



Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression¹

This standard is issued under the fixed designation D 3148; 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 determination of elastic moduli of intact rock core specimens in uniaxial compression. It specifies the apparatus, instrumentation, and procedures for determining the stress-axial strain and the stress-lateral strain curves, as well as Young's modulus, E , and Poisson's ratio, ν .

NOTE 1—This test method does not include the procedures necessary to obtain a stress-strain curve beyond the ultimate strength.

1.2 For an isotropic material, the relation between the shear and bulk moduli and Young's modulus and Poisson's ratio are:

$$G = \frac{E}{2(1 + \nu)} \quad (1)$$

$$K = \frac{E}{3(1 - 2\nu)} \quad (2)$$

where:

- G = shear modulus,
- K = bulk modulus,
- E = Young's modulus, and
- ν = Poisson's ratio.

The engineering applicability of these equations is decreased if the rock is anisotropic. When possible, it is desirable to conduct tests in the plane of foliation, bedding, etc., and at right angles to it to determine the degree of anisotropy. It is noted that equations developed for isotropic materials may give only approximate calculated results if the difference in elastic moduli in any two directions is greater than 10 % for a given stress level.

NOTE 2—Elastic moduli measured by sonic methods may often be employed as preliminary measures of anisotropy.

1.3 The test method given for determining the elastic constants does not apply to rocks that undergo significant inelastic strains during the test, such as potash and salt. The elastic moduli for such rocks should be determined from unload-reload cycles, which is not covered by this test method.

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:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids²
- D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²
- D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction²
- D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances²
- E 4 Practices for Load Verification of Testing Machines³
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁴

3. Terminology

3.1 *Definitions:* See Terminology D 653 for general definitions.

3.2 *Definitions of Terms Specific to This Standard:*

- 3.2.1 *bulk modulus, K [FL^{-2}]*—average normal stress divided by the change in volume per original volume.
- 3.2.2 *shear modulus, G [FL^{-2}]*—ratio of the shear stress to the corresponding shear strain below the proportional limit.

4. Summary of Test Method

4.1 A rock core sample is cut to length, and the ends are machined flat. The specimen is placed in a loading frame and, if required, heated to the desired test temperature. Axial load is continuously increased on the specimen, and deformation is monitored as a function of load.

5. Significance and Use

5.1 The elastic constants are used to calculate the stress and deformation in rock structures.

5.2 The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect

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² *Annual Book of ASTM Standards*, Vol 04.08.

³ *Annual Book of ASTM Standards*, Vol 03.01.

⁴ *Annual Book of ASTM Standards*, Vol 14.02.

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

large-scale in situ properties, because the latter are strongly influenced by joints, faults, inhomogeneities, weakness planes, and other factors. Therefore, laboratory values for intact specimens must be employed with proper judgment in engineering applications.

NOTE 3—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 D 3740 are generally considered capable of competent and objective testing/sampling/inspection/ and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Loading Device*—The loading device shall be of sufficient capacity to apply load at a rate conforming to the requirements specified in 10.5. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and comply with the requirements prescribed therein. The loading device may be equipped with a displacement transducer that can be used to advance the loading ram at a specified rate.

6.2 *Elevated-Temperature Enclosure*—The elevated temperature enclosure may be either an enclosure that fits in the loading apparatus or an external system encompassing the complete test apparatus. The enclosure may be equipped with humidity control for testing specimens in which the moisture content is to be controlled. For high temperatures, a system of heaters, insulation, and temperature measuring devices are normally required to maintain the specified temperature. Temperature shall be measured at three locations, with one sensor near the top, one at midheight, and one near the bottom of the specimen. The average specimen temperature based on the midheight sensor shall be maintained to within $\pm 1^\circ\text{C}$ of the required test temperature. The maximum temperature difference between the midheight sensor and either end sensor shall not exceed 3°C .

NOTE 4—An alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a dummy specimen that has temperature sensors located in drill holes at a minimum of six positions: along both the centerline and specimen periphery at midheight and at each end of the specimen. The temperature controller set point shall be adjusted to obtain steady-state temperatures in the dummy specimen that meet the temperature requirements at each test temperature (the centerline temperature at midheight shall be within $\pm 1^\circ\text{C}$ of the required test temperature, and all other specimen temperatures shall not deviate from this temperature by more than 3°C). The relationship between controller set point and dummy specimen temperature can be used to determine the specimen temperature during testing provided that the output of the temperature feedback sensor (or other fixed-location temperature sensor in the triaxial apparatus) is maintained constant within $\pm 1^\circ\text{C}$ of the required test temperature. The relationship between temperature controller set point and steady-state specimen temperature shall be verified periodically. The dummy specimen is used solely to determine the temperature distribution in a specimen in the triaxial apparatus; it is not to be used to determine elastic constants.

6.3 *Temperature Measuring Device*—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least $\pm 1^\circ\text{C}$ with a resolution of 0.1°C .

6.4 *Platens*—Two steel platens are used to transmit the axial

load to the ends of the specimen. They shall have a hardness of not less than 58 HRC. One of the platens should be spherically seated and the other on a plain rigid platen. The bearing faces shall not depart from a plane by more than 0.015 mm when the platens are new and shall be maintained within a permissible variation of 0.025 mm. The diameter of the spherical seat shall be at least as large as that of the test specimen but shall not exceed twice the diameter of the test specimen. The center of the sphere in the spherical seat shall coincide with that of the bearing face of the specimen. The spherical seat shall be properly lubricated to ensure free movement. The movable portion 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 a spherical seat is not used, the bearing faces of the platens shall be parallel to 0.0005 mm/mm of platen diameter. The platen diameter shall be at least as great as the specimen but shall not exceed the specimen diameter by more than 1.50 mm. This platen diameter shall be retained for a length of at least one-half the specimen diameter.

6.5 *Strain/Deformation Measuring Devices*—The strain/deformation measuring system shall measure the strain with a resolution of at least 25×10^{-6} strain and an accuracy within 2 % of the value of readings above 250×10^{-6} strain and accuracy and resolution within 5×10^{-6} for readings lower than 250×10^{-6} strain, including errors introduced by excitation and readout equipment. The system shall be free from noncharacterizable long-term instability (drift) that results in an apparent strain of $10^{-8}/\text{s}$.

NOTE 5—The user is cautioned about the influence of temperature on the output of strain and deformation sensors located within the heated environment.

6.5.1 *Axial Strain Determination*—The axial deformations or strains may be determined from data obtained by electrical resistance strain gages, compressometers, linear variable differential transformers (LVDTs), or other suitable means. The design of the measuring device shall be such that the average of at least two axial strain measurements can be determined. Measuring positions shall be equally spaced around the circumference of the specimen close to midheight. The gage length over which the axial strains are determined shall be at least 10 grain diameters in magnitude.

6.5.2 *Lateral Strain Determination*—The lateral deformations or strains may be measured by any of the methods mentioned in 6.5.1. Either circumferential or diametric deformations (or strains) may be measured. A single transducer that wraps around the specimen can be used to measure the change in circumference. At least two diametric deformation sensors shall be used if diametric deformations are measured. These sensors shall be equally spaced around the circumference of the specimen, close to midheight. The average deformation (or strain) from the diametric sensors shall be recorded.

NOTE 6—The use of strain gage adhesives requiring cure temperatures above 65°C is not allowed unless it is known that microfractures do not develop at the cure temperature.

7. Safety Precautions

7.1 Many rock types fail in a violent manner when loaded to

failure in compression. A protective shield should be placed around the test specimen to prevent injury from flying rock fragments. Elevated temperatures increase the risks of electrical shorts and fire.

8. Sampling

8.1 The specimen shall be selected from the cores to represent a valid average of the type of rock under consideration. This can be achieved by visual observations of mineral constituents, grain sizes and shape, partings and defects such as pores and fissures, or by other methods, such as ultrasonic velocity measurements.

9. Test Specimens

9.1 *Preparation*—Prepare test specimens in accordance with Practice D 4543.

9.2 Moisture condition of the specimen at the time of test can have a significant effect upon the deformation of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of the specimen should be preserved until the time of test. On the other hand, there may be reasons for testing specimens at other moisture contents including zero. In any case, the moisture content of the test specimen should be tailored to the problem at hand and reported in accordance with 12.1.3. If the moisture content of the specimen is to be determined, follow the procedures given in Test Method D 2216.

9.3 If moisture content is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, seal the specimen using a flexible membrane or apply a plastic or silicone rubber coating to the specimen sides.

10. Procedure

10.1 Check the ability of the spherical seat to rotate freely in its socket before each test.

10.2 Place the lower platen on the base or actuator rod of the loading device. Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and place the test specimen on the lower platen. Place the upper platen on the specimen and align properly. A small axial load, approximately 100 N, may be applied to the specimen by means of the loading device to properly seat the bearing parts of the apparatus.

10.3 When appropriate, install elevated-temperature enclosure and deformation transducers for the apparatus and sensors used.

10.4 If testing at elevated temperature, raise the temperature at a rate not exceeding 2°C/min until the required temperature is reached (Note 7). The test specimen shall be considered to have reached temperature equilibrium when all deformation transducer outputs are stable for at least three readings taken at equal intervals over a period of no less than 30 min (3 min for tests performed at room temperature). Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations. Record the initial deformation readings. Consider this to be the zero for the test.

NOTE 7—It has been observed that for some rock types microcracking will occur for heating rates above 1°C/min. The operator is cautioned to select a heating rate such that microcracking is not significant.

10.5 Apply the axial load continuously and without shock until the load becomes constant, reduces, or a predetermined amount of strain is achieved. Apply the load in such a manner as to produce either a stress rate or a strain rate as constant as feasible throughout the test. Do not permit the stress rate or strain rate at any given time to deviate by more than 10 % from that selected. The stress rate or strain rate selected should be that which will produce failure of a similar test specimen in unconfined compression in a test time between 2 and 15 min. The selected stress rate or strain rate for a given rock type shall be adhered to for all tests in a given series of investigation (Note 8). Observe and record readings of deformation at a minimum of 10 load levels that are evenly spaced over the load range. Continuous data recording is permitted, provided that the recording system meets the precision and accuracy requirements of 6.5.

NOTE 8—Results of tests by other investigators have shown that strain rates within this range will provide strength and moduli values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates are permissible, if required by the investigation. The drift of the strain measuring system (see 6.5) shall be more stringent, corresponding to the longer duration of the test.

NOTE 9—Loading a high-strength specimen to failure in a loading frame that is not stiff will often result in violent failure, which will tend to damage the strain/deformation measuring devices.

11. Calculation

11.1 The axial strain, ϵ_a , and lateral strain, ϵ_l , may be obtained directly from strain-indicating equipment, or may be calculated from deformation readings, depending on the type of apparatus or instrumentation employed.

11.1.1 Calculate the axial strain, ϵ_a , as follows:

$$\epsilon_a = \frac{\Delta L}{L} \quad (3)$$

where:

L = original undeformed axial gage length, and

ΔL = change in measured axial length (negative for a decrease in length).

NOTE 10—Tensile stresses and strains are used as being positive. A consistent application of a compression-positive sign convention may be employed if desired. The sign convention adopted needs to be stated explicitly in the report. The formulas given are for engineering stresses and strains. True stresses and strains may be used if desired.

NOTE 11—If the deformation recorded during the test includes deformation of the apparatus, suitable calibration for apparatus deformation must be made. This may be accomplished by inserting into the apparatus a steel cylinder having known elastic properties and observing differences in deformation between the assembly and steel cylinder throughout the loading range. The apparatus deformation is then subtracted from the total deformation at each increment of load to arrive at specimen deformation from which the axial strain of the specimen is computed. The accuracy of this correction should be verified by measuring the elastic deformation of a cylinder of material having known elastic properties (other than steel) and comparing the measured and computed deformations.

11.1.2 Calculate the lateral strain, ϵ_l , as follows:

$$\epsilon_l = \frac{\Delta D}{D} \quad (4)$$

where:

- D = original undeformed diameter, and
- ΔD = change in diameter (positive for increased in diameter).

NOTE 12—Many circumferential transducers measure change in chord length and not change in arc length (circumference). The geometrically nonlinear relationship between change in chord length and change in diameter must be used to obtain accurate values of lateral strain.

11.2 Calculate the compressive stress in the test specimen from the compressive load on the specimen and the initial computed cross-sectional area as follows:

$$\sigma = \frac{P}{A} \quad (5)$$

where:

- σ = stress,
- P = load, and
- A = area.

11.3 Plot the stress-versus-strain curve for the axial and lateral direction (Fig. 1). The complete curve gives the best description of the deformation behavior of rocks having nonlinear stress-strain relationships at low and high stress levels.

11.4 The axial Young's modulus, E , may be calculated using any of several methods employed in engineering practice. The most common methods, described in Fig. 2, are as follows:

11.4.1 Tangent modulus at a stress level that is some fixed percentage (usually 50 %) of the maximum strength.

11.4.2 Average slope of the more-or-less straight-line portion of the stress-strain curve. The average slope may be calculated either by dividing the change in stress by the change in strain or by making a linear least squares fit to the stress-strain data in the straight-line portion of the curve.

11.4.3 Secant modulus, usually from zero stress to some fixed percentage of maximum strength.

11.5 The value of Poisson's ratio, ν , is greatly affected by nonlinearities at low stress levels in the axial and lateral stress-strain curves. It is suggested that Poisson's ratio be calculated from the equation:

$$\nu = -\frac{\text{slope of axial curve}}{\text{slope of lateral curve}} = -\frac{E}{\text{slope of lateral curve}} \quad (6)$$

where the slope of the lateral curve is determined in the same manner as was done in 11.4 for Young's modulus, E .

NOTE 13—The denominator in the equation in 11.5 will have a negative value if the sign convention is applied properly.

12. Report

12.1 The report shall include the following:

- 12.1.1 Source of sample, including project name and location (often the location is specified in terms of the drill hole number and depth of specimen from collar of hole).
- 12.1.2 Lithologic description of the rock, formation name, and load direction with respect to lithology.
- 12.1.3 Moisture condition of specimen before test.
- 12.1.4 Specimen diameter and height, conformance with dimensional requirements.
- 12.1.5 Temperature at which test was performed.
- 12.1.6 Rate of loading or deformation rate.
- 12.1.7 Plot of the stress-versus-strain curves (Fig. 1).
- 12.1.8 Young's modulus, E , method of determination as given in Fig. 2, and at what stress level or levels determined.
- 12.1.9 Poisson's ratio, ν , method of determination in 11.5, and at what stress level or levels determined.
- 12.1.10 A description of physical appearance of specimen after test, including visible end effects such as cracking, spalling, or shearing at the platen-specimen interfaces.
- 12.1.11 If the actual equipment or procedure has varied from the requirements contained in this test method, each variation and the reasons for it shall be discussed.

13. Precision and Bias

13.1 An interlaboratory study was conducted in which eight 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 grinding of the ends and testing. The study was carried out in accordance with Practice E 691. Values of the elastic modulus were determined using the tangent modulus method at stress levels equal to 25, 50, and 75 % of the compressive strength. Details of the study are given in ISR Research Report No. PS #D18.12-R01, 1992. Table 1, Table 2, and Table 3 give the repeatability (within a laboratory) and reproducibility (between laboratories) for the method. At each level of determination, both the repeatability and reproducibility limits increase with the values of the elastic modulus.

13.1.1 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 the reproducibility limit.

13.1.2 The repeatability and reproducibility standard deviation is equal to the limit values given divided by 2.83 ($2\sqrt{2}$).

13.2 Bias cannot be determined since there is no standard value of each of the elastic constants that can be used to compare with values determined using this test method.

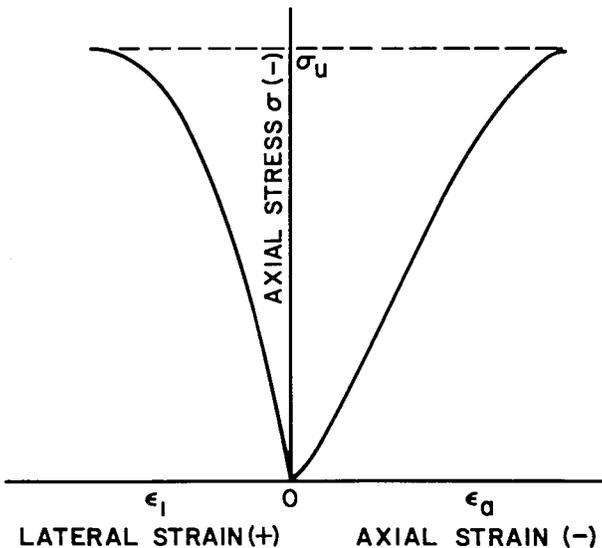
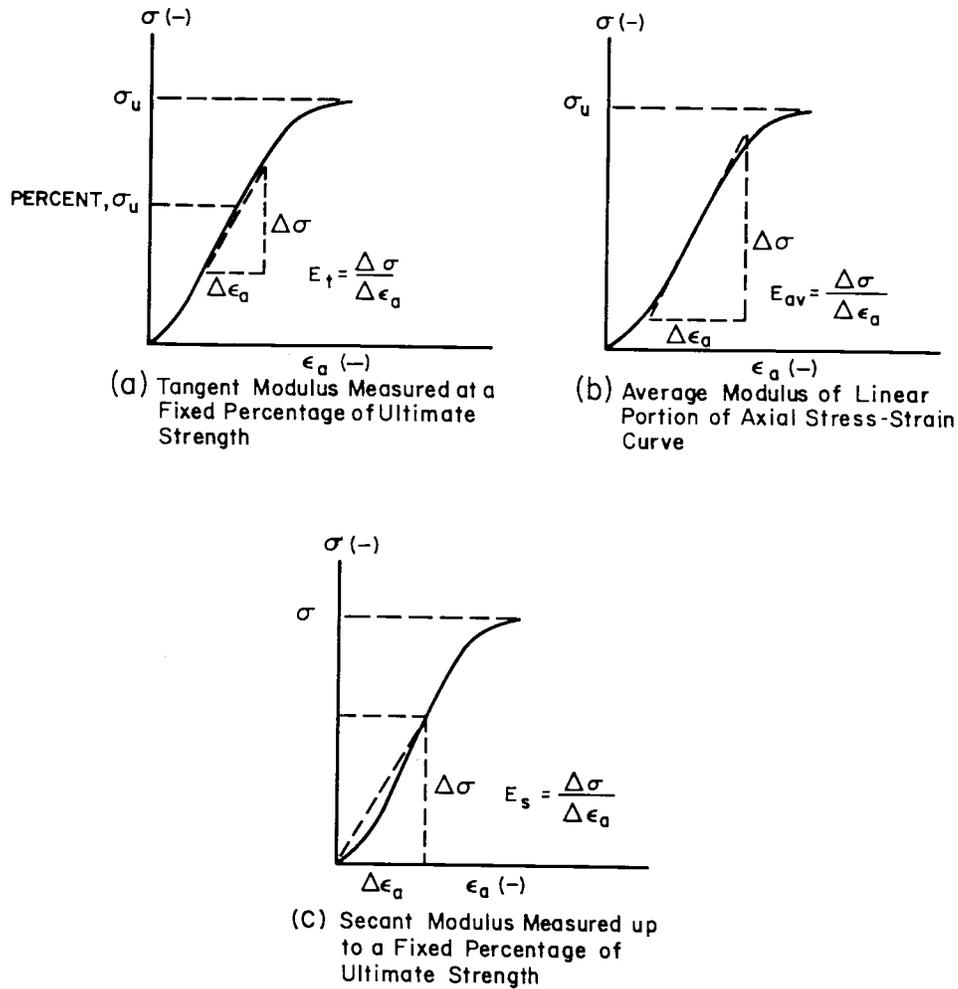


FIG. 1 Format for Graphical Presentation of Data


FIG. 2 Methods for Calculating Young's Modulus From Axial Stress-Axial Strain Curve
TABLE 1 Elastic Modulus (GPa) @ 25 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	12.44	32.88	76.31	46.90
Repeatability Limit (d25)	3.37	10.50	14.85	6.12
Reproducibility Limit (d25)	4.17	12.54	17.17	6.45

TABLE 3 Elastic Modulus (GPa) @ 75 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	17.15	27.27	65.57	53.11
Repeatability Limit (d25)	4.48	3.29	13.60	7.99
Reproducibility Limit (d25)	4.84	6.26	13.60	8.47

TABLE 2 Elastic Modulus (GPa) @ 50 %

	Berea Sandstone	Salem Limestone	Tennessee Marble	Barre Granite
Average Value	16.74	32.00	74.19	54.21
Repeatability Limit (d25)	4.15	4.21	10.13	6.75
Reproducibility Limit (d25)	5.19	5.47	12.33	7.77

14. Keywords

14.1 compression testing; loading tests; modulus of elasticity; modulus-Young's; rock

SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition that may impact the use of this standard.

- (1) Standards D 653 and D 3740 were added to Section 2. added because they are not in D 653.
- (2) Terminology Section was added. (4) Required caveat for D 3740 was added.
- (3) Definitions for bulk modulus and shear modulus were

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