Designation: D7070 – 16

Standard Test Methods for Creep of Rock Core Under Constant Stress and Temperature[1]

This standard is issued under the fixed designation D7070; 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 These test methods cover the creep behavior of intact weak and hard rock core in fixed states of stress at ambient (room) or elevated temperatures. For creep behavior at lower temperatures refer to Test Method D5520. The methods specify the apparatus, instrumentation, and procedures necessary to determine the strain as a function of time under sustained load at constant temperature and when applicable, constant humidity.

1.1.1 Hard rocks are considered those with a maximum axial strain at failure of less than 2 %. Weak rocks include such materials as salt, potash, shale, and weathered rock, which often exhibit very large strain at failure.

1.2 This standard consists of three methods that cover the creep capacity of core specimens.

1.2.1 *Method A*—Creep of Hard Rock Core Specimens in Uniaxial Compression at Ambient or Elevated Temperature.

1.2.2 *Method B*—Creep of Weak Rock Core Specimens in Uniaxial Compression at Ambient or Elevated Temperature.

1.2.3 *Method C*—Creep of Rock Core Specimens in Triaxial Compression at Ambient or Elevated Temperature.

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

1.4 The procedures used to specify how data are collected/recorded and 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 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 commensurate with these considerations. It is beyond the scope of these test methods to consider significant digits used in analysis methods for engineering design.

1.5 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered 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 to determine the applicability of regulatory limitations prior to use. For specific precautionary statements, see Section 7.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2845 Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4543 Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances
D5079 Practices for Preserving and Transporting Rock Core Samples
D5520 Test Method for Laboratory Determination of Creep Properties of Frozen Soil Samples by Uniaxial Compression
D6026 Practice for Using Significant Digits in Geotechnical Data
E4 Practices for Force Verification of Testing Machines
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

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

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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**

3. Terminology

3.1 *Definitions:*

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hard rock*—rock core exhibiting less than 2 % strain at failure when tested in uniaxial compression.

3.2.2 *weak rock*—rock core exhibiting 2 % or greater strain at failure when tested in uniaxial compression.

3.2.3 *true stress*—a constant stress applied to a specimen as a result of a varying vertical load based upon changes in the specimen diameter.

4. Summary of Test Method

4.1 A section of rock core is cut to length, and the ends are machined flat or are capped in a manner to produce a cylindrical test specimen.

4.2 For Methods A and B, (Uniaxial Compression Method) the specimen is positioned onto a loading frame. A specified axial load is applied rapidly to the specimen and sustained throughout the test duration. The specimen may be subjected to an elevated temperature and/or constant humidity environment if so desired. The axial deformation is monitored as a function of elapsed time. The lateral deformation may also be monitored as a function of elapsed time if so desired.

4.3 For Method C (Triaxial Compression Method), the specimen is placed into a triaxial chamber and then positioned onto a loading frame. The specimen is subjected to a constant confining pressure. A specified axial load is rapidly applied to the specimen and maintained throughout the test duration. If desired, the specimen, while positioned in the triaxial cell, can be subjected to elevated temperature. The axial deformation is monitored as a function of elapsed time. The lateral deformation may also be monitored as a function of elapsed time if so desired.

5. Significance and Use

5.1 There are many underground structures that are constructed for permanent or long-term use. Often, these structures are subjected to a relatively constant load. Creep tests provide quantitative parameters for stability analysis of these structures.

5.2 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 test results of intact specimens shall be utilized with proper judgment in engineering applications.

NOTE 1—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 these factors.

6. Apparatus

6.1 *Loading Device*—The loading device shall be of sufficient capacity to meet the requirements of the testing program and capable of applying the test load at a rate conforming to the requirements specified in 9.5. The device shall be capable of maintaining the specified test load to within ±2 %. The force measurement device or load cell shall be calibrated in accordance with the procedures outlined in Practice E4 and following the schedule provided in Practice D3740.

NOTE 2—By definition, creep is the time-dependent deformation under constant stress. The loading device is specified to maintain constant axial load and therefore, constant engineering stress. The true stress, however, decreases as the specimen deforms and the cross-sectional area increases. Because of the associated experimental ease, constant load testing is recommended. However, the procedure permits constant true-stress testing, provided that the applied load is increased with specimen deformation so that true stress is constant within ±2 %.

6.2 *Triaxial Apparatus*—The triaxial apparatus shall consist of a chamber in which the test specimen is subjected to a constant lateral hydraulic pressure and the required axial load. The triaxial apparatus shall have a working pressure that exceeds the specified confining stress. The triaxial apparatus shall have safety valves where applicable, suitable entry ports for filling the chamber, hoses, pressure gauges, and shutoff valves as required. Fig. 1 shows a typical test apparatus and associated equipment.

6.3 *Triaxial Flexible Membrane*—The membrane encases the rock specimen and extends over the platens to prevent infiltration of the confining fluid. A sleeve of natural or synthetic rubber or plastic is satisfactory for ambient (room) temperature tests. Metal or high-temperature rubber jackets such as viton are normally required for elevated temperature tests. The membrane shall be inert relative to the confining fluid and shall cover small pores in the sample without rupturing when the confining pressure is applied. Plastic or silicone rubber coatings may be applied directly to the sample, provided these materials do not penetrate or strengthen the specimen. Care must be exercised 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.

6.4 *Triaxial Pressure-Maintaining Device*—A hydraulic pump, pressure intensifier, or other system of sufficient capacity to maintain constant the desired lateral pressure. The pressurization system shall be capable of maintaining the confining pressure constant to within ±1 % throughout the test duration. The confining pressure shall be measured with a hydraulic pressure gauge or electronic transducer and readout having an accuracy of at least ±1 % of the confining pressure and a resolution of at least 0.5 % of the confining pressure.

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

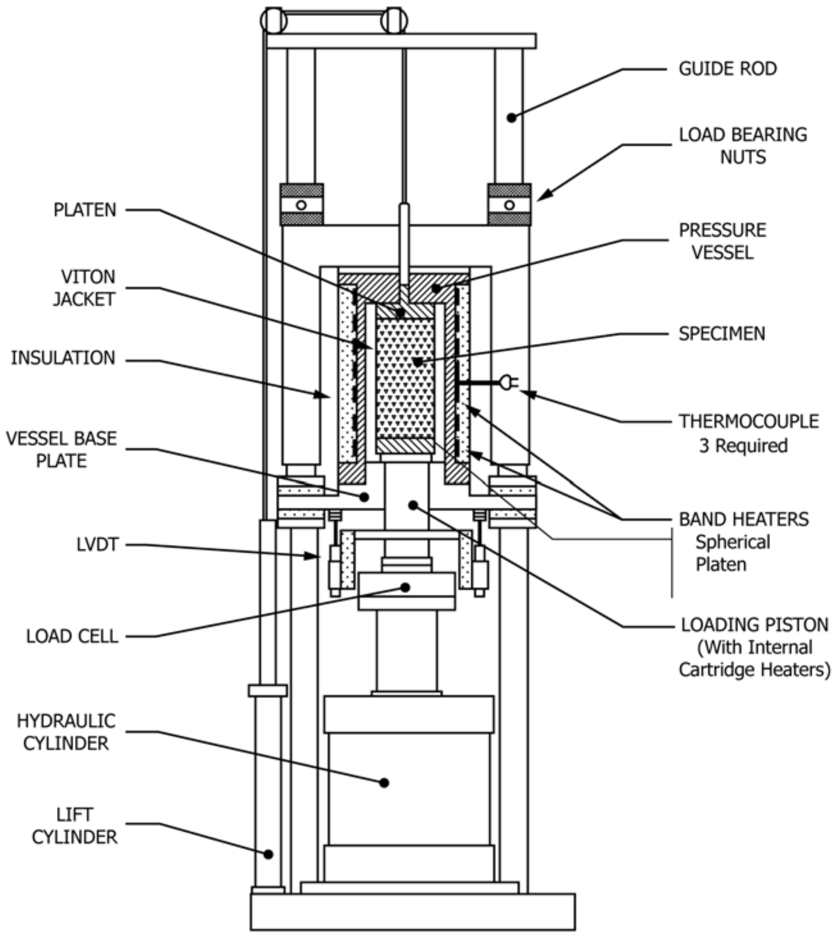

FIG. 1 Typical Triaxial Test Apparatus

6.6 *Elevated-Temperature Device*—The elevated temperature device may be an enclosure that fits in or over the loading apparatus, for Method A and B tests. For Method C (triaxial) tests an internal system that fits in the triaxial apparatus, an external system encompassing the triaxial cell or an enclosure that completely encompasses the entire test apparatus may be used. The enclosure, used for Methods A and B, may be equipped with humidity control for testing specimens in which the moisture content is to be controlled.

6.6.1 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 positioned near the top, one at midheight, and one near the bottom of the specimen. The average specimen temperature shall be maintained to within ±1°C (±2°F) of the required test temperature and be based solely on the midheight sensor readings. The maximum temperature difference between the midheight sensor and either end sensor shall not exceed ±3°C (±5°F).

6.6.2 An alternative to measuring the temperature at three locations along the specimen during the test is to determine the temperature distribution in a substitute specimen that has temperature sensors located in ports at three positions similar to the configuration of the actual test specimen and having the same temperature requirements as outlined in 6.6.1.

6.6.3 The enclosure shall be equipped with humidity control for testing specimens in which the moisture content is to be kept constant. A controlled humidity enclosure shall be used when testing weak rock such as shale or weathered rock that may be susceptible to cracking or degrading due to moisture loss. In place of a humidity enclosure, the test load apparatus may be housed in a humidity controlled room.

6.7 *Temperature Measuring Device*—Thermocouples or platinum resistance thermometers (RTDs) having an accuracy of ±1°C (±2°F) with a resolution of 0.1°C (0.2°F).

6.8 *Platens*—Two steel platens are used to transmit the axial load to the ends of the specimen. They shall have a hardness of 58 HRC or greater. One of the platens shall be spherically seated and the other a plain rigid platen. The bearing faces shall not depart from a plane by more than 0.015 mm (0.0006 in.) when the platens are new and shall be maintained within a permissible variation of 0.025 mm (0.0010 in.). 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.

6.8.1 *Hard Rock Specimens*—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 (0.060 in.). This platen diameter shall be retained for a length of at least one-half the specimen diameter.

6.8.2 *Weak Rock Specimens*—The platen diameter shall be at least as great as the specimen but shall not exceed the specimen diameter by more than 10 % of the specimen diameter. Because weak rocks can deform significantly in creep tests, it is important to reduce friction in the platen-specimen interfaces to facilitate relative slip between the specimen ends and the platens. Effective friction-reducing precautions include polishing the platen surfaces to a mirror finish and attaching a thin, 0.15 mm (0.0060 in.) thick Teflon sheet to the platen surfaces.

6.9 *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 ±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 rate of 10^{-8}/s.

NOTE 3—Pressure and temperature used during the test may influence the output of strain and deformation sensors located within the triaxial environment. Caution shall be exercised to verify the readings represent accurate values.

6.9.1 *Axial Strain Determination*—The axial deformations or strains may be determined from data obtained by electrical resistance strain gauges, 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 gauge length over which the axial strains are determined shall be at least 10 grain diameters in magnitude.

6.9.2 *Lateral Strain Determination*—The lateral deformations or strains may be measured by any of the methods mentioned in 6.9.1. 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. A minimum of 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. The average lateral strain may also be determined from dilatometric measurements of volumetric strain after accounting for the axial strain component.

6.9.3 The use of strain gauge adhesives requiring cure temperatures above 65°C (149°F) shall not be used unless it is verified that microfractures do not develop in the adhesive at the cure temperature.

7. Hazards

7.1 Danger exists near loading and triaxial testing equipment because of the high pressures and loads developed within the system. Elevated temperatures increase the risks of electrical shorts and fire. Test systems shall be designed and constructed with adequate safety factors, assembled with properly rated fittings, and provided with protective shields to protect people from system failure.

7.2 The use of a gas as the confining pressure component introduces potential for extreme violence and shall not be used.

7.3 A fluid shall be used as the component to confine the specimen under pressure. The flash point of the confining fluid shall be higher than the target operating temperature during the test.

8. Samples and Specimens

8.1 Samples may be either drilled cores obtained directly from the in situ rock or obtained from block samples cored in the field or in the laboratory.

8.1.1 The core orientation to vertical shall be determined for the test.

8.2 The moisture condition at the time of testing may have a significant effect upon the deformation of the rock. Test specimens shall meet all requirements determined in 8.2.1. Therefore, the field moisture condition of the samples shall be maintained during and after sampling. This may require special collection and handling techniques such as those outlined in Practices D2113 and D5079.

8.2.1 If it is desired that the specimens be tested at other than "as sampled" water contents, including zero it shall be noted in the test report. If the moisture content of the specimen is to be determined, follow the procedures outlined in Test Method D2216.

8.3 The location of each test specimen shall be selected from the cores to represent a valid average of the type of rock and lithology 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.

8.4 The number of specimens required to obtain a specific level of statistically valid results may be determined using Practice E122. However, it may not be economically possible to achieve specific confidence levels and professional judgment may also be necessary.

8.5 *Specimen Preparation*—Prepare test specimens from the drilled core samples in accordance with Practice D4543 and 8.2, 8.2.1, and 8.3. The specimen shall have a height to diameter ratio of between 2.5 and 3.0 to 1.

8.5.1 Weak rock specimens may be difficult or impossible to obtain proper end preparation. If this condition exists, the specimens may be capped using a plaster, neat cement or other suitable material that is capable of providing a plane surface. The compressive strength of the capping material must be higher than the specified axial stress.

9. Procedure

9.1 Check the ability of the spherical seat to rotate freely in its socket prior to each test.

9.2 *Methods A and B (Uniaxial Setup)*—Place the lower platen on the base or actuator rod of the loading device.

9.2.1 Wipe clean the bearing faces of the upper and lower platens and of the test specimen, and position the test specimen on the lower platen.

9.2.2 Position the upper platen on the specimen and align properly.

9.2.3 If desired for the testing program, install the elevated-temperature device.

9.2.4 Position the axial and lateral deformation measuring transducers for the apparatus.

9.2.5 If constant water content of the specimen is important, a means of controlling the humidity surrounding the specimen shall be positioned.

9.2.6 A small axial load, of approximately 100 N (22.5 lb), may be applied to the specimen by means of the loading device in order to properly seat the bearing parts of the apparatus.

9.3 *Method C (Triaxial Setup)*—Follow the steps outlined in 9.1 through 9.2.2.

9.3.1 Place the membrane over the specimen and platens sealing the specimen from the confining fluid. Place the specimen into the test chamber, and facilitate a proper seal with the base.

9.3.2 Position the triaxial cell onto the loader and attach the restraining mechanisms so the cell is anchored to the loader.

9.3.3 Connect the confining pressure lines.

9.3.4 If required, install an elevated-temperature device.

9.3.5 Position the axial deformation measuring transducers for the apparatus and the lateral deformation transducers if desired.

9.3.6 Introduce the confining fluid into the chamber and increase the confining pressure uniformly to the specified level. The axial load must be applied simultaneously maintaining an axial stress application that differs from the confining stress by no more than 5 %.

9.4 *Methods A, B, and C*—If testing at an elevated temperature, raise the temperature at a rate not exceeding 2°C/min until the required temperature is reached (Note 4). The test specimen shall be considered to have reached pressure and thermal 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).

9.4.1 Where independent data demonstrates that the 30 minute criterion is not adequate depending on specimen size and composition, then the operator may increase the time to equilibrium. Stability is defined as a constant reading showing only the effects of normal instrument and heater unit fluctuations. Record the initial deformation readings as zero for the test.

NOTE 4—It has been observed that for some rock types microcracking will occur for heating rates above 1°C/min (2°F/min). The operator is cautioned to select a heating rate such that microcracking is not significant.

9.5 Apply the axial load continuously and without shock to the required test load within a 20-s interval for hard rock and 60 s for weak rock. The faster the test load is reached, the more accurate the test. The applied load shall be ±2 % of the target value. Thereafter, the test load shall be held constant for the remainder of the test for constant load testing or adjusted with specimen deformation for constant true stress testing.

9.6 Record the strain/deformation immediately after the required test load has been applied. Thereafter record the strain or deformation at suitable time intervals. During the transient straining, readings shall be taken every few minutes to several hours until the deformation rate slows and becomes relatively constant. Readings shall be taken at least twice daily until the test is terminated. If the test extends into the tertiary creep period, frequency of reading shall be increased appropriately.

9.7 Record the load, pressure and specimen temperature continuously or each time the strain or deformation is read.

9.8 After completion of Method C tests, visually observe the specimen membrane to verify that no confining fluid has penetrated the specimen and carefully check for fissures or punctures at the completion of each triaxial test. If these conditions exist, there may have been inaccurate confining stress application and a duplicate test may need to be performed.

10. Calculation

10.1 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.

10.1.1 Calculate the axial strain, ε_a, as follows:

$$\varepsilon_a = \frac{\Delta L}{L} \tag{1}$$

where:

L = original undeformed axial gauge length, and
ΔL = change in measured axial length (negative for a decrease in length).

NOTE 5—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 6—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.

10.1.2 Calculate the lateral strain, ε_l, as follows:

$$\varepsilon_l = \frac{\Delta D}{D} \tag{2}$$

where:

D = original undeformed diameter, and

ΔD = change in diameter (positive for increase in diameter).

NOTE 7—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.

NOTE 8—If volumetric strain is measured, then lateral strain maybe calculated using the relationship $\varepsilon_v = \varepsilon_a + 2\varepsilon_l$.

10.2 Calculate the total axial stress on the test specimen from the compressive load and the initial computed cross-sectional area as follows:

$$\sigma = \frac{P}{A} \quad (3)$$

where:

σ = stress,
P = load, and
A = area.

NOTE 9—If the specimen diameter is not the same as the piston diameter through the triaxial apparatus, a correction must 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 triaxial apparatus.

10.3 Plot the strain-versus-time curves for the axial and lateral directions (Fig. 2). The strain measure in the plot shall be the total strain as deformation zero was established at the hydrostatic stress state (9.4). The total strain measure includes the elastic and inelastic strain induced during axial load application (9.5) and the inelastic strain that accumulates with time. For plots of creep strain versus time, the time and strain origin for the test shall be moved to the data point that represents the end of the axial load application. The plot must clearly designate the strain measure being used.

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

11.1 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.

11.2 Record as a minimum the following information (data):

11.2.1 Source of sample including project name, project number, and location.

11.2.2 Date of the test report.

11.2.3 Name of person who performed the test.

11.2.4 Boring number, sample number or run number, depth.

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

11.2.6 Moisture condition of the specimen before test.

11.2.7 Moisture content before and after the test on weak rock specimens.

11.2.8 The orientation of the core to vertical.

11.2.9 Specimen diameter and height and conformance with dimensional requirements.

11.2.10 Confining stress at which the test was performed (Method C only).

11.2.11 Temperature at which the test was performed.

11.2.12 Axial stress at which the test was performed. Indicate whether engineering or true stress was held constant.

11.2.13 Plot(s) of the axial strain-versus-time and lateral strain-versus-time, if measured (Fig. 2).

11.2.14 Tabulation of selected strain and time data.

11.2.15 A description of the physical appearance of the specimen after testing, including visible end effects such as cracking, spalling, or shearing at the platen-specimen interfaces.

11.2.16 If the actual equipment or procedure has varied from the requirements contained in this test method, each variation shall be outlined.

11.2.17 Photos of the specimen before and after testing (optional).

12. Precision and Bias

12.1 *Precision*—Due to the nature of the rock materials tested by this test method, it is either not feasible or too costly at this time to produce multiple specimens that have uniform mechanical properties. Any variation observed in the data is just as likely to result from specimen variation as from operator or laboratory testing variation. Subcommittee D18.12 welcomes proposals that would allow for development of a valid precision statement.

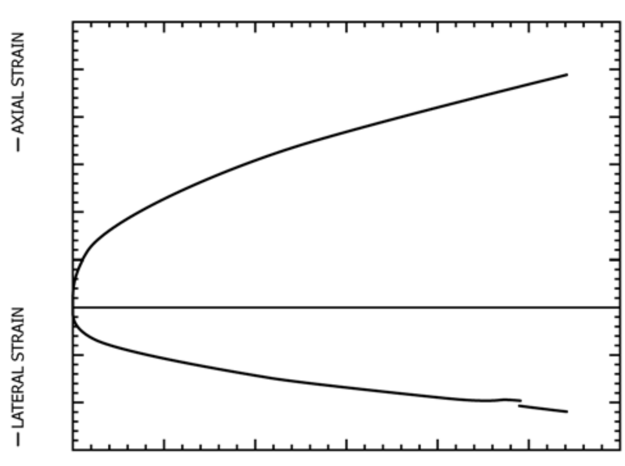

FIG. 2 Typical Strain-Versus-Time Curves

12.2 *Bias*—Bias cannot be determined since there is no standard creep deformation that can be used to compare with values determined using this test method.

13. Keywords

13.1 compression testing; creep; deformation; loading tests; rock; triaxial compression

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D7070 – 08) that may impact the use of this standard. (November 1, 2016)

(1) Revised Section 1 to more clearly define the three methods.
(2) Added 1.4 to address how data are collected and significant digits.
(3) Section 2, Reference Documents, added references to D2845 and D5520.
(4) Section 3, Terminology, added terms unique to the standard.
(5) Revised Section 4 outlining the differences between the test methods.
(6) Clarified the wording in Section 6, Apparatus.
(7) Combined Sections 8 and 9.
(8) Changed old Note 3 to mandatory information and renumbered notes.
(9) Revised old Section 12 (Report section) renamed to Section 11 and expanded required information.
(10) Corrected grammar and clarified wording throughout the standard.