Disturbance Effects of Field Vane Tests in a Varved Clay

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Keywords: in situ, field vane, soil disturbance, varved clay, sensitivity

ABSTRACT: A field investigation was performed to evaluate the influence of disturbance on the measured undrained strength of a varved clay deposit using the Field Vane Test at the National Geotechnical Experimentation Site at the University of Massachusetts, Amherst. Four different field vanes of the same height and diameter but having different blade thickness were used to conduct FVT profiles over a depth of 3.6 m to 20.1 m. The geometry of the vanes used produced perimeter ratios ranging from 3.1% to 12.4%. The results show that the measured peak strengths are inversely proportional to the perimeter ratio of the vane. Extrapolation of the data to a vane of "zero" thickness may give a better indication of the in situ undisturbed strength for the use in design. In addition to giving lower peak strengths, the results indicate that thicker vanes do not give sufficient definition of the post-peak strength, a result of this behavior being "masked" by the soil disturbance. As the remolded strengths given by the vanes were essentially the same, the thicker vanes also give lower values of sensitivity. The results illustrate how field vane test results may easily be misinterpreted.

1 INTRODUCTION

The Field Vane Test (FVT) is still considered by many engineers as the preferred field method for providing reference values of undrained shear strength of soft and medium stiff clays. In addition to providing a measure of the peak undrained strength, the vane can also give an indication of the post-peak strength and the remolded (destructured) strength, and therefore soil sensitivity, s_t. It is the only in situ test with this capability at this time. Like nearly all in situ tests, however, the FVT is subject to disturbance effects resulting from the insertion of the vane into the ground. The study presented herein investigated the effects of vane thickness and resulting disturbance on undrained shear strength of Connecticut Valley Varved Clay (CVVC).

2 BACKGROUND

There are a number of factors that can affect the results obtained with the FVT and can therefore affect the interpretation of the undrained shear strength value obtained. These factors include both variations in the equipment used and variations in the test procedure. A number of the most important factors affecting the test results are given in Table 2.1.

Disturbance produced by inserting a vane should be related the geometry of the vane for the same soil. It is logical that the more soil that must be displaced to allow the vane to be inserted the more the amount of disturbed soil. In order the quantify the level of disruption caused by the vane, Cadling and Odenstad (1950) suggested that the amount of disturbance could be described using the vane "perimeter ratio," defined as:

$$\alpha = \frac{4e}{\pi D} \quad (1)$$

where:

α = perimeter ratio (usually expressed as %)
e = thickness of vane blade (mm)
D = diameter of vane (mm)

Table 2.1 Factors that May Affect the Results of the FVT.

Factor	Reference
Vane Geometry	Calding and Odenstad (1950) Osterberg (1956) Bazett et al. (1961)
Soil Fabric	Lo (1965) Lo and Milligan (1967) Loh and Holt (1974) Andrawes et al. (1975)
Rate of Shearing	Skempton (1948) Cadling and Odenstad (1950) Bazett et al. (1961) Aas (1965) Wiesel (1973) Perlow & Richards (1977)
Stress Distribution	Flaate (1966a) Donald et al. (1977) Menzies & Merrifield (1980) Wroth (1984)
Time Effects	Aas (1965) Torstensson (1977)

The parameter, α, is illustrated in Figure 2.1. If the zone of undisturbed soil adjacent to the vane blades is related to the blade thickness, then for the same diameter vane, a larger amount of "undisturbed" soil for testing will result from thinner blades. Thick blades on the vane will produce more disturbance for a vane with a constant diameter. Similarly, vanes with the same blade thickness, but different diameter should show less disturbance effects as the diameter increases.

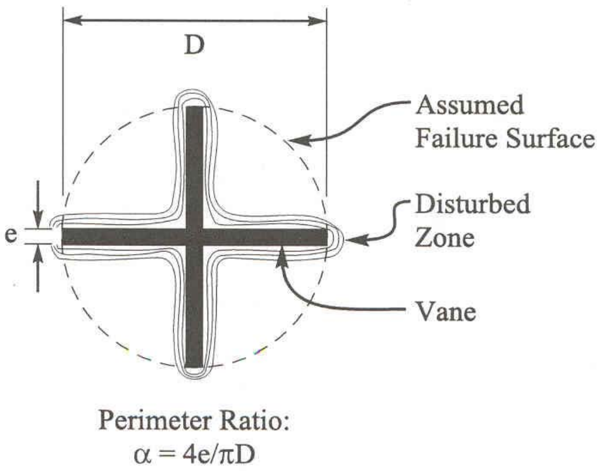

Figure 2.1 Disturbance caused by intrusion of the vane into clay.

The undrained strength measurement should be more representative of "undisturbed" conditions. Equation 1 suggests that in order to reduce disturbance effects, either blade thickness must be reduced, or vane diameter must be increased, or both. There is a practical problem with machining vanes with blades that are too thin since they will have reduced strength and may bend or break during testing. Typical commercial vanes have perimeter ratios in the range of 4 to 8%.

LaRochelle et al. (1973) illustrated the importance of disturbance on the resulting undrained strength profiles obtained in sensitive Champlain Sea Clay (s_t = 12) by using vanes of the same diameter but different blade thickness. All other test procedures were held constant and the NGI vane device was used for all the tests. The resulting strength profiles are shown in Figure 2.2. These results show that for most for the tests in this soil, the measured undrained shear strength increases as the vane blade thickness decreases, i.e., as α decreases, which is expected.

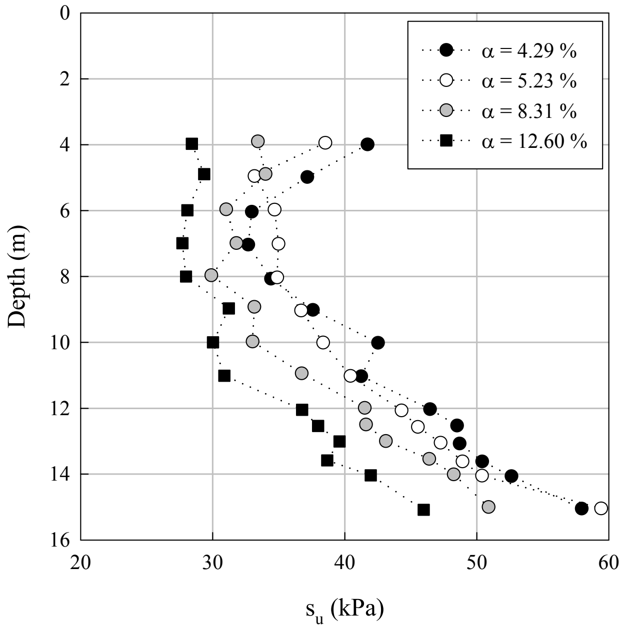

Figure 2.2 FVT Results in Champlain Clay (data from LaRochelle et al. 1973).

The results presented in Figure 2.2 were used by LaRochelle et al. (1973) to back extrapolate the measured undrained strength to a blade thickness of zero, providing a perimeter ratio of zero and therefore a condition of "zero disturbance." The results of this back extrapolation procedure for tests performed on Champlain Sea Clay indicated an approximate linear relationship between perimeter ratio and undrained shear strength for α = 4.3 to 12.6 %. An increase in the extrapolated undisturbed strength of about 15% is suggested over the value obtained from the "standard" (α = 4.3%) vane. Similar results have been presented by Roy and Leblanc (1988) who showed that for sensitive marine clays at Saint-Alban and Saint- marine clays at Saint-Alban and Saint-Louis in Canada, the linear extrapolation gave undrained strength values approximately 6.5 and 9 % higher than the standard vane (α = 4.3 %) strength. They noted that not only does disturbance vary with blade thickness, but also with clay type.

Data from these previous studies, in which a perimeter ratio of about 5% was used as a reference, suggest that extrapolation to zero vane thickness can result in an increase in estimated shear strength on the order of 6 to 15%; at least for sensitive clays. Some soils, such as clays with low sensitivity, may be relatively insensitive to blade thickness.

3 INVESTIGATION

In this study, the undisturbed strength was evaluated by conducting four parallel vane profiles with vanes of the same diameter but different blade thicknesses. This provided an estimate of the undisturbed strength of the Connecticut Valley Varved Clay (CVVC).

3.1 *Site Geology*

Tests were performed at the National Geotechnical Experimentation Site at the University of Massachusetts, Amherst. The site is situated within the Connecticut River Valley and within the extent of the former glacial Lake Hitchcock. The lacustrine sediment deposits were formed as a result of an ice-wall dam, which formed across the Valley in northern Connecticut creating seasonal deposition and settling of fine-grained particles over the coarser glacial till for a period of approximately 4000 years. This soil is locally known as Connecticut Valley Varved Clay (CVVC) and extends from Northern Vermont to Central Connecticut in the present Connecticut River Valley.

3.2 *Field vane tests*

The FVT measures the maximum torque applied to the vane through a rod system. This torque is then converted into the undrained shear strength assuming the distribution of the shear strength is uniform across the ends of the cylinder and around the perimeter (ASTM D2573). Four field vane profiles were conducted using vanes having different perimeter ratios ranging from 3.1 % to 12.5 %. The vanes were rectangular, four-bladed vanes with heights of 13.0 cm and diameters of 6.5 cm, providing height to diameter ratios of 2. The only difference then was the blade thickness, e, (1.58 mm, 3.18 mm, 4.76 mm and 6.35 mm). The blade thickness was varied in order to provide different values of α. The diameter of the vanes was held constant to give the same shear velocity. Table 3.1 presents the vane dimensions.

Table 3.1 Dimensions of Vanes.

Test #	Diameter (mm)	Height (mm)	Blade Thickness (mm)	Rod Diameter (mm)	Perimeter Ratio (%)
FVT-4	65	130	1.58	20	3.1
FVT-6	65	130	3.18	20	6.2
FVT-7	65	130	4.76	20	9.3
FVT-8	65	130	6.35	20	12.4

The Nilcon Vane Borer Model M-1000, which uses unprotected rods and an unprotected vane with a rod slip coupling, was used in the testing program (Figure 3.1). The rods had a diameter of 20 mm. The small diameter of the rods was to reduce the amount of rod friction, although the diameter of the rods had to be sufficient enough so that the elastic limit was not exceeded when the vane was stressed to its capacity.

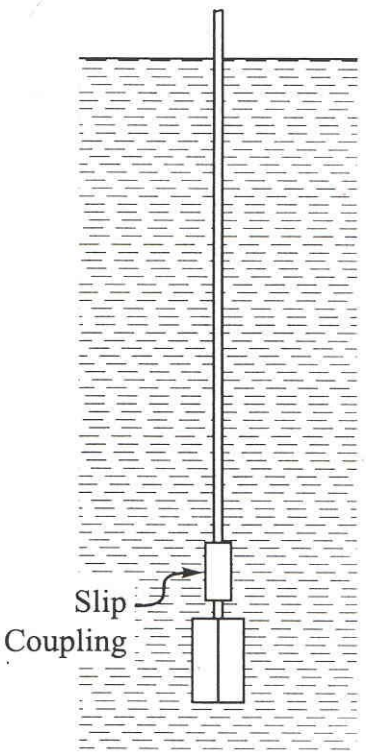

Figure 3.1 Unprotected Vane and Rods.

Predrilled 76 mm diameter, 3.0 m deep holes were prepared prior to testing at each location to avoid damage to the vane during advancement through the stiff surficial crust and fill. The field vane, slip coupling and starting rod were placed through the center of the torque recording head. The slip coupling was located about 60 mm above the vane to permit 15° slip between the vane and the rods before the vane engaged. The torque head contained a self-recording device that utilized a steel pointer to scribe the corresponding torque on a waxed paper disc.

The vane was advanced in 0.6 m increments with testing starting at approximately 3.05 to 3.66 m below grade. Once the vane was in position, torque was applied to the vane by a hand operated gear drive through 20 mm diameter torque rods extending to the surface. The applied rate of torque to the vane was approximately 0.1°/sec resulting in an average time to failure of 7 to 9 minutes.

Following failure of the soil at its peak strength, the test was continued at the same rate of torque to evaluate the post peak strength of the soil. Once this post peak strength was measured, the torque was removed and the rods manually rotated 10 complete revolutions to remold the soil in a cylindrical failure zone around the circumference of the vane. The remolded shear strength of the soil was then determined. This measurement allowed the determination of the soil sensitivity, s_t. A sample recording of the measured torque showing the rod friction, peak strength, post peak strength and the remolded strength scribed onto the paper disc is shown in Figure 3.2.

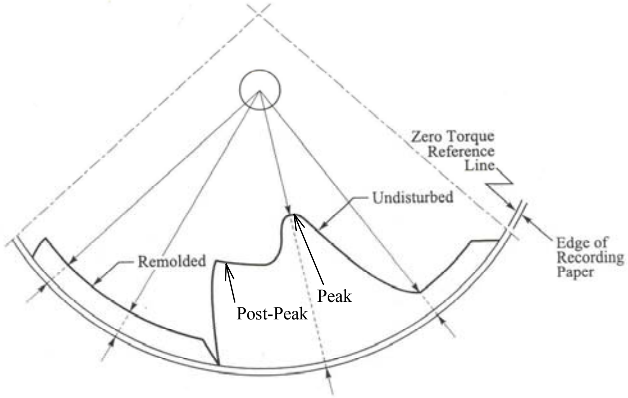

Figure 3.2 Sample Nilcon Field Vane Torque Trace.

4 RESULTS

The results from the FVT profiles are presented in Figure 4.1. These results show that undrained shear strength decreases as vane thickness increases. The extrapolated strength values shown in Figure 4.1 denote the “zero disturbance” shear strength values found by extrapolating the results of the vane tests back to a vane thickness of 0, or a perimeter ratio of 0. This extrapolation is illustrated in Figure 4.2, which shows results from three different depths in the profile. These results indicate an approximate linear relationship between perimeter ratio and undrained shear strength. An increase in the estimated undisturbed strength of about 16 % is suggested over the value obtained from the “standard” vane, ($\alpha = 3.1\%$), which is slightly higher than other researchers have

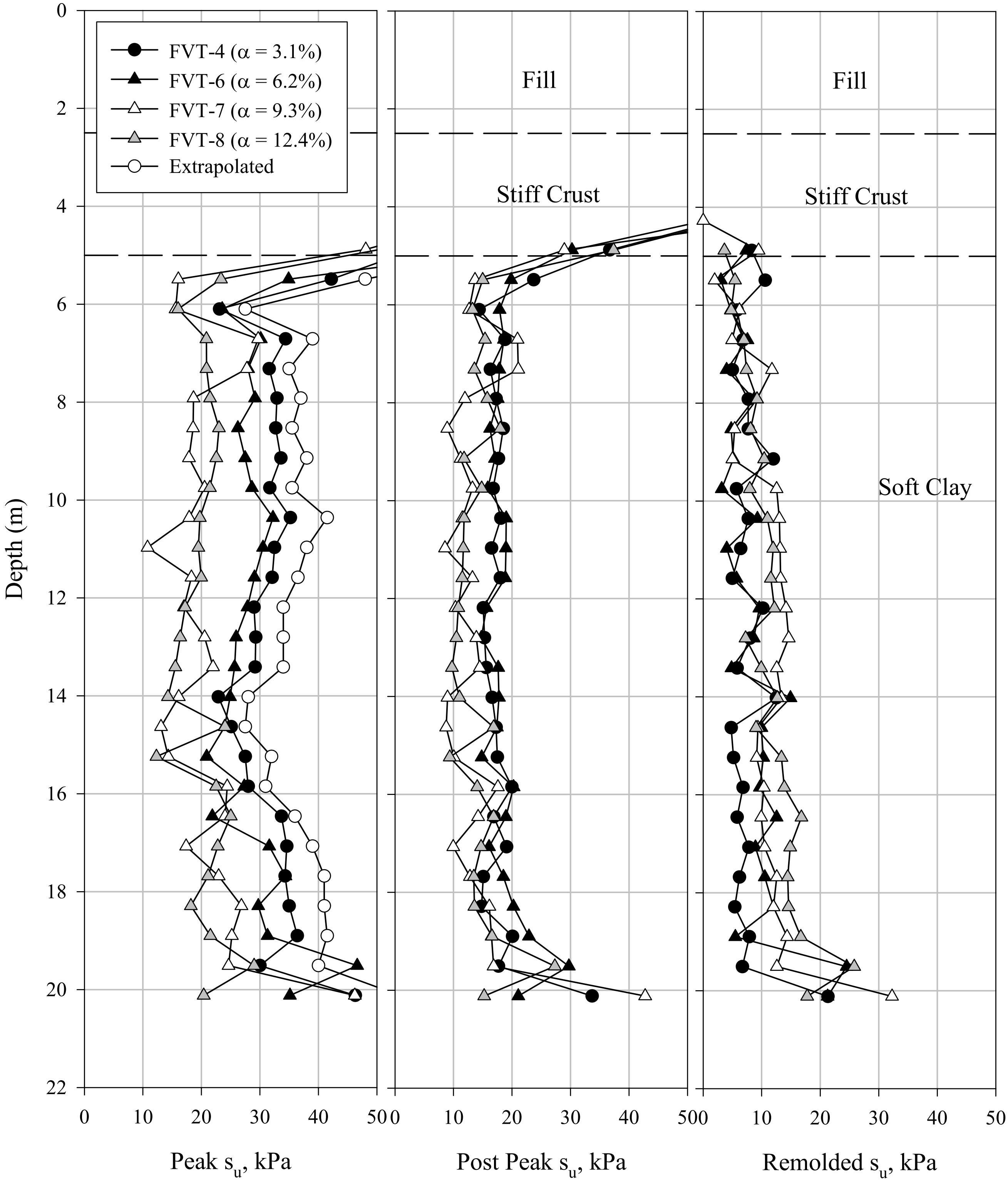

Figure 4.1 Results of FVT Tests in CVVC.

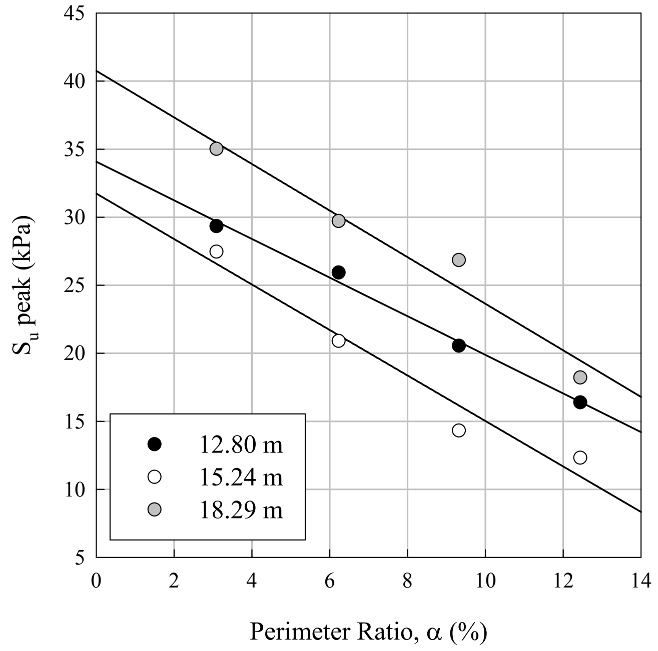

Figure 4.1 “Zero Disturbance” Extrapolation.

suggested, most likely because the reference vane used in this study had a slightly smaller perimeter ratio than previous studies. Post peak strength values are also lower with thicker vane blades and were difficult to interpret. The disturbance produced by the thicker blades tends to “mask” the post peak behavior.

Since the remolded strength represents a completely “destructured” or fully disturbed condition, it should be expected that these values would be independent of vane blade thickness. That is, completely remolding the soil produces a minimum strength and therefore it should not make a difference on how the soil arrives at that condition on the resulting strength. The results shown in Figure 4.1 support this and do not show any consistent trend. The consequence of disturbance is really three-fold; 1.) peak values of undrained strength are lower as disturbance increases; 2.) post-peak strength is lower and poorly defined and 3.) soil sensitivity is lower.

The Undrained Brittleness Index, first suggested by Bishop (1971) may be used to define the reduction of undrained strength from peak to the residual (large strain) strength as:

$$BI = \frac{s_{up} - s_{upp}}{s_{up}} \tag{4}$$

where:

s_{up} = Peak Undrained Shear Strength (kPa)
s_{upp} = Post Peak Undrained Shear Strength (kPa)

and may be related to the loss of soil structure. The sensitivity, s_t, of the soil was calculated using the peak strength and the remolded strength and is defined as:

$$s_t = s_{up}/s_{ur} \tag{5}$$

Figure 4.3 presents the results of the Brittleness Index (BI) and the sensitivity (s_t). The BI of this soil ranges from approximately 0.25 to 0.5 and the sensitivity ranges from approximately 1 to 10.

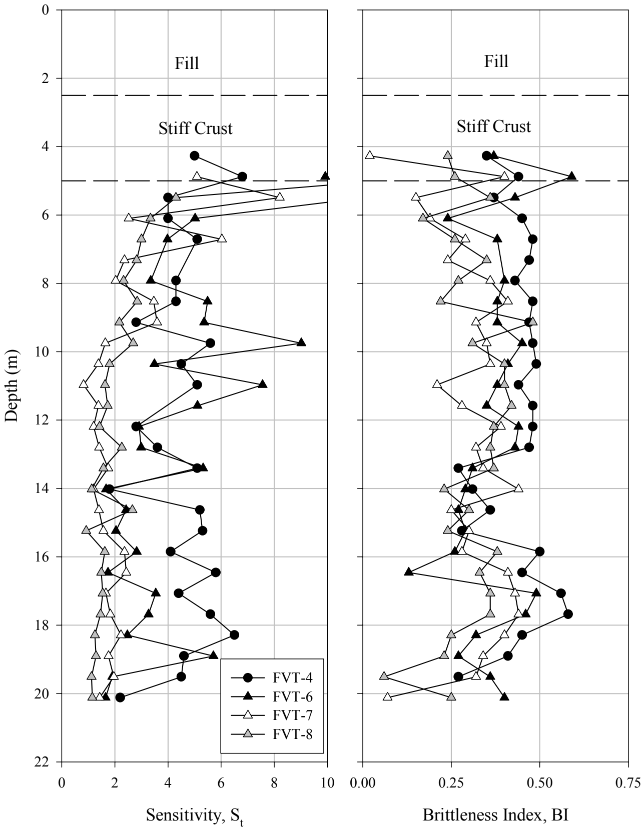

Figure 4.2 FVT s_t and BI Results.

5 CONCLUSIONS

Field Vane undrained shear strengths are directly related to the thickness of vane blades used within perimeter ratios ranging from 3 to 12 %. The results show that the measured peak strengths are inversely proportional to the perimeter ratio of the vane. In addition to giving lower peak strengths, the results indicate that thicker vanes do not give sufficient definition of the post-peak strength, a result of this behavior being “masked” by the soil disturbance. As the remolded strengths given by the vanes were essentially the same, the thicker vanes also give lower values of sensitivity.

In a site investigation, it is important to know the exact type of equipment used in the testing program, since all vanes will not give the same strength values in a given soil. Therefore, the results of the testing must be reviewed with caution. For large projects, it would be helpful to perform two profiles with vanes of different geometries in order to understand disturbance effects in the particular soil and to allow an accurate prediction of shear strength for use in design.

Engineers may wish to consider the increase in undrained shear strength obtained by extrapolation to zero perimeter ratio over the value that is measured in the field. Extrapolation for a vane of "zero" thickness may give a better indication of the in situ undisturbed strength for the use in design. For some soils this should be accounted for in design as a real component of undrained shear strength, which is available but undetected in normal testing procedures. Ignoring this available strength is conservative in design.

REFERENCES

Aas, G. 1965. A Study of the Effect of Vane Shape and Rate of Strain in the Measured Values of In Situ Shear Strength of Clays. Proceedings of the 6th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 141-145.

Andrawes, K.Z. Krishnamurthy, D.N. and Barden, L. 1975. Anisotropy of Strength in Clays Containing Plates of Increasing Size. Proceedings of the 4th Southeast Asian Conference on Soil Engineering, Kuala Lumpur, Malaysia, Vol. 1, pp. 6-12.

Bazzet, D.J., Adams, J.I. and Matyas, E.L. 1961. An Investigation of Studies in a Test Trench Excavated in Fissured Sensitive Marine Clay. Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering, Paris, Vol. 1, pp. 431-436.

Cadling, L. and Odenstad, S. 1950. The Vane Borer. Proceedings of the Royal Swedish Geotechnical Institute, No. 2, pp. 1-87.

Donald, I.B., Jordan, D.O., Parker, R.J. and Toh, C.T. 1977. The Vane Test – A Critical Appraisal. Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1, pp. 81-88.

Flaate, K. 1966. Factors Influencing the Results of Vane Tests. Canadian Geotechnical Journal, Vol. 3, No. 1, pp. 18-31.

LaRochelle, P., Roy, M. and Tavenas, F. 1973. Field Measurements of Cohesion in Champlain Clays. Proceedings of the 8th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1.1, pp. 229-236.

Lo, K.Y. 1965. Stability of Slopes in Anisotropic Soils. Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 91, SM1, pp. 85-106.

Lo, K.Y. and Milligan, B. 1967. Shear Strength Properties of Two Stratified Clays. Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 93, SM1, pp. 1-15.

Loh, A.K. and Holt, R.T. 1974. Directional Variation and Fabric of Winnipeg Upper Brown Clay. Canadian Geotechnical Journal. Vol. 11, No. 3, pp. 430-437.

Menzies, B.K. and Merrifield, C.M. 1980. Measurements of Shear Stress Distribution on the Edges of a Shear Blade. Geotechnique, Vol. 22, No. 3, pp. 451-457.

Osterberg, J.O. 1956. Introduction to Vane Testing of Soil. ASTM Special Technical Publication, 193. pp. 1-7.

Perlow, M. and Richards, A.F. 1977. Influences of Shear Velocity on Vane Shear Strength. Journal of the Geotechnical Engineering Division, ASCE, Vol. 103, No. GT1, pp. 19-32.

Roy, M. and Leblanc, A. 1988. Factors Affecting the Measurement and Interpretation of the vane Strength in Soft Sensitive Clays. Vane Strength Testing in Soils: Field and Laboratory Studies, ASTM STP 1014, pp. 117-128.

Skempton, A.W. 1948. Vane Test in the Alluvial Plains of River Froth Near Grange Mouth. Geotechnique, Vol. 1, No. 2, pp. 111-124.

Torstensson, B.A. 1977. Time-Dependent Effects in the Field Vane Test. Proceedings of the International Symposium on Soft Clays, Bangkok, pp. 387-397.

Wiesel, C.E. 1973. Some Factors Influencing In Situ Vane Test Results. Proceedings of the 8th International Conference on Soil Mechanics and Foundation Engineering, Vol. 1.2, pp. 475-479.

Wroth, C.P. 1984. Interpretation of In Situ Tests. Geotechnique, Vol. 34, No. 4, pp. 449-489.