APPENDIX IX:

DRAINED (S) DIRECT SHEAR TEST

1. INTRODUCTION. The direct shear test is used to measure the shear strength of a soil under drained conditions. In this test, a relatively thin, square specimen of soil is placed in a rigid box that is divided horizontally into two frames, the specimen is confined under a vertical or normal stress, and a horizontal force is applied so as to fail the specimen along a horizontal plane at its midheight. Generally, a minimum of three specimens, each under a different normal stress, are tested to establish the relation between shear strength and normal stress. The magnitude of the normal stresses used depends on the range of stresses anticipated for design. Because of the difficulties involved in controlling drainage of the soil specimen during the direct shear test, only the drained (S) test method, in which complete consolidation is permitted under each increment of normal and shear stress, shall be used.

2. APPARATUS. The apparatus should consist of the following:

a. Shear box, of bronze or stainless steel, open at the top and divided horizontally into two frames that can be fitted together accurately with alignment pins and elevating screws. A schematic diagram of a direct shear box is shown in Figure 1. The lower frame of the

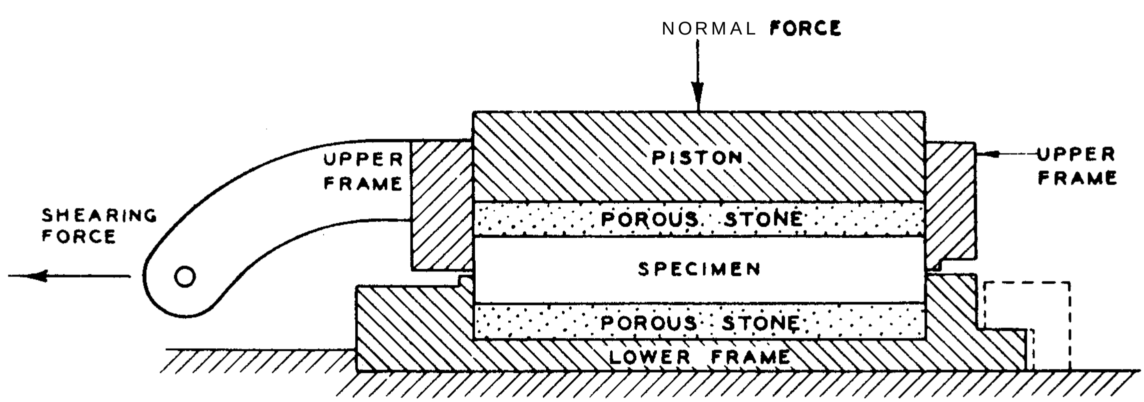


Figure 1. Schematic diagram of direct shear box

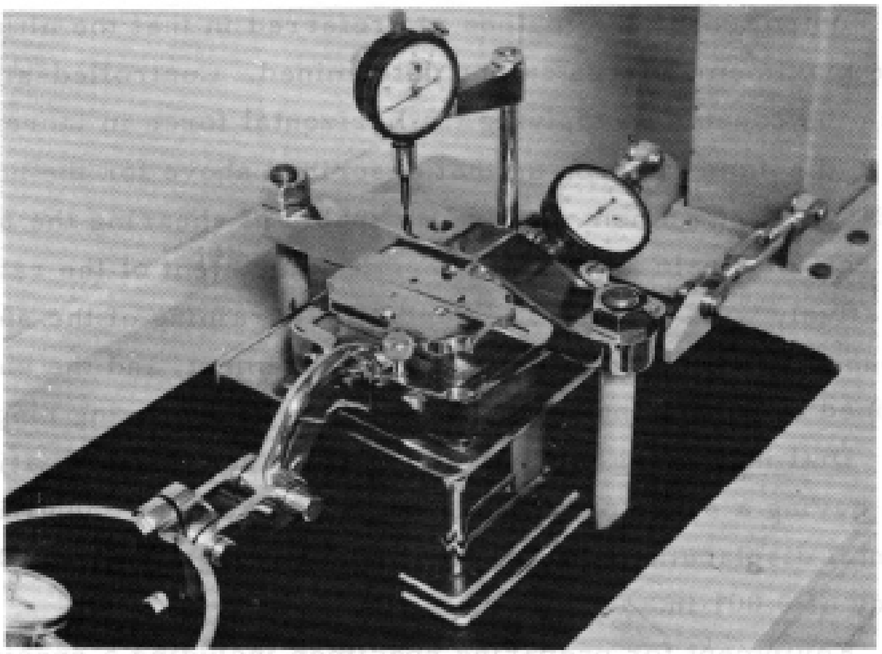
shear box shall contain a reservoir for water, with the bottom grooved or provided with a grooved area to permit drainage. The upper frame of the shear box should contain an accurately machined piston, the bottom of which is also grooved to permit drainage. The upper frame shall be provided with horizontal locking screws to lock it to the piston within the upper frame of the box. The various metal parts of the shear box shall be of a like, noncorrosive material. A typical shear box, assembled and unassembled, is shown in Figure 2; a narrow-edged shear box as shown is preferable to a wide-edged one. Generally, shear boxes for direct shear tests shall have minimum inside dimensions of 3 by 3 in. The maximum thickness of a 3- by 3-in. specimen shall be 1/2 in. after consolidation. If the soil to be tested contains particles larger than the No. 4 sieve, the test should be performed in a larger shear box or else the shear strength should be determined by means of the triaxial test.

b. Porous stones shall be smooth, coarse grade Alundum or Carborundum, finish-ground except for the surface in contact with the specimen, which shall be rough-finished by sandblasting or by using handtools. Porous metal plates of similar porosity and texture may also be used. It is very important that the permeability of porous stones not be reduced by the collection of soil particles in the pores of the stones; hence, frequent checking and cleaning (by flushing and boiling, or by ultrasonic cleaner) are required to ensure the necessary permeability (see page VIII-3).

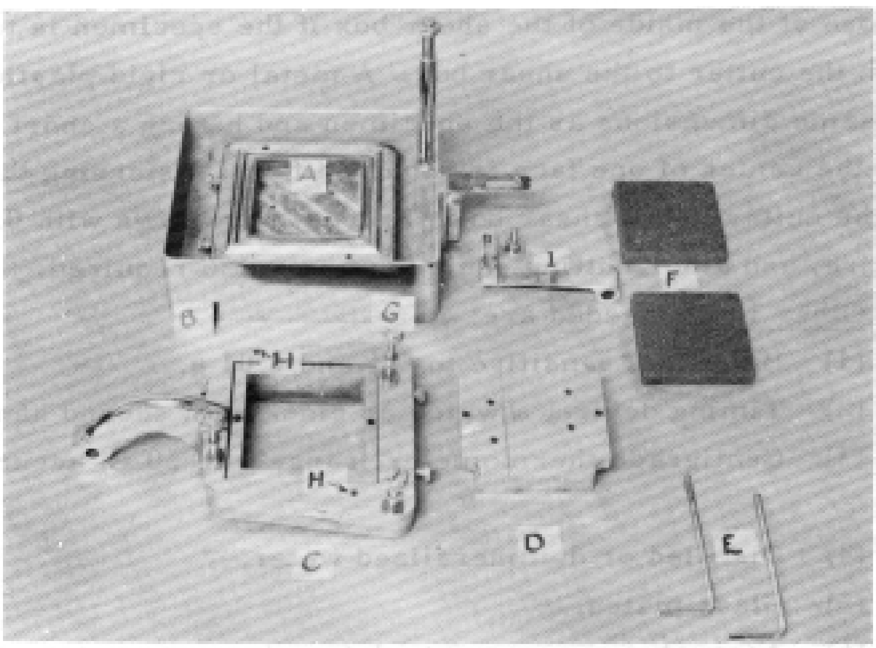
c. Loading devices for applying the normal load and horizontal shear force to the specimen. Any type of loading device may be used that meets the following requirements:

(1) For applying normal load. The equipment for applying the normal load shall be capable of transmitting the load to the specimen quickly, without impact, and maintaining the load constant for the duration of the test. The equipment should be calibrated to ensure that the loads indicated are those actually applied to the soil specimen.

(2) For applying shear force. The horizontal shear force may be applied by either controlled-stress or controlled-strain methods,



a. Assembled in loading apparatus



b. Unassembled

A, lower frame; B, water reservoir; C, upper frame; D, piston; E, alignment pins; F, porous stones; G, elevating screws; H, holes for alignment pins; I, bracket for vertical dial indicator.

Figure 2. Typical direct shear box

though the controlled-strain method is preferred in that the ultimate, as well as the maximum, stress can be determined. Controlled-stress equipment should be capable of applying the horizontal force in increments to the specimen in the same manner as that described above for the normal load. Controlled-strain equipment should be capable of shearing the specimen at a uniform rate of strain and should permit adjustment of the rate of strain over a relatively wide range. The controlled straining of the specimen is usually done with a motor and gear box arrangement, and the shear force is determined by a load-indicating device such as a proving ring or frame.

d. Dial indicators for measuring (1) vertical deformation of the specimen, having a range of 0.25 in. and an accuracy of 0.0001 in.; and (2) horizontal displacement of the specimen, having a range of 0.5 in. and an accuracy of 0.001 in.

e. Equipment for preparing specimen including a specimen cutter with sharp cutting edges. The cutter shall have inside dimensions the same as those of the inside of the shear box if the specimen is to be transferred from the cutter to the shear box. A metal or rigid plastic plate having the same dimensions as the specimen and having a short handle attached at the center of one face is required for transferring the specimen from the cutter to the shear box. Knives, wire saws with 0.010-in.-diameter wire, and other cutting equipment are also required.

f. Other items needed are:

(1) Balances, sensitive to 0.1 and 0.01 g.

(2) Timing device, a watch or clock with second hand.

(3) Centigrade thermometer, range 0 to 50 C, accurate to 0.1 C.

(4) Distilled or demineralized water.

(5) Glass plates.

(6) Apparatus necessary to determine water content and specific gravity (see Appendixes I, WATER CONTENT - GENERAL, and IV, SPECIFIC GRAVITY).

3. PREPARATION OF SPECIMEN. A sample sufficient to provide a minimum of three identical specimens is required. Specimens shall be prepared jn a humjd room to prevent evaporation of moisture. The specimen is generally prepared by progressive trimming in front Of the specimen cutter. However, satisfactory specimens of hard soils often may be obtained by cutting and trimming wjthout using the specimen cutter. Specimens of very soft, sensitive soils may be obtained more conveniently by pushing the cutter into the sample without preliminary trimming. Extreme care shall be taken jn preparjng undisturbed specimens of sensitive soils to prevent disturbance of their natural structure. Preferably, specimens of compacted soil should be trimmed from samples compacted in a compaction mold, using a pressing or kneading action of a tamper having an area less than one-sixth the area of the sample. A less desirable procedure is to compact the soil to the desired density and water content directly in the shear box, in a single layer using a similar kneading action. The procedure usually used in preparing specimens by progressive trimming follows :

a. Cut a sample of soil approximately 1-1/4 in. high and 4-1/2 in. in diameter from the sample to be tested.

b. Place the sample of soil on a glass plate and center the specimen cutter on top of the sample. Push the cutter vertically into the sample not more than 1/4 in. and carefully trjm the soil from the edge of the Cutter. Repeat the operation until the specimen protrudes above the top of the cutter. Care should be taken to insure that no voids are formed between the cutter and specimen.

c. Remove the portion of the specimen protruding above the cutter, using a wire saw for soft specimens, and a straightedge, knives, or other convenient tools for harder specimens. Trim the specimen flush with the top of the cutter. If a pebble or other protrusion is encountered on the surface, remove it and fill the void with soil.

d. Place a previously weighed glass plate on the surface of the specimen. Many soils will adhere to glass; consequently, it is advisable to use waxed paper or similar material between the specimen and glass plate. Invert the specimen, trim the bottom as described in step c, and on this surface place another weighed glass plate.

e. From the soil trimmings obtain 200 g of material for water content and specific gravity determinations (see Appendixes I, WATER CONTENT - GENERAL, and IV, SPECIFIC GRAVITY).

f. Repeat the procedures outlined above to produce two additional specimens.

4. PROCEDURE. a. Preliminary. The procedure for setting up the test specimen shall consist of the following:

(1) Record all identifying information for the specimen, such as project, boring number, and other pertinent data, on the data sheet (Plate IX-1 is a suggested form); note any difficulties encountered in preparation of the specimen. Measure the inside area and height of the shear box and record as the initial dimensions of the specimen on the data sheet. Weigh and record the weight of specimen plus tare (specimen cutter and glass plates).

(2) Assemble the shear box with the upper frame held in alignment with the lower frame by means of the alignment pins or screws. Place a previously saturated porous stone, rough side up, on the baseplate of the shear box in the bottom of the lower frame.

(3) Insert the specimen cutter, sharpened edge first, into the upper frame of the shear box until it is wedged firmly and is parallel with the top of the upper frame (the inside edge of the upper frame should be beveled slightly to accept the cutter). Lay a piece of waxed paper, slightly smaller than the specimen, on the surface of the specimen, and with a smooth, continuous press of the transferring plate, force the specimen from the cutter and into firm contact with the porous stone. While pressing the specimen from the cutter, care must be exercised to prevent tilting or otherwise disturbing the specimen. Withdraw the transferring

plate, remove the specimen cutter, and peel the waxed paper from the specimen. Place a previously saturated porous stone, rough side down, on top of the specimen and lower the piston onto this porous stone.

(4) Place the shear box in position on the loading apparatus. At this stage of the test the upper and lower frames are in contact. Assemble the loading equipment, and mount the two dial indicators to be used for measuring vertical and horizontal deformation. The dial indicator measuring vertical deformation should be set so that it can measure movement in either direction.

b Consolidation. The procedure for consolidating the specimen shall consist of the following:

(1) Apply the desired normal load gently to the specimen. The range of normal loads for the three specimens will depend on the loadings expected in the field. The maximum normal load should be at least equal to the maximum normal load expected in the field in order that the shear strength data need not be extrapolated for use in design analysis. Generally, normal loads less than about 3 tons per sq ft may be applied in a single increment, whereas greater normal loads should be applied in several increments to prevent the soil from squeezing out of the box, For very soft soils it is usually necessary to apply even the relatively lighter normal loads in increments.

(2) As soon as possible after applying the normal load, fill the water reservoir with distilled or demineralized water to a point above the top of the specimen. Maintain this water level during the consolidation and subsequent shear phases so that the specimen is at all times effectively submerged.

(3) Allow the specimen to drain and consolidate under the desired normal load or increments thereof prior to shearing. During the consolidation process, record on the data sheet (see Plate VIII-2 of Appendix VIII, CONSOLIDATION TEST) the vertical dial readings after various elapsed times. Readings at 0.1, 0.2, 0.5, 1, 2, 4, 8, 15, and 30 min,

and 1, 2, 4, 8, and 24 hr for each increment of normal load are usually satisfactory. During the course of the test, plot the dial readings versus elapsed time on a semilogarithmic plot (see Fig. 5 of Appendix VIII, CONSOLIDATION TEST). Allow each load increment to remain on the specimen until it is determined that primary consolidation is complete (see Appendix VIII, CONSOLIDATION TEST).

c. Shear Test. The procedure for shearing the specimen after consolidation shall consist of the following:

(1) Raise the upper frame of the shear box about 1/16 in. by turning the elevating screws. The amount of clearance between the upper and lower frames should be sufficient to prevent the two frames from coming in contact during the shear test, yet not permit the soil to extrude between the frames. Lock the upper frame to the loading piston by means of the horizontal locking screws. In raising the upper frame, the applied load on the specimen is increased by an amount equal to the weight of the upper frame. Adjust vertical load by reducing applied load by this amount. Retract the elevating screws.

(2) Remove the alignment pins.

(3) Shear the specimen at a relatively slow rate so that a fully drained condition (no excess pore pressures) exists at failure. The following equation shall be used as a guide in determining the minimum time required from start of test to shear failure:

$$t_f = 50t_{50}$$

where

t_f = total. elapsed time to failure in minutes

t_{50} = time in minutes required for the specimen to achieve 50 percent consolidation† under the normal load or increments thereof (see Fig. 5 of Appendix VIII, CONSOLIDATION TEST). It is to be noted, however, that time-consolidation curves indicated by soils that exhibit a tendency to swell under a given increment of normal load are not meaningful and, therefore, cannot be used in determining minimum times required to failure. In such instances, the following procedures may be used to obtain valid time-consolidation curves:

(a) An increment of normal load is applied to the specimen and the specimen is inundated with water and allowed to come to equilibrium; the time-consolidation curve for any increment of normal stress applied thereafter is valid.

(b) Alternatively, the specimen may be inundated with water following the completion of primary consolidation under the final increment of normal load. However, the specimen must be allowed to come to equilibrium after inundation (prior to shear). Prior to inundation, the specimen should be maintained in a humid atmosphere by covering the shear box and filling the water reservoir with moist paper towels, cotton, or other cellular material.

(4) Considerable experience and judgment are generally required in determining the proper rate of shear load application. The following discussions will provide guidance in this respect:

(a) Controlled-stress test. The rate of load application may be determined approximately by the following procedure. Estimate the maximum shear stress and select an initial load increment of about 10 percent of the estimated failure load. Apply each increment to the specimen and permit at least 95 percent consolidation before applying the next increment. The time-consolidation curve obtained during the

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† If the time for 50 percent consolidation is difficult to determine, values for higher percentages of consolidation may be used to compute t_f. The following relations may be used: $t_f = 35t_{60} = 25t_{70} = 18t_{80} = 12t_{90}$.

consolidation sequence of the test may be used for determining if 95 percent consolidation has been achieved. When 50 to 70 percent of the estimated failure load has been applied to the specimen (depending on the shape of the stress-deformation curve), reduce the size of the increments to one-half the initial size. As failure is approached, use a series of increments equal to one-fourth of the initial load increment to accurately define the failure load.

(b) Controlled-strain test. The rate of strain may be determined approximately by dividing the estimated horizontal deformation at maximum shear stress by the computed time to failure, t_f. The test shall be continued until the shear stress becomes essentially constant, as shown in Figure 3b, or until a horizontal deformation of 0.5 in. has been reached.

(5) The horizontal and vertical deformations and the applied shear force shall be observed at convenient intervals. Plate IX-2 is a

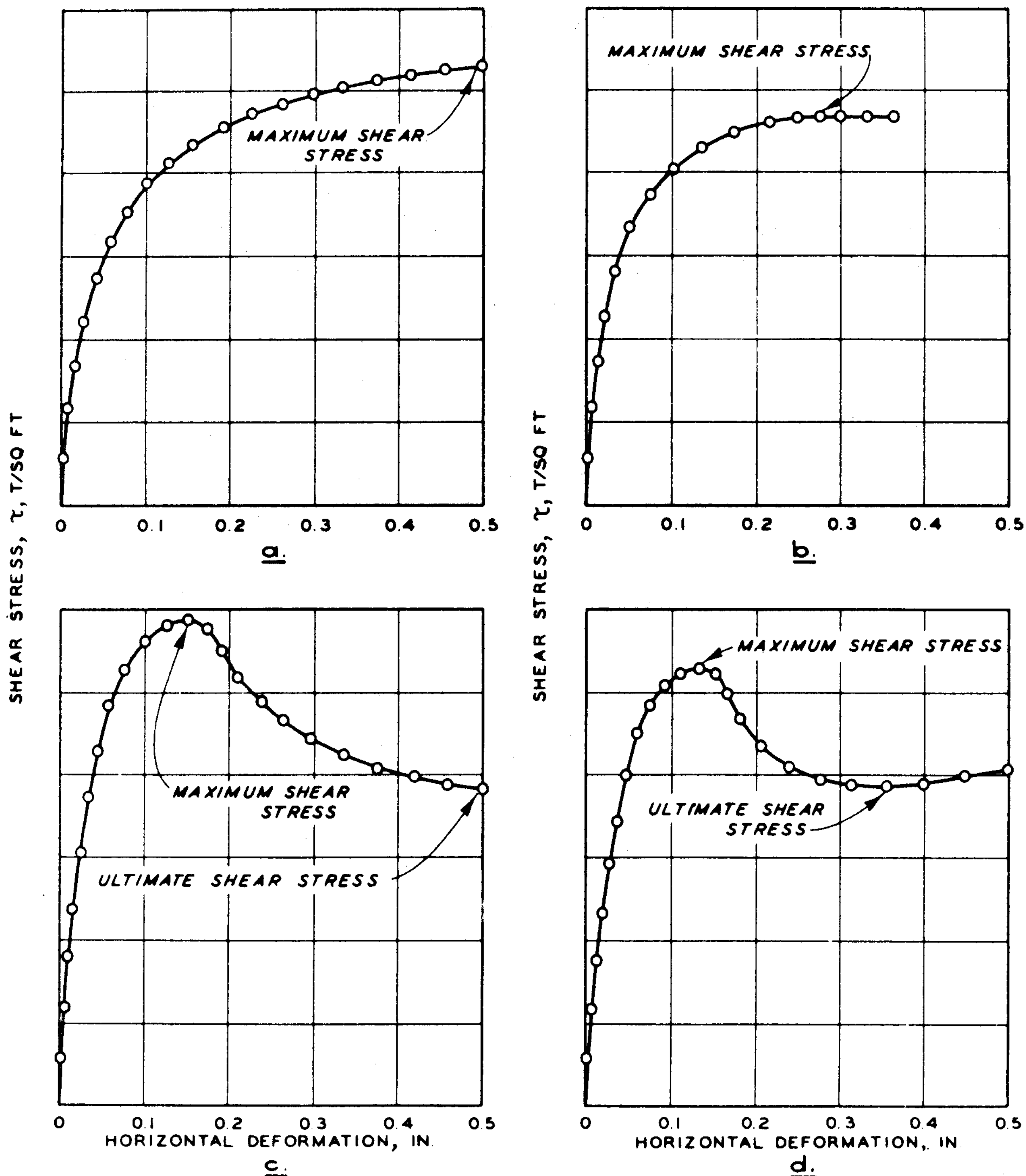

Figure 3. Examples of stress-deformation curves

suggested form for recording the observations.

(6) Remove the specimen from the shear box, blot any excess moisture, and trim away a minimum of 1/16 in. from all sides of the specimen to form a rectangular block. Determine the water content of the specimen (see Appendix I, WATER CONTENT - GENERAL). The dry weight of the specimen should be computed using the water content based on specimen trimmings taken at the start of the test.

5. COMPUTATIONS. The computations shall consist of the following:

a. From the recorded data compute and record on the data sheet (see Plate IX-1) the initial and final water contents (see Appendix I, WATER CONTENT - GENERAL). Compute also the void ratio before test, after consolidation, and after test, and the initial and final degrees of saturation, and dry density before test, using the following equations:†

$$\text{Void ratio before test, } e_o = \frac{V_o - V_s}{V_s}$$

$$\text{Void ratio after consolidation, } e_c = \frac{V_c - V_s}{V_s}$$

$$\text{Void ratio after test, } e_f = \frac{V_f - V_s}{V_s}$$

† Equations in brackets are based on units of measurement shown on the following page in explanation of symbols.

Initial degree of saturation, S_o, percent = $\dfrac{\dfrac{w_o}{100} \times \dfrac{W_s}{\gamma_w}}{V_o - V_s} \times 100,$

or $\left[\dfrac{w_o \times W_s}{V_o - V_s}\right]$

Final degree of saturation, S_f, percent = $\dfrac{\dfrac{w_f}{100} \times \dfrac{W_s}{\gamma_w}}{V_f - V_s} \times 100,$

or $\left[\dfrac{w_f \times W_s}{V_f - V_s}\right]$

Dry density before test, γ_d, lb per cu ft = $\left[\dfrac{W_s}{H_o \times A} \times 62.4\right]$

where

W_s = weight of dry soil, g
A = area of specimen, sq cm
G_s = specific gravity of solids
γ_w = unit weight of water, g per cc
w_o = water content of specimen before test, percent
w_f = water content of specimen after test, percent
H_o = initial height of specimen, cm
H_c = height of specimen after consolidation, cm
H_f = height of specimen at end of test, cm
V_s = volume of solids, cc; W_s/G_s
V_o = volume of specimen before test, cc; $A \times H_o$
V_c = volume of specimen after consolidation, cc; $A \times H_c$
V_f = volume of specimen after test, cc = $A \times H_f$

Units of measurement are those commonly used in computations for the direct shear tests.

b. Complete the data sheet, Plate IX-2.

c. The shear stress, τ, in tons per square foot may be calculated from the following equation:

$$\tau = \frac{F}{A} \times 0.465$$

where

F = applied shear force, lb

A = horizontal cross-sectional area of the specimen, sq cm (assumed to be constant and equal to the initial area for routine testing)

6. PRESENTATION OF RESULTS. The results of the direct shear test shall be shown on the report form, Plate IX-3. The shear stress and vertical deformation during shear shall be plotted versus the horizontal deformation. As shown in Figure 3, the maximum shear stress, τ_{max}, is either the actual maximum or peak shear stress or, if the shear stress increases continuously during the test, the shear stress at 0.5-in. horizontal deformation. When the shear stress decreases after reaching a maximum value, the minimum shear stress attained before 0.5-in. horizontal deformation is considered to be the ultimate shear stress, τ_{ult}, as shown in Figures 3c and 3d. The time to failure, t_f, is the elapsed time between the start of shear and the maximum shear stress. The maximum shear stress shall be plotted against the normal stress, as shown in Figure 4, and the strength envelope drawn to determine the drained or effective angle of internal friction, ϕ. In normally consolidated soils (see Fig. 4a), the strength envelope is based on normal stresses greater than any past or existing overburden pressure.

A brief description of undisturbed specimens should be given on the report form under "Remarks." The description should include color, approximate consistency, and any unusual features (such as stratification,

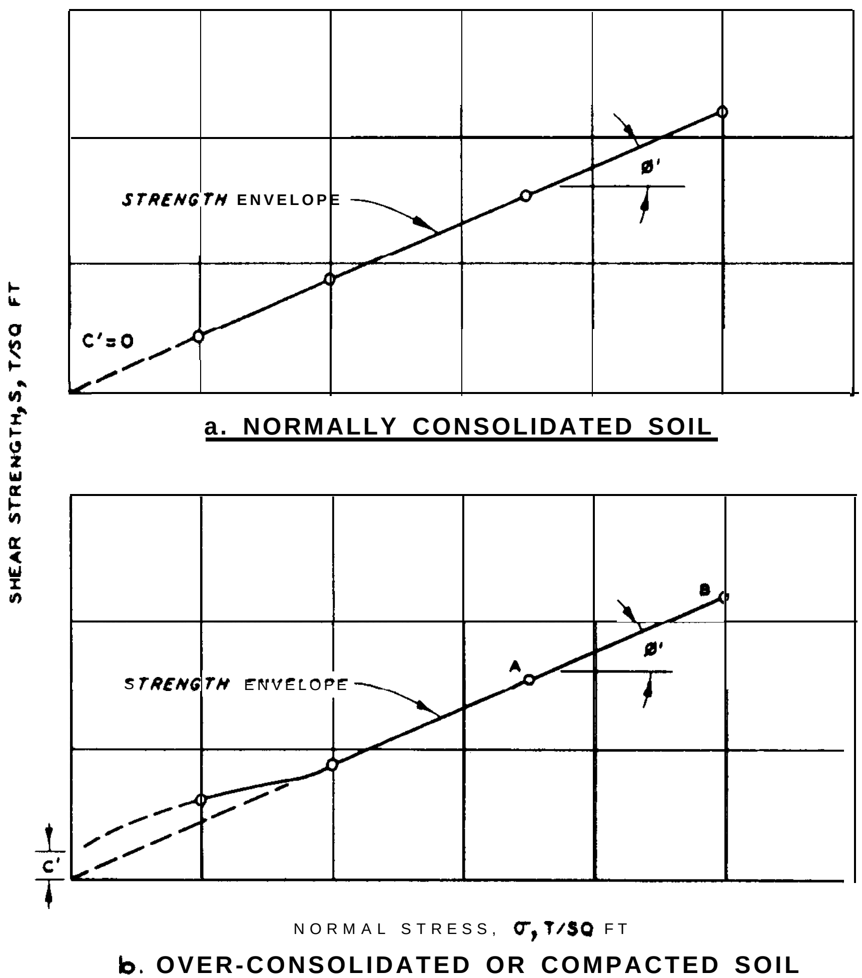

Figure 4. Examples of strength envelopes

fissures, roots, shells, sand pockets, etc.). For compacted specimens, give method of compaction used and the relation to maximum density and optimum water content.

7. SIMPLIFIED PROCEDURE FOR DRAINED (S) DIRECT SHEAR TESTS. In problems involving the long-term stability of fine-grained soils, the cohesion intercept, c', due to over-consolidation generally is ignored. The drained direct shear test may be performed by shearing duplicate specimens under the maximum normal stress expected in the

field. The strength envelope for determining the effective angle of internal friction, ϕ', shall be drawn as a straight line from the origin to the average value of the maximum shear stresses under this normal stress. Regardless of the magnitude of the expected normal stress, the normal stress used in this simplified procedure for testing compacted specimens must be at least 3 tons per sq ft to avoid the effects of prestressing caused by the compaction.

Although the testing of duplicate specimens under the same normal stress is satisfactory for relatively pervious or normally consolidated soils, it may not be conservative for preconsolidated clays. For the latter soils, the duplicate specimens should be sheared under different normal stresses, both of which are known to exceed the preconsolidation pressure, as illustrated by points A and B in Figure 4b.

a. POSSIBLE ERRORS: Following are possible errors that would cause inaccurate determinations of strength and stress-deformation characteristics:

a. Specimen disturbed while trimming. The 'trimming of specimens must be done in the humid room with every care taken to minimize disturbance of the natural soil structure or change in the natural water content. As a rule, the effect of trimming disturbance is inversely proportional to the size of the specimen.

b. Specimen disturbed while fitting into shear box. The specimen must exactly fit the inside of the shear box to insure complete lateral confinement, yet a pretrimmed specimen must be inserted without flexing or compressing. The specimen cutter must have the identical inside dimensions as those of the shear box.

c. Galvanic action in shear box. To prevent any change in the strength or stress-deformation characteristics due to galvanic currents in tests of long duration, all metal parts of the shear box should be of the same noncorrosive material.

d. Permeability of porous stones too low. Unless the porous stones are frequently cleaned, they may become clogged by soil particles and full drainage of the specimen inhibited.

e. Slippage between porous stone and specimen. When testing undisturbed firm or stiff clays, particularly under low normal loads, it may not be possible to transfer the required shear force to the specimen by means of the standard porous stone. In such a case, slippage of the porous stone will result and a portion of the shear force will be applied to the specimen by the rear edge of the upper frame. The slippage may be marked by tilting of the upper frame and the development of an inclined shear plane through the upper rear corner rather than one through the midheight of the specimen. The use of dentated porous stones or of wire cloth or abrasive grit between the stone and the specimen may be necessary to effect the transfer of shear stress.

f. Rate of strain too fast. The time to failure in the drained (S) direct shear test must be long enough to achieve essentially complete dissipation of excess pore pressure at failure. The criterion given in paragraph 4c(3) should be considered as no more than an approximate guide to the minimum time to failure; twice this time may be necessary for some soils. In general, it is safer to shear too slowly.

DIRECT SHEAR TEST
(Specimen Data)

Date ____________

Project ____________

Boring No. ____________ Sample No. ____________

Shear Box No.	Normal Stress T/sq ft
Specimen No.	Classification

			Before Test			After Test	
			Specimen	Trimmings		Specimen	
Tare No.			Cutter and Glass Plates				
Weight in grams	Tare plus wet soil						
	Tare plus dry soil		X				
	Water	W_w	X	W_{wo}		W_{wf}	
	Tare						
	Wet soil	W		X		X	
	Dry soil	W_s					
Water content		w	%	w_c	%	w_f	%

Initial Condition of Specimen

Area in sq cm	A		Volume of solids in cc	V_s	
Height in cm	H_o		Void ratio = $(V_o - V_s) \div V_s$	e_o	
Volume in cc = $A \times H_o$	V_o		Saturation, %	S_o	
Specific gravity of solids	G_s		Dry density in lb/cu ft	γ_d	

Condition of Specimen After Consolidation

Change in height during consolidation, in.	ΔH_o		Volume in cc = $A \times H_c$	V_c	
Height in cm = $H_o - 2.54\Delta H_o$	H_c		Void ratio = $(V_c - V_s) \div V_s$	e_c	

Condition of Specimen After Test

Change in height during shear test, in.	ΔH		Volume in cc = $A \times H_f$	V_f	
Height in cm = $H_c - 2.54\Delta H$	H_f		Void ratio = $(V_f - V_s) \div V_s$	e_f	
Saturation, %	S_f				

$$W_s = \frac{W}{1 + \frac{w_o}{100}}, \quad V_s = \frac{W_s}{G_s}, \quad S_o = \frac{\frac{w_o}{100} \times \frac{W_s}{\gamma_w}}{V_o - V_s} \times 100, \quad S_f = \frac{\frac{w_f}{100} \times \frac{W_s}{\gamma_w}}{V_f - V_s} \times 100, \quad \gamma_d = \frac{W_s}{V_o} \times 62.4$$

Remarks ____________

Technician ____________ Computed by ____________ Checked by ____________

PLATE IX-1 ENG FORM 1 JUN 65 3850

DIRECT SHEAR TEST

(Time-Shear Stress Data)   Date ____________

Project ____

Boring No. ____________   Sample No. ____________   Normal Stress ____________

Time	Elapsed Time min	Time Intervals min	Proving Ring Dial Reading 10^{-} in.	Shear Stress T/sq ft	Vertical Dial Reading 10^{-} in.	Horizontal Dial Reading 10^{-} in.

Technician ____________

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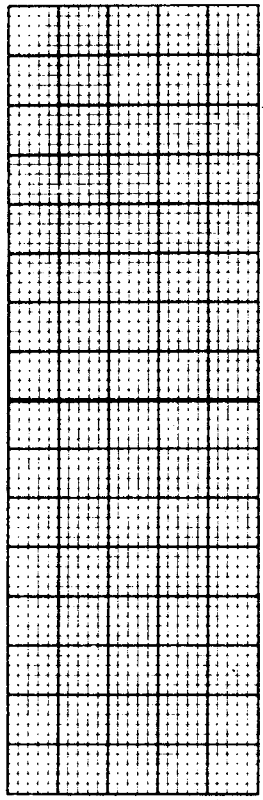
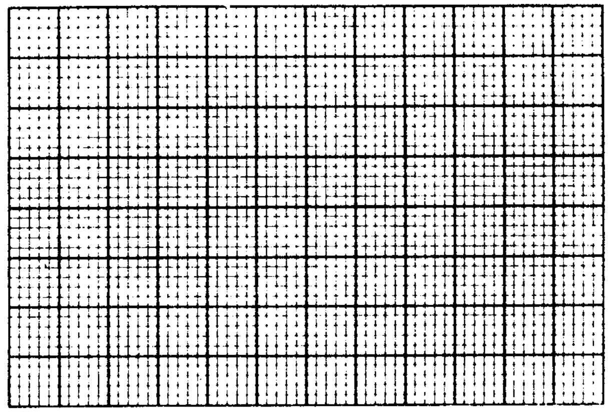
PLATE IX-2





Shear Strength Parameters

φ' = ________ °

tan φ' = ________

[redacted] = ________ T/sq ft

☐ Controlled stress

☐ Controlled strain

Test No.						
Initial	Water content	w_o	%	%	%	%
	Void ratio	e_o				
	Saturation	S_o	%	%	%	%
	Dry density, lb/cu ft	γ_d				
Void ratio after consolidation		e_c				
Time for 50 percent consolidation, min		t_{50}				
Final	Water content	w_f	%	%	%	%
	Void ratio	e_f				
	Saturation	S_f	%	%	%	%
Normal stress, T/sq ft		σ				
Maximum shear stress, T/sq ft		τ_{max}				
Actual time to failure, min		t_f				
Rate of strain, in./min						
Ultimate shear stress, T/sq ft		τ_{ult}				

Type of specimen		in. square	in. thick
Classification			
LL	PL	PI		G_s

Remarks ________

Project	
Area	
Boring No.	Sample No.
Depth El	Date
DIRECT SHEAR TEST REPORT	

PLATE IX-3 ENG FORM 1 JUN 65 2092