL(1.,-.25,.1,24HTIP RESISTANCE VS. DEPTH,
$0.,.24)
CALL SYMBOL(1.,-.40,.1,26HRELATIVE DENSITY = LAYERED,0.,.26)
CALL SYMBOL(1.,-.55,.1,
$20H( % TOP, % BOTTOM),0.,.20)
CALL NUMBER(1.1,-.55,.1,DRT,0.,-1)
CALL NUMBER(1.95,-.55,.1,DRB,0.,-1)
CALL PLOT(2.0,-.65,-3)
C ** LEGEND PLOT **
CALL SYMBOL(.95,-.25,.1,2,0.,-1)
CALL SYMBOL(.95,-.40,.1,3,0.,-1)
CALL SYMBOL(.95,-.55,.1,0,0.,-1)
CALL SYMBOL(.95,-.70,.1,6,0.,-1)
C CALL SYMBOL(.95,-.85,.1,5,0.,-1)
C CALL SYMBOL(.95,-1.00,.1,0,0.,-1)
C CALL SYMBOL(.95,-1.15,.1,6,0.,-1)
CALL SYMBOL(1,-.15,.1,
$12HTEST SYMBOL,0.,.12)
CALL SYMBOL(.25,-.3,.10,1H2,0.,.1)
CALL SYMBOL(.25,-.45,.1,1H3,0.,.1)
CALL SYMBOL(.25,-.6,.1,1H6,0.,.1)
CALL SYMBOL(.25,-.75,.1,1H7,0.,.1)
C CALL SYMBOL(.25,-.9,.1,1H5,0.,.1)
C CALL SYMBOL(.25,-1.05,.1,1H6,0.,.1)
C CALL SYMBOL(.25,-1.2,.1,1H7,0.,.1)
CALL PLOT(0.,.0.,-3)
CALL PLOT(1.4,0.,-2)
CALL PLOT(0.,-0.8,-2)
CALL PLOT(-1.4,0.,-2)
CALL PLOT(0.,0.8,-2)
CALL PLOT(12.,-1.5,999)
800 FORMAT(F20.10)
810 FORMAT(I3)
STOP
END
/*
//GO.SYSIN DD *

```

Figure A. 14(cont.)

```

//B000038 JOB 306DS,TKWIAT
/*PRIORITY STANDARD
/*JOBPARM LINES=1,CARDS=100
//STEP1 EXEC FTG1CGV
//FORT.SYSIN DD *
C
C *** FUGRO VS. MINI-CONE PLOT PROGRAM ***
C
      DIMENSION CR(175,5),TRANS(175,5),N(175)
      READ(5,800)DR
      READ(5,810)NC
      DO 200 J=1,NC
        READ(5,810)N(J)
        NJ=N(J)
        DO 190 I=1,NJ
          READ(5,800)CR(I,J)
          READ(5,800)TRANS(I,J)
          CR(I,J)=CR(I,J)/100.
          TRANS(I,J)=-TRANS(I,J)/5.
190      CONTINUE
200      CONTINUE
      CALL PLOTS(0.,0.,.50)
      CALL PLOT(3.,9.25,-3)
      CALL PLOT(4.,0.,-2)
      CALL PLOT(0.,-7.00,-2)
      CALL PLOT(-4.,0.,-2)
      CALL PLOT(0.,7.00,-2)
      DO 100 I=1,7
        CALL PLOT(.5,0.,-3)
        CALL PLOT(0.,-.05,2)
        CALL PLOT(0.,-7.,3)
        CALL PLOT(0.,-6.95,2)
100      CONTINUE
      CALL PLOT(-3.5,0.,-3)
      DO 110 I=1,6
        CALL PLOT(0.,-1.,-3)
        CALL PLOT(.05,0.,2)
        CALL PLOT(4.,0.,3)
        CALL PLOT(3.95,0.,2)
110      CONTINUE
      CALL PLOT(0.,6.,-3)
      DO 150 J=1,NC
        IF(J.EQ.1)NSY=1
        IF(J.EQ.2)NSY=2
        NJ=N(J)
        DO 140 I=1,NJ
          CALL SYMBOL(CR(I,J),TRANS(I,J),.05,
          $ NSY,0.,-1)
140      CONTINUE
150      CONTINUE
      CALL PLOT(0.,-.05,-3)
      CALL SYMBOL(-.3,0.,1.2H 0,0.,2)
      CALL SYMBOL(-.3,-1.,1.2H 5,0.,2)
      CALL SYMBOL(-.3,-2.,1.2H10,0.,2)
      CALL SYMBOL(-.3,-3.,1.2H15,0.,2)
      CALL SYMBOL(-.3,-4.,1.2H20,0.,2)
      CALL SYMBOL(-.3,-5.,1.2H25,0.,2)
      CALL SYMBOL(-.3,-6.,1.2H30,0.,2)
      CALL SYMBOL(-.3,-7.,1.2H35,0.,2)
      CALL PLOT(0.,.05,-3)
      CALL SYMBOL(-.40,-4.5,.1,14HDEPTH (INCHES),90.,14)
      CALL SYMBOL(-.05,.1,.1
      $42H0 100 200 300 400,0.,42)
      CALL SYMBOL(1.,-.3,.1,21HCONE RESISTANCE (PSI),0.,21)
      CALL SYMBOL(1.,-.25,.1,24HTIP RESISTANCE VS. DEPTH,
      $0.,24)
      CALL SYMBOL(1.,-.55,.1,22HRELATIVE DENSITY = %,0.,22)
      CALL NUMBER(2.9,-.55,1,DR,0.,-1)
      CALL SYMBOL(1.,-.40,.1
      $28HFUGRO CONE VS. MINI-ELECTRIC,0.,28)
      CALL PLOT(1.8,-.65,-3)
C *** LEGEND PLOT ***
      CALL SYMBOL(.20,-.15,.1,
      $12HCONE SYMBOL,0.,12)
      CALL SYMBOL(.15,-.35,.1,5HFUGRO,0.,5)
      CALL SYMBOL(.20,-.50,.1,4HMINI,0.,4)
      CALL SYMBOL(1.10,-.30,.1,2,0.,-1)
      CALL SYMBOL(1.10,-.45,.1,1,0.,-1)
      CALL PLOT(0.,0.,-3)
      CALL PLOT(1.6,0.,-2)
      CALL PLOT(0.,-.55,-2)
      CALL PLOT(-1.6,0.,-2)
      CALL PLOT(0.,.55,-2)
      CALL PLOT(12.,-1.5,999)
800      FORMAT(F20.10)
810      FORMAT(I3)
      STOP
      ENH
/*
//GO.SYSIN DD *

```

Figure A.15: FORTRAN Program FUGRO

A.5 SUMMARY

In sum, this user's guide is presented to complement the experimental procedure chapter of the thesis body. First, the hardware is described, and then instructions are issued for assembling the data acquisition system. Second, an overview of disk operating procedures and the software of the system is provided. The third and final section lists each of the BASIC data acquisition programs and the FORTRAN plotting programs with execution instructions. The appendix to this user's guide provides a list of the values of the constants required in each program. The values are representative of the first-generation miniature electrical cone penetrometer only.

CALIBRATION FACTORS AND CONSTANTS

Area

$$\begin{aligned}\text{Projected Area of Miniature Electrical Cone Tip} &= \pi D^2/4 \\ &= \pi(0.825)^2/4 \\ &= 0.55 \text{ sq.in.} \\ &.(0.53 \text{ sq.in.})\end{aligned}$$

$$\begin{aligned}\text{Area of Friction Sleeve} &= \text{sleeve length} * \pi * D \\ &= 3.25 * \pi *.825 = 8.576 \text{ sq.in.} \\ &(8.42 \text{ sq.in.})\end{aligned}$$

Note that the numbers in the parentheses are actually the correct values. The higher values were used in the first few penetrometer tests. To keep the data consistent for the remaining tests, the lower values were not used.

Projected Area of the Standard 10 sq.cm. Cone = 1.55 sq.in.

Calibration Factors

Cone Tip = 107 lb/millivolt

Friction Sleeve = 66 lb/millivolt

Position Transducer = 7.69 inches/volt

Standard 10 sq.cm. Cone = 967 lb/millivolt

Initial Voltages

Cone Tip \approx 14.95 millivolts

Friction Sleeve \approx 7.61 millivolts

Position Transducer = 0 volts at 0 inch extension

Rate of Penetration of Crane Insertion System = 1.7 in./sec

Computer Constants for Generating Depth

PTCALCS = 0.91 in./reading

ASUMCALCS = 1.38 in./reading

ASUMLAYERS = 1.38 in./reading

Number of Readings to Penetrate 35 inches

PTCALCS = N = 35

ASUMCALCS = N = 23

ASUMLAYERS = N = 23

APPENDIX B: CALIBRATION FACTORS

APPENDIX B. CALIBRATION FACTORS

B.1 PURPOSE

The purpose of this appendix section is to provide a listing of the programs used to calibrate the first generation miniature electrical cone penetrometer, the standard 10 sq.cm. electrical cone penetrometer, and the position transducer.

The three programs, MINI, FUGRO, and PTCAL, are based on the same command structure as the Applesoft BASIC/Labsoft programs described in the user's guide in Appendix 1. The calibration program listings are in figures B.3 and B.4.

B.2 THE MINIATURE ELECTRICAL CONE PENETROMETER

Program: MINI:

Prior to performing cone penetrometer tests, the miniature electrical cone penetrometer is calibrated to obtain the constant for converting millivolt signals into pound forces.

Program MINI has no variables or arrays that are different from the BASIC programs in appendix 1. The analog signals are read in exactly the same as in program ISAAC. The execution of program MINI is presented below.

Lines 5-13 identify the calibration program. Line 14 defines D\$ to represent control character "D" to allow disk access to the file name which is selected in line 15. In line 16 the computer prompts the user for the number of load increments such that the array in line 18 is dimensioned. In lines 21-23 the user must decide to create a file or read an existing file. To create the file, the program continues to lines 26-27 where the user inputs initial tip and sleeve voltages as determined from program ISAAC. Lines 50-80 control the rate of channel sampling. The rate is user determined. The rate therefore, is governed by the amount of time it takes to add (or subtract) weights to the cone loading rod, since no readings are recorded until "B" is typed in line 75. After five seconds, the voltage readings for both the tip and the friction sleeve are read in by the I-140 in channels 0 and 1. The data file is created or placed on the disk in lines 200-300 and is read from the disk in lines 320-400. In line 410 the user must decide whether or not to obtain a copy of the data from the printer. Lines 440-620 activate the printer and control the printing format. The program ends in line 5000.

The results of the miniature electrical cone calibration test are plotted in figure B.1. A calibration factor is derived from the plot for both the cone tip and the friction sleeve based on these linear relationships. The results are close to values previously plotted from hand calculations by Rude (1984).

The calibration factors obtained from program MINI are 107 lb/millivolt for the cone tip and 66 lb/millivolt for the friction sleeve.

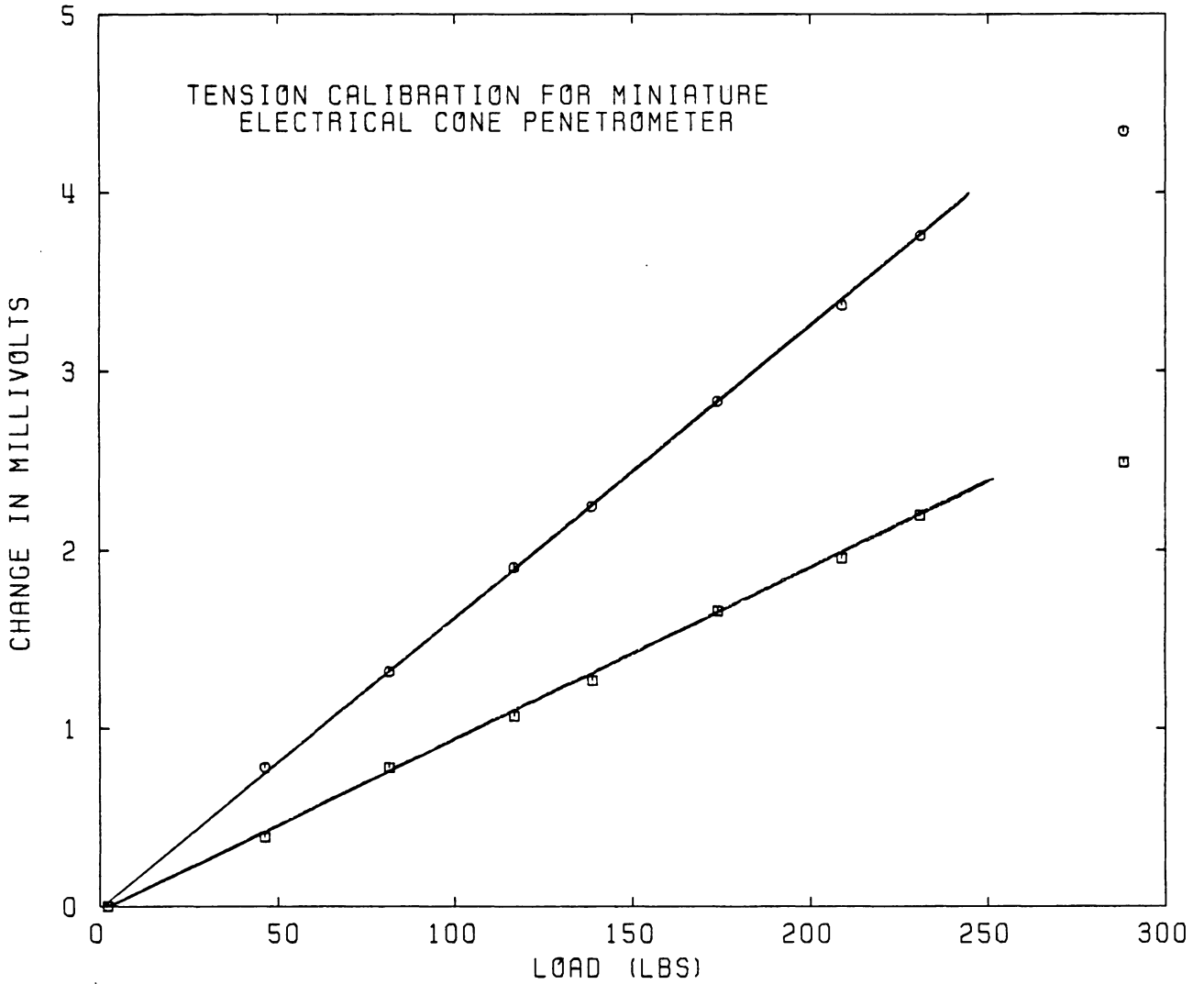


Figure B.1: Calibration Plot for the Miniature Electrical Cone Penetrometer (Generation 1)

B.2.1 The Standard 10 sq.cm. Electrical Cone Penetrometer

Program: FUGRO:

The method for calibrating the standard sized cone is different from the miniature cone. Placing the standard cone in tension is not feasible since a weight rod cannot be machined to screw into the tip of the cone. The machine shop at Virginia Tech is equipped for machining standard American threads. Since the cone was originally designed in the Netherlands, all threading on the cone is metric. Therefore, some steel pieces were machined to fit into both ends of the cone without actually threading into place. The fit is not snug. The only way to calibrate the cone is to place the cone with these steel adapter rods into compression. The calibration test performed on the cone utilizes a Tinius-Olsen compression machine to provide a stress-controlled test.

The calibration procedure was performed three times. The first calibration test loaded and unloaded the cone to 4000 pounds in increments of 500 pounds. The second calibration test loaded and unloaded the cone to 4000 pounds in increments of 400 pounds. The third and final calibration test loaded the cone to 4000 pounds in 200 pound increments.

Program FUGRO is a modified version of program MINI. The program differs in lines 70-80. These lines control the channel sampling rate. The Tinius-Olsen machine is continuously loading, therefore, if the program paused the five seconds before reading the voltage channel then the load would be representative of some load greater than the desired load.

Lines 160-175 were included in this program in order to calculate voltage change between increments, (in addition to taking immediate readings), since the loading and unloading occurs in equal increments.

The results of the stress-controlled calibration tests for the standard size cone varied linearly as evidenced in figure B.2. The calibration factor derived from the test results for the cone tip is 967 lb/millivolt. The friction sleeve was not calibrated.

B.3 THE POSITION TRANSDUCER

Program: PTCAL:

The calibration procedure for the position transducer was previously described in the body of the thesis. Program PTCAL uses no new variables or arrays. The program execution is explained below.

Lines 10-13 identify the program. Line 14 defines D\$ to represent control character "D" to allow disk access to the file name selected in line 15. Lines 17-25 require the typical user input (number of length increments and the option to create a file or to read an existing file), and dimension the arrays. Lines 50-150 read in the voltage values. When the program "beeps" in line 60, the user increases the transducer cable one inch. Channel number 1 of the ISAAC 91A reads in the value of the transducer the same as in the program ISAACPT. After all the voltages are read, lines 160-175 calculate the change in voltage between each reading. Lines 200-300 create the data text file and lines 320-400 read

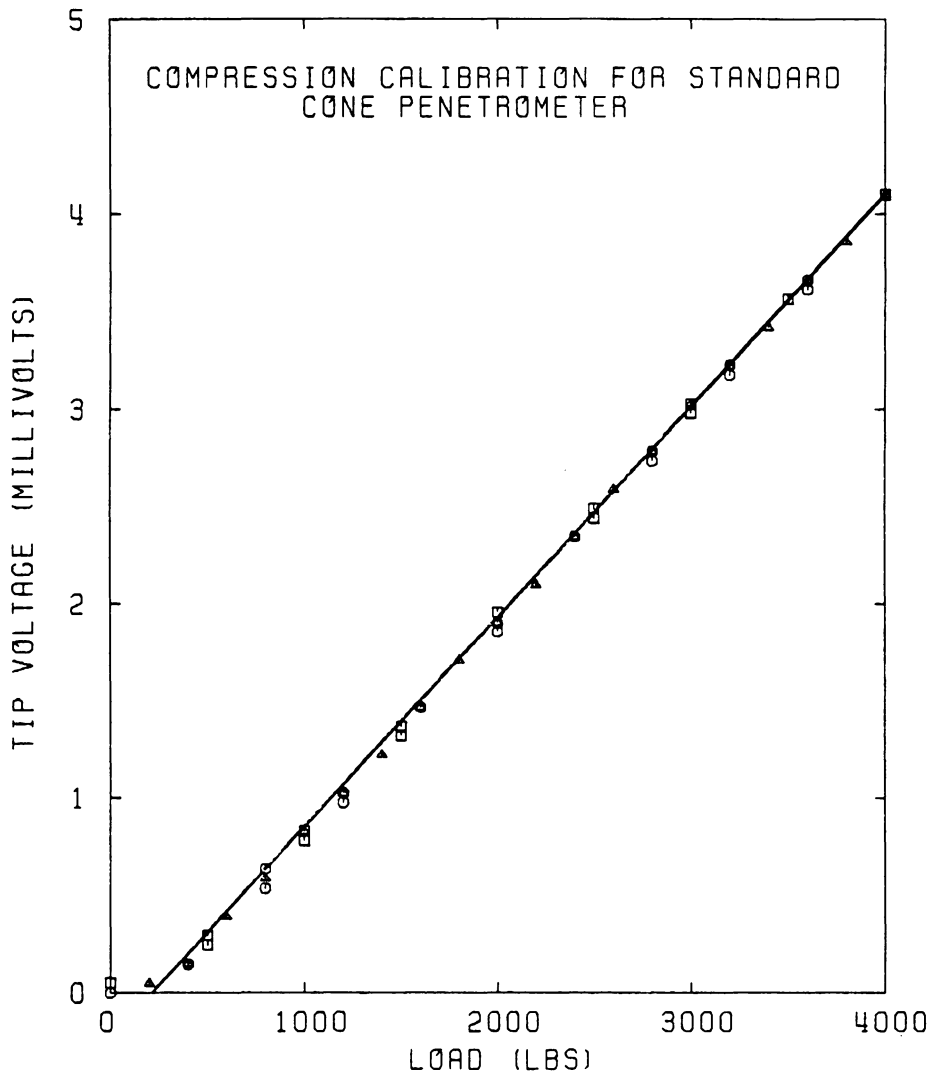


Figure B.2: Compression Calibration for the Earth Technology Standard Size Cone Penetrometer

the file. Line 410 asks the user whether or not to have the file printed. Lines 410-620 control the printer. The program ends in line 5000.

The calibration test was repeated three times by the data acquisition system and one time by hand recording the voltages from a digital voltmeter. The calibration factor derived from the numerical results is equal to 7.69 inches/millivolt.


```

JLOAD MINI
JLIST

5 HOME : VTAB 5
10 PRINT "MINIATURE ELECTRICAL CONE CALIBRATION PROGRAM"
11 PRINT
12 PRINT "THIS PROGRAM ASSUMES A TENSION LOAD TEST"
13 PRINT
14 D$ = CHR$(4): REM DOS CONTROL-D
15 INPUT "TEXT FILENAME? ";FLNAM$
16 PRINT
17 INPUT "NUMBER OF LOAD INCREMENTS = ";N
18 DIM TEST(1,N)
20 PRINT
21 PRINT "IS THIS OPTION 1:CREATE THE FILE OR OPTION 2:READ THE F
ILE AND PRINT ?"
22 INPUT "TYPE '1' OR '2': ";OPT
23 IF OPT = 2 THEN GOTO 320
24 HOME : VTAB 5
25 PRINT
26 INPUT "INITIAL TIP VOLTAGE (MV) = ";ICVOLT
27 INPUT "INITIAL SLEEVE VOLTAGE (MV) =";FIVOLT
30 PRINT
40 HOME
50 FOR J = 0 TO N - 1
60 & BEEP
65 HOME : VTAB 5
70 PRINT "INCREASE OR DECREASE THE LOAD": PRINT
71 PRINT "TYPE 'B' AND THE READINGS WILL BE TAKEN IN 5-SECONDS"
75 INPUT "TYPE 'B': ";B$
76 IF B$ = "B" THEN GOTO 90
80 & PAUSE = 5
90 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
95 I = 0
100 & AIN, (TV) = 0, (C#) = 0, (D#) = 1, (FU) = FN VOLTS(RAW%)
105 I = I + 1
110 IF I < 2 THEN GOTO 100
115 TEST(0,J) = 0
116 TEST(0,J) = ABS (TEST(0,J) - ICVOLT)
120 I = 0
125 & AIN, (TV) = 0, (C#) = 1, (D#) = 1, (FU) = FN VOLTS(RAW%)
130 I = I + 1
135 IF I < 2 THEN GOTO 125
140 TEST(1,J) = 0
141 TEST(1,J) = ABS (TEST(1,J) - FIVOLT)
144 PRINT
145 PRINT "LOAD INCREMENT = ";J
150 PRINT "TIP RESISTANCE (MV) = ";TEST(0,J)
155 PRINT "SLEEVE FRICTION (MV) = ";TEST(1,J)
156 PRINT : PRINT
159 NEXT J
200 REM OPTION 1: CREATE FILE
210 PRINT D$;"OPEN ";FLNAM$
220 PRINT D$;"DELETE ";FLNAM$
230 PRINT D$;"OPEN ";FLNAM$
240 PRINT D$;"WRITE ";FLNAM$
250 PRINT N
260 FOR I = 0 TO N - 1

```

Figure B.3: BASIC Program MINI

```

270 PRINT I
275 PRINT TEST(0,I)
280 PRINT TEST(1,I)
290 NEXT I
300 PRINT D$;"CLOSE ";FLNAM$
310 GOTO 5000
320 REM OPTION 2: READ DATA FILE
330 PRINT D$;"OPEN ";FLNAM$
340 PRINT D$;"READ ";FLNAM$
350 INPUT N
360 FOR I = 0 TO N - 1
370 INPUT I
375 INPUT TEST(0,I)
380 INPUT TEST(1,I)
390 NEXT I
400 PRINT D$;"CLOSE ";FLNAM$
410 PRINT "DO YOU WANT A COPY OF DATA NOW?"
420 INPUT "TYPE 'Y' OR 'N' ";YES$
430 IF YES$ = "N" THEN GOTO 5000
440 REM PRINT ROUTINE
450 PRINT "TURN PRINTER POWER ON"
460 INPUT "TYPE 'C' TO CONTINUE: ";C$
470 IF C$ = "C" THEN GOTO 480
480 PRINT CHR$(4);"PR#1"
490 PRINT CHR$(9);"8ON"
500 PRINT CHR$(9);"6L"
510 PRINT "CALIBRATION FOR THE MINIATURE ELECTRICAL CONE PENETROM
ETER"
511 PRINT "(FIRST-GENERATION DESIGN)"
512 PRINT "THIS IS A TENSION LOAD TEST"
513 PRINT
520 PRINT "NUMBER OF LOAD INCREMENTS: ";N
530 PRINT : PRINT "INITIAL DATA:"
540 PRINT "INITIAL TIP RESISTANCE (MV) = ";TEST(0,0)
545 PRINT "INITIAL SLEEVE FRICTION (MV) = ";TEST(1,0)
550 PRINT : PRINT "VOLTAGE DATA"
560 PRINT SPC(5)"LOAD INCREMENT" SPC(8)"TIP VOLTAGE" SPC(8)"S
LEEVE VOLTAGE"
580 FOR I = 0 TO N - 1
590 PRINT TAB(10)I TAB(17)TEST(0,I) TAB(13)TEST(1,I)
600 NEXT I: PRINT
610 PRINT CHR$(4);"PR#0"
620 PRINT "END OF FILE"
5000 END

```

Figure B.3(cont.)

```

JLOAD FUGRO
JLIST

5 HOME : VTAB 5
10 PRINT "FUGRO CALIBRATION PROGRAM": PRINT
11 PRINT "THIS PROGRAM ASSUMES A STRESS-CONTROLLED COMPRESSION TEST"
13 PRINT
14 D$ = CHR$(4): REM DOS CONTROL-D
15 INPUT "TEXT FILENAME? ";FLNAM$
16 PRINT
17 INPUT "NUMBER OF LOAD INCREMENTS = ";N
18 DIM TEST(1,N)
19 DIM CCHANGE(N)
20 PRINT
21 PRINT "IS THIS OPTION 1:CREATE THE FILE OR OPTION 2:READ THE FILE AND PRINT ?"
22 INPUT "TYPE '1' OR '2': ";OPT
23 IF OPT = 2 THEN GOTO 320
24 HOME : VTAB 5
25 PRINT
26 INPUT "INITIAL TIP VOLTAGE (MV) = ";ICVOLT
28 PRINT
30 INPUT "WHAT IS THE LOAD INCREMENT? ";P
31 PRINT
35 INPUT "INITIAL LOAD = ";IL
40 HOME
50 FOR J = 0 TO N - 1
60 & BEEP
65 HOME : VTAB 5
70 PRINT "INCREASE OR DECREASE THE LOAD"
71 PRINT "TYPE 'B' AND THE READINGS WILL BE TAKEN IMMEDIATELY"
75 INPUT "TYPE 'B': ";B$
76 IF B$ = "B" THEN GOTO 90
90 DEF FN VOLTS(X) = ABS (X / 20.48 - 100)
95 I = 0
100 & AIN,(TV) = Q,(C#) = 0,(D#) = 1,(FU) = FN VOLTS(RAW%)
105 I = I + 1
110 IF I < 2 THEN GOTO 100
115 TEST(0,J) = Q
116 TEST(0,J) = ABS (TEST(0,J) - ICVOLT)
140 PRINT
145 PRINT "LOAD INCREMENT = ";J
150 PRINT "TIP RESISTANCE (MV) = ";TEST(0,J)
156 PRINT : PRINT
159 NEXT J
160 REM CALCULATE CHANGE IN VOLTS
165 FOR J = 1 TO N - 1
170 CCHANGE(J) = ABS (TEST(0,J) - TEST(0,J - 1))
175 NEXT J
200 REM OPTION 1: CREATE FILE
210 PRINT D$;"OPEN ";FLNAM$
220 PRINT D$;"DELETE ";FLNAM$
230 PRINT D$;"OPEN ";FLNAM$
240 PRINT D$;"WRITE ";FLNAM$
250 PRINT N
255 PRINT P
256 PRINT IL

```

Figure B.4: BASIC Program FUGRO

```

260 FOR I = 0 TO N - 1
270 PRINT I
275 PRINT TEST(0,I)
290 NEXT I
291 FOR I = 1 TO N - 1
292 PRINT CCHANGE(I)
294 NEXT I
300 PRINT D$;"CLOSE ";FLNAM$
310 GOTO 5000
320 REM OPTION 2: READ DATA FILE
330 PRINT D$;"OPEN ";FLNAM$
340 PRINT D$;"READ ";FLNAM$
350 INPUT N
355 INPUT P
356 INPUT IL
360 FOR I = 0 TO N - 1
370 INPUT I
375 INPUT TEST(0,I)
390 NEXT I
391 FOR I = 1 TO N - 1
392 INPUT CCHANGE(I)
394 NEXT I
400 PRINT D$;"CLOSE ";FLNAM$
410 PRINT "DO YOU WANT A COPY OF DATA NOW?"
420 INPUT "TYPE 'Y' OR 'N' ";YES$
430 IF YES$ = "N" THEN GOTO 5000
440 REM PRINT ROUTINE
450 PRINT "TURN PRINTER POWER ON"
460 INPUT "TYPE 'C' TO CONTINUE: ";C$
470 IF C$ = "C" THEN GOTO 480
480 PRINT CHR$(4);"PR#1"
490 PRINT CHR$(9);"80N"
500 PRINT CHR$(9);"6L"
510 PRINT "CALIBRATION FOR FUGRO CONE PENETROMETER"
512 PRINT "(THIS IS A STRESS-CONTROLLED COMPRESSION TEST)"
513 PRINT
520 PRINT "NUMBER OF LOAD INCREMENTS: ";N
526 PRINT "THE LOAD INCREMENT IS (LB): ";P
530 PRINT : PRINT "INITIAL DATA:"
535 PRINT "INITIAL LOAD (LB) = ";IL
540 PRINT "INITIAL TIP RESISTANCE (MV) = ";TEST(0,0)
550 PRINT : PRINT "VOLTAGE DATA"
560 PRINT SPC(5)"LOAD INCREMENT" SPC(8)"TIP VOLTAGE"
580 FOR I = 0 TO N - 1
590 PRINT TAB(10)I TAB(17)TEST(0,I)
600 NEXT I: PRINT
601 PRINT SPC(5)"INCREMENT CHANGE" SPC(5)"TIP VOLTAGE CHANGE"
602 FOR I = 1 TO N - 1
603 PRINT TAB(12)I TAB(16)CCHANGE(I)
604 NEXT I
610 PRINT CHR$(4);"PR#0"
620 PRINT "END OF FILE"
5000 END

```

Figure B.4(cont.)

APPENDIX C: FACTORS AFFECTING CONE PENETROMETER MEASUREMENTS

APPENDIX C. FACTORS AFFECTING THE MEASUREMENTS OF CONE PENETROMETERS

There are several significant factors that affect measured cone resistance data. The following appendix presents some of these aspects, broken down into three general categories:

1. Equipment Design
2. Testing Procedures
3. Soil Type

1. EQUIPMENT DESIGN

- Cone Apex Angle - The cone apex angle strongly influences the shape of the theoretical soil failure mechanism and therefore affects the derived bearing capacity factors used to predict and interpret cone tip resistance. For example, the bearing capacity factor for a cone-shaped penetrometer would be greatly overestimated if a factor for a flat-ended penetrometer were used instead. The apex angle also influences the surface roughness of the penetrometer.
- Surface Roughness - The rougher the penetrometer surface, the greater the resistance to penetration. The machined surface of

a cone penetrometer is expressed in the ratio of penetrometer to soil friction angle, δ / ϕ . The penetrometer to soil friction ratio was experimentally determined by running a series of direct shear interface tests in which the upper half of the shear box contained the test sand while the lower half held a solid sample of penetrometer material. The results of these tests yielded $\delta / \phi = 0.0$ to 0.9, as shown in figure C.1, where $\delta / \phi = 0.0$ represents a smooth cone or for a perfectly rough base $\delta / \phi = 0$. For machined surfaces typical of most penetrometers used in practice, δ / ϕ is approximately 0.5. Additional test results show that the roughness value is independent of the soil void ratio, friction angle and confining pressure. For rough surfaces, bearing capacity factors are independent of α (where $\alpha =$ one half the cone apex angle) for α greater than $(45 - \phi/2)$. For smooth and semi-rough surfaces, bearing capacity factors are dependent on tip angle as is shown in figure C.2.

- Inclination - Many cones have the capability to incorporate slope sensors in their design which could monitor the non-verticality of the cone during penetration. Once the tip of a cone is deflected due to an obstruction, it will proceed along a curved path. A deflection with a curvature greater than 1 or 2 degrees could cause errors in the readings as well as permanent damage to the rods.

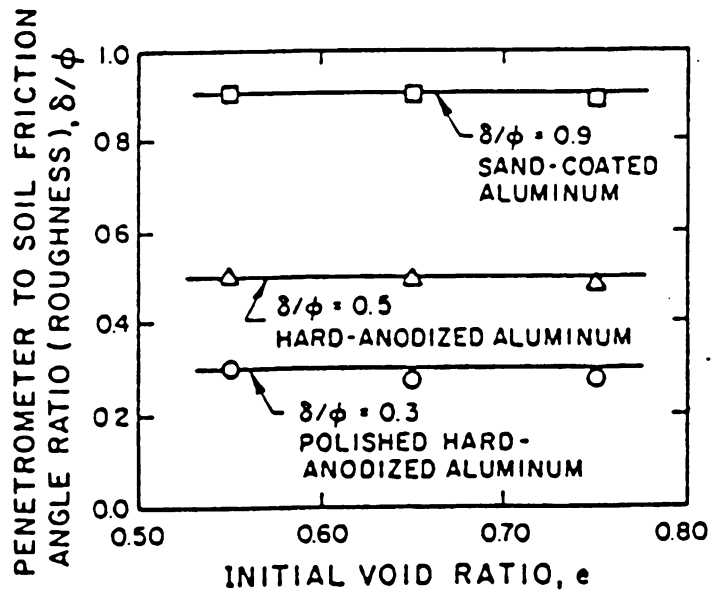


Figure C.1: Roughness Characteristics of Different Penetrometer Materials. (δ = soil to solid friction angle, ϕ = soil friction angle)

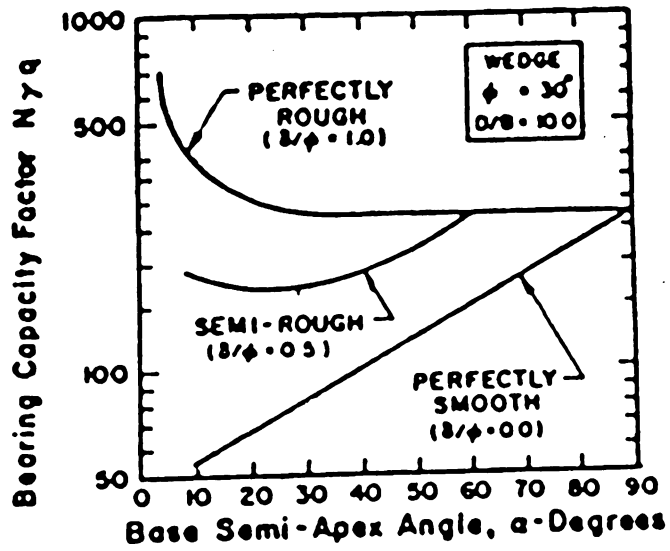


Figure C.2: Variation of Penetration Resistance Factors with Base Semi-Apex Angle and Surface Roughness

could cause errors in the readings as well as permanent damage to the rods.

- Mechanical Problems - Soil ingress along the joints of the cone affects the friction readings. Each cone should be equipped with o-ring seals to prevent soil from entering the strain gage housing.
- Machine Tolerance - The allowed diametral error between the cone base and the friction sleeve is 0.010 inches. Therefore, tolerance for the 0.825 inch cone should not exceed 0.006 inches. If machine error and wear exceed tolerance, variations in the sleeve friction result. If the tip diameter is greater than the friction sleeve, the result is lower friction readings.
- Size and Boundary Conditions of Test Chamber - Parkin and Lunne (1982) have concluded that laboratory cone calibration chamber readings are influenced by the size of the calibration chamber and boundary conditions. Provided that the cone reading can be accepted free from boundary effects, then it is possible to correlate the CPT performance in calibration chambers to that found in a large in situ sand body. For tests in loose sand, the disturbed zone around the penetrometer tip is localized sufficiently such that it is not influenced by the chamber boundary. For dense sand, however, distortions penetrate through the sand and into the chamber boundary for all diameter ratios, R_d (where: $R_d =$

diameter of chamber (d_c) / diameter of the probe (d_p). Cone resistance in loose sand ($D_r \approx 15$ to 30%) is independent of boundary effects; whereas, in dense sand ($D_r \approx 90\%$) a minimum diameter ratio of 50 is recommended for normally consolidated sands. For samples of inadequate size the cone resistance is controlled by the chamber boundary lateral stress which is not representative of in situ behavior.

2. Testing Procedures

- Rate of Penetration - The effects of the rate of penetration on cone bearing and side friction values have contradictory conclusions. The standard penetration rate accepted by Europe and the USA is 2 cm/sec (0.8 in./sec). However, rates which fall within + or - 25% of the standard rate (1 cm/sec to 3 cm/sec) do not significantly influence the cone data.

Jezquel (1969) performed penetrometer tests varying the type of penetrometer, speed of penetration and soil type. The cone bearing and friction values varied with soil type and not with penetration rate. For clean, loose sand above the water table there is no effect. Below the water table the value of tip resistance at 1 cm/sec was 20% lower than at 10 cm/sec.

L. Kok (1974) tested four types of electrical Dutch static cone penetrometers at varied speeds. There were no statistical differences in values due to speed. The differences were due to cone design.

Villet and Mitchell (1981) tested fine-dense and medium-dense sands with a standard 10 sq.cm. cone and varied the penetration rates between 1 and 4 cm/sec. There were no significant cone value differences.

Ponte (1977) tested fine-dense and medium-dense sands with a standard 10 sq.cm. cone. For speeds 0.01 to 4 in/sec, the tip resistance and sleeve friction values slightly decreased for slower rates of penetration and slightly increased for faster rates. However, the effect is considered negligibly small.

Campanella and Robertson (1984) report that rate effects are generally due to pore pressure effects and to some extent due to creep and particle crushing.

In general, after examining a 15 year history of penetration rate, the tip resistance and sleeve friction values are affected only in saturated soils. (In saturated soils, the dynamic pore pressures are allowed to dissipate as the cone is driven resulting in higher values for both cone bearing and side friction.) However, for consistent results, each researcher recommends performing penetration tests at as close to the standard rate as possible.

- Vibratory Effect - Any vibratory effects during testing tend to densify the soil resulting in underestimating the soil susceptibility to liquefaction due to increased cone resistance values.

- Temperature - Calibration for the cone is performed in the laboratory which is approximately 68 degrees (F). The cone is driven into soil which is cooler than the atmosphere. This affect is more significant in field testing. The difference in temperature can effect the friction values.

3. Soil Type

- Compressibility - An advancing cone displaces particle packing. The more compressible the soil, the easier it is to displace; and the result is lower tip resistance. Grain crushing causes the soil to appear to increase in compressibility.
- Cementation - Cementation commonly occurs in older soil deposits. It causes the soil to reduce in compressibility resulting in increased tip resistance.
- Position of the Water Table - In saturated soil, water can enter the space between the cone base and the friction sleeve. This causes the recorded resistance value to become slightly less than true bearing pressure. The effect of encountering the water table during penetration results in a slight decrease in tip resistance.
- Age - In older soils that are relatively free-draining, a higher resistance layer forms around present or past groundwater levels.

Fluctuations in the ground-water level produce wetting and drying cycles which may produce chemical precipitation causing some cementation between soil grains.

- Grain Size - For standard cones, gravelly soils produce sharp peaks in the resistance versus depth plot. A danger with these soils exists since the cone tip could become deformed during driving causing undiscoverable errors in data.

APPENDIX D. MINIATURE ELECTRICAL CONE PENETROMETER TEST RESULTS

(Cone resistance versus depth for homogeneous samples)

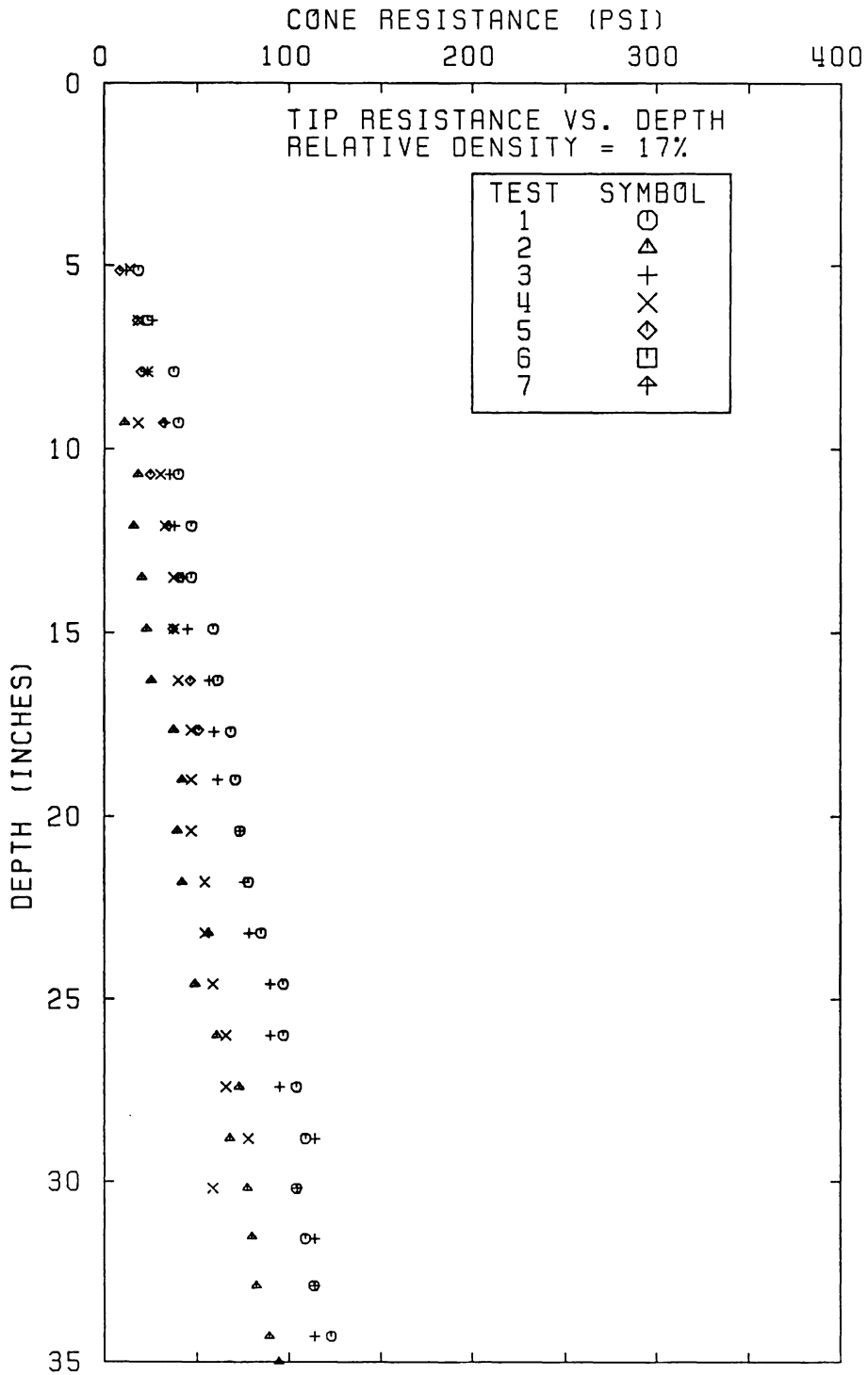


Figure D.1: Homogeneous Sample $17 \pm 2\%$

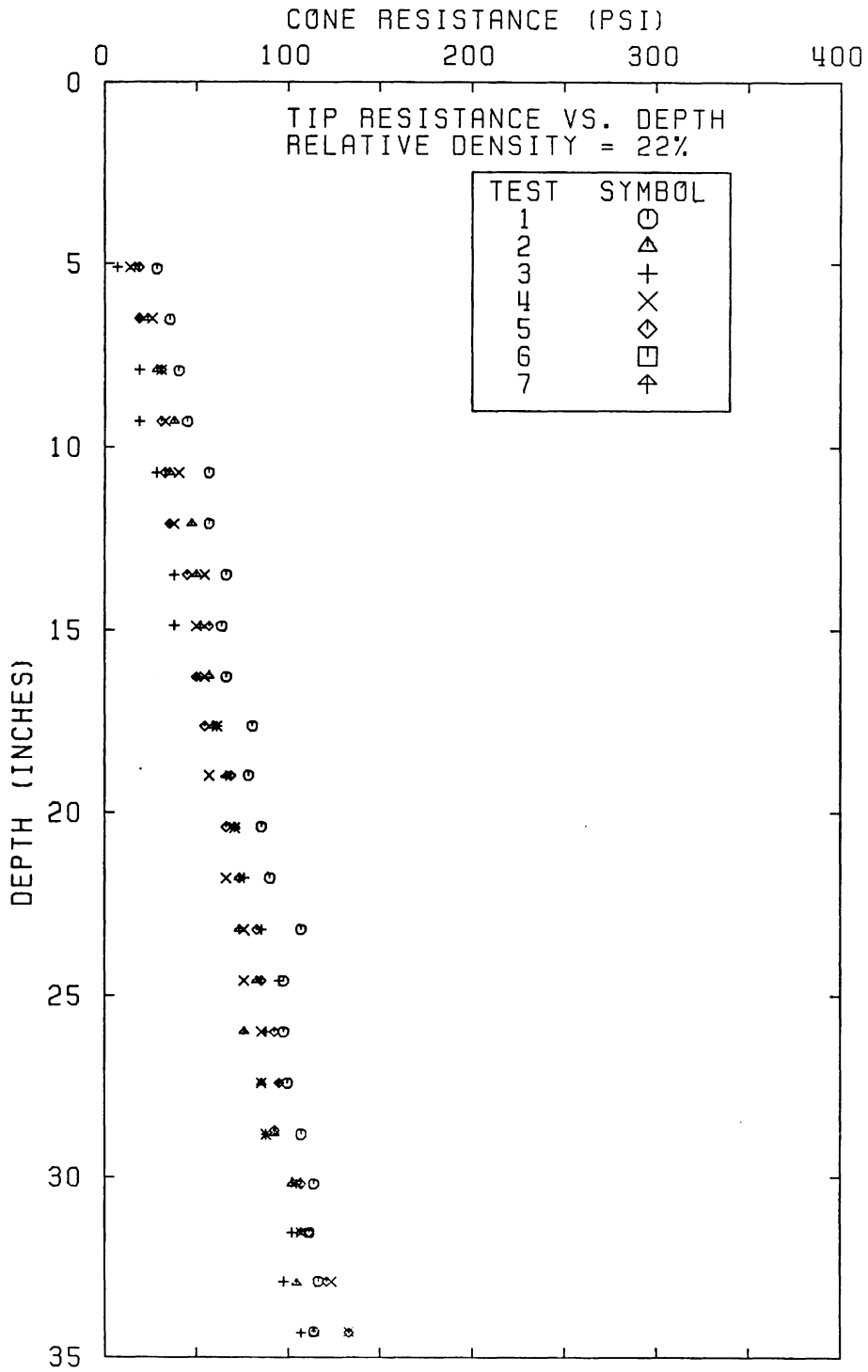


Figure D.2: Homogeneous Sample $22 \pm 2\%$

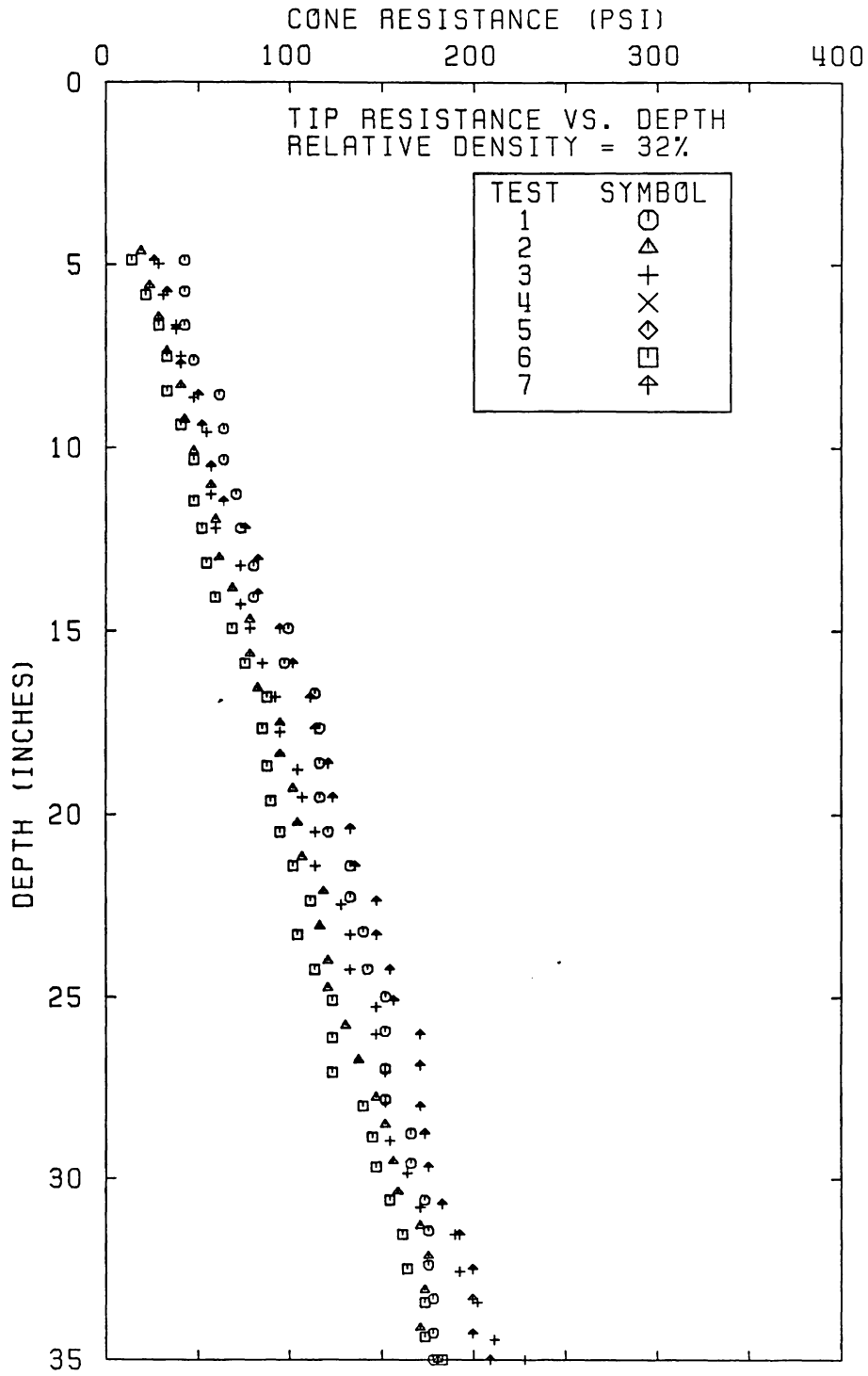


Figure D.3: Homogeneous Sample $32 \pm 2\%$

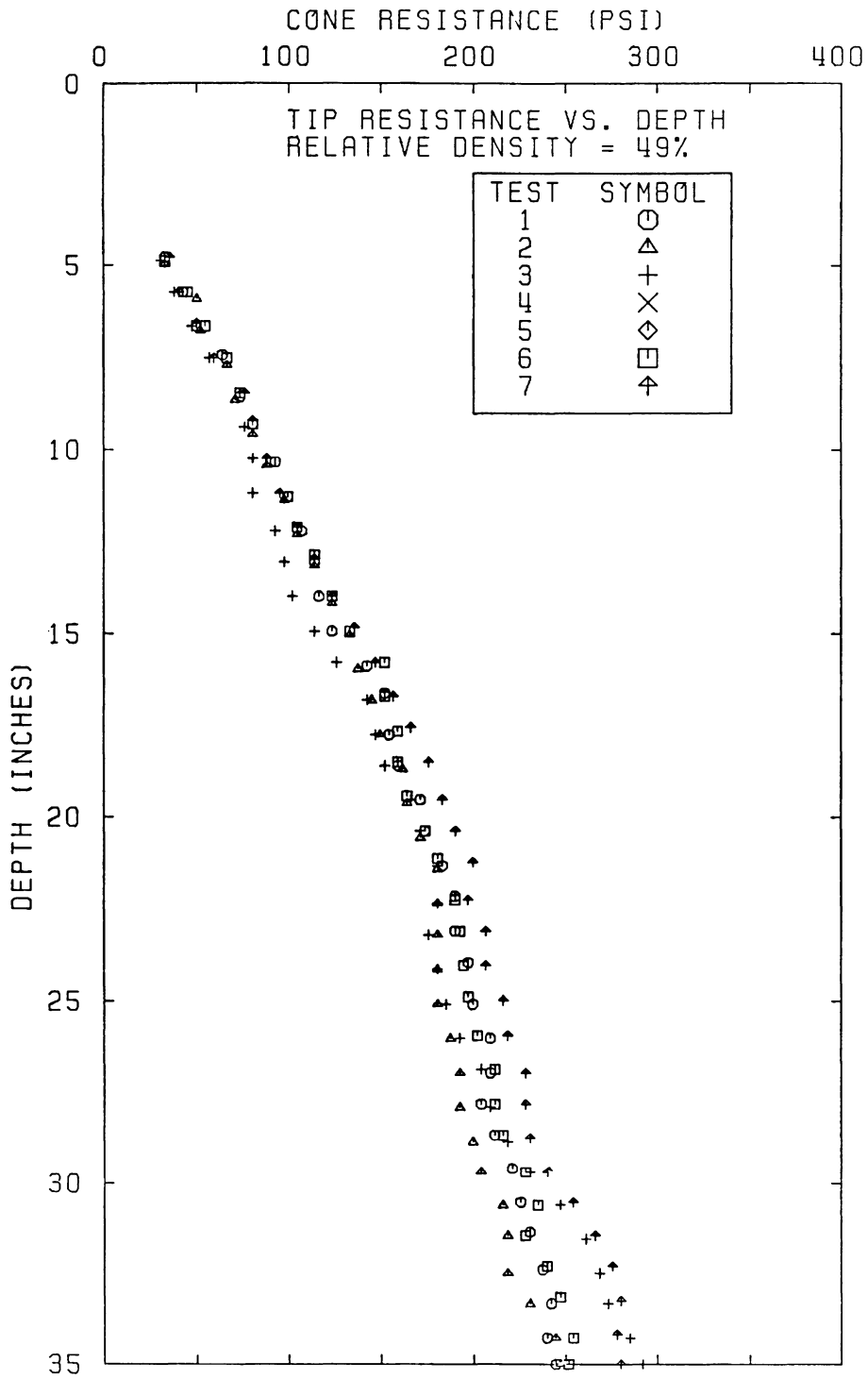


Figure D.4: Homogeneous Sample $49 \pm 2\%$

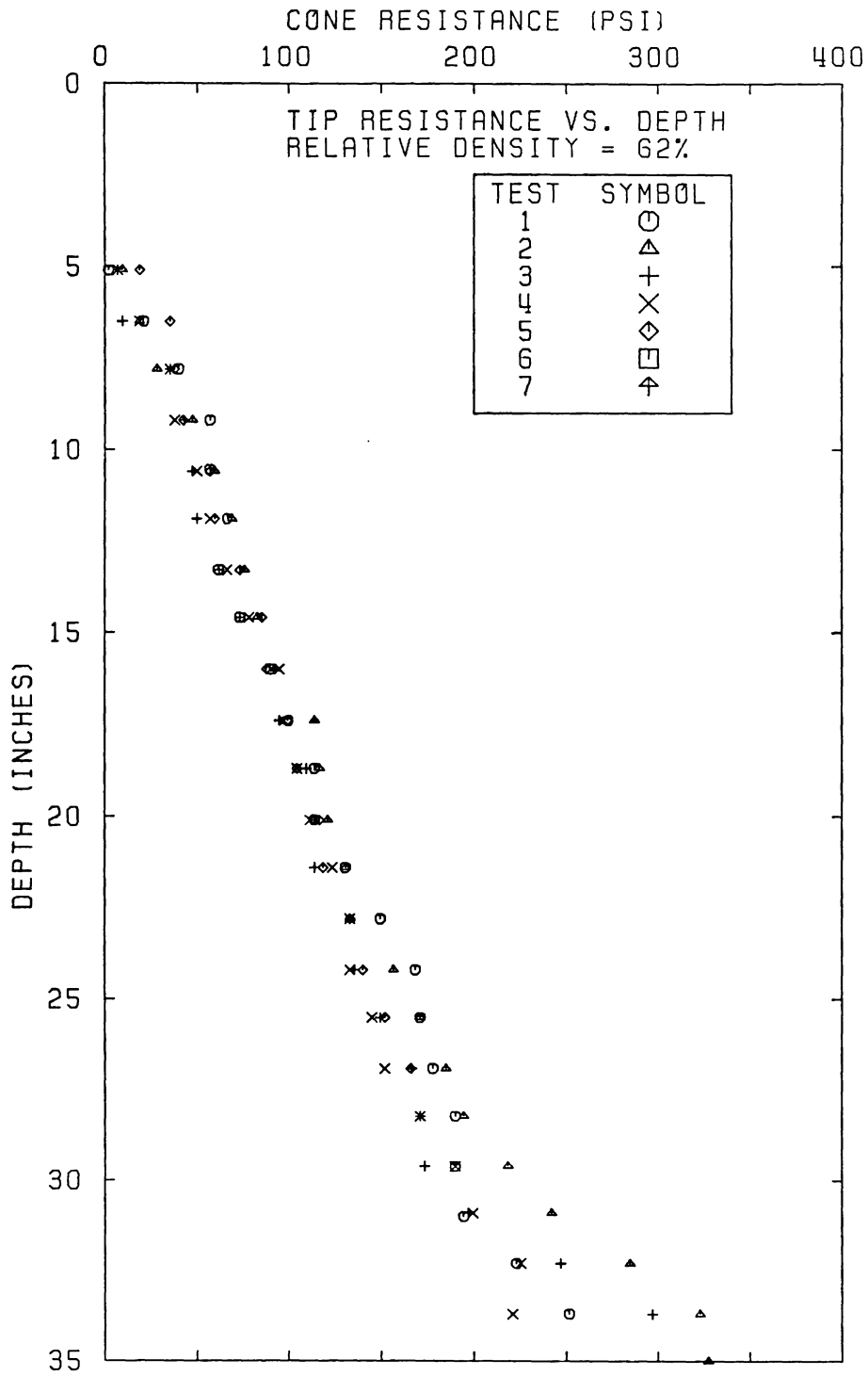


Figure D.5: Homogeneous Sample $62 \pm 2\%$

REFERENCES

- ASTM, "Tentative Method for Deep, Quasi-Static Cone and Friction-Cone Penetration Test of Soil", ASTM Designation: D3441 - 75T.
- Baldi, G., Bellotti, R., Ghionna, V., Jamiolkowski, M., and Pasqualini, E., "Cone Resistance in Dry NC and OC Sands", Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division at the ASCE National Convention, St. Louis, Missouri, October, 1981.
- Campagnella, R.G. and Robertson, P.K. "Applied Cone Research", Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division at the ASCE National Convention, St. Louis, Missouri, October, 1981. Edited by G.M. Norris and R.D. Holtz.
- Christian, J.T. and Swiger, W.F., "Statistics of Liquefaction and SPT Results", Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, GT11, November, 1975, pp. 1135-1150.
- Clough, G.W. and Rude, L.C., "Development of a Portable Field Soil Exploration Unit for Earthquake Reconnaissance", Proposal no. 83-1475-04, April, 1983.
- De Beer, E.E., "Interpretation of Results of Static Penetration Tests", Proceedings of the European Symposium on Penetration Testing, Vol. 2.1, Stockholm, Sweden, June, 1974.
- De Ruiter, J., "Current Penetrometer Practice", Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division, ASCE, at the ASCE National Convention, St. Louis, MO, October, 1981. Edited by G.M. Norris and R.D. Holtz.
- DiBiagio, S., Hansen, S. Borg and Wetlesen, T., "Instrumentation and Data Acquisition", Contributions to the Seminar on Shell Brent B Instrumentation Project, November, 1979, Norwegian Geotechnical Institute Publication No. 137, Oslo, 1981.
- Douglas, B.J. and Olsen, R.S., "Soil Classification Using Electric Cone Penetrometers", Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division, ASCE, at the ASCE National Convention, St. Louis, MO, October, 1981. Edited by G.M. Norris and R.D. Holtz.

- Duncan, J.M., "Review of Literature on Interpretation of Cone Penetrometer Tests", Manual written for the Department of Civil Engineering, University of California at Berkeley, September, 1983.
- Duncan, J.M., Byrne, P., Wong, K.S., Mabry, P., "Strength, Stress-Strain and Bulk Modulus Parameters for Finite Element Analyses of Stresses and Movements in Soil Masses", Report No. UCB/GT/180-01, August, 1980.
- Durgunoglu, H.T., "Influence of Penetrometer Characteristics on Static Penetration Resistance", Proceedings of the European Symposium on Penetration Testing, Vol. 2, 1974.
- Durgunoglu, H.T. and Mitchell, J.K., "Static Penetration Resistance of Soils: I. Analysis", Proceedings, ASCE Specialty Conference on In-Situ Measurement of Soil Properties, Vol. I, 1975.
- Durgunoglu, H.T. and Mitchell, J.K., "Static Penetration Resistance of Soils: II. Evaluation of Theory and Implications for Practice", Proceedings, ASCE Specialty Conference on In-Situ Measurement of Soil Properties, Vol. I, 1975.
- European Symposium on Penetration Testing, Stockholm, Sweden, Vol. 1, 2.1, 2.2, 1974.
- Gardner, W.S. and Nathan, S.V., "The Suitcase Cone System", Cone Penetration Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division, ASCE, at the ASCE National Convention, St. Louis, MO, October, 1981. Edited by G.M. Norris and R.D. Holtz.
- Jacobsen, Moust, "On Pluviation Compaction of Sand", Report No. 9, Laboratoriet for Fundering, University of Aalborg, Denmark, 1976.
- Janbu, N. and Senneset, K., "Effective Stress Interpretation of In Situ Static Penetration Tests", Proceedings of the European Symposium on Penetration Testing, Vol. 2, 1974.
- Kamata, M., "A New Continuous Cone Penetration Test Method with a Deep-Sounding Vehicle", Proceedings of the European Symposium on Penetration Testing, Vol. 2, 1974.
- Kok, L., "The Effect of the Penetration Speed and the Cone Shape on the Dutch Static Cone Penetrometer Test Results", Proceedings of the European Symposium on Penetration Testing, Vol. 2, 1974.
- Kovacs, W.D. and Salomone, L.A., "SPT Hammer Energy Measurements", Journal of the Geotechnical Engineering Division, April, Vol. 108, No. GT4, pp. 599-620.

- Lunne, T. and Kleven, A., "Role of CPT in North Sea Foundation Engineering", Norwegian Geotechnical Institute Publication No. 139, Oslo, 1982.
- Marcuson, W. and Bieganousky, W.A., "Uniform Placement of Sand", Journal of the Geotechnical Engineering Division, Vol. 102, No. GT3, March, 1976, pp. 229-233.
- Meyerhof, G.G., "Penetration Testing Outside Europe", General Report, Proceedings of the European Symposium on Penetration Testing, Stockholm, Sweden, Vol. 2.2, 1974.
- Mitchell, J.K. and Lunne, T.A., "Cone Resistance as a Measure of Sand Strength", Journal of the Geotechnical Engineering Division, ASCE, Vol. 104, No. GT7, July, 1978, pp. 995-1012.
- Muromachi, T., "Cone Penetrometer Testing in Japan", Proceedings of the European Symposium on Penetration Testing, Vol. 1, 1974.
- Norris, G.M. and Holtz, R.D., Cone Penetration Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division at the ASCE National Convention, St. Louis, MO, October, 1981.
- Parkin, A.K. and Lunne, T., "Boundary Effects in the Laboratory Calibration of a Cone Penetrometer in Sand", Norwegian Geotechnical Institute Publication No. 138, Oslo, 1982.
- Peck, R.B., "Liquefaction Potential: Science versus Practice", Journal of the Geotechnical Engineering Division, ASCE, Vol. 101, GT11, November, 1975, pp. 393-397.
- Rad, N.S. and Clough, G.W., "The Influence of Cementation on the Static and Dynamic Behavior of Sands", Report Prepared for USGS Department of the Interior Office of Earthquake Studies, Stanford University, 1982.
- Rahardjo, P.P., "A Laboratory Study of Cone Penetrometer Resistance in Dry Sand Using a Miniature Solid Cone", Thesis submitted to the Graduate Faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science, September, 1983.
- Robertson, P.K. and Campanella, R.G., "Interpretation of Cone Penetration Tests. Part 1: Sand", Geotechnique, Vol. 20, 1983, pp. 718-733.
- Robertson, P.K., Campanella, R.G., and Wightman, A., "SPT - CPT Correlations", Journal of Geotechnical Engineering, Vol. 109, No. GT11, November, 1983, pp. 1449-1459.

- Robertson, P.K. and Campanella, R.G. , "Evaluation of Liquefaction Potential Using the Cone Penetration Test", Department of Civil Engineering at the University of British Columbia, Vancouver, Canada, 1983.
- Robertson P.K. and Campanella, R.G. , "Guidelines for Use and Interpretation of the Electronic Cone Penetration Test", Soil Mechanics Series No. 69, Department of Civil Engineering at the University of British Columbia, Vancouver, Canada, February, 1984.
- Rude, L.C. , Personal Communication, 1984.
- Sanglerat, G. , The Penetrometer and Soil Exploration, Elsevier Publishing Company, Amsterdam, the Netherlands, 1972.
- Schmertmann, J.H. , "Guidelines for Cone Penetration Testing Performance and Design", Federal Highway Administration, Report FHWA-TS-78-209, Washington, July 1978, 145 pgs.
- Seed, H.B. , "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes", Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, February, 1979, pp. 201-255.
- Seed, H.B. and Idriss, I.M. , "Simplified Procedure for Evaluating Soil Liquefaction Potential", Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 97, No. SM9, September, 1971.
- Seed, H.B. , Idriss, I.M. and Arrango, I. , "Evaluation of Liquefaction Potential Using Field Performance Data", Journal of Geotechnical Engineering, ASCE, Vol. 109, No. 3, March, 1983, pp. 458-482.
- Selig, E.T. and Ladd, R.S. , Evaluation of Relative Density and its Role in Geotechnical Projects Involving Cohesionless Soils, A symposium presented at the seventy-fifth annual meeting for ASTM, Los Angeles, California, June, 1972.
- Shields, D.H. , "Should ASTM Adopt the European Standard CPT?" Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division at the ASCE National Convention, St. Louis, MO, October, 1981.
- Trofimenkov, J.G. , "Penetration Testing in USSR", SOA Report, European Symposium on Penetration Testing, Stockholm, Sweden, Vol. 2.2, 1974.
- Veismanis, A. , "A Laboratory Investigation of Electrical Friction-Cone Penetrometers in Sand", Proceedings of the European Symposium on Penetration Testing, Stockholm, Sweden, Vol. 2.2, 1974.
- Vesic, A.S. , "Expansion of Cavities in Infinite Soil Mass", Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM3, March, 1972, pp. 265-290.

Villet, W.C.B. and Mitchell, J.K. , "Cone Resistance, Relative Density and Friction Angle", Cone Penetrometer Testing and Experience, Proceedings of a session sponsored by the Geotechnical Engineering Division at the ASCE National Convention, St. Louis, Missouri, October, 1981.

Walker B.P. and Whitaker, T. , "An Apparatus for Forming Uniform Beds of Sand for Model Foundation Tests", *Geotechnique*, Vol. 17, No. 2, June, 1967, pp. 161-167.

Zhou, S. , "Evaluation of the Liquefaction of Sand by Static Cone Penetration Test", Proceedings of the Seventh World Conference on Earthquake Engineering, Vol. 3, Istanbul, Turkey.

ADDITIONAL REFERENCES

(Guides for the Apple II and the ISAAC Units)

Apple II The DOS Manual, Apple Computer, Inc., California, 1981.

Applesoft II BASIC Programming Reference Manual, Apple Computer, Inc., California, 1981.

Applesoft Tutorial, Apple Computer, Inc., California, 1981.

Miller, David, Apple Files, Reston Publishing Company, Virginia, 1982.

VISITERM, User's Guide for the Apple II and II Plus. Program by Tom Keith. Manual by J.E. Levinger and R.P. Merges, Visicorp, 1982.

Curtis, R.O., ISAAC Labsoft Reference Manual, Cyborg Corporation, 1982.

Curtis, R.O., ISAAC/Labsoft User's Guide and System Index, Cyborg Corporation, 1982.

Curtis, R.O., ISAAC 91A System Reference, Cyborg Corporation, 1982.

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