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Presentation and interpretation  
of seismic cone penetration test data,  
Fraser River delta, British Columbia

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**D.J. Woeller, J.L. Luternauer, J.A. Hunter**

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**PRESENTATION & INTERPRETATION  
OF SEISMIC CONE PENETRATION TEST DATA,  
FRASER RIVER DELTA, BRITISH COLUMBIA**

**D.J. Woeller<sup>1</sup>, J.L. Luternauer<sup>2</sup>, and J.A. Hunter<sup>3</sup>**

<sup>1</sup> ConeTec Investigations Ltd.  
Vancouver, British Columbia V6P 6R9  
(604) 327-4311

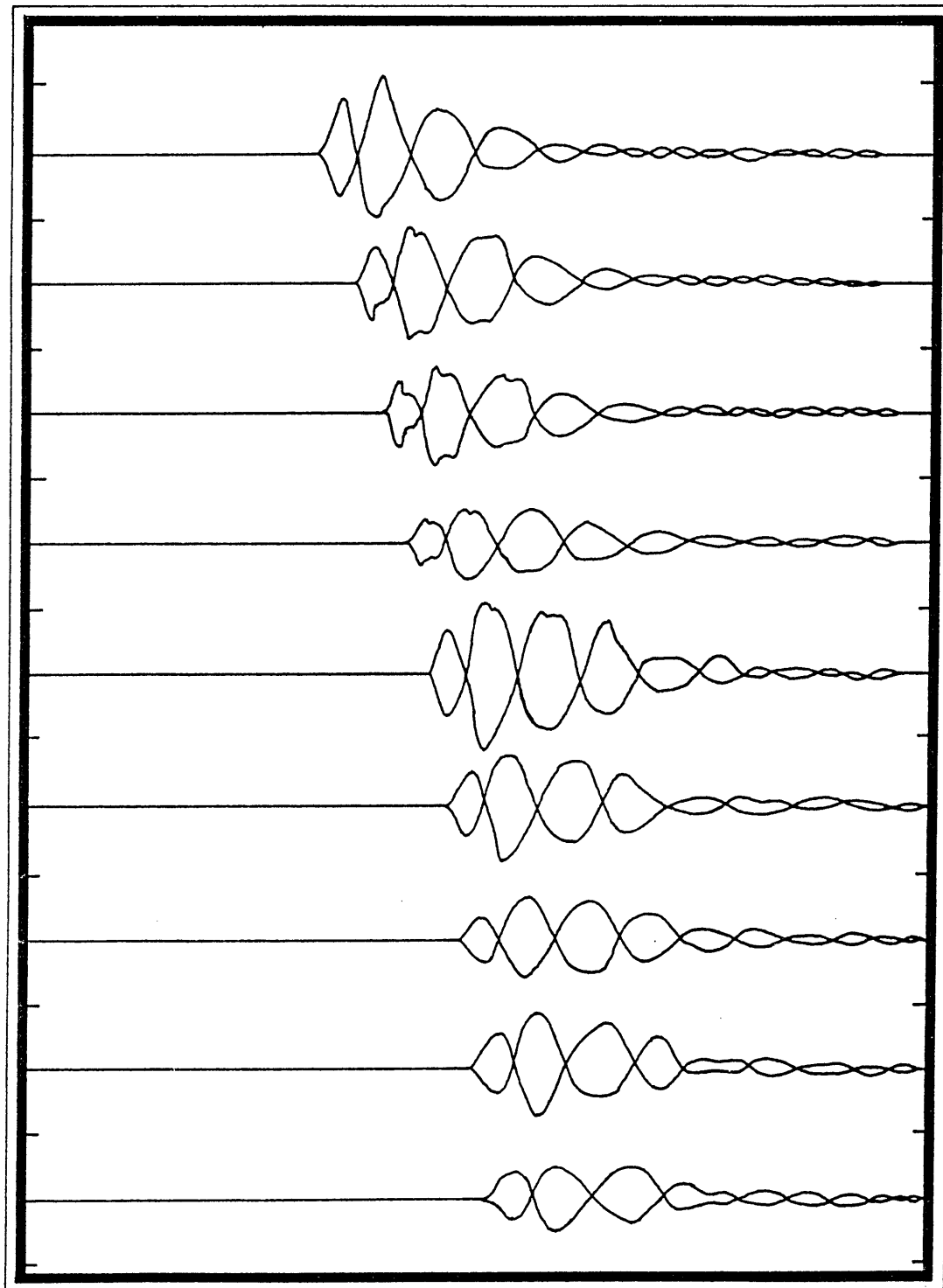
<sup>2</sup> Geological Survey of Canada  
100 West Pender Street  
Vancouver, British Columbia V6B 1R8

<sup>3</sup> Geological Survey of Canada  
601 Booth Street  
Ottawa, Ontario K1A 0E8

Geological Survey of Canada  
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FRASER RIVER DELTA, BRITISH COLUMBIA**



Prepared by:

ConeTec Investigations Ltd.  
Unit 3, 9113 Shaughnessy Street  
Vancouver, B.C.  
V6P 6R9

Prepared for:

Energy, Mines & Resources Canada  
Geological Survey of Canada  
100 West Pender Street  
Vancouver, B.C.  
V6B 1R8

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# **CPT BASED GEOTECHNICAL ANALYSIS OF THE FRASER RIVER DELTA, REGIONAL LIQUEFACTION POTENTIAL AND HAZARD MAPPING**

## **1.0 INTRODUCTION**

This report presents the results of a seismic resistivity cone penetration test (SRCPT) program carried out at four locations in Richmond, B.C. between November 1991 and April 1992. A site location plan is shown on Figure 1. The work is part of a continuing geotechnical program being carried out by the Geological Survey of Canada (GSC) regarding regional liquefaction potential and hazard mapping.

The testing was carried out in accordance with terms and conditions set out in DSS contract No. 23254-1-0236/01-XSB.

## **2.0 FIELD WORK**

Four sites in the municipality of Richmond were tested, the locations of which can be seen in figure 1. The SRCPT testing was done from November 91 to January 92. At each location the tests were conducted within 5 metres of previously drilled boreholes. In addition to the SRCPT's, at two of the sites solid stem auger drilling and sampling was done to 9 metres. The holes were logged in the field and samples were collected at approximately 1 m intervals. The water level was noted at about 1 m below surface at all four sites.

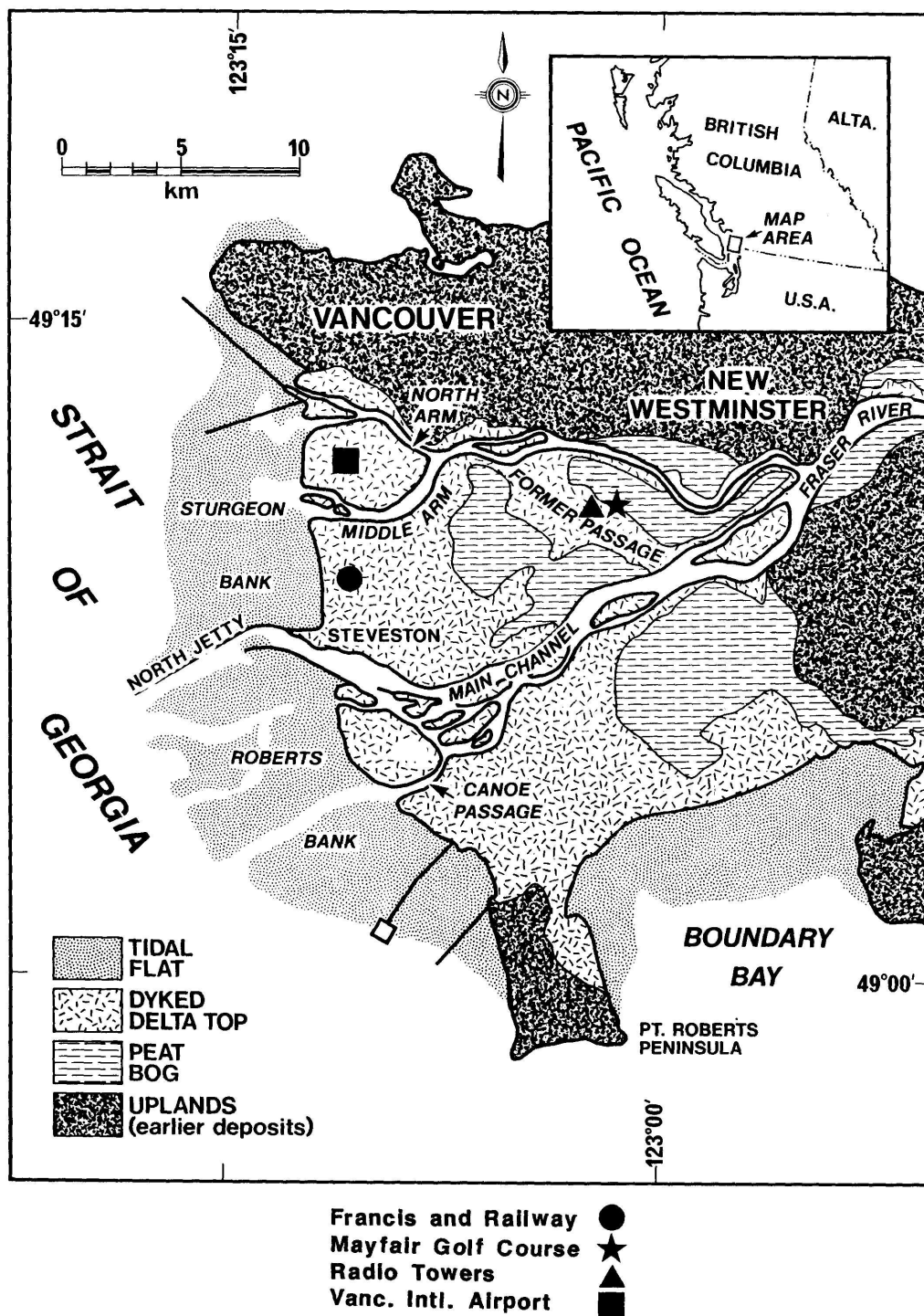


Figure 1: Location of test sites

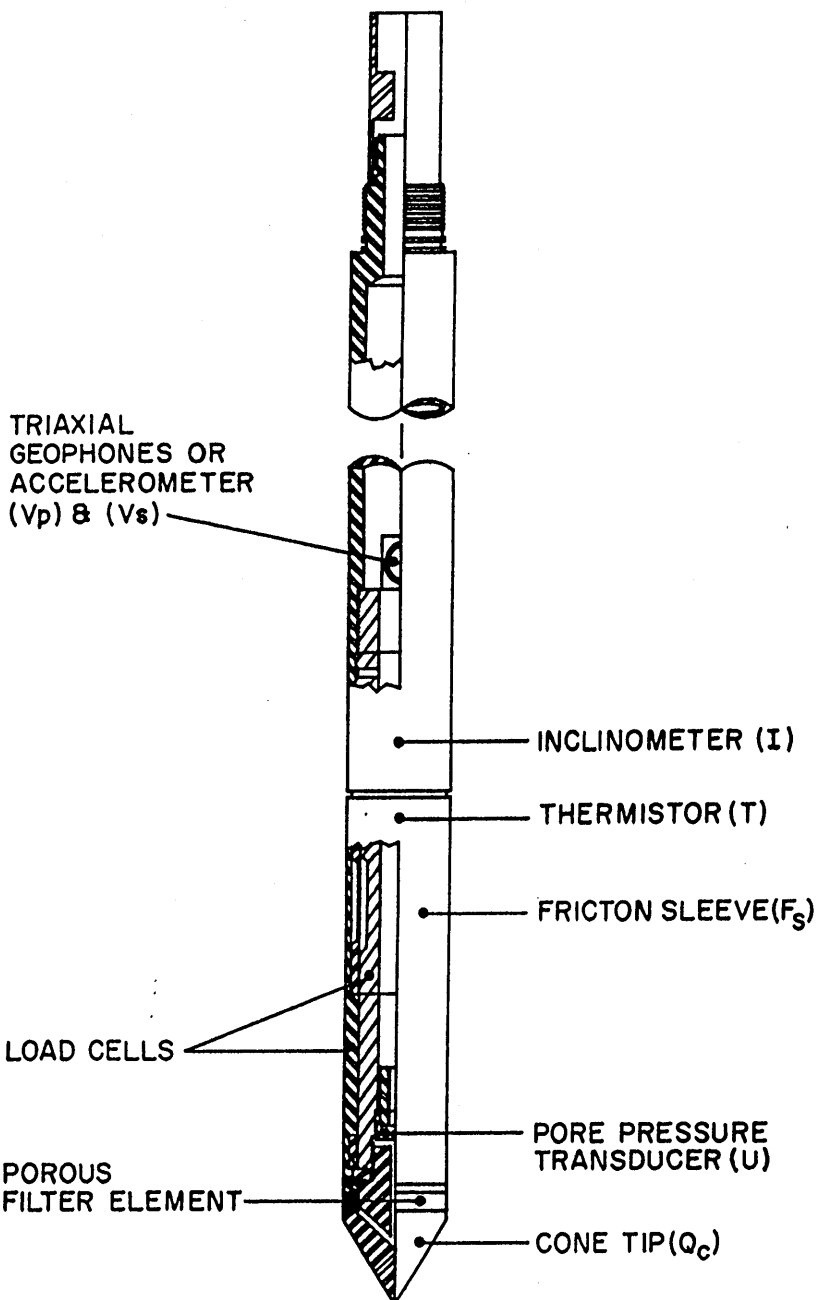
## 2.1 ELECTRIC CONE TESTING

The electric cones used in the field testing program were supplied by Conetec Investigations Ltd. The cones were deployed using a specially modified drill rig (MARL-10) having a maximum thrust of 14 tons. The drill rig was supplied and operated by Mud Bay Drilling Co. Ltd. of Surrey B.C.

A ten ton subtraction cone (refer to figure 2) was used for all of the soundings. This cone has a standard tip area of 10 sq. cm. and a friction sleeve area of 150 sq. cm. The cone is designed with an equal end area friction sleeve and tip end area ratio of 0.85. A pore pressure filter was located immediately behind the cone tip. The filter is made of porous plastic and was 5.0 mm thick. The pore pressure filters are saturated in glycerin under vacuum prior to penetration. The porous filter allows water pressure communication between the soil and a pore pressure transducer located inside the cone. A resistivity module located immediately behind the cone was used to measure resistivity. The module measures bulk soil resistivity with an accuracy of better than 0.1 % of the measured value. The cone was equipped with a geophone to measure shear wave velocities.

The cone was capable of continuous data collection. The following data was collected at the standard interval of 5 cm:

# THE SEISMIC CONE PENETROMETER



The seismic cone penetration test (SCPT) combines the seismic downhole method and the logging capabilities of the cone penetration test (CPT) to provide a rapid, reliable and economic means of determining soil stratigraphy, relative density, strength, shear and compressional wave velocities. From interval shear wave velocity ( $V_s$ ) and the mass density ( $\rho$ ) of a soil layer, the dynamic shear modulus ( $G_{max}$ ) of the soil over a specific interval can be calculated according to the following expression:

$$G_{max} = \rho \times V_s \times V_s$$

The dynamic shear modulus ( $G_{max}$ ) is a key parameter for the analysis of soil behaviour in response to dynamic loading from earthquakes, ice, vibrating machine foundations, waves and wind.

To the left is an illustration of Gregg In Situ's specially modified seismic cone penetrometer. Figure 1 on the overleaf shows the layout of the downhole seismic system. In addition to using a hammer as an energy source, shotgun shells and standard seismic caps may also be employed to generate seismic waves.

Figure 2

Cone Bearing ( $Q_c$ )

Sleeve Friction ( $F_s$ )

Dynamic Penetration Pore Pressure ( $U_t$ )

Temperature ( $T$ )

Cone Inclination ( $i$ )

Resistivity ( $\rho$ )

The above parameters were recorded on a bubble cassette and printer simultaneously for future analysis and reference. Also during pauses in penetration for addition of rods, time based pore pressure and seismic shear wave signals were recorded. The pore pressure data is collected at 5 sec. intervals.

A complete set of baselines were recorded before and after every cone sounding to determine if any temperature shifts or zero load offsets had occurred during the sounding. Correction of these effects can be very important, especially when recorded loads are very small. In sandy soils these corrections are generally negligible. Plots of all CPT data are presented in appendix B.

The inferred stratigraphic profiles at each CPT test location is given in appendix C. The stratigraphic interpretations are based on relationships between cone bearing,  $Q_c$ , sleeve friction,  $F_s$ , and dynamic pore pressure,  $U_t$ . The friction ratio, ( $R_f = F_s/Q_c * 100 \%$ ) is a calculated parameter which is used to identify the soil type and is based on empirical results that relate soil behaviour to soil type.

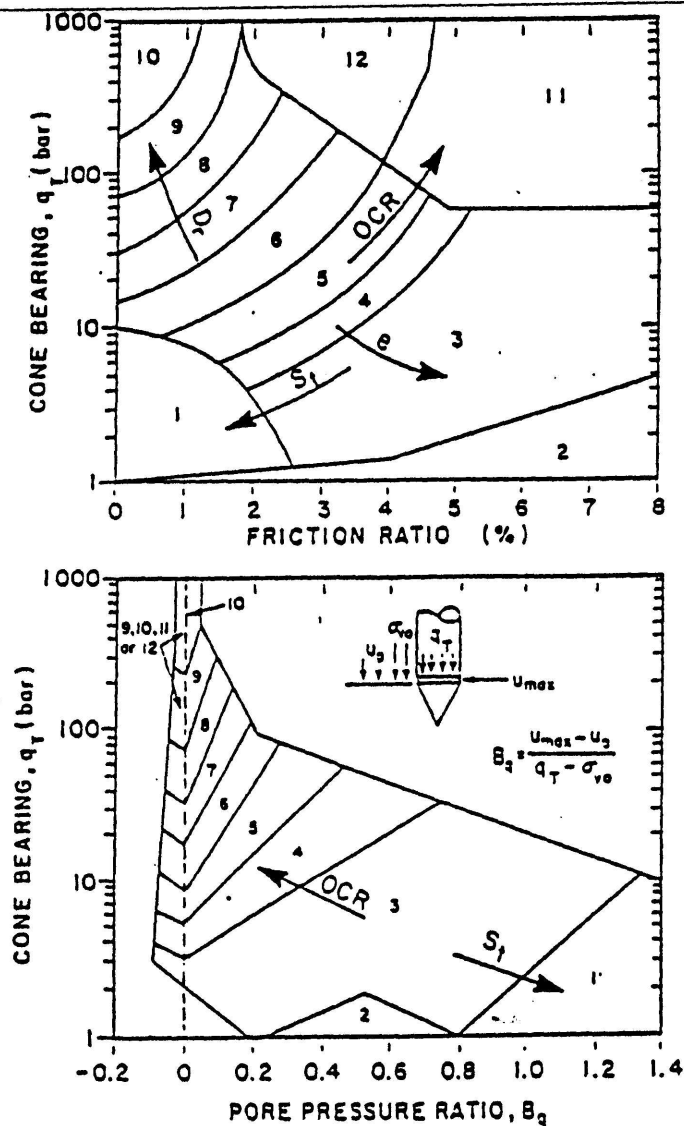


Generally, soft cohesive soils have high friction ratios, low cone bearing pressures and generate large positive excess pore pressures during penetration. Cohesionless soils have lower friction ratios, high cone bearing pressures and generate little in the way of pore water pressure during penetration.

The classification of soils encountered on this project was carried out using the correlations developed by Robertson et al.(1986a) shown in figure 3. It is not always possible to clearly identify a soil type based on  $Q_c$  and  $R_f$  alone. Experience, judgement and analyses of pore water pressure generation during penetration and subsequent dissipation were used in arriving at soil type in these ambiguous situations. Soil types, identified with the aid of the chart in figure 2, along with estimates of some associated geotechnical parameters are presented in appendix C for each cone sounding. The classification of soils can also be enhanced with the use of measured bulk resistivity. Work by Campanella and Weemees (1991) and more recently by Kokan (1992) show that resistivity can be used as a useful parameter to aid in soil classification.

## **2.2 SEISMIC WAVE VELOCITY MEASUREMENTS**

Seismic wave velocity measurements were conducted each time cone penetration was stopped to add additional push rods. The CPT rods are 1 m long, and therefore accurate depth intervals are ensured by always pushing the cone rods 1 m. At the end of the first rod and at 1m intervals thereafter, shear wave velocity measurements were made according to procedures described by Robertson et al (1986b).



Zone	Soil Behaviour Type
1	sensitive fine grained
2	organic material
3	clay
4	silty clay to clay
5	clayey silt to silty clay
6	sandy silt to clayey silt
7	silty sand to sandy silt
8	sand to silty sand
9	sand
10	gravelly sand to sand
11	very stiff fine grained*
12	sand to clayey sand*

\* overconsolidated or cemented.

Proposed soil behaviour type classification system  
from CPTU data. (Robertson et. al, 1986)

Figure 3

Before taking wave velocity measurements, the rods were decoupled from the drill rig to avoid transmission of energy down the rods.

The variation in shear wave velocity with depth for each sounding are shown graphically in appendix D. The velocity profiles are based on velocities at the mid-points of the 1 m test intervals. Pertinent data for each of the seismic profiles are tabulated in appendix E. The shear wave velocities in the penetrated sediments vary between 100 m/sec and 280 m/sec. Velocities from all 4 sites can be seen in figure 4.

### **2.3 BOREHOLE SAMPLING**

Samples were collected from solid stem auger drill rods to a depth of 9 m at Francis & Railway and Mayfair Golf Course locations. Stratigraphic summaries of the soils encountered at both of these sites are presented in appendix F. Samples collected were presented to the GSC for laboratory testing.

### **3.0 LIQUEFACTION POTENTIAL AT THE SITE**

The evaluation of liquefaction potential at the sites was done according to the methodology described in appendix A. The reader is therefore referred to this for details on the analysis. The methodology is based on two empirical approaches, namely critical cone penetration resistance, and critical shear wave velocity.

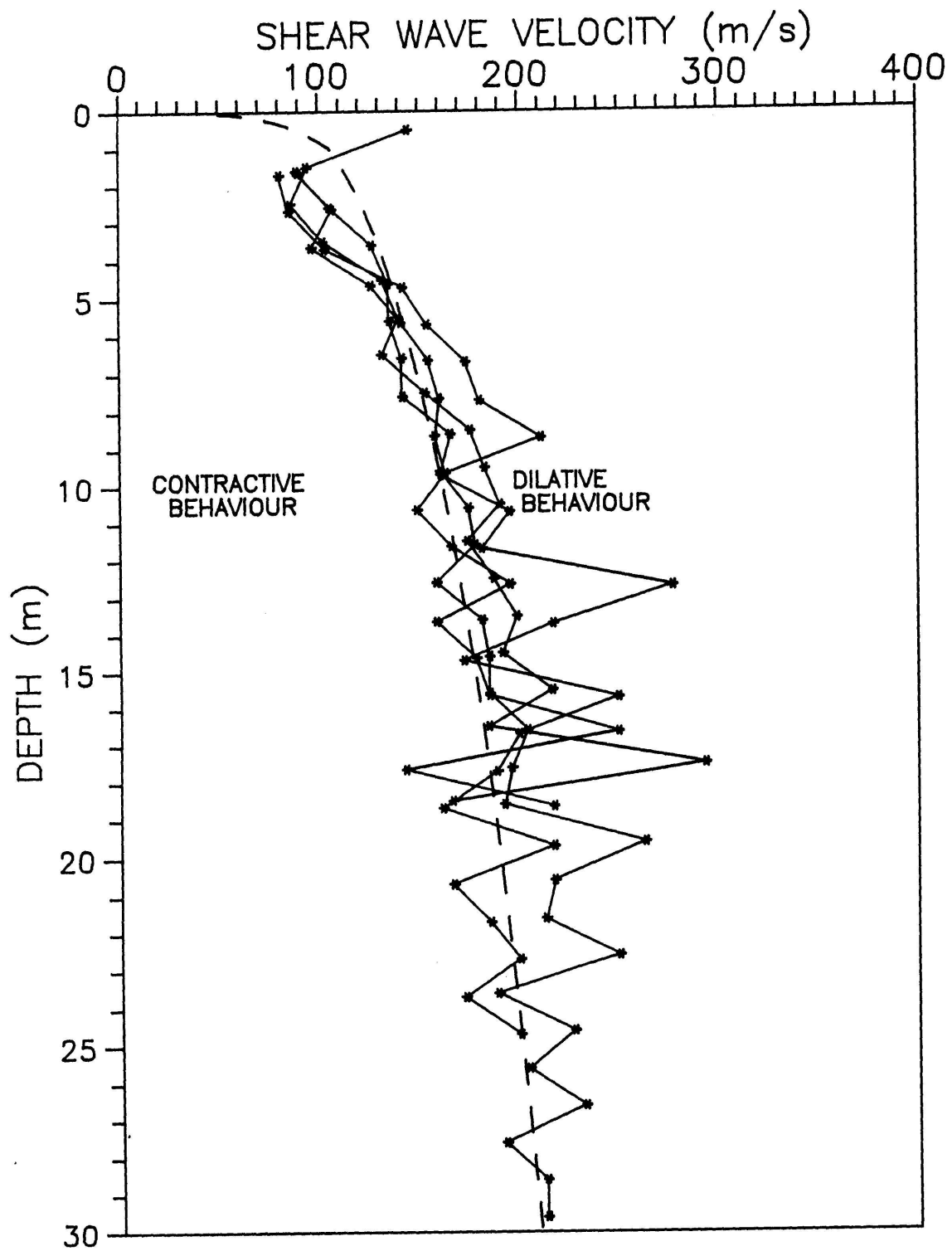


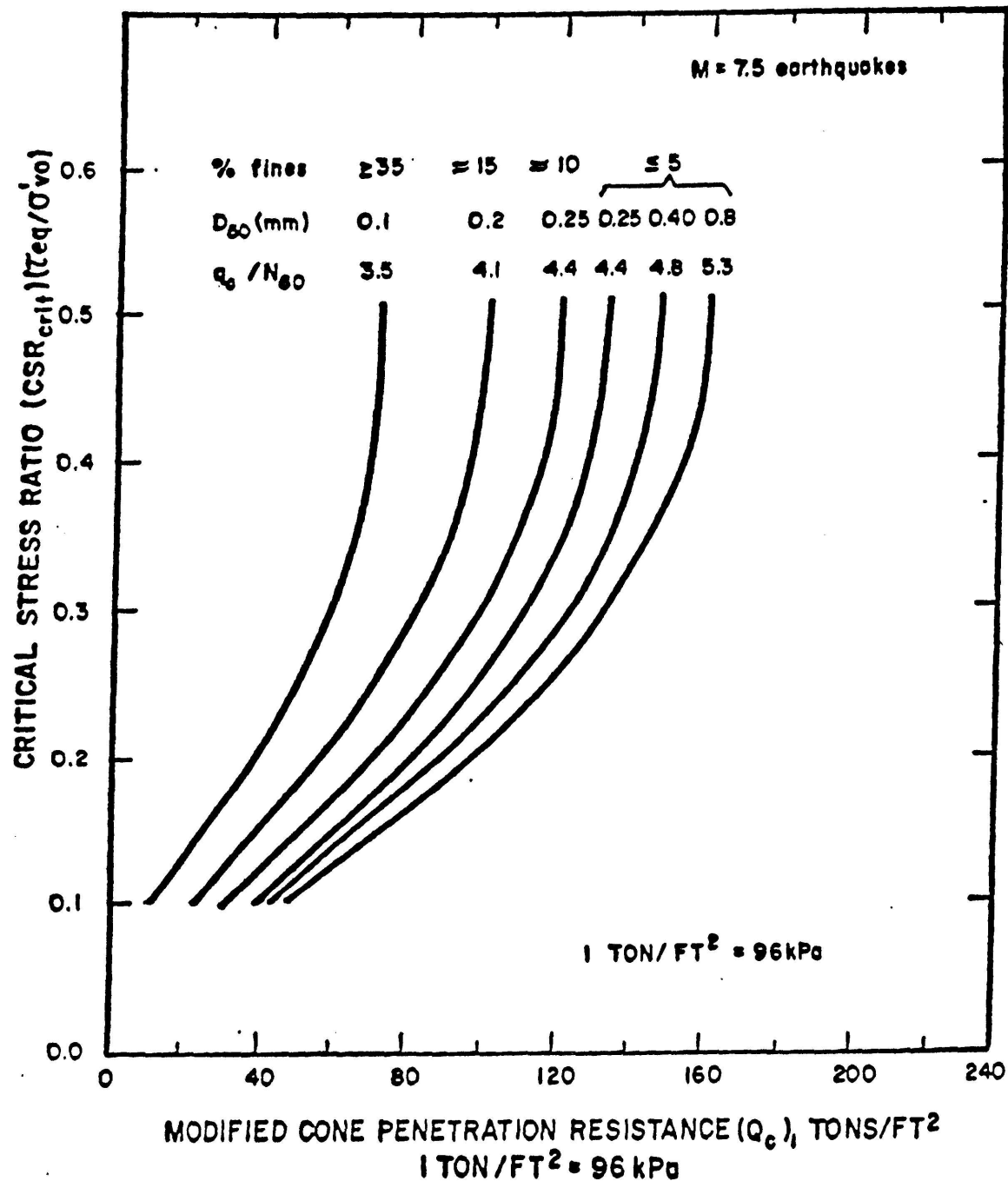
Figure 4 Shear Wave Velocity vs Depth for All Sites Tested

### 3.1 CRITICAL CONE PENETRATION RESISTANCE CRITERION

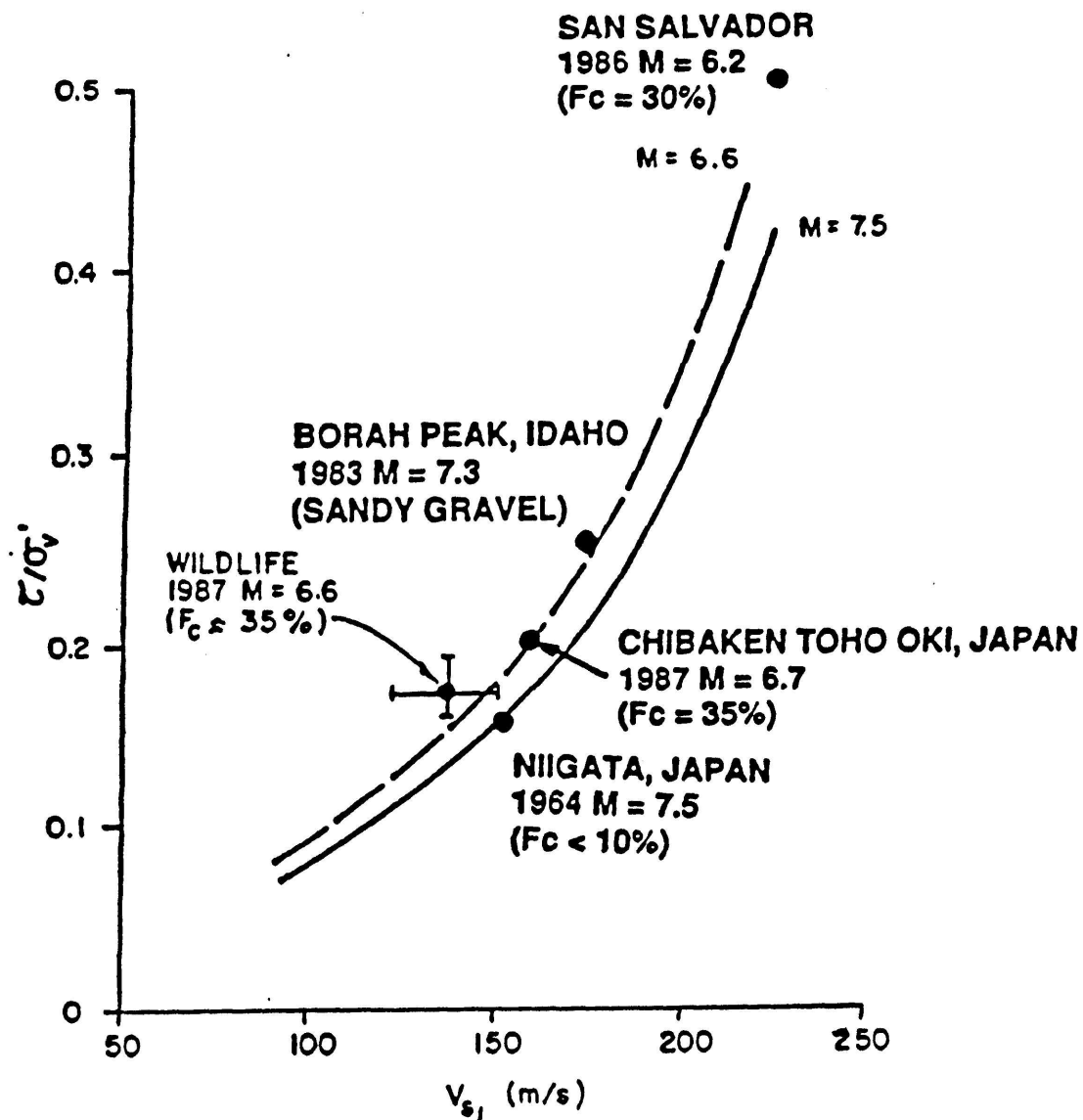
This approach, developed by Seed and De Alba, is based on the penetration resistance of the soil as measured using the (CPT). The evaluation of liquefaction potential is based on whether the critical cone penetration resistance required to prevent liquefaction,  $Q_{C,CRIT}$ , is exceeded by the normalized cone penetration resistance,  $Q_{C1}$ , measured in the field. The value of  $Q_{C,CRIT}$  for a given magnitude and peak acceleration can be determined from the Seed and De Alba chart (1986) shown in figure 5. For more details on this approach the reader is directed to appendix A.  $Q_{C1}$  vs depth as well critical  $Q_C$  for two different peak horizontal accelerations (0.17g and .22g) for each site is presented in appendix G. In July 1991 the design peak horizontal acceleration was increased to 0.3 g

### 3.2 CRITICAL SHEAR WAVE VELOCITY CRITERION

Normalized Shear Wave velocity,  $V_{S1}$  may be used as index of soil resistance to liquefaction in the same manner as  $Q_{C1}$ . A liquefaction resistance chart in terms of  $V_{S1}$  is shown in figure 6. This chart is analogous to the one in figure 5 for  $Q_{C1}$ . When the critical shear wave velocity,  $V_{S1,CRIT}$ , exceeds the measured normalized shear wave velocity,  $V_{S1}$ , liquefaction is expected during the design earthquake ( $m=7.0$ ,  $a=0.3g$ ). The shear wave velocity criterion for liquefaction assessment appears to be particularly appropriate in silty sands since shear wave velocity appears to be independent of fines content (Robertson and Woeller, 1992).



**Figure 5** Correlation Between Normalized Cone Penetration Resistance and Critical Stress Ratio to Cause Liquefaction (after Seed and DeAlba, 1986)



**Figure 6** Proposed Correlation Between Normalized Shear Wave Velocity and Cyclic Stress Ratio (CSR) to Cause Liquefaction

Therefore correction for fines content are not necessary. Figure 7 shows normalized shear wave velocities for the four sites plotted with depth. Overlaid on the data is a liquefaction boundary based on the most recent design criterion proposed by Byrne & Anderson (1991).

### 3.3 COMPARISON BETWEEN $Q_{c1}$ AND $V_{s1}$

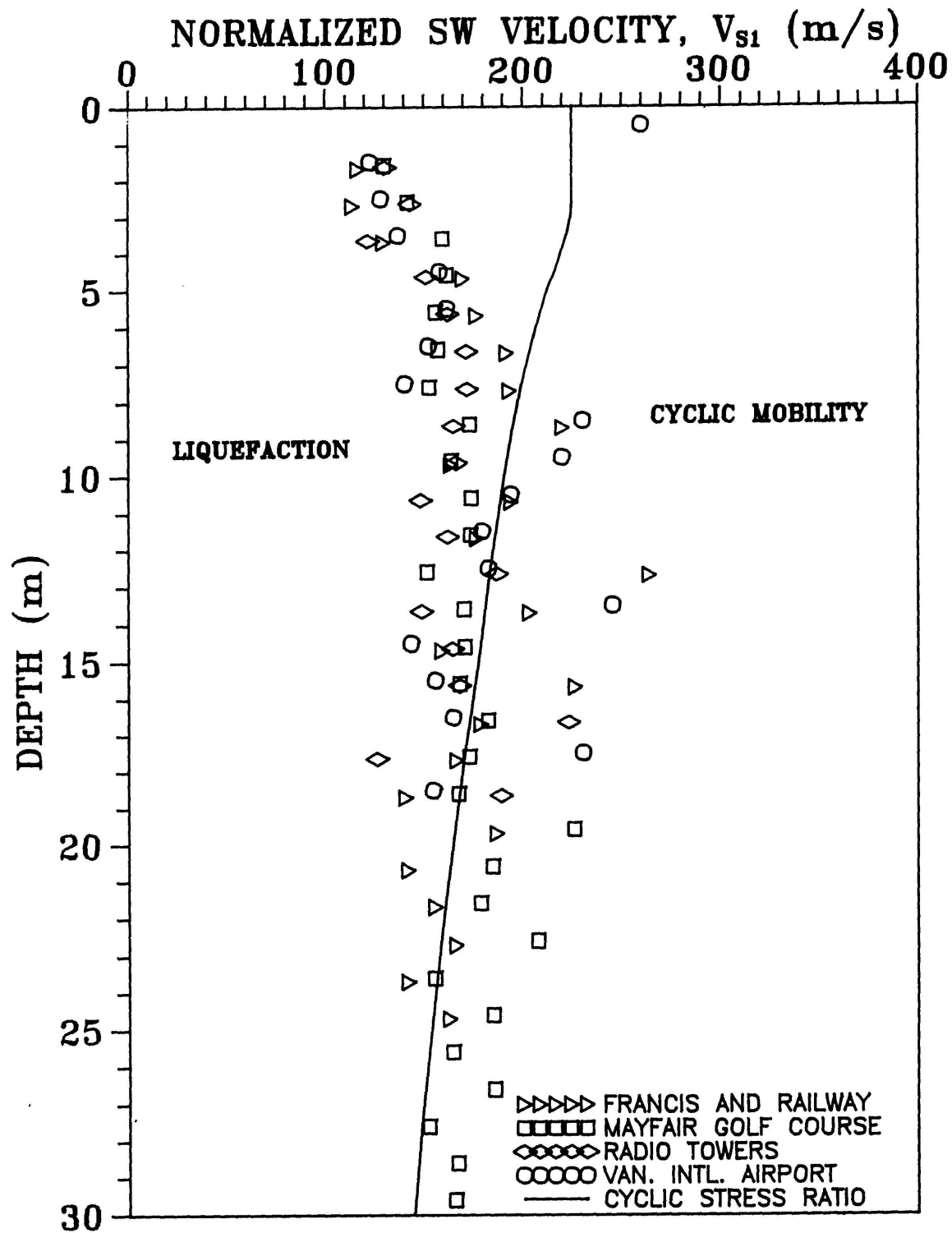
Penetration resistance and shear wave velocity are both effected by density, in situ stress as well as other factors, therefore it seems reasonable to compare  $Q_{c1}$  with  $V_{s1}$  to see if there is a relationship between the two measured parameters. Figure 8 shows  $V_{s1}$  as a function of  $Q_{c1}$  for the four sites tested. Regression analyses carried out on this data suggests that  $V_{s1}$  is related to  $Q_{c1}$  according to the following:

$$V_{s1} = 60 (Q_{c1}/Pa)^{0.25}$$

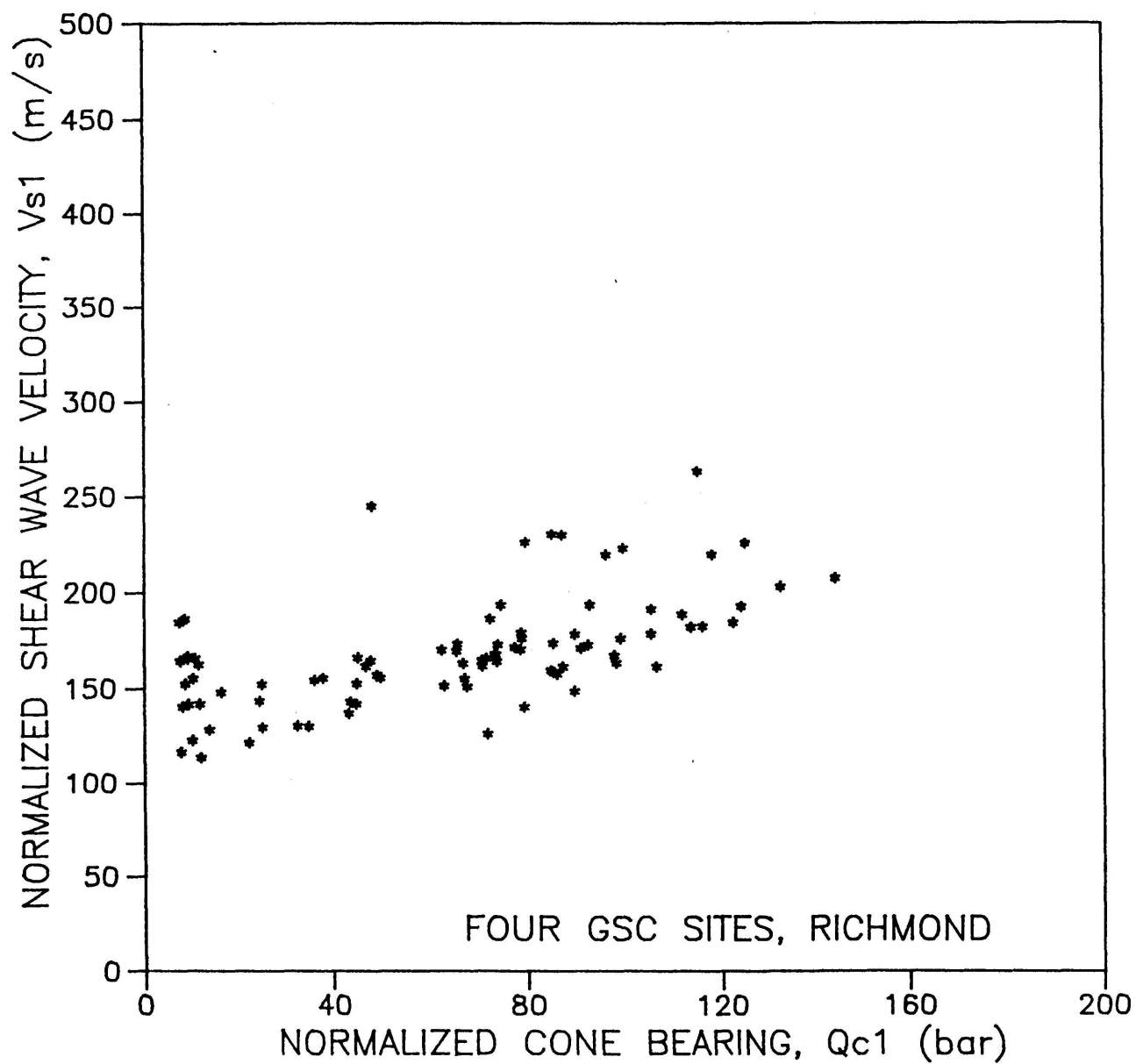
### 4.0 CONTRACTIVE DILATIVE BOUNDARY

Soil response to cyclic loading depends primarily on two factors: the intensity and duration of loading and the behaviour of soil during loading. For sands, behaviour during both static and monotonic loading has been studied extensively in the laboratory. Lab results indicate that the behaviour of sand during monotonic loading is intimately related to its behaviour during cyclic loading.





**Figure 7** Cyclic Stress Resistance of Sites Tested, Compared With Cyclic Stress Ratio of a Design Earthquake Based on  $V_{s1}$  (M7, 03g HORZ. ACC. After Byrne and Anderson, 1991)



**Figure 8:** Normalized Shear Wave Velocity vs Normalized Cone Bearing for Sites Tested

Understanding the volume change behaviour that a sand undergoes during shear is important in establishing its strength characteristics for increasing levels of strain. Furthermore the volume change that the sand skeleton undergoes during shear is fundamentally related to the pore pressure that is generated during undrained loading and hence the tendency towards liquefaction. Sands that are loose have a tendency to collapse during loading, exhibiting contractive behaviour. Compact to dense sands on the other hand tend to dilate during loading, exhibiting strain hardening or dilative behaviour. Several methods have been developed to identify the contractive dilative boundary in sands. It is important to note that if a sand is contractive during cyclic loading there is the potential for unlimited flow or unlimited deformation. Whereas if a sand is dilative during cyclic loading there is the potential for deformations (settlements). The magnitude of these deformations can vary depending upon the intensity and duration of shaking.

#### **4.1 CONE RESISTANCE CRITERION**

Since cone resistance in sands is largely a function of density and sand behaviour depends on the density of the sand with respect to critical density, it is reasonable to expect cone resistance to be related to contractive dilative behaviour. Work by Sladen and Hewitt (1989) suggests that a normalized cone resistance value equal to 70 bars represents a good fit to data collected from back analyses of failed hydraulic fill structures.

Thus the boundary between contractive and dilative behaviour as suggested by Sladen and Hewitt can be approximated by the following:

$$Q_c/(\rho_{vo}')^{0.65} = 70$$

Comparison of field data for the four sites with Sladens' contractive dilative boundary can be found in appendix H.

#### 4.2 SHEAR WAVE VELOCITY CRITERION

Data analyzed to date suggests that a normalized shear wave velocity of 160 m/sec represents the approximate boundaries for contractive dilative behaviour. This value is based on data available as well as  $Q_{c1}$   $V_{s1}$  correlations that have been developed. More data is required to better define these boundaries as well as to establish the limitations if any of this approach. The shear wave velocity data with respect to the contractive dilative boundary is presented in appendix D.

#### 4.3 RESISTIVITY CRITERION

Recently an analytical approach to analyzing contractive dilative behaviour has been developed using a resistivity method (Kokan, 1992). Resistivity is measured at different radial distances from a penetrating probe (CPT) during a CPT sounding.

## **6.0 RECOMMENDATIONS FOR FURTHER WORK**

The data presented herein suggests that a design earthquake could produce substantial liquefaction in surface sediments within the municipality of Richmond. While some sites appear to be marginally more resistant than others there is not sufficient data to begin to regionalize the data. Regional mapping of hazard can only commence when a larger data base has been established so that boundaries can be identified.

Although the criterion presented for liquefaction and contractive dilative boundaries seem to agree for the most part, more effort must be directed towards defining these boundaries. As suggested before, dual electrode resistivity logging shows promise as an analytical method of measuring dilatancy in situ.

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## **APPENDIX A**

### **Liquefaction Methodology**

#### **A.1 - Liquefaction Phenomenon**

#### **A.2 - Empirical Assessment of Liquefaction**



## A.1 LIQUEFACTION PHENOMENON

Granular soils, such as sands, derive their strength from intergranular effective stress. When these soils are saturated with water, the effective stress is the difference between the total stress (due to the total weight of overburden) and the water pressure in the soil pores. Hence, the strength and deformation properties of granular soils are dependent on the level of porewater pressure.

During cyclic loading induced by earthquake shaking, the grains of soil tend to move to form a denser arrangement. If the water in the pore spaces is unable to drain away to accommodate the compaction, the porewater pressure increases. This decreases the effective intergranular stress and the soil becomes weaker and more deformable. In very loose granular soils, the rise in pore water pressure can be extremely large due to collapse of the soil structure and there can be a very significant loss of strength. This phenomenon has traditionally been referred to as soil liquefaction.

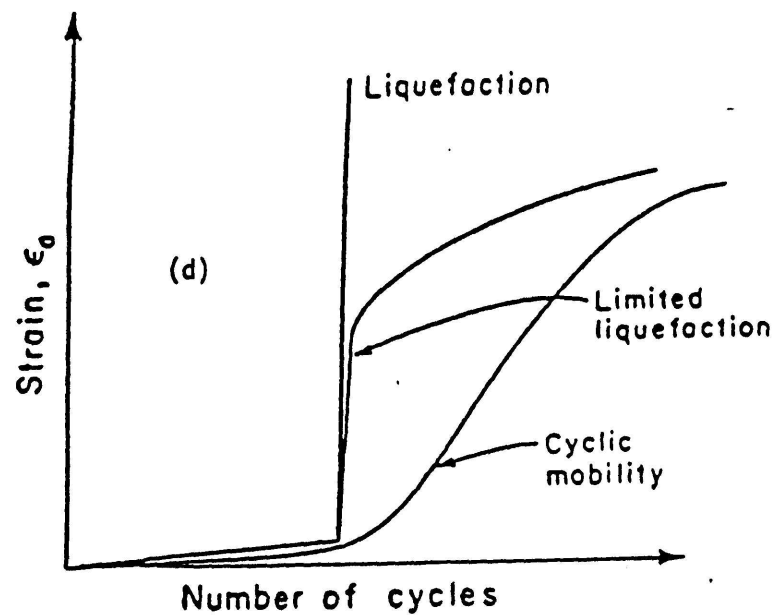
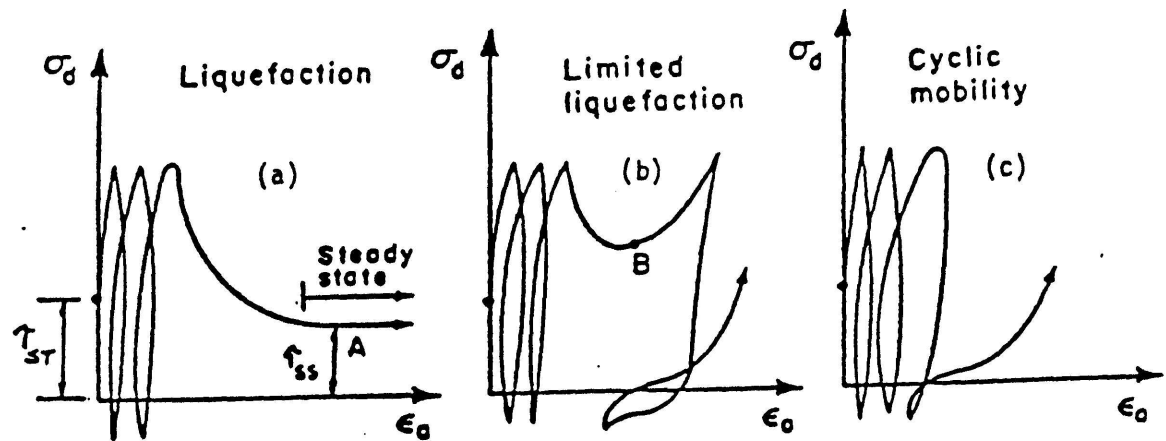
However, in recent years, research has shown that the behaviour of granular soils during cyclic loading is more complex. Figure A1 presents the results of undrained cyclic loading tests on sand at various densities. When the sand is contractive (Figure A1(a)), the sand strain softens after the peak deviator stress has been attained and the undrained strength reaches a minimum value which remains constant over a large range in strain. The minimum constant undrained strength is called the steady state or residual strength. This continued flow at constant resistance is called liquefaction.

Figure A1(b) shows the response of a sand that is initially contractive but then becomes dilative. The undrained strength reaches minimum values but then increases as the sand becomes dilative. This phenomenon is called limited liquefaction.

If the sand is dense, porewater pressures still develop during seismic shaking and may become large enough to eject sand and water and create sand volcanoes. But since the sands are dense they do not undergo flow deformation. However, the porewater pressure does reduce the stiffness of the sand and the strength at small strains. Therefore deformations tend to increase with duration of loading (Figure A1(c)) and may become large enough in some cases to constitute failure. This phenomenon is called cyclic mobility and also occurs during the dilative stage of limited liquefaction.

The deformation patterns of these sands are shown together in Fig. A1(d).

The magnitude of potential deformations at a liquefied site depends on whether the static driving shear stresses are less than or greater than the residual strength. If greater, large scale flow deformation may occur. The extent of the deformation depends on the extent to which the driving stress exceeds the residual strength.



**Figure A1** Definition of Liquefaction, Limited Liquefaction and Cyclic Mobility Under Cyclic Loading

If the residual strength is greater than the driving shear stresses, large scale deformations will not occur. In this case, the extend of the deformations depends on the duration and intensity of loading.

This problem is similar to cyclic mobility.

Procedures for cyclic loading analyses for these different conditions are illustrated in Figure A2.

## A.2 EMPIRICAL ASSESSMENT OF LIQUEFACTION

In a previous report, (Finn et al., 1988) on stage II of the GSC study, a methodology was described for evaluating the potential for liquefaction. The following sections will briefly review and expand the proposed methodology:

The liquefaction potential is evaluated using procedures based on the cone penetration resistance and shear wave velocity. The procedures involve three steps:

- 1) characterizing the dynamic effects of the earthquake,
- 2) characterizing the in situ state of the soil, and
- 3) application of a criterion for the incidence of soil liquefaction

### A.2.1 Characterizing the Earthquake

Seismic shear stresses play a major role in the development of liquefaction. Time histories of these stresses are usually very non-uniform and are difficult to apply in empirical methods. Seed (1979) suggested replacing the irregular time history by a number of uniform cycles and normalizing the shear stresses by dividing by the effective overburden stress. Seed proposed that this uniform cyclic shear stress ratio (CSR) be determined by:

$$CSR = \tau_{eq}/\sigma' = 0.65 * \sigma/\sigma' * a_{max} * r_d$$

where

$\tau_{eq}$	=	equivalent average shear stress
$\sigma_v$	=	total overburden stress
$\sigma_v'$	=	effective overburden stress
$a_{max}$	=	maximum surface acceleration as a fraction of acceleration due to gravity
$r_d$	=	a reduction factor to account for soil flexibility and depth

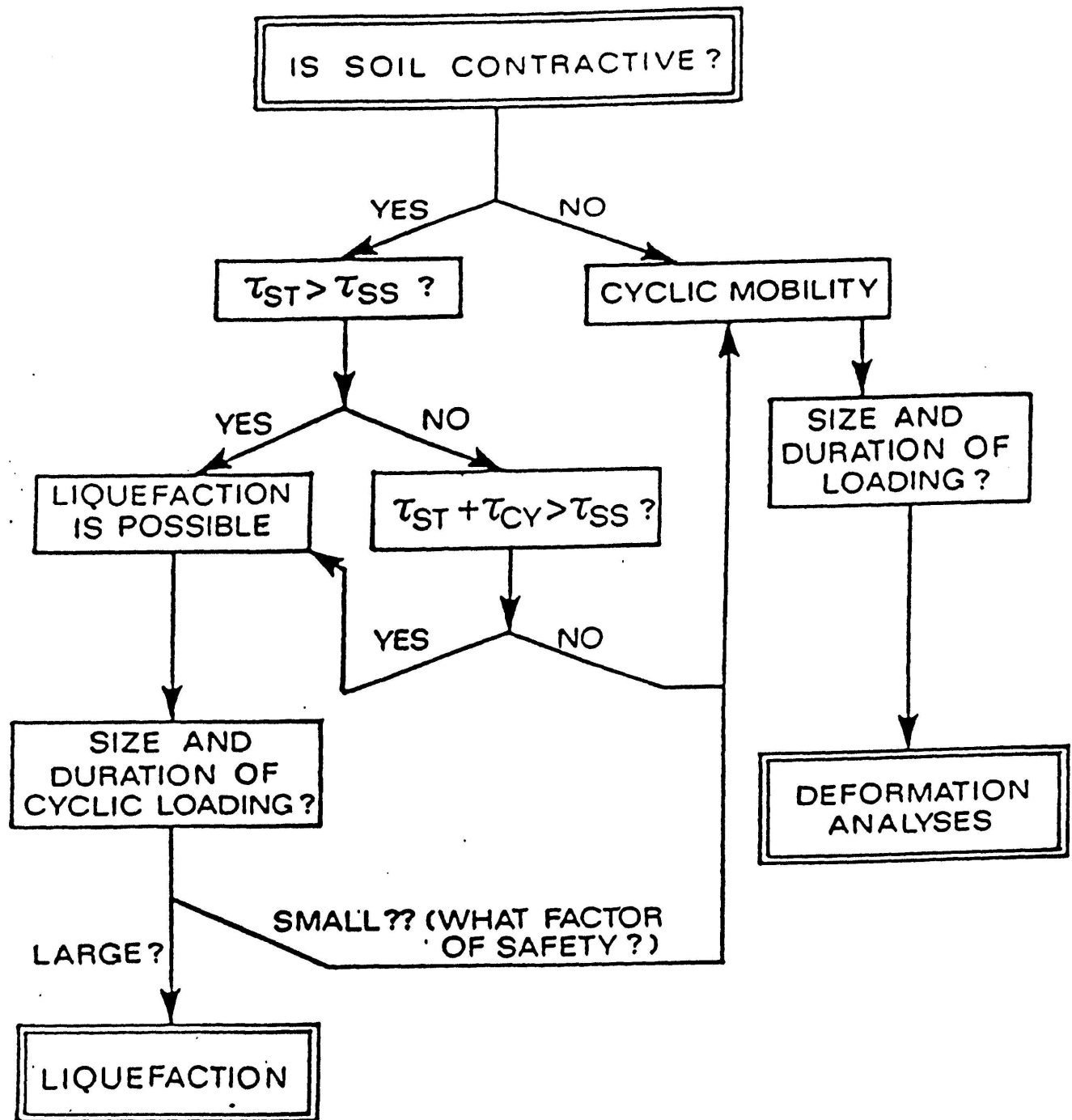


Figure A2

Flow Chart for Cyclic Loading Analyses

Iwasaki et al. (1981) proposed that the reduction factor  $r_d$  could be approximated using the following expression:

$$r_d = 1 - (0.015 * z)$$

where

$z$  = depth in meters

### **A.2.2 Characterizing the In Situ State of the Soil**

The in situ state of the soil can be characterized by in situ testing or by testing undisturbed samples obtained from boreholes or test pits. Granular soils are extremely difficult to sample without disturbance. Hence, methods to characterize the in situ state rely heavily on in situ tests. The most widely used methods are the standard penetration (SPT) and the cone penetration test with pore pressure measurement (CPTU).

#### **A.2.2.1. Standard Penetration Test (SPT)**

Seed and his colleagues (Seed, 1979; Seed et al. 1983 and Seed et al. 1985) developed correlations between the SPT  $N$  value and the cyclic stress ratio to cause liquefaction ( $CSR_{crit}$ ) (Figure A3). These correlations are based on observed behaviour of sites before and after earthquakes. Seed normalized the SPT to an energy level of 60% of the free fall potential energy of the hammer and an effective overburden pressure of 1 tsf (100 Kpa). Hence, the correlation presented in Figure A3 shows the normalized SPT  $N$  value,  $(N_1)_{60}$ . The curves presented in Figure A3 were based on the observed response of sites during earthquake loading. Sites were considered to have liquefied based on observed surface features, such as sand boils.

The correlations shown in Figure A3 are representative of earthquakes with a magnitude  $M = 7.5$ . The critical correlations for earthquakes of other magnitudes may be established by multiplying the critical cyclic stress ratios by the magnitude dependent correction factors in Table A1 (Seed, 1979). The corresponding liquefaction resistance curves are shown in Figure A4 (Koester and Franklin, 1985).

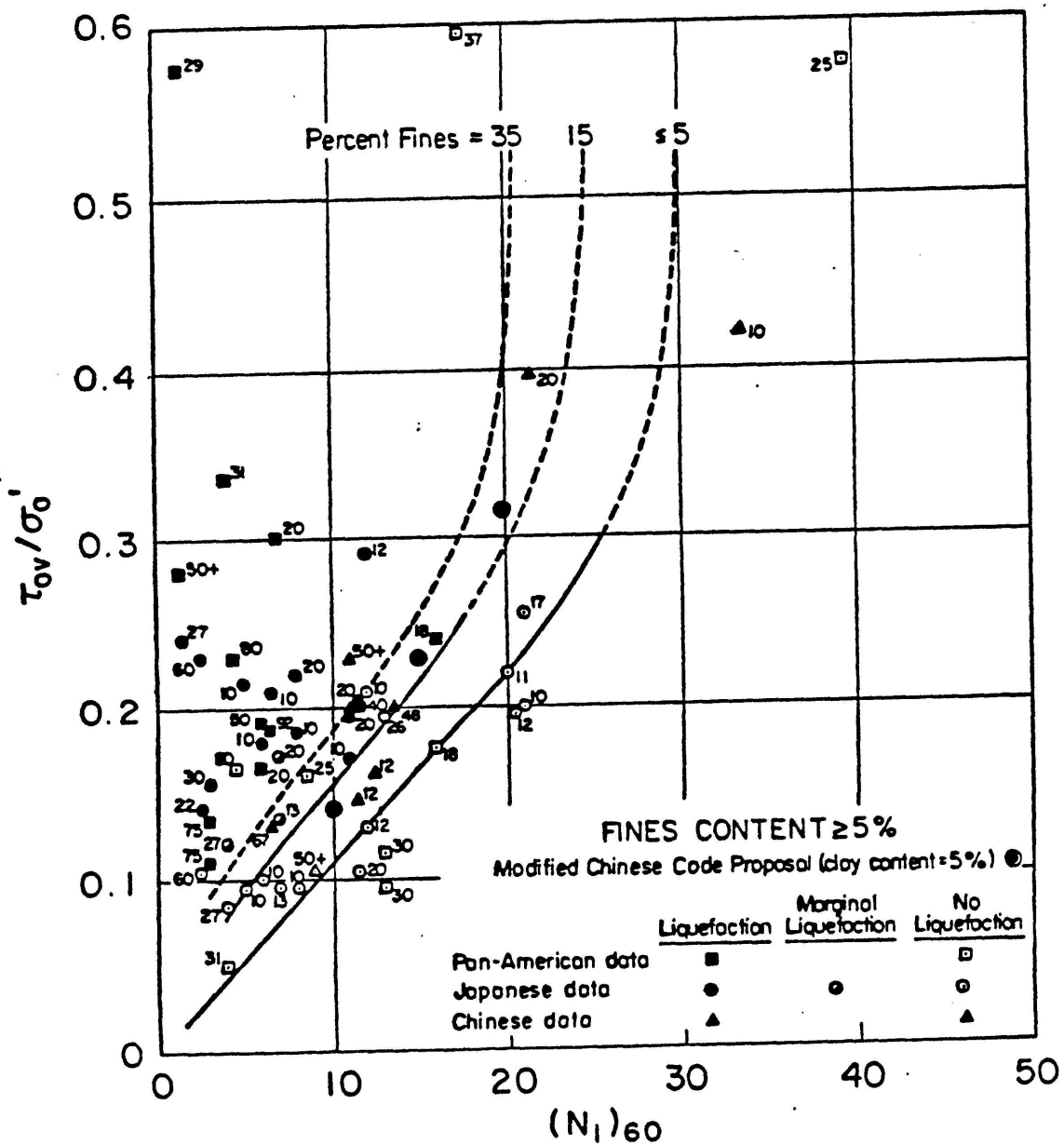
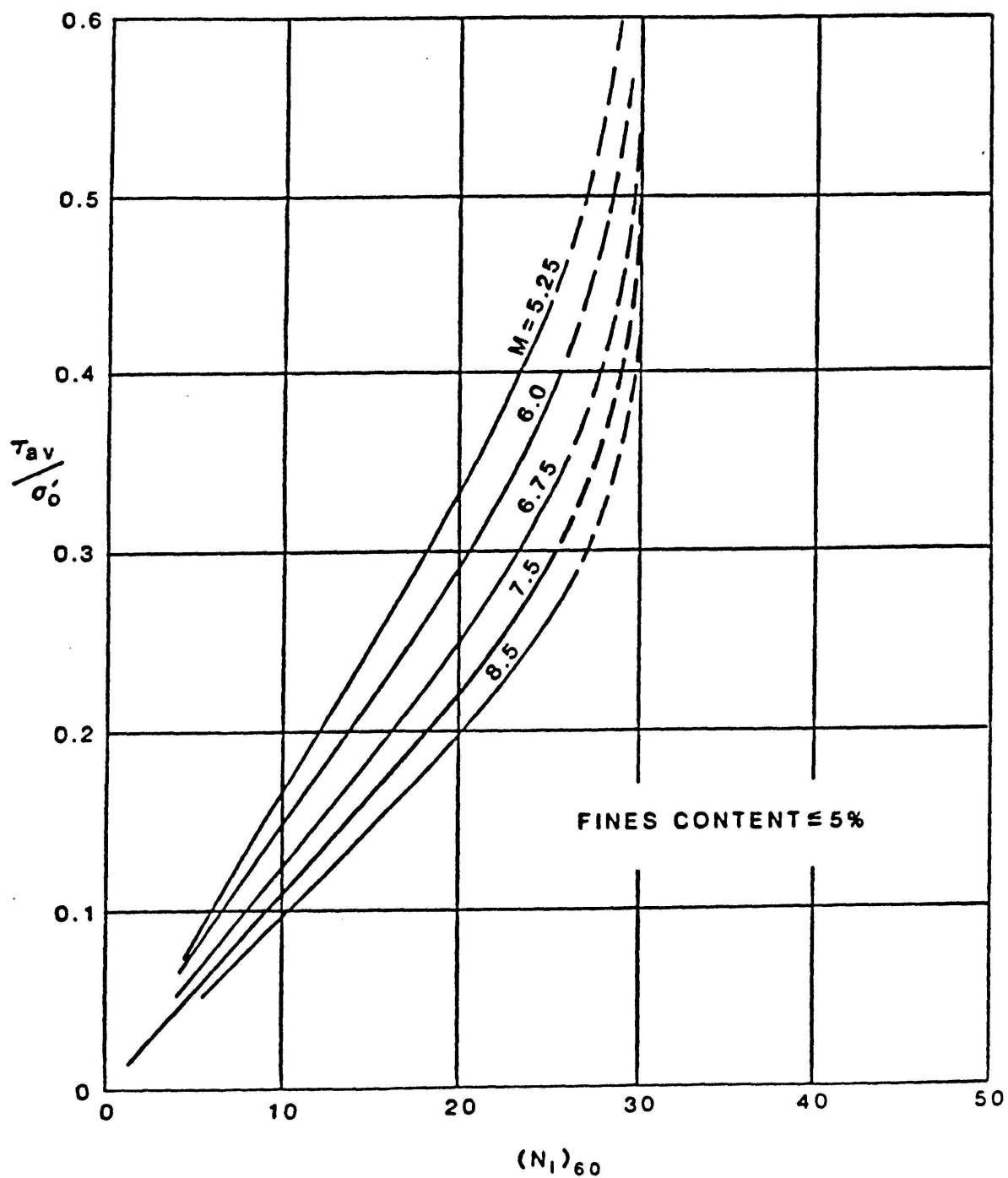


Figure A3

Relationships Between Cyclic Stress Ratios Causing Liquefaction and  $(N_1)_{60}$  for Silty Sands  $M = 7.5$



**Figure A4**      **Liquefaction Assessment Chart for Clean Sands for Various Earthquake Magnitudes (Koester & Franklin, 1985)**

**TABLE A1**

Earthquake Magnitude (M) (Figures A3 & A5)	Correction Factor No. of Significant Cycles	
8.5	26	0.89
7.5	15	1.0
6.75	10	1.13
6.0	5-6	1.32
5.25	2-3	1.5

The data base for Figure A3 is limited to sites where liquefaction occurred under effective overburden pressures less than 150 Kpa (1.5 tsf). For overburden pressures greater than this, it is necessary to make an appropriate reduction in the critical stress ratio (Seed, 1983).

Many of the SPT measurements made in the Fraser River Delta region as part of site investigations for industrial and other developments were conducted primarily to recover samples for soil identification and for foundation design. They were generally not conducted with the assessment of liquefaction potential in mind, and, in general, did not follow the guidelines developed by Seed et al (1984). It is possible to make generalized corrections to this SPT data to meet modern standards based on the type of hammer used and assuming that all other procedures were followed correctly. But this is necessarily a very crude assumption.

For the GSC study such data will not be ignored but will be treated with caution and only used in the absence of more reliable and repeatable data. Fortunately a wealth of more reliable data is becoming available. The Richmond area is unique in that large amounts of data on near surface sediments have been obtained in recent years by state of the art methods. The Seismic Cone Penetration Test with pore pressure measurements (SCPTU) is one of these new methods and gives reliable data on a number of critical soil parameters on a nearly continuous basis at each test location.

#### **A.2.2.2 Cone Penetration Test (CPT)**

Electric cone tip penetration resistance ( $Q_c$ ) has been measured at few sites as yet where the occurrence of nonoccurrence of liquefaction during actual earthquakes have been documented. Therefore, the data base on cone penetration resistances at liquefied sites has been extended by converting the well documented correlation between liquefaction potential and standard penetration resistance to cone penetration resistance.



There have been a number of studies on the correlation between cone resistance and standard penetration resistance (Douglas et al 1981; Robertson et al. 1983). Figure A5 indicates that the ratio of cone resistance to blow count increases with increasing mean grain diameter (Robertson et al., 1983). This correlation is considered to be the one most relevant to the Fraser Delta, because some of the data to develop the relationship was obtained from comparative tests in the area.

The liquefaction assessment chart in Figure A3 based on  $(N_1)_{60}$  can now be converted to a chart based on  $Q_{c1}$  as shown in Figure A6.

#### Fines Content

Seed et al (1985) reviewed sites that did and did not liquefy during earthquakes where the fines content was greater than 5%. They found that for the same penetration resistance the liquefaction resistance increased with increasing fines content (Figures A3, A6). Corrections to the normalized cone penetration resistance with fines  $(Q_{c1})_f$  can be established from Figure 6 that may be used to reduce penetration resistance data from the test sites to penetration resistances of clean sand with similar liquefaction potential. The correction is given by:

$$Q_{c1} = (Q_{c1})_f + \Delta Q_{c1}$$

where  $\Delta Q_{c1}$  are given in Figure A7

It is possible to estimate the fines content (FC) directly from the CPTU data. Figure A8 presents the latest soil classification chart based on normalized CPTU data. Soils that fall in zone 6 are generally clean sands or silty sands with a small amount of fines. Soils that fall in zone 5 are silty sands and sandy silts that generally have fines contents greater than about 15%.

Based on data collected in the Richmond area a correlation has been established by Finn et al., (1989) between fines content and the time for 50% dissipation ( $T_{50}$ ) of the pore pressures developed during penetration (Figure A9). The results in Figure A10 suggest that for  $T_{50} > 50$  sec the fines content is greater than 40%. For  $T_{50}$  between 10 sec and 50 sec the cone penetration process is partially drained and there is a poor correlation between  $T_{50}$  and fines content.

If the fines are plastic, additional criteria based on field data from Chinese earthquakes must be taken into account (Wang, 1979) to determine if the soil will liquefy. Liquefaction of sands with plastic fines can occur if all the following conditions are satisfied:

Percent finer than 0.005 mm	<15%
Liquid Limit	<35%
Water Content	>0.9 IL
Liquidity Index	>0.75

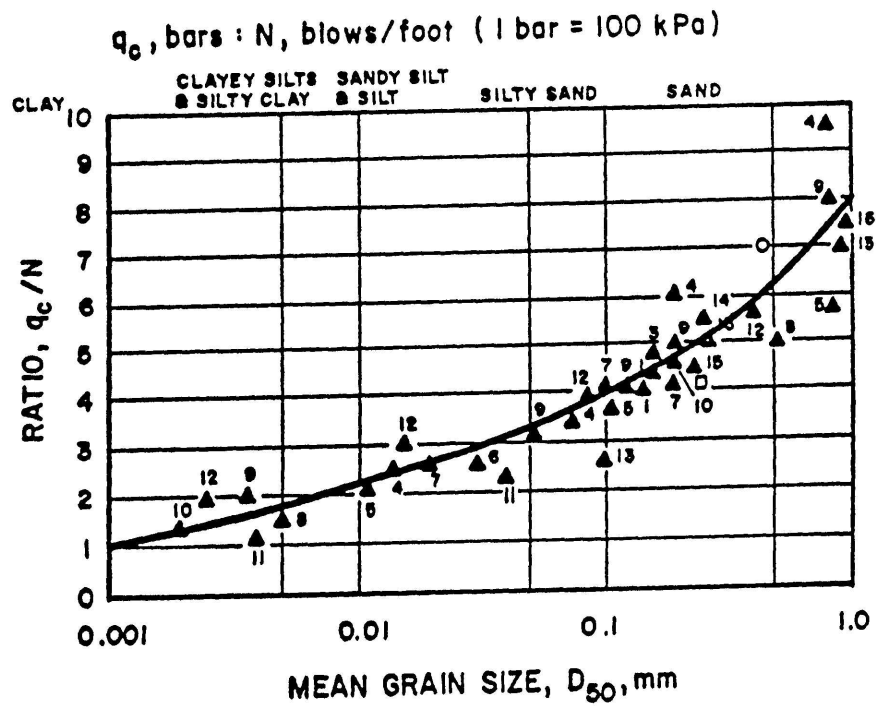


Figure A5

Relationship Between  $q_c/N_{SPT}$  and Medium Grain Size  $D_{50}$   
 Numbers Next to Data Points Indicate Various Sources of Data  
 (Robertson et al, 1983)

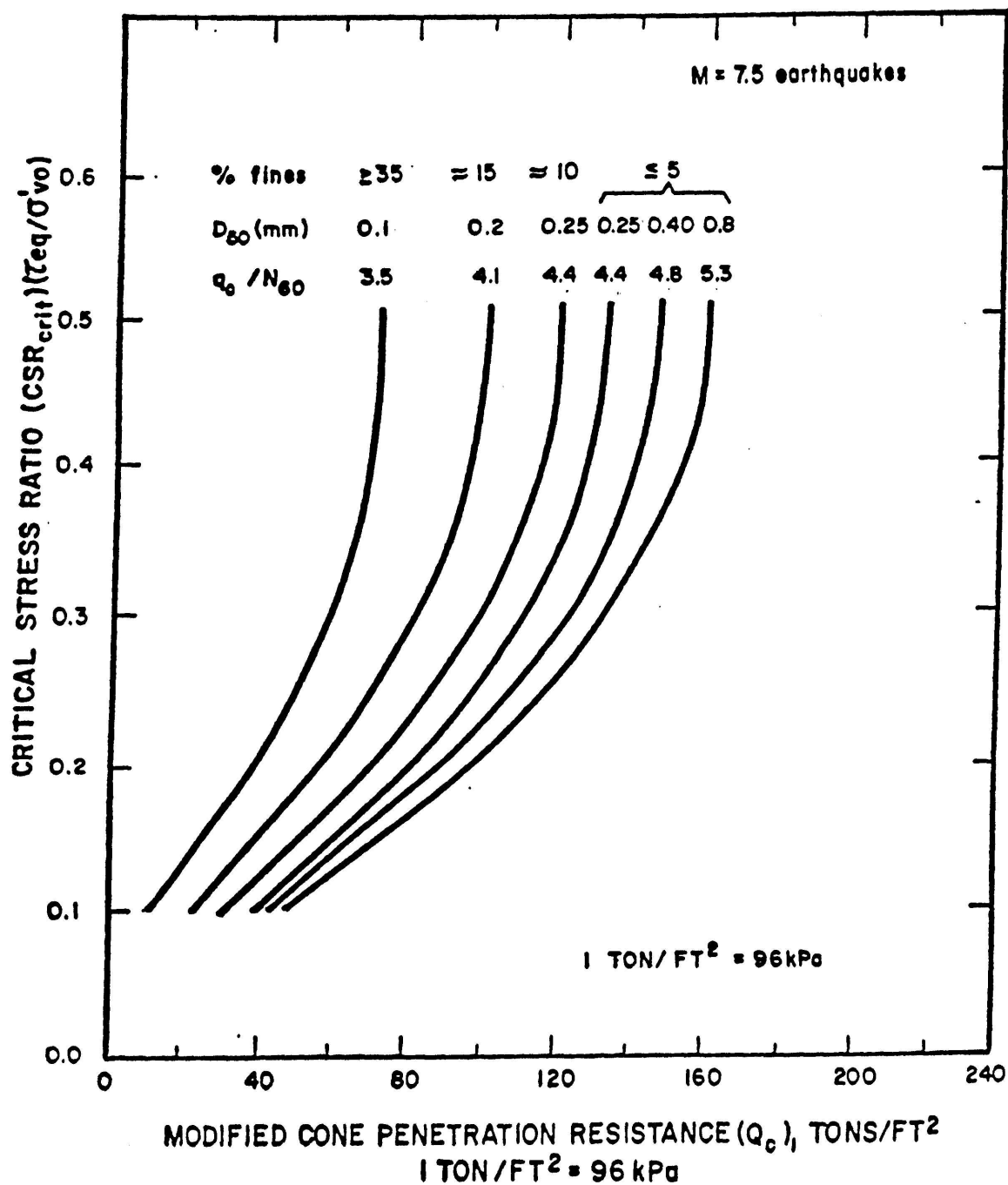


Figure A6

Relationship Between Critical Cyclic Stress Ratio Causing Liquefaction and Cone Tip Resistance for Sands and Silty Sands

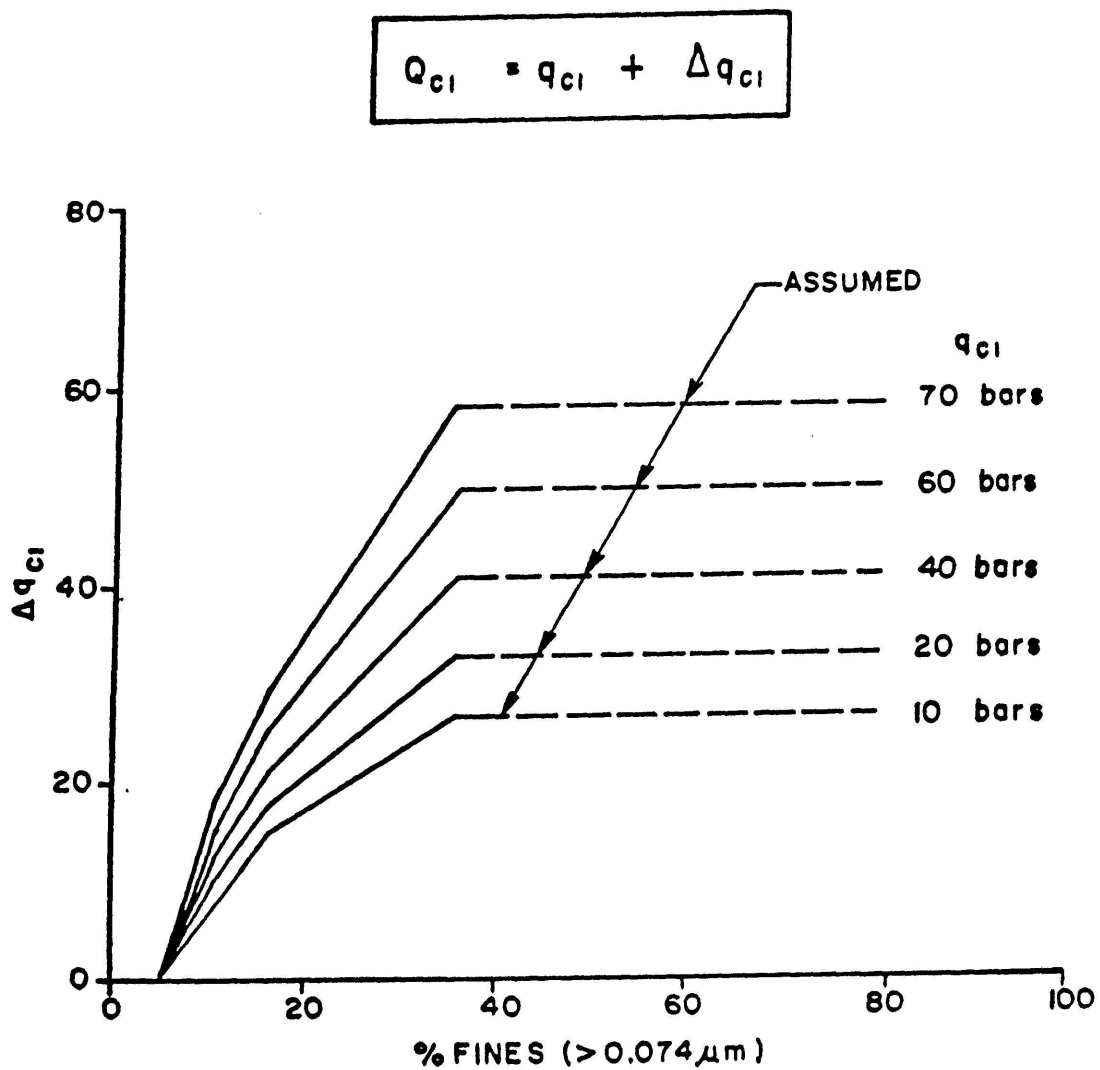
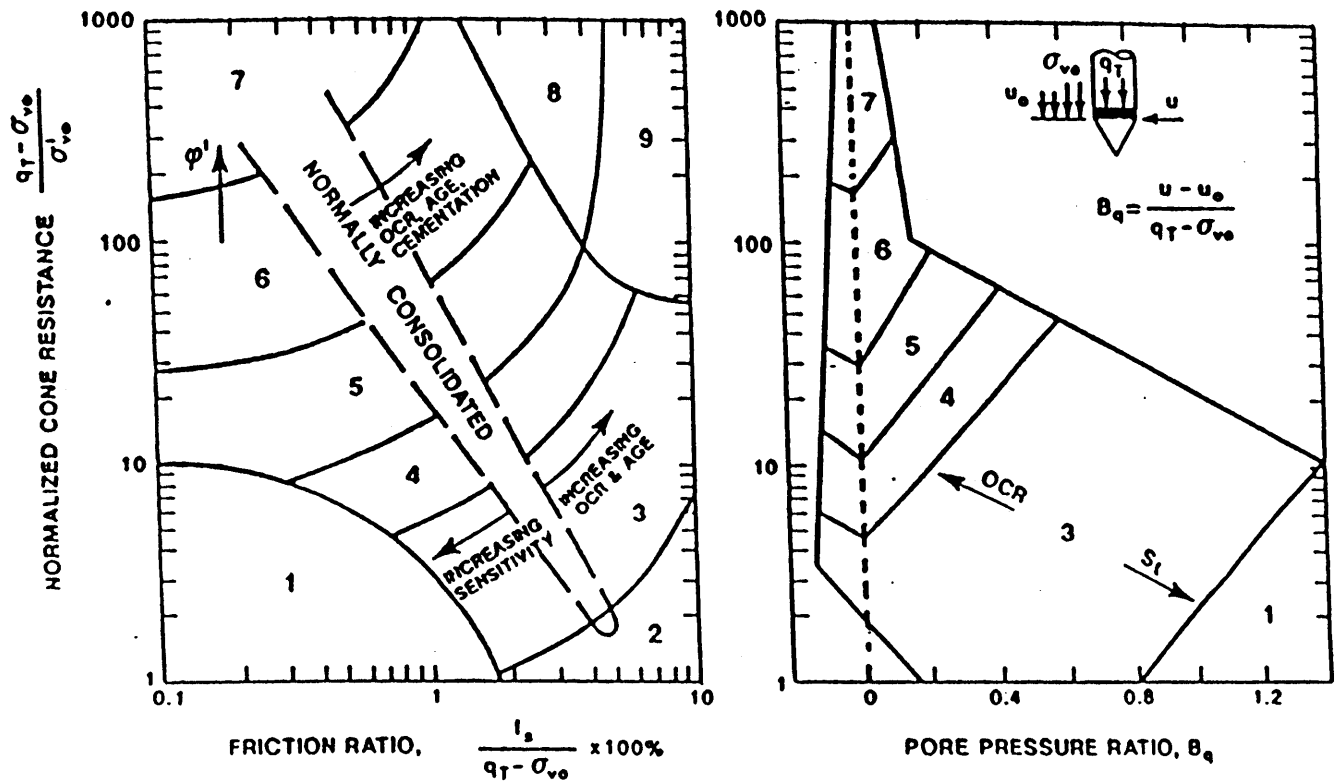


Figure A7

Correction for Fines Content to CPT Data Based on Seed et al. (1985)



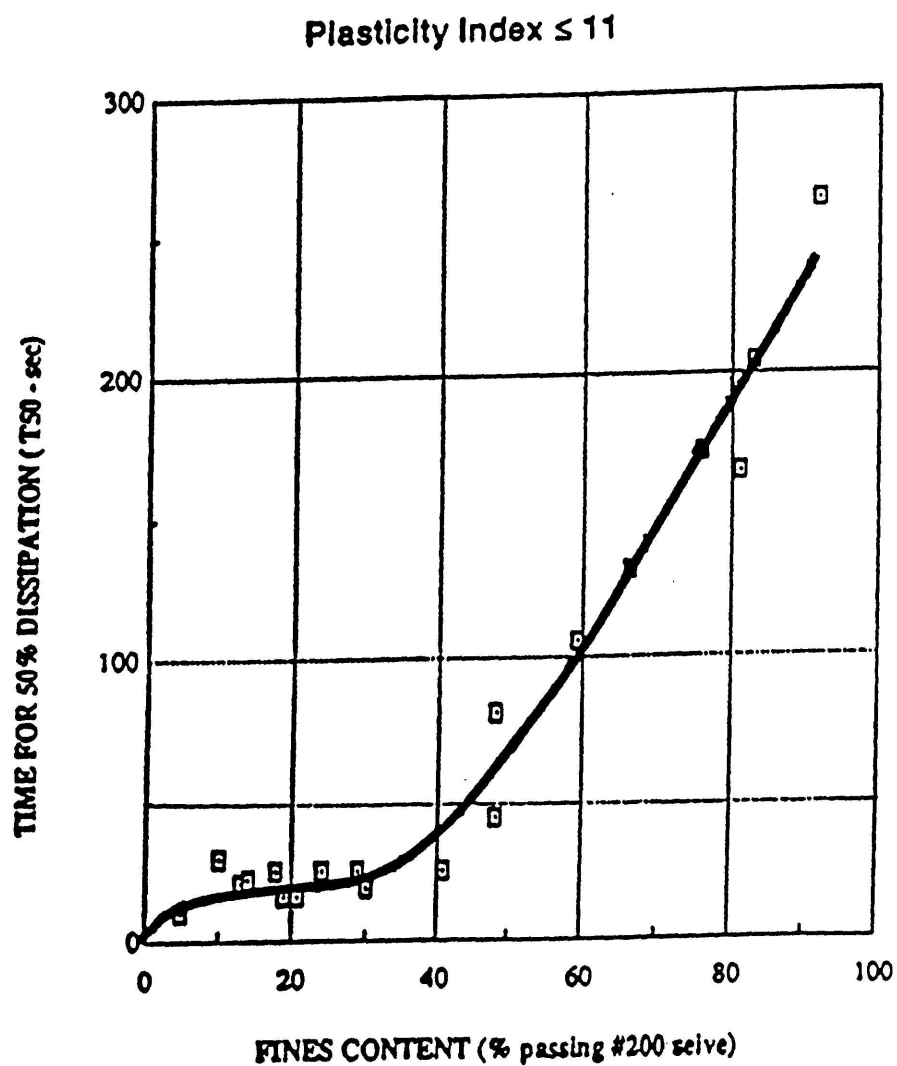
1. SENSITIVE FINE GRAINED
2. ORGANIC SOILS - PEATS
3. CLAYS - CLAY TO SILTY CLAY
4. SILT MIXTURES - CLAYEY SILT TO SILTY CLAY
5. SAND MIXTURES - SILTY SAND TO SANDY SILT

6. SANDS - CLEAN SAND TO SILTY SAND
7. GRAVELLY SAND TO SAND
8. VERY STIFF SAND TO CLAYEY\* SAND
9. VERY STIFF FINE GRAINED\*

(\*) HEAVILY OVERCONSOLIDATED OR CEMENTED

Figure A8

Proposed Soil Classification Chart Based on Normalized CPT and CPTU Data (Robertson 1990)



**Figure A9**

**Correlation Between Fines Content and Time for 50% Dissipation From CPTU (Finn, et al. 1989)**

These criteria should not be applied strictly but with recognition of the likely errors in measuring fines content, liquid limit and water content.

### A.2.3 Liquefaction Assessment from Shear Wave Velocity

Empirical methods have been developed to evaluate liquefaction resistance directly from shear wave velocity (Bierschwale & Stokoe, 1984). Over the past 15 years significant advances have been made in measuring shear wave velocities in the field. Accurate and detailed profiles can be determined with conventional crosshole and downhole seismic methods (Stokoe & Hoar, 1987; Wood, 1987). Shear wave velocity,  $V_s$ , is influenced by many of the variables that influence liquefaction potential, such as soil density, confinement, stress history and geologic age. Thus,  $V_s$  has promise as a field index in evaluating liquefaction susceptibility. The most significant advance in recent years has been the development of the seismic cone penetration test (Robertson et al 1986).

The major advantage of using shear wave velocity as an index of liquefaction resistance is that it can be measured in soils that are difficult to sample, such as silts and sands or difficult to penetrate, such as gravels.

### Direct Shear Wave Velocity Correlations

The limiting shear wave velocities separating liquefied from non-liquefied sites for a given intensity and duration of shaking must be determined from field data. So far the data base is quite limited but it clearly shows that shear wave velocities may be a useful index of liquefaction potential. Data from sites in the Imperial Valley, California which liquefied during the 1979 Imperial Valley, 1981 Westmorland and 1987 Superstition Hills earthquakes, suggest that the limiting shear wave velocity separating liquefiable from non-liquefiable sites is about 140 m/s for earthquakes of local magnitude  $M_L = 6.5$  generating peak ground accelerations of about 0.17g (Holzer et al., 1988; Youd and Wieczorak, 1984).

Shear wave velocity is a function of sediment type void ratio and effective confining stress. Hence, for a sand of constant void ratio (constant density) shear wave velocity will increase with increasing depth. Therefore, a correlation between  $V_s$  and CSR to cause liquefaction should be based on effective overburden stress, similar to the manner in which penetration resistance is normalized with depth. Shear wave velocity being proportional to the square root of the shear modulus is a function of the effective overburden stress to the power 0.25,

$$V_s = f [(\sigma_v')^{0.5}]$$

Therefore, a normalized shear wave velocity can be established using the relationship,

$$V_{s1} = V_s (P_a / \sigma_{vo}')^{0.25}$$

where

$$\begin{array}{ll} P_a & = \text{reference stress, typically 100 Kpa} \\ \sigma_{vo} & = \text{effective overburden stress in same units as } P_a \end{array}$$

The proposed correlation between normalized shear wave velocity and the critical cyclic stress ratio necessary to prevent liquefaction is shown in Figure A10. The data base is still very small so it is still too soon to use the shear wave velocity criterion alone in practice.



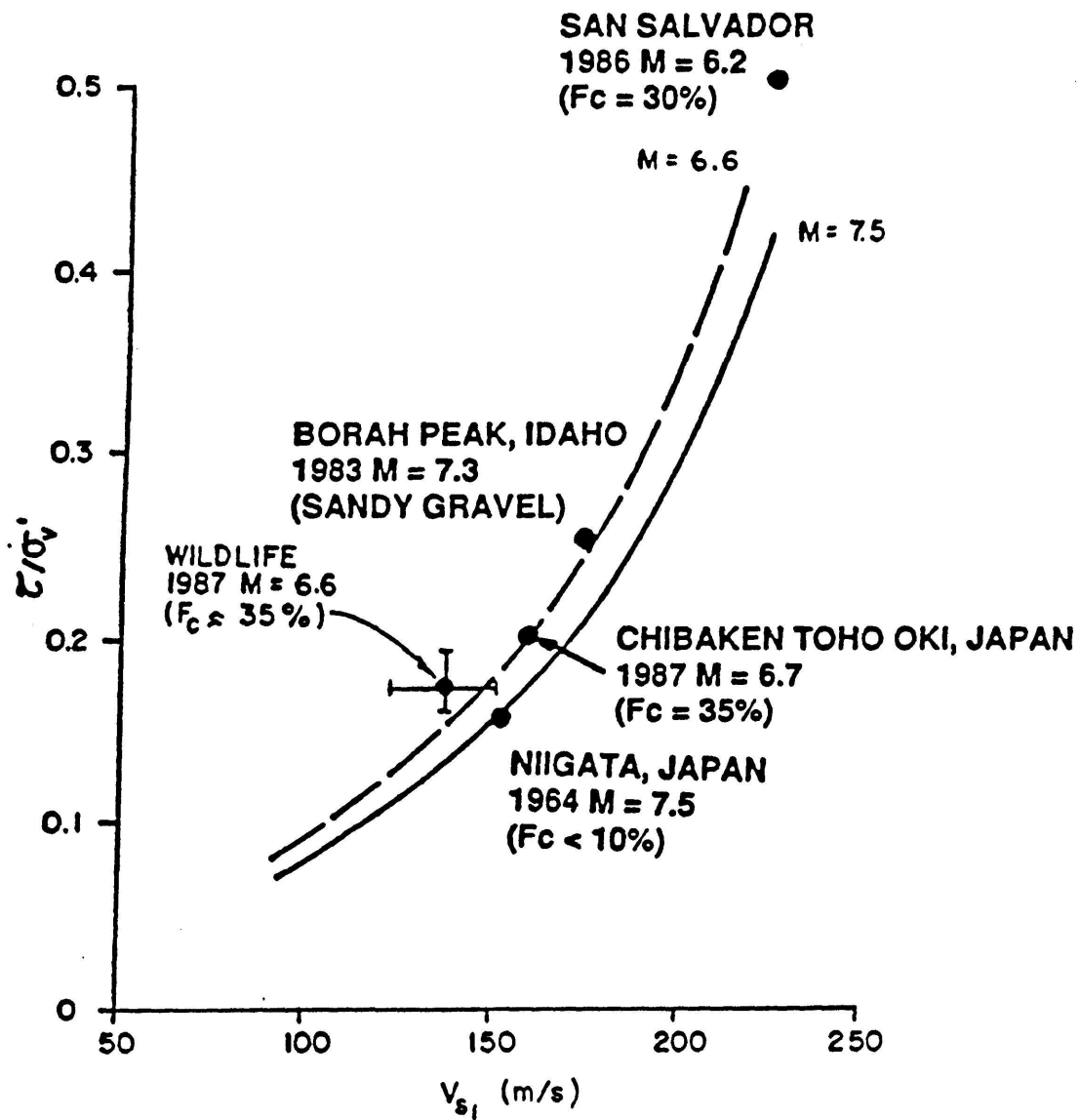


Figure A10

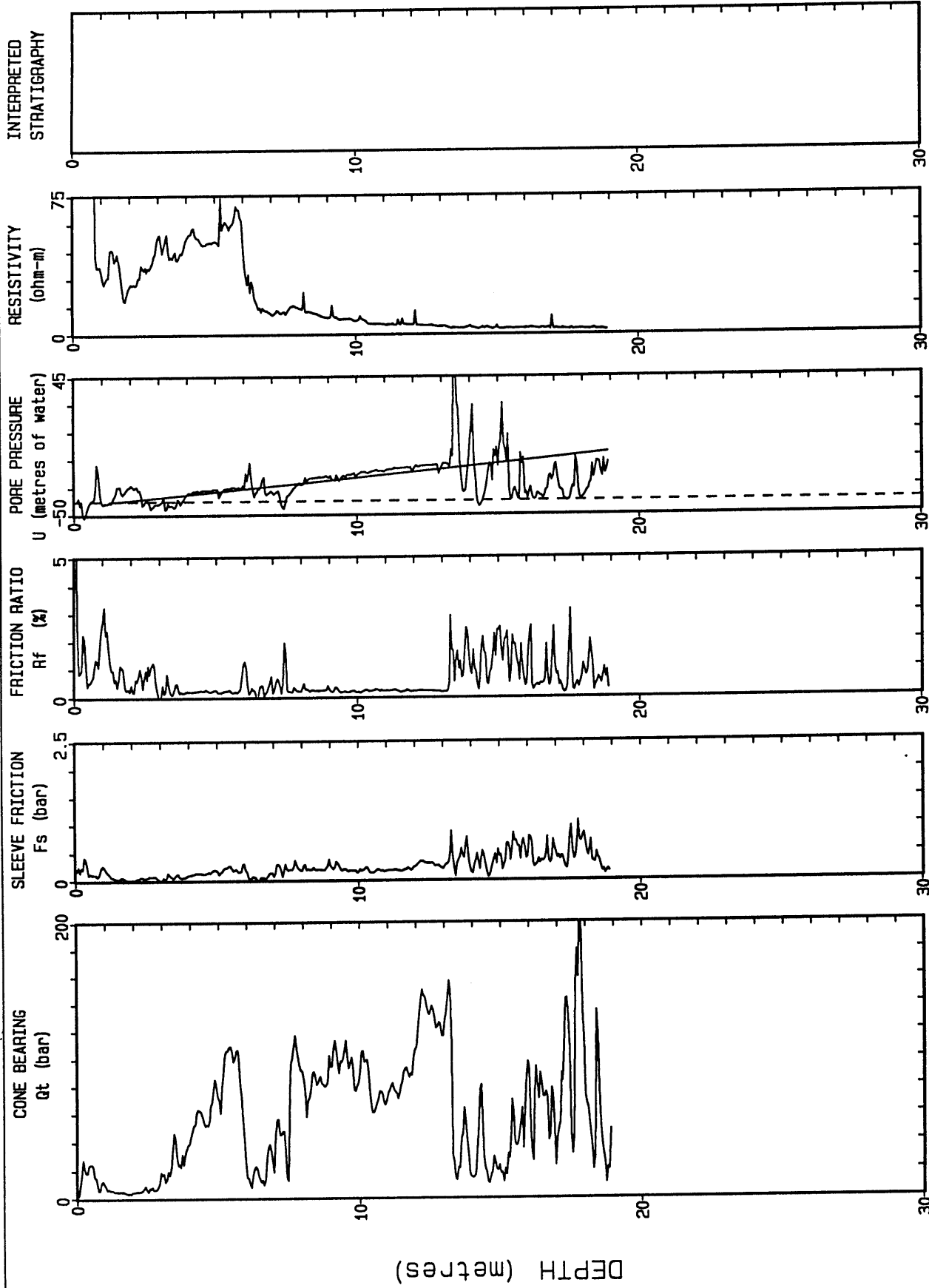
Proposed Correlation Between Normalized Shear Wave Velocity and Cyclic Stress Ratio (CSR) to Cause Liquefaction

## **APPENDIX B**

# G . S . C .

CONTRACTOR: CONETEC  
LOCATION: AIRPORT

FILE: gsc-air.cor  
DATE: 111/21/91  
HOLE: GSC RCPT-1 BT  
CONE: 2 TON HT NO.340



Depth Increment : .05 m

Max Depth : 18.90 m

GSC

CONTRACTOR: CONETEC

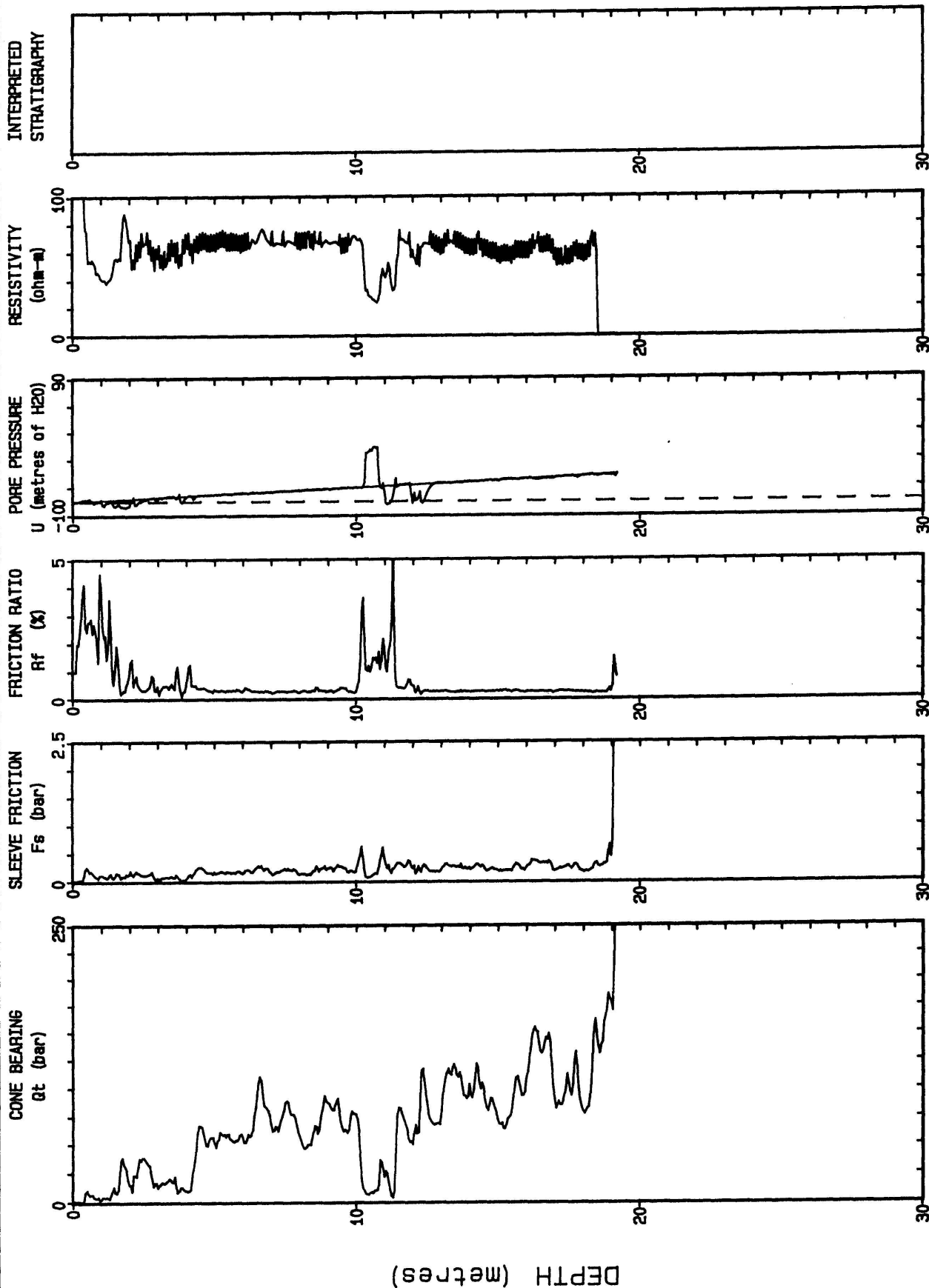
LOCATION: RADIO TOWER

DATE: 01/27/92 10:20

CONE: 2 TON HT NO. 340

FILE: 103cpt3.cor

HOLE: 92-103 CPT-3 BT



Depth Increment : .05 m

Max Depth : 19.20 m

GSC

CONTRACTOR: CONETEC

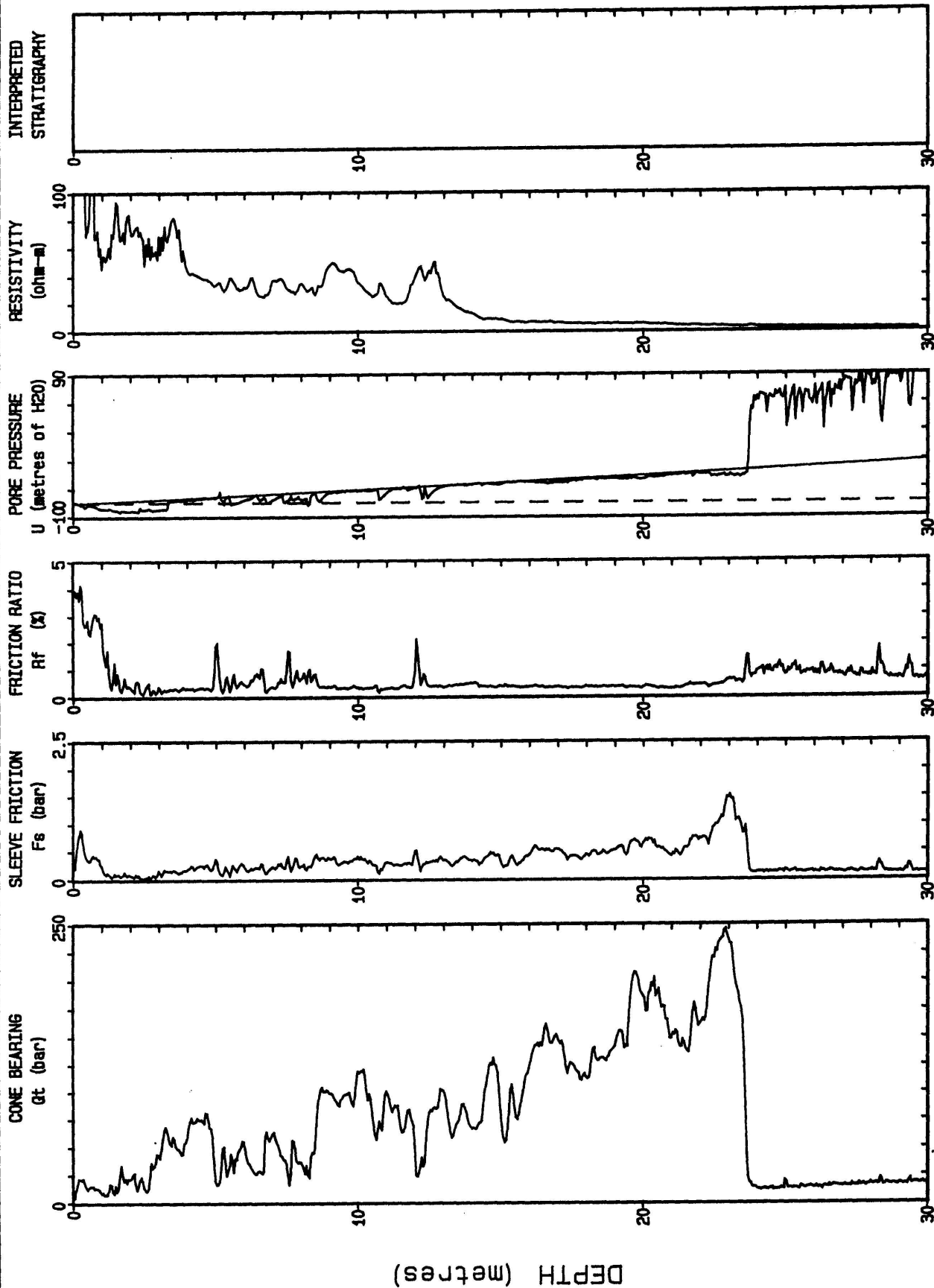
LOCATION: MAYFAIR - NO 7 R

DATE: 01/16/92 15:00

CONE: D TON HT NO. 340

FILE: 103RCPT2.COR

HOLE: 92-103 CPT-2 BT



Depth Increment : .05 m

Max Depth : 30.30 m

# GSC

CONTRACTOR: CONETEC

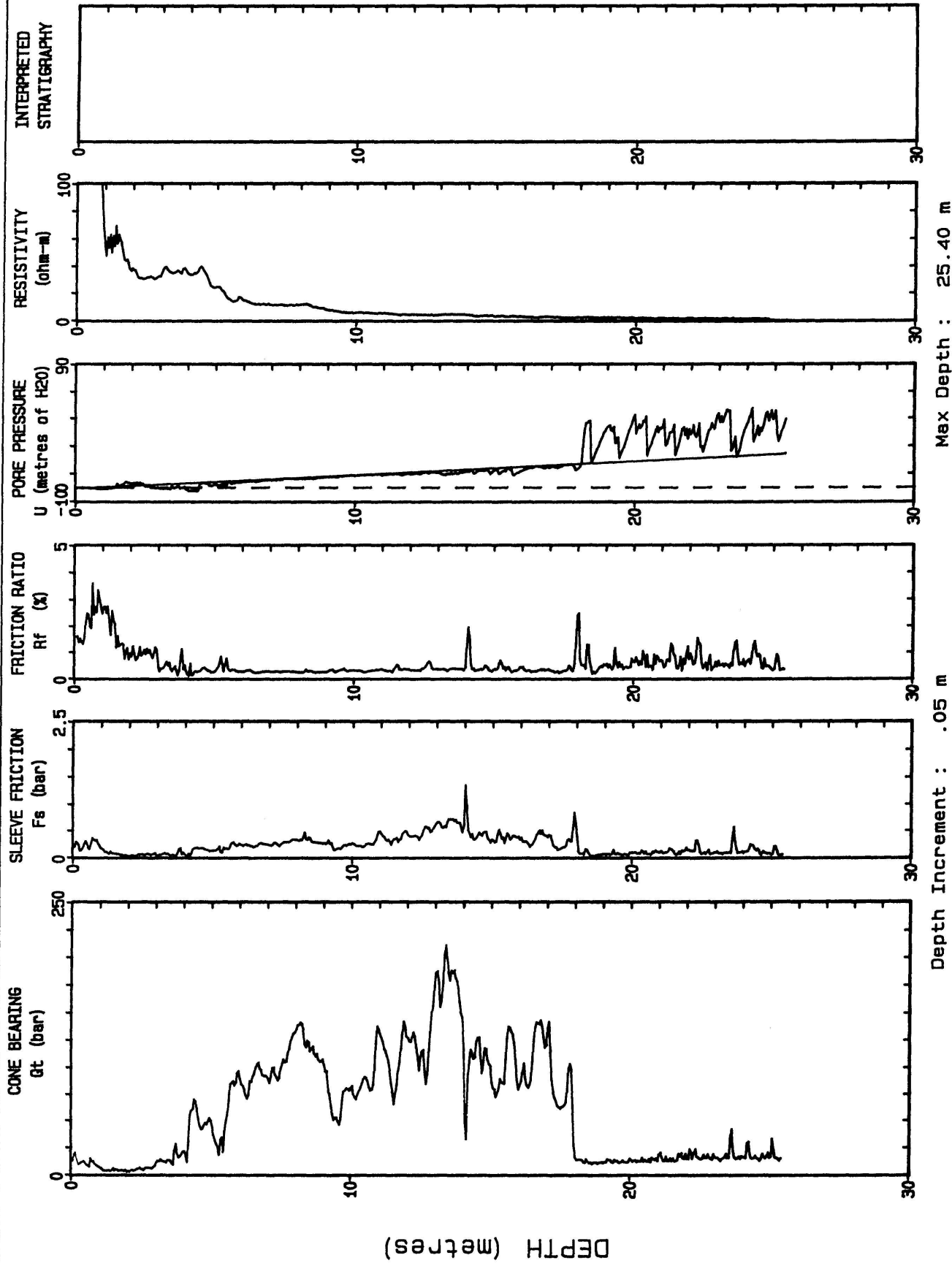
LOCATION: FRANCIS & RAILWAY

DATE: 01/16/92 10:30

CONE: 2 TON HT NO. 340

FILE: 103RCPT1.COR

HOLE: 92-103 CPT-1 BT





## **APPENDIX C**



# G.S.C.

Contractor : CONETEC  
 Location : FRANCIS & RAILWAY  
 Hole Number: 92-103 CPT-1 BT  
 Tot. Unit Wt. (avg) : 19.5 kN/m<sup>3</sup>

CPT Date : 01/16/92 10:30  
 Cone Used : 2 TON HT NO. 340  
 Water table (meters) : 1

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
0.25	0.82	15.13	0.23	1.51	2.44	sandy silt to clayey silt	UNDFND	UNDFD	6	120.82
0.50	1.64	11.16	0.22	2.01	7.31	clayey silt to silty clay	UNDFND	UNDFD	6	88.67
0.75	2.46	10.49	0.26	2.52	12.18	clayey silt to silty clay	UNDFND	UNDFD	5	82.94
1.00	3.28	9.17	0.26	2.81	17.06	silty clay to clay	UNDFND	UNDFD	6	72.02
1.25	4.10	4.49	0.12	2.58	20.70	clay	UNDFND	UNDFD	4	34.18
1.50	4.92	4.37	0.08	1.88	23.12	silty clay to clay	UNDFND	UNDFD	3	32.81
1.75	5.74	4.26	0.06	1.36	25.55	sensitive fine grained	UNDFND	UNDFD	2	31.57
2.00	6.56	3.65	0.03	0.93	27.97	sensitive fine grained	UNDFND	UNDFD	2	26.30
2.25	7.38	3.78	0.03	0.90	30.39	sensitive fine grained	UNDFND	UNDFD	2	26.95
2.50	8.20	5.35	0.05	1.01	32.81	sensitive fine grained	UNDFND	UNDFD	3	39.12
2.75	9.02	5.79	0.06	1.00	35.23	sensitive fine grained	UNDFND	UNDFD	3	42.19
3.00	9.84	6.79	0.06	0.88	37.65	sensitive fine grained	UNDFND	UNDFD	3	49.81
3.25	10.66	12.83	0.05	0.41	40.08	sandy silt to clayey silt	UNDFND	UNDFD	5	97.79
3.50	11.48	12.71	0.06	0.47	42.50	sandy silt to clayey silt	UNDFND	UNDFD	5	96.43
3.75	12.30	16.90	0.05	0.28	44.92	silty sand to sandy silt	<40	30-32	6	UNDEFINED
4.00	13.12	18.42	0.11	0.60	47.34	sandy silt to clayey silt	UNDFND	UNDFD	7	141.28
4.25	13.94	27.42	0.05	0.18	49.76	silty sand to sandy silt	40-50	34-36	9	UNDEFINED
4.50	14.76	64.02	0.18	0.28	52.18	sand to silty sand	60-70	38-40	16	UNDEFINED
4.75	15.58	45.30	0.17	0.38	54.60	sand to silty sand	50-60	36-38	11	UNDEFINED
5.00	16.40	49.11	0.13	0.27	57.03	sand to silty sand	50-60	36-38	12	UNDEFINED
5.25	17.22	32.84	0.16	0.47	59.45	silty sand to sandy silt	40-50	34-36	11	UNDEFINED
5.50	18.04	29.07	0.14	0.49	61.87	silty sand to sandy silt	<40	32-34	10	UNDEFINED
5.75	18.86	68.80	0.23	0.33	64.29	sand to silty sand	60-70	38-40	17	UNDEFINED
6.00	19.69	89.66	0.24	0.27	66.71	sand	60-70	38-40	18	UNDEFINED
6.25	20.51	81.85	0.24	0.29	69.13	sand	60-70	38-40	16	UNDEFINED
6.50	21.33	82.19	0.22	0.26	71.56	sand	60-70	38-40	16	UNDEFINED
6.75	22.15	99.98	0.25	0.25	73.98	sand	70-80	38-40	20	UNDEFINED
7.00	22.97	93.21	0.25	0.27	76.40	sand	60-70	38-40	19	UNDEFINED
7.25	23.79	93.32	0.25	0.27	78.82	sand	60-70	38-40	19	UNDEFINED
7.50	24.61	92.36	0.25	0.27	81.24	sand	60-70	38-40	18	UNDEFINED
7.75	25.43	106.64	0.29	0.27	83.66	sand	70-80	38-40	21	UNDEFINED
8.00	26.25	126.28	0.34	0.27	86.08	sand	70-80	40-42	25	UNDEFINED
8.25	27.07	138.54	0.34	0.25	88.51	sand	70-80	40-42	28	UNDEFINED
8.50	27.89	124.36	0.38	0.30	90.93	sand	70-80	40-42	25	UNDEFINED
8.75	28.71	114.86	0.29	0.25	93.35	sand	70-80	38-40	23	UNDEFINED
9.00	29.53	107.30	0.27	0.25	95.77	sand	60-70	38-40	21	UNDEFINED
9.25	30.35	89.57	0.27	0.31	98.19	sand	60-70	36-38	18	UNDEFINED
9.50	31.17	55.08	0.16	0.29	100.61	sand to silty sand	50-60	34-36	14	UNDEFINED

Dr - All sands (Jamolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC

Location : FRANCIS & RAILWAY

Page No. 2

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
9.75	31.99	58.13	0.20	0.34	103.04	sand to silty sand	50-60	34-36	15	UNDEFINED
10.00	32.81	79.90	0.25	0.31	105.46	sand	60-70	36-38	16	UNDEFINED
10.25	33.63	74.86	0.23	0.31	107.88	sand to silty sand	50-60	34-36	19	UNDEFINED
10.50	34.45	84.64	0.22	0.26	110.30	sand	60-70	36-38	17	UNDEFINED
10.75	35.27	83.64	0.26	0.31	112.72	sand	60-70	36-38	17	UNDEFINED
11.00	36.09	114.79	0.40	0.35	115.14	sand	60-70	38-40	23	UNDEFINED
11.25	36.91	122.32	0.37	0.30	117.57	sand	70-80	38-40	24	UNDEFINED
11.50	37.73	95.22	0.30	0.32	119.99	sand	60-70	36-38	19	UNDEFINED
11.75	38.55	85.00	0.34	0.40	122.41	sand	50-60	34-36	17	UNDEFINED
12.00	39.37	130.90	0.46	0.35	124.83	sand	70-80	38-40	26	UNDEFINED
12.25	40.19	126.76	0.40	0.32	127.25	sand	70-80	38-40	25	UNDEFINED
12.50	41.01	112.67	0.38	0.34	129.67	sand	60-70	36-38	23	UNDEFINED
12.75	41.83	100.95	0.55	0.55	132.09	sand	60-70	36-38	20	UNDEFINED
13.00	42.65	145.22	0.55	0.38	134.52	sand	70-80	38-40	29	UNDEFINED
13.25	43.47	173.72	0.62	0.36	136.94	sand	70-80	38-40	35	UNDEFINED
13.50	44.29	194.84	0.65	0.34	139.36	sand	80-90	40-42	39	UNDEFINED
13.75	45.11	184.58	0.70	0.38	141.78	sand	70-80	38-40	37	UNDEFINED
14.00	45.93	160.78	0.59	0.37	144.20	sand	70-80	38-40	32	UNDEFINED
14.25	46.75	78.05	0.73	0.94	146.62	sand to silty sand	50-60	34-36	20	UNDEFINED
14.50	47.57	113.96	0.38	0.33	149.05	sand	60-70	36-38	23	UNDEFINED
14.75	48.39	112.99	0.45	0.40	151.47	sand	60-70	36-38	23	UNDEFINED
15.00	49.21	108.93	0.36	0.33	153.89	sand	60-70	36-38	22	UNDEFINED
15.25	50.03	78.44	0.36	0.46	156.31	sand to silty sand	50-60	32-34	20	UNDEFINED
15.50	50.85	85.34	0.36	0.43	158.73	sand	50-60	34-36	17	UNDEFINED
15.75	51.67	127.84	0.40	0.31	161.15	sand	60-70	36-38	26	UNDEFINED
16.00	52.49	105.41	0.38	0.36	163.57	sand	60-70	34-36	21	UNDEFINED
16.25	53.31	91.89	0.31	0.34	166.00	sand	50-60	34-36	18	UNDEFINED
16.50	54.13	88.22	0.25	0.28	168.42	sand	50-60	34-36	18	UNDEFINED
16.75	54.95	136.50	0.44	0.32	170.84	sand	60-70	36-38	27	UNDEFINED
17.00	55.77	129.40	0.43	0.33	173.26	sand	60-70	36-38	26	UNDEFINED
17.25	56.59	111.73	0.31	0.28	175.68	sand	60-70	34-36	22	UNDEFINED
17.50	57.41	65.10	0.16	0.25	178.10	sand to silty sand	40-50	30-32	16	UNDEFINED
17.75	58.23	66.54	0.25	0.38	180.53	sand to silty sand	40-50	30-32	17	UNDEFINED
18.00	59.06	78.00	0.53	0.68	182.95	sand to silty sand	50-60	32-34	19	UNDEFINED
18.25	59.88	13.62	0.14	1.03	185.37	sandy silt to clayey silt	UNDFND	UNDFD	5	80.65
18.50	60.70	11.75	0.10	0.82	187.79	sandy silt to clayey silt	UNDFND	UNDFD	5	65.35
18.75	61.52	10.43	0.03	0.27	190.21	sandy silt to clayey silt	UNDFND	UNDFD	4	54.35
19.00	62.34	10.30	0.05	0.52	192.63	sandy silt to clayey silt	UNDFND	UNDFD	4	52.98
19.25	63.16	11.57	0.06	0.48	195.05	sandy silt to clayey silt	UNDFND	UNDFD	5	62.75
19.50	63.98	12.27	0.08	0.68	197.48	sandy silt to clayey silt	UNDFND	UNDFD	5	67.95
19.75	64.80	11.56	0.05	0.47	199.90	sandy silt to clayey silt	UNDFND	UNDFD	5	61.89
20.00	65.62	11.57	0.07	0.59	202.32	sandy silt to clayey silt	UNDFND	UNDFD	5	61.52

Dr - All sands (Jamolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*

# G.S.C.

Contractor : CONETEC

Location : FRANCIS & RAILWAY

Page No. 3

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
20.25	66.44	12.31	0.09	0.70	204.74	sandy silt to clayey silt	UNDFND	UNDFD	5	67.11
20.50	67.26	12.44	0.10	0.79	207.16	sandy silt to clayey silt	UNDFND	UNDFD	5	67.71
20.75	68.08	12.50	0.07	0.54	209.58	sandy silt to clayey silt	UNDFND	UNDFD	5	67.82
21.00	68.90	13.79	0.10	0.75	212.01	sandy silt to clayey silt	UNDFND	UNDFD	6	77.78
21.25	69.72	15.59	0.09	0.60	214.43	sandy silt to clayey silt	UNDFND	UNDFD	6	91.78
21.50	70.54	13.50	0.14	1.02	216.85	sandy silt to clayey silt	UNDFND	UNDFD	5	74.65
21.75	71.36	14.00	0.07	0.50	219.27	sandy silt to clayey silt	UNDFND	UNDFD	6	78.24
22.00	72.18	16.55	0.14	0.83	221.69	sandy silt to clayey silt	UNDFND	UNDFD	7	98.24
22.25	73.00	17.06	0.13	0.74	224.11	sandy silt to clayey silt	UNDFND	UNDFD	7	101.94
22.50	73.82	17.89	0.20	1.14	226.53	sandy silt to clayey silt	UNDFND	UNDFD	7	108.21
22.75	74.64	15.14	0.09	0.61	228.96	sandy silt to clayey silt	UNDFND	UNDFD	6	85.80
23.00	75.46	15.80	0.08	0.48	231.38	sandy silt to clayey silt	UNDFND	UNDFD	6	90.69
23.25	76.28	14.13	0.08	0.58	233.80	sandy silt to clayey silt	UNDFND	UNDFD	6	76.93
23.50	77.10	15.26	0.08	0.54	236.22	sandy silt to clayey silt	UNDFND	UNDFD	6	85.64
23.75	77.92	25.12	0.29	1.17	238.64	sandy silt to clayey silt	UNDFND	UNDFD	10	164.10
24.00	78.74	15.02	0.09	0.60	241.06	sandy silt to clayey silt	UNDFND	UNDFD	6	82.91
24.25	79.56	20.50	0.15	0.71	243.49	silty sand to sandy silt	<40	<30	7	UNDEFINED
24.50	80.38	15.74	0.18	1.16	245.91	sandy silt to clayey silt	UNDFND	UNDFD	6	87.89
24.75	81.20	14.52	0.09	0.61	248.33	sandy silt to clayey silt	UNDFND	UNDFD	6	77.74
25.00	82.02	16.14	0.07	0.42	250.75	sandy silt to clayey silt	UNDFND	UNDFD	6	90.31
25.25	82.84	20.08	0.13	0.66	253.17	silty sand to sandy silt	<40	<30	7	UNDEFINED

Dr - All sands (Jamiołkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC  
 Location : MAYFAIR - NO 7 R  
 Hole Number: 92-103 CPT-2 BT  
 Tot. Unit Wt. (avg) : 19.5 kN/m<sup>3</sup>

CPT Date : 01/16/92 15:00  
 Cone Used : D TON HT NO. 340  
 Water table (meters) : 1

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
0.25	0.82	15.76	0.61	3.87	2.44	silty clay to clay	UNDFND	UNDFND	11	125.85
0.50	1.64	17.91	0.54	3.03	7.31	clayey silt to silty clay	UNDFND	UNDFND	9	142.71
0.75	2.46	14.76	0.39	2.66	12.18	clayey silt to silty clay	UNDFND	UNDFND	7	117.12
1.00	3.28	11.89	0.34	2.86	17.06	clayey silt to silty clay	UNDFND	UNDFND	6	93.73
1.25	4.10	8.93	0.12	1.32	20.70	clayey silt to silty clay	UNDFND	UNDFND	4	69.65
1.50	4.92	13.87	0.08	0.56	23.12	sandy silt to clayey silt	UNDFND	UNDFND	6	108.79
1.75	5.74	21.77	0.08	0.38	25.55	silty sand to sandy silt	40-50	36-38	7	UNDEFINED
2.00	6.56	20.83	0.10	0.46	27.97	silty sand to sandy silt	40-50	36-38	7	UNDEFINED
2.25	7.38	21.13	0.07	0.33	30.39	silty sand to sandy silt	<40	34-36	7	UNDEFINED
2.50	8.20	18.68	0.04	0.21	32.81	silty sand to sandy silt	<40	34-36	6	UNDEFINED
2.75	9.02	19.35	0.05	0.25	35.23	silty sand to sandy silt	<40	34-36	6	UNDEFINED
3.00	9.84	38.23	0.10	0.25	37.65	sand to silty sand	50-60	38-40	10	UNDEFINED
3.25	10.66	56.15	0.14	0.25	40.08	sand to silty sand	60-70	40-42	14	UNDEFINED
3.50	11.48	58.08	0.16	0.28	42.50	sand to silty sand	60-70	40-42	15	UNDEFINED
3.75	12.30	50.68	0.15	0.29	44.92	sand to silty sand	50-60	38-40	13	UNDEFINED
4.00	13.12	51.21	0.17	0.33	47.34	sand to silty sand	50-60	38-40	13	UNDEFINED
4.25	13.94	72.63	0.23	0.31	49.76	sand to silty sand	60-70	40-42	18	UNDEFINED
4.50	14.76	75.22	0.25	0.33	52.18	sand to silty sand	60-70	40-42	19	UNDEFINED
4.75	15.58	76.55	0.26	0.34	54.60	sand to silty sand	60-70	40-42	19	UNDEFINED
5.00	16.40	50.26	0.25	0.50	57.03	sand to silty sand	50-60	36-38	13	UNDEFINED
5.25	17.22	26.57	0.17	0.62	59.45	silty sand to sandy silt	<40	32-34	9	UNDEFINED
5.50	18.04	34.95	0.16	0.45	61.87	silty sand to sandy silt	40-50	34-36	12	UNDEFINED
5.75	18.86	38.33	0.20	0.53	64.29	silty sand to sandy silt	40-50	34-36	13	UNDEFINED
6.00	19.69	51.58	0.26	0.51	66.71	sand to silty sand	50-60	36-38	13	UNDEFINED
6.25	20.51	38.82	0.19	0.48	69.13	sand to silty sand	40-50	34-36	10	UNDEFINED
6.50	21.33	27.87	0.21	0.76	71.56	silty sand to sandy silt	<40	32-34	9	UNDEFINED
6.75	22.15	34.40	0.22	0.64	73.98	silty sand to sandy silt	40-50	32-34	11	UNDEFINED
7.00	22.97	60.32	0.19	0.31	76.40	sand to silty sand	50-60	36-38	15	UNDEFINED
7.25	23.79	55.52	0.25	0.44	78.82	sand to silty sand	50-60	36-38	14	UNDEFINED
7.50	24.61	39.79	0.27	0.67	81.24	silty sand to sandy silt	40-50	32-34	13	UNDEFINED
7.75	25.43	35.84	0.27	0.76	83.66	silty sand to sandy silt	40-50	32-34	12	UNDEFINED
8.00	26.25	39.57	0.30	0.76	86.08	silty sand to sandy silt	40-50	32-34	13	UNDEFINED
8.25	27.07	30.27	0.23	0.76	88.51	silty sand to sandy silt	<40	30-32	10	UNDEFINED
8.50	27.89	40.94	0.32	0.78	90.93	silty sand to sandy silt	40-50	32-34	14	UNDEFINED
8.75	28.71	92.83	0.40	0.43	93.35	sand	60-70	38-40	19	UNDEFINED
9.00	29.53	101.01	0.38	0.37	95.77	sand	60-70	38-40	20	UNDEFINED
9.25	30.35	95.54	0.37	0.38	98.19	sand	60-70	38-40	19	UNDEFINED
9.50	31.17	92.34	0.30	0.32	100.61	sand	60-70	36-38	18	UNDEFINED

Dr - All sands (Jamolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*

# G.S.C.

Contractor : CONETEC

Location : MAYFAIR - NO 7 R

Page No. 2

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
9.75	31.99	97.95	0.32	0.33	103.04	sand	60-70	36-38	20	UNDEFINED
10.00	32.81	100.66	0.38	0.38	105.46	sand	60-70	36-38	20	UNDEFINED
10.25	33.63	119.12	0.38	0.32	107.88	sand	70-80	38-40	24	UNDEFINED
10.50	34.45	93.56	0.31	0.33	110.30	sand	60-70	36-38	19	UNDEFINED
10.75	35.27	65.54	0.20	0.31	112.72	sand to silty sand	50-60	34-36	16	UNDEFINED
11.00	36.09	83.46	0.25	0.29	115.14	sand	60-70	36-38	17	UNDEFINED
11.25	36.91	89.27	0.29	0.32	117.57	sand	60-70	36-38	18	UNDEFINED
11.50	37.73	81.51	0.27	0.33	119.99	sand	50-60	34-36	16	UNDEFINED
11.75	38.55	70.73	0.28	0.40	122.41	sand to silty sand	50-60	34-36	18	UNDEFINED
12.00	39.37	71.17	0.35	0.49	124.83	sand to silty sand	50-60	34-36	18	UNDEFINED
12.25	40.19	29.83	0.31	1.04	127.25	silty sand to sandy silt	<40	<30	10	UNDEFINED
12.50	41.01	56.13	0.30	0.53	129.67	sand to silty sand	40-50	32-34	14	UNDEFINED
12.75	41.83	84.63	0.33	0.39	132.09	sand	50-60	34-36	17	UNDEFINED
13.00	42.65	96.95	0.37	0.38	134.52	sand	60-70	36-38	19	UNDEFINED
13.25	43.47	81.26	0.31	0.39	136.94	sand to silty sand	50-60	34-36	20	UNDEFINED
13.50	44.29	65.30	0.28	0.43	139.36	sand to silty sand	50-60	32-34	16	UNDEFINED
13.75	45.11	83.67	0.38	0.46	141.78	sand to silty sand	50-60	34-36	21	UNDEFINED
14.00	45.93	72.56	0.36	0.49	144.20	sand to silty sand	50-60	32-34	18	UNDEFINED
14.25	46.75	68.03	0.32	0.47	146.62	sand to silty sand	50-60	32-34	17	UNDEFINED
14.50	47.57	87.87	0.34	0.39	149.05	sand	50-60	34-36	18	UNDEFINED
14.75	48.39	124.54	0.46	0.37	151.47	sand	60-70	36-38	25	UNDEFINED
15.00	49.21	110.74	0.41	0.37	153.89	sand	60-70	36-38	22	UNDEFINED
15.25	50.03	60.44	0.24	0.40	156.31	sand to silty sand	40-50	32-34	15	UNDEFINED
15.50	50.85	94.58	0.37	0.39	158.73	sand	50-60	34-36	19	UNDEFINED
15.75	51.67	82.55	0.29	0.35	161.15	sand	50-60	32-34	17	UNDEFINED
16.00	52.49	113.06	0.40	0.36	163.57	sand	60-70	34-36	23	UNDEFINED
16.25	53.31	137.26	0.55	0.40	166.00	sand	60-70	36-38	27	UNDEFINED
16.50	54.13	144.60	0.53	0.37	168.42	sand	70-80	36-38	29	UNDEFINED
16.75	54.95	154.48	0.52	0.34	170.84	sand	70-80	36-38	31	UNDEFINED
17.00	55.77	148.98	0.52	0.35	173.26	sand	70-80	36-38	30	UNDEFINED
17.25	56.59	142.72	0.49	0.34	175.68	sand	60-70	36-38	29	UNDEFINED
17.50	57.41	123.36	0.39	0.32	178.10	sand	60-70	34-36	25	UNDEFINED
17.75	58.23	121.04	0.41	0.34	180.53	sand	60-70	34-36	24	UNDEFINED
18.00	59.06	113.66	0.39	0.34	182.95	sand	60-70	34-36	23	UNDEFINED
18.25	59.88	122.84	0.46	0.37	185.37	sand	60-70	34-36	25	UNDEFINED
18.50	60.70	132.48	0.47	0.35	187.79	sand	60-70	36-38	26	UNDEFINED
18.75	61.52	130.78	0.48	0.37	190.21	sand	60-70	34-36	26	UNDEFINED
19.00	62.34	138.00	0.50	0.36	192.63	sand	60-70	36-38	28	UNDEFINED
19.25	63.16	152.68	0.57	0.37	195.05	sand	60-70	36-38	31	UNDEFINED
19.50	63.98	148.62	0.50	0.33	197.48	sand	60-70	36-38	30	UNDEFINED
19.75	64.80	199.42	0.68	0.34	199.90	sand	70-80	38-40	40	UNDEFINED
20.00	65.62	193.56	0.62	0.32	202.32	sand	70-80	36-38	39	UNDEFINED

Dr - All sands (Jamiolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC

Location : MAYFAIR - NO 7 R

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DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
20.25	66.44	181.80	0.71	0.39	204.74	sand	70-80	36-38	36	UNDEFINED
20.50	67.26	194.14	0.64	0.33	207.16	sand	70-80	36-38	39	UNDEFINED
20.75	68.08	181.06	0.54	0.30	209.58	sand	70-80	36-38	36	UNDEFINED
21.00	68.90	157.36	0.45	0.28	212.01	sand	60-70	36-38	31	UNDEFINED
21.25	69.72	152.22	0.47	0.31	214.43	sand	60-70	36-38	30	UNDEFINED
21.50	70.54	143.08	0.50	0.35	216.85	sand	60-70	34-36	29	UNDEFINED
21.75	71.36	149.80	0.66	0.44	219.27	sand	60-70	34-36	30	UNDEFINED
22.00	72.18	168.68	0.74	0.44	221.69	sand	70-80	36-38	34	UNDEFINED
22.25	73.00	167.58	0.73	0.44	224.11	sand	70-80	36-38	34	UNDEFINED
22.50	73.82	210.34	0.81	0.39	226.53	sand	70-80	36-38	42	UNDEFINED
22.75	74.64	231.90	1.04	0.45	228.96	sand	70-80	38-40	46	UNDEFINED
23.00	75.46	240.94	1.35	0.56	231.38	sand	80-90	38-40	48	UNDEFINED
23.25	76.28	218.46	1.36	0.62	233.80	sand	70-80	36-38	44	UNDEFINED
23.50	77.10	180.86	1.01	0.56	236.22	sand	70-80	36-38	36	UNDEFINED
23.75	77.92	62.30	0.59	0.95	238.64	sand to silty sand	40-50	<30	16	UNDEFINED
24.00	78.74	12.86	0.11	0.89	241.06	sandy silt to clayey silt	UNDFND	UNDFD	5	65.61
24.25	79.56	10.65	0.12	1.11	243.49	sandy silt to clayey silt	UNDFND	UNDFD	4	47.58
24.50	80.38	10.89	0.12	1.14	245.91	sandy silt to clayey silt	UNDFND	UNDFD	4	49.07
24.75	81.20	10.73	0.13	1.17	248.33	sandy silt to clayey silt	UNDFND	UNDFD	4	47.45
25.00	82.02	12.64	0.14	1.11	250.75	sandy silt to clayey silt	UNDFND	UNDFD	5	62.34
25.25	82.84	12.72	0.13	1.05	253.17	sandy silt to clayey silt	UNDFND	UNDFD	5	62.54
25.50	83.66	11.44	0.14	1.19	255.59	sandy silt to clayey silt	UNDFND	UNDFD	5	51.95
25.75	84.48	12.69	0.12	0.95	258.01	sandy silt to clayey silt	UNDFND	UNDFD	5	61.52
26.00	85.30	12.79	0.13	1.02	260.44	sandy silt to clayey silt	UNDFND	UNDFD	5	61.97
26.25	86.12	12.48	0.13	1.03	262.86	sandy silt to clayey silt	UNDFND	UNDFD	5	59.11
26.50	86.94	12.61	0.13	1.03	265.28	sandy silt to clayey silt	UNDFND	UNDFD	5	59.75
26.75	87.76	14.01	0.14	1.01	267.70	sandy silt to clayey silt	UNDFND	UNDFD	6	70.56
27.00	88.58	13.60	0.12	0.91	270.12	sandy silt to clayey silt	UNDFND	UNDFD	5	66.85
27.25	89.40	13.52	0.12	0.90	272.54	sandy silt to clayey silt	UNDFND	UNDFD	5	65.82
27.50	90.22	14.14	0.13	0.91	274.97	sandy silt to clayey silt	UNDFND	UNDFD	6	70.38
27.75	91.04	14.63	0.13	0.90	277.39	sandy silt to clayey silt	UNDFND	UNDFD	6	73.91
28.00	91.86	14.55	0.12	0.85	279.81	sandy silt to clayey silt	UNDFND	UNDFD	6	72.91
28.25	92.68	15.17	0.16	1.07	282.23	sandy silt to clayey silt	UNDFND	UNDFD	6	77.51
28.50	93.50	16.94	0.21	1.26	284.65	sandy silt to clayey silt	UNDFND	UNDFD	7	91.22
28.75	94.32	15.09	0.12	0.78	287.07	sandy silt to clayey silt	UNDFND	UNDFD	6	76.04
29.00	95.14	14.71	0.11	0.75	289.50	sandy silt to clayey silt	UNDFND	UNDFD	6	72.66
29.25	95.96	14.94	0.13	0.84	291.92	sandy silt to clayey silt	UNDFND	UNDFD	6	74.10
29.50	96.78	16.61	0.19	1.13	294.34	sandy silt to clayey silt	UNDFND	UNDFD	7	87.02
29.75	97.60	15.71	0.11	0.71	296.76	sandy silt to clayey silt	UNDFND	UNDFD	6	79.43
30.00	98.43	15.76	0.11	0.72	299.18	sandy silt to clayey silt	UNDFND	UNDFD	6	79.44
30.25	99.25	15.89	0.11	0.70	301.60	sandy silt to clayey silt	UNDFND	UNDFD	6	80.14

Dr - All sands (Jamiołkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC  
 Location : RADIO TOWER  
 Hole Number: 92-103 CPT-3 BT  
 Tot. Unit Wt. (avg) : 19.5 kN/m<sup>3</sup>

CPT Date : 01/27/92 10:20  
 Cone Used : 2 TON HT NO. 340  
 Water table (meters) : 1

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
0.25	0.82	1.04	0.02	1.72	2.44	organic material	UNDFND	UNDFND	1	8.15
0.50	1.64	4.80	0.13	2.79	7.31	clay	UNDFND	UNDFND	5	37.79
0.75	2.46	6.54	0.18	2.72	12.18	silty clay to clay	UNDFND	UNDFND	4	51.36
1.00	3.28	3.48	0.09	2.65	17.06	clay	UNDFND	UNDFND	3	26.44
1.25	4.10	4.52	0.09	2.08	20.70	silty clay to clay	UNDFND	UNDFND	3	34.43
1.50	4.92	8.62	0.11	1.23	23.12	clayey silt to silty clay	UNDFND	UNDFND	4	66.79
1.75	5.74	22.75	0.12	0.53	25.55	silty sand to sandy silt	40-50	36-38	8	UNDEFINED
2.00	6.56	25.06	0.12	0.47	27.97	silty sand to sandy silt	40-50	36-38	8	UNDEFINED
2.25	7.38	18.80	0.16	0.85	30.39	sandy silt to clayey silt	UNDFND	UNDFND	8	147.05
2.50	8.20	36.23	0.14	0.38	32.81	silty sand to sandy silt	50-60	38-40	12	UNDEFINED
2.75	9.02	32.65	0.13	0.40	35.23	silty sand to sandy silt	50-60	36-38	11	UNDEFINED
3.00	9.84	16.05	0.09	0.56	37.65	sandy silt to clayey silt	UNDFND	UNDFND	6	123.91
3.25	10.66	16.33	0.06	0.37	40.08	sandy silt to clayey silt	UNDFND	UNDFND	7	125.79
3.50	11.48	19.04	0.09	0.48	42.50	silty sand to sandy silt	<40	32-34	6	UNDEFINED
3.75	12.30	14.13	0.09	0.64	44.92	sandy silt to clayey silt	UNDFND	UNDFND	6	107.41
4.00	13.12	11.73	0.03	0.27	47.34	sandy silt to clayey silt	UNDFND	UNDFND	5	87.77
4.25	13.94	15.51	0.11	0.74	49.76	sandy silt to clayey silt	UNDFND	UNDFND	6	117.64
4.50	14.76	54.81	0.23	0.42	52.18	sand to silty sand	50-60	38-40	14	UNDEFINED
4.75	15.58	56.59	0.22	0.38	54.60	sand to silty sand	50-60	38-40	14	UNDEFINED
5.00	16.40	54.83	0.17	0.30	57.03	sand to silty sand	50-60	36-38	14	UNDEFINED
5.25	17.22	55.37	0.17	0.30	59.45	sand to silty sand	50-60	36-38	14	UNDEFINED
5.50	18.04	58.98	0.18	0.30	61.87	sand to silty sand	50-60	36-38	15	UNDEFINED
5.75	18.86	54.04	0.17	0.31	64.29	sand to silty sand	50-60	36-38	14	UNDEFINED
6.00	19.69	56.97	0.18	0.31	66.71	sand to silty sand	50-60	36-38	14	UNDEFINED
6.25	20.51	55.27	0.21	0.37	69.13	sand to silty sand	50-60	36-38	14	UNDEFINED
6.50	21.33	74.75	0.21	0.29	71.56	sand to silty sand	60-70	38-40	19	UNDEFINED
6.75	22.15	100.82	0.26	0.26	73.98	sand	70-80	40-42	20	UNDEFINED
7.00	22.97	78.00	0.22	0.28	76.40	sand to silty sand	60-70	38-40	20	UNDEFINED
7.25	23.79	63.89	0.16	0.25	78.82	sand to silty sand	50-60	36-38	16	UNDEFINED
7.50	24.61	76.67	0.21	0.27	81.24	sand to silty sand	60-70	36-38	19	UNDEFINED
7.75	25.43	82.43	0.22	0.27	83.66	sand	60-70	38-40	16	UNDEFINED
8.00	26.25	67.40	0.18	0.27	86.08	sand to silty sand	50-60	36-38	17	UNDEFINED
8.25	27.07	49.16	0.14	0.28	88.51	sand to silty sand	40-50	34-36	12	UNDEFINED
8.50	27.89	53.31	0.15	0.29	90.93	sand to silty sand	50-60	34-36	13	UNDEFINED
8.75	28.71	66.14	0.23	0.35	93.35	sand to silty sand	50-60	36-38	17	UNDEFINED
9.00	29.53	87.61	0.25	0.28	95.77	sand	60-70	36-38	18	UNDEFINED
9.25	30.35	83.21	0.24	0.28	98.19	sand	60-70	36-38	17	UNDEFINED
9.50	31.17	79.32	0.28	0.35	100.61	sand to silty sand	60-70	36-38	20	UNDEFINED

Dr - All sands (Jamiolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC

Location : RADIO TOWER

Page No. 2

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
9.75	31.99	62.48	0.22	0.35	103.04	sand to silty sand	50-60	34-36	16	UNDEFINED
10.00	32.81	77.34	0.19	0.24	105.46	sand	50-60	36-38	15	UNDEFINED
10.25	33.63	41.59	0.45	1.08	107.88	silty sand to sandy silt	40-50	30-32	14	UNDEFINED
10.50	34.45	7.19	0.11	1.48	110.30	clayey silt to silty clay	UNDFND	UNDFD	4	41.30
10.75	35.27	8.66	0.13	1.50	112.72	clayey silt to silty clay	UNDFND	UNDFD	4	52.70
11.00	36.09	26.79	0.43	1.60	115.14	sandy silt to clayey silt	UNDFND	UNDFD	11	197.33
11.25	36.91	16.91	0.24	1.42	117.57	sandy silt to clayey silt	UNDFND	UNDFD	7	117.90
11.50	37.73	42.62	0.28	0.67	119.99	silty sand to sandy silt	40-50	30-32	14	UNDEFINED
11.75	38.55	74.92	0.29	0.39	122.41	sand to silty sand	50-60	34-36	19	UNDEFINED
12.00	39.37	54.67	0.31	0.57	124.83	sand to silty sand	40-50	32-34	14	UNDEFINED
12.25	40.19	66.55	0.22	0.32	127.25	sand to silty sand	50-60	34-36	17	UNDEFINED
12.50	41.01	105.20	0.25	0.24	129.67	sand	60-70	36-38	21	UNDEFINED
12.75	41.83	71.57	0.19	0.27	132.09	sand to silty sand	50-60	34-36	18	UNDEFINED
13.00	42.65	69.68	0.18	0.26	134.52	sand to silty sand	50-60	34-36	17	UNDEFINED
13.25	43.47	106.03	0.29	0.27	136.94	sand	60-70	36-38	21	UNDEFINED
13.50	44.29	116.18	0.28	0.24	139.36	sand	60-70	36-38	23	UNDEFINED
13.75	45.11	109.00	0.27	0.25	141.78	sand	60-70	36-38	22	UNDEFINED
14.00	45.93	94.66	0.24	0.25	144.20	sand	60-70	34-36	19	UNDEFINED
14.25	46.75	102.86	0.26	0.25	146.62	sand	60-70	36-38	21	UNDEFINED
14.50	47.57	105.50	0.28	0.27	149.05	sand	60-70	36-38	21	UNDEFINED
14.75	48.39	85.36	0.21	0.24	151.47	sand	50-60	34-36	17	UNDEFINED
15.00	49.21	81.44	0.22	0.27	153.89	sand	50-60	34-36	16	UNDEFINED
15.25	50.03	66.43	0.19	0.28	156.31	sand to silty sand	40-50	32-34	17	UNDEFINED
15.50	50.85	74.53	0.20	0.26	158.73	sand to silty sand	50-60	32-34	19	UNDEFINED
15.75	51.67	103.57	0.29	0.28	161.15	sand	60-70	34-36	21	UNDEFINED
16.00	52.49	97.76	0.22	0.23	163.57	sand	50-60	34-36	20	UNDEFINED
16.25	53.31	133.18	0.33	0.25	166.00	sand	60-70	36-38	27	UNDEFINED
16.50	54.13	145.43	0.36	0.25	168.42	sand	70-80	36-38	29	UNDEFINED
16.75	54.95	138.65	0.33	0.24	170.84	sand	60-70	36-38	28	UNDEFINED
17.00	55.77	120.67	0.28	0.23	173.26	sand	60-70	34-36	24	UNDEFINED
17.25	56.59	85.03	0.22	0.26	175.68	sand	50-60	32-34	17	UNDEFINED
17.50	57.41	99.94	0.26	0.26	178.10	sand	50-60	34-36	20	UNDEFINED
17.75	58.23	109.54	0.27	0.25	180.53	sand	60-70	34-36	22	UNDEFINED
18.00	59.06	93.76	0.22	0.23	182.95	sand	50-60	32-34	19	UNDEFINED
18.25	59.88	82.52	0.18	0.21	185.37	sand	50-60	32-34	17	UNDEFINED
18.50	60.70	139.44	0.28	0.20	187.79	sand	60-70	36-38	28	UNDEFINED
18.75	61.52	141.08	0.29	0.20	190.21	sand	60-70	36-38	28	UNDEFINED
19.00	62.34	176.39	0.46	0.26	192.63	sand	70-80	36-38	35	UNDEFINED

Dr - All sands (Jamiolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*



# G.S.C.

Contractor : CONETEC  
 Location : AIRPORT  
 Hole Number : GSC RCPT-1 BT  
 Tot. Unit Wt. (avg) : 19.5 kN/m<sup>3</sup>

CPT Date : 11/21/91  
 Cone Used : 2 TON HT NO.340  
 Water table (meters) : 1

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
0.25	0.82	15.49	0.21	1.33	2.44	sandy silt to clayey silt	UNDFND	UNDFND	6	123.74
0.50	1.64	22.27	0.26	1.18	7.31	sandy silt to clayey silt	UNDFND	UNDFND	9	177.54
0.75	2.46	13.80	0.10	0.75	12.18	sandy silt to clayey silt	UNDFND	UNDFND	6	109.44
1.00	3.28	10.03	0.19	1.92	17.06	clayey silt to silty clay	UNDFND	UNDFND	5	78.84
1.25	4.10	6.25	0.14	2.18	20.70	silty clay to clay	UNDFND	UNDFND	4	48.24
1.50	4.92	5.08	0.04	0.71	23.12	sensitive fine grained	UNDFND	UNDFND	3	38.49
1.75	5.74	4.43	0.04	0.90	25.55	sensitive fine grained	UNDFND	UNDFND	2	32.90
2.00	6.56	3.91	0.01	0.31	27.97	sensitive fine grained	UNDFND	UNDFND	2	28.35
2.25	7.38	4.95	0.02	0.48	30.39	sensitive fine grained	UNDFND	UNDFND	2	36.28
2.50	8.20	6.77	0.05	0.71	32.81	sensitive fine grained	UNDFND	UNDFND	3	50.45
2.75	9.02	7.29	0.07	0.96	35.23	sensitive fine grained	UNDFND	UNDFND	4	54.22
3.00	9.84	12.37	0.03	0.27	37.65	sandy silt to clayey silt	UNDFND	UNDFND	5	94.47
3.25	10.66	16.15	0.05	0.32	40.08	sandy silt to clayey silt	UNDFND	UNDFND	6	124.29
3.50	11.48	34.54	0.07	0.20	42.50	sand to silty sand	40-50	36-38	9	UNDEFINED
3.75	12.30	25.52	0.08	0.31	44.92	silty sand to sandy silt	<40	34-36	9	UNDEFINED
4.00	13.12	37.50	0.07	0.19	47.34	sand to silty sand	40-50	36-38	9	UNDEFINED
4.25	13.94	55.47	0.12	0.21	49.76	sand to silty sand	60-70	38-40	14	UNDEFINED
4.50	14.76	57.68	0.13	0.23	52.18	sand to silty sand	60-70	38-40	14	UNDEFINED
4.75	15.58	58.85	0.14	0.23	54.60	sand to silty sand	60-70	38-40	15	UNDEFINED
5.00	16.40	77.34	0.18	0.24	57.03	sand	60-70	40-42	15	UNDEFINED
5.25	17.22	87.63	0.17	0.19	59.45	sand	70-80	40-42	18	UNDEFINED
5.50	18.04	105.73	0.25	0.23	61.87	sand	70-80	40-42	21	UNDEFINED
5.75	18.86	99.61	0.18	0.18	64.29	sand	70-80	40-42	20	UNDEFINED
6.00	19.69	42.58	0.22	0.52	66.71	sand to silty sand	40-50	34-36	11	UNDEFINED
6.25	20.51	14.19	0.06	0.45	69.13	sandy silt to clayey silt	UNDFND	UNDFND	6	103.98
6.50	21.33	17.20	0.03	0.15	71.56	silty sand to sandy silt	<40	<30	6	UNDEFINED
6.75	22.15	19.92	0.04	0.20	73.98	silty sand to sandy silt	<40	<30	7	UNDEFINED
7.00	22.97	32.42	0.11	0.35	76.40	silty sand to sandy silt	<40	32-34	11	UNDEFINED
7.25	23.79	49.74	0.23	0.47	78.82	sand to silty sand	50-60	34-36	12	UNDEFINED
7.50	24.61	37.11	0.18	0.50	81.24	silty sand to sandy silt	40-50	32-34	12	UNDEFINED
7.75	25.43	106.38	0.24	0.22	83.66	sand	70-80	38-40	21	UNDEFINED
8.00	26.25	92.97	0.22	0.23	86.08	sand	60-70	38-40	19	UNDEFINED
8.25	27.07	70.70	0.23	0.33	88.51	sand to silty sand	50-60	36-38	18	UNDEFINED
8.50	27.89	86.20	0.20	0.24	90.93	sand	60-70	36-38	17	UNDEFINED
8.75	28.71	83.33	0.20	0.24	93.35	sand	60-70	36-38	17	UNDEFINED
9.00	29.53	90.88	0.26	0.29	95.77	sand	60-70	36-38	18	UNDEFINED
9.25	30.35	102.86	0.26	0.25	98.19	sand	60-70	38-40	21	UNDEFINED
9.50	31.17	103.12	0.21	0.21	100.61	sand	60-70	38-40	21	UNDEFINED

Dr - All sands (Janiolkowski et al. 1985)

PHI -

Durgunoglu and Mitchell 1975

Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*

# G.S.C.

Contractor : CONETEC

Location : AIRPORT

Page No. 2

DEPTH (meters)	DEPTH (feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	Su kPa
9.75	31.99	96.74	0.18	0.18	103.04	sand	60-70	36-38	19	UNDEFINED
10.00	32.81	81.51	0.16	0.20	105.46	sand	60-70	36-38	16	UNDEFINED
10.25	33.63	101.17	0.20	0.19	107.88	sand	60-70	36-38	20	UNDEFINED
10.50	34.45	70.44	0.17	0.24	110.30	sand to silty sand	50-60	34-36	18	UNDEFINED
10.75	35.27	70.57	0.18	0.25	112.72	sand to silty sand	50-60	34-36	18	UNDEFINED
11.00	36.09	70.83	0.16	0.23	115.14	sand to silty sand	50-60	34-36	18	UNDEFINED
11.25	36.91	78.51	0.18	0.23	117.57	sand	50-60	34-36	16	UNDEFINED
11.50	37.73	76.69	0.18	0.23	119.99	sand	50-60	34-36	15	UNDEFINED
11.75	38.55	90.36	0.19	0.21	122.41	sand	60-70	36-38	18	UNDEFINED
12.00	39.37	98.70	0.21	0.21	124.83	sand	60-70	36-38	20	UNDEFINED
12.25	40.19	138.28	0.31	0.22	127.25	sand	70-80	38-40	28	UNDEFINED
12.50	41.01	136.72	0.31	0.23	129.67	sand	70-80	38-40	27	UNDEFINED
12.75	41.83	129.68	0.29	0.22	132.09	sand	70-80	38-40	26	UNDEFINED
13.00	42.65	122.26	0.24	0.20	134.52	sand	60-70	36-38	24	UNDEFINED
13.25	43.47	137.89	0.34	0.24	136.94	sand	70-80	38-40	28	UNDEFINED
13.50	44.29	20.31	0.39	1.90	139.36	sandy silt to clayey silt	UNDFND	UNDFD	8	141.63
13.75	45.11	45.05	0.44	0.97	141.78	silty sand to sandy silt	<40	30-32	15	UNDEFINED
14.00	45.93	23.57	0.44	1.86	144.20	sandy silt to clayey silt	UNDFND	UNDFD	9	166.88
14.25	46.75	38.28	0.31	0.80	146.62	silty sand to sandy silt	<40	<30	13	UNDEFINED
14.50	47.57	41.54	0.37	0.89	149.05	silty sand to sandy silt	<40	<30	14	UNDEFINED
14.75	48.39	16.80	0.15	0.87	151.47	sandy silt to clayey silt	UNDFND	UNDFD	7	111.56
15.00	49.21	21.09	0.42	2.00	153.89	sandy silt to clayey silt	UNDFND	UNDFD	8	145.54
15.25	50.03	19.14	0.38	1.99	156.31	sandy silt to clayey silt	UNDFND	UNDFD	8	129.54
15.50	50.85	48.83	0.60	1.22	158.73	silty sand to sandy silt	40-50	30-32	16	UNDEFINED
15.75	51.67	47.53	0.60	1.27	161.15	silty sand to sandy silt	<40	30-32	16	UNDEFINED
16.00	52.49	74.87	0.56	0.75	163.57	sand to silty sand	50-60	32-34	19	UNDEFINED
16.25	53.31	55.08	0.56	1.01	166.00	silty sand to sandy silt	40-50	30-32	18	UNDEFINED
16.50	54.13	79.03	0.32	0.40	168.42	sand to silty sand	50-60	32-34	20	UNDEFINED
16.75	54.95	60.93	0.45	0.74	170.84	sand to silty sand	40-50	30-32	15	UNDEFINED
17.00	55.77	52.73	0.49	0.94	173.26	silty sand to sandy silt	40-50	30-32	18	UNDEFINED
17.25	56.59	76.69	0.41	0.53	175.68	sand to silty sand	50-60	32-34	19	UNDEFINED
17.50	57.41	113.93	0.39	0.34	178.10	sand	60-70	34-36	23	UNDEFINED
17.75	58.23	113.15	0.60	0.53	180.53	sand	60-70	34-36	23	UNDEFINED
18.00	59.06	147.26	0.83	0.56	182.95	sand	60-70	36-38	29	UNDEFINED
18.25	59.88	51.95	0.59	1.13	185.37	silty sand to sandy silt	<40	<30	17	UNDEFINED
18.50	60.70	75.65	0.38	0.50	187.79	sand to silty sand	50-60	32-34	19	UNDEFINED
18.75	61.52	31.51	0.21	0.66	190.21	silty sand to sandy silt	<40	<30	11	UNDEFINED

Dr - All sands (Janiolkowski et al. 1985)

PHI - Durgunoglu and Mitchell 1975

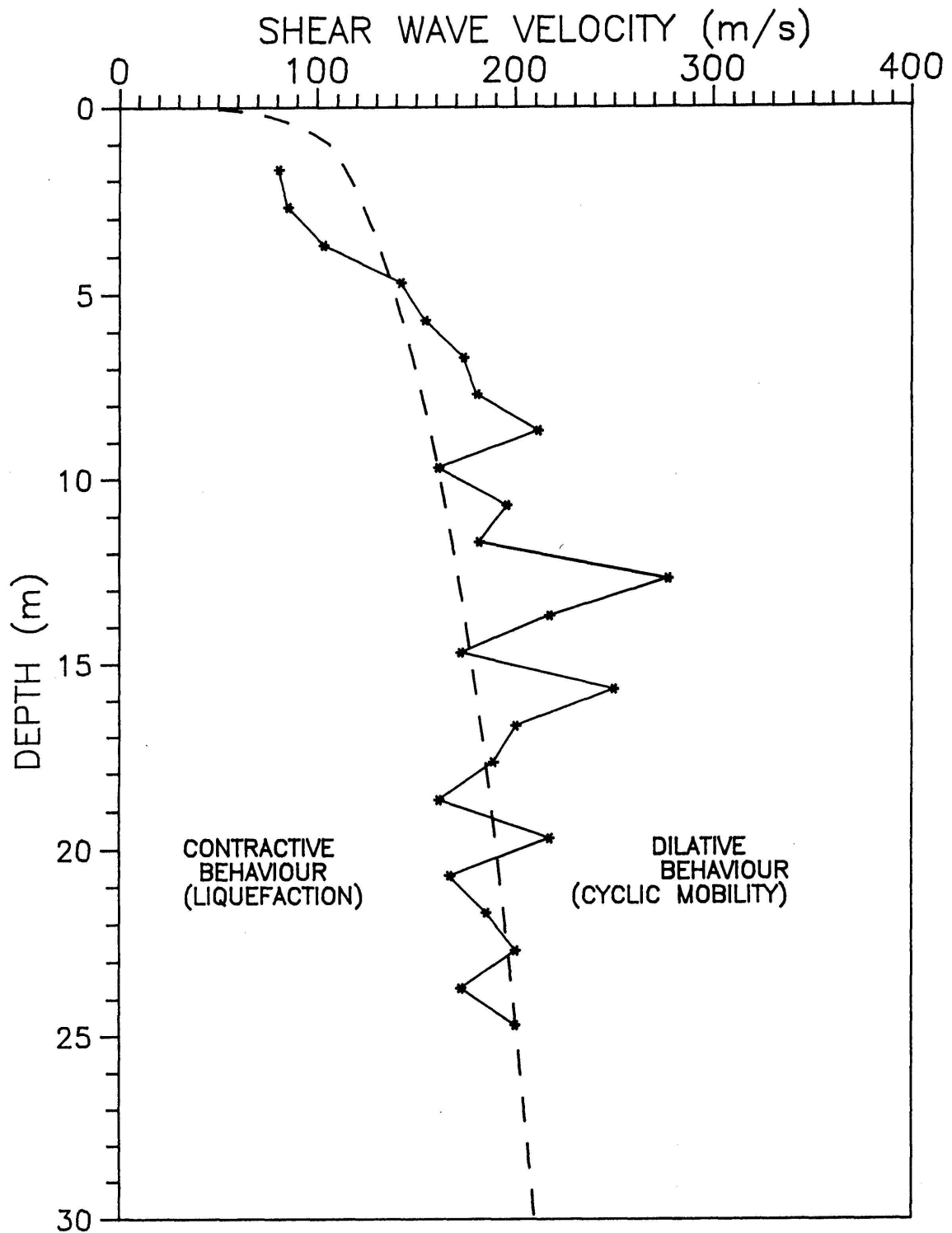
Su: Nk= 12.5

\*\*\*\* Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.02) \*\*\*\*



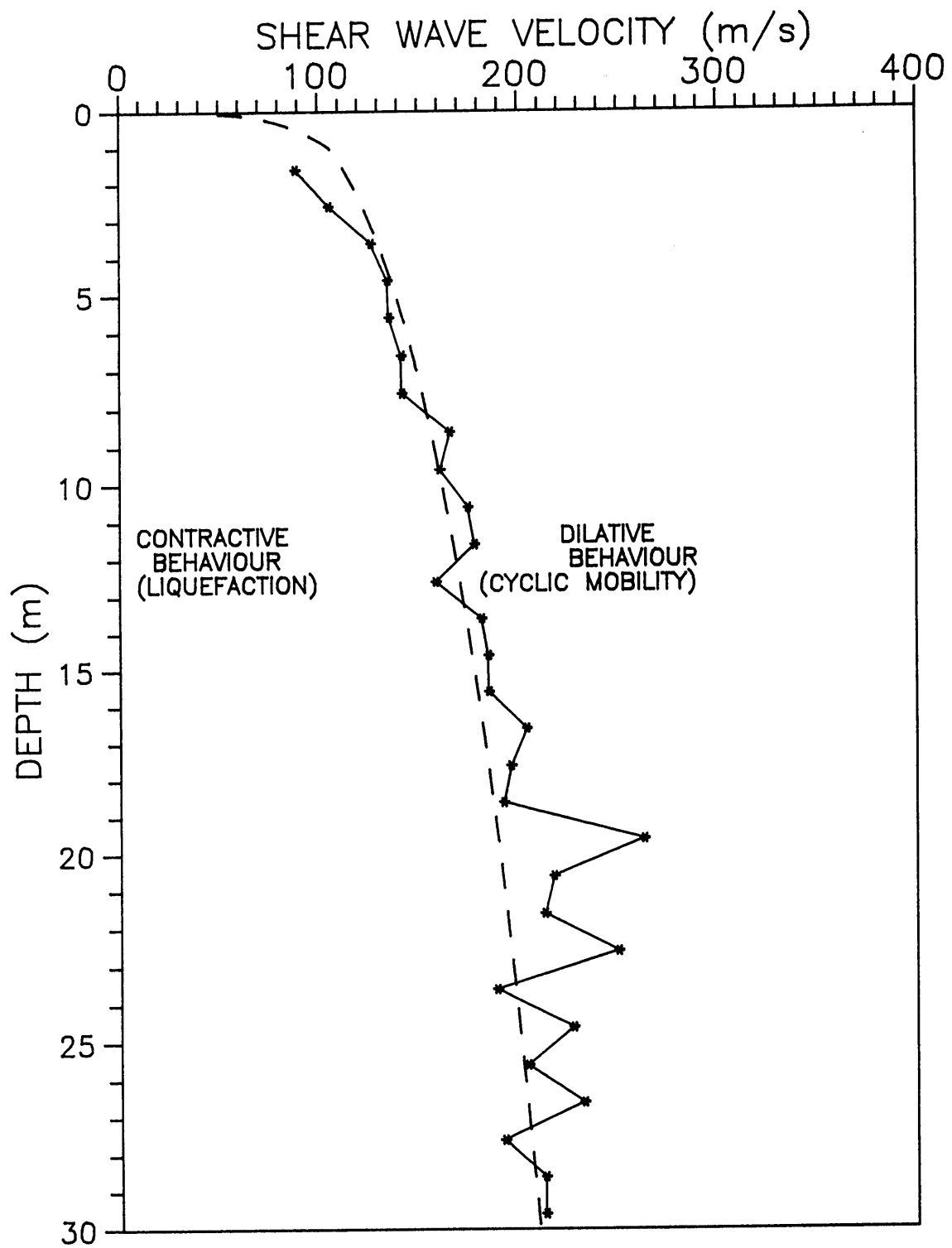
## **APPENDIX D**

# SHEAR WAVE VELOCITY vs DEPTH



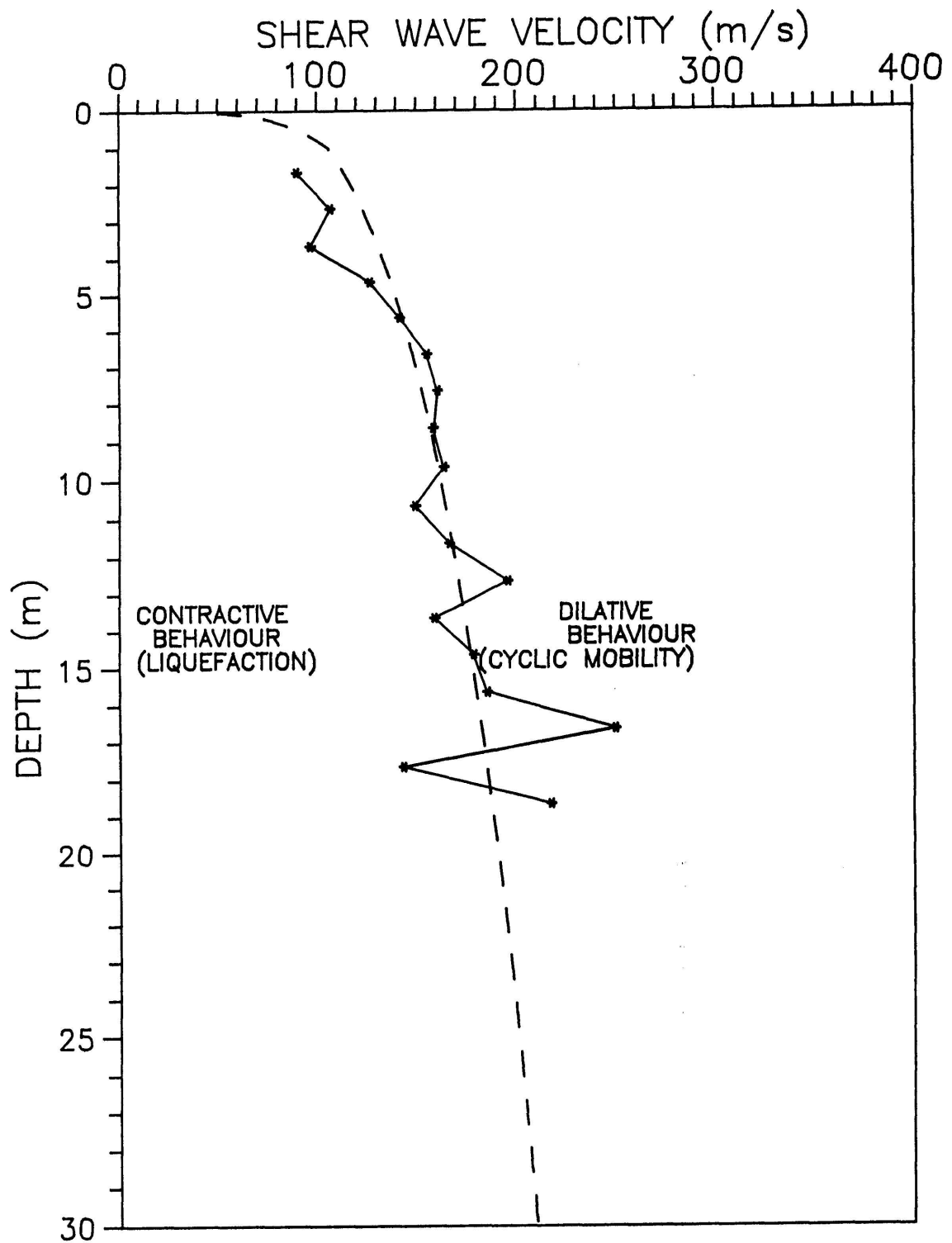
LOCATION: FRANCIS AND RAILWAY

# SHEAR WAVE VELOCITY vs DEPTH



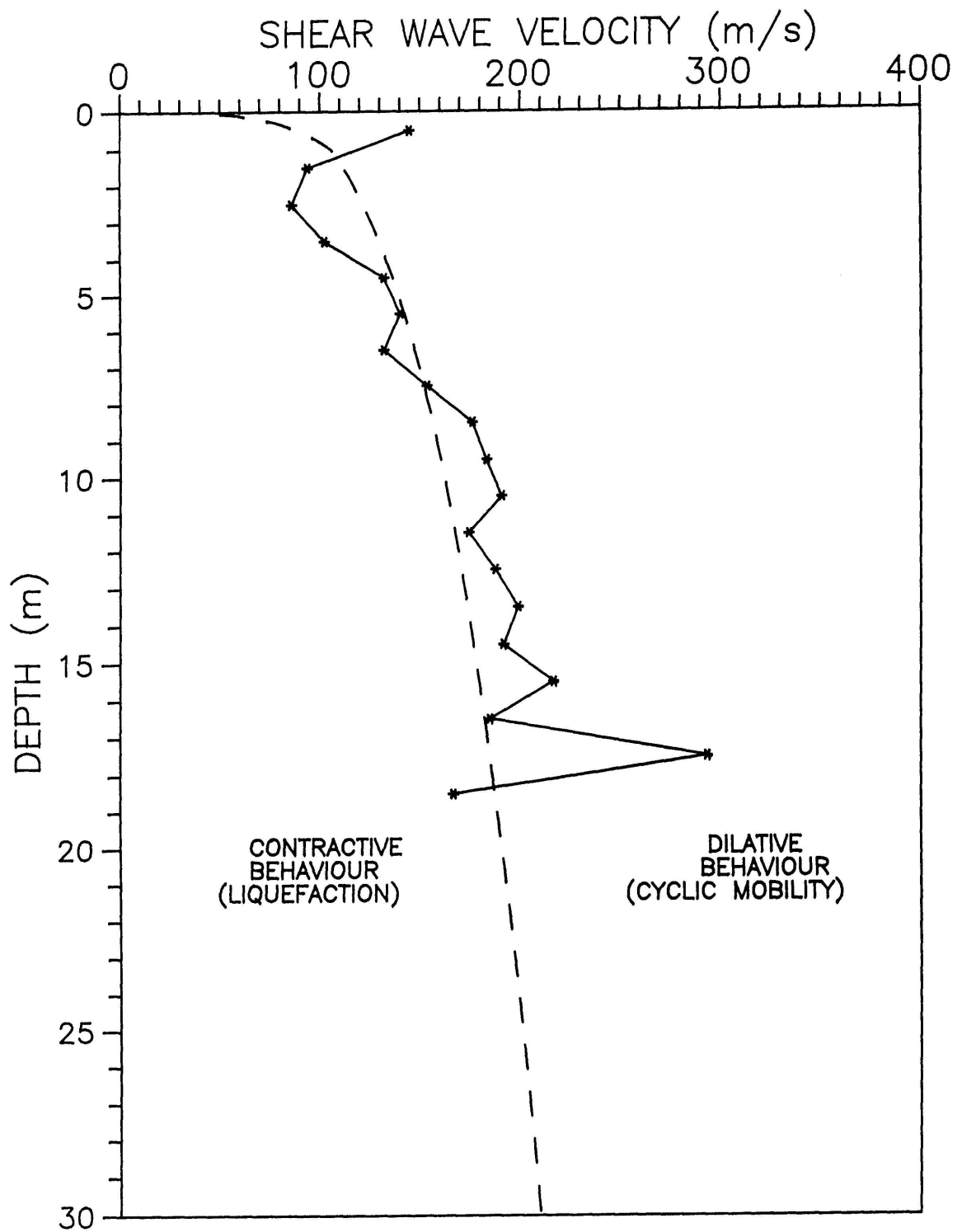
LOCATION: MAYFAIR GOLF COURSE

# SHEAR WAVE VELOCITY vs DEPTH



LOCATION: RADIO TOWERS

# SHEAR WAVE VELOCITY vs DEPTH



LOCATION: VAN. INTL. AIRPORT





## **APPENDIX E**

ConeTec Seismic Shear Wave Velocity Data Reduction Sheet

Hole: RSCPT 92-1

Location: FRANCIS AND RAILWAY

Date: January 16, 1992

Cone: HT N0. 340 (geophone)

Source: Hammer and Beam    Offset: 0.60 m

Geophone Depth (m)	Travel Path (m)	Crossover Time (ms)	Corrected Time (ms)	Velocity (m/s)	Interval Depth (m)	Normalized Vs (m/s)
1.20	1.34	17.90	16.01			
2.20	2.28	29.50	28.46	80.32	1.70	116.2
3.20	3.26	40.90	40.20	85.19	2.70	113.4
4.20	4.24	50.40	49.89	103.16	3.70	129.1
5.20	5.23	57.30	56.92	142.27	4.70	169.4
6.20	6.23	63.70	63.40	154.29	5.70	176.2
7.20	7.22	69.40	69.16	173.72	6.70	191.4
8.20	8.22	74.90	74.70	180.50	7.70	192.8
9.20	9.22	79.60	79.43	211.37	8.70	219.6
10.20	10.22	85.80	85.65	160.75	9.70	162.9
11.20	11.22	90.90	90.77	195.39	10.70	193.6
12.20	12.21	96.40	96.28	181.36	11.70	176.0
13.20	13.21	100.00	99.90	276.76	12.70	263.4
14.20	14.21	104.60	104.51	216.92	13.70	202.8
15.20	15.21	110.40	110.31	172.20	14.70	158.4
16.20	16.21	114.40	114.32	249.53	15.70	225.9
17.20	17.21	119.40	119.33	199.77	16.70	178.2
18.20	18.21	124.70	124.63	188.51	17.70	165.9
19.20	19.21	130.90	130.84	161.19	18.70	140.0
20.20	20.21	135.50	135.44	217.20	19.70	186.3
21.20	21.21	141.50	141.44	166.58	20.70	141.2
22.20	22.21	146.90	146.85	185.08	21.70	155.1
23.20	23.21	151.90	151.85	199.89	22.70	165.7
24.20	24.21	157.70	157.65	172.34	23.70	141.4
25.20	25.21	162.70	162.65	199.91	24.70	162.4

# ConeTec Seismic Shear Wave Velocity Data Reduction Sheet

Hole: RSCPT 92-2

Location: MAYFAIR GOLF COURSE

Date: January 16, 1992

Cone: HT N0. 340 (geophone)

Source: Hammer and Beam Offset: 0.60 m

Geophone Depth (m)	Travel Path (m)	Crossover Time (ms)	Corrected Time (ms)	Velocity (m/s)	Interval Depth (m)	Normalized Vs (m/s)
1.10	1.25	16.30	14.31			
2.10	2.18	26.60	25.58	88.76	1.60	129.6
3.10	3.16	35.70	35.05	105.56	2.60	141.5
4.10	4.14	43.40	42.94	126.69	3.60	159.3
5.10	5.14	50.70	50.35	134.95	4.60	161.3
6.10	6.13	58.00	57.72	135.71	5.60	155.5
7.10	7.13	65.00	64.77	141.89	6.60	156.8
8.10	8.12	72.00	71.80	142.16	7.60	152.3
9.10	9.12	78.00	77.83	165.90	8.60	172.8
10.10	10.12	84.20	84.05	160.75	9.60	163.3
11.10	11.12	89.90	89.77	174.91	10.60	173.6
12.10	12.11	95.50	95.38	178.13	11.60	173.2
13.10	13.11	101.80	101.69	158.46	12.60	151.1
14.10	14.11	107.30	107.20	181.50	13.60	170.0
15.10	15.11	112.70	112.61	184.91	14.60	170.3
16.10	16.11	118.10	118.02	184.95	15.60	167.7
17.10	17.11	123.00	122.92	203.82	16.60	182.1
18.10	18.11	128.10	128.03	195.87	17.60	172.6
19.10	19.11	133.30	133.23	192.14	18.60	167.1
20.10	20.11	137.10	137.04	262.83	19.60	225.7
21.10	21.11	141.70	141.64	217.21	20.60	184.3
22.10	22.11	146.40	146.35	212.62	21.60	178.3
23.10	23.11	150.40	150.35	249.80	22.60	207.3
24.10	24.11	155.70	155.65	188.59	23.60	154.9
25.10	25.11	160.10	160.05	227.14	24.60	184.6
26.10	26.11	165.00	164.96	203.99	25.60	164.2
27.10	27.11	169.30	169.26	232.44	26.60	185.4
28.10	28.11	174.50	174.46	192.24	27.60	152.0
29.10	29.11	179.20	179.16	212.69	28.60	166.7
30.10	30.11	183.90	183.86	212.70	29.60	165.3

ConeTec Seismic Shear Wave Velocity Data Reduction Sheet

Hole: RSCPT 92-3

Location: WESTMINSTER HWY & NO 7 RD

Date: January 27, 1992

Cone: HT N0. 340 (geophone)

Source: Hammer and Beam Offset: 0.60 m

Geophone Depth (m)	Travel Path (m)	Crossover Time (ms)	Corrected Time (ms)	Velocity (m/s)	Interval Depth (m)	Normalized Vs (m/s)
1.15	1.30	17.30	15.34			
2.15	2.23	27.50	26.49	89.69	1.65	129.8
3.15	3.21	36.50	35.86	106.75	2.65	142.7
4.15	4.19	46.70	46.22	96.49	3.65	121.1
5.15	5.18	54.50	54.13	126.35	4.65	150.8
6.15	6.18	61.50	61.21	141.33	5.65	161.7
7.15	7.18	67.90	67.66	154.97	6.65	171.1
8.15	8.17	74.10	73.90	160.31	7.65	171.5
9.15	9.17	80.40	80.23	158.04	8.65	164.4
10.15	10.17	86.50	86.35	163.36	9.65	165.7
11.15	11.17	93.20	93.07	148.90	10.65	147.7
12.15	12.16	99.20	99.08	166.28	11.65	161.5
13.15	13.16	104.30	104.19	195.61	12.65	186.4
14.15	14.16	110.60	110.50	158.50	13.65	148.3
15.15	15.16	116.20	116.11	178.31	14.65	164.1
16.15	16.16	121.60	121.52	184.94	15.65	167.6
17.15	17.16	125.60	125.52	249.56	16.65	222.8
18.15	18.16	132.60	132.53	142.77	17.65	125.7
19.15	19.16	137.20	137.13	217.15	18.65	188.7

SEISMIC WORKSHEET FOR GSC AIRPORT SITE  
 HORZ. OFFSET 1.470544

DEPTH (m)	XO-T (ms)	XO-VEL (m/sec)	ARR-T (ms)	ARR-VEL (m/sec)	DEPTH B.G.	NORM-VEL
1	17.6	144.58	12.3	144.5806	0.5	259.5729
2	26.8	76.53221	19.8	93.87951	1.5	122.2978
3	36.3	90.37836	29.8	85.85944	2.5	127.9407
4	45.1	104.6267	38.8	102.3017	3.5	136.5501
5	52.5	128.3806	46	131.9468	4.5	157.5999
6	59.5	137.9735	52.9	139.9731	5.5	161.2531
7	66.7	135.4466	60.3	131.7859	6.5	151.9326
8	74.3	129.1101	66.7	153.3182	7.5	139.8081
9	78.8	218.9586	72.3	175.9489	8.5	229.8892
10	83.4	214.8258	77.7	182.9998	9.5	219.4340
11	88.5	194.1791	82.9	190.4448	10.5	193.4927
12	93.9	183.6867	88.6	174.0189	11.5	178.9594
13	99.1	190.9885	93.9	187.3849	12.5	182.2671
14	102.9	261.6083	98.9	198.8223	13.5	244.9416
15	109.3	155.4516	104.1	191.3251	14.5	142.9897
16	115.1	171.6422	108.7	216.4184	15.5	155.2895
17	120.5	184.4534	114.1	184.4534	16.5	164.3085
18	124.3	262.2329	117.5	293.0838	17.5	230.2028
19	129.9	178.0095	123.5	166.1422	18.5	154.1231



## **APPENDIX F**



January 16, 1992

Auger Hole No. 92-1  
(1.5 m west of RSCT 92-1)

Location: Francis & Railway

DEPTH (m)	SOIL DESCRIPTION	SAMPLE DEPTH		SAMPLE NUMBER
		(m)	ft.	
0 - 0.15	TOP SOIL			
0.15 - 0.45	- SILT Stiff, brown, clayey	0.3	1	1
0.45 - 0.75	- Stiff, grey, clayey			
0.75 - 2.75	- CLAY Soft, grey, silty	1.2 2.17	4 7	2 3
2.75 - 4.00	- SAND Fine grey to shell fragments	3.04 4.0	10 13	4 5
4.00 - 9.15	- medium sand	4.9	16	6
		5.8	19	7
		6.7	22	8
		7.0	25	9
		8.2	27	10
		9.1	30	11

Samples are labelled 2-1', 2-4', 2-7' .....

January 16, 1992

Auger Hole No. 92-2  
(1.5 m east of RSCT 92-2)

Location: Near maintenance entrance Mayfair Golf Course

DEPTH (m)	SOIL DESCRIPTION	SAMPLE DEPTH		SAMPLE NUMBER
		(m)	ft.	
0 - 1.8	SILT	0	1	1
1.8 - 2.75	SAND	1.2	4	2
2.75 - 9.1	- very fine to silt	2.1	7	3
	- medium grained	3.0	10	4
	- wood fragments at	4.0	13	5
	8.5 m	4.9	16	6
		5.8	19	7
		6.7	22	8
		7.6	25	9
		8.2	28	10
		9.1	30	11

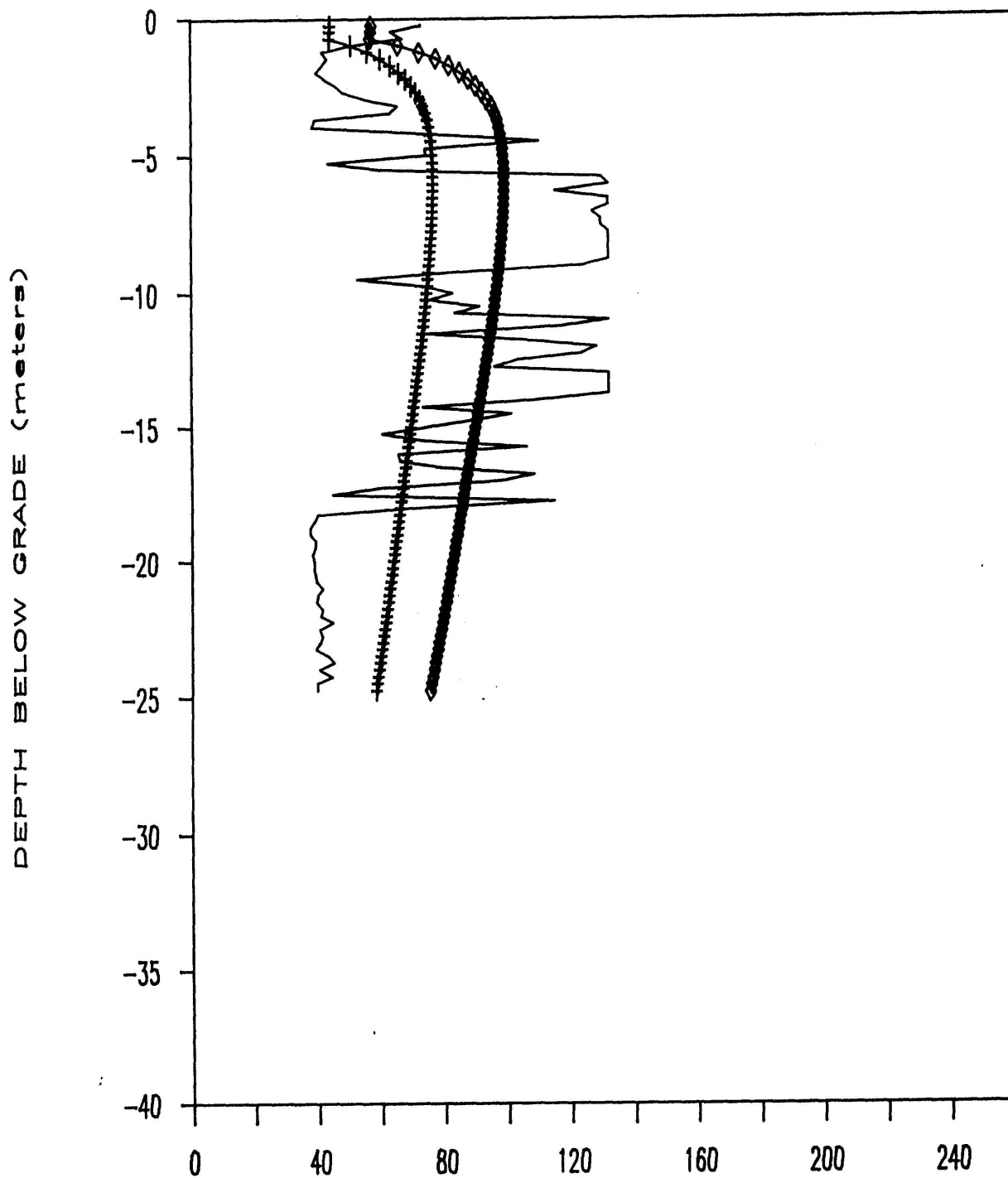
Samples are labelled 3-1', 3-4', 3-7' .....



## **APPENDIX G**

# CRITICAL QC SANDS <5% FINES D50=0.25

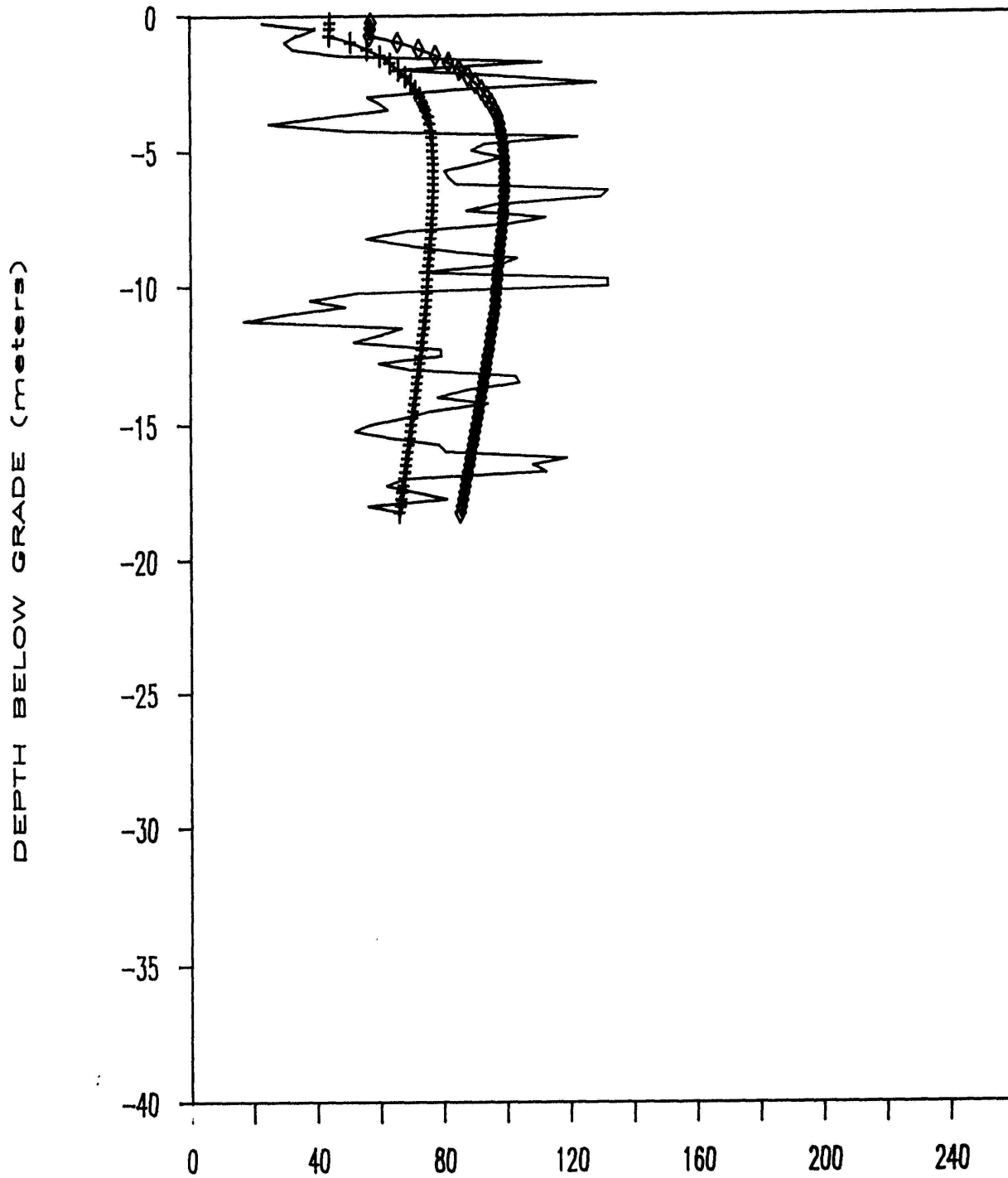
GSC, FRANCIS & RAILWAY, RICHMOND



— Critical QC  
+ EQratio1 = 0.17  
◇ EQratio2 = 0.22  
Ref: SEED (1986)

# CRITICAL QC SANDS <5% FINES D50=0.25

GSC, RADIO TOWERS, RICHMOND



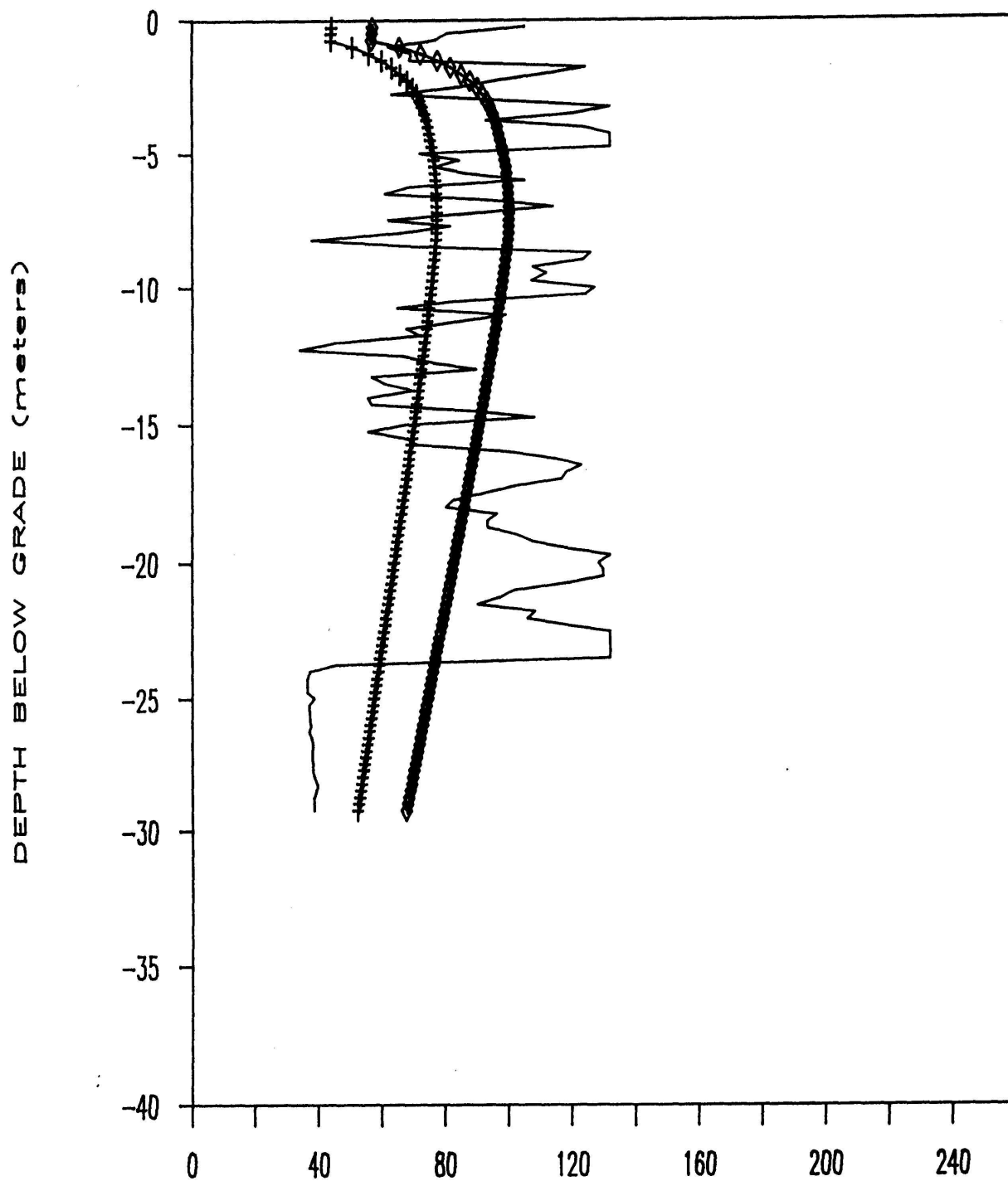
CONE PENETRATION RESISTANCE  $q_{ci}$  [tsf]

— Critical QC  
◇ EQratio2 = 0.22

+ EQratio1 = 0.17  
Ref: SEED (1986)

# CRITICAL QC SANDS <5% FINES D50=0.25

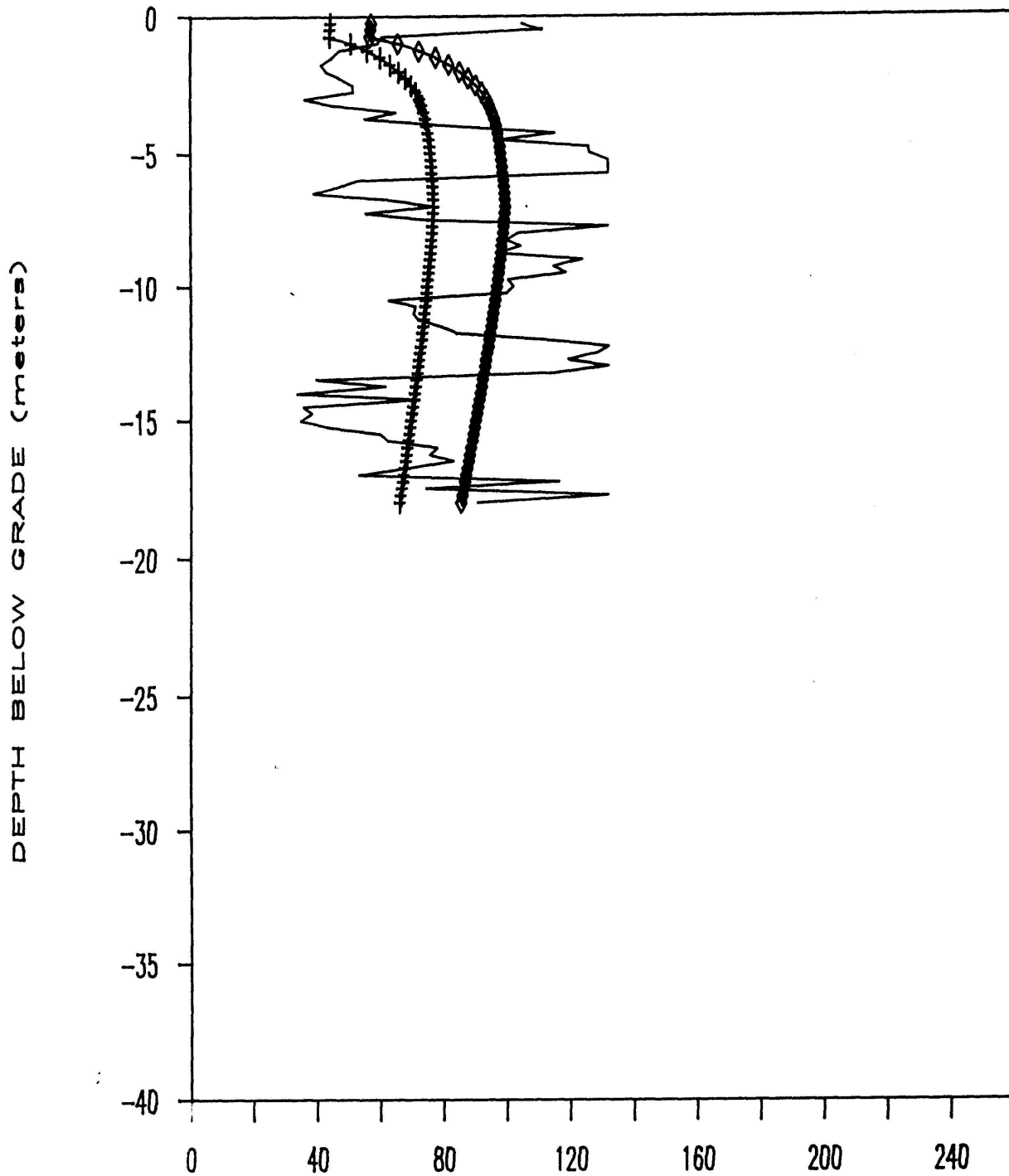
GSC, MAYFAIR GOLF COURSE, RICHMOND



— Critical QC  
+ EQratio1 = 0.17  
◇ EQratio2 = 0.22  
Ref: SEED (1986)

# CRITICAL QC SANDS <5% FINES D50=0.25

GSC, VAN. INTL. AIRPORT, RICHMOND

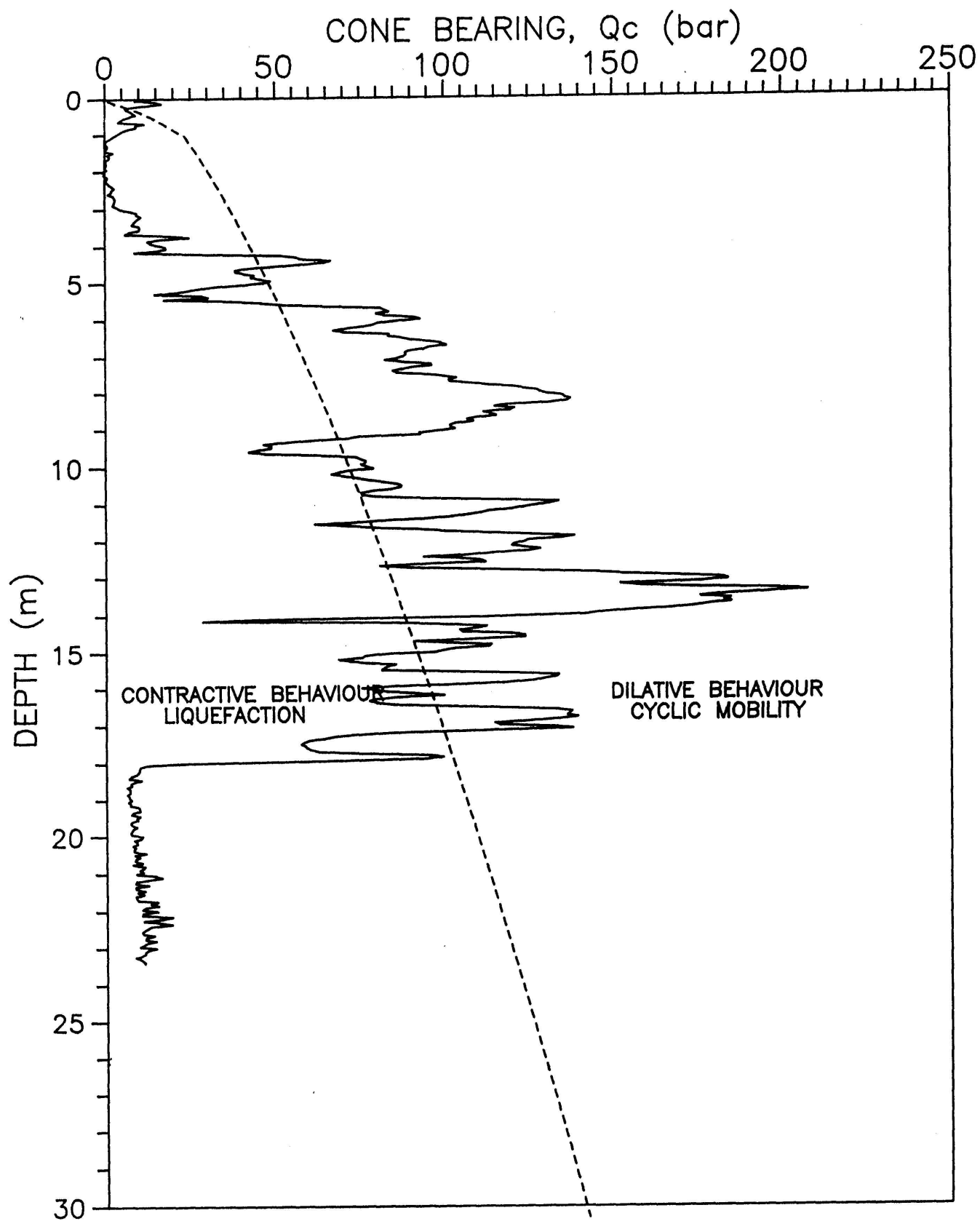


— Critical QC  
+ EQratio1 = 0.17  
◇ EQratio2 = 0.22  
Ref: SEED (1986)

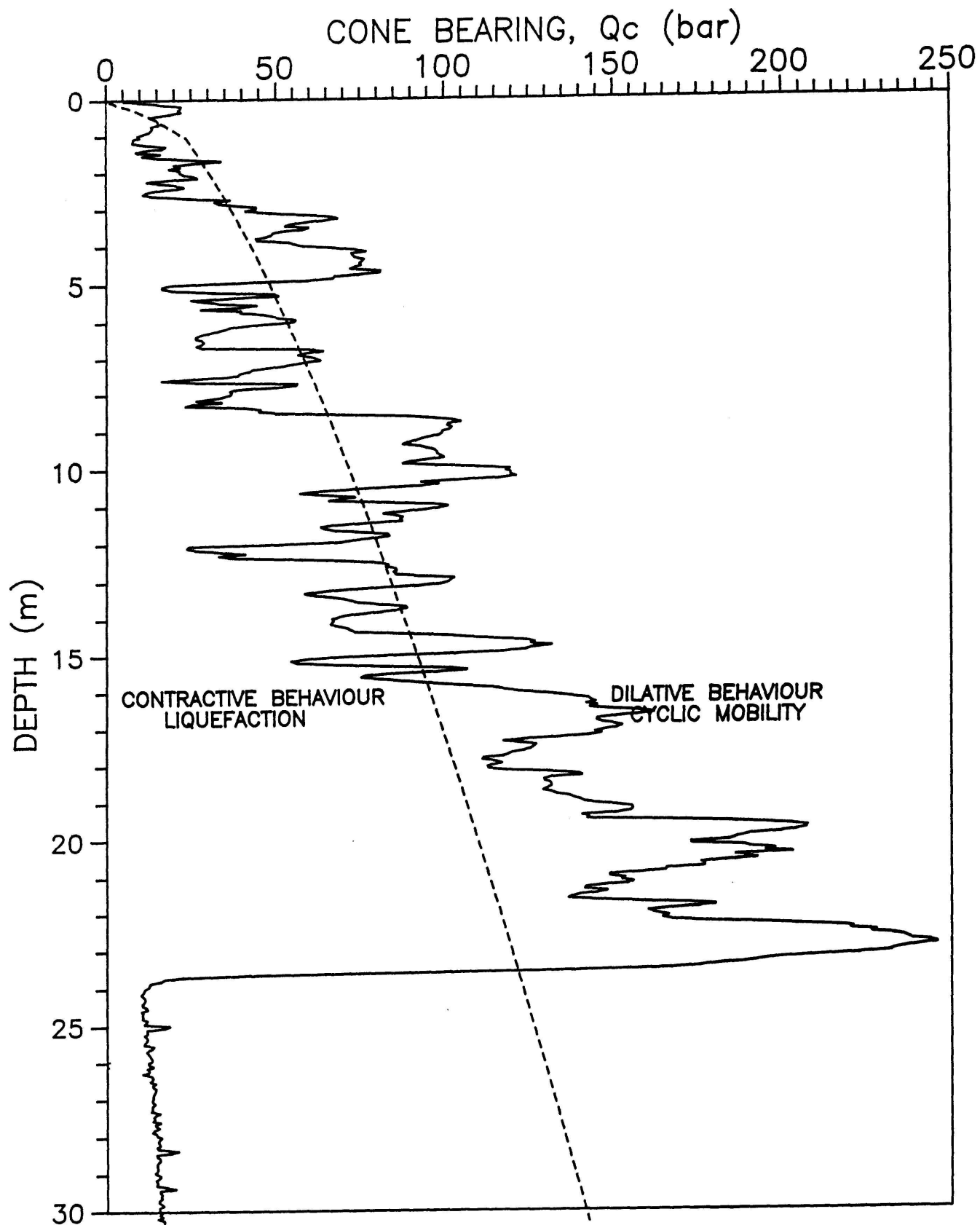




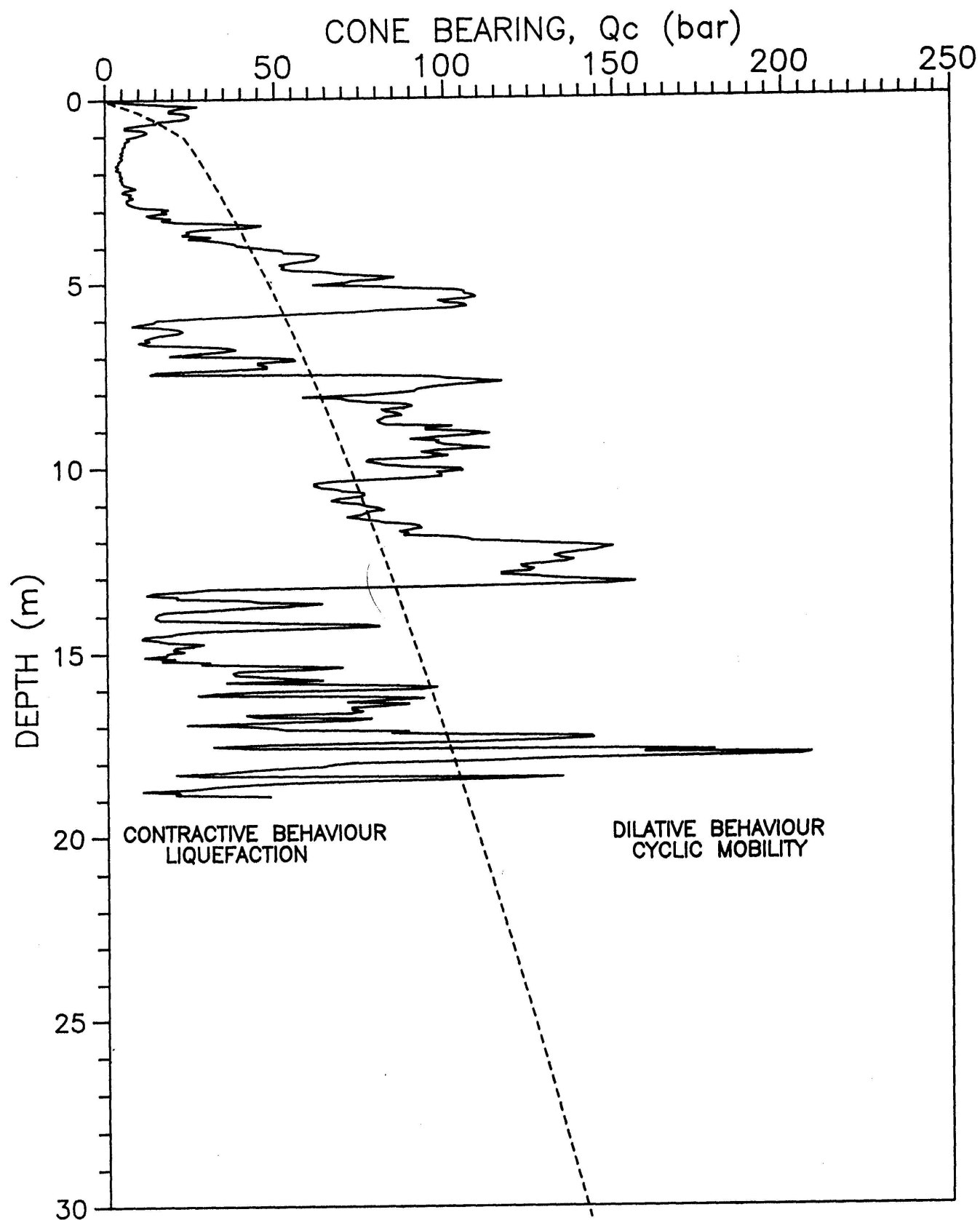
## **APPENDIX H**



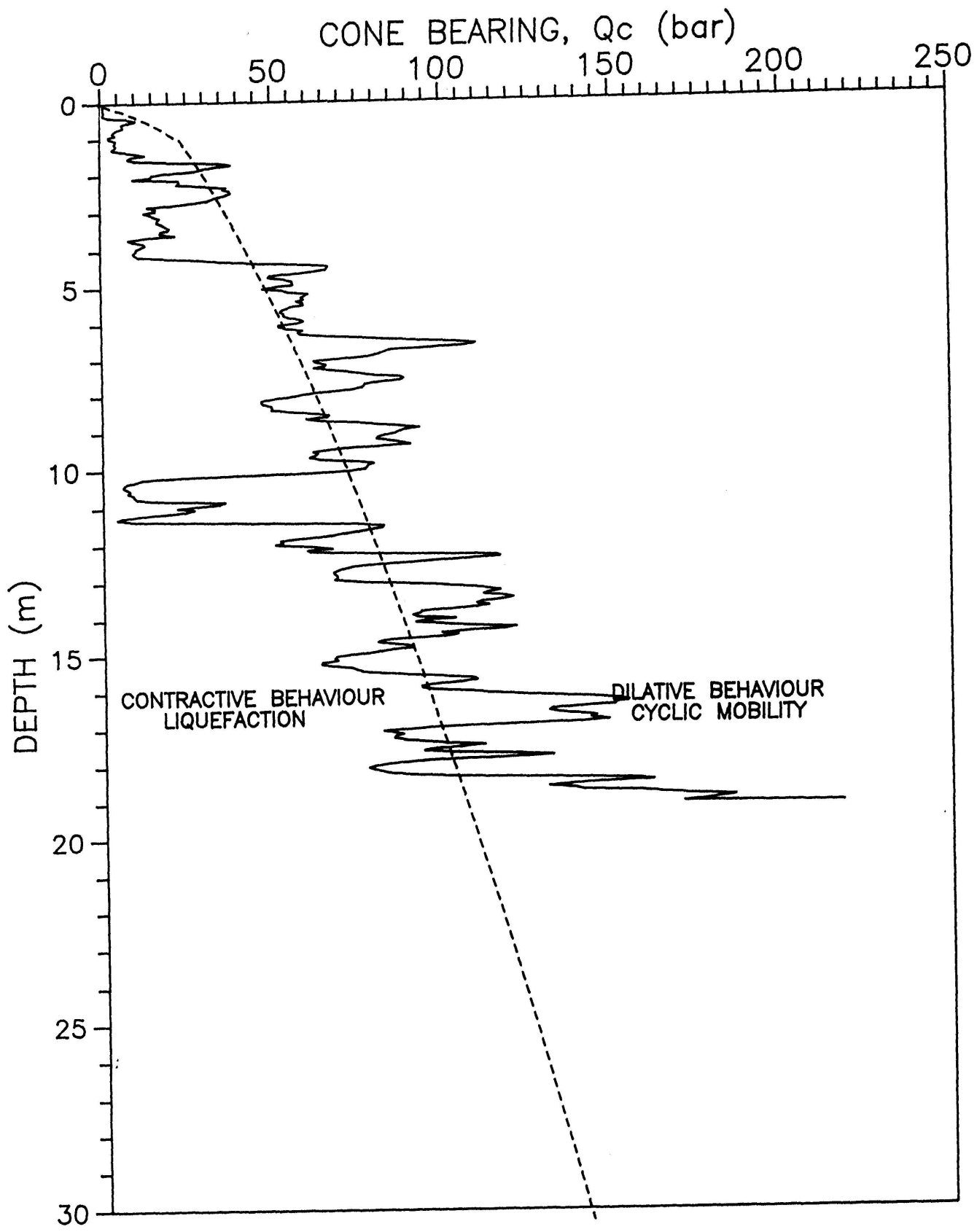
LOCATION: FRANCIS AND RAILWAY



LOCATION: MAYFAIR GOLF COURSE



LOCATION: VAN. INTL. AIRPORT



LOCATION: RADIO TOWERS