Designation: D3967 – 16

Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens[1]

This standard is issued under the fixed designation D3967; 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 testing apparatus, specimen preparation, and testing procedures for determining the splitting tensile strength of rock by diametral line compression of disk shape specimens.

NOTE 1—The tensile strength of rock determined by tests other than the straight pull test is designated as the "indirect" tensile strength and, specifically, the value obtained in Section 9 of this test is termed the "splitting" tensile strength.

1.2 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units, which are provided for information only and are not considered standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

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

1.3.1 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design

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. Referenced Documents

2.1 *ASTM Standards:*[2]

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

D6026 Practice for Using Significant Digits in Geotechnical Data

E4 Practices for Force Verification of Testing Machines

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E2586 Practice for Calculating and Using Basic Statistics

3. Terminology

3.1 *Definitions:*

3.1.1 For common definitions of terms in this standard, refer to Terminology D653.

4. Summary of Test Method

4.1 Samples are selected from rock cores or cored from platen samples for testing as described. A section of rock core sample is cut perpendicular to the core axis to produce disk shape specimens until the required number of specimens are obtained. Each specimen is then marked to indicate the desired orientation of the applied loading on the specimen by drawing a diametral line on each end surface on the specimen. Each specimen is positioned inside the testing machine in such way that diametrical line is coincidental with the loading axis of the testing machine either curved or flat platens. Each specimen is then tested by applying a continuously increasing compressive load until it fails within 1 to 10 minutes of the start of loading.

5. Significance and Use

5.1 By definition the tensile strength is obtained by the direct tensile test. However, the direct tensile test is difficult

[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 Nov. 1, 2016. Published November 2016. Originally approved in 1981. Last previous edition approved in 2008 as D3967 – 08. DOI: 10.1520/D3967-16.

[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**

and expensive for routine application. The splitting tensile test appears to offer a desirable alternative, because it is much simpler and inexpensive. Furthermore, engineers involved in rock mechanics design usually deal with complicated stress fields, including various combinations of compressive and tensile stress fields. Under such conditions, the tensile strength should be obtained with the presence of compressive stresses to be representative of the field conditions.

5.2 The splitting tensile strength test is one of the simplest tests in which such stress fields occur. Also, by testing across different diametrical directions, possible variations in tensile strength for anisotropic rocks can be determined. Since it is widely used in practice, a uniform test method is needed for data to be comparable. A uniform test is also needed to make sure that the disk specimens break diametrically due to tensile stresses perpendicular to the loading diameter.

NOTE 2—The quality of the results 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 *Loading Device*—A device of sufficient capacity to apply and measure the load at a rate conforming to the requirements in 8.3. It shall be verified at suitable time intervals in accordance with Practices E4 and shall comply with the requirements prescribed therein.

6.1.1 *Bearing Platens*—The loading device shall be equipped with two opposing steel bearing platens having a Rockwell hardness of not less than 58 HRC through which loading is transmitted. The bearing faces shall not depart from a plane by more than 0.0125 mm (0.0005 in.) when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The bearing platens diameter shall be at least as great as the specimen's thickness (see Note 3).

6.1.2 *Spherical Seating*—One of the bearing surfaces on the loading device should be spherically seated and the other one a plain rigid platen. The diameter of the spherical seat shall be at least as large as the test specimen, but the diameter of the sperical seat shall not exceed from twice the diameter of specimen. Center of the sphere in the spherical seat coincides with the center of loaded side of the specimen. The spherical seat shall be lubricated to assure its free movement. The movable part of the platen shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction. If the spherical seat's diameter exceeds twice the diameter of the test specimen, then the spherical seat shall be placed in the locked position with the faces of the bearing platens meeting the requirements of 6.1.1.

6.1.3 *Rigid Seating*—If a spherical seat is not used, then the faces of the loading device bearing platens shall be parallel to 0.0005 mm/mm of the platen diameter. This criterion shall be met when the platens are in the loading device and separated approximately by diameter of the test specimen.

NOTE 3—False platens, due to the contact with abrasive rocks, these platens tend to roughen after a number of specimens have been tested, and hence need to be surfaced from time to time.

6.2 *False, Flat or Curved Bearing Platens*—During testing, the specimen can be placed in direct contact with the loading device bearing platens or false platens with bearing faces conforming to the requirements of this standard, may be used (see Fig. 1 for false flat platens). These shall be oil hardened to more than 58 HRC, and surface ground. With contact by abrasive rocks, these platens tend to roughen after a number of specimens have been tested, and hence need to be re-surfaced from time to time.

6.2.1 *False Flat Bearing*—The bearing faces of false flat bearing platens shall not depart from a plane by more than 0.0125 mm (0.0005 in.) when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The bearing platen's diameter shall be at least as great as the specimen thickness.

6.2.2 *Curved Supplementary Bearing Platens*—These may be used to reduce the contact stresses on the test specimen. The radius of curvature of the supplementary bearing platens shall be so designed that their arc of contact with the specimen will in no case exceed 15° or that the width of contact is less than $D/6$, where D is the diameter of the specimen.

NOTE 4—Since the equation used in 9.1 for splitting tensile strength is derived based on a line load, the applied load should be confined to a very narrow strip if the splitting tensile strength test is to be valid. But a line

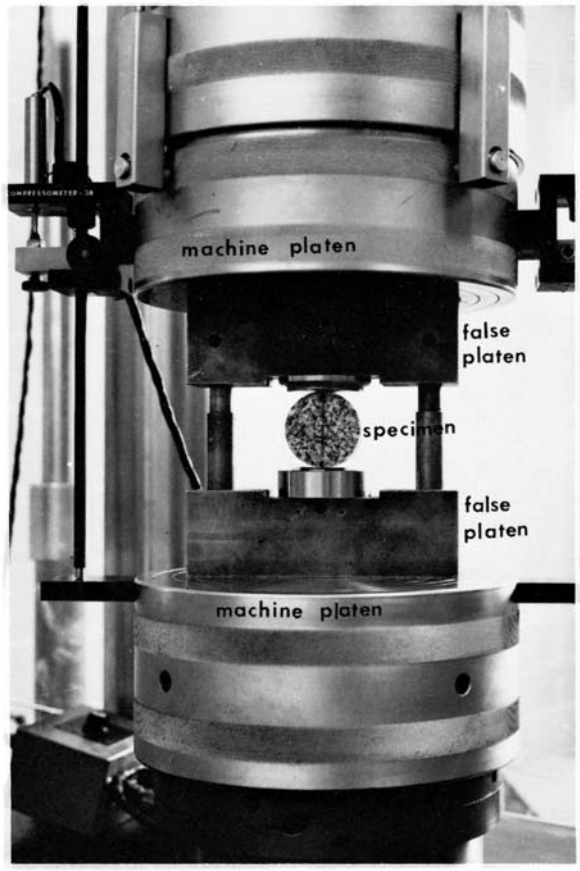

FIG. 1 One Proposed Testing Setup for Splitting Tensile Strength

load creates extremely high contact stresses which cause premature cracking. A wider contact strip can reduce the problems significantly. Studies show that an arc of contact smaller than 15° causes no more than 2 % of error in principal tensile stress while reducing the incidence of premature cracking greatly.

6.3 *Bearing Strips (optional)*—0.01 *D* thick cardboard cushions, where *D* is the specimen's diameter; or up to 6.4 mm (0.25 in.) thick plywood cushions are recommended to be placed between the machine bearing surfaces (or supplementary-bearing plates; if used) and the specimen to reduce high stress concentration.

NOTE 5—Experience has indicated that test results using the curved supplementary bearing plates and bearing strips, as specified in 6.2.2 and 6.3, respectively, do not significantly differ from each other, but there may be some consistent difference from the results of tests in which direct contact between the specimen and the machine platen is used.

7. Sampling, Test Specimens, and Test Units

7.1 The samples shall be selected by visual observation to include a range of specimens based on rock type, mineral constituents, grain sizes and shape, partings, and defects such as pores and fissures.

7.2 *Test Specimens:*

7.2.1 *Dimensions*—The test specimen shall be a circular disk with a thickness-to-diameter ratio (*t/D*) between 0.2 and 0.75. The diameter of the specimen shall be at least 10 times greater than the largest mineral grain constituent. A diameter of 54 mm (NX core) will generally satisfy this criterion.

NOTE 6—When cores smaller than the specified minimum must be tested because of the unavailability of material, notation of the fact shall be made in the test report.

NOTE 7—If the specimen shows apparent anisotropic features such as bedding or schistosity, care shall be exercised in preparing the specimen so that the orientation of the loading diameter relative to anisotropic features can be determined precisely.

7.2.2 *Number of Specimens*—At least ten specimens shall be tested to obtain a meaningful average value. If the reproducibility of the test results is good (coefficient of variation less than 5 %), a smaller number of specimens is acceptable.

7.2.3 The circumferential surface of the specimen shall be smooth and straight to 0.50 mm (0.02 in.).

7.2.4 Cut the ends of the specimen parallel to each other and at right angles to the longitudinal axis. The ends of the specimen shall not deviate from perpendicular to the core axis by more than 0.5°. This requirement can be generally met by cutting the specimen with a precision diamond saw.

7.2.5 Determine the diameter of the specimen to the nearest 0.25 mm (0.01 in.) by recording at least three measurements, one of which shall be along the loading diameter, and calculating the average.

7.2.6 Determine the thickness of the specimen to the nearest 0.25 mm (0.01 in.) by recording at least three measurements, one of which shall be at the center of the disk, and calculating the average.

7.2.7 The moisture conditions of the specimen at the time of test can have a significant effect upon the indicated strength of the rock. The field moisture condition for the specimen shall be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents, including zero, and preconditioning of specimen when moisture control is needed. In any case, tailor the moisture content of the test specimen to the problem at hand and record it in accordance with 10.4.2.

NOTE 8—It is recommended that the moisture condition be more precisely determined when possible and reported as either water content by Test Methods D2216 or degree of saturation.

8. Procedure

8.1 *Marking*—The desired vertical orientation of the specimen shall be indicated by marking a diametral line on each end of the specimen. These lines shall be used in centering the specimen in the testing machine to make sure proper orientation, and they are also used as the reference lines for thickness and diameter measurements.

NOTE 9—If the specimen is anisotropic, take care to make sure that the marked lines in each specimen refer to the same orientation.

8.2 Set up specimen in testing machine.

8.2.1 *Positioning*—Position the test specimen between the top and bottom loading platens so that the diametral plane of the two lines marked on the ends of the specimen lines up with the center of thrust of the spherically seated bearing surface to within 1.25 mm (0.05 in.). Each specimen is positioned inside the testing machine in such way that the marked diametrical line is coincidental with the loading axis of testing machine with either curved or false flat platens.

8.2.2 *Preloading*— To achieve it, slowly bring the loading platens together until the top platen barely and gently contacts the specimen, with little or no load on it. Assure the positioning criterion noted in 8.2.1 is still met.

NOTE 10—A good line loading can often be attained by rotating the specimen about its axis until there is no light visible between the specimen and the loading platens. Back lighting helps in making this observation.

NOTE 11—Application of bearing strips as it is noted in 6.3, or putting masking tape around specimen's circumference will help to better positioning of specimen and a good line loading.

8.3 *Loading*—After preloading, apply a continuously increasing compressive load to produce an approximately constant rate of loading such that failure will occur within 1 to 10 min of loading, which should fall between 0.05 and 0.35 MPa/s (500 and 3,000 psi/min) of loading rate, depending on the rock type. The maximum load sustained by the specimen shall be recorded. Load readings shall be recorded to the appropriate number of significant figures (usually 3).

NOTE 12—Results of tests by several investigators indicate that rates of loading at this range are reasonably free from rapid loading effects.

9. Calculation

9.1 The splitting tensile strength of the specimen with the flat platens (1) or curved platens (2) shall be calculated accordingly as follows:

$$\sigma_t = 2P/\pi tD \quad (1)$$

$$\sigma_t = 1.272\ P/\pi tD \quad (2)$$

Radius of jaws shall be 1.5× specimen's radius and the result shall be expressed to the appropriate number of significant figures (usually 3),

where:

σ_t = splitting tensile strength, MPa (psi),
P = maximum applied load indicated by the testing machine, N (or lbf),
t = thickness of the specimen, mm (or in.), and
D = diameter of the specimen, mm (or in.).

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

10.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.3.

10.2 Record as a minimum the following general information (data):

10.2.1 Sample/specimen identifying information, such as Project No., Boring No., Sample No., Depth (units). When possible, also record sources of the specimen including project name and location, dates of sampling, and if known, storage environment.

10.2.2 Physical description of the specimen including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or inhomogeneities, if any. A sketch or photograph may be used to describe the specimen.

10.2.3 Dates of testing, name or initials of the person doing the testing.

10.3 Record as a minimum the following test specimen data:

10.3.1 Specimen diameter and length, conformance with dimensional requirements, direction of loading if anisotropy exists. Type of contact between the specimen and the loading platens.

10.4 Record as a minimum the following test data:

10.4.1 Rate of loading.

10.4.2 General indication of moisture condition of the specimen at time of test such as as-received, saturated, laboratory air dry, or oven dry.

10.4.3 Splitting tensile strength of each specimen as calculated, average splitting tensile strength of all specimens, standard deviation or coefficient of variation, see Guide E2586.

10.4.4 Type and location of failure.

NOTE 13—A sketch or photograph of the fractured specimen is recommended.

10.4.5 For purposes of comparing calculated values with specified limits, the calculated values shall be rounded to the nearest decimal given in the specification limits in accordance with the provisions of Practice D6026 as it is referenced in 1.3 and 1.3.1.

11. Precision and Bias

11.1 An inter-laboratory study was conducted in which seven laboratories each tested five specimens of four different rocks. The specimens were cored by a single laboratory from a common set of samples and randomly distributed to the testing laboratories for testing. The study was carried out in accordance with Practice E691. Details of the study are given in ISR Research Report No. PS #D18.12-R01, 1992, and its Addendum, 1994. The table below gives the repeatability limit (within a laboratory) and reproducibility limit (between laboratories) for the method.

11.1.1 The probability is approximately 95 % that two test results obtained in the same laboratory on the same material will not differ by more than the repeatability limit. Likewise, the probability is approximately 95 % that two test results obtained in different laboratories on the same material will not differ by more than reproducibility limit.

TABLE 1 Splitting Tensile Strength (MPa)

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	3.85	4.92	9.39	13.66
Repeatability Limit	1.24	1.56	3.63	4.31
Reproducibility Limit	1.37	1.74	5.38	4.98

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

12. Keywords

12.1 compression testing; indirect tensile strength; loading tests; rock; splitting tensile strength; tension (tensile) properties/tests

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D3967 – 09) that may impact the use of this standard. (November 1, 2016)

(1) Revised 1.2.
(2) Added D2216 and E2586 to 2.1.
(3) Revised 3.1.1.
(4) Added Section 4, Summary of Test Method.
(5) Renumbered sections 4-12 and renumbered all references to sections.
(6) Revised 5.1.
(7) Revised Note 2.
(8) Revised 6.2, 6.2.1,6.2.2, 6.2.3 and 6.3.
(9) Added dimension in English system, 6.2.1 and 6.3.
(10) Revised Note 4.
(11) Removed 6.2.3 and 6.2.4.
(12) Revised title of Section 7.
(13) Revised 7.1.
(14) Revised title of 8.2.
(15) Added 8.2.2.
(16) Revised 8.3.
(17) Revised 8.5, 8.6 and 8.7.

(18) Revised 9.1, 9.2, and 9.3.
(19) Revised Note 8.
(20) Added to Section 9, specific formula of calculation of splitting tensile strength for curved shape platens.
(21) Revised title of Section 10.
(22) Added 11.1, 11.2 and 11.3.
(23) Split 10.2.1 into two sections.
(24) Revised section 10.2.3.
(25) Added Note 10.
(26) Added Note 12.
(27) Removed 11.4.6.
(28) Revised Summary of Changes.