



Designation: D4535 – 13

Standard Test Methods for Measurement of Thermal Expansion of Rock Using Dilatometer¹

This standard is issued under the fixed designation D4535; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 These test methods cover the laboratory measurement of the one-dimensional linear thermal expansion of rocks using a dilatometer.

1.2 These test methods are applicable between temperatures of 25°C to 300°C. Both bench top and confined measurement techniques are presented. Test Method A is used for unconfined or bench top measurements and Test Method B is used for confined conditions. Rocks of varying moisture content can be tested.

1.3 For satisfactory results in conformance with these test methods, the principles governing the size, construction, and use of the apparatus described in these test methods should be followed. If the results are to be reported as having been obtained by either test method, then the pertinent requirements prescribed by that test method shall be met.

1.4 These test methods do not establish details of construction and procedures to cover all test situations that might offer difficulties to a person without technical knowledge concerning the theory of heat flow, temperature measurement, and general testing practices. Standardization of these test methods does not reduce the need for such technical knowledge.

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

1.6 The procedures used to specify how data are collected/recorded or 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 the 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 be commensurate with these considerations. It is beyond the scope

of this standard to consider significant digits used in analytical methods for engineering design.

1.7 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.

1.8 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

E83 Practice for Verification and Classification of Extensometer Systems

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

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

3.2 Definitions of Terms Specific to This Standard:

¹ These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Nov. 1, 2013. Published December 2013. Originally approved in 1985. Last previous edition approved in 2004 as D4535 – 08. DOI: 10.1520/D4535-13.

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.

3.2.1 *specimen thermal strain, ϵ_r* —change in length, $(L_2 - L_1)$, divided by the original length, L_0 , of the specimen when the specimen is subjected to heat. Specimen thermal strain is also equal to the corrected thermal expansion, δ_t , divided by the original specimen length.

3.2.2 *mean coefficient of linear expansion, α_m* —a value, often expressed in parts per million per degree. It is obtained by dividing the linear thermal strain, $((L_2 - L_1)/L_0)$, by the change in temperature units cm/cm (in./in.) per temperature change in °C (°F).

3.2.3 The sign convention used for α_m is as follows: α_m will be a positive value indicating an increase in the length of the rock specimen ($T_2 > T_1$) and α_m will be a negative value indicating a decrease or contraction of the rock specimen

4. Summary of Test Methods

4.1 The application of heat to a rock causes it to expand. This expansion divided by the original length of the rock specimen is the thermal strain from which coefficients of expansion can be calculated. This standard covers two methods for measuring rock expansion. The primary difference between the two methods is in the type of dilatometer used.

4.1.1 Test Method A is used when making unconfined or bench top measurements. The method and apparatus are similar to that described in Test Method E228. The rock specimen's thermal displacement is measured using a dilatometer as shown in Fig. 1. The specimen displacement is measured by a transducer located outside the heated area of the specimen; therefore, apparent strain due to apparatus expansion and contraction is minimized.

4.1.2 Test Method B is most suited for the measurement of rock thermal strain under confined conditions and employs a dilatometric device which is located inside the heated zone, as shown in Fig. 2. Test Method B is amenable to confined thermal strain determinations; however, confined tests may be most appropriate when:

4.1.2.1 Pore pressure must be imposed in the pore space to maintain the liquid phase of water through the desired temperature range.

4.1.2.2 The thermal strain of the rock is sensitive to confining stress.

4.1.2.3 The specimen is fragile or friable, or both, and cannot be machined into the shapes required for Test Method A.

4.2 In both test methods, specimen expansion is measured continuously as temperature is gradually increased or allowed to stabilize at discrete temperature points.

5. Significance and Use

5.1 Information concerning the thermal expansion characteristics of rocks is important in the design of any underground excavation where the surrounding rock may be heated. Thermal strain causes thermal stresses which ultimately affect excavation stability. Examples of applications where rock thermal strain is important include: nuclear waste repositories, underground power stations, compressed air energy storage facilities, and geothermal energy facilities.

5.2 The coefficient of thermal expansion, α , of rock is known to vary as the temperature changes. These methods provide continuous thermal strain values as a function of temperature, and therefore provide information on how the coefficient of thermal expansion changes with temperature.

5.3 Rocks are also often anisotropic, thus displaying different thermal strains depending on the orientation of strain measurement. These methods allow for measuring strain in one direction only. If anisotropy is expected, specimens with different orientations should be prepared and tested.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Interferences

6.1 Care should be exercised in the interpretation of thermal strain data of rocks with significant moisture content. Under certain temperature and pressure conditions, steam may be produced in the pore space. Steam may cause errors because of microcrack production or changes in the pore pressure. The phase change from water to steam in the pore space can result in several phenomena which complicate data analysis, as follows:

6.1.1 Evolved steam may change the pore pressure and thus the effective stress in the rock, resulting in anomalous strain readings.

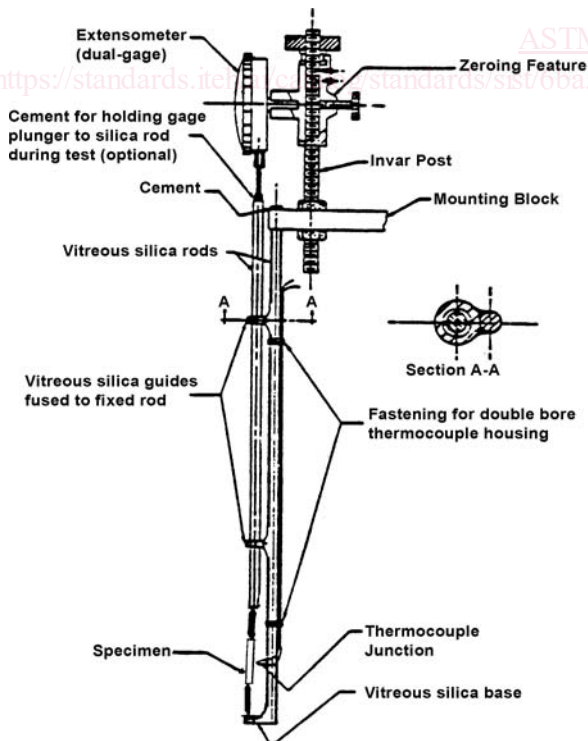


FIG. 1 Apparatus Commonly Used to Perform Bench Top (Test Method A) Thermal Expansion Measurements

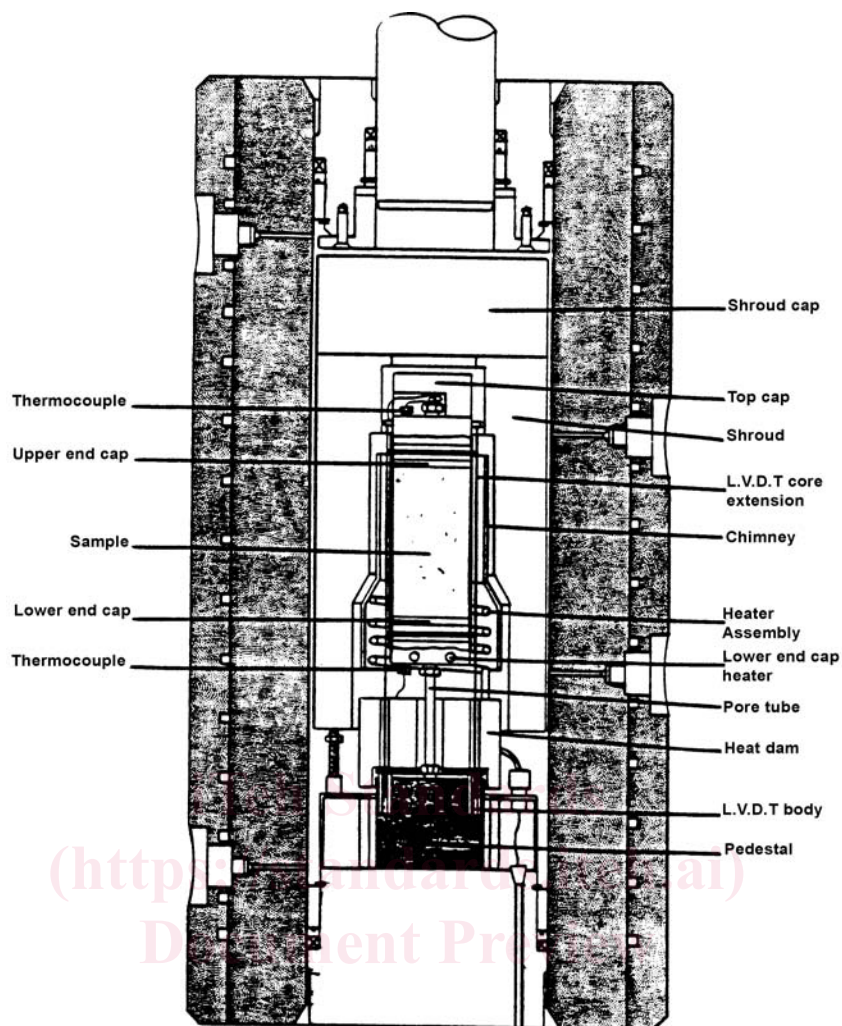


FIG. 2 Apparatus Commonly Used to Perform Confined (Test Method B) Thermal Expansion Measurements

6.1.2 Losing all the moisture may dehydrate clays in the pore space and thus change expansion characteristics, especially in layered rocks

6.1.3 Good judgment should be used when deciding how to make the thermal expansion measurement so that it accurately represents the conditions in the field.

7. Apparatus

7.1 Dilatometer:

7.1.1 *Test Method A*—The dilatometer used for bench measurements may be of the tube or rod type, as shown in Fig. 1. Those components of the dilatometer exposed to elevated temperatures should be fabricated of materials with coefficients of linear expansion that are as small as practicable.

7.1.2 *Test Method B*—The entire dilatometer is exposed to elevated temperature; therefore, transducers, rods, and other components should be fabricated of materials with low thermal expansions. For example, fused silica, and super invar. When the apparatus is tested with a quartz calibration specimen, the

apparatus strain should be less than 20 % of the anticipated rock strain (refer to Fig. 2).

7.2 *Extensometer*—Extensometers measure length change. In principle, any accurate length measuring device with good long-term stability may be used; including dial gauges, linear variable differential transducers, or capacitive transducers. Whichever device is selected, it must have sufficient resolution to measure 0.01 % specimen strain (Refer to Practice E83).

7.2.1 Devices used in Test Method B must be fabricated of materials that allow direct exposure of the device to the anticipated temperature. Also, transducer bodies should be vented for operation in a pressure environment. At least two transducers are used, as shown in Fig. 2, and their outputs averaged.

7.3 *Furnace*—The furnace shall be large enough to contain the specimen and apparatus and maintain uniform temperature along the axis of the specimen with variations no greater than $\pm 1^\circ\text{C}$. The mean sample temperature shall be controlled within