Designation: D4554 – 12

Standard Test Method for In Situ Determination of Direct Shear Strength of Rock Discontinuities[1]

This standard is issued under the fixed designation D4554; 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.

1. Scope*

1.1 This test method covers the measurement of peak and residual direct shear strength in a drained condition of in situ rock discontinuities as a function of stress normal to the sheared plane. This sheared plane is usually a significant discontinuity that may or may not be filled with gouge or soil-like material.

1.2 The measured shear properties are affected by scale factors. The severity of the effect of these factors must be assessed and applied to the specific problems on an individual basis.

1.3 The values stated in SI units are to be regarded as the standard. No other units of measurements are included in this standard.

1.4 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.5 *This standard does not purport to address all of the safety concerns, if any, 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:*[2]

D422 Test Method for Particle-Size Analysis of Soils

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D6026 Practice for Using Significant Digits in Geotechnical Data

D6913 Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *discontinuities*—any surface across which some property of the rock mass is not continuous. Discontinuities include joints, schistosity, faults, bedding planes, cleavage, and zones of weakness, along with any filling material.

3.2.2 *peak shear strength*—the maximum shear stress in the complete curve of stress versus displacement obtained for a specified constant normal stress.

3.2.3 *residual shear strength*—the shear stress at which nominally no further rise or fall in shear strength is observed with increasing shear displacement and constant normal stress as shown in Fig. 1. A true residual strength may only be reached after considerably greater shear displacement than can be achieved in testing. The test value should be regarded as approximate and should be assessed in relation to the complete shear stress – displacement curve.

3.2.4 *shear strength parameter, c*—apparent cohesion; the projected intercept on the shear stress axis of the plot of shear stress versus normal stress as shown in Fig. 2.

3.2.5 *shear strength parameter, φ*—friction angle; the angle of the tangent to the failure curve at a normal stress that is relevant to design as shown in Fig. 2.

3.2.5.1 *Discussion*—Different values of c and φ relate to different stages of a test, for example, c', c_r', φ_a , and φ_b, of Fig. 2.

4. Summary of Test Method

4.1 This test method is performed on rectangular-shaped blocks of rock that are isolated on all surfaces, except for the shear plane surface.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Aug. 1, 2012. Published November 2012. Originally approved in 1985. Last previous edition approved in 2006 as D4554 – 02 (2006). DOI: 10.1520/D4554-12.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

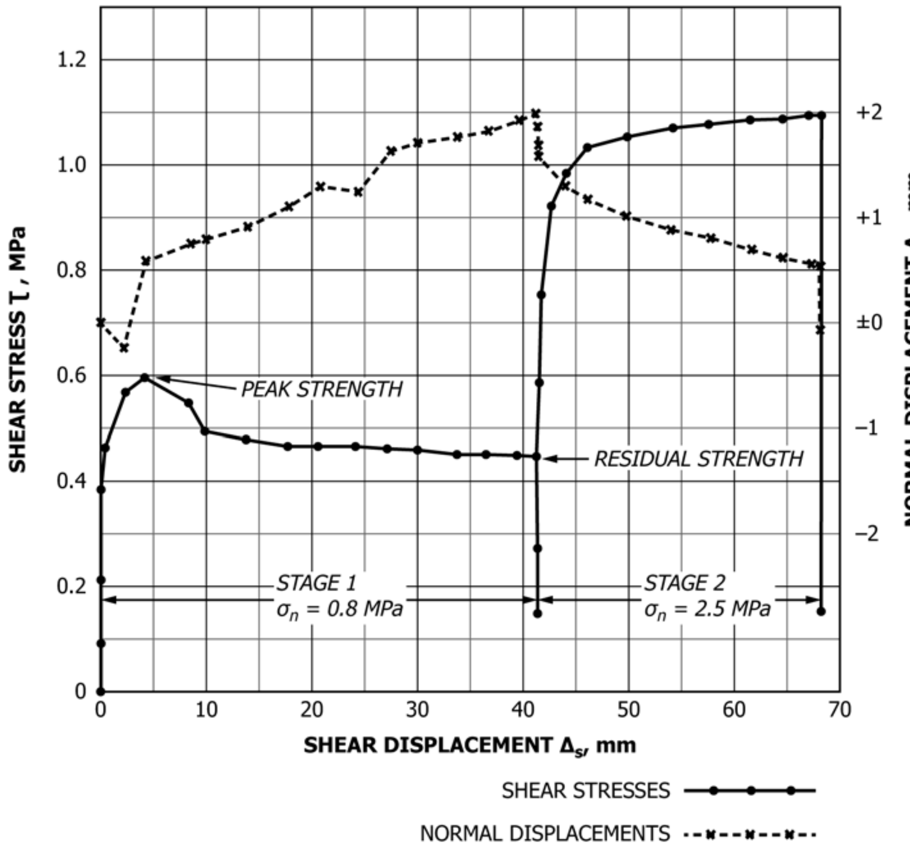


FIG. 1 Shear Stress – Displacement Graphs

4.2 The blocks are not to be disturbed during preparation operations. The base of the block coincides with the plane to be sheared.

4.3 A normal load is applied perpendicular to the shear plane and then a side load is applied to induce shear along the plane and discontinuity. A typical equipment configuration is shown in Fig. 3.

5. Significance and Use

5.1 Because of scale effects, there is no simple method of predicting the in situ shear strength of a rock discontinuity from the results of laboratory tests on small specimens; in situ tests on large specimens are the most reliable means.

5.2 Results can be employed in stability analysis of rock engineering problems, for example, in studies of slopes, underground openings, and dam foundations. In applying the test results, the pore water pressure conditions and the possibility of progressive failure must be assessed for the design case, as they may differ from the test conditions.

5.3 Tests on intact rock that are free from planes of weakness are usually accomplished using laboratory triaxial testing. Intact rock can, however, be tested in situ in direct shear if the rock is weak and if the specimen block encapsulation is sufficiently strong.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

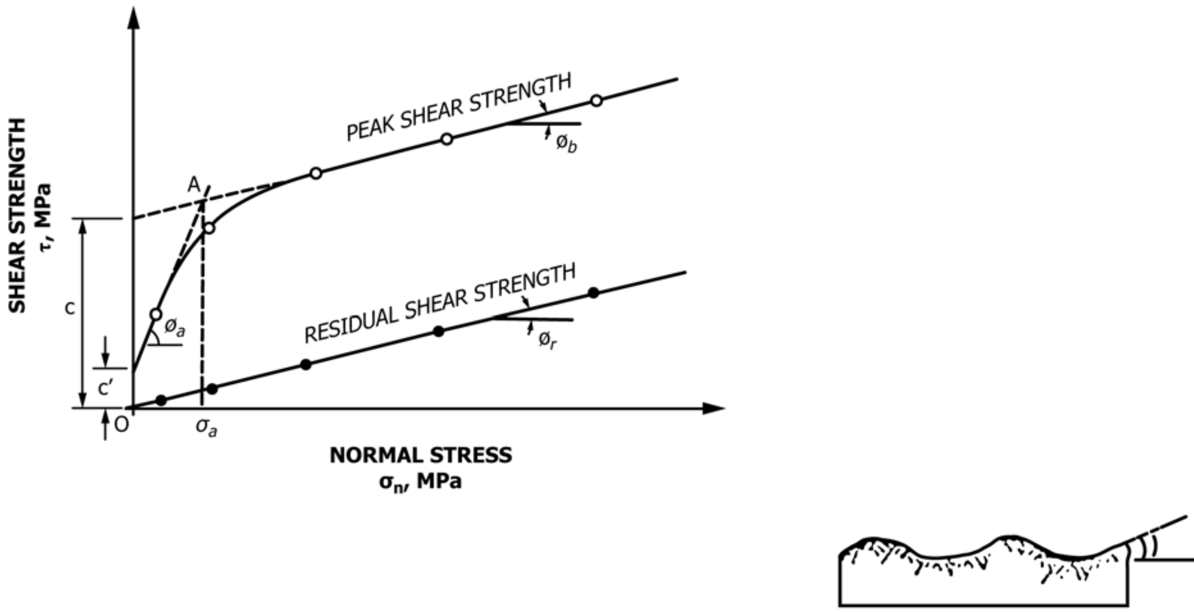
6. Apparatus

6.1 *Equipment for Cutting and Encapsulating the Test Block*—This equipment includes rock saws, drills, hammer and chisels, formwork of appropriate dimensions and rigidity, expanded polystyrene sheeting or weak filler, and materials for reinforced concrete encapsulation.

6.2 *Equipment for Applying the Normal Load*—This equipment includes flat jacks, hydraulic rams, or dead load of sufficient capacity to apply the required normal loads as shown in Fig. 3.

NOTE 2—If a dead load is used for normal loading, precautions are required to ensure accurate centering and stability. If two or more hydraulic rams are used for loading, care is needed to make sure their operating characteristics are identically matched and they are in exact parallel alignment.

6.2.1 Each hydraulic ram should be provided with a spherical seat. The travel of rams, and particularly of flat jacks, should be sufficient to accommodate the full-anticipated specimen displacement. The normal displacement may be estimated from the content and thickness of the filling and roughness of the shear surfaces. The upper limits would be the filling thickness.



NOTE 1—In this case, intercept c_r on shear axis is zero.

φ_r	=	residual friction angle,
φ_a	=	apparent friction angle below stress σ_a; point A is a break in the peak shear strength curve resulting from the shearing off of major irregularities on the shear surface. Between points O and A, φ_a will vary somewhat; measure at stress level of interest. Note also that $\varphi_a = \varphi_u + i$ where:
φ_u	=	friction angle obtained for smooth surfaces of rock on rock, and
i	=	inclination angle of surface asperities.
φ_b	=	apparent friction angle above stress level σ_a (Point A); note that φ_a will usually be equal to or slightly greater than φ_r and will vary somewhat with stress level; measure at the stress level of interest, *r*.
c'	=	cohesion intercept of peak shear strength curve; it may be zero.
c	=	apparent cohesion at a stress level corresponding to φ_b, and
c_r	=	cohesion intercept of residual shear strength which is usually negligible.

FIG. 2 Shear Strength – Effective Normal Stress Graph

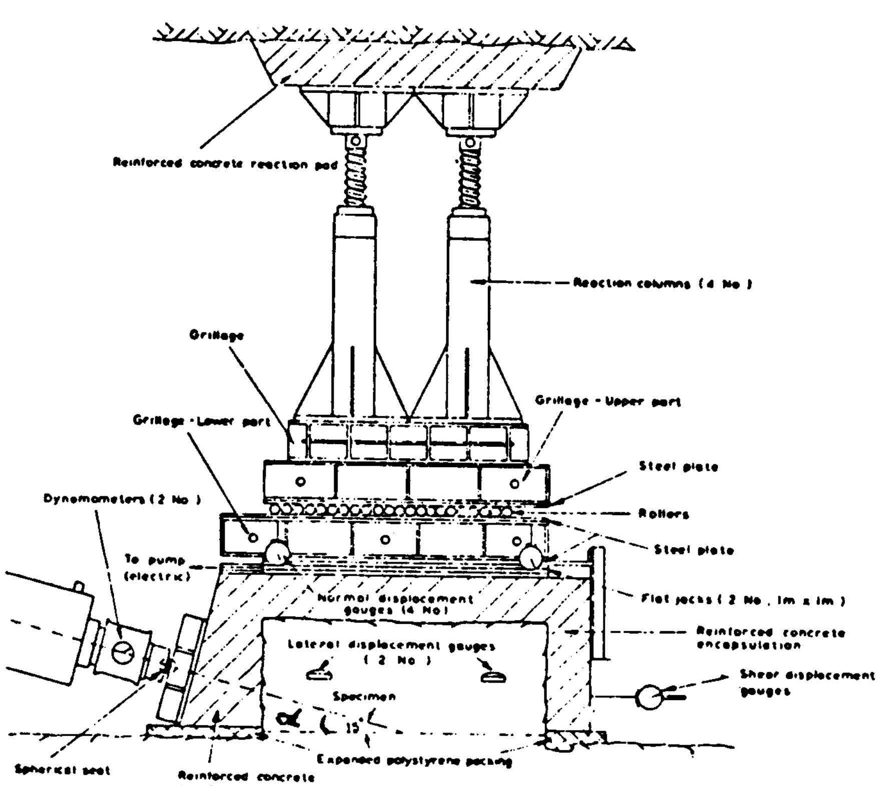


FIG. 3 Typical Arrangement of Equipment for In Situ Direct Shear Test

6.2.2 *Hydraulic System*—A hydraulic system, if used, should be capable of maintaining a normal load to within 2 % of a selected value throughout the test.

6.2.3 *Reaction System*—A reaction system to transfer normal loads uniformly to the test block includes rollers or a similar low friction device to make sure that at any given normal load, the resistance to shear displacement is less than 1 % of the maximum shear force applied in the test. Rock anchors, wire ties, and turnbuckles are usually required to install and secure the equipment.

6.3 *Equipment for Applying the Shear Force*—Hydraulic rams of adequate total capacity with at least 150 mm of travel.

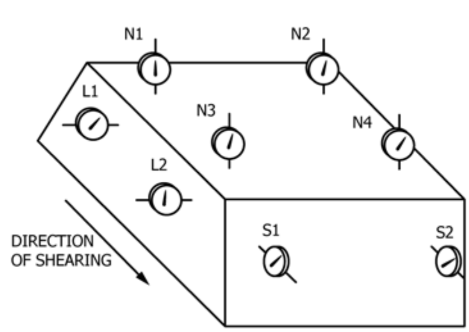
6.3.1 *Hydraulic Pump*—Capable of pressurizing the shear force system.

6.3.2 *Reaction System*—A reaction system to transmit the shear force to the test block. The shear force should be uniformly distributed along one face of the specimen. The resultant line of applied shear forces should pass through the center of the base of the shear plane at an angle approximately 15° to the shear plane with an angular tolerance of ±5°. The exact angle should be measured to ±1°.

NOTE 3—Tests where both shear and normal forces are provided by a single set of jacks inclined at greater angles to the shear plane are not recommended, as it is then impractical to control shear and normal stresses independently.

6.4 *Equipment for Measuring the Applied Force*—This equipment includes one system for measuring normal force and another for measuring applied shearing force with an accuracy better than ±2 % of the maximum forces reached in the test. Load cells, dynamometers or flat jack pressure measurements may be used. Recent calibration data applicable to the range of testing should be appended to the test report. If possible, the gauges should be calibrated both before and after testing.

6.5 *Equipment for Measuring Shear, Normal, and Lateral Displacement*—Displacement should be measured, for example, using micrometer dial gauges, at eight locations on the specimen block or encapsulating material, as shown in Fig. 4 (Note 4). The shear displacement measuring system should have a travel of at least 100 mm and accuracy better than 0.1 mm. The normal and lateral displacement measuring systems should have a travel of at least 20 mm and an accuracy better than 0.05 mm. The measuring reference system (beams, anchors, and clamps) should, when assembled, be sufficiently rigid to meet these requirements. Resetting of gauges during the test should be avoided, if possible.



NOTE 1—Gauges S1 and S2 are for shear displacement, L1 and L2 for lateral displacement, N1 through N4 for normal displacement.

FIG. 4 Arrangement of Displacement Gauges

NOTE 4—The surface of encapsulating material is usually insufficiently smooth and flat to provide adequate reference for displacement gauges; glass plates may be cemented to the specimen block for this purpose. These plates should be of adequate size to accommodate movement of the specimen. Alternatively, a temperature calibrated tensioned wire and pulley system with gauges remote from the specimen may be used. The system, as a whole, must be reliable and must conform to the specified accuracy requirements. Particular care is needed in this respect when employing electric transducers or automatic recording equipment.

7. Preparation of Test Specimens

7.1 Outline a test block such that the base of the block coincides with the plane to be sheared. The direction of shearing should correspond, if possible, to the direction of anticipated shearing in the full-scale structure to be analyzed using the test results. To inhibit relaxation, swelling, and to prevent premature sliding, it is necessary to apply a normal load to the upper face of the test specimen as soon as possible after excavation of the opening and prior to sawing the sides. Screw props or a system of rock bolts and crossbeams, may, for example, provide the load approximately equal to the overburden pressure. Maintain the load until the test equipment is in position. Saw the test block to the required dimensions, approximately 700 mm by 700 mm by 350 mm using methods that avoid disturbance or loosening of the block. See Note 5. Saw a channel approximately 20 mm deep by 80 mm wide around the base of the block to allow freedom of displacements during testing and also to facilitate possible required saturation. The block and particularly the shear plane should, unless otherwise specified, be retained as close as possible to its natural in situ conditions during preparation and testing.

NOTE 5—A test block size of 700 by 700 by 350 mm is suggested as standard for in situ testing. Smaller blocks are permissible, if, for example, the surface to be tested is relatively smooth; larger blocks may be needed when testing very irregular surfaces. For convenience, the size and shape of the test block may be adjusted so that the faces of the block coincide with joints or fissures. This adjustment minimizes block disturbance during preparation. Irregularities that would limit the thickness or emplacement of encapsulation material or reinforcement should be removed.

7.1.1 Apply a layer of weak material, such as foamed polystyrene at least 20 mm thick around the base of the test block, and then encapsulate the remainder of the block in concrete or similar material of sufficient strength and rigidity to prevent collapse or significant distortion during testing. Design the encapsulation formwork to make sure the load bearing faces are flat to a tolerance of ±3 mm and at the correct inclination to the shear plane to a tolerance of ±2°.

7.1.2 Carefully position and align reaction pads, anchors, and alike if required, to carry the thrust from normal and shear load systems to adjacent sound rock. Allow all concrete time to gain adequate strength prior to testing.

8. Calibration/Verification

8.1 Equipment used to measure the normal and shear forces shall be calibrated at least annually and verified before and after testing.

8.2 Equipment used to measure displacement shall be verified annually.

9. Procedure

9.1 Prepare the test block as described in Section 7.

9.2 *Consolidation of Test Specimen:*

9.2.1 The consolidation stage of testing is necessary in order to allow pore water pressures, in the rock and especially in any filling material adjacent to the shear plane, to dissipate under full normal stress before shearing. Behavior of the specimen during consolidation may also impose a limit on permissible rate of shearing. See section 9.3.3.

9.2.2 Check all displacement gauges for rigidity, adequate travel, and freedom of movement, and record a preliminary set of load and displacement readings.

9.2.3 Raise the normal load to the full value specified for the test, recording any consequent normal displacements during consolidation of the test block as a function of time and applied loads as shown in Figs. 5 and 6.

9.2.4 If consolidation occurs, it may be considered complete when the rate of change in normal displacement recorded at each of the four gauges is less than 0.005 mm/min for at least 10 min. Shear loading may then be applied.

9.3 *Shear Testing:*

9.3.1 The purpose of shearing is to establish values for the peak and residual direct shear strengths of the test plane. Corrections to the applied normal load may be required to hold the normal stress constant, see section 10.5. A shear determination should preferably be comprised of at least five tests per block, tested at different but constant normal stress. If conditions warrant, test more than one block for each shear plane.

9.3.2 Apply the shear force either incrementally or continuously.

9.3.3 Take approximately 10 sets of readings before reaching peak strength as shown in Fig. 1 and Fig. 3. The rate of shear displacement should be less than 0.1 mm/min in the 10-min period before taking a set of readings. This rate may be increased to not more than 0.5 mm/min between sets of readings, provided the peak strength itself is adequately recorded. For a drained test, particularly when testing clay-filled discontinuities, the total time to reach peak strength should exceed $6t_{100}$, as determined from the consolidation curve, see 10.1 and Fig. 6. If necessary, the rate of shear should be reduced and the application of later shear force increments delayed to meet this requirement.

NOTE 6—The requirement that the total time to reach peak strength should exceed $6t_{100}$ is derived from a conventional soil mechanics consolidation theory assuming a requirement of 90 % pore water pressure dissipation.[3] This requirement is most important when testing a clay-filled discontinuity. In other cases, it may be difficult to define t_{100} with any precision because a significant proportion of the observed "consolidation" may be due to rock creep and other mechanisms unrelated to pore pressure dissipation. Provided the rates of shear specified in the text are followed, the shear strength parameters may be regarded as having been measured under conditions of effective stress (drained conditions).

9.3.4 After reaching peak strength, take readings at evenly spaced increments from 0.5 to 5 mm shear displacement, as necessary to adequately define the force-displacement curves as shown in Fig. 1. The rate of shear displacement should be 0.02 to 0.2 mm/min in the 10-min period before a set of readings is taken, and may be increased to not more than 1 mm/min between sets of readings.

[3] Gibson, R. E., and Henkel, D. J., *Geotechnique 4*, 1954, pp. 10–11.

DIRECT SHEAR TEST DATA SHEET

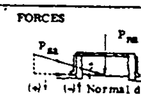
Client: Project: Concrete Dam Location: Alcântara Loc. No.: Block No.:

TEST BLOCK SPECIFICATION See drawings & photographs Nos.:

General rock description, index properties and water conditions
Phyllite, sound to moderately weathered Normal conditions

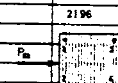
Description and index properties of surface to be sheared Type;
Dip; Dip direction; Roughness; Filling & alteration;
Persistance; Spacing of set; Surface dimensions; 0.70 x 0.70 Initial area A; 0.490 m^2

FORCES



$P_n = P_{na} + P_{sa} \sin\alpha$
$P_s = P_{sa} \cos\alpha$
$\sigma_n = P_n/A$
$\tau = P_s/A$
$\alpha = 15°$ σ_n (nominal)

1 Time elapsed (min)	2 Applied normal force P_n: Reading	2 Force (kN)	3 Normal displacement Δ_n: Reading 1	Reading 2	Reading 3	Reading 4	Average (mm)	4 Applied shear force P_s: Reading	4 Force (kN)	5 Shear displacement Δ_s: Reading 1	Reading 2	Average (mm)	6 Contact area A (corrected) m^2	7 P_{na} (kN)	8 σ_n (MP_a)	9 P_{sa} (kN)	10 τ (MP_a)
10		196	0.100	0.070	0.130	0.070			0	0	0	-	0.490	196		0	
35		233	0.130	0.065	0.140	0.090			137	0.05	0.05	0.05		•		142	
48		270	0.050	0.065	0.285	0.290			275	0.55	0.35	0.45		•		284	
64		306	-0.200	0.010	0.435	0.495			412	1.35	1.10	1.22		•		426	
87		343	-0.710	-0.205	0.600	0.720			549	2.55	2.30	2.42		•		568	
109		380	-1.165	-0.445	0.680	0.850			686	3.90	3.50	3.70		•		710	
131		417	-1.675	-0.615	0.710	0.970			824	5.15	4.60	4.88		•		853	
154		453	-1.965	-0.745	0.720	1.050			961	6.10	5.50	5.80		•		995	
172		490	-2.245	-0.880	0.720	1.105			1098	7.20	6.50	6.85		•		1137	
189		527	-2.480	-1.055	0.695	1.165			1235	8.20	7.40	7.80		•		1279	
206		504	-2.750	-1.205	0.640	1.165			1373	9.45	8.45	8.95		•		1421	
234		601	-3.075	-1.505	0.465	1.100			1510	11.00	10.00	10.50		•		1563	
252		637	-3.350	-1.830	0.280	0.910			1647	12.45	11.40	11.92		•		1705	
264		674	-3.675	-2.185	0.050	0.720			1784	14.00	12.80	13.40		•		1847	
276		711	-4.005	-2.665	-0.290	0.360			1922	15.55	14.40	14.98		•		1989	
289		748	-4.585	-3.125	-0.890	-0.020			2059	17.60	16.45	17.02		•		2132	
293	Rupture	784	-4.975	-3.375	-1.250	-0.290			2196	20.00	19.55	19.78		•		2274	



Calibration data

Remarks

Tested by; Dates;
Checked by; Date;

FIG. 5 Example Layout of Direct Shear Test Data Sheet

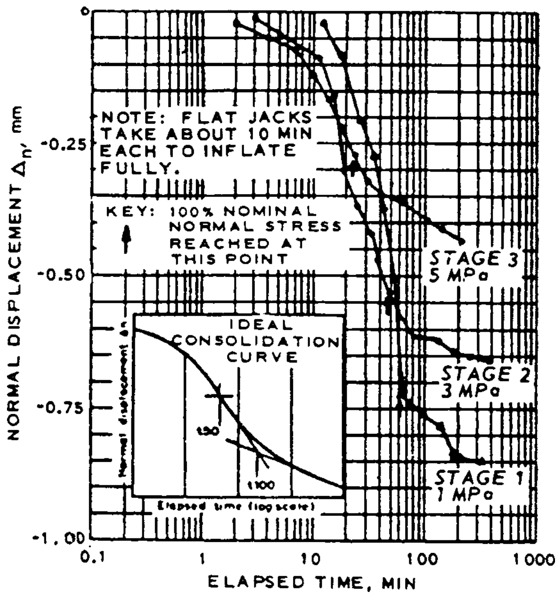


FIG. 6 Consolidation Curves for a Three-Stage Direct Shear Test, Showing the Construction Used to Estimate t_{100}

9.3.5 It may be possible to establish a residual strength value when the specimen is sheared at constant normal stress and at least four consecutive sets of readings are obtained which show not more than 5 % variation in shear stress over a shear displacement of 10 mm.

NOTE 7—An independent check on the residual friction angle should be made by testing in the laboratory two prepared, flat surfaces of the representative rock. The prepared surfaces should be saw-cut and then ground flat with No. 80 silicon carbide grit or finer, depending upon the rock grain size.

9.3.6 Having established a residual strength, the normal stress may be increased or reduced and shearing continued to obtain additional residual strength values. Reconsolidate the specimen under each new normal stress until the requirements of 9.2.4 are met and continue shearing in accordance with 9.3.3 – 9.3.5.

NOTE 8—The normal load should, when possible, be applied in increasing rather than decreasing stages. Reversals of shear direction or resetting of the specimen block between normal load stages, sometimes used to allow a greater total shear displacement than would otherwise be possible, are not recommended because the shear surface is likely to be disturbed and subsequent results may be misleading. It is generally advisable, although more expensive, to use a different specimen block.

9.3.7 After the test, invert the block, photograph in color, and fully describe (see Section 10). Measure and record the area, roughness, dip, and dip direction of the sheared surface. Take samples of rock, infilling, and shear debris for index testing.

10. Calculation

10.1 Plot a consolidation curve as shown in Fig. 6 during the consolidation stage of testing. Determine the time, t_{100}, for completion of primary consolidation by constructing tangents to the curve, as shown in Fig. 6. The time to reach peak strength from the start of shear loading should be greater than $6t_{100}$ to allow pore pressure dissipation (see Note 6).

10.2 Average displacement readings to obtain values of mean shear and normal displacements, Δ_s and Δ_n respectively. Record lateral displacements only to evaluate specimen behavior during the test; although, if appreciable, lateral displacements should be taken into account when computing corrected contact area.

10.3 Shear and normal stresses are computed as follows:

$$\text{Shear stress, } \tau = \frac{P_s}{A} = \frac{P_{sa}(\cos\alpha)}{A} \quad (1)$$

$$\text{Normal stress, } \sigma_n = \frac{P_n}{A} = \frac{P_{na} + P_{sa}(\sin\alpha)}{A} \quad (2)$$

where:

P_s = total shear force, MPa,
P_n = total normal force, MPa,
P_{sa} = applied shear force, MPa,
P_{na} = applied normal force, MPa,
α = inclination of the applied shear force to the shear plane; if $\alpha = 0$, $\cos\alpha = 1$, and $\sin\alpha = 0$, and
A = area of shear surface overlap (corrected to account for shear displacement), mm.

If α is greater than zero, reduce the applied normal force after each increase in shear force by an amount P_{sa} (sinα) in order to maintain the normal stress approximately constant. The applied normal force may be further reduced during the test to compensate for area changes by an amount:

$$\frac{\Delta_s \cdot P_n}{700} \quad (3)$$

where:

Δ_s = mean shear displacement, mm.

10.4 For each test specimen, plot graphs of shear stress or shear force and normal displacement versus shear displacement as shown in Fig. 1. Annotate graphs to show the nominal normal stress and any changes in normal stress during shearing. Values of peak and residual shear strengths and the normal stresses and shear and normal displacements at which these occur are abstracted from these graphs.

10.5 From the combined results for all test specimens, plot graphs of peak and residual shear strengths versus normal stress. Shear strength parameters, φ_a, φ_b, φ_r, and c are abstracted from these graphs, as shown in Fig. 2.

10.6 Roughness can be evaluated according to the Joint Roughness Coefficient (JRC). If the JRC value cannot be measured directly then the Barton graph can be used to obtain a JRC value as shown in Fig. 7.

11. Report: Test Data Sheet(s)/Form(s)

11.1 Record as a minimum the following information:

11.2 A diagram, photograph, and detailed description of test equipment and a description of methods used for specimen preparation and testing. Note any departures from the prescribed techniques.

11.3 For each specimen, a full geological description of the intact rock, sheared surface, filling, and debris. This information is preferably accompanied by relevant index test data, for example, Atterberg limits as described in Test Methods D4318, water content as described in Test Methods D2216, and grain-size distribution of filling materials as in Test Method D422 and Test Methods D6913.

11.4 Photographs of each sheared surface together with diagrams giving the location, dimensions, area, roughness, dip, and dip direction, and showing the directions of shearing and any peculiarities of the blocks.

11.5 For each test block, a set of data tables, a consolidation graph, and graphs of shear stress and normal displacement versus shear displacement (Fig. 1, Fig. 5, and Fig. 6). Tabulate abstracted values of peak and residual shear strengths with the corresponding values of normal stress, together with derived values for the shear strength parameters (Fig. 2).

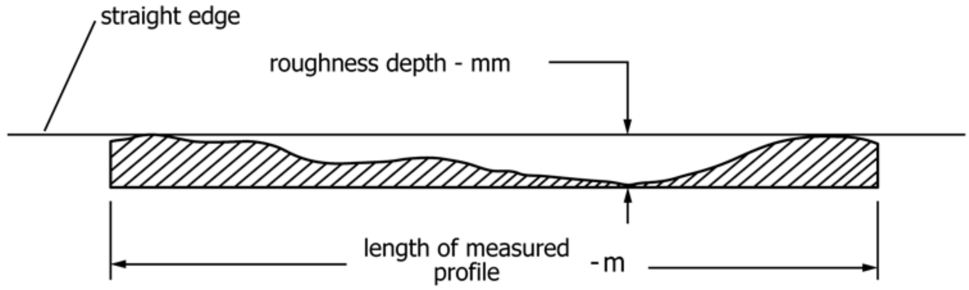
12. Precision and Bias

12.1 *Precision*—Due to the nature of rock materials tested by this test method, it is, at this time, either not feasible or too costly to produce multiple specimens that have uniform physical properties. Therefore, since specimens that would yield the same test results cannot be tested, Subcommittee D18.12 cannot determine the variation between tests since any variation observed is just as likely to be due to specimen variation as to operator or laboratory testing variation. Subcommittee D18.12 welcomes proposals to resolve this problem that would allow for development of a valid precision statement.

12.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

13. Keywords

13.1 direct shear strength; in situ stress; loading tests; rock discontinuities



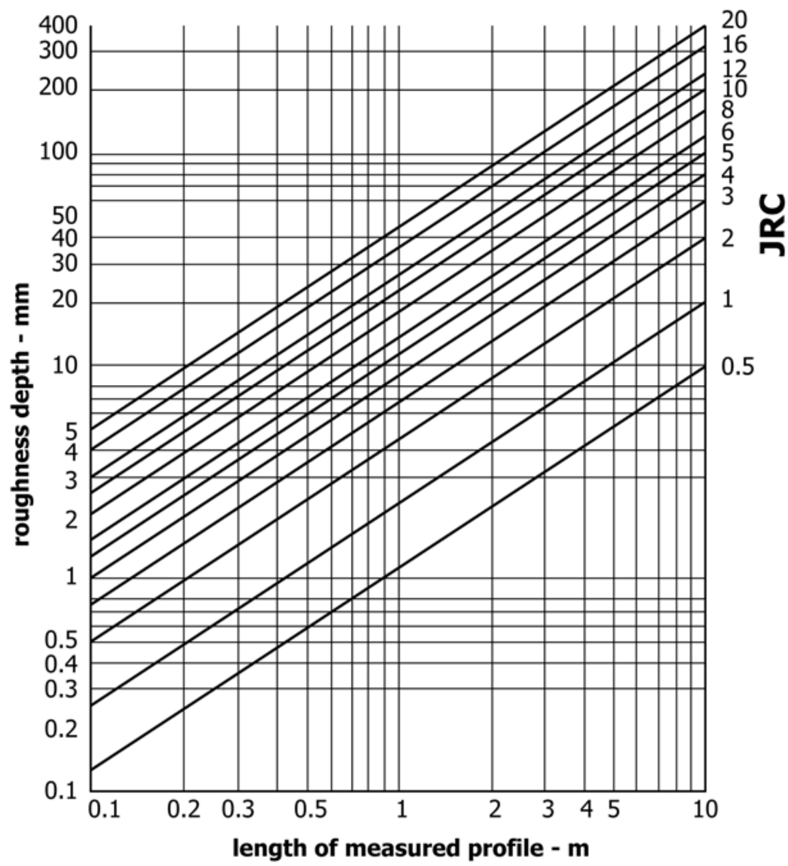


FIG. 7 Barton Graph Showing the Variation of the Coefficient JRC as a Function of Length of Profile and Roughness Depth

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this test method since the last issue, D4554-02(2006), that may impact the use of this test method. (Approved August 1, 2012)

(*1*) Added required footnote for Summary of Changes section.
(*2*) Added Referenced Document section.
(*3*) Reference to Terminology D653 and Practice D3740were added to Referenced Document section.
(*4*) Reference to Terminology D653 was added to Terminology section.
(*5*) The required caveat for Practice D3740 was added to the Significance and Use section.