Designation: D4435 – 13ε1

Standard Test Method for Rock Bolt Anchor Pull Test[1]

This standard is issued under the fixed designation D4435; 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.

ε[1] NOTE—Editorial corrections were made throughout in February 2014.

1. Scope*

1.1 The objective of this test method is to measure the working and ultimate capacities of a rock bolt anchor. This method does not measure the entire roof support system. This method also does not include tests for pretensioned bolts or mine roof support system evaluation.

1.2 This test method is applicable to mechanical, cement grout, resin, (epoxy, polyester, and the like), or other similar anchor systems.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard. Reporting of test results in units other than inch-pound shall not be regarded as nonconformance with this test method.

1.3.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs.

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

1.4.1 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.

1.5 *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]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

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

3. Terminology

3.1 *Definitions*—For definitions of common technical terms in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *displacement*—the movement of the rock bolt head.

3.2.2 *failure*—in rock bolt testing, failure is defined as the inability of the anchor system or rock to sustain increased load without rapidly increasing deformation. In some instances, the peak load itself cannot be sustained.

3.2.3 *load*—the total axial force on the rock bolt.

3.2.4 *ultimate capacity*—the maximum load sustained by the anchor system.

3.2.5 *working capacity*—the load on the anchor system at which significantly increasing displacement begins.

4. Summary of Test Method

4.1 A rock bolt is installed in the same manner and in the same material as its intended construction use. The bolt is pulled hydraulically and the displacement of the bolt head is measured concurrently. The bolt is pulled until the anchor system or rock fails. The ultimate and working capacities of the bolt are calculated from the plot of load versus displacement.

[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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[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**

5. Significance and Use

5.1 Rock bolts are used for support in a variety of mining and civil engineering situations.[3] The pull test may be used to provide a quantitative measure of the relative performance of different anchor systems in the same rock type. Anchor systems may be different mechanical anchors or different bond materials or lengths for grouted anchors. Such data can be used to choose an anchor type and determine bolt length, spacing, and size.

5.2 The objective of the method is to measure anchor performance, and not the performance of the rock bolt itself. Thus, to make sure the bolt response during the test is minimal and predictable, high strength, short-length (6 to 8 ft (1.8 to 2.5 m)) bolts have been specified. The bolt should be just long enough to make sure that failure occurs in the anchor system and not from the reaction pad bearing down on the rock mass.

5.3 Ideally, the rock bolt anchor should fail by shear at the anchor-rock interface or bond. Therefore, the local characteristics of the rock, such as roughness and induced fractures, are significant factors in the anchor strength. To obtain realistic strength values, the test holes should be drilled using the same methods as the construction rock bolt holes.

5.4 Rocks with significant time-dependent behavior, such as rock salt or shale, may respond to the anchor system itself and change the anchor strength. In these cases, consideration should be given to testing bolts over a period of time.

5.5 In establishing a testing program, the following factors should be considered:

5.5.1 Anchor pull tests should be conducted in all rock types in which construction bolts will be installed. If the rock is anisotropic, for example, bedded or schistose, the tests should be conducted in various orientations relative to the anisotropy, including those at which the construction bolt may be installed.

5.5.2 In each rock type, at each orientation, and for each anchor system, a sufficient number of tests should be conducted to determine the average bolt capacities within a fixed uncertainty at the 95 % confidence level. The allowable uncertainty band depends on the project and involves such factors as the rock quality, expected project lifetime, and importance of the areas to be bolted. Its determination will require considerable engineering judgment. As a rough guideline, at least 10 to 12 pull tests for a single set of variables have been found necessary to satisfy the statistical requirements.

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 test method 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.

[3] For additional information see, "Suggested Method for Determining the Strength of a Rock Bolt Anchor (Pull Test)," *Suggested Methods for Rock Bolt Testing*, International Society for Rock Mechanics Commission on Standardization of Laboratory and Field Tests, 1974.

6. Apparatus

6.1 *Loading System*—The system for pulling the rock bolts shall consist of a hollow-center hydraulic ram and mounting/reaction frame. The hydraulic ram shall be of sufficient capacity to fail the anchor and shall have a travel range of at least 2 in. (50 mm). The mounting/reaction frame shall be usable against uneven rock surfaces. The loading system shall apply a force that deviates by no more than 5° from the long axis of the bolt during the test.

6.2 *Load Transducer*—An electronic load cell is recommended to measure the load on the rock bolt. The cell shall have an accuracy of at least ±200 lbf (±890 N), including errors introduced by the excitation and readout system, and a resolution of at least 100 lbf (445 N). Other types of load transducers may be used if their performance meets these specifications. Alternatively, a pressure gauge or electronic transducer may be used to measure the pressure applied to the ram, provided the load measurement requirements above are satisfied, including the effects of friction in the hydraulic ram, and the like.

6.3 *Displacement Transducer*—A dial gauge is recommended to measure the displacement of the rock bolt head. It shall have an accuracy of at least ±0.001 in. (0.025 mm), a resolution of at least 0.0005 in. (0.013 mm), and a range of at least 2 in. (50 mm). It shall be mounted along the axis of the rock bolt within 5°. The end of the rock bolt, or pulling rod if used, shall be smooth with a counter-sink area approximately ¼ in. (6 mm) in diameter to accommodate the measuring tip of the dial gauge. Other types of displacement transducers may be used provided they satisfy the requirements of this section.

6.4 *Displacement Transducer Support*— The displacement transducer shall be supported from a point no closer than 3 ft (0.9 m) to the reaction frame, if attached to the same rock face. The support shall be sufficiently rigid such that no deflection or instability occurs during testing.

6.5 *Anchor Systems*—The anchors used for testing shall be from the manufacturer's standard production stock. Mechanical anchors shall be inspected to make sure that no defective anchors are tested. Mechanical anchors should be of correct size for the hole diameter and the anchorage size should be known. Grout or resin shall be fresh (within the shelf life) and obtained from unopened containers. If grouted anchors are to be tested, make sure resin cartridge sizes are compatible with hole diameter, rock bolt bar diameter and length of anchorage required. For anchorages utilizing injected grout, make sure mixing and injection equipment and systems are compatible with manufacturer's recommendations.

6.6 *Rock Bolt and Accessories*—The rock bolt shall be of sufficient diameter and strength that its elastic range is not exceeded during testing. Standard bearing plates, washers, and the like may be used as required.

6.7 *Drilling Equipment*—The same type of drilling equipment and drill bits that will be used for installing rock bolts during the construction phase of the project shall be used as much as practical to drill the test holes.

6.8 *Torque Wrench*—If expandable shell mechanical anchors are used, a torque wrench shall be used to set them. The wrench shall have a capacity at least 20 % greater than the manufacturer's recommended anchor-setting torque. The torque wrench shall have an accuracy of at least ±2 % of the full-scale reading, and a resolution of at least 1 % of the full-scale reading.

6.9 *Borehole Diameter Measuring Gauge*— A gauge shall be used to measure the diameter of the borehole at the anchor location. It shall have an accuracy of at least ±0.02 in. (0.5 mm) and resolution of at least 0.01 in. (0.25 mm)

6.10 *Thermometer*—A thermometer shall be used to measure temperature in the borehole, within the anchor zone if resin or cement grout anchorages are being tested. The temperature of the resin or grout shall also be measured at the time of injection. The thermometer should have an accuracy of at least ±0.5°F (±0.1°C) and a resolution of at least 1°F (0.5°C). See Note 2.

6.11 Fig. 1 shows a typical test setup.

NOTE 2—The accuracy and resolution for the thermometer are presented in both Fahrenheit and Celsius units such that either type of thermometer can be used as long as the accuracy and resolution requirements as stated are met. The Celsius values are not direct conversions from Fahrenheit.

7. Procedure

7.1 *Drilling the Test Hole:*

7.1.1 Drill the test hole using the same procedure that will be used during construction. Wash or blow the borehole clean of all cuttings.

7.1.2 The hole need not be as deep as the proposed length of the rock bolts. It shall, however, be deep enough to set the anchor past the zone of disturbance caused by the excavation and the zone of stress concentration caused by the reaction of the pulling frame. For mechanical shell anchors, drill the hole 1 ft (0.3 m) past the end of the anchor. A hole approximately 6 ft. (1.8 m) in length has generally been found to be adequate.

7.1.3 Inspect the test hole visually using a flashlight or mirror to reflect sunlight down the hole. If more than one half of the bottom of the hole cannot be seen, the hole is not sufficiently straight for a pull test and shall not be used.

7.1.4 Measure and record to the nearest 0.01 in. (0.25 mm) the test hole diameter in two perpendicular directions at the top and bottom of the anchor location borehole using a diameter measuring gauge for a total of four measurements.

7.2 *Preparation of Anchors*—If any anchor preparations, such as degreasing or rust removal, will be done during construction, prepare the test anchors in the same way. If no special preparation will be done during construction, do not prepare the test anchors.

7.3 *Setting the Anchor:*

7.3.1 If mechanical anchors are used, lightly lubricate the downhole end of the rock bolt and screw on the anchor. When in position, torque the bolt to the manufacturer's recommended level to set the anchor. A pair of jam-nuts on the upper end of the rod may be used to apply torque without producing axial load in the bolt. If the manufacturer's torque cannot be achieved because of anchor rotational slippage due to shear failure in the rock, note the maximum torque reading and install subsequent anchors to 80 % of this value. Do not test anchors where rotation occurs between the rock surface and the anchor. In all cases, record any slipping or other anomalous behavior as shown in Fig. 2.

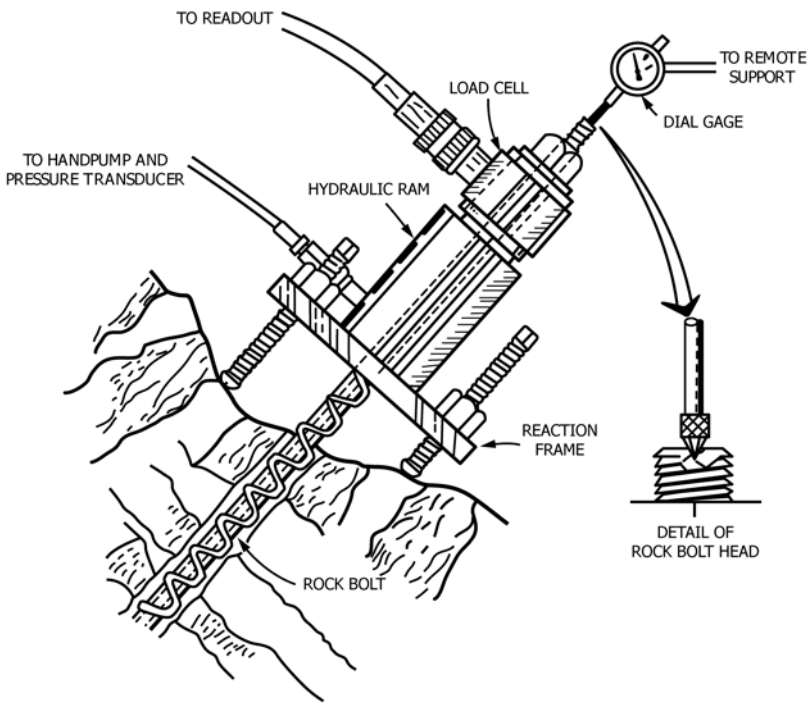

FIG. 1 Typical Rock Bolt Pull Test Schematic

Rock Bolt Anchor Pull Test
Test Data Sheet—Sample Form

Project _____ Anchor: Type _____
Feature _____ Depth _____
Test Location _____ Inst. Torque _____
Rock Type _____ Bolt: Type _____
Test Number _____ Length _____
Orientation _____ Diameter _____

Equipment Description	Serial No.	Data of Next Calibration

Borehole diameter _____ _____ _____ _____
Average _____

Time	Pressure/ Load Reading	Displacement	Net Displacement

Time	Pressure/ Load Reading	Displacement	Net Displacement

Remarks:

Test Supervisor _____ Date _____
Checked by _____ Date _____
Project Engineer _____ Date _____

FIG. 2 Rock Bolt Anchor Pull Test Sample Form

7.3.2 Install cement grout or resin anchors according to the manufacturer's recommendations.

7.4 *Testing:*

7.4.1 All tests are performed on untensioned bolts. Measure and record the temperature in the borehole within the anchor zone, the temperature of the resin or grout at the time of injection, and the ambient air temperature to the nearest 1°F (0.5°C). Ideally the test anchorages should be installed under the same temperature conditions as expected during construction. The time required for resin or grout anchorages to reach their design strengths is temperature dependent and may vary significantly. Consult the resin or grout manufacturer's literature for recommended curing times under various temperature conditions. Curing times may be varied between 1 to 5 days under similar temperature conditions to assess the effects of curing time on strength. To evaluate the influence of grouted bond length on anchor strength, several anchorage lengths should be tested, ideally under similar temperature conditions and curing times.

7.4.2 On at least half of the tests, perform three loading and unloading cycles to check for pre-failure anchor movements. Apply the load with the hydraulic ram in cycles to ¼, ½, and ¾ of the estimated failure load. Load the bolt in ten equal increments and unload it in ten equal decrements.

7.4.3 Apply the load smoothly and rapidly.

7.4.4 After the third cycle, pull the bolt in the same increments as used during the last cycle or in 500 lbf (2.2 kN) increments, whichever is less, until the anchor system fails or the limit of the loading system is reached.

7.4.5 Test non-cycled bolts to failure in 20 equal load increments or increments of 500 lbf (2.2 kN), whichever is less.

7.4.6 Read and record displacement to the nearest 0.0005 in. (0.013 mm) and load to the nearest 100 lbf (0.44 kN) after each pressure increment or decrement.

7.4.7 Failure is the peak load sustained by the bolt, as shown on Fig. 3, or a total deflection of 0.5 in. (12.7 mm).

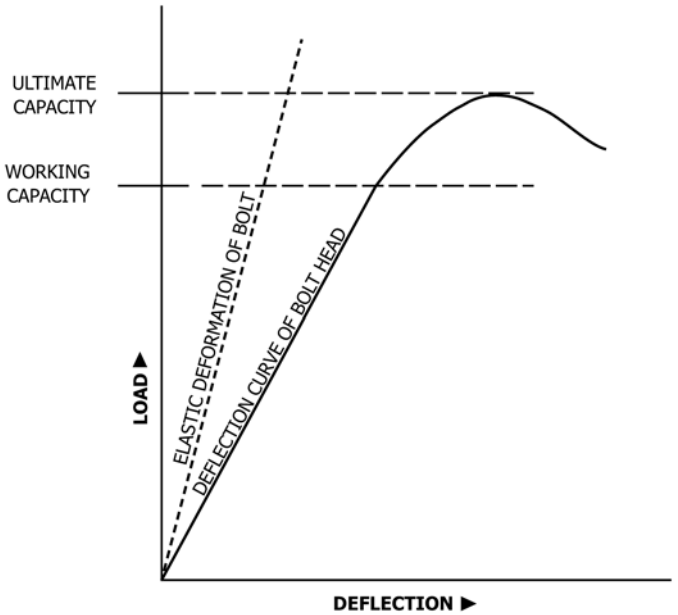

FIG. 3 Typical Load versus Deflection Curve for Rock Bolt Pull Test

7.4.8 Pull the bolt 0.5 in. (12.7 mm) beyond the failure displacement. Record the load every 0.05 in. (1 mm).

8. Calculation

8.1 Calculate the stress on the bolt as follows:

$$\sigma_b = \frac{P}{A} \quad (1)$$

where:

σ_b = stress on the bolt, psi (MPa)
P = load on the bolt, lbf (N)
A = cross-sectional area of the bolt, in.^{2} (mm^2)

8.2 Calculate the elastic deformation of the bolt as follows:

$$U_b = \frac{\sigma_b}{E} \times L \quad (2)$$

where:

U_b = elastic deformation on the bolt, in. (mm)
σ_b = stress on the bolt, psi (MPa)
L = exposed length of bolt between the anchor and the head, in. (mm)
E = elastic modulus of the steel in the bolt, psi (MPa)

8.3 Calculate the corrected bolt head displacement, U_c, which is the same as the displacement of the anchor, as follows:

$$U_c = U_t - U_b \quad (3)$$

where:

U_c = corrected bolt head displacement in. (mm)
U_b = elastic deformation of the bolt in. (mm)
U_t = total displacement of bolt head in. (mm)

8.4 Determine the working and ultimate capacities of the anchor system from the plot of load versus anchor displacement. A typical curve is shown in Fig. 3. Interpretation of the curve often requires some engineering judgment.

8.5 For each group of tests on a similar rock type with the same anchor type and orientation (if applicable), calculate the mean and uncertainty of the results at the 95 % confidence level[4].

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

9.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s) as given below, is covered in 1.4 and Practice D6026.

9.2 Record as a minimum the following general information (data):

9.2.1 Project information, including, as applicable, the project name and number.

9.2.2 Test location.

9.2.3 Bolt type, length, and diameter.

9.2.4 Borehole diameter for each borehole and the average of the boreholes tested.

9.2.5 Describe the rock material(s) in which the anchors were tested, including the composition, texture, and any structural features which could affect anchor capacities, such as joints, weathering, and the like.

9.2.6 Type(s) of anchors tested, including anchor depth and instrument torque.

9.2.7 Names of the personnel who performed the test(s) and checked or reviewed the test(s) data. Include the dates the testing and reviewing was performed.

9.2.8 A summary of the test program including test number, anchor type, rock type, orientation, and test depth.

9.2.9 List the equipment, other than anchors, with model numbers, serial numbers, or dimensions as appropriate. Include the range, accuracy, and resolution of any devices used to make measurements.

9.3 Record as a minimum the following test information:

9.3.1 The stress on the bolt, σ_b, psi (MPa).

9.3.2 The elastic deformation of the bolt, U_b, in. (mm).

9.3.3 The corrected bolt head displacement, U_c, in. (mm).

9.3.4 For each increment/decrement the: time, load reading, lbf (N), displacement, in. (mm), and net displacement, in. (mm).

9.3.5 The working and ultimate capacity of each anchor type in each rock type, with anchor type, number of tests, mean working capacity, range, and uncertainty of the mean. If resin or grouted anchorages were tested, record the measurements made during installation of borehole, grout and ambient temperatures.

9.3.6 A plot of load versus corrected bolt head displacement for each test, a description of the nature of any failures or any other observations pertinent to the test.

9.3.7 For the evaluation of grouted rock bolts, the results of several tests should be presented graphically to show the influence of grout cure time and bond length on anchor

[4] To calculate the mean and uncertainty of the results see, "Statistical Considerations," *Rock Testing Handbook,* U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, 1980, Section 104-80.

strength. Data concerning temperature effects should be presented to indicate the effects of temperature on cure times and the recommended installation procedures to be followed during construction.

10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented 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 have ten or more agencies participate in an in situ testing program at a given site. Subcommittee D18.12 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

10.2 *Bias*—There is no accepted reference value for this test method; therefore, bias cannot be determined.

11. Keywords

11.1 anchors (rock); displacement; field testing; loading tests; mines; pull testing; rock; shear testing

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4435 – 08) that may impact the use of this standard. (Approved Nov. 1, 2013.)

(1) Revised standard throughout.
(2) Added 1.3.1 and Note 2.
(3) Rewrote Section 9.