Procedure for Performing Direct Shear and Sliding Friction Testing Using a Portable Direct Shear Device Introduction

This procedure is under the jurisdiction of the Materials Engineering and Research Laboratory, code 86-68180, Technical Service Center, Denver, Colorado. The procedure is issued under the fixed designation USBR 6255. The number immediately following the designation indicates the first year of acceptance or the year of last revision.

1. Scope

1.1 *Explanation.*- This designation establishes the guidelines, requirements, and procedure for performing direct shear (break bond) and sliding friction testing (see note 1) using a portable direct shear device. This test method covers the determination of the direct shear and sliding friction strengths of intact specimens and specimens that contain a natural or artificial joint or discontinuity. Peak and residual shear strengths are calculated as a function of applied normal stress to the plane of shearing. From the test results, four relationships are derived:

(1) shear stress and normal stress

(2) shear stress and shear displacement (shear stiffness)

(3) normal stress and normal displacement (normal stiffness)

(4) normal displacement and shear displacement (angle of asperities)

The test is conducted in the undrained state with a normal external loading applied.

Note 1.-This method makes no provision for pore pressure measurements. Thus, the strengths determined are in terms of total stress, uncorrected for pore pressure.

Note 2.-This method becomes inappropriate when local dilatation of a non-planar joint is inhibited either totally or partially because of the stiffness of the surrounding joint or the prevalent local boundary conditions. In such cases, more elaborate testing not discussed here should be undertaken.

1.2 *Context.*-This designation is described in the context of obtaining field data for the indexing of rock for designs of slopes or foundations for Reclamation structures.

1.3 *Application.*-This designation applies to hard and soft rock.

1.4 *Units.*- Stating the values in SI/metric (inch-pound) units is to be regarded as standard.

1.5 *Caveats.*- This designation does not purport to address all the safety issues associated with its use and may involve use of hazardous materials, equipment, and operations. The user has the responsibility to establish and adopt appropriate safety and health practices. Also, the user must comply with prevalent regulatory codes while using this procedure.

1.6 *Sources.*- This designation reflects the information available from American Society for Testing and Materials, International Society of Rock Mechanics, and Reclamation.

2. Applicable Documents

2.1 USBR Procedures:

USBR 1000 Standards for Linear Measurement Devices

USBR 1007 Calibrating Dial Indicators

USBR 1040 Calibrating Pressure Gages

USBR 3000 Using Significant Digits in Calculating and Reporting Laboratory Data

USBR 3910 Standard Terms and Symbols Relating to Rock Mechanics

USBR 5300 Determining Moisture Content of Soil and Rock by the Oven Method

USBR 6540 Performing In Situ Direct Shear Testing of Rock

USBR 6545 Performing *In Situ* Direct Shear Testing of Rock using Borehole Shear Device

USBR 9300 Checking, Rounding, and Reporting of Laboratory Data

2.2 ASTM Documents:

ASTM D 4554 Standard Test Method for *In Situ* Determination of Direct Shear Strength of Rock Discontinuities

2.3 ISRM Documents:

Part 2: Suggested Method for Laboratory Determination of Shear Strength, Rock Characterization Testing and Monitoring, E. T. Brown (ed.), Pergamon Press, 1981, PP. 135-137.

3. Summary of Method

3.1 *Open Discontinuities.*-To test the shear strength of a rock specimen containing an open discontinuity (i.e., joint), carefully encapsulate the upper and lower halves of the rock specimen into separate upper and lower halves of the mold. Ensure that the plane of the contained joint (discontinuity) during testing is coincident with the contact surface of the upper and lower halves of the shear box. After proper hardening of the encapsulating material, remove the encapsulated halves of the specimen and place them into respective halves of the portable shear box. Conduct the shear tests by applying shear and normal load.

3.2 *Intact.* For conducting a shear test on an intact specimen, first encapsulate its lower half and then its upper half in separate molds. Conduct the shear test by applying normal and shear loads.

4. Significance and Use

4.1 *Shear Strength.*-Shear strength of rock is a critical parameter for the design of rock slopes, dam foundations, tunnels, shafts, waste repositories, and underground chambers for storage and other purposes.

4.2 *Use.*-Portable shear box field shear tests are performed on weakly jointed rock specimens (i.e., rock specimens that have joints that are open or clay seams or other weaknesses.

4.3 *Site Coverage* .-Conducting laboratory or *in situ* shear strength tests are expensive. When dam foundation or slope stability designs require an extensive testing program, a portable shear box can be used to perform shear strength tests inexpensively and rapidly over large test sites. Doing so provides information on the shear strength variations over an entire site and on site areas that would need more detailed sampling and testing at a later date.

Note 3.- The shear strength of a joint or discontinuity depends on the :

(1) Joint filling material, joint thickness, joint roughness, orientation and dip of joints, spacing of joints, persistence of joint aperture, and number of joint sets

(2) Wall strength

(3) Block size

(4) Seepage

(5) Boundary conditions

(6) Magnitude of normal stress

(7) Type of loading (static or dynamic)

(8) Rate of shear displacement

(9) Imbrication (natural arrangements of jointing

(10) Degree of interlocking

(11) Angle of asperities, size of asperities: micro, macro, meso, or mega

(12) Normal stiffness of joints

(13) Velocity of applied shear

(14) Magnitude of shear displacement.

In addition, a non-planar joint (see section 5.1) subjected to shear stress undergoes dilation. Therefore, the shear strength of a joint or a discontinuity is not a precise value; the shear strength contains some degree of variance and uncertainty.

Note 4.-The components of shear strength are cohesion and angle of internal friction. Cohesion depends on the scale effect of the sample, whereas the angle of internal friction is independent of the scale effects. The influence of scale effect generally decreases with an increase in confining pressure. Scale effects do not influence residual shear strength (see section 5.4). Peak shear strength (see section 5.3), peak shear displacement, and shear stiffness are all scale-dependent parameters (see figure 1).

Note 5.-A moist specimen yields lower shear strength than a dry specimen because of low friction and cohesion and the inability of the moisture to migrate freely through the rock pores. During testing, entrapped moisture causes a pore pressure build-up that leads to low rock strength.

4.4 *Seismic Loading.*-In situations of seismic loading, rock joints may slide back and forth. In those cases, properties of joints subjected to reversible shear loads will be required. Portable shear box tests can provide such data. A typical shear test result on a joint under reversible shear load is shown on figure 2.

Note 6.-Shear strength is lower under dynamic conditions than under static conditions.

4.5 *Other Influences.*-Rock shear strength is proportional to the or slope stability design require an extensive testing overburden pressure. Also, the shear strength of a rock is influenced by the size, shape, and moisture content of the specimen; the method of testing; and the rate of shear loading.

4.6 *Representative Shear Strength.*-Conduct laboratory or *in situ* tests to predict a representative shear strength of the rock mass (USBR 6540 and USBR 6545) rather than using the portables shear box shear test data..

5. Description of Terms Specific to This Designation

5.1 *Asperity*.-Roughness of a surface.

5.2 *Discontinuities*.-Joints, bedding planes, fractures, cracks, and other geological features contained in the rock mass. A discontinuity may be planar (smooth) or non-planar (containing asperities). A non-planar discontinuity has an irregular, uneven, or wavy structure or form. In a non-planar discontinuity, an applied shear load forces the sliding portion of the joint or discontinuity to ride up or slide down the asperity, causing dilation or compression of the joint. Because of the contained asperity, the shear strength of a joint becomes dependent on the direction of shear displacement.

5.3 *Dilatancy*.-The apparent increase in the initial volume of rock when it is about to fail under external shear loading. Dilation is caused by riding over the asperities.

5.4 *Peak Shear Stress.*-The maximum shear stress along a sheared surface attained during a shear test (see figure 3).

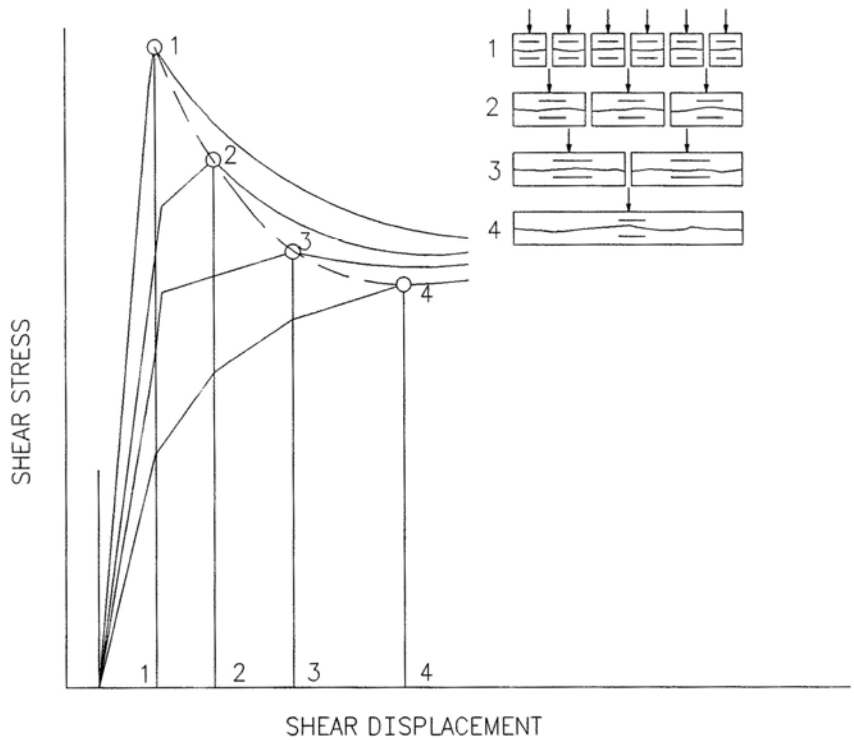

Figure 1. - Scale dependency of shear strength parameters.

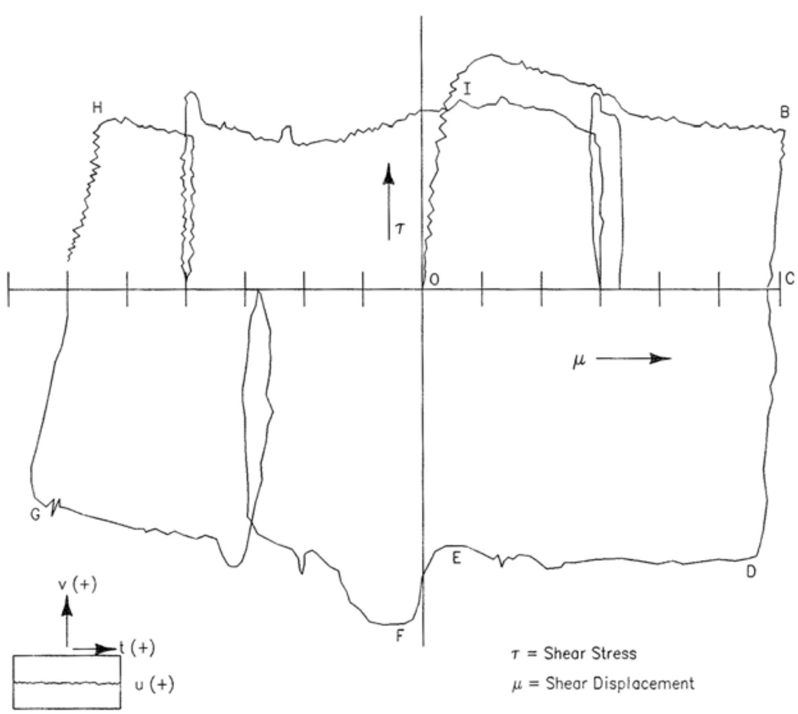

Figure 2. - Shear stresses-shear displacements of a rock joint under reversible shear load.

5.5 *Residual Shear Stress*.-During early stages of a shear test, a rock specimen has increasing shear strain with increasing shear load. After the peak shear stress is obtained, shear displacement continues to increase up to point A (see figure 3), but at a somewhat slower rate than during pre-peak shear. The shear stress obtained after attaining point A is called “residual shear stress.”

5.6 *Bond Breaking Shear Strength*.-The shear strength of rock specimens with no open joint or discontinuity.

5.7 *Sliding Friction Shear Strength*.-The shear strength of a specimen that contains an open joint or discontinuity.

5.8 *Other Terms*.-See USBR 3910.

6. Apparatus

6.1 Portable Direct Shear Box.-A welded steel box with separable upper and lower halves. The upper half of the shear box includes a single acting, push-type, hydraulic ram installed vertically and two wire ropes installed horizontally. The lower half of the shear box includes two single acting, push-type, hydraulic rams installed horizontally and one wire rope installed vertically. The rams have an effective area of 640 mm^2 (0.994 in^2) and a maximum load capacity of 45 kN (5 tons). Ropes are 7-strand, 25- wire ropes (nominal strength 120 kN [13.3 tons]). The vertical ram and rope are used for applying normal load, whereas the horizontal rams and ropes are used for applying shear load in either direction. The shear box can move 18 mm (¾ in) in either direction. Figure 4 shows the shear box.

6.2 *Hydraulic Pumps*.-Two manually operated, single speed, hydraulic pumps capable of exerting pressures up to 70 MPa (10,000 lbf/in^2) each are used to activate the rams to apply normal and shear loads. The pump applying normal load is equipped with a low-friction actuator that can maintain normal pressure within ±1 %. The hydraulic pumps are shown on figure 5.

6.3 *Encapsulation Molds*.-Two clear plastic specimen encapsulation molds used to encapsulate the rock specimens (one specimen per mold) and are shown on figure 6.

6.4 *Pressure Gages*.-Two hydraulic pressure gages, used to measure the normal and shear pressures, are shown on figure 7. (The pressure gages may have a capacity of 7 to 70 MPa [1,000 to 10,000 lbf/in^2] and an accuracy of 70 to 700 kPa [10 to 100 lbf/in^2).

6.5 *Displacement Measuring Device*.-Reclamation uses dial gages as normal and shear displacement measuring devices. Four vertically placed dial gages are used to measure the normal displacement or joint closure and provide a check on specimen rotation. One dial gage, magnetically mounted and horizontally placed, measures the shear displacement. The dial gages have a range of ± 25 mm (±1 in) (dial gage is shown on figure 7).

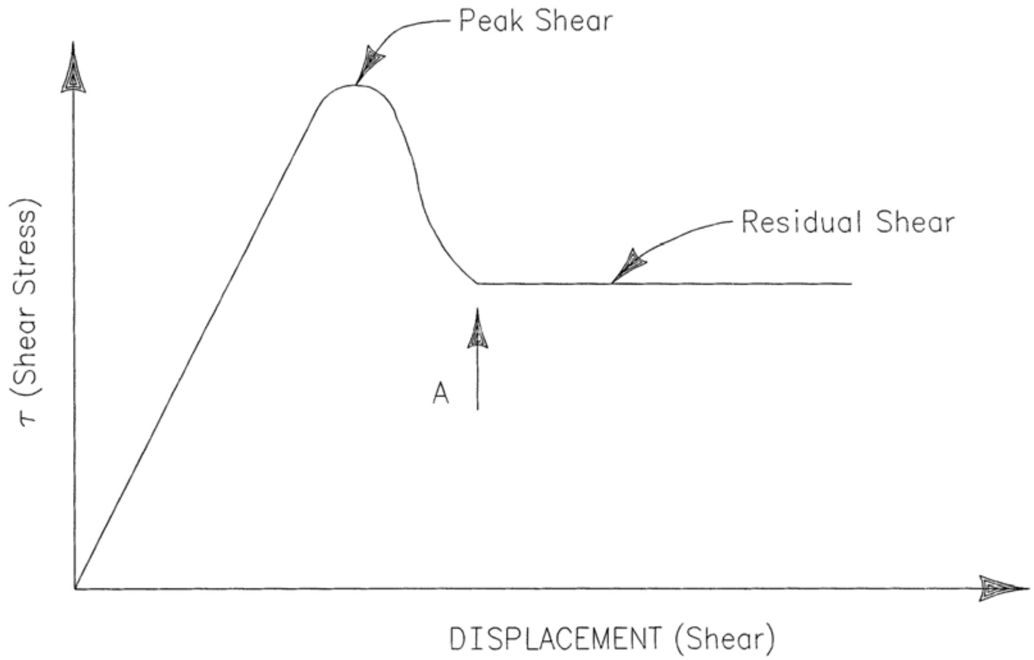

Figure 3.- Generalized shear stress and shear displacement curve.

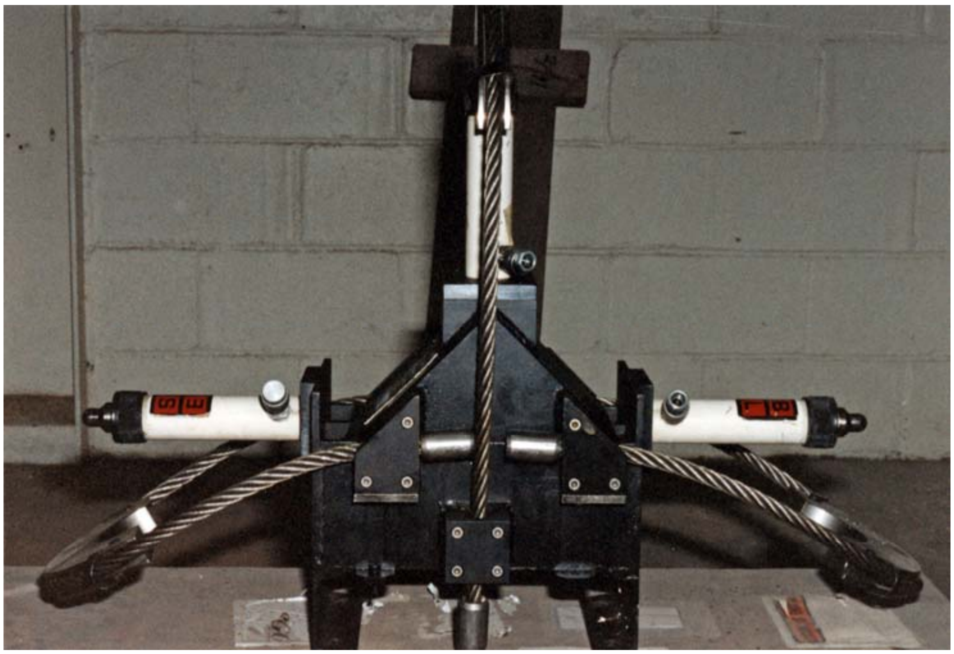

Figure 4.- Shear box—portable direct shear device.

Figure 5.- Hydraulic pump setup—portable direct shear device.

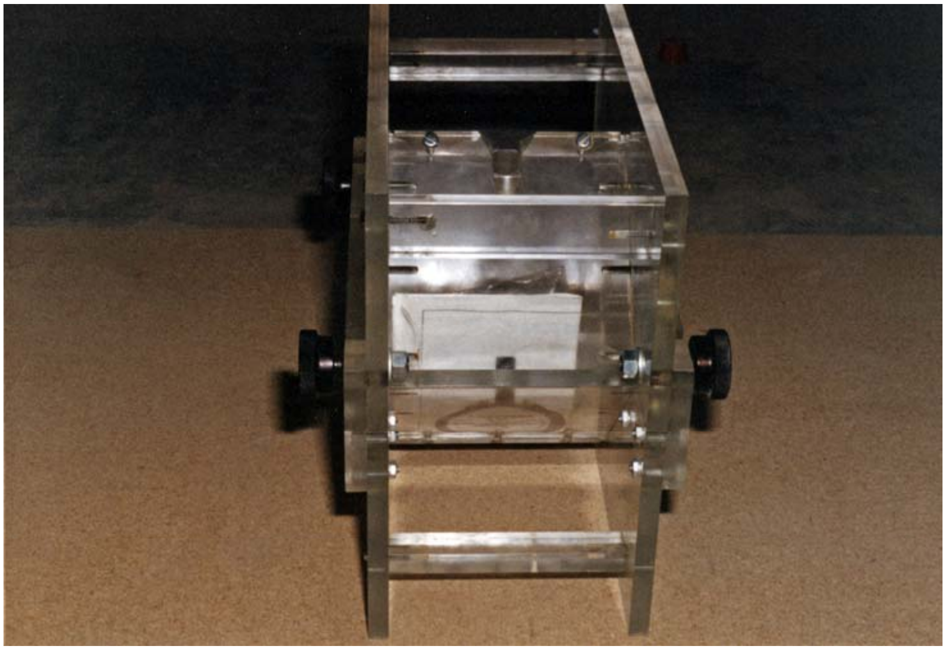

Figure 6.- Encapsulation mold—portable direct shear device.

Figure 7.- Pressure gages and dial gage—portable direct shear device.

6.6 *Miscellaneous Items.*-Water cooled diamond saw, masonry saw, bench saw, carpenter's contour gage (for measuring joint surface roughness), roughness chart, planimeter, filler or modeling clay, wire screens (see figure 7), calipers, spatula, encapsulating material, circular clamps, utility knife, towels, markers, plotting paper, camera, and other miscellaneous items or materials as required for conducting the tests.

7. Calibration and Standardization

7.1 Pressure Gages. -The pressure gages are to be calibrated using USBR 1040.

7.2 Dial Gages.-The dial gages are to be calibrated using USBR 1007.

7.3 Calipers. -Calipers must meet requirements in USBR 1000.

8. Test Specimens

8.1 *Preparation:*

8.1.1 *Rock Specimen with a Single Joint.*- Samples containing the test horizon are collected using methods selected to minimize disturbance in such a way as to retain natural moisture content. The specimen dimensions and the location of the test horizon (i.e., joint or discontinuity) within the block shall allow, if possible, the mounting of the specimen without further trimming, and shall provide sufficient clearance for adequate encapsulation. The test plane should have a minimum area of 2500 mm^2 (4 in^2). The mechanical integrity of the specimen may be preserved by binding tightly with wire or tape which is to be left in position until immediately before testing. A portable saw may be used to carefully trim the specimen.

Note 7.-To obtain meaningful parameters for designing, constructing, or maintaining Reclamation structures, the test specimens must represent the host rock properties as far as practicable.

8.2 *Size and Shape.*-The specimen length is controlled by the dimensions of the mold (see note 8). The shape of the specimen may be circular, rectangular, square, or any other shape that allows the cross sectional area to be easily determined. The least cross-sectional dimension of the specimen shall be related to the size of the largest grain size in the rock by the ratio of at least 10:1.

9. Procedure

9.1 Moisture Content.-Determine and report the moisture content of a companion rock specimen according to USBR 5300.

9.2 *Test Specimen:*

9.2.1 *Measurements:*

9.2.1.1 *Cross-Sectional Area.*-Determine and record the lateral dimensions of the specimen to the nearest 0.025 mm (0.001 in) by averaging two measurements at right angles to each other at about upper height, mid height, and lower height of the specimen. Calculate and record the average cross-sectional area of the specimen. Alternatively, obtain the cross-sectional area by planimetering tracings of outlines of the test surface. For intact rocks and filled joint specimens, the cross-sectional area is determined by averaging the end cross-sectional areas.

9.2.1.2 *Joint Roughness.*-Using a carpenter's contour gage, measure the joint roughness in the direction of the anticipated shear displacement. Compare the measured joint roughness with the standard roughness chart (see figure 8), and determine the joint roughness coefficient.

9.2.2 Encapsulation:

9.2.2.1 Encapsulate one-half of a specimen at a time. To prevent the encapsulating material from adhering to the mold, coat the inside surface of the mold either with oil or spray with a no-stick cooking product. Complete the encapsulation within the pot life (10 to 15 minutes) of the encapsulating compound.

9.2.2.2 The first half of the encapsulation process is the most critical because the shear horizon has to be positioned at the correct planar attitude. Usually, this positioning can be done by placing the specimen in contact with the bottom of the mold and stabilizing or bracing it with modeling clay or by placing it on a wire screen platform.

9.2.2.3 Fill the bottom half of the mold with encapsulating material without interfering with the test horizon. Allow the encapsulating material to harden for about 20 to 30 minutes. When a specimen is already separated prior to encapsulation, place the other half of the specimen in the correct position on the encapsulated half of the specimen. Place a layer of molding clay around the specimen and on top of the surface of the dried encapsulation material to an elevation which completely isolates the test horizon.

9.2.2.4 Position the upper half of the mold over the lower half of the mold. For specimens containing a discontinuity, take care to ensure that the two halves of the rock specimen make a good match. Pour the encapsulation material through the fill hole opening of the top mold until the level of encapsulating material is just below the hole opening. If any of the fill hole volume is filled with encapsulating material, a ridge forms which interferes with proper seating of the casted specimen in the shear box. This ridge requires filing to remove it.

9.2.2.5 After the encapsulation material is hardened, carefully remove the encapsulated specimen from the mold, mark it with appropriate identification, and transfer the lower half of the encapsulated specimen to the lower half of the portable shear box.

Note 8.-A larger size specimen requires trimming to match the encapsulation requirement in the mold. Also, the embedment length of the encapsulated rock specimen is controlled by the dimensions of the mold. Exercise care to at least get an embedment length equal to the least dimension of the test horizon. Limit the maximum specimen size to about 100-mm (4-in) diameter cores or equivalent.

9.3 *Mounting into the Shear Box.*- For specimens containing a discontinuity, remove the modeling clay and the wire meshes holding the discontinuity. Carefully place the upper shear box containing the encapsulated upper half of the specimen over the lower half of the shear box without disturbing the test horizon. For intact specimens, mount the encapsulated specimen into the shear box.

9.4 *Accessory Installation* .-Install the four vertical dial gages for measuring the vertical (normal) displacements. Install the magnet mounted dial gage to measure horizontal (shear) displacements. Connect the hydraulic hoses and place the wire ropes (see figure 4) in the appropriate configuration. Connect the hydraulic pump and pressure gages.

9.5 *Testing:*

9.5.1 Set the peak pressure indicator on the shear pressure gage to zero.

9.5.2 To ensure full contact of shear surfaces of the rock specimen and of the two halves of the portable shear box, apply an initial normal load corresponding to a normal stress of 0.69 MPa (10 lbf/in^2).

9.5.3 Take and record initial readings of pressures and displacements.

9.5.4 Apply the designated normal test load by activating the normal pressure application hydraulic pump, and then apply the shear load by activating the shear application hydraulic pump. The shear loads are to be applied in increments so that at least ten increments are obtained

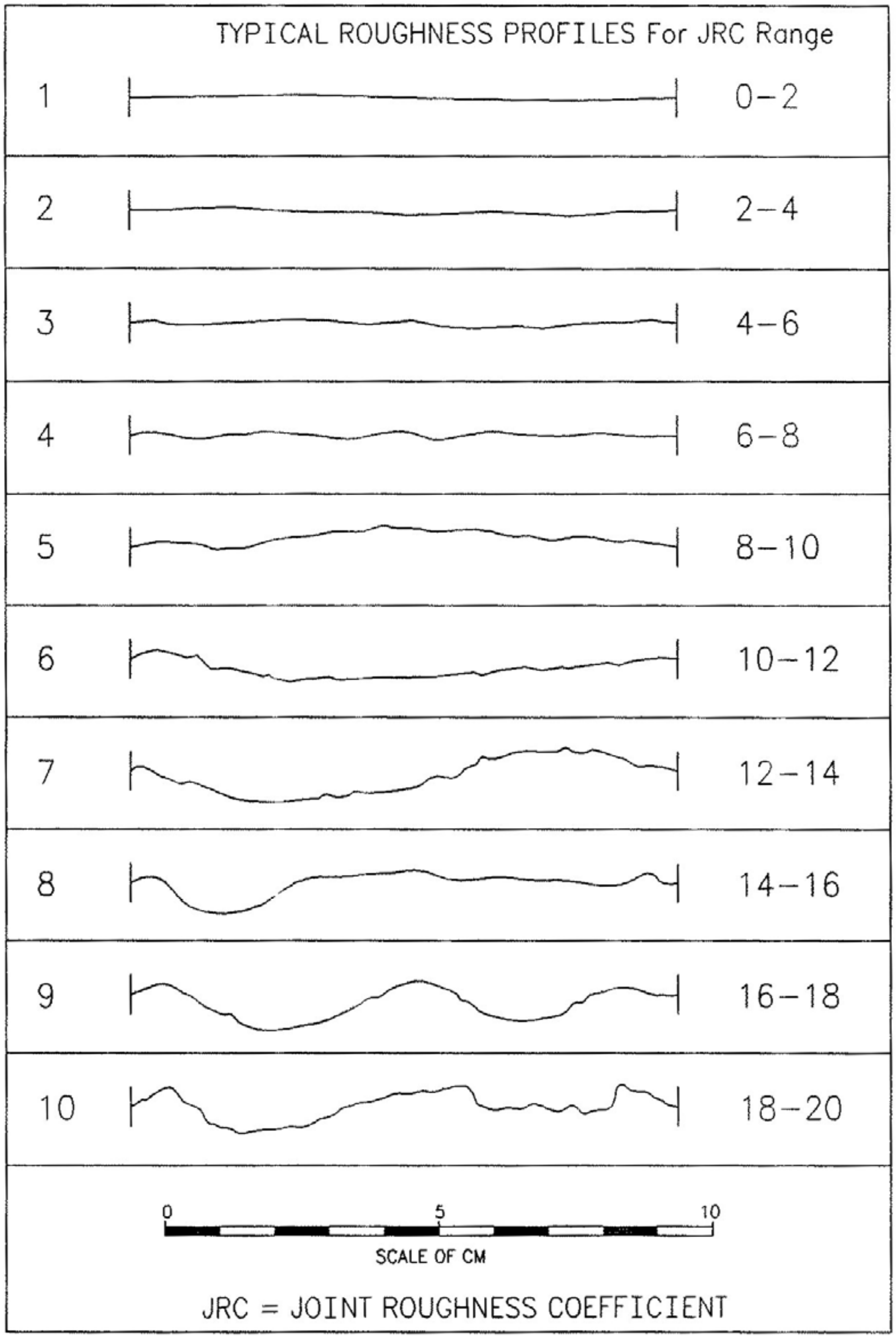

Figure 8. - The standard roughness chart.

before rock specimen failure. Read and record the pressure and displacement measuring devices at each increment of shear pressure. Also, read and record the peak shear pressure at failure (from the peak pressure indicator on the shear pressure gauge). Record all readings on the data sheet.

Note 9.-The normal pressure is to be held as constant as possible throughout the test by pumping or manually adjusting the two-way valve on the hydraulic pump. The normal pressure is usually controlled by a pneumatic pressure maintainer.

9.5.5 Maintain the normal pressure on the rock specimen and reduce the shear pressure to zero.

9.5.6 Switch the hydraulic lines from one shear ram (horizontally installed) to the other if the direction of shearing needs to be reversed.

9.5.7 Repeat steps 9.5.1 through 9.5.5 for the reversed shear loading, if required.

Note 10.-This step is to obtain residual shear data at each normal stress in reversed shear directions.

9.5.8 For a multi-stage test, increase the normal pressures to the next designated increments.

9.5.9 Repeat steps 9.5.1 through 9.5.4, and 9.5.8, if required (multi-stage test only).

9.5.10 After completing the test, depressurize the hydraulic rams and disassemble the top half of the shear box.

9.5.11 Carefully remove and separate both halves of the encapsulated test specimen from the shear box.

9.5.12 Weigh the top half of the shear box along with the top half of the encapsulated specimen (this measurement gives the dead mass exerted on the shear plane).

Note 11.-The number of rock specimens to be tested depends upon availability, but a minimum of three specimens is preferred.

9.6 *Photographing.*-After completion of a test, take photographs of the sheared surface.

10. Calculations

10.1 *Area.*- Calculate the average cross-sectional area of the test specimen from the cross-sectional dimensions (see section 9.2.1.1) and express the results to the nearest 0.01 mm2 (0.01 in2).

10.2. *Stress.*- Make the following calculations:

Normal Stress, $\sigma = P_n/A$, MPa (lbf/in^2)
Normal Stress, $\tau = P_s/A$, MPa (lbf/in^2)

where:

P_n= normal load, kN (lbf)
P_s = shear load, kN (lbf)
A = nominal or apparent cross sectional area, mm^2 (in^2)

10.3 *Roughness.*-Compare the measured joint roughness (see section 9.2.1.2) and read the roughness from the standard roughness chart (see figure 8).

10.4 *Graphs.*- Make the following graphical plots:

10.4.1 Plot curves as shown on figure 9 to depict the relationships between (a) shear stresses versus shear displacements, and (b) shear stresses versus normal stresses.

10.4.2 Plot curves as shown on figure 10 to depict the relationships between (a) changes in normal stresses versus joint aperture, and (b) changes in joint aperture versus shear displacements.

10.4.3 Plot curves as shown on figures 11, 12, 13, and 14 for different preselected normal stresses to show the relationships between the (a) shear stresses versus shear displacements, and (b) normal displacements versus shear displacements.

11. Report

11.1. *Contents.*- The report should include the following:

11.1.1 Source of sample including project name, location, and, if known, storage environment. The location of the source of the rock sample may be specified in terms of borehole number and depth of sample from collar of hole.

11.1.2 Physical description of sample including rock type; location and orientation of discontinuities, such as apparent weakness planes, bedding planes, and schistosity; and large inclusions or inhomogeneities, if any.

11.1.3 General indication of the moisture condition of the test specimen at the time of testing, such as saturated, received, or air dry. In some cases, the actual moisture content may need to be reported as determined by procedure USBR 5300.

11.1.4 The cross-sectional area of the rock specimen.

11.1.5 The dial gage readings.

11.1.6 The applied loads (normal and shear).

11.1.7 Date of sampling and testing.

11.1.8 The number of specimens tested.

11.1.9 Type and location of failure, including color photographs of the specimen before and after the test.

11.2. *Data Organization*-The standard reporting format used by Reclamation is appended as:

Table 1. - Test records.

Table 2. - Final data.

Table 3. - Data summary.

Figure 9. –
(a) Shear stress and shear displacement.

(b) Shear stress and normal stress.

Figure 10. –
(a) Change in normal stress and joint aperture.
(b) Change in joint aperture and shear displacement.

Figure 11. –
(a) Shear stress and shear displacement.
(b) Normal displacement and shear displacement.

Figure 12. - At selected normal stress, σ_{L11} :
(a) Shear stress and shear displacement
(b) Normal displacement relationship and shear displacement

Figure 13. - At selected normal stress, σ_{L12} :
(a) Shear stress and shear displacement
(b) Normal displacement relationship and shear displacement.

Figure 14. - At selected normal stress, σ_{L13}:
(a) Shear stress and shear displacement.
(b) Normal displacement relationship and shear displacement.

11.3 *Test Results*.-The test results shall be reported in accordance with Reclamation designations USBR 3000 and USBR 9300.

12. Precision and Bias

The precision and bias for this designation have not been determined. Any variation observed in the data is just as likely to be caused by specimen variation as by operator or laboratory testing variations. Because of the variability of rock, this test procedure has no reference value.

Table 1.-Test records

Project:		Feature:		Spec No:	Tested by:	Date:
Diameter:		Area:		Delta Load:	Delta Disp:	NorDeadLoad:

Normal lbf	Shear lbf	Shear Disp in	Micrometer Reading (Normal)					Time
				Za in	*Zb* in	*Zc* in	*Zd* in	

Table 2.-Final data

Project:
Feature:
Type:
Spec No.:
Tested by:
Date tested:
Area:

Normal Stress (lbf/in^2)	Shear Stress (lbf/in^2)	Displacement	
		Shear (in)	Normal (in)
________	________	________	________
________	________	________	________
________	________	________	________

Table 3.-Data Summary

Date: Time:
File:

Data Summary:

Project:
Feature:
Type:
Spec. No.:
Index No.:
Tested by:
Date tested:
Area:

Normal load (lbf)	Shear load (lbf)	Displacement Normal (in)	Displacement Shear (in)	Normal Stress (lbf/in^2)	Shear Stress (lbf/in^2)
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______

SUM X*X =
SUM Y*Y =
SUM X*Y =
SUM X =
SUM Y =

Sliding Friction Results

S = + (N)
Cohesion = lbf/in^2
PHI= degrees COR COEF =

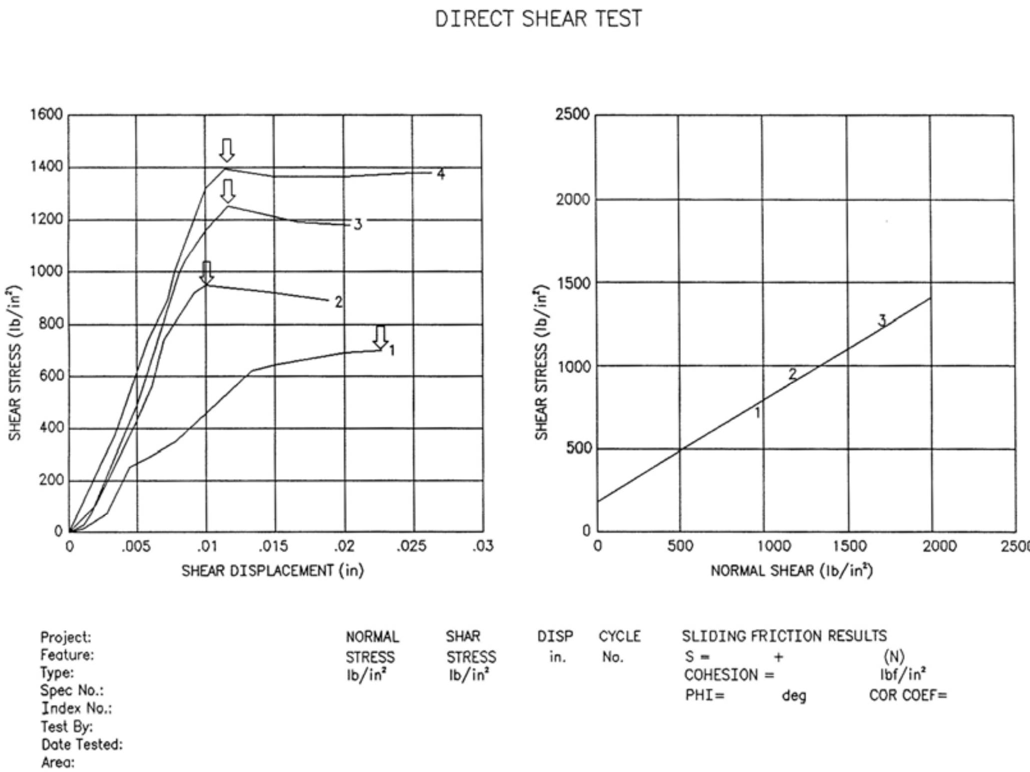

Figure 9. –
(a) Shear stress and shear displacement.
(b) Shear stress and normal stress.

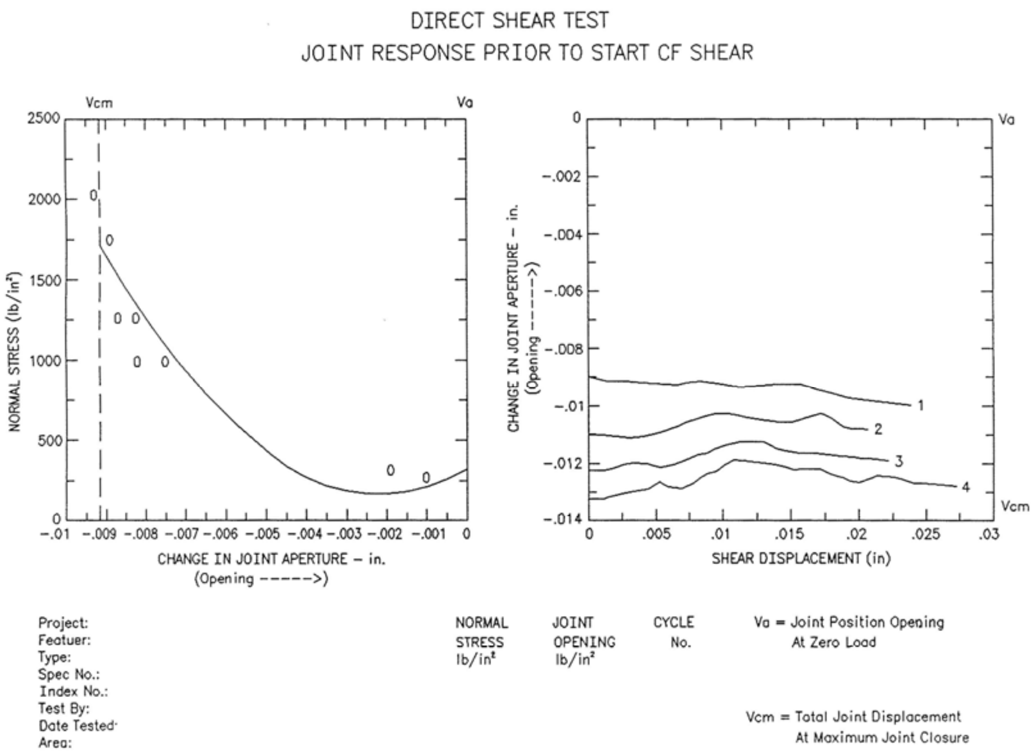

Figure 10. –
(a) Change in normal stress and joint aperture.
(b) Change in joint aperture and shear displacement.

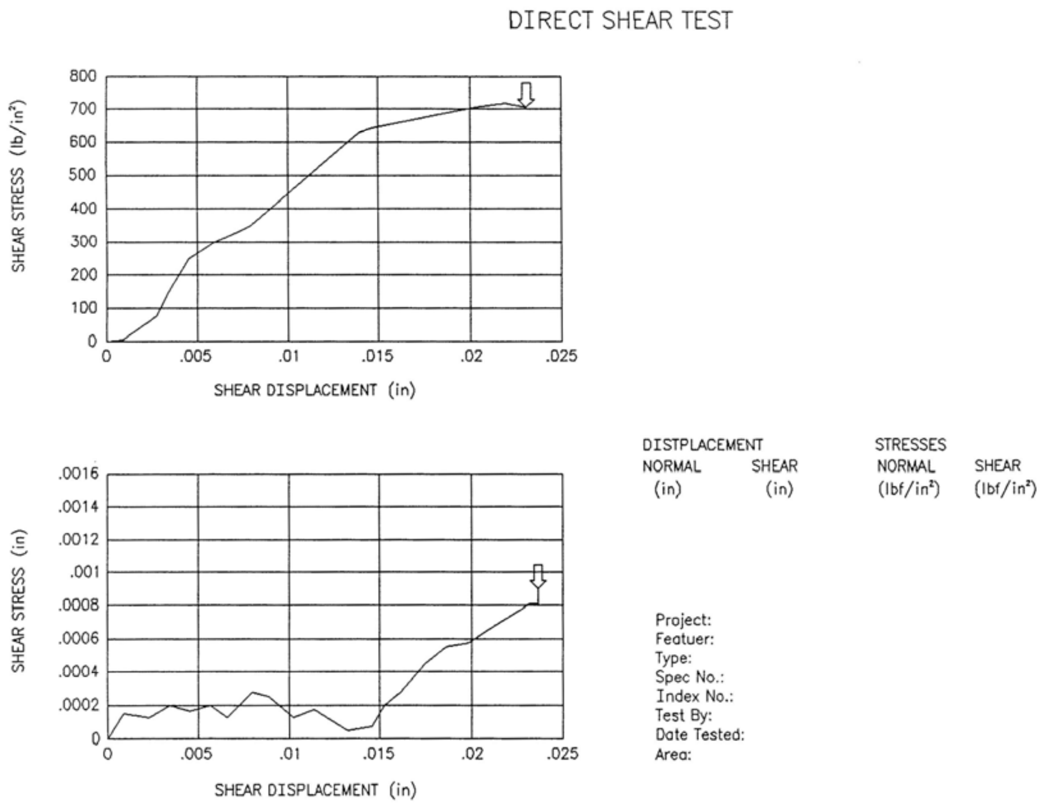

Figure 11. –
(a) Shear stress and shear displacement.
(b) Normal displacement and shear displacement.

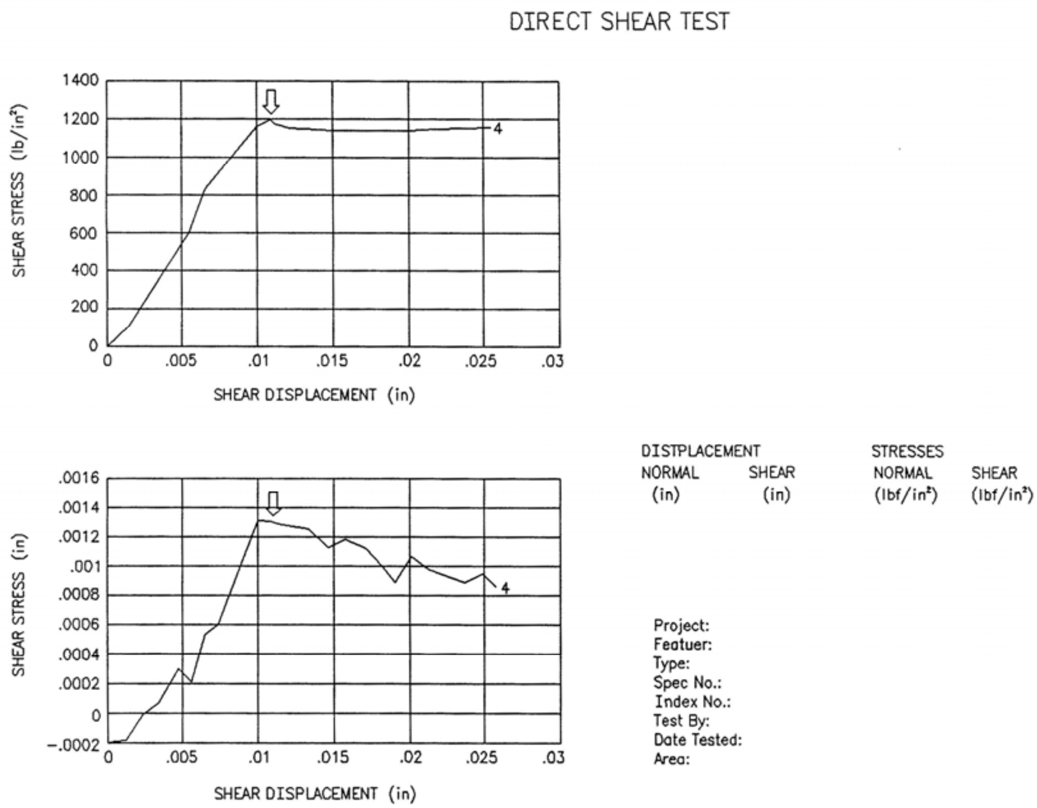

Figure 12. - At selected normal stress, σ_{L11} :
(a) Shear stress and shear displacement
(b) Normal displacement relationship and shear displacement

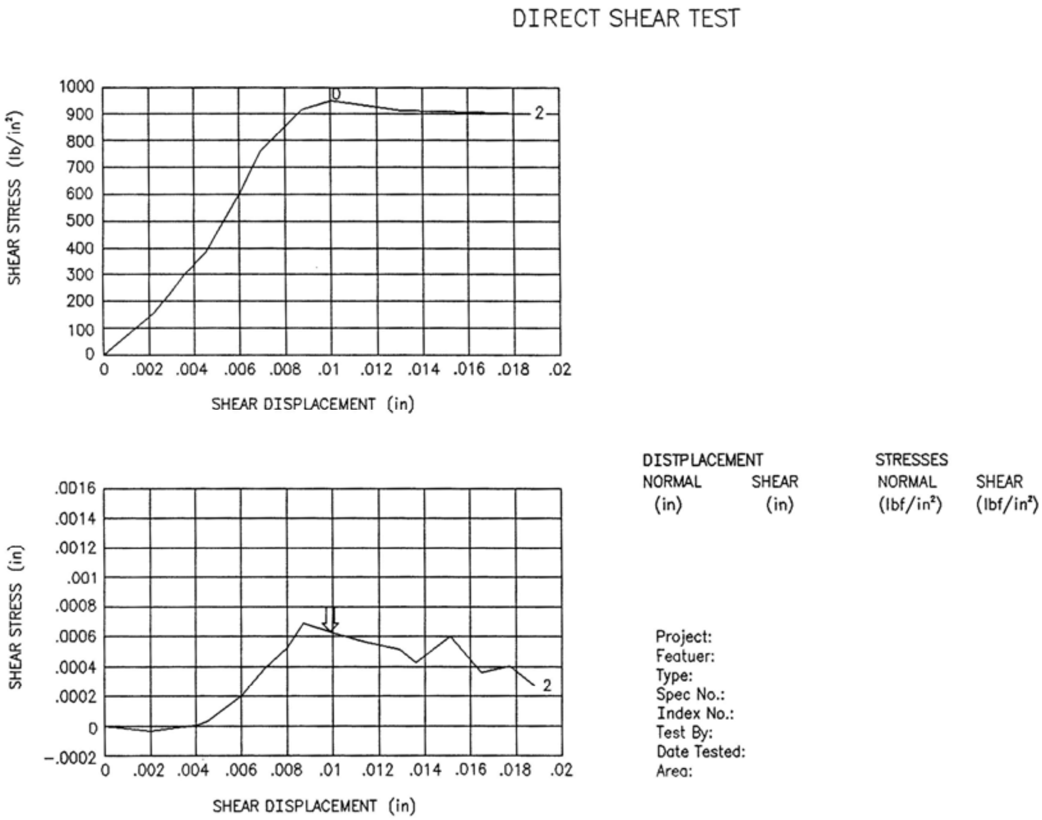

Figure 13. - At selected normal stress, σ_{L12} :
(a) Shear stress and shear displacement
(b) Normal displacement relationship and shear displacement.

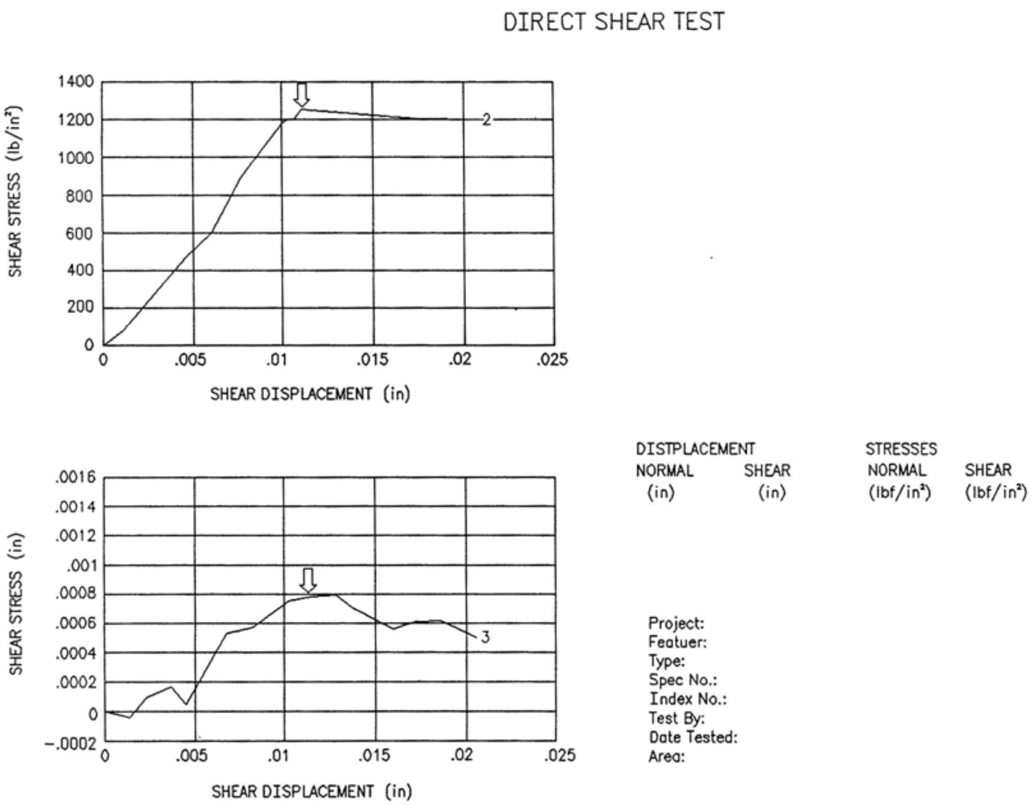

Figure 14. - At selected normal stress, σ_{L13}:
(a) Shear stress and shear displacement.
(b) Normal displacement relationship and shear displacement.