- **Sliding Block Analogy**

  - When component of gravity acting parallel to inclined plane exceeds the frictional force resisting sliding, then the block will slide.

  - Force resisting sliding, \( F_s \)
    \[
    F_s = \mu N
    \]
    where \( \mu \) = coefficient of sliding
    \( N \) = normal force (acts perpendicular to the inclined plane)

- **Free Body Diagram**
- **Equilibrium**
  - y-direction
    
    \[ N - W \cos \theta = 0 \]
    \[ N = W \cos \theta \]
  - x-direction
    
    \[ F_s - W \sin \theta = 0 \]
    \[ F_s = W \sin \theta \]
    \[ \mu N = W \sin \theta \]
    \[ \mu = \frac{W \sin \theta}{N} \]
    \[ F_s = \mu N \text{ (previous page)} \]

    But \( \frac{W}{N} = \frac{\text{hypotenuse}}{\text{side adjacent}} = \frac{1}{\cos \theta} \)

    \[ \mu = \frac{\sin \theta}{\cos \theta} \]

    \[ \mu = \tan \theta \]

- **Direct Shear Test**
  - **Purpose**
    
    - To determine \( \mu \) for soil sliding upon soil
    - \( \mu \) is also called \( \phi \), which is the internal angle of friction

- **Test Apparatus**
- Direct Shear Test (cont.)
  
  * Test Data
    
    * Test 1
      
      \[ F \] vs \[ \delta \text{ (displacement)} \]
      
      \[ \text{Peak (F)} \]
    
    * Test 2 \( (N_2 > N_1) \) (increase normal stress)
      
      \[ F \] vs \[ \delta \]
      
      \[ \text{Peak (F)} \]
    
    * Test 3 \( (N_3 > N_2) \)
      
      \[ F \] vs \[ \delta \]
      
      \[ \text{Peak (F)} \]
- Direct Shear Test (cont)
  - Plotting of Test Data to Determine $\mu$ (or $\phi$)

\[ F \quad F_1 \quad F_2 \quad F_3 \]

\[ \mu, \phi \]

Best fit line through origin $(0,0)$

$\mu$ or $\phi$ (in degrees) is equal to the arc tangent of the slope of the best-fit line.
Subject: Direct Shear Test (DST)  
By: S. Bartlett  
Checked By:  
Date: 4/17/2000  

**Diagram: Direct Shear Box**

- **N** = applied load normal to box
- **τ** = applied stress \((N/A)\) where: \(A\) = area of specimen
- **τ** = shear stress
- **F** = tensile force
- **ΔH** = change in height of specimen
- **δ** = horizontal deformation

**Advantages**
- Inexpensive
- Fast
- Simple
- Good for determining sliding resistance

**Disadvantages**
- Only suitable for drained conditions (i.e., granular soils or cohesive soils sheared slowly)
- Predetermined failure plane (not necessarily weakest)
- Stress concentrations at sample boundaries
- Uncontrolled rotation of principal stresses
**Direct Shear Test Results**

\[ \tau = \frac{E}{A} \]

\[ \n_{(0)} = \frac{N_1}{A} \]

\[ \n_{(1)} = \frac{N_2}{A} \]

\[ \n_{(2)} = \frac{N_3}{A} \]

\[ \Delta H / \delta \]

\[ \phi \]

Mohr Diagram
Determination of Principal Axis for Direct Shear Test

Initial conditions (before shearing)

\[ \frac{\tau_0}{\tau_n} = V_0 = V_n \]

\[ V = K_0 V_0 = V_{30} \]

At failure

Note: Slight rotation of \( \tau_i \) and \( \tau_s \) during shear

see p. 461 Holze & Kodač

see also p. 463 Holze & Kodač


\[ A_c = \text{Area corrected} = \text{Area of active shear} \]

\[ A_0 = \text{Initial area} = \text{length x width of box} \]

\[ A_0 = \lambda \times w \]

\[ A_c = (\lambda - S)(w) \]

**Example**

\[ \lambda = 76 \text{ mm} \]
\[ F = 356 \text{ N} \]
\[ N = 2.25 \text{ kN} \]
\[ w = 76 \text{ mm} \]
\[ S = 0.07 \text{ mm} \]

Find

\[ V, T \] for \( S = 0.07 \text{ mm} \)

\[ V = \frac{N}{A_c} = \frac{2.25 \text{ kN}}{(76 \text{ mm})(76 \text{ mm} - 0.07 \text{ mm})} = 0.0004 \text{ kN/mm}^2 \]

\[ T = \frac{F}{A_0} = \frac{356 \text{ N}}{(76 \text{ mm})(76 - 0.07 \text{ mm})} = 61.63 \text{ kN/m}^2 \]
Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions

This standard is issued under the fixed designation D 3080; 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 superscripted (c) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the consolidated drained shear strength of a soil material in direct shear. The test is performed by deforming a specimen at a controlled strain rate on or near a single shear plane determined by the configuration of the apparatus. Generally, three or more specimens are tested, each under a different normal load, to determine the effects upon shear resistance and displacement, and strength properties such as Mohr strength envelopes.

1.2 Shear stresses and displacements are nonuniformly distributed within the specimen. An appropriate height cannot be defined for calculation of shear strains. Therefore, stress-strain relationships or any associated quantity such as modulus, cannot be determined from this test.

1.3 The determination of strength envelopes and the development of criteria to interpret and evaluate test results are left to the engineer or office requesting the test.

1.4 The results of the test may be affected by the presence of soil or rock particles, or both, (see Section 7).

1.5 Test conditions including normal stress and moisture environment are selected which represent the field conditions being investigated. The rate of shearing should be slow enough to ensure drained conditions.

1.6 The values stated in inch-pound units are to be regarded as the standard. Within this test method the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of each other.

1.7 This standard does not purport to address all safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D 422 Method for Particle-Size Analysis of Soils
D 653 Terminology Relating to Soil, Rock, and Contained Fluids
D 698 Test Methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 5.5 lb (2.49 kg)

Rammer and 12-in. (305 mm) Drop
D 5854 Test Method for Specific Gravity of Soils
D 1557 Test Methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 10-lb (4.54 kg) Rammer and 18-in. (457 mm) Drop
D 1587 Practice for Thin-Walled Tube Sampling of Soils
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil Aggregate Mixtures
D 2435 Test Method for One Dimensional Consolidation Properties of Soils
D 2487 Test Method for Classification of Soils for Engineering Purposes
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
D 4220 Practices for Preserving and Transporting Soil Samples
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D 4753 Specifications for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing

3. Terminology

3.1 Definitions—For definitions of terms used in this test method, refer to Terminology D 653.

3.2 Description of Terms Specific to This Standard:

3.2.1 Relative lateral displacement—the horizontal displacement of the top and bottom shear box halves.

3.2.2 Failure—the stress condition at failure for a test specimen. Failure is often taken to correspond to the maximum shear stress attained, or the shear stress at 15 to 20 percent relative lateral displacement. Depending on soil behavior and field application, other suitable criteria may be defined.

4. Summary of Test Method

4.1 This test method consists of placing the test specimen in the direct shear device, applying a predetermined normal stress, providing for wetting or draining of the test specimen, or both, consolidating the specimen under the normal stress, unlocking the frames that hold the test specimen, and displacing one frame horizontally with respect to the other at a constant rate of shearing deformation and measuring the shearing force and horizontal displacements as the specimen is sheared (Fig. 1).

5. Significance and Use

5.1 The direct shear test is suited to the relatively rapid determination of consolidated drained strength properties...
because the drainage paths through the test specimen are short, thereby allowing excess pore pressure to be dissipated more rapidly than with other drained stress tests. The test can be made on all soil materials and undisturbed, remolded, or compacted materials. There is however, a limitation on maximum particle size (see 7.2).

5.2 The test results are applicable to assessing strength in a field situation where complete consolidation has occurred under the existing normal stresses. Failure is reached slowly under drained conditions so that excess pore pressures are dissipated. The results from several tests may be used to express the relationship between consolidation stress and drained shear strength.

5.3 During the direct shear test, there is rotation of principal stresses, which may or may not follow field conditions. Moreover, failure may not occur on the weak plane since failure is forced to occur on or near a horizontal plane at the middle of the specimen. The fixed location of the plane in the test can be an advantage in determining the shear resistance along recognizable weak planes within the soil material and for testing interfaces between dissimilar materials.

5.4 Shear stresses and displacements are nonuniformly distributed within the specimen, and an appropriate height is not defined for calculating shear strains or any associated engineering quantities. The slow rate of displacement provides dissipation of excess pore pressures, but it also permits erosion of soil particles. Care should be taken to ensure that the testing conditions represent those conditions being investigated.

5.5 The range in normal stresses, rate of shearing, and vertical test conditions should be selected to approximate the soil conditions being investigated.

4. Apparatus

6.1 Shear Device—a device to hold the specimen securely between two porous inserts in such a way that torque is not applied to the specimen. The shear device shall provide means of applying a normal stress to the faces of the specimen, for measuring change in thickness of the specimen, for permitting drainage of water through the porous inserts at the top and bottom boundaries of the specimen, and for submerging the specimen in water. The device shall be capable of applying a shear force to the specimen in water. The device shall be capable of applying a shear force to the specimen along a predetermined shear plane (single shear) parallel to the faces of the specimen. The frames that hold the specimen shall be sufficiently rigid to prevent their distortion during shearing. The various parts of the shear device shall be made of material not subject to corrosion by moisture or substances within the soil, for example, stainless steel, bronze, or aluminum, etc. Dissimilar metals, which may cause galvanic action, are not permitted.

6.2 Shear Box, a shear box, either circular or square, made of stainless steel, bronze, or aluminum, with provisions for drainage through the top and bottom. The box is divided vertically by a horizontal plane into two halves of equal thickness which are fitted together with alignment screws. The shear box is also fitted with gap screws, which control the space (gap) between the top and bottom halves of the shear box.

6.3 Porous Inserts, porous inserts function to allow drainage from the soil specimen along the top and bottom boundaries. They also function to transfer horizontal shear stress from the insert to the top and bottom boundaries of the specimen. Porous inserts shall consist of silicon carbide, aluminum oxide, or metal which is not subject to corrosion by soil substances or soil moisture. The proper grade of insert depends on the soil being tested. The permeability of the insert should be substantially greater than that of the soil, but should be textured fine enough to prevent excessive intrusion of the soil into the pores of the insert. The diameter or width of the top porous insert or plate shall be 0.01 to 0.02 in. (0.2 to 0.5 mm) less than that of the inside of the ring. If the insert functions to transfer the horizontal stress to the soil, it must be sufficiently coarse to develop interlock. Sandblasting or tallowing the insert may help, but the surface of the insert should not be so irregular as to cause substantial stress concentrations in the soil.

Note 1—Exact criteria for insert texture and permeability have not been established. For normal soil testing, medium grade inserts with a permeability of about 0.5 to 1.0 × 10⁻³ ft/yr (5.0 × 10⁻⁷ to 1.0 × 10⁻⁶ cm/s) are appropriate for testing silts and clays, and coarse grade inserts with a permeability of about 0.5 to 1.0 × 10⁻² ft/yr (0.05 to 0.10 cm/s) are appropriate for sands. It is important that the permeability of the porous insert is not reduced by the collection of soil particles in the pores of the insert; hence frequent checking and cleaning (by flushing and boiling, or by ultrasonic cleaning) are required to ensure the necessary permeability.

6.4 Loading Devices:

6.4.1 Device for Applying and Measuring the Normal Force—The normal force is applied by a lever loading yoke which is activated by dead weights (masses) or by a pneumatic loading device. The device shall be capable of maintaining the normal force to within ±1 percent of the specified force quickly without exceeding it.

6.4.2 Device for Shearing the Specimen—The device shall be capable of shearing the specimen at a uniform rate of displacement, with less than ±5 percent deviation, and should permit adjustment of the rate of displacement from 0.0001 to 0.04 in./min (0.0025 to 1.0 mm/min). The rate to be applied depends upon the consolidation characteristics of the soils (see 9.12.1). The rate is usually maintained with an electric motor and gear box arrangement and the shear force is determined by a load indicating device such as a proving ring or load cell.

6.4.3 The weight of the top shear box should be less than 1 percent of the applied normal force: this may require that the top shear box be modified and supported by counter force.

Note 2—Shearing the test specimen at a rate greater than specified may produce partially drained shear results that will differ from the drained strength of the material.
6.5 **Shear force measurement device**—A proving ring or load cell accurate to 0.5 lbf (2.5 N), or 1 percent of the shear force at failure, whichever is greater.

6.6 **Shear box bowl**—A metallic box which supports the shear box and provides either a reaction against which one half of the shear box is restrained, or a solid base with provisions for aligning one half of the shear box, which is free to move coincident with applied shear force in a horizontal plane.

6.7 **Controlled High Humidity Room**, if required, for preparing specimens, such that water content gain or loss during specimen preparation is minimized.

6.8 **Trimmer or Cutting Ring**, for trimming oversized samples to the inside dimensions of the shear box with a minimum of disturbance. An exterior jig may be needed to maintain the shear box alignment.

6.9 **Balances**—in accordance with Test Method D 2216.

6.10 **Deformation Indicators**—Either dial gauges or displacement transformers capable of measuring the change in thickness of the specimen, with a sensitivity of at least 0.0001 in. (0.0025 mm) and to measure horizontal displacement with sensitivity of at least 0.001 in. (0.025 mm).

6.11 **Apparatus for Determination of Water Content**, as specified in Test Method D 2216.

6.12 **Equipment for Remolding or Compacting Specimens**, if applicable.

6.13 **Miscellaneous Equipment**, including timing device with a second hand, distilled or deionized water, spatulas, knives, straightedge, wire saws, etc., used in preparing the specimen.

### 7. Test Specimen

7.1 The sample used for specimen preparation should be sufficiently large so that a minimum of three similar specimens can be prepared. Prepare the specimens in a controlled temperature and humidity environment to minimize moisture loss or gain.

7.1.1 Extreme care should be taken in preparing undisrupted specimens of sensitive soils to prevent disturbance to the natural soil structure. Determine the initial mass of the wet specimen for use in calculating the initial water content and unit weight of the specimen.

7.2 The minimum specimen diameter for circular specimens, or width for square specimens, shall be 2.0 in. (50 mm), or not less than 10 times the maximum particle size diameter, whichever is larger, and conform to the width to thickness ratio specified in 7.4.

7.3 The minimum initial specimen thickness shall be 0.5 in. (12 mm), but not less than six times the maximum particle diameter.

7.4 The minimum specimen diameter to thickness or width to thickness ratio shall be 2:1.

Note 3—If large soil particles are found in the soil after testing, a particle size analysis should be performed in accordance with Method D 422 to conform to the visual observations, and the result should be provided with the test report.

7.5 **Specimen Preparation**:

7.5.1 **Undisturbed specimens**—Prepare undisrupted specimens from large undisturbed samples or from samples secured in accordance with Practice D 1587, or other undisrupted tube sampling procedures. Undisturbed samples shall be preserved and transported as outlined for Group C or D samples in Practice D 4220. Handle specimens carefully to minimize disturbance, changes in cross section, or loss of water due to evaporation. If compactness of a type of soil is of concern, the disturbance would be exacerbated by the evulsion device, the sample tube lengthwise or cut it off in small sections to facilitate removal of the specimen with minimum disturbance. Prepare trimmed specimens, whenever possible, in a manner so that the entire specimen will minimize the gain or loss of specimen moisture.

Note 4—A controlled high-humidity room is desirable for the purpose.

7.5.2 **Compacted specimens**—Specimens shall be prepared using the compaction method, water content, and unit weight prescribed by the individual assigning the test. Assemble and secure the shear box. Place a moist porous insert in the bottom of the shear box. Specimens may be molded by either kneading or tamping each layer until the cumulative mass of soil placed in the shear box is compacted to a known volume, or by adjusting the number of layers, the number of tamps per layer, and the force per tamp. The top of each layer shall be scarified prior to the addition of material for the next layer. The compacted layer boundaries should be positioned so they are not coincident with the shear plane defined by the shear box halves, unless this is the stated purpose for a particular test. The tamper used to compact the material shall have an area in contact with the soil equal to or less than 3/2 the area of the mold. Determine the mass of wet soil required for a single compacted lift and place it in the shear box. Compact the soil until the desired unit weight is obtained. Continue placing and compacting soil until the entire specimen is compacted.

Note 5—A light coating of grease applied to the inside of the shear box may be used to reduce friction between the specimen and the shear box during consolidation. However, the upper ring in some shear devices requires friction to support the ring after the shear plates have been gapped. A light coating of grease applied between the halves of the shear box may be used to reduce friction between the halves of the shear box during shear. TFE-fluorocarbon coating may also be used on these surfaces instead of grease to reduce friction.

Note 6—The required thickness of the compacted lift may be determined by directly measuring the thickness of the lift, or from the marks on the tamping rod which correspond to the thickness of the lift being placed.

Note 7—The decision to dampen the porous inserts by inundating the shear box before applying the normal force depends on the problem under study. For undisturbed samples obtained below the water table, the porous inserts are usually dampened. For swelling soils, the sequence of consolidation, wetting, and shearing should model field conditions. Determine the compacted mass of the specimen from either the measured mass placed and compacted in the mold, or the difference between the mass of the shear box and compacted specimen and the tare mass of the shear box.

7.6 Material required for the specimen shall be batched by thoroughly mixing soil with sufficient water to produce the desired water content. Allow the specimen to stand prior to compaction in accordance with the following guidance:

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum Standing Time</th>
<th>No Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>SP</td>
<td>SC, ML, CL</td>
<td>18</td>
</tr>
<tr>
<td>SM</td>
<td>MH, CH</td>
<td>36</td>
</tr>
</tbody>
</table>

7.7 Compressed specimens may also be prepared by comp-
sectioning soil using the procedures and equipment used to
terminate moisture-density relationships of soils (Test
methods D 698 or D 1557), and trimming the direct shear
specimen from the larger test specimen as though it were
a undisturbed specimen.

Calibration
8.1 The calibration is to determine the deformation of the
apparatus when subject to the consolidation load, so that for
which normal consolidation load the apparatus deflection may
be subtracted from the observed deformations. Therefore,
only deformation due to sample consolidation will be
recorded for complete tests. Calibration for the equipment
and deformation characteristics need to be performed on
the apparatus when first placed in service, or when apparatus
sets are changed.
8.2 Assemble the direct-shear device with a metal calibration
disk or plate of a thickness approximately equal to the
desired test specimen and about 1/4 in. (5 mm) smaller in
diameter or width.
8.3 Position the normal displacement indicator. Adjust
as indicator so that it can be used to measure either
consolidation or swell from the calibration disk or plate
reading. Record the zero or "no load" reading.
8.4 Apply increments of normal force up to the equip-
ment limitations, and record the normal displacement indi-
cator readings and normal force. Remove the applied normal
tree in reverse sequence of the applied force, and record
the normal displacement indicator readings and normal force.
Average the values and plot the load deformation of the
apparatus as a function of normal load. Retain the results for
future reference in determining the thickness of the test
specimen and compression within the test apparatus itself.
8.5 Remove the calibration disk or plate.
Note 8—Other methods of proven accuracy for calibrating the
apparatus are acceptable.
1. Procedures
9.1 Assemble the shear box.
9.1.1 Undisturbed Specimen—Place moist porous inserts
over the exposed ends of the specimen in the shear box; place
the shear box containing the undisturbed specimen and
porous inserts into the shear box bowl and attach the shear
box.
Note 9—For some apparatus, the top half of the shear box is held
in place by a notched rod which fits into a receptacle in the top half of
the shear box. The bottom half of the shear box is held in place in the shear
box bowl retaining bolts. For some apparatus, the top half of the shear
box is held in place by an anchor plate.
9.1.2 Compacted Specimen—Place the shear box con-
aining the compacted specimen and porous inserts into the
shear box bowl and attach the shear box.
9.2 Connect and adjust the shear force loading system so
that no force is imposed on the load measuring device.
9.3 Properly position and adjust the horizontal displace-
ment measurement device used to measure shear displace-
ment. Obtain an initial reading or set the measurement
device to indicate zero displacement.
9.4 Place a moist porous insert and load transfer plate on
the top of the specimen in the shear box.
9.5 Place the normal force loading yoke into position and
adjust it so the loading bar is horizontal. For dead load lever
loading systems, level the lever. For pneumatic loading
systems, adjust the yoke until it sits snugly against the recess
in the load transfer plate, or place a ball bearing on the load
transfer plate and adjust the yoke until the contact is snug.
9.6 Apply a small normal load to the specimen. Verify
that all components of the loading system are seated and
aligned. The top porous insert and load transfer plate must
be aligned so that the movement of the load transfer plate
into the shear box is not inhibited. Record the applied
vertical load and horizontal load on the system.
Note 10—The normal stress applied to the specimen should be
approximately 1 lb/in.² (7 kPa).
9.7 Adjust and adjust the vertical displacement measure-
ment device. Obtain initial reading for the vertical measure-
ment device and a reading for the horizontal displacement
measurement device.
9.8 If required, fill the shear box with water, and keep it
full for the duration of the test.
9.9 Calculate and record the normal force required to
achieve the desired normal stress or increment thereof.
Apply the desired normal stress by adding the appropriate
mass to the lever arm hanger, or by increasing the pneumatic
pressure.
Note 11—The normal force used for the specimen will depend
upon the data required. Application of the normal force in an increment may
be appropriate for relatively firm soils. For relatively soft soils, applica-
tion of the normal force in several increments may be necessary to
prevent damage to the specimen.
9.10 Apply the desired normal load or increments thereof
to the specimen and begin recording the normal deformation
readings against elapsed time. For all load increments, verify
completion of primary consolidation before proceeding (see
Test Method D 2435). Plot the normal displacement versus
either log of time or square root of time (in min).
9.11 After primary consolidation is completed, remove
the alignment screws or pins from the shear box. Open the
gap between the shear box halves to approximately 0.025 in.
(0.64 mm) using the gap screws. Back out the gap screws.
Note 12—There may be instances when the gap between the
plates should be increased to accommodate sand sizes greater than the
specified gap. Presently there is insufficient information available for
specifying gap dimension based on particle size distribution.
9.12 Shear the specimen.
9.12.1 Select the appropriate displacement rate. Shear the
specimen at a relatively slow rate so that no excess pore
pressure would exist at failure. The following equation shall
be used as a guide to determine the estimated minimum time
required from the start of the test to failure:
where:
\[
\tau_f = 50\tau_0
\]

\[
\tau_f = \text{total estimated elapsed time to failure, min,}
\]

\[
\tau_0 = \text{time required for the specimen to achieve 50 percent
consolidation under the specified normal stress (or increments thereof), min.}
\]

Note 13—If the normal displacement versus square root of time
used, \(\tau_0\), can be calculated from the time to complete 90% consola-
dation using the following expression:

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where:

\[ t_{50} = \frac{t_{90}}{4.28} \]

where: 

\( t_{50} \) = time required for the specimen to achieve 90 percent consolidation under the specified normal stress (or increment thereof), min.

4.28 = constant, relates displacement and time factors at 50 and 90 percent consolidation.

Note 14—If the material exhibits a tendency to swell, the soil must be remolded with water added to the specimen to keep the swell tendency before the minimum time to failure can be determined. The time-consolidation curve for subsequent normal stress increments are then valid for use in determining \( t_{50} \).

Note 15—Some soils, such as dense sands and over consolidated clays, may exhibit a well defined time-settlement curve. Consequently, the calculation of \( t_{50} \) may produce an inappropriate estimate of the time required to fail the specimen under drained conditions. For over consolidated clays which are tested under normal stresses less than the soil's pre-consolidation pressure, it is suggested that a time to failure be estimated using a value of \( t_{90} \) equivalent to one obtained from normal consolidation time-settlement behavior. For clean dense sands which drain quickly, a value of 10 min may be used for \( t_{50} \). For dense sands with more than 5% fines, a value of 60 min may be used for \( t_{50} \). If an alternative value of \( t_{50} \) is selected, the rationale for the selection shall be explained with the test results.

9.13 Determine the appropriate displacement from the following equation:

\[ d_i = d_j / t_j \]

where:

\( d_i \) = displacement rate (in./min, mm/min),

\( d_j \) = estimated horizontal displacement at failure (in., mm),

\( t_j \) = total estimated elapsed time to failure, min.

Note 16—The magnitude of the estimated displacement at failure is dependent on many factors including the type and initial stress history of the soil. As a guide, use \( d_j = 0.5 \) in. (12 mm) if the material is normally or lightly over consolidated fine-grained soil, otherwise use \( d_j = 0.2 \) in. (5 mm).

9.13.1 Select and set the displacement rate—For some types of apparatus, the displacement rate is achieved using combinations of gear wheels and gear lever positions. For other types the displacement rate is achieved by adjusting the motor speed.

9.13.2 Record the initial time, vertical and horizontal displacements, and normal and shear forces.

9.13.3 Start the apparatus and initiate shear.

9.13.4 Obtain data readings of time, vertical and horizontal displacement, and shear force at desired interval of displacement. Data readings should be taken at displacement intervals equal to 2 percent of the specimen diameter or width to accurately define a shear stress-displacement curve.

Note 17—Additional readings may be helpful in identifying the value of peak shear stress of over consolidated or brittle material.

Note 18—It may be necessary to stop the test and re-gap the shear box halves to maintain clearance between the shear box halves.

9.13.5 After reaching failure, stop the test apparatus. This displacement may range from 10 to 20 percent of the specimen's original diameter or length.

9.13.6 Remove the normal force from the specimen by removing the mass from the lever and hanger, or by releasing the pressure.

9.14 For cohesive test specimens, separate the shear box halves with a sliding motion along the failure plane. Do not pull the shear box halves apart perpendicularly to the failure surface, since it would damage the specimen. Photograph, sketch, or described in writing the failure surface. This procedure is not applicable to cohesionless specimens.

9.15 Remove the specimen from the shear box and determine its water content according to Test Method D2216.

9.16 Calculate and plot the following:

9.16.1 Nominal shear stress versus relative lateral displacement.

10. Calculation

10.1 Calculate the following:

10.1.1 Nominal shear stress, acting on the specimen is, 

\[ \tau = \frac{F}{A} \]

where:

\( \tau \) = nominal shear stress (lb/in.\(^2\), kPa),

\( F \) = shear force (lbf, N),

\( A \) = initial area of the specimen (in.\(^2\), mm\(^2\)).

10.1.2 Normal stress acting on the specimen is,

\[ \sigma_n = \frac{N}{A} \]

where:

\( \sigma_n \) = normal stress (lb/in.\(^2\), kPa),

\( N \) = normal vertical force acting on the specimen (lbf, N).

Note 19—Factors which incorporate assumptions regarding the actual specimen surface area over which the shear and normal forces are measured can be applied to the calculated values of shear or normal stress, or both. If a correction(s) is made, the factor(s) and rationale for using the correction shall be explained with the test results.

10.1.3 Displacement rate—Calculate the actual displacement rate by dividing the relative lateral displacement by the elapsed time, or report the rate used for the test.

\[ d_i = \frac{d_a}{t_e} \]

where:

\( d_i \) = displacement rate (in./min, mm/min),

\( d_a \) = relative lateral displacement (in./mm),

\( t_e \) = elapsed time of test (min).

10.1.4 Compute the initial void ratio, water content, dry unit weight and degree of saturation based on the specific gravity, and mass of the total specimen. Specimen volume is determined by measurements of the shear box lengths or diameter and of the measured thickness of the specimen.

11. Report

11.1 The report shall include the following:

11.1.1 Sample identification, project and location.

11.1.2 Description of type of shear device used in test.

11.1.3 Description of appearance of the specimen, based on Practice D2488 (Test Method C2487 may be used as an alternative), Atterberg limits (Test Method D4318), and grain size data (Method D422), if obtained (see 7.4).

11.1.4 Description of soil structure, that is whether the specimen is undisturbed, remolded, compacted, or otherwise prepared.

11.1.5 Initial and final water content.
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Special loading sequence or special testing requirements.

12. Provision and Bias

12.1 Provision and Bias

12.1.1 A loading sequence is being evaluated to determine the performance of the data. The test method is the standard test method. Therefore, that cannot be determined.

13. Keywords

13.1 compacted specimens; consolidated; direct-shear tests; standard conditions; Mohr strength envelope; shear strength; undrained shear strength.