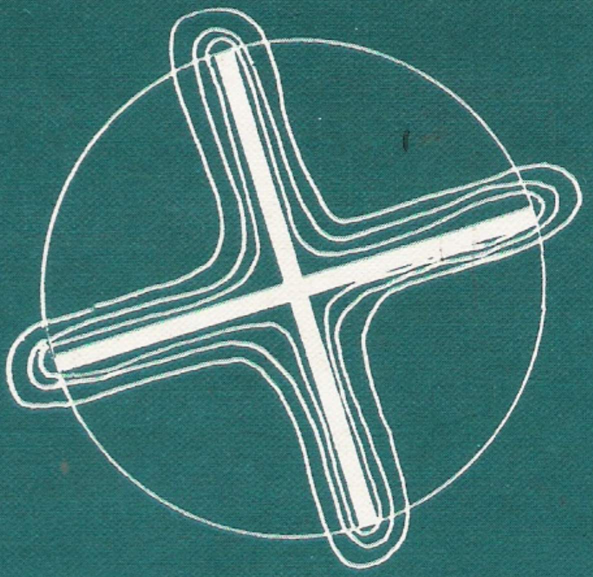
Vane Shear Strength Testing in Soils



Field and Laboratory Studies

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EDITOR

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Errors Caused by Friction in Field Vane Tests

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ABSTRACT: Field vane tests have been traditionally employed with reported success in design on soft soils. In Brazil, most of the available vane test equipment requires preboring. With these devices soil-rod friction influences the data and should be accounted for through calibration tests. An investigation was carried out on Rio de Janeiro clay, and the results showed that soil-rod friction tests can provide unreliable results. Therefore, friction should be eliminated through a better mechanical design, as accomplished in the vaneborer apparatus, with which field vane (FV) tests have shown less data scatter. The FV strength profile was evaluated in a stability analysis of an embankment failure on Rio de Janeiro clay, and a factor of safety close to one was obtained in this highly plastic clay. This led to the conclusion that recommended FV correction factors are too conservative for the Rio de Janeiro clay.

KEY WORDS: field vane tests, Rio de Janeiro clays, calibration tests, soil-rod friction, correction factors

Early attempts to obtain the undrained strength of soft clays through field vane tests (FVT) go back as far as the 1920s and 1930s, in Sweden and Germany. Many years later, the test was introduced in Brazil, circa 1948, but only after a decade a field vane apparatus became commercially available through a local manufacturer in Rio de Janeiro. Since then, this test gained widespread use in Brazil.

A FV testing program in the Rio de Janeiro soft clay using the commercially available apparatus has led to difficulties for data evaluation and correction for soil-rod friction and to excessive data scatter. Therefore, alterations in the mechanical design of the equipment were introduced in order to reduce friction to a negligible value.

This paper presents the results of this campaign, comparing the data from two different FV apparatuses, and finally the strength profile of the Rio de Janeiro soft clay and FV correction factors are evaluated.

FV Equipment Types

According to the installation method, FV equipment can be classified into four different categories as shown in Fig. 1.

Unprotected Rods and Vane, Through a Prebored Hole (Fig. 1a)

Despite being the earliest equipment model, this device is still in use today. The measured torque includes soil friction on the rods just above the vane, and the results have to

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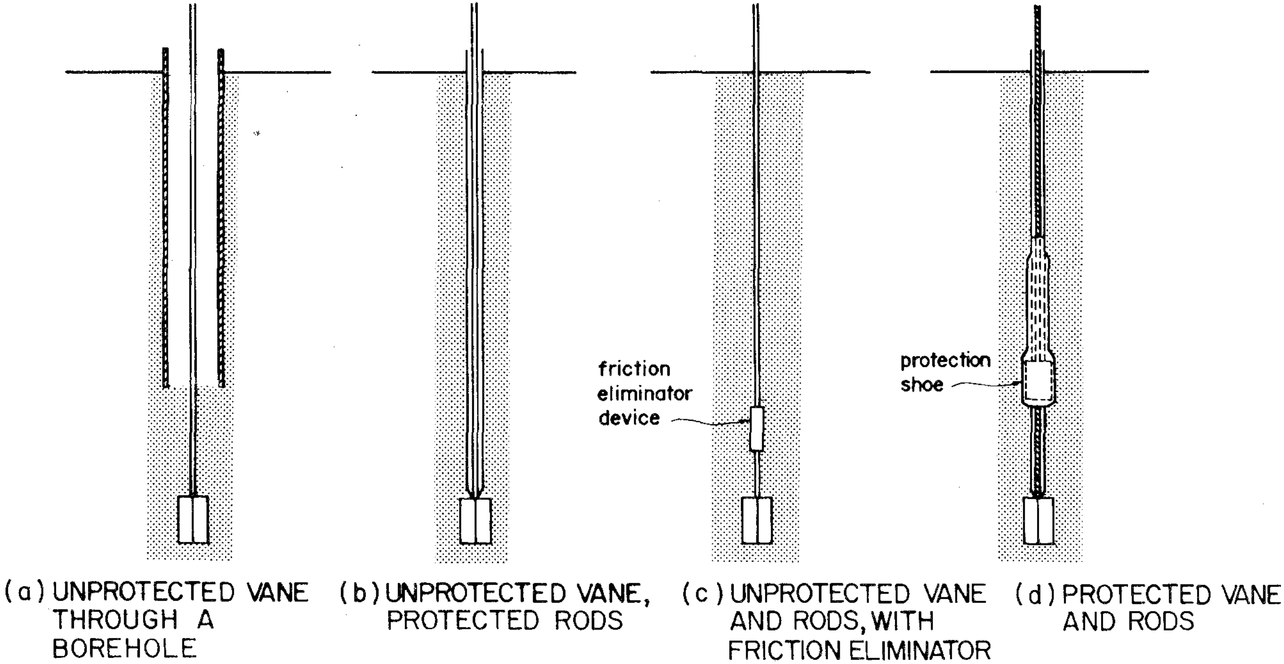

FIG. 1—*Classification of FV equipment according to the method of installation.*

be corrected. Calibration tests without the vane are suggested for this correction (for example, ASTM Method for Field Vane Shear Test in Cohesive Soils [D 2573]).

*Protected Rods and Unprotected Vane (Fig. 1*b*)*

An example of an equipment with this feature is the LCPC (Laboratoire Central des Ponts et Chaussées) [*1*]. A rod protection pipe is required by some standards, such as British Standard (BS) Methods of Test for Soils for Civil Engineering Purposes (BS 1377), or the German Standard (DIN) Vane testing (English translation DIN 4096, 1980).

*Unprotected Vane with a Friction Eliminator Device (Fig. 1*c*)*

This is the case of the vaneborer manufactured by the Swedish company Nilcon AB. The friction elimination device allows a rod rotation of 45° before actuating the vane.

*Protected Rods and Vane (Fig. 1*d*)*

As designed by Cadling and Odenstad [*2*], the vane is installed in a retracted position in a protection shoe. The rods are fully protected, and therefore, friction can be totally eliminated. This type of apparatus is often referred to as the vaneborer.

The FVT Campaign in the Rio de Janeiro Clay

FVT were carried out in the Rio de Janeiro clay during a major research program which involved construction of full-scale instrumented embankments [*3,4*].

At the site of the tests the clay stratum is 11 m thick and its properties are as shown in Table 1.

Figure 2 shows the FV equipment initially employed in this investigation. Manufactured in Brazil for about 15 years and used by many local site investigation firms, FV equipment comprised a 100-mm-diameter casing and 41-mm-diameter AX rods connected to the vane through a 750-mm-long 12-mm-diameter rod.

At least two rod spacers provided with ball bearings were employed in the investigation, one at the top and the other at the bottom. The torque measuring unit comprised a 7200:1 reduction gear, which enabled rotating the vane at the standard rate of 6°/min. A system of spring and deflection gage enabled accurate torque measurements.

The vane was 90 mm in diameter and 180 mm in height, in order to match the torque values to the more accurate range of the torque-spring system. Vanes of different sizes were also used in a previous attempt to investigate the clay's anisotrophy [5].

Some tests with this equipment employed a friction elimination device allowing a 45° free rotation of the rods before actuation of the vane.

TABLE 1—*Properties of Rio de Janeiro clay.*

Property	Value
Liquid limit, %	160 to 120
Plastic limit, %	80 to 60
Water content, %	180 to 120
Mean plasticity index, %	80
Total unit weight, kN/m^3	13

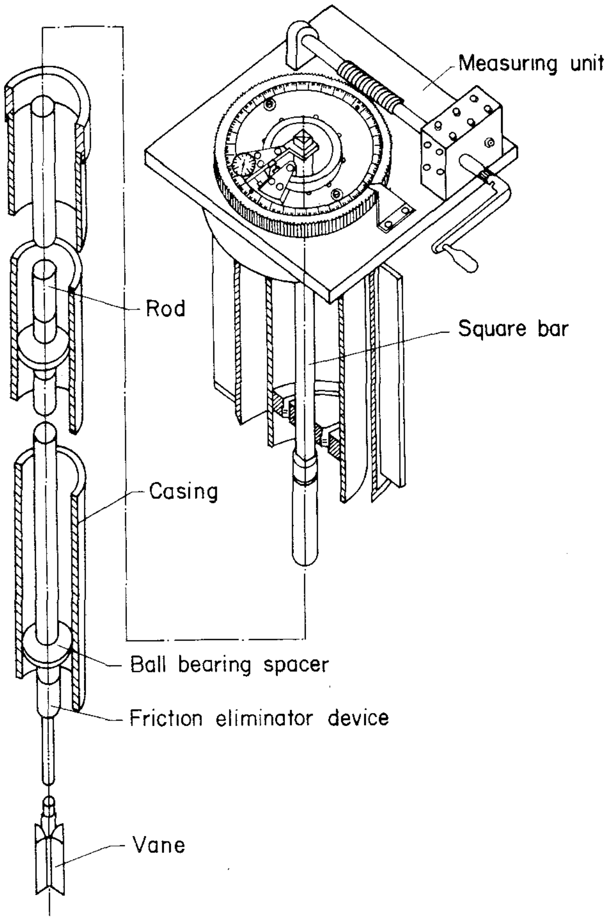

FIG. 2— *Details of the FV equipment requiring preboring.*

Test Results from the FV Equipment Requiring Preboring

Uncorrected FVT data, that is, those including the effect of friction, are plotted in Fig. 3, showing a maximum range of scatter around 8 kPa for the undisturbed tests and about half of this value for the remolded tests.

Calibration or dummy tests without the vane were then carried out to evaluate the effect of friction. Typical test curves are shown in Fig. 4, and peak values, that is, the maximum measured torques on the vane rod only, are plotted in Fig. 5. There is excessive scattering in these data, and maximum values are about 20 Nm, which is equivalent to an undrained strength of 8 kPa, if a 90 by 180 mm (diameter by height) vane was in place. This value is inconsistent with the data in Fig. 3, about twice the mean value given by the tests in remolded clay.

Therefore, it was concluded that the excessive scattering and the high values of friction test data were caused rather by internal friction of the instrument than by soil-rod friction. This excessive amount of internal friction was not present when the vane was in use, as the data of Fig. 3 show.

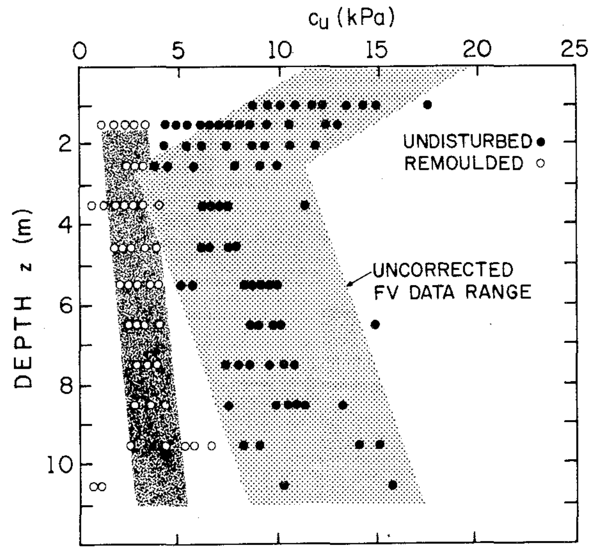

FIG. 3—*FVT data, uncorrected for friction.*

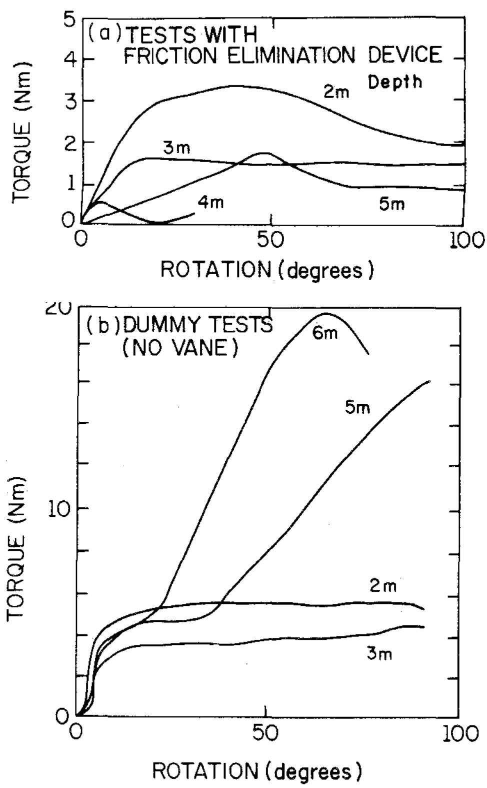

FIG. 4—*Calibration test results for the evaluation of friction: with the* (a) *friction elimination device and* (b) *dummy tests without the vane.*

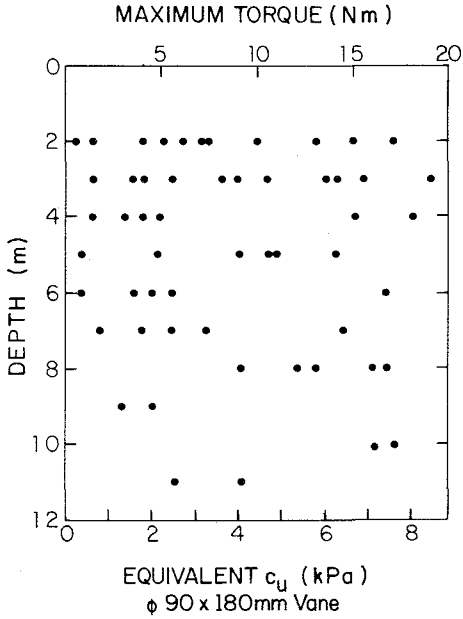

FIG. 5—*Data scatter in friction calibration tests.*

Attempts to minimize this problem by employing well aligned rods and by changing the rod spacers were unsuccessful.

It is interesting to note that similar difficulties with dummy tests were reported some 30 years ago in the United States [*6, 7*] with the same type of FV apparatus.

In order to overcome these difficulties, Collet [*8*] proposed an acceptance criterion for the friction test data. Only the torque-rotation curves, which appeared not to be significantly influenced by internal friction, were taken into account. Therefore, returning to Fig. 4*b*, the curves corresponding depths of 5 and 6 m were disregarded because their pattern presented a sudden increase in torque caused by internal frictions. However, those corresponding to depths of 2 and 3 m presented an acceptable pattern and were taken into account.

After all test curves had been filtered by this process, torque peak values from the selected curves were gathered in Fig. 6. As should be expected, linear correlations of these data indicated an increase of friction with depth. Mean friction values were about 5 Nm, which corresponds to an equivalent undrained strength, that is, if measured with a 90 by 180 mm (diameter by height) vane of about 2 kPa. This is a reasonable value, and it is compatible with uncorrected FV data shown in Fig. 3.

Finally, the correlation shown in Fig. 6*a* was selected to represent the effect of friction versus test depth. The resulting corrected FV data are plotted in Fig. 7. Excessive data scatter still remains making it difficult to select a design on profile.

The Vaneborer

In 1980, the aforementioned difficulties and errors led the writers to a complete redesign of the FV equipment, in order to eliminate or reduce friction to negligible values. Figure

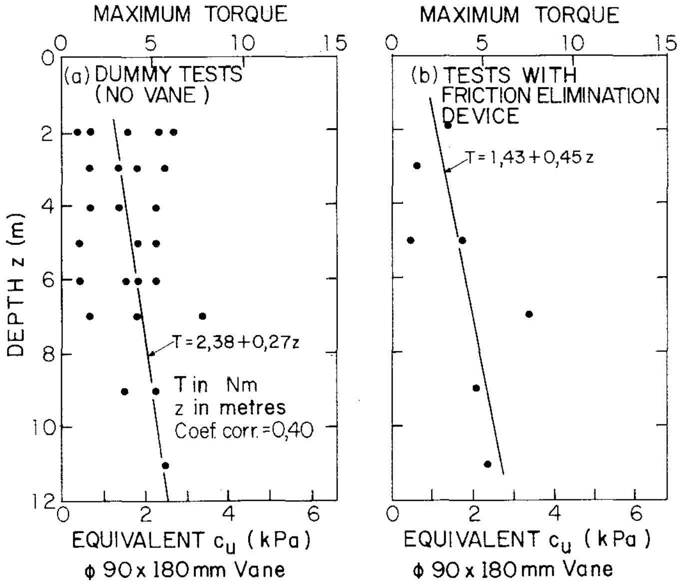

FIG. 6—*Maximum torques measured in friction calibration after data filtering* (a) *without the vane and* (b) *with friction eliminator device.*

8 presents the apparatus that was built according to the original conception of Cadling and Odenstad [*2*].

Torque was transmitted by 20-mm-diameter rods in sections of 1 m, operating inside a 38-mm-diameter protective casing. In order to avoid internal friction, special steel bars and pipes were selected and were carefully machined, in order to keep the axial alignment.

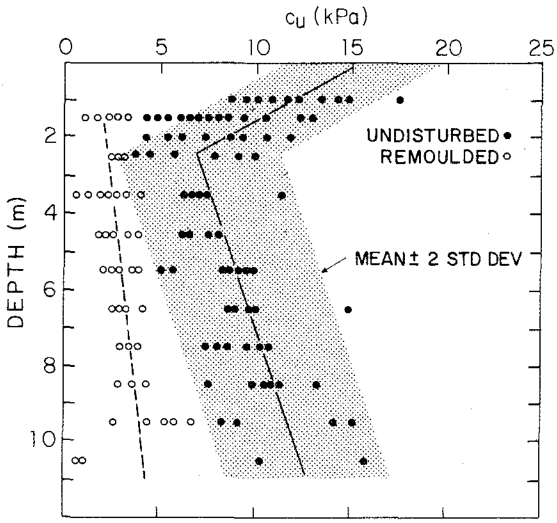

FIG. 7—*FV results from tests with the equipment that requires preboring.*

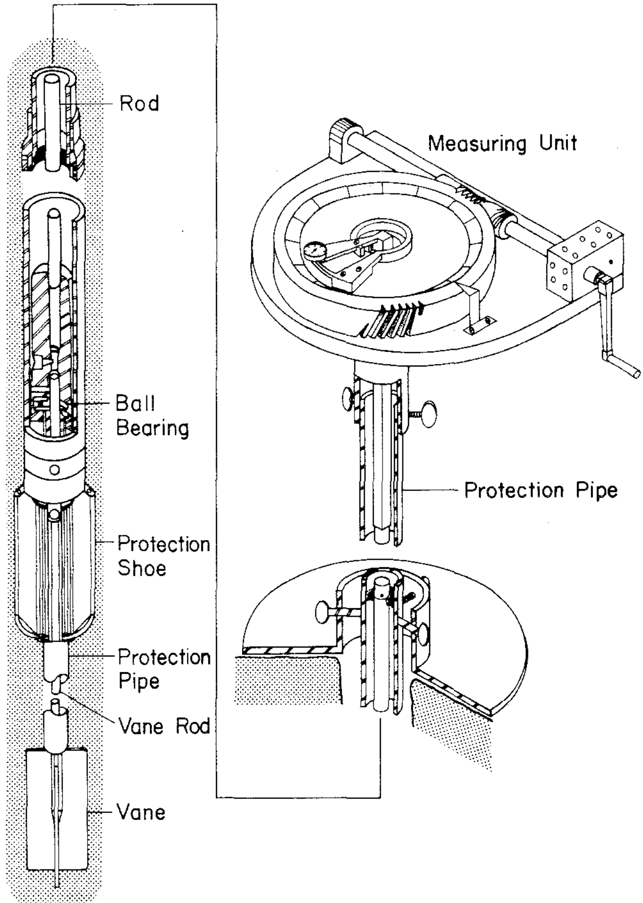

FIG. 8—*The vaneborer.*

Additionally, ball bearing spacers were provided to maintain clearance between the pipes and rods.

The lower part of the apparatus contained a protective shoe that accommodated a vane up to 130 mm long and 65 mm in diameter, protecting it during insertion by pushing the equipment into the soft ground.

A male-female cone-type clamp, apparently more effective than the one used by Cadling and Odenstad [*2*], was located in the lower part of the apparatus. This device enabled the rods to be kept in the upward position until the equipment reached the desired depth, when the rods were unlocked by a quick blow on their top and the vane was inserted 0.50 m into the clay. A 20-mm-diameter protective pipe was used to avoid any soil-rod friction with the 10-mm-diameter rod connected to the vane.

The readout unit was modified in order to sit directly on and to be attached to the protective pipe. A 300-mm-diameter footing provided with a central hole was attached to the protective pipe so as to keep the readout unit stable during the tests. Additionally, a more sensitive torque spring and a 1-μm deflection gage were fitted.

Vaneborer Calibrations

Calibrations carried out on the vaneborer consisted of field tests with and without the vane until it could be assured that the internal frictions were negligible. The readout unit was calibrated with several load-unload torque cycles, and the results, after simple statistical treatment, are summarized in Fig. 9, enabling a choice between a 50 by 100-mm or a 65 by 130-mm (diameter by height) vane, to select the calibration constant and to estimate the accuracy of the torque measurements.

For example, reading this figure with a c_u value of 20 kPa, a torque value of 20 Nm is obtained for the larger vane. This vane size is preferred because it led to a smaller error of less than 2% of the torques, as shown in the upper part of the figure. This chart also shows that for torques less than 7 Nm the error can be considerable and the spring element presents nonlinearity in its calibration constant. Therefore, it can be concluded that the minimum c_u that can be measured with a reasonable accuracy with the 65- by 130-mm vane is about 5 kPa.

Vaneborer Test Results

FVT data obtained with the vaneborer at 0.5-m-depth increments in six boreholes are plotted in Fig. 10. These data are compared with the previous series in Fig. 11 and have their statistical correlations presented in Tables 2 and 3. Figure 12 compares the sensitivities of the clay, that is, the ratio between the clay strength in the undisturbed state and after remolding with some 20 turns of the vane.

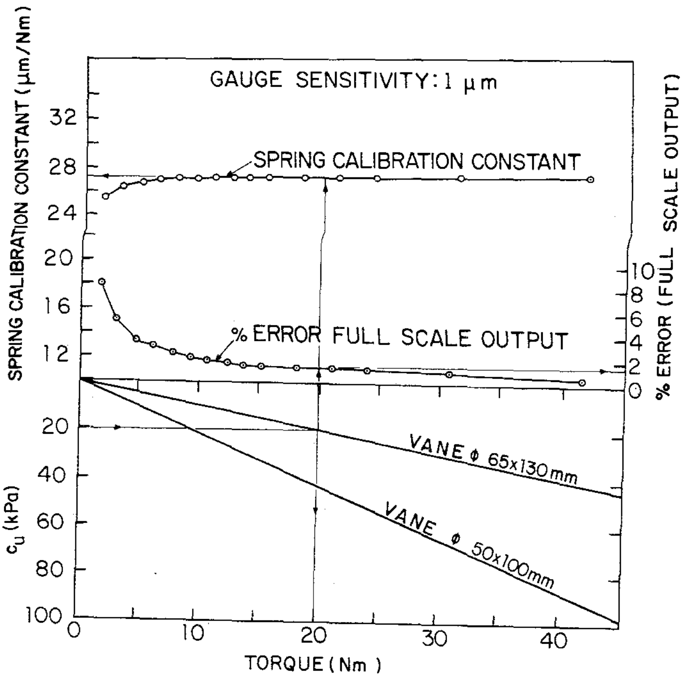

FIG. 9—*Readout unit calibration results.*

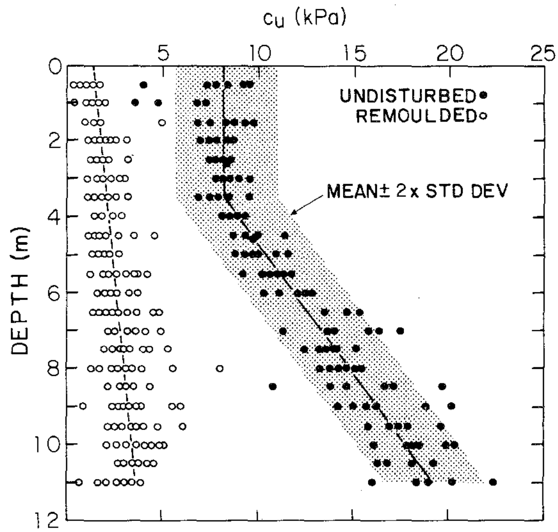

FIG. 10—*FVT results with the vaneborer.*

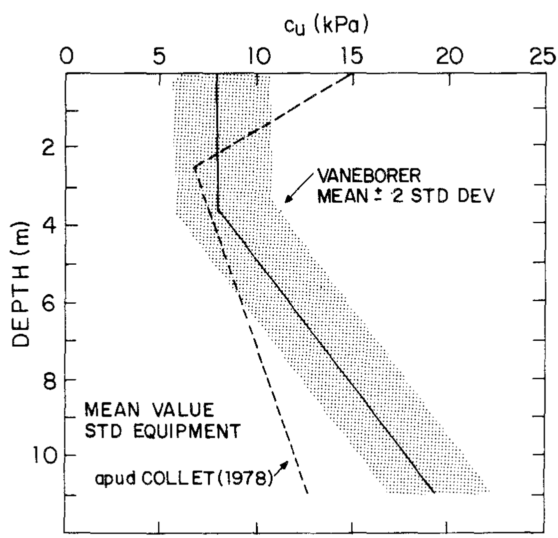

FIG. 11—*Comparison between FV profiles obtained with the vaneborer and with the preboring equipment.*

TABLE 2—*Correlations with the undisturbed test data.*

Equipment Type	Depth, m	Equation[a]	Coefficient of Correlation	Standard Error of Estimate, kPa
	upper crust			
Requiring preboring	$z \leqq 2.5$	$c_u = 15.3 + 4.0z$	0.58	2.46
	$z > 2.5$	$c_u = 4.97 + 0.69z$	0.59	2.15
	upper crust			
Vaneborer	$z \leqq 3.5$	$c_u = 7.36 + 0.19z$	0.107	1.35
	$z > 3.5$	$c_u = 3.00 + 1.48z$	0.913	1.53

[a] c_u = undrained strength, kPa, and z = depth, m.

TABLE 3—*Correlations with the remolded test data.*

Equipment Type	Equation[a]	Coefficient of Correlation	Standard Error of Estimate, kPa
Requiring preboring	$c_{ur} = 0.6 + 0.44z$	0.65	. . .
Vaneborer	$c_{ur} = 1.38 + 0.22z$	0.57	0.992

[a] c_{ur} = remolded undrained strength, kPa, and z = depth, m.

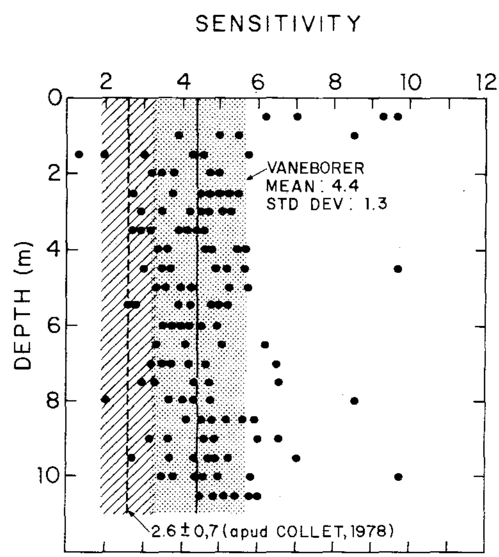

FIG. 12—*Comparison between sensitivity data obtained with the vaneborer and with the preboring equipment.*

of these three cases the organic content was low, around 5%, therefore not supporting this suggestion.

Conclusions

The FV equipment using an unprotected vane through a prebored hole is still used in Brazil and certainly in other countries. Results of the investigation carried out with it in the Rio de Janeiro clay showed that the soil-rod and internal frictions affected significantly the results and are difficult to eliminate.

A frictionless vaneborer device was built according to Cadling and Odenstad [2], leading to results showing less scattering of data. A new FV mean profile was obtained and evaluated in an analysis of an embankment failure in the same test site, yielding a safety factor very close to one at failure, therefore contradicting widely accepted FV strength corrections. The reasons for this are still being investigated.

Acknowledgments

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