Standard Test Method for Determining Deformability and Strength of Weak Rock by an In Situ Uniaxial Compressive Test[1]

This standard is issued under the fixed designation D4555; 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 the deformability and strength of large in situ specimens of rock by a uniaxial compressive test. The test results take into account the effect of both intact material behavior and the behavior of discontinuities contained within the specimen block.

1.2 This test method does not cover which type of specimen should be tested or whether anisotropic factors should be considered. The specifics of the test program need to be developed prior to testing and possibly even before sampling. Such specifics would be dependent on the intended use of the data, as well as any budgetary constraints and other factors, which are outside the scope of this test method.

1.3 Theoretically there is no limit to the size of the test specimen; however, size will be controlled by the strength of the test specimen relative to the capacity of any loading apparatus and bearing capacity of the surface the apparatus must react against. Furthermore, the orientation and strength of discontinuities relative to the specimen geometry will be a factor limiting specimen size too.

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

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *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

D6032 Test Method for Determining Rock Quality Designation (RQD) of Rock Core

D7012 Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

3. Terminology

3.1 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 *rock quality designation, RQD*—a method for quantitatively describing the nature of a rock mass from core borings. RQD is obtained by measuring the total length of all unweathered pieces of core greater than or equal to 100 mm and dividing the total by the length of the particular core run. This quantity is expressed as a percent and is used to classify in situ rock. See Test Method D6032.

3.2.2 *average joint fragment volume*—the average size of discrete rock blocks delineated by joints (discontinuities) in the test specimen.

3.2.2.1 *Discussion*—Average joint fragment volume is similar to other rock mass rating factors such as block volume and

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[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**

other methods described by Palmstrom[3] that take into account discontinuities breaking up an otherwise intact rock mass into discrete rock blocks of various sizes, and can estimate the average volume and statistical distribution of all the discrete blocks in a volume of rock. This is analogous to measuring or sieving all the discrete blocks in a rock mass and determining a distribution of block sizes, much the same as is used to describe the particle sizes of a soil specimen. Such information may explain any differences between test results. This could be a one, two or three dimensional value depending on the way it was measured and the requirements of the program for which it is to be used.

3.2.3 *volumetric joint count (J_v)*—the total number of joints (discontinuities) per unit length for each joint (discontinuity) set which is then added together to give the total number of joints per cubic meter.

3.2.3.1 *Discussion*—This could be a unidirectional measurement when done on drill core and therefore dependent on the direction of the drill hole(s) relative to the orientation of the discontinuity sets. Nonparallel (preferably orthogonal) scan line fracture surveys as well as drill holes could be used as well to take into account spatial orientations issues. Palmstrom related volumetric joint count (J_v) to RQD with the following formula: $J_v = (115 - RQD)/3.3$, with RQD = 0 for $J_v > 35$.

3.2.3.2 *Discussion*—From a review of the literature, Dr. Hoek refers to volume joint count (J_v) as joints per meter, whereas Bieniawski refers to it as joints per cubic meter. Therefore, there may be some differences in how the definition of volumetric joint count is interpreted or used.

4. Significance and Use

4.1 Since there is no reliable method of predicting the overall strength and deformation data of a rock mass from the results of laboratory tests on small specimens, in situ tests on large specimens are necessary, especially if the specimen size required for a given grain size would exceed the size that can be obtained for or tested in a laboratory as stated in Test Method D7012. Such tests also have the advantage that the rock specimen is tested under similar environmental conditions as prevailing for the rock mass.

4.2 Since the strength of rock is dependent on the size of the test specimen and discontinuities, it is necessary to test several specimens (laboratory or field, or both) of progressively increasing size until an asymptotically constant strength value is found. This value is taken to represent the strength of the rock mass.[4,5]

NOTE 1—Notwithstanding the statements on precision and bias contained in this test method; the precision of this test method 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. Users of this test method are cautioned that compliance with Practice D3740 does not in itself assure reliable testing. Reliable testing depends on many factors. Practice D3740 provides a means of evaluating some of those factors.

4.3 The test method is shown only being conducted underground and vertical. However, this test method could be done in a quarry or on the surface if a reaction frame could be set up to behave as a reactive surface in place of a tunnel crown.

5. Apparatus

5.1 *Preparation Equipment:*

5.1.1 Equipment for cutting specimen blocks from existing underground exposed faces, for example, a road header machine, drills for line drilling, pneumatic chisel, or other rock excavation or shaping tools.

5.1.2 If needed, equipment to make test area safe for preparation of specimen such as rock bolts, steel mesh, or other ground support hardware.

5.1.3 No explosives are permitted.

5.1.4 Cement and other associated equipment to mix, handle and cast loading cap and load bearing pad above and below the loading system.

5.2 *Loading System:*

5.2.1 *Hydraulic Cylinder/Ram or Flat Jacks*—This equipment is required to apply a uniformly distributed load to the complete upper face of the specimen. The loading system shall be of sufficient capacity and travel to load the specimen to failure. Multiple hydraulic jacks fed by a common manifold should be avoided. Hydraulic cylinder/ram jacks are usually preferred because of the available higher load and displacement ranges than what can be obtained with flat jacks.

5.2.2 *Loading platen*—Platens are used to transmit the axial load to the top of the specimen. The dimensional widths of the bearing surface of the platen shall be at least as great as the specimen dimensional widths, but shall not exceed 1.10 times any dimensional width of the specimen. The platen thickness shall be at least one-half the specimen average width. The platen is ideally made of aluminum for ease of handling, but other materials may be used if strong enough.

5.2.3 *Steel cables,* or other suitable method, attached between the loading system components placed on the test specimen and the overlying support for safety reasons as well as preventing equipment damage due to falling to floor after the specimen fails.

5.2.4 *Hydraulic Pumping System*—This system needs to supply oil at the required pressure to the jacks, the pressure being controlled to give a constant rate of displacement or strain, rather than a constant rate of stress increase.

NOTE 2—Experience has shown that deformation-controlled loading is preferable to stress-controlled loading because it results in a more stable, and thus safer, test. This result is a consequence of the strain softening nature of most rock or rock-like materials. A single stress level may correspond to different values of strain during any test, with the level of strain continuing to increase throughout a test. One way to achieve uniform deformation of the specimen is to use a separate pump for each jack and to set the oil delivery rate of each pump to the same value. Standard diesel fuel injection pumps have been found suitable and are capable of supplying pressures up to 100 MPa. The delivery rate of these pumps can be set very accurately.

[3] Palmstrom, A, "The volumetric joint count a useful and simple measure of the degree of rock jointing", Proceedings of the 4th International Congress on Rock Mechanics, ISRM, Vol. 2, 1982, pp. 221-228.

[4] Bieniawski, Z. T., and Van Heerdan, W. L., "The Significance of Large-Scale In Situ Tests," *International Journal of Rock Mechanics Mining Sciences*, Vol 1, 1975.

[5] Heuze, F. E., "Scale Effects in the Determination of Rock Mass Strength and Deformability," *Rock Mechanics*, Vol 12, 1980, pp 167–192.

5.3 *Equipment to Measure Applied Load and Deformation in the Specimen:*

5.3.1 *Load Measuring Equipment*—This equipment, for example, electric, hydraulic, or mechanical load cells, permits the applied load to be measured with an accuracy better than ±5 % of the maximum in the test.

5.3.2 *Deformation Measurement Devices*—Mechanical or electrical, or similar displacement measuring devices, with robust fittings to enable the instruments to be mounted so that the strain in the central third of each specimen face can be determined with an accuracy better than $\pm 10^{-5}$. Deformation is to be measured in the direction of applied load and also in a perpendicular direction if Poisson's ratio values are to be determined. Remote reading of any such devices is required due to the safety issues of taking readings up close while the specimen is being loaded and during failure.

5.4 *Calibration Equipment*—Equipment to calibrate the loading and displacement measuring systems, the accuracy of calibration to be better than the accuracies of test measurement specified in 5.3.1 and 5.3.2. Calibrate all measuring instruments both before and after each test series.

6. Procedure

6.1 *Preparation of Specimens:*

6.1.1 Besides rock type, selection of test sites should include planning the specimen location to minimize any known geologic factors from causing the final specimen or bearing areas to fail during preparation or the test. This may require mapping the prospective test volume and then estimating the best location within that volume for the specimen prior to excavation rather randomly picking a site. Furthermore, as mentioned in Section 4.2, the strength of rock is dependent on the size of the test specimen. Therefore, if such data is necessary then several specimens (laboratory or field, or both) of progressively increasing size will need to be prepared.

6.1.2 Label or name each test specimen or site according to some logical sequence of alpha-numeric text.

6.1.3 Cut specimens of the required dimensions from the exposed rock faces (Fig. 1). The specimen shall have a height-to-minimum-width dimension ratio of 2.0 to 2.5. The ratio of the maximum width of the specimen to the minimum width shall be as near to 1.0 as practicable.

6.1.3.1 First, remove loose and damaged rock. Make vertical cuts as shown in Fig. 1 to form the vertical faces of the specimen. Dimensional uniformity of each vertical face of the test specimen should not deviate by more than 20 mm. If there is such deviation, abandon the specimen. Make a horizontal cut

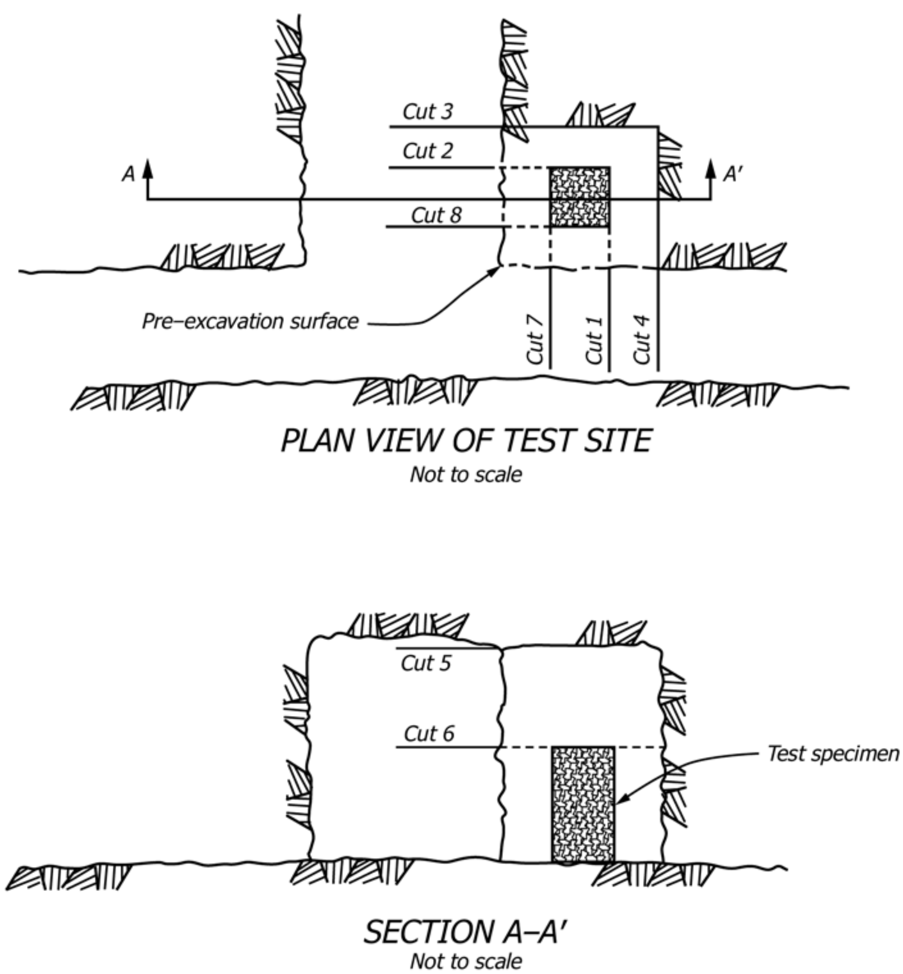


FIG. 1 Plan and Cross Sectional Views of a Hypothetical Underground Test Site Adjacent to a Tunnel or Adit Wall and Showing a Suggested Excavation Sequence for Specimen Preparation.

to form the top face of the specimen. Remove loose rock and trim the specimen to final size using hand tools.

NOTE 3—Specimen dimensions cannot be specified because they depend on the rock properties, for example, the thickness of strata, the spacing and orientation of discontinuities, and the ease with which specimens can be prepared. It is recommended that a number of tests be done with a specimen with a width of about 0.5 m and that the size of subsequent specimens should be increased until an asymptotically constant strength value is reached. It is probable that the largest test specimen will have a minimum width which meets the average grain size recommended in Test Method D7012, of at least 10 times greater than, but may not meet the recommended average dimension of the rock blocks defined by the discontinuities. For weak rock types, which behave more like soil (for example, weakly cemented sandstone), the minimum specimen width shall be at least six times the maximum particle diameter.

6.2 *Pretesting Specimen Documentation:*

6.2.1 Clean and inspect the specimen.

6.2.2 Record in detail the geological structure of the block and nature of the reaction faces of the block.

6.2.3 Measure specimen geometry, including the geometry of defects in the block, with accuracy better than 5 mm so that the average specimen dimensions and each discontinuities volumetric joint count can be determined.

6.2.4 Prepare photographs and drawings to illustrate both geological and geometric characteristics.

6.3 *Preparation of Reaction Surfaces for Loading Apparatus:*

6.3.1 Cast a concrete pad, suitably reinforced, to cover the top face of the specimen (Fig. 2). This pad shall be sufficient to give adequate strength under the full applied load. The top face of the pad shall be flat to within ±5° of the basal plane of the block.

6.3.2 If needed, remove any additional rock from above the specimen to make space for the loading jacks. Cut back the rock to a stratum of sufficient strength to provide safe reaction. Generally, a concrete reaction pad must be cast to distribute the load on the roof and to prevent undue deformation and movement of the jacks during the test. Wood cribbing or similar material that is less rigid than concrete is not recommended. The lower face of the reaction block shall be flat to within ±5 mm and shall be parallel to the upper face of the specimen block within ±5°. Cure all concrete for a sufficient period to provide adequate strength under the fully applied load.

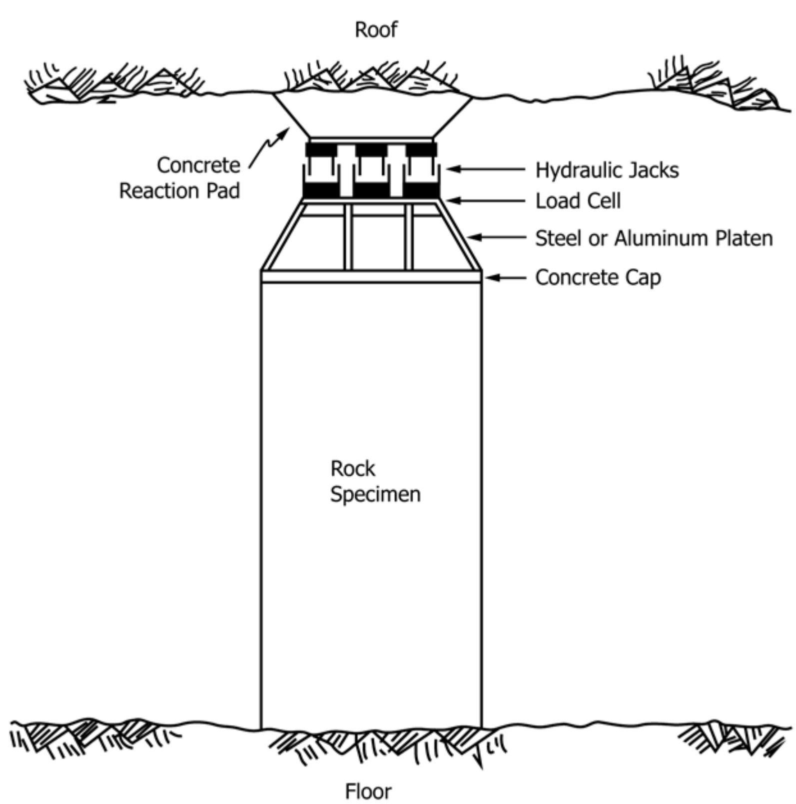
NOTE 4—If a suitably designed concrete cap to the specimen is not employed, the corners and sides of the specimen will often fail before the central portion. The corner jacks will then cease to operate, and the test results will be suspect. The concrete cap should, if possible, be designed to ensure that the stress distributions in the top and bottom thirds of the specimen are nearly identical.

6.4 *Setting up Test Apparatus:*

6.4.1 Calibrate all measuring instruments both before and after each test series.

6.4.2 Install the loading jacks, platen, and load measuring equipment and check to ensure that they operate as intended.

6.4.3 Install and check displacement measuring equipment.



NOTE 1—Rock bolts or other rock beneficiation of work area or bearing areas needed for safety or strengthening reasons are not shown.

FIG. 2 Test Arrangement

6.4.4 Set up monitoring station for readout units in a safe location away from test specimen. Test specimen area should not be between monitoring station and exit route.

6.5 *Testing:*

6.5.1 Take zero readings of load and displacement.

6.5.2 Apply an initial load of approximately one-tenth of the estimated full test load and check the jacks to ensure that each is in firm contact with the loading platen. Again check displacement measuring equipment to ensure that it is rigidly mounted and is functioning correctly.

6.5.3 Increase the specimen load by applying the same slow and constant oil delivery to each jack. The rate of axial specimen strain shall be constant across the test surface, such that a displacement rate of between 5 and 15 mm/h is recorded at each of the four faces of the specimen block.

6.5.4 Record readings of applied load and displacement at intervals such that the load—displacement or stress—strain curve can be adequately defined. There shall be at least ten points on this curve, evenly spaced from zero to the failure load.

6.5.5 Unless otherwise specified, terminate the test when the specimen fails. Specimen failure is indicated by a drop of hydraulic pressure to less than one-half the maximum applied, or by disintegration of the specimen to an extent that the loading system becomes inoperative or the test dangerous to continue.

6.6 *After Testing:*

6.6.1 Record the mode of specimen failure and document all developed cracks and failure surfaces using sketches, photographic, digital recordings, or combinations thereof.

6.6.2 Determine the moisture content on sample(s) from the test specimen in accordance with D6032 if needed or relevant to the test program. Depending on the specific geology of the test specimen, moisture contents may be required on the rock substance or discontinuities (or both).

7. Calculation

7.1 Calculate the mean cross-sectional area of the test specimen by multiplying the two average horizontal dimensions for the specimen determined in Section 6.2.3.

7.2 Calculate the mean volume of the test specimen by multiplying the mean cross-sectional area determined in Section 7.1 with the average height for the specimen determined in Section 6.2.3.

7.3 *(Optional)* Calculate the 1, 2 or 3 dimensional, average, joint fragment volume of each specimen using the methods shown by Palmstrom. A unidirectional or multidirectional volumetric joint count J_v can be determined from drill core or scan lines using the following relationships:

$$J_v = 1/S_1 + 1/S_2 + 1/S_3 + \ldots\ldots\ 1/S_i \quad (1)$$

where:

J_v = total number of joints (discontinuities) per meter,
$S_{1,\ 2,\ 3,\ldots i}$ = the total number of joints (discontinuities) belonging to each distinct set from 1, 2, 3,...i and measured normal to the joint (discontinuity) set mean orientation, per meter.

or,

$$RQD = 115 - 3.3\,(J_v)\ (0 < RQD < 100\ for\ 35 > J_v > 4.5) \quad (2)$$

or

$$J_v = 35 - RQD/3.3\ (0 < RQD < 100\ for\ 35 > J_v > 4.5) \quad (3)$$

where:

J_v = volumetric joint count in the direction of the drill hole, number of joints (discontinuities) per meter,
RQD = rock quality designation using Test Method D6032, in the depth range of the drill hole relevant to the testing, %
115 = an empirical factor, %
3.3 = an empirical factor for SI units, %

7.4 Calculate the uniaxial compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the original mean cross-sectional area of the specimen calculated in 7.1.

7.5 Calculate the stress and strain values from the load and deformation values according to Test Method D7012.

7.6 The deformation modulus for the specimen shall, unless otherwise specified, be calculated as the tangent modulus E_{t50} at one-half the peak uniaxial compressive strength. This modulus is found by drawing a tangent to the stress-strain curve at 50 % maximum load, as shown in Test Method D7012. Show on the stress-strain curve the construction and calculations used in deriving this, and any other modulus values using other criteria.

7.7 If lateral deformation data was collected, the Poisson's ratio shall, unless specified otherwise, be calculated as the tangent modulus (μ_{t50}) at one-half the peak uniaxial compressive strength as shown in Test Method D7012. Show on a stress-strain curve the construction and calculations used in deriving this value, and any other calculated Poisson's values.

7.8 If a number of specimens of different sizes were tested, then the trends in strength values due to size effects can be plotted graphically, as shown in Fig. 3.

8. Report

8.1 Report the following information:

8.1.1 A diagram showing the details of the locations of specimens tested, the specimen numbering system used, and the situation of each specimen with respect to the geology and geometry of the site.

8.1.2 Photographs, drawings, and tabulations giving full details of the geological and geometrical characteristics of each specimen, preferably including index test data to characterize the rock. Give particular attention to a detailed description of the pattern of joints, bedding planes, and other discontinuities in the specimen block as well as any other relevant geologic data.

8.1.3 A description, with diagrams, of the test equipment and method used and test personnel involved.

8.1.4 Tabulated test results, including recorded values of load and displacements, together with all derived data, calibration results, and details of all corrections applied.

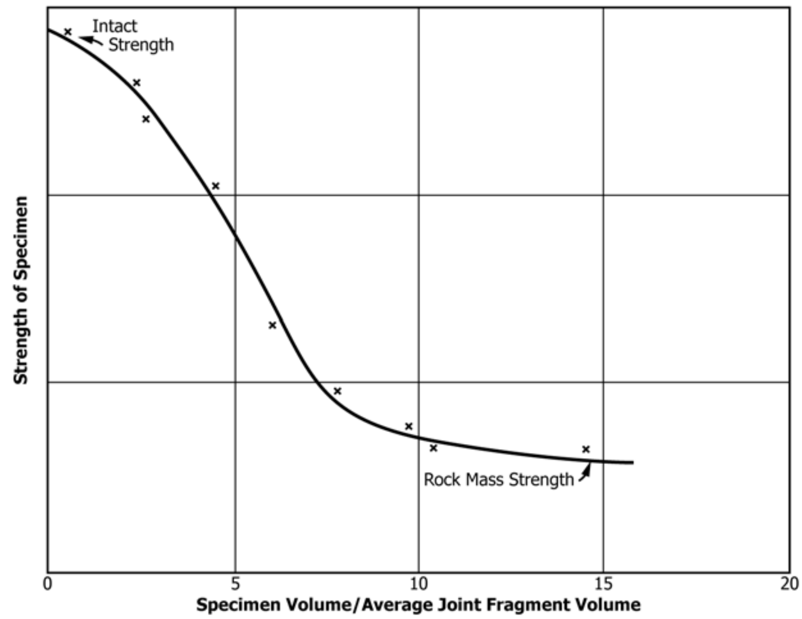


FIG. 3 Hypothetical Example Showing One Method of Analzing Strength Data versus Specimen Volume Divided by the Average Joint Fragment Volume.

8.1.5 Graphs showing load versus displacement or stress versus strain, including points representing all recorded data, and a curve fitted to these points.

8.1.6 Show the uniaxial compressive strength value, together with all constructions used in determining the deformation modulus and other elastic parameters.

8.1.7 Show by diagram and describe the mode of specimen failure.

8.1.8 Summary tables and graphs giving the values of uniaxial compressive strength deformation modulus, Poisson's ratio (if measured) and showing how these values vary as a function of specimen shape and size and the character of the rock tested; example shown in Fig. 3.

9. Precision and Bias

9.1 *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.

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

10. Keywords

10.1 compression testing; deformation; in situ stress loading tests

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4555 – 01 (2005)) that may impact the use of this standard. (Approved January 15, 2010.)

(1) "Weak rock" was dropped from the title and text.
(2) Scope was expanded, Sections 1.2 and 1.3, to be more representative of the test.
(3) Significant figures caveat for D6026 was added as required by ASTM and D18.
(4) Section 2—missing or require references D653, D2216, D6026, D6032, and D7012 were added.
(5) Section 3—correct format was applied and D653 referenced. Definition of weak rock was removed since it was removed in title. Definitions for existing terms average fragment volume and volumetric joint count were added.
(6) Section 4—wording that testing could possibly be configured to be run outside a tunnel was added.

(7) Section 5—missing components of the apparatus were added and incorrectly described components were corrected, in particular when stress, strain, deformation, or load were used inconsistently or incorrectly.
(8) Section 6.1, Preparation of Specimens—preparation of specimen was expanded to include geologic issues that need to be considered.
(9) Section 6.2—added the measurement of joint volume.
(10) Sections 6.4 and 6.5—added steps that were missing or implied in the narrative.
(11) Section 7, Calculations—previous standard was non-specific and only verbally mentioned calculating a failure stress. Section was expanded to include missing formulas or more detailed description of calculations and other data required. Calculations and formulas for average joint fragment volume, Poisson's ratio, and volumetric joint count were added as well as using strain, deformation, load and stress in a more consistent manner.
(12) Section 8, Report—added geology and test personnel to report.
(13) Figure 1 was completely redone to show more accurately were the specimen would be and to move the cross section to the proper location.
(14) Figure 2 was rotated so that it was vertical.
(15) Title on Figure 3 was corrected to more accurately reflect the content.