Standard Test Method for Creep of Cylindrical Rock Core Specimens in Triaxial Compression[1]

This standard is issued under the fixed designation D 4406; 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 creep behavior of intact cylindrical rock core specimens' in triaxial compression. It specifies the apparatus, instrumentation, and procedures for determining the strain as a function of time under sustained load.

1.2 *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.* For specific precautionary statements, see Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock[2]

D 4341 Test Method for Creep of Cylindrical Hard Rock Core Specimens in Uniaxial Compression[2]

D 4543 Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances[2]

E 4 Practices for Load Verification of Testing Machines[3]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[4]

3. Summary of Test Method

3.1 A rock core sample is cut to length, and the ends are machined flat. The specimen is placed in a triaxial loading chamber, subjected to confining pressure, and, if required, heated to the desired test temperature. Axial load is rapidly applied to the specimen and sustained. Deformation is monitored as a function of elapsed time. Sample deformation is monitored periodically.

4. Significance and Use

4.1 There are many underground structures that are created for permanent or long-term use. Often these structures are subjected to an approximately constant load. Creep tests provide quantitative parameters for stability analysis of these structures.

4.2 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 values for intact specimens must be employed with proper judgment in engineering applications.

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 and shall be able to maintain the specified load within 2 %. 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 this test method.

NOTE 1—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 %.

5.2 *Triaxial Apparatus*—The triaxial 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. Fig. 1 shows a typical test apparatus and associated equipment.

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 jackets[5] are usually required for elevated temperature tests. The membrane shall be inert relative to the confining fluid and shall cover small pores in the

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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.

[5] For example, viton.

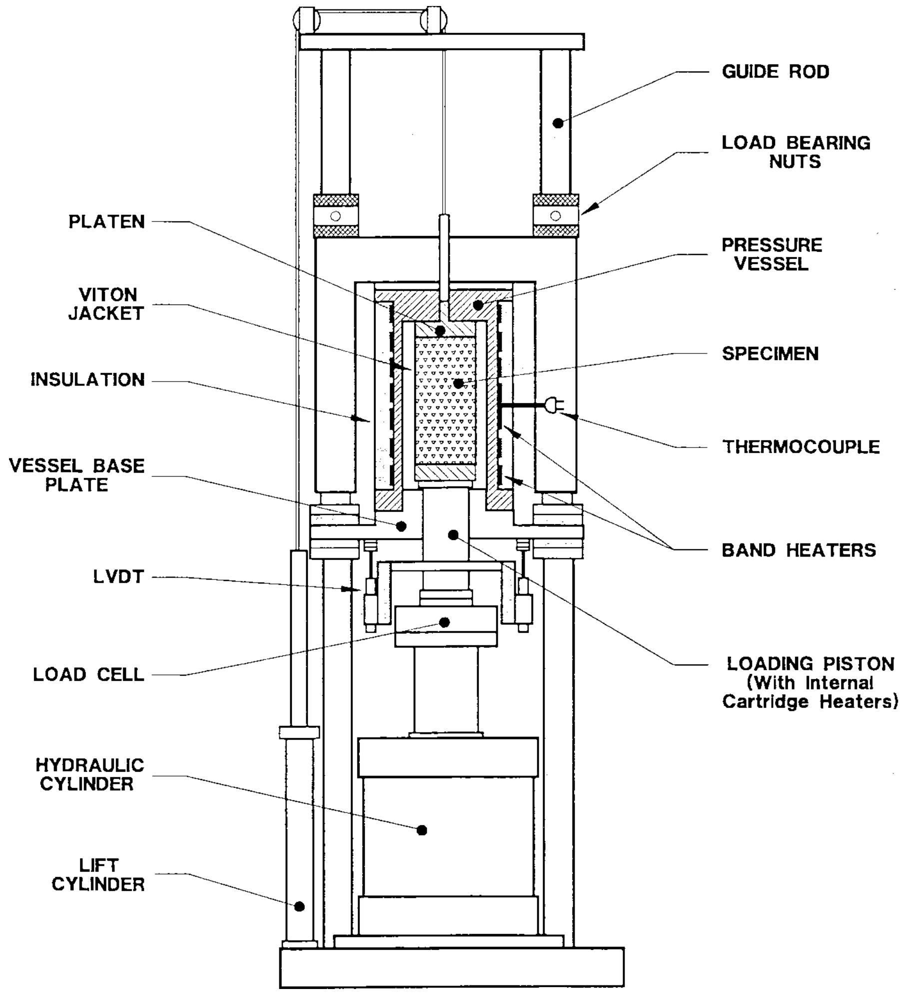

FIG. 1 Test Apparatus

sample without rupturing when confining pressure is applied. Plastic or silicone rubber coatings may be applied directly to the sample, provided these materials do not penetrate and strengthen 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 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. The confining pressure shall be measured with a hydraulic pressure gage or electronic transducer having an accuracy of at least ±1 % 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 should 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 may be either an internal system that fits in the triaxial apparatus, an external system enclosing the entire triaxial 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 2—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 ±1°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 ±1°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 creep behavior.

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

5.8 *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 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.

5.8.1 *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. This platen diameter shall be retained for a length of at least one-half the specimen diameter.

5.8.2 *Soft 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 soft 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-thick teflon sheet to the platen surfaces.

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 noncharacterizable long-term instability (drift) that results in an apparent strain of 10^{-8}/s.

NOTE 3—The user is cautioned about the influence of pressure and temperature on the output of strain and deformation sensors located within the triaxial environment.

5.9.1 *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.

5.9.2 *Lateral Strain Determination*—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 4—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.

6. Safety Hazards

6.1 Danger exists near 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 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. The flash point of the confining pressure fluid should be above the operating temperatures during the test.

7. Sampling

7.1 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.

8. Test Specimens

8.1 *Preparation*—Prepare test specimens 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 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 11.1.3. If the moisture content of the specimen is to be determined, follow the procedures given in Test Method D 2216.

9. Procedure

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

9.2 Place the lower platen on the base or activator 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. Fit the membrane over the specimen and platens to seal the specimen from the confining fluid. Place the specimen in the test chamber, ensuring proper seal with the base and connect the confining pressure lines. A small axial load, approximately 100 N, may be applied to the triaxial compression chamber by means of the loading device in order 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 Put the confining fluid in the chamber and raise the confining stress uniformly to the specified level within 5 min. Do not allow the lateral and axial components of the confining stress to differ by more than 5 % of the instantaneous pressure at any time.

9.5 If testing at elevated temperature, raise the temperature at a rate not exceeding 2°C/min until the required temperature is reached (Note 5). 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). 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 zero for the test.

NOTE 5—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.

9.6 Apply the axial load continuously and without shock to the required test load within 20 s. Thereafter, the test load shall be held constant for the remainder of the test for constant load testing or increased with specimen deformation for constant true stress testing.

9.7 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 few 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.

9.8 Record the load and specimen temperature continuously or each time the strain or deformation is read.

9.9 To make sure that no testing fluid has penetrated into the specimen, the specimen membrane shall be carefully checked for fissures or punctures at the completion of each triaxial test.

10. Calculation

10.1 The axial strain, ϵ_a, and 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:

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

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

NOTE 6—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 7—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:

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

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

NOTE 8—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.

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

$$\sigma = \frac{P}{A} \tag{3}$$

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).

11. Report

11.1 Report the following information:

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.

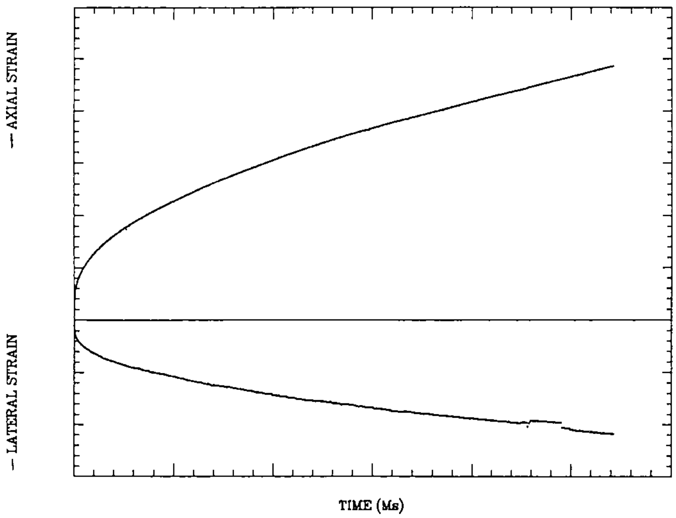

FIG. 2 Typical Strain-Versus-Time Curves

11.1.5 Confining stress level at which test was performed.

11.1.6 Temperature at which test was performed.

11.1.7 Stress level at which test was performed. Indicate whether engineering or true stress was held constant.

11.1.8 Plot of the strain-versus-time curve (Fig. 2).

11.1.9 Tabulation of selected strain and time data.

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

11.1.11 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.

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.

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