Appendix E

VANE SHEAR TEST

The vane shear test (VST) is a moderately rapid and economical in-situ method for determining the peak and remolded undrained shear strength of soft to medium stiff clays. The test involves pushing a four-bladed vane into a clay stratum and slowly rotating it while measuring the resisting torque.

PROCEDURE

The procedure for the VST is described in ASTM D2573 (1). Important related issues are given elsewhere (2, 3, 4). The test generally is used to determine the shear strength of a cohesive soil once its location has been established. In the test, a shear vane similar to those shown in Figure E-1 is pushed into undisturbed soil and is rotated from the surface at a standard rate of 0.1 degrees per second. The peak

<table>
<thead>
<tr>
<th>Casing</th>
<th>Diameter, D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in.</td>
</tr>
<tr>
<td>AX</td>
<td>1.5</td>
</tr>
<tr>
<td>BX</td>
<td>2.0</td>
</tr>
<tr>
<td>NX</td>
<td>2.5</td>
</tr>
<tr>
<td>4 in. (102 mm)</td>
<td>3.625</td>
</tr>
</tbody>
</table>

Figure E-1. Vane Geometries and Sizes

torque which develops is related to the peak shear strength on a cylindrical failure surface by a constant, which is a function of the shape and dimensions of the vane. Details are given in ASTM D2573 (1). The VST may be conducted either at the bottom of a prebored hole or, in soft clays, by merely pushing the vane rods to the desired test depth. The latter method requires a correction for rod friction.

After the peak torque has been determined, the vane is rotated quickly about ten times to remold the soil. The torque then is measured again to determine the remolded shear strength. The sensitivity ($S_v$) may be calculated as the ratio of the peak to remolded strength. Numerous tests can be performed sequentially in the same deposit, but individual tests should be separated vertically by at least 0.75 m (30 in).

Another method of testing uses vane borers, as shown in Figure E-2. With the SOI device, the rods are surrounded by a sleeve to minimize friction losses, and the vane is covered by a protective shoe during penetration. At the desired test
depth, the vane is advanced into the soil beneath the protective shoe. The other device is the Nilcon vane borer, which does not have either a protective sleeve or shoe. However, the vane is followed by a slip coupling during penetration, which provides for rod friction calibration before each test.

The maximum measured torque (T) in the VST is used to calculate the undrained shear strength \( (s_u) \) as follows (1):

\[
s_u = \frac{T}{K} \tag{E-1}
\]

in which \( T \) = torque in N-m or lb-ft and \( K \) = constant depending on the dimensions and shape of the vane \( (m^3 \text{ or ft}^3) \), where:

\[
K = \pi(D^2H/2) \left[ 1 + \left( D/3H \right) \right] \quad \text{for } D \text{ and } H \text{ in meters} \tag{E-2}
\]

\[
K = \frac{\pi}{1728} \left( D^2H/2 \right) \left[ 1 + \left( D/3H \right) \right] \quad \text{for } D \text{ and } H \text{ in inches} \tag{E-3}
\]

A number of assumptions are made in calculating the undrained shear strength from these torque measurements (3), including:

- The soil is completely undrained, i.e., no consolidation takes place during insertion of the vane or during the test.
- No disturbance is caused by the boring operation or installation of the vane.
- The remolded zone around the vane is very small.
- There is no progressive failure so that the maximum applied torque overcomes the fully-mobilized shear strength along the cylindrical surface.
- Isotropic strength conditions exist in the soil mass.

ADVANTAGES AND DISADVANTAGES

The VST has many advantages when used in soil deposits for which it is intended. The test is moderately rapid and economical, and it is reproducible in homogeneous deposits. The scatter in test results is on the same order as that for the confined and unconfined compression tests with which it is compared. The test has had extensive usage during the past few decades, and a large body of literature is available for use in correlations with other test and design methods. The effect of the vane size is minor in most types of soil and, by using two vanes with different length to diameter ratios in the same stratum, the soil strength anisotropy
can be inferred. Additionally, the test is an inexpensive way to determine the properties of sensitive clays, which are characteristically difficult to obtain in the laboratory without extreme care.

The VST has a number of important limitations that influence its usefulness. The test is most easily interpreted for soft and medium stiff clays which have been previously identified by some other test or sampling procedure. Also, it is useful mainly for analyses requiring the undrained shear strength.

**Sources of Error, Reliability, and Cost**

The VST may be in error because of excessive rod friction, poor torque calibrations, non-standard rotation rates, and other factors (4, 5, 6). A list of the major sources of error with the VST is given in Table E-1.

In addition to these test uncertainties, the theoretical nature of the failure

| Table E-1
| MAJOR SOURCES OF ERROR IN THE VANE SHEAR TEST |

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
<th>Influence on Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction between torque rods and soil or casing</td>
<td>Measured torque includes spurious component of resistance</td>
<td>Increases</td>
</tr>
<tr>
<td>Poorly calibrated torque measurement</td>
<td>Inaccurate torque</td>
<td>Increases or decreases</td>
</tr>
<tr>
<td>Vane rotated too quickly</td>
<td>Soil sheared too rapidly</td>
<td>Increases</td>
</tr>
<tr>
<td>Test performed in disturbed soil</td>
<td>Soil structure broken down</td>
<td>Decreases</td>
</tr>
<tr>
<td>Damaged vane</td>
<td>Disturbed soil excessively</td>
<td>Decreases peak strength</td>
</tr>
<tr>
<td>Unknown sand/silt/shell lenses</td>
<td>Drainage during test</td>
<td>Increases</td>
</tr>
<tr>
<td>Isolated gravel/cemented nodules</td>
<td>Measured torque includes spurious component of resistance</td>
<td>Increases</td>
</tr>
</tbody>
</table>

Source: Adapted from Kulhawy, et al. (3), p. 5-34.
mechanism is not fully understood. Therefore, the correlation between field and laboratory measurements of the same soil contains a significant element of uncertainty. On the basis of published studies, the random variations between tests made in the same soil are much smaller than the uncertainties associated with the test procedure.

Vane shear tests are comparable in cost to the SPT, taking into account that both require a test boring. During an average shift, approximately 10 to 15 tests can be performed. Based on 1990 drilling costs, this indicates that the average cost of a VST is about $70 to $150. However, it should be noted that the VST can be alternated with the SPT in a single test boring to optimize the return of information from a single borehole.

REFERENCES


5 IN SITU TESTING

This section discusses the use of the field vane test (FVT) and the piezcone (CPTU) for the purpose of measuring spatial variations in undrained shear strength and stress history. It also evaluates the ability of these tests to obtain design values of \( s_u \) and OCR as opposed to only relative changes in these parameters.

5.1 Field Vane Test

**Testing Technique** The preferred approach for measuring \( s_u(FV) \) in medium to soft clays \((s_u \leq 50 \text{ kPa})\) has the following features.

- Equipment: four blades of 2 mm thickness with sharpened square ends, diameter \((d) = 50 \text{ to } 75 \text{ mm and height } (h) = 2d\); a gear system to rotate the vane and measure the torque (T); and the ability to account for rod friction. The SGI-Geonor device (designation H-10, wherein the vane head is encased in a sheath at the bottom of the casing and then extended to run a test) and the highly portable Nilonon device (wherein a rod pushes the vane into the ground) are recommended. The Acker (or similar) device with thick tapered blades which are rotated via a hand-held torque wrench is not recommended due to increased disturbance during insertion followed by shearing at a rate that is much too fast (failure in seconds rather than minutes).

- Procedure: push vane tip to at least 5 times \( d \) (or borehole diameter); after about one minute, rotate at \( 6^\circ/\text{min} \) to obtain the peak strength within several minutes; then rotate vane 10 times prior to measuring the remolded strength. Compute the peak and remolded strengths using

\[
s_u(FV) = \frac{T}{\pi \left( \frac{d^3 h}{2} + \frac{d^3}{6} \right)} = \frac{6T}{\pi d^3 h} \quad \text{(for } h = 2d) \quad (5.1)
\]

which assumes full mobilization of the same shear stress on both the top and sides of a cylindrical failure surface.

**Interpretation of Undrained Shear Strength.** It is well established that the measured \( s_u(FV) \) differs from the \( s_u(ave) \) appropriate for undrained stability analyses due to installation disturbances, the peculiar and complex mode of failure and the fast rate of shearing (e.g., Art. 20.5 of Terzaghi et al. 1996). Hence the measured values should be adjusted using Bjerrum's (1972) empirical correction factor \((\mu)\) vs. Plasticity Index derived from circular arc stability analyses of embankment failures \([\mu = 1/FS \text{ computed using } s_u(FV)]\). Figure 5.1 shows this correlation, the data used by Bjerrum and more recent case histories. The coefficient of variation (COV) ranges from about 20% at low PI to about 10% at high PI for *homogeneous* clays (however, Fig. 20.21 of Terzaghi et al. 1996 indicates COV \(\approx 20\%\) independent of PI). Note that the presence of shells and sandy zones can cause a large increase in \( s_u(FV) \), as shown by the "FRT" data point (very low \( \mu \) for a mud flat deposit).

Bjerrum's correction factor ignores three-dimensional end effects, which typically increase the computed FS by \( 10 \pm 5\% \) compared to plane strain (infinitely long) failures (Azzouz et al. 1983). Hence the \( \mu \) factor should be reduced by some 10% for field situations approaching a plane strain mode of failure or when the designer wants to explicitly consider the influence of end effects (see Section 7).

**Interpretation of Stress History.** Table VI and Fig. 8 of Jamiołkowski et al. (1985) indicate that the variation in \( s_u(FV)/\sigma'_{w0} \) with overconsolidation ratio can be approximated by the SHANSEP equation

\[
\frac{s_u(FV)}{\sigma'_{w0}} = S_{FV}(OCR)^{m_{FV}} \quad (5.2a)
\]

where \( S_{FV} \) is the NC undrained strength ratio for clay at OCR = 1. Chandler (1988) adopted Bjerrum's (1972) correlation between \( s_u(FV)/\sigma'_{w0} \) for OCR = 1 "young" clays vs. Plasticity Index and \( m_{FV} = 0.95 \) in order to predict OCR from field vane data, i.e.,

\[
OCR = \left( \frac{s_u(FV)/\sigma'_{w0}}{S_{FV}} \right)^{1.05} \quad (5.2b)
\]

Figure 5.2 compares measured values of \( S_{FV} \) and \( m_{FV} \) for ten sites having homogeneous clays (no shells or sand) and PI \(\approx 10\) to 60% with Chandler's proposed correlation. The agreement in \( S_{FV} \) is quite good (error \( = 0.024 \pm 0.017 \)), and excluding the three cemented Canadian clays (for which \( m_{FV} > 1 \)), \( m_{FV} = 0.89 \pm 0.08 \) compared to 1/1.05 = 0.95 selected by Chandler (1988). Less well documented experience suggests that Eq. 5.2b and Fig. 5.2 also yield reasonable predictions.
of OCR for highly plastic CH clays with PI > 60%. It is interesting to note that the decrease in $\mu$ and increase in $S_{FV}$ with PI vary such that $\mu S_{FV} = 0.21 \pm 0.015$ for PI > 20%, which is close to the 0.22 recommended by Mesri (1975) for clays with m near unity.

Figure 5.1 Field Vane Correction Factor vs. Plasticity Index Derived from Embankment Failures (after Ladd et al. 1977)

Figure 5.2 Field Vane Undrained Strength Ratio at OCR = 1 vs. Plasticity Index for Homogeneous Clays (no shells or sand) [data points from Lacasse et al. 1978 and Jamiolkowski et al. 1985]
Case History. Figure 5.3 shows the location of approach abutments with preload fills for two bridges that are part of a highway reconstruction project founded on 40 m of a varved to irregularly layered CH deposit in Northern Ontario. Construction of the preload fills started on the East side in early October, 2000. Massive failures occurred almost simultaneously at both abutments when the steeply sloped reinforced fill reached a thickness of about 4 m. The sliding mass extended to the opposite (West) bank of the river. The figure also shows the location of three preconstruction CPTU soundings and two borings (B95-9 and B97-12) with 75 mm push tube samples and FVT tests. Boring B01-8 on the West side was made after the failure, but before any filling, and did not include FVT tests. Subsequent discussion focuses on the upper 15 to 20 m of clay since it is most relevant to the stability and settlement of the preload fills.

![Figure 5.3 Location Plan of Bridge Abutments with Preload Fill and Preconstruction Borings and In Situ Tests](image)

Figure 5.3 Location Plan of Bridge Abutments with Preload Fill and Preconstruction Borings and In Situ Tests

Figure 5.4 presents summary plots of water contents, measured FVT strengths and stress history prepared by the first author, who was hired to investigate the failure by the design-build contractor. The clay has an average PI of about 50% and a Liquidity Index near unity. The two $s_v(FV)$ profiles on either side of the river are very similar, with an essentially linear increase with depth. The scatter is relatively small considering the fact that the tests were run with thick, Acker type blades and a torque wrench. However, the recorded sensitivity of only $S_t = 3 - 6$ is too low based on the high Liquidity Index of the clay. It is interesting to note that the two CPTU soundings on the West side predicted strengths some 25% and 80% higher than the one sounding on the East side, i.e., much larger differences than shown by the field vane data. The preconstruction site investigation included only two consolidation tests within the upper 15 m. The range in $\sigma_v'$ shown in Fig. 5.4 reflects uncertainty in the location of the break in the S-shaped compression curves because the tests doubled the load for each increment (LIR = 1).

Chandler's (1988) method was used with $S_{rv} = 0.28$ in Eq. 5.2b (for PI = 50%) to predict the variation in $\sigma_v'(FV)$ with depth. The results are plotted in Fig. 5.5 and show good agreement with the two lab tests. Because the agreement may have been fortuitous, and due to uncertainty in virgin compressibility and an appropriate design $s_v/\sigma_v'$ for the layered deposit, tube samples from boring B97-12 were sent to MIT for testing. The tubes were X-rayed and clay extruded using the cutting-debonding technique illustrated in Fig. 4.3 for several CRS consolidation and SHANSEP CKDU direct simple shear (DSS) tests. In spite of using 4-year old samples, the test results were of exceptional quality, e.g., see the CRS consolidation data in Fig. 6.5. Four values of $\sigma_v'$ from the MIT tests are plotted in Fig. 5.5, leading to the conclusion that the $\sigma_v'(FV)$ profiles were reasonable for virgin clay (Note: three DSS tests on NC clay gave $s_v/\sigma_v' = 0.205 \pm 0.004$ SD).

5.2 Piezocone Test

Testing Technique. Figure 5.6 illustrates the business end of a 10 to 20 metric ton capacity 60° piezocone having a base area of 10 cm² (15 cm² is less common), a base extension of $h_c = 5$ mm, a filter element of $h_f \approx 5$ mm to measure penetration pore pressures (denoted as $u_d$ for the filter located at the cylindrical extension of the cone), a dirt seal at the bottom of the friction sleeve and an O-ring to provide a water tight seal. A temperature compensated strain gage load cell measures the force ($Q_v$) required to penetrate the cone (cone resistance $q_c = Q_v/A_i$, $A_i$ = internal area of recessed top of cone) and a pressure transducer measures $u_d$. The porous filter element (typical pore size ≤ 200 μm) is usually plastic and filled with glycerin or a high viscosity silicon oil (ASTM D5778). Since the $u_d$ pressure acts around the recessed top rim of the cone, the corrected actual tip resistance is

$$q_c = q_d + u_d(1-a) \quad (5.3)$$

where $a$ = net area ratio = $A_i/A_{cone}$ (should approach 0.8, but may be only 0.5 or lower, and must be measured in a pressure vessel).
4. FIELD VANE SHEAR TEST (VST)

One of the objectives of this research is to correlate the high quality CRS laboratory results discussed in Section 3 with in situ methods so that the latter can be used in geotechnical evaluations. The field vane shear test (VST) is the most widely used method for estimation of the in-situ undrained shear strength of soft clays. In this report, the undrained shear strength of the Lake Bonneville clays was determined by using the VST and by a new method developed herein that uses the constant rate strain (CRS) consolidation test results.

4.1. Vane Shear Test Apparatus

The VST tests were performed using the University of Utah’s VST device manufactured by Geotech Inc. of Sweden. The VST device comes with an electrical control box for applying and recording the torque (torquemeter), a series of vanes and rod and a slip coupling (Figure 4.1). The extension rods are fed through the recording box to lower the vane to the appropriate test depth. The tapered vanes are of high quality nickel-chromium steel and are specially designed to penetrate the soil with minimal disturbance. Their maximum measuring range is 100 kPa for 65 x 130 mm vane and 200 kPa for 50 x 110 mm vane. When testing, the extension rod is coupled with the recording box by locking mechanism and thereafter the box rotates the vane.
4.2. Procedure

The vane testing was done in conjunction with hollow-stem auger drilling. The hollow stem was advanced to a depth approximately 0.3 m above the test interval. The vane was further advanced to the test depth by pushing the vane rods with the drill rig. For the testing, a rotation speed 0.1%/s was chosen, which is in the range suggested by ASTM standard D2573. The applied torque is measured with strain gauges, and the rotational angles are recorded every half of a degree. Once the yield point of the soil has been reached, the rotation of the vane is continued in order to characterize the soil’s strength at very large strain (i.e., residual strength).

In a second part of the test, the vane was released from the recording torquemeter and rotated clockwise ten times with a pipe wrench to completely remold the soil. As soon as thereafter, the torquemeter was once again locked onto the extension rods and the test was repeated to determine the soil’s remolded undrained shear strength. To aid in the interpretation of the test, the shape of the curve can be seen from a lap top computer, which is connected to the torquemeter (Figure 4.2).
Figure 4.1 Geotech Vane Shear Test System (Torquemeter)

Figure 4.2 Field Vane Shear Test
4.3. Field Vane Shear Test Results

An appropriate sized vane was selected based on the anticipated peak undrained shear strength for the soils encountered at the site. A large vane (65x130 mm) was used for the upper Lake Bonneville Clay and small vane (50x110 mm) was used for lower Bonneville Clay, which are little stiffer than the upper zone. Typical undisturbed and remolded vane shear test results from North Temple research site can be seen in Figures 4.3 and 4.4, respectively. Note that the first 23 degrees of rotation shown in the Figure 4.3 is due to rod friction only, before the vane has started to shear the soil. (The couple made by Geotech is intentionally made with a certain amount of rotational play so that the rod friction can be measured independently of the torque required to shear the soil. This is done so that the rod friction can be subtracted from the total torque to determine the part contributed by the soil’s shear strength).

![North Temple Site Vane Shear Test Result](image)

Figure 4.3 VST undisturbed shear strength results for N. Temple 1281.98m
Figure 4.4 VST remolded shear strength results for N. Temple 1281.98m

As shown by the Figures 4.3 and 4.4, the amount of torque required to turn the rods is first registered, then the total torque applied to both the rods and the vane until failure is registered. The difference between these values was used to calculate the shear strength of the soil. VST results were summarized in Table 4.1 and Figure 4.5. The complete set of VST test curves are presented in Appendix F.
Standard Test Method for
Field Vane Shear Test in Cohesive Soil

This standard is issued under the fixed designation D 2573; the number immediately following the designation indicates the year of
original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A
superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and
Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This method covers the field vane test in soft, satu-
rated cohesive soils. Knowledge of the nature of the soil in
which each vane test is to be made is necessary for
assessment of the applicability and interpretation of the test.

2. Summary of Method

2.1 The vane shear test basically consists of placing a
four-bladed vane in the undisturbed soil and rotating it from
the surface to determine the torsional force required to cause
a cylindrical surface to be sheared by the vane; this force is
then converted to a unit shear resistance of the cylindrical
surface. It is of basic importance that the friction of the vane
rod and instrument be accounted for; otherwise, the friction
would be improperly recorded as soil strength. Friction
measurements under no-load conditions (such as the use of a
blank stem in place of the vanes, or a vane that allows some
free rotation of the rod prior to loading) are satisfactory only
provided that the torque is applied by a balanced moment
that does not result in a side thrust. As torsional forces
become greater during a test, a side thrust in the instrument
will result in an increase in friction that is not accounted for
by initial no-load readings. Instruments involving side thrust
are not recommended. The vane rod may be of sufficient
rigidity that it does not twist under full load conditions;
otherwise a correction must be made for plotting torque-
rotation curves.

3. Apparatus

3.1 The vane shall consist of a four-bladed vane as
illustrated in Fig. 1. The height of the vane shall be twice the
diameter. Vane dimensions shall be as specified in Table I.
Sizes other than those specified in Table I shall be used only
with the permission of the engineer in charge of the boring
program. The ends of the vane may be tapered (see Fig. 1).
The penetrating edge of the vane blade shall be sharpened
having an included angle of 90°.

3.2 The vane shall be connected to the surface by means of
steel torque rods. These rods shall have sufficient diameter
such that their elastic limit is not exceeded when the vane is
stressed to its capacity (Note 1). They shall be so coupled
that the shoulders of the male and female ends shall meet to
prevent any possibility of the coupling tightening when the
torque is applied during the test. If a vane housing is used
the torque rods shall be equipped with well-lubricated
bearings where they pass through the housing. These be-
arings shall be provided with seals to prevent soil from enter-
ing them. The torque rods shall be guided so as to prevent
friction from developing between the torque rods and the
walls of casing or boring.

Note 1—If torque versus rotation curves are to be determined, it is
essential that the torque rods be calibrated (prior to use in the field). The
amount of rod twist (if any) must be established in degrees per foot per
unit torque. This correction becomes progressively more important as
the depth of the test increases and the calibration must be made at
or near to the maximum depth of testing anticipated.

3.3 Torque shall be applied to the torque rods, then to
the vane. The accuracy of the torque reading should be such
that it will produce a variation not to exceed ±0.25 lbf/ft2 (13
kPa) shear strength.

3.4 It is preferable to apply torque to the vane with a
gear drive. In the absence of a geared drive, it is acceptable
to apply the torque directly by hand with a torque wrench.

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1 This method is under the jurisdiction of ASTM Committee D-18 on Soil and
Rock and is the direct responsibility of Subcommittee D18.02 on Sampling and
Related Field Testing for Soil Investigations.

published as D 2573 - 67 T. Last previous edition D 2573 - 67 T.
### TABLE 1 Recommended Dimensions of Field Vanes

<table>
<thead>
<tr>
<th>Casing Size</th>
<th>Diameter, in. (mm)</th>
<th>Height, in. (mm)</th>
<th>Thickness of Blade, in. (mm)</th>
<th>Diameter of Vane Rod, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AX</td>
<td>1(\frac{1}{4}) (28.1)</td>
<td>3 (76.2)</td>
<td>(\frac{3}{4}) (1.9)</td>
<td>(\frac{3}{8}) (12.7)</td>
</tr>
<tr>
<td>BX</td>
<td>2 (50.8)</td>
<td>4 (101.6)</td>
<td>(\frac{3}{4}) (1.9)</td>
<td>(\frac{3}{8}) (12.7)</td>
</tr>
<tr>
<td>4 in. (101.6 mm)(^a)</td>
<td>2(\frac{1}{2}) (63.5)</td>
<td>5 (127.0)</td>
<td>(\frac{1}{4}) (0.3)</td>
<td>(\frac{1}{4}) (0.3)</td>
</tr>
<tr>
<td>4 in. (101.6 mm)(^b)</td>
<td>2(\frac{1}{2}) (63.5)</td>
<td>5 (127.0)</td>
<td>(\frac{1}{4}) (0.3)</td>
<td>(\frac{1}{4}) (0.3)</td>
</tr>
</tbody>
</table>

\(\text{\(^a\) Selection of the vane size is directly related to the consistency of the soil being tested, that is, the softer the soil the larger the vane diameter.}

\(\text{\(^b\) Inside diameter.}

---

### 4. Procedure

1. In the case where a vane housing is used, advance the housing to a depth which is at least five vane housing diameters less than the desired depth of the vane tip. Where no vane housing is used, stop the hole in which the vane is lowered at a depth such that the vane tip may penetrate undisturbed soil for a depth of at least five times the diameter of the hole.

2. Advance the vane from the bottom of the hole or the vane housing in a single thrust to the depth at which the test is to be conducted. Take precautions to make sure no torque is applied to the torque rods during the thrust.

3. With the vane in position, apply the torque to the vane at a rate which should not exceed 0.17/s. This generally requires a time to failure of from 2 to 5 min, except in very soft clays where the time to failure may be as much as 10 to 15 min. In stiff materials, which reach failure at small deformations, it may be desirable to reduce the rate of deformation so that a reasonable determination of the stress-strain properties can be obtained. During the rotation of the vane, hold it at a fixed elevation. Record the maximum torque. With apparatus with geared drives, it is desirable to record intermediate values of torque at intervals of 15 s or at lesser frequency if conditions require.

4. Following the determination of the maximum torque, remove the vane rapidly through a minimum of 10 revolutions; the determination of the remoulded strength should be started immediately after completion of rapid rotation and in all cases within 1 min after the remoulding process.

5. In the case where soil is in contact with the torque rod, the determination of the friction between the soil and the rod by means of torque tests conducted on similar rods at similar depths with no vane attached. Conduct the rod friction test at least once on each site; this shall consist of a series of tests at varying depths.

6. In apparatus in which the torque rod is completely isolated from the soil, conduct a friction test with a blank rod.

Note 2—In some cases it is not necessary to remove the vane for the test. As long as the vane is not in contact with the soil, that is, if it is retracted into the casing, the friction measurement is not affected.

Conduct undisturbed and remoulded vane tests at intervals of not less than 2\(\frac{1}{2}\) ft (0.76 m) throughout the soil profile when conditions permit vane testing (Note 3). Do not conduct the vane test in any soil that will permit drainage or dilates during the test period, such as sands or silts or in soils where stones or shells are encountered by the vane in such a manner as to influence the results.

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### 5. Calculation

5.1 Calculate the shear strength of the soil in the following manner: The turning moment required to shear the soil is as follows:

\[ T = s \times K \]

where:
- \(T\) = torque, lb\(\cdot\)ft (or N\(\cdot\)m),
- \(s\) = shear strength of the clay, lb/ft\(^2\) (or kPa), and
- \(K\) = constant, depending on dimensions and shape of the vane, ft\(^2\) (or m\(^2\)).

5.2 Assuming the distribution of the shear strength is uniform across the ends of a cylinder and around the perimeter, calculate the value of \(K\) as follows:

#### Inch-Pound Units:

\[ K = \left(\frac{\pi}{1728}\right) \times \left(\frac{D^2 H/2}{1 + D/3H}\right) \]

#### Metric Units:

\[ K = \left(\frac{\pi}{10^6}\right) \times \left(\frac{D^2 H/2}{1 + D/3H}\right) \]

where:
- \(D\) = measured diameter of the vane, in. (or cm), and
- \(H\) = measured height of vane, in. (or cm).

It is important that these dimensions are checked periodically to ensure the vane is not distorted or worn.

5.3 As the ratio of length to breadth of the vane is 2:1, the value of \(K\) may be simplified in terms of the diameter so that it becomes the following:

#### Inch-Pound Units:

\[ K = 0.0021D^3 \]

#### Metric Units:

\[ K = 0.00000366D^3 \]

5.4 Since the value of \(s\) is required, it is more useful to write the equation as follows:

\[ s = T \times \frac{1}{K} \]

where:
- \(k = 1/K\) and
- \(T\), the torque, is measured so that \(s\) can be calculated.

5.5 For the tapered vane of Fig. 1, the following modified equation may be used for the vane constant:

#### Inch-Pound Units:

\[ K = 1/1728 \times [sD^2 + 0.37 (2D^3 - d^3)] \]

#### Metric Units:

\[ K = 1/10^6 \times [sD^3 + 0.37 (2D^3 - d^3)] \]
where:
\( d \) = rod diameter, in. (cm). For a \( \frac{1}{2} \)-in. (1.27-cm) rod this reduces to:

**Inch-Pound Units:**
\[
K = 0.00225D^3 - 0.00003
\]

**Metric Units:**
\[
K = 0.00000388D^3 - 0.00000076
\]

6. Report

6.1 For each vane test record the following observations:

6.1.1 Date of the test,
6.1.2 Boring number,
6.1.3 Size and shape of the vane (tapered or rectangular),
6.1.4 Depth of the vane tip,
6.1.5 Depth of the vane tip below the housing or bottom of the hole,
6.1.6 Maximum torque reading, and intermediate readings if required for the undisturbed test,
6.1.7 Time to failure of the test,
6.1.8 Rate of remoulding,
6.1.9 Maximum torque reading for the remoulded test, and
6.1.10 Notes on any deviations from standard test procedure.

6.2 In addition, record the following observations for the boring:

6.2.1 Boring number,
6.2.2 Location,
6.2.3 Log of the soil conditions,
6.2.4 Reference elevation,
6.2.5 Method of making the hole,
6.2.6 Description of the vane, that is, housed or not,
6.2.7 Description of the method of applying and measuring the torque,
6.2.8 Notes on the driving resistance,
6.2.9 Name of the drilling foreman, and
6.2.10 Name of the supervising engineer.

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