Designation: D 7012 – 04

Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures[1]

1. Scope

1.1 This test method covers the determination of the strength of intact rock core specimens in uniaxial compression and confined compression. The tests provide data in determining the strength of rock, namely: the uniaxial strength, shear strengths at varying pressures and varying temperatures, angle of internal friction, (angle of shearing resistance), and cohesion intercept. The test method 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, υ. It should be observed that this method makes no provision for pore pressure measurements and specimens are undrained (platens are not vented). Thus the strength values determined are in terms of total stress, that is, are not corrected for pore pressures. This test method does not include the procedures necessary to obtain a stress-strain curve beyond the ultimate strength.

1.1.1 This standard replaces and combines the following Standard Test Methods for: D 2664 Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements; D 5407 Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements; D 2938 Unconfined Compressive Strength of Intact Rock Core Specimens; and D 3148 Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression.

1.1.2 The original four standards are now referred to as Methods in this standard as follows: Method A — Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements; Method B — Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements; Method C — Unconfined Compressive Strength of Intact Rock Core Specimens; Method D — Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression; and Option A — Elevated Temperatures.

1.1.3 The original four standards are now referred to as Methods in this standard as follows: Method A (D2664) Triaxial Compressive Strength of Undarined Rock Core Specimens Without Pore Pressure Measurements; Method B (D5407) Elastic Moduli of Undrained Rock Core Specimens in Triaxial Compression Without Pore Pressure Measurements, Method C (D2938 Unconfined Compressive Strength of Intact Rock Core Specimens; Method D (d3148) Elastic Moduli of Intact Rock Core Specimerns in Uniaxial Compression; and Option A Elevated Temperatures.

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

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

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

where:

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

1.2.1 The engineering applicability of these equations decreases with increasing anisotropy of the rock. It is desirable to conduct tests in the plane of foliation, cleavage or bedding 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 two orthogonal directions is greater than 10 % for a given stress level.

NOTE 1—Elastic moduli measured by sonic methods (Test Method D 2845) may often be employed as preliminary measures of anisotropy.

1.3 This 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

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[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.

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elastic moduli for such rocks should be determined from unload-reload cycles, that are not covered by this test method.

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

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]

D 653 Terminology Relating to Soil, Rock and Contained Fluids

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock

D 2845 Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Constants of Rock

D 3740 Practice for Minimum Requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances

E 4 Practices for Force Verification of Testing Machines

E 122 Practices for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process

E 691 Practices for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Summary of Test Method

3.1 A rock core specimen is cut to length and the ends are machined flat. The specimen is placed in a loading frame and if required, placed in a loading chamber and subjected to confining pressure. In an elevated temperature test the specimen is heated to the desired test temperature. Axial load is increased continuously on the specimen, and deformation is measured as a function of load until peak load and failure are obtained.

4. Significance and Use

4.1 The parameters obtained from these procedures are in terms of undrained total stress (as already mentioned in 1.1.1.). However, there are some cases where either the rock type or the loading condition of the problem under consideration will require the effective stress or drained parameters be determined.

4.2 Unconfined compressive strength of rock is used in many design formulas and is sometimes used as an index property to select the appropriate excavation technique. Deformation and strength of rock are known to be functions of confining pressure. The confined compression test is commonly used to simulate the stress conditions under which most underground rock masses exist. The elastic constants are used to calculate the stress and deformation in rock structures.

4.3 The deformation and strength properties of rock cores measured in the laboratory usually do not accurately reflect 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 2—Notwithstanding the statements on precision and bias contained in this test method; the measures of precision of these test methods are dependent on the competence of the personnel performing them , and on 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. Users of this test method are cautioned that compliance with Practice D 3740 does not in itself assure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means for evaluating some of those factors.

5. Apparatus

5.1 *Loading Device*—The loading device shall be of sufficient capacity to apply load at a rate conforming to the requirements specified in 9.6. It shall be verified at suitable time intervals in accordance with the procedures given in Practices E 4 and comply with the requirements prescribed in the method. The loading device may be equipped with a displacement transducer that can be used to advance the loading ram at a specified rate.

NOTE 3—If the load-measuring device is located outside the confining compression apparatus, calibrations to determine the seal friction need to be made to ensure the accuracy specified in Practices E 4.

5.2 *Confining Apparatus*[3]—The confined pressure apparatus shall consist of a chamber in which the test specimen may be subjected to a constant lateral fluid pressure and the required axial load. The apparatus shall have safety valves, suitable entry ports for filling the chamber, and associated hoses, gages, and valves as needed.

5.3 *Flexible Membrane*—This membrane encloses the rock specimen and extends over the platens to prevent penetration by the confining fluid. A sleeve of natural or synthetic rubber or plastic is satisfactory for room temperature tests; however, metal or high-temperature rubber (for example, viton) jackets are usually required for elevated temperature tests. The membrane shall be inert relative to the confining fluid and shall cover small pores in the specimen without rupturing when confining pressure is applied. Plastic or silicone rubber coatings may be applied directly to the specimen provided these materials do not penetrate and strengthen or weaken the specimen. Care must be taken to form an effective seal where the platen and specimen meet. Membranes formed by coatings shall be subject to the same performance requirements as elastic sleeve membranes.

5.4 *Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system shall have sufficient capacity to

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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.

[3] Assembly and detail drawings of an apparatus that meets these requirements and which is designed to accommodate 2⅛-in. (53.975-mm) diameter specimens and operate at a confining fluid pressure of 68.9 Mpa (10 000 psi) are available from Headquarters. Request Adjunct No. 12-426640-00.

maintain constant the desired lateral pressure. The pressurization system shall be capable of maintaining the confining pressure constant to within ±1 % throughout the test. The confining pressure shall be measured with a hydraulic pressure gage or electronic transducer having an accuracy of at least ±1 percent of the confining pressure, including errors due to readout equipment, and a resolution of at least 0.5 % of the confining pressure.

5.5 *Confining-Pressure Fluids*—For room temperature tests, hydraulic fluids compatible with the pressure-maintaining device shall be used. For elevated temperature tests, the fluid must remain stable at the temperature and pressure levels designated for the test.

5.6 *Elevated-Temperature Enclosure*—The elevated temperature enclosure shall be either an internal system that fits inside the loading apparatus or the confining pressure apparatus, an external system enclosing the entire confining pressure apparatus, or an external system encompassing the complete test apparatus. 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 ±1°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 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 each end of the specimen. The specimen may originate from the same batch as the test specimens and conform to the same dimensional tolerances and to the same degree of intactness. The temperature controller set point may be adjusted to obtain steady-state temperatures in the specimen that meet the temperature requirements at each test temperature (the centerline temperature at midheight may be within ±1°C of the required test temperature, and all other specimen temperatures may not deviate from this temperature by more than 3°C). The relationship between controller set point and 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 ±1°C of the required test temperature. The relationship between temperature controller set point and steady-state specimen temperature may be verified periodically. The specimen is used solely to determine the temperature distribution in a specimen in the triaxial apparatus. It is not to be used to determine compressive strength or elastic constants.

5.7 *Temperature Measuring Device*—Special limits-of-error thermocouples or platinum resistance thermometers (RTDs) having accuracies of at least ± 1°C with a resolution of 0.1°C shall be used.

5.8 *Platens*—Two steel platens are used to transmit the axial load to the ends of the specimen. They shall be made of tool-hardened steel to a minimum Rockwell Hardness of 58 on the "C" scale. One of the platens shall be spherically seated and the other shall be 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 assure 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 blocks shall be parallel to 0.0005 mm/mm of platen diameter. The platen diameter shall be at least as great as that of the specimen and have a length-to-diameter ratio of at least 1:2.

5.9 *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 non-characterized long-term instability (drift) that results in an apparent strain of 10^{-8}/s or greater.

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

5.9.1 *Determination of Axial Strain*—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 ten grain diameters in magnitude.

5.9.2 *Determination of Lateral Strain*—The lateral deformations or strains may be measured by any of the methods mentioned in 5.9.1. 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 and mineralogical changes do not occur at the cure temperature.

6. Safety Precautions

6.1 Danger exists near confining pressure testing equipment because of the high pressures and loads developed within the system. Test systems must be designed and constructed with adequate safety factors, assembled with properly rated fittings, and provided with protective shields to protect people in the area from unexpected system failure. The use of a gas as the confining pressure fluid introduces potential for extreme violence in the event of a system failure.

6.2 Many rock types fail in a violent manner when loaded to failure in compression. A protective shield shall be placed around the unconfined test specimen to prevent injury from flying rock fragments.

6.3 Elevated temperatures increase the risks of electrical shorts and fire. The flash point of the confining pressure fluid shall be above the operating temperatures during the test.

7. Sampling

7.1 The specimens for each sample shall be selected from cores representing 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. The diameter of rock test specimens shall be at least ten times the diameter of the largest mineral grain. For weak rock types, which behave more like soil (for example, weakly cemented sandstone), the specimen diameter shall be at least six times the maximum particle diameter. The specified minimum specimen diameter of approximately 47 mm this satisfy this criterion in the majority of cases. When cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger diameter core, as is often the case in the mining industry, suitable notation of this fact shall be made in the report.

7.2 The number of specimens required to obtain a specific level of statistically results may be determined using Test Method E 122. However, it may not be economically possible to achieve a specific confidence levels and professional judgment may be required too.

8. Test Specimens

8.1 *Preparation*—Test specimens shall be prepared in accordance with Practice D 4543.

8.2 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 shall be made upon specimens representative of field conditions. Thus, it follows that the field moisture condition of 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. In any case, the moisture content of the test specimen shall be tailored to the problem at hand and reported in accordance with 11.1.3. If the moisture content of the specimen is to be determined, follow the procedures given in Method D 2216. If moisture condition is to be maintained, and the elevated temperature enclosure is not equipped with humidity control, the specimen shall be sealed using a flexible membrane or by applying a plastic or silicone rubber coating to the specimen sides. If the specimen is to be saturated, porous sandstones may present little or no difficulty. For siltstone, saturation may take longer. For tight rocks such as intact granite, saturation by water may be impractical.

9. Procedure

9.1 The spherical seat shall rotate freely in its socket before each test.

9.2 The lower platen shall be placed on the base or actuator rod of the loading device. The bearing faces of the upper and lower platens and of the test specimen shall be wiped clean, and the test specimen shall be placed on the lower platen. The upper platen shall be placed on the specimen and aligned properly. When appropriate, the membrane shall be fitted over the specimen and platens to seal the specimen from the confining fluid. The specimen shall be placed in the test chamber, ensuring proper seal with the base, and connection to the confining pressure lines. A small axial load, <1 % of anticipated ultimate strength, may be applied to the confining compression chamber by means of the loading device to properly seat the bearing parts of the apparatus.

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

9.4 If the test is in confined compression, the chamber shall be filled with confining fluid and the confining stress shall be raised uniformly to the specified level within 5 min. The lateral and axial components of the confining stress shall not be allowed to differ by more than 5 percent of the instantaneous pressure at any time.

9.5 If testing at elevated temperature, the temperature shall be raised at a rate not exceeding 2°C/min until the required temperature is reached (Note 8). The test specimen shall be considered to have reached pressure and 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, which are to be taken as zeroes 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 does not significantly affect the test result.

9.6 The axial load shall be applied continuously and without shock until the load becomes constant, is reduced, or a predetermined amount of strain is achieved. The load shall be applied in such a manner as to produce either a stress rate or a strain rate as constant as feasible throughout the test. The stress rate or strain rate shall not be permitted at any given time to deviate by more than 10 % from that selected. The stress rate or strain rate selected shall be that which will produce failure of a cohort 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 9). The predetermined confining pressure shall be maintained approximately throughout the test. Readings of deformation shall be observed and recorded at a minimum of ten load levels that are evenly spaced over the load range. Continuous data recording shall be permitted provided that the recording system meets the precision and accuracy requirements of 5.9. The maximum load sustained by the specimen shall be recorded. Load readings in kilonewtons shall be recorded to 2 decimal places. Stress readings in megapascals shall be recorded to 1 decimal place.

NOTE 8—Results of tests by other investigators have shown that strain rates within this range will provide strength values that are reasonably free from rapid loading effects and reproducible within acceptable tolerances. Lower strain rates may be permissible, if required by the investigation. The drift of the strain measuring system (see 5.9) may be constrained more stringently, 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 and be hazardous to the operator.

9.7 To make sure that no confining fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures and the specimen shall be examined with a hand lens at the completion of each confining test.

10. Calculations

10.1 The compressive strength of the test specimen shall be calculated as follows:

$$\sigma = (\sigma_1 - \sigma_3) \tag{3}$$

where:
σ = differential failure stress,
σ_1 = total failure stress, and
σ_3 = confining stress.

10.1.1 The most desirable specimen length to diameter ratio is 2.00:1.00 (L/D = 2.00). Any L/D < 2.00 ± 0.05 is unacceptable. Laboratory values for intact specimens must be employed with proper judgment in engineering applications.

NOTE 10—For L/D > 2.00 the recorded uniaxial compressive strength may be reduced by multiplying a correction factor as follows:

$$\sigma_c = \sigma / (0.88 + 0.222\,(d/t)) \tag{4}$$

where:
σ_c = corrected failure stress,
σ = failure stress,
d = specimen diameter, and
I = specimen length

NOTE 11—Tensile stresses and strains are normally recorded 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, provided that the specimen diameter at the time of peak load is known.

NOTE 12—If the specimen diameter is not the same as the piston diameter through the triaxial apparatus, a correction may be applied to the measured load to account for the confining pressure acting on the difference in area between the specimen and the loading piston where it passes through the seals into the apparatus.

10.2 Axial strain, ϵ_a and lateral strain, ϵ_1, shall be obtained directly from strain-indicating equipment or shall be calculated from deformation readings, depending on the type of apparatus or instrumentation employed. Strain readings shall be recorded to six decimal places.

10.2.1 Axial strain, ϵ_a shall be calculated as follows:

$$\epsilon_a = \frac{\Delta L}{L} \tag{5}$$

where:
L = original undeformed axial gage length, and
ΔL = change in measured axial length (negative for decrease in length).

NOTE 13—If the deformation recorded during the test includes deformation of the apparatus, suitable calibration for apparatus deformation shall 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.

10.2.2 Lateral strain, ϵ_1, shall be calculated as follows:

$$\epsilon_1 = \frac{\Delta D}{D} \tag{6}$$

where:
D = original undeformed diameter, and
ΔD = change in diameter (positive for increase in diameter).

NOTE 14—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.

10.3 The stress-versus-strain curves shall be plotted for the axial and lateral directions (see 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.

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

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

10.4.2 Average slope of the more-or-less straight-line portion of the stress-strain curve. The average slope shall 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.

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

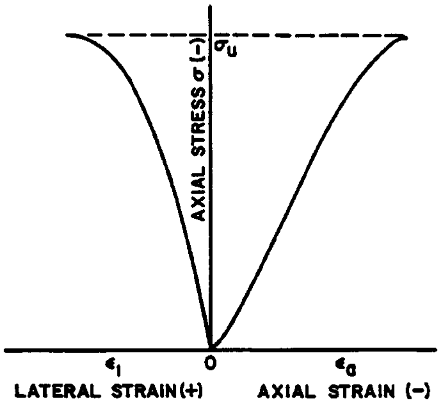
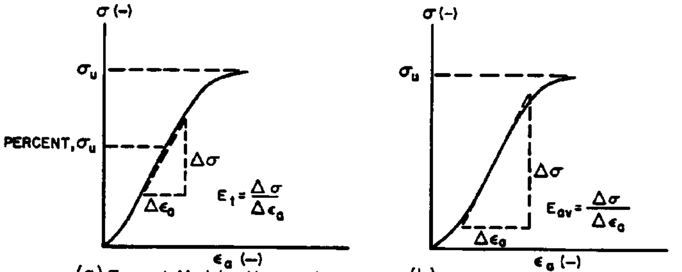
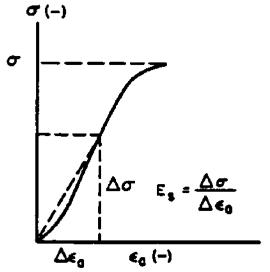


FIG. 1 Format for Graphical Presentation of Data



(a) Tangent Modulus Measured at a Fixed Percentage of Ultimate Strength

(b) Average Modulus of Linear Portion of Axial Stress-Strain Curve



(C) Secant Modulus Measured up to a Fixed Percentage of Ultimate Strength

FIG. 2 Methods for Calculating Young's Modulus from Axial Stress-Axial Strain Curve

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

$$\upsilon = -\frac{\text{slope of axial curve}}{\text{slope of lateral curve}} \tag{7}$$

$$= -\frac{E}{\text{slope of lateral curve}}$$

where the slope of the lateral curve is determined in the same manner as was done in 10.4 for Young's modulus, *E*.

NOTE 15—The denominator in the equation in 10.5 will usually have a negative value if the sign convention is applied properly.

10.6 The Mohr stress circles shall be constructed on an arithmetic plot with shear stress as the ordinate and normal stress as the abscissa. At least three confined compression tests shall be conducted, each at a different confining pressure, on the same material to define the envelope to the Mohr stress circles. Because of the heterogeneity of rock and the scatter in results often encountered, good practice requires making at least three tests on essentially identical specimens at each confining pressure or single tests at nine different confining pressures covering the range investigated. Individual stress circles shall be plotted and used in drawing the envelope.

10.6.1 A "best-fit," smooth curve or straight line (Mohr envelope) shall be drawn approximately tangent to the Mohr circles, as shown in Fig. 3. The figure shall also include a brief note indicating whether a pronounced failure plane was or was not developed during the test and the inclination of this plane with reference to the plane of major principal stress. If the envelope is a straight line, the angle the line makes with the horizontal shall be reported as the angle of internal friction, ϕ (or the slope of the line as tan ϕ depending upon preference), and the intercept of this line at the vertical axis reported as the cohesion intercept, *c*. If the envelope is not a straight line, values of ϕ (or tan ϕ) shall be determined by constructing a tangent to the Mohr circle for each confining pressure at the point of contact with the envelope and the corresponding cohesion intercept noted.

11. Report

11.1 The report shall include the following depending on test parameters:

11.1.1 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 the collar of the hole),

11.1.2 Lithologic description of the rock, formation name, and load direction with respect to lithology,

11.1.3 Moisture condition of specimen before test,

11.1.4 Specimen diameter and height, conformance with dimensional requirements,

11.1.5 Confining stress level at which a confined test was performed,

11.1.6 Temperature at which test was performed,

11.1.7 Rate of loading or deformation rate,

11.1.8 Unconfined compressive strength,

11.1.9 Plot of the stress-versus-strain curves (see Fig. 1),

11.1.10 Plot of the Mohr stress circles (see Fig. 3),

11.1.11 Young's modulus, *E*, method of determination as given in Fig. 2, and at which stress level or levels determined,

11.1.12 Poisson's ratio, υ, method of determination in 10.5, and at what stress level or levels determined,

11.1.13 Description of physical appearance of specimen after test, including visible end effects such as cracking,

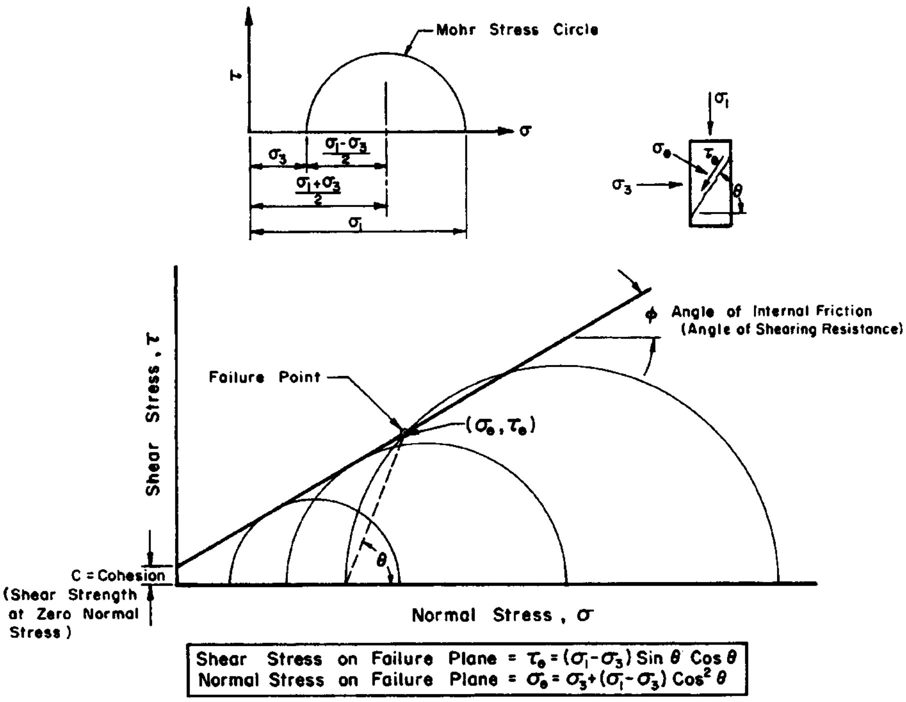


FIG. 3 Typical Mohr Stress Circles

spalling, or shearing at the platen-specimen interfaces. A sketch of the fractured specimen is recommended, and

NOTE 16—If failure is ductile, with the load on the specimen still increasing when the test is terminated, the strain at which the compressive strength was calculated may be reported.

11.1.14 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 presented in detail.

12. Precision and Bias

12.1 The data in Tables 1-5 are the products of the Interlaboratory Testing Program. Table 1 is the product of the work of seven laboratories with five replications. Table 5 is the product of the work of eight laboratories with five replications. Round 1 involved four rock types, but only the data from three were displayed here that were rock types used in all the series of tests. The remaing tables (Tables 6-10) are the products of Round 2 in which six laboratories each tested five specimens of three different rocks, three confining pressures and four replication. Details of the study are references in Section 2.2. The tables give the repeatability (within a laboratory) and reproducibility (between laboratories) for the compressive and confined methods and values for Young's Modulus and Poisson's ratio calculated for the intervals from 25 to 50 % and 40 to 60 % of the maximum differential stress at confining

TABLE 1 Compressive Strength (MPa) at 0 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	62.0	142.0	217.0
Repeatability	15.8	20.4	15.7
Reproducibility	22.4	38.0	27.7

TABLE 2 Compressive Strength (MPa) at 10 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	127.0	173.0	282.0
Repeatability	5.29	32.2	13.5
Reproducibility	22.5	38.3	25.7

TABLE 3 Compressive Strength (MPa) at 25 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	179.0	206.0	366.0
Repeatability	8.69	43.3	22.5
Reproducibility	34.7	51.8	31.0

TABLE 4 Compressive Strength (MPa) at 40 MPa Confining Pressure

	Berea Sandstone	Tennessee Marble	Barre Granite
Average Value	215.0	237.0	N/A
Repeatability	7.95	42.4	N/A
Reproducibility	52.0	73.5	N/A

TABLE 5 Young's Modulus (GPa) at 0 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25 %	50 %	25 %	50%	25 %	50 %
Average Value	12.4	16.7	76.3	74.2	46.9	54.2
Repeatability	3.37	4.15	14.8	10.1	6.12	6.75
Reproducibility	4.17	5.18	17.2	12.3	6.45	7.77

TABLE 6 Young's Modulus (GPa) at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	23.5	22.5	71.1	65.2	60.4	59.8
Repeatability	0.90	1.28	11.4	9.15	2.53	2.49
Reproducibility	3.34	3.47	13.9	11.6	6.80	6.12

TABLE 7 Young's Modulus (GPa) at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	24.2	22.8	70.0	63.4	61.9	60.6
Repeatability	1.09	0.79	9.60	9.57	2.27	2.49
Reproducibility	3.82	3.57	9.69	9.57	5.95	5.34

TABLE 8 Poisson's Ratio at 10 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.28	0.34	0.30	0.33	0.26	0.30
Repeatability	0.03	0.04	0.03	0.07	0.03	0.03
Reproducibility	0.05	0.05	0.06	0.09	0.04	0.04

pressures of 10, 25, and 40 Mpa and 25 % and 50 % for the compressive test case. Additional Reference Material found in ASTM Geotechnical Journal.[4,5]

TABLE 9 Poisson's Ratio at 25 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.23	0.27	0.31	0.34	0.28	0.33
Repeatability	0.02	0.02	0.05	0.05	0.03	0.03
Reproducibility	0.04	0.04	0.06	0.05	0.04	0.05

TABLE 10 Poisson's Ratio at 40 MPa Confining Pressure

	Berea Sandstone		Tennessee Marble		Barre Granite	
	25-50 %	40-60 %	25-50 %	40-60 %	25-50 %	40-60 %
Average Value	0.20	0.24	0.32	0.34	0.29	0.33
Repeatability	0.01	0.02	0.04	0.05	0.03	0.04
Reproducibility	0.03	0.03	0.04	0.05	0.05	0.06

12.1.1 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 *r*. 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 *R*. The precision statistics are calculated from:

$$r = 2(\sqrt{2})s_r \tag{8}$$

where:

s_r = the repeatability standard deviation.

$$R = 2(\sqrt{2})s_R \tag{9}$$

where:

s_R = the reproducibility standard deviation.

12.2 *Bias*—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.

13. Keywords

13.1 compression testing; compressive strength; confined compression; loading tests; modulus of elasticity; repeatability; reproducibility; rock; uniaxial compression; Young's Modulus

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[4] ASTM Geotechnical Journal, "Interlaboratory Testing Program for Properties: Round One- Longitudinal and Transverse Pulse Velocities, Unconfined Compressive Strength, Uniaxial Modulus, and Splitting Tensile Strength" by Howard J. Pincus, Vol. 16, No.1, March 1993 and Addendum Vol. 17, No. 2, June 1993; pp. 138–163 and 256–258.

[5] ASTM Geotechnical Testing Journal, "Interlaboratory Testing Program for Rock Properties: Round Two- Confined Compression: Young's Modulus, Poisson's Ratio, and Ultimate Strength″ by Howard J. Pincus, Vol. 19, No.3, September 1996; pp. 321–336