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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for In Situ Determination of Direct Shear Strength of Rock Discontinuities[1]

This standard is issued under the fixed designation D 4554; 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 of in situ rock discontinuities as a function of stress normal to the sheared plane. This sheared plane is usually a significant discontinuity which 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.

1.4 *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. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *discontinuities*—this includes joints, schistosity, faults, bedding planes, cleavage, and zones of weakness, along with any filling material.

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

2.1.3 *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 (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.

2.1.4 *shear strength parameter, c* (see Fig. 2)—the projected intercept on the shear stress axis of the plot of shear stress versus normal stress (see Note).

2.1.5 *shear strength parameter,* ϕ (see Fig. 2)—the angle of the tangent to the failure curve at a normal stress that is relevant to design.

2.1.5.1 *Discussion*—Different values of c and ϕ relate to different stages of a test (for example, c', c_r', ϕa, and ϕb, of Fig. 2).

3. Summary of Test Method

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

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

3.3 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 (see Fig. 3).

4. Significance and Use

4.1 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.

4.2 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.

4.3 Tests on intact rock (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.

5. Apparatus

5.1 *Equipment for Cutting and Encapsulating the Test Block*—This 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.

5.2 *Equipment for Applying the Normal Load (see* Fig. 3*)*—This includes flat jacks, hydraulic rams, or dead load of sufficient capacity to apply the required normal loads.

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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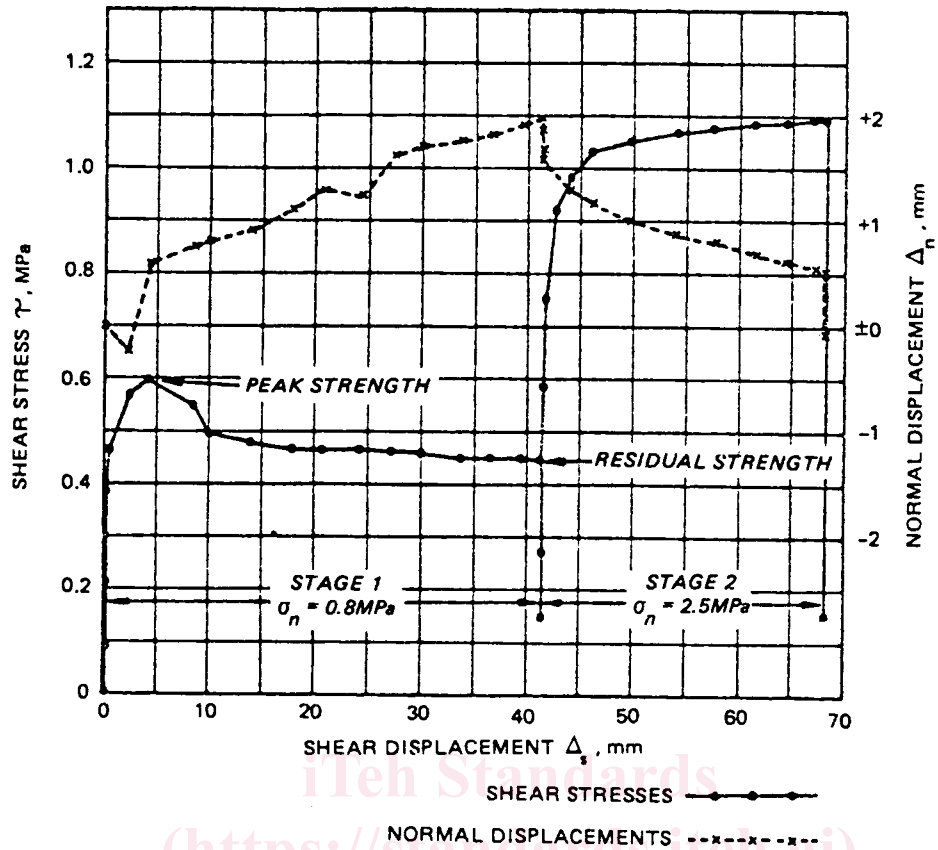


FIG. 1 Shear Stress – Displacement Graphs

NOTE 1—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 ensure that their operating characteristics are identically matched and they are in exact parallel alignment.

5.2.1 Each 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.

5.2.2 *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.

5.2.3 *Reaction System*—A reaction system to transfer normal loads uniformly to the test block includes rollers or a similar low friction device to ensure 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.

5.3 *Equipment for Applying the Shear Force (see* Fig. 3*)*:

5.3.1 *One or More Hydraulic Rams*, of adequate total capacity with at least 150-mm travel.

5.3.2 *Hydraulic Pump*, to pressurize the shear force system.

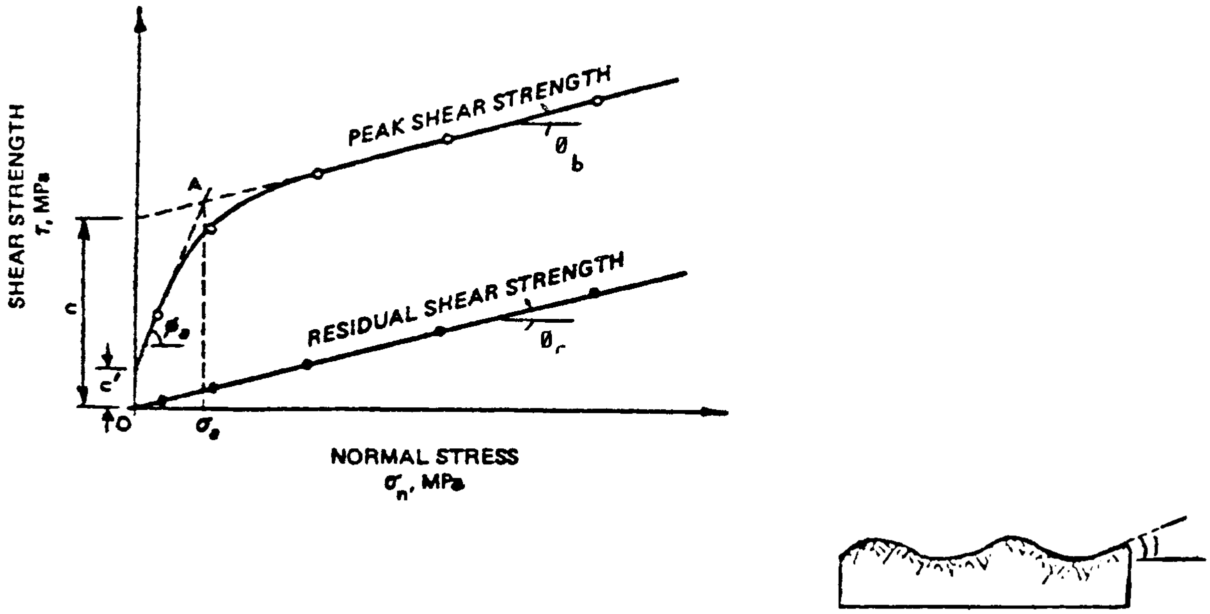
5.3.3 *Reaction System*—A reaction system to transmit the shear force to the test block. The shear force should be distributed uniformly along one face of the specimen. The resultant line of applied shear forces should pass through the center of the base of the shear plane at an angle approximately 15°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

NOTE 2—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.

5.4 *Equipment for Measuring the Applied Force*—This 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 gages should be calibrated both before and after testing.

5.5 *Equipment for Measuring Shear, Normal, and Lateral Displacement*—Displacement should be measured (for example, using micrometer dial gages) at eight locations on the specimen block or encapsulating material, as shown in Fig. 4 (Note 3). The shear displacement measuring system should have a travel of at least 100 mm and an 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 gages during the test should be avoided, if possible.

NOTE 3—The surface of encapsulating material is usually insufficiently



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 $\phi_a = \phi_u$ + 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

smooth and flat to provide adequate reference for displacement gages; 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 gages remote from the specimen may be used. The system, as a whole, must be reliable and must conform with specified accuracy requirements. Particular care is needed in this respect when employing electric transducers or automatic recording equipment.

6. Procedure

6.1 *Preparation of Test Specimen*:

6.1.1 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 and 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. The load, approximately equal to the overburden pressure, may, for example, be provided by screw props or a system of rock bolts and crossbeams. Maintain the load until the test equipment is in position. Saw the test block to the required dimensions (usually 700 by 700 by 350 mm) using methods that avoid disturbance or loosening of the block. Saw a channel approximately 200 mm deep by 80 mm wide around the base of the block to allow freedom of displacements during testing. 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 4—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.

6.1.2 Apply a layer of weak material at least 20 mm thick (for example, foamed polystyrene) 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 ensure that the load bearing faces are flat (tolerance ±3 mm) and at the correct inclination to the shear plane (tolerance ±2°).

6.1.3 Carefully position and align reaction pads, anchors, etc., 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.

6.2 *Consolidation of Test Specimen*:

6.2.1 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