Designation: D4403 – 20

Standard Practice for Extensometers Used in Rock[1]

This standard is issued under the fixed designation D4403; 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 practice covers the description, application, selection, installation, data collecting, and data reduction of the various types of contact type extensometers used in the field of rock mechanics. Laser or other non-contact extensometers are not covered here.

1.2 Limitations of each type of extensometer system are covered in Section 5.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard. Add if appropriate, "Reporting of test results in units other than inch-pound shall not be regarded as nonconformance with this standard.

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 analysis methods for engineering design.

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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*—Terms not defined below may appear in Terminology D653.

4. Significance and Use

4.1 Extensometers are widely used in the field of engineering and include most devices used to measure displacements, separation, settlements, convergence, and the like.

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[1] This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.23 on Field Instrumentation.

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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**

4.2 For tunnel instrumentation, extensometers are generally used to measure roof and sidewall movements and to locate the tension arch zone surrounding the tunnel opening.

4.3 Extensometers are also used extensively as safety monitoring devices in tunnels, in underground cavities, on potentially unstable slopes, and in monitoring the performance of rock support systems.

4.4 An extensometer should be selected on the basis of its intended use, the preciseness of the measurement required, the anticipated range of deformation, and the details accompanying the installation. No single instrument is suitable for all applications.

4.5 In applications for construction in rock, precise measurements will usually allow the identification of significant, possibly dangerous, trends in rock movement; however, precise measurement is much less important than the overall pattern of movement.

4.6 Data collection of extensometers can be simple or low tech, such as manual readings at the instrument location, or complex or high tech where there are electronic readings taken at the site and either downloaded at the instrument locations or transmitted to a data collection and analysis center.

4.7 It is important to realize the pros and cons and costs between each type of extensometers. In the case of manual readings, not as much data may be collected, important data may be missed and the person taking the readings may be put in harm's way and may not be able to safely continue collecting data just when the data is needed the most or becomes more important. Whereas, with electronic data collection as the system becomes more sophisticated, the data collected can be done more safely, provide important data that might be missed, and may allow for real-time data analyses that are timelier and more accurate.

4.8 When very accurate measurements are dictated by certain excavations, for example, the determination of the tension arch zone around a tunnel opening, extensometers which can be adjusted in the field after installation shall be used. In all cases, the accuracy of extensometers, either determined through calibration, should be given in addition to the sensitivity of the transducers.

NOTE 1—Notwithstanding 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 these test methods are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable testing depends on many factors; Practice D3740 provides a means of evaluating some of those factors.

5. Apparatus

5.1 *General*—Experience, safety considerations, costs, and engineering judgment are required to match the proper type of extensometer systems to the nature of the investigation for a given project.

5.1.1 The required precision of measurements necessary will vary with the application, as well as the capability of the measurement device. Examples of precision requirements are as follows:

5.1.1.1 Precision levels better than 0.0012 in. (0.02 mm) for measurements used to determine rock properties using in-situ rock testing (such as plate-jack tests),

5.1.1.2 Precision levels in the range of 0.001 to 0.01 in. (0.025 to 0.25 mm) for measurements in underground tunnels and general construction in rock,

5.1.1.3 Precision levels in the range of 0.01 to 0.04 in. (0.25 to 1 mm) for larger underground openings or rock slopes, and weak rock or soil conditions,

5.1.1.4 Precision levels in the range of 1% of the expected range of movement for very large excavations, such as open pit mines and large moving landslides.

5.1.2 Greater precision is also required for long-term monitoring applications, where displacements are typically smaller than those that occur during construction.

5.2 *Extensometers:*

5.2.1 *Rod Extensometers*—A large variety of rod extensometers are manufactured. They range from simple single-point units to complicated multi-position systems using either a manual, an electronic, or combination of manual and electronic measurement devices.. The single-point extensometer is generally used to detect support system failures. The rod can also serve as a safety warning device in hazardous areas. Generally, the rod extensometer is read with a depth-measuring instrument such as a dial gage or depth micrometer, however, various electrical transducers such as LVDTs (linear variable differential transformers), linear potentiometers, and vibrating wire displacement transducers have been used where remote, threshold or continuous readings are required (as shown in Fig. 1). Another type of readout or transducer is a noncontact removable sonic probe digital readout system, which is interchangeable with the depth micrometer type. Depending on the diameter of the hole, multi-position rod extensometers can have up to eight measuring points. Reduced rod diameters are

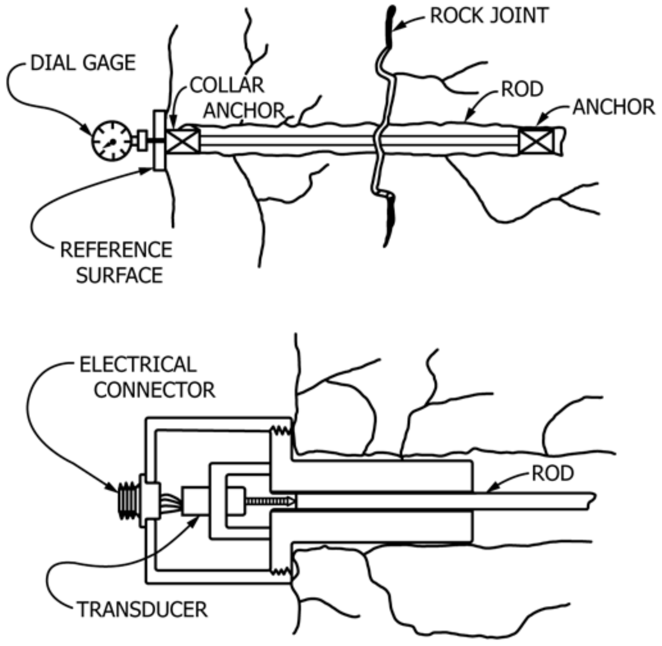


FIG. 1 Examples of Rod Extensometer, Single Point (top) with a Manual Readout and (bottom) Electronic Readout

required for multi-position instruments and have reportedly been used effectively to depths of at least 350 ft (107 m). The rod acts as a rigid member and must react in both tension and compression. When used in deep applications, friction caused by drill hole misalignment and rod interference can cause erroneous readings. Rods are usually constructed of some type of stainless steel or fiberglass. To reduce temperature effects, something that is typically an issue or concern, rods can be constructed of invar steel, graphite, or composite carbon fiber.

5.2.2 *Bar Extensometers*—Bar extensometers are generally used to measure diametric changes in tunnels. Most bar extensometers consist of spring-loaded, telescopic tubes that have fixed adjustment points to cover a range of several feet. The fixed points are generally spaced at 1 to 4-in. (25 to 100mm) increments. A dial gage is used to measure the displacements between the anchor points in the rock (as shown in Fig. 2). If the device is not constructed from invar steel, ambient temperature should be recorded, and the necessary corrections applied to the results. Bar extensometers are primarily used for safety monitoring devices in mines and tunnels.

5.2.3 *Tape Extensometers*—Such devices are designed to be used in much the same manner as bar extensometers; however, tape extensometers allow the user to measure much greater distances, such as found in large tunnels or powerhouse openings. Tape extensometers consist of a steel tape (preferably invar steel), a tensioning device to maintain constant tension, and a readout head. Lengths of tape may be pulled out from the tape spool according to the need. The readout may be a dial gage, a vernier, or another suitable gage. and the tensioning mechanism may be a spring-loading device or a dead-weight (as shown in Fig. 3 and Fig. 4). The tape and readout head are fastened, or stretched in tension, between the points to be measured. Accuracies of 0.010 to 0.002 in. (0.25 to 0.05 mm) can be expected, depending on the length of the tape and the ability to tension the tape to the same value on subsequent readings, and provided that temperature corrections are made when necessary.

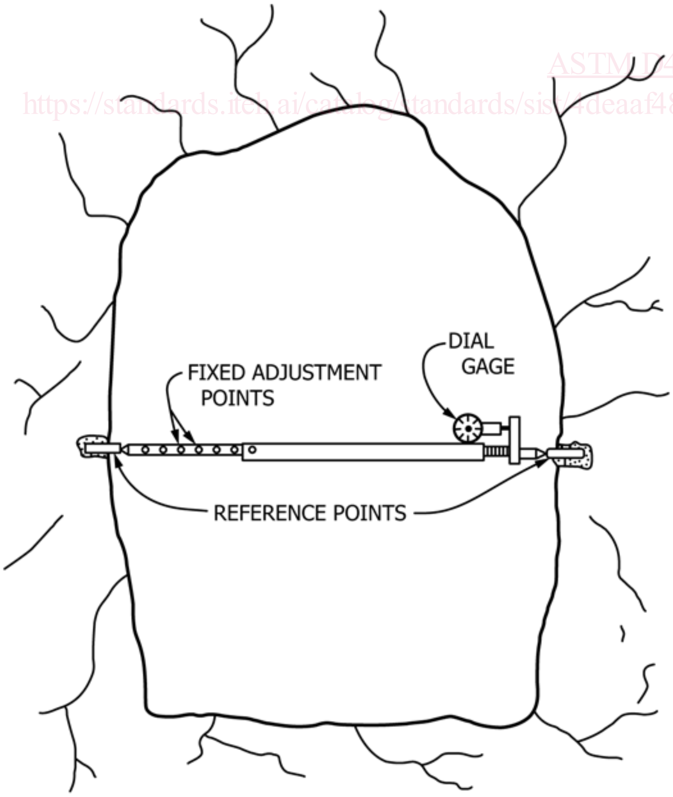


FIG. 2 Bar Extensometer

5.2.4 *Joint or Crack Meters*—One type of a joint or crack meters consists of an extensometer fixed across an exposed rock surface containing a joint (as demonstrated in Fig. 5), and are used to measure displacements along or across joints. The example shown here shows a dial gage, but it could be an electronic or vibrating wire LVDT type transducer that measures the displacement as well. The joint movements to be measured may be the opening or closing of the joint or slippage along the joint. Rod-type extensometers are generally used as joint or crack meters with both ends fixed on opposite sides of the joint and situated such that deformations normal or parallel to the joint surface trace is measured. Preset limit switches are often mounted on the joint meter to serve as a warning device in problem areas such as slopes and foundations.

5.2.5 *Wire Extensometers*—Such devices utilize a thin stainless steel wire to connect the reference point and the measuring point of the instrument (as shown in Fig. 6). This allows a greater number of measuring points to be placed in a single drill hole. The wire or wires are tensioned by springs or weights. The wire is extended over a roller shiv and connected to a hanging weight. Wire extensometers tensioned by springs have the advantage of variable spring tension caused by anchor movements. This error must be accounted for when reducing the data. Wire-tensioned extensometers have been used to measure large displacements at drill hole depths up to approximately 500 ft (150 m). The instruments used for deep measurements generally require much heavier wire and greater spring tensions. Although wire extensometers are often used in open drill holes for short-term measurements, in areas of poor ground or unstable holes, it is necessary to run a protective sleeve or tube over the measuring wires between the anchors.

5.3 *Anchor Systems:*

5.3.1 *Groutable Anchors*—These were one of the first anchoring systems used to secure wire extensometer measuring points in the drill hole. Groutable anchors are also used for rod type extensometers. Initially PVC (poly(vinyl chloride)) pipes clamped between the anchor points were employed to isolate the measuring wires from the grout column (as shown in Fig. 7), however, this arrangement was unreliable at depths greater than 25 ft (7.5 m) because the hydrostatic head pressure of the grout column or the heat of hydration of the cement in the grout often collapsed the PVC tubing when the rated capacity was exceeded. To counteract this condition, oil-filled PVC tubes were tried. The use of oil enabled this method to be used to depths of over 50 ft (15 m) but is no longer recommended because of environmental issues. This can be avoided if PVC schedule 80 is used or if ABS plastic is used instead of PVC, or the temperature of the grout is controlled using ice or cold water in the grout mix. Oil filed tubes. This alternative system

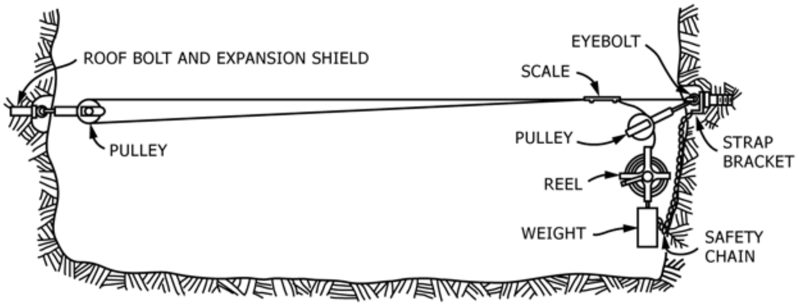


FIG. 3 Tape Extensometer with Vernier Readout and Deadweight

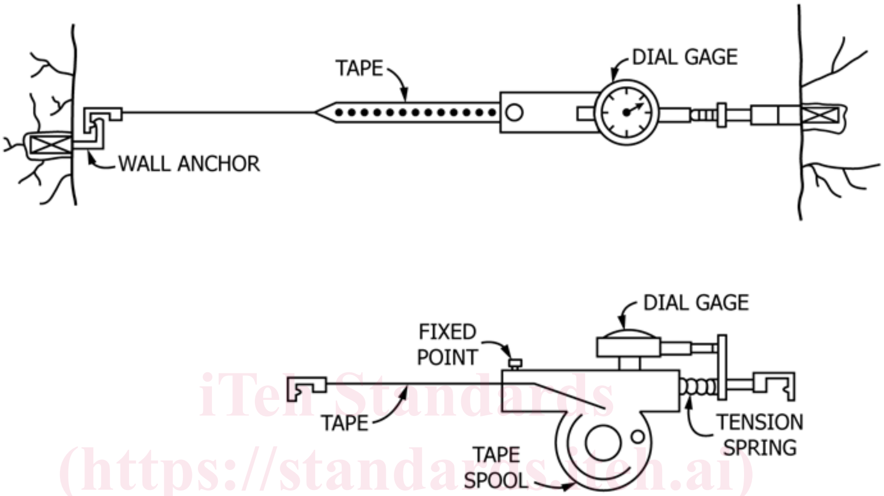


FIG. 4 Side and Top View of Tape Extensometer with Dial Gage and Tension Spring

seems to work well and can be used in most applications. Resin anchors fall in this category and are very successful, as well.

5.3.2 *Wedge- or Expansion-Type Anchors*—These consist of a mechanical anchor that has been widely used for short-term anchoring applications in hard rock. There are different types of wedge and expansion anchors; Fig. 8 shows the two basic types of wedge anchors: (*1*) the self-locking spring-loaded anchor, and (*2*) the mechanical-locking anchor. Self-locking anchors, when used in areas subject to shock load vibrations caused by blasting or other construction disturbances, may tend to slip in the drill holes or become more deeply-seated, causing the center wedge to move. Another disadvantage of the wedge anchor is that no protection is offered, if using wires, to the measuring wires in the drill hole against damage that might be caused by water or loose rock. The expansion anchor is retrievable, and it is discussed in 5.3.4.

5.3.3 *Hydraulic Anchors*—These anchors have proven to be successful in most types of rock and soil conditions. Fig. 9 shows the two basic types of hydraulic anchors manufactured for use with extensometer systems: (*1*) the uncoiling Bourdon tube anchor, and (*2*) the hydraulic piston of grappling hook anchor, which is limited to soft rock and soils. Both anchors have the disadvantage of being more costly than other types of anchors and require activation through hydraulic lines routed to the head of the hole. The Bourdon tube anchor works well in most rock and soil conditions, and the complete anchor system can be fabricated before installing it in the drill hole. There

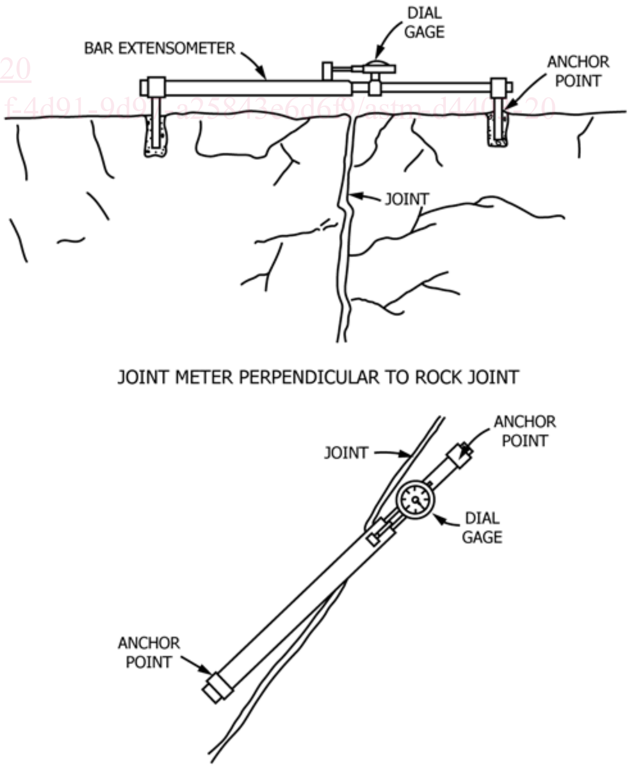
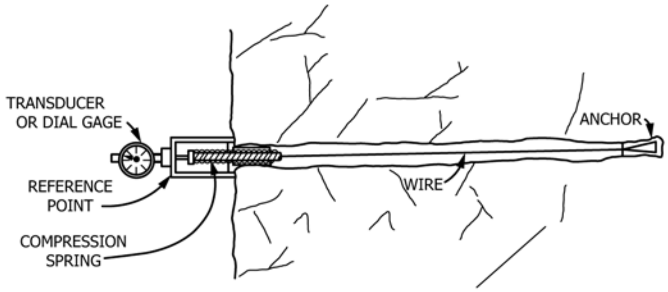


FIG. 5 Extensometer Set Up as Joint or Crack Meter to Measure Dilation or Shear



SPRING TENSIONED WIRE EXTENSOMETER

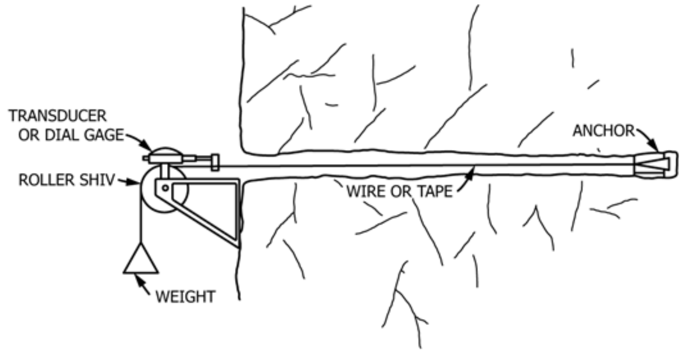


FIG. 6 Wire Extensometers

have been other specialized anchor systems developed; however, these systems have proven to be too costly and unsuccessful for most applications.

5.3.4 *Retrievable Anchors (see* Fig. 10*)*—These can be a mechanical or hydraulic/pneumatic anchor.

5.3.4.1 The special design of the mechanical anchor allows complete system retrievability. The mechanical anchor discussed here consists of a cylindrical body and three contacting shoes spaced at 120° angle that isis in a collapse configuration that is smaller than the borehole diameter. Using the installation tool and rods, the anchor is placed in the drill hole to the depth required. The anchor is spring-loaded and is actuated from the collar of the hole, and the shoes make immediate contact with the borehole walls. The central screw is then turned to exert a radial force from the shoes to the drill hole wall. The anchoring capacity is very high, and the contacting shoes are designed to adjust to small borehole deformations while still exerting the anchoring force. This process is reversed to then remove the anchors one at a time, starting from closest anchor to the borehole collar.

5.3.4.2 For the retrievable hydraulic anchor the string of sensors is assembled (with variable lengths of connecting rods to enable positioning of the anchors at the required depths), inserted into the pipe or borehole, and then locked in position by pneumatically or hydraulically actuating the various anchors, which remain fully expanded throughout the monitoring period. When monitoring has been completed, the pressure is released, which retracts the anchor pistons and allows removal of the string for further use.

5.3.5 *Snap Ring Anchors (see* Fig. 11*)*—This type of anchor is quickly and easily installed in boreholes in hard or competent rock. Anchors are pushed to the required depth on the end of setting rods, and then a cord is pulled to remove the locking pin, which allows two retaining rings on each anchor to snap outward and grip the borehole. Up to eight anchors can be installed at various depths in a 3-in. (76 mm) diameter borehole. Particularly useful in upward-directed boreholes. Anchors can only be used with rigid rods and are not likely affected by blasting.

5.3.6 *Packer Anchor*—This type of extensometer anchor is a solution for where it is important that the surrounding strata between anchors are not affected by grout. The borehole between each anchor is therefore left open or filled with compressible material resulting in the anchors being insensitive to shear displacements. This not only ensures no interference but also reduces the amount of grout needed in comparison to grout able anchors. Packer anchors can be used in rock or soils. The anchor employs a geotextile bladder that is inflated with grout. The geotextile allows water to go thru but retain all solids. Once the grout sets, it forms an effective and stable anchor.

NOTE 2—There have been other specialized anchor systems developed; however, these systems have proven to be too costly and unsuccessful for most applications.

5.4 *Extensometer Transducers*—These extensometers convert displacements occurring in in situ materials between two anchored points to mechanical movements that can be measured with conventional measuring devices such as dial gages, LVDTs, strain gages, and the like.

5.4.1 *Depth-Measuring Instruments*—A dial gage, or a depth micrometer are the simplest and most commonly used mechanical measuring instruments. Used in conjunction with extensometers, they provide the cheapest and surest methods of making accurate measurements. When using the dial gage or depth micrometer, the operator is required to take readings at the instrument head; however, local readings may not be practical or possible due to the instrument location or area conditions.

5.4.2 *Electrical Transducers*—For remote or continuous readings, electrical transducers are used rather than dial gages. Vibrating Wire Displacement Transducers (VWDT) are often used because of their accuracy, small size, and availability however, LVDT, potentiometer, and sonic readouts are or have been used. The advantage of VWDT is that they are very stable, can be connected to very long signal cables (1 km+) if needed, and they are easily read with manual readouts or automatic data loggers with wireless telemetry. LVDTs require electrical readout equipment consisting of an a-c regulated voltage source and an accurate voltmeter, such as a digital voltmeter or bridge circuit. The use of linear potentiometers or strain gages is often desirable because of the simplicity of the circuitry involved. The disadvantage of using linear potentiometers is their inherently poor linearity and resolution.

NOTE 3—When possible, provisions should always be made for mechanical readout capability for redundancy and verification purposes.

5.5 *Temperature Measurement*—For extensometers that require a temperature correction for any of the data reduction, some way to measure the temperature that gives data meaningful to the instrument configuration is needed. Any means of

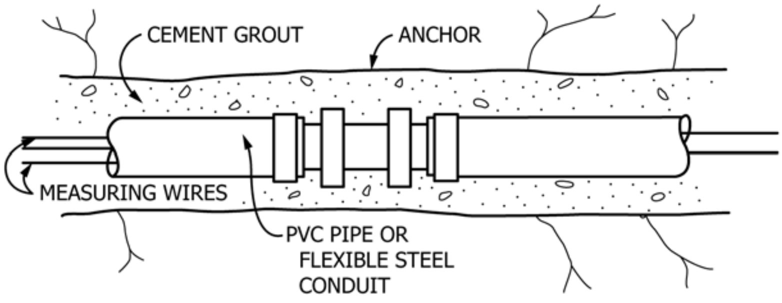
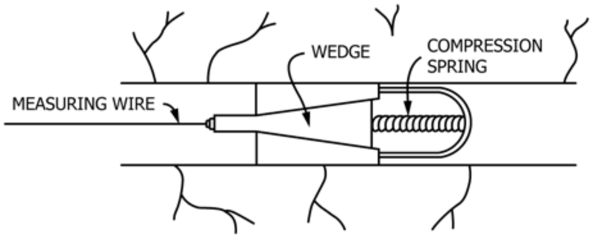
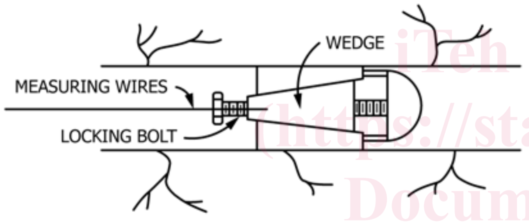


FIG. 7 Grouted Anchor System



SELF-LOCKING WEDGE ANCHOR



MECHANICAL-LOCKING WEDGE ANCHOR

FIG. 8 Wedge Anchors

obtaining pertinent temperature data may be used, that is, manual or electronic thermometer. Electrical thermometers are typically used and especially thermistors because of their size, accuracy, and low cost; the thermisters can be placed where they can best measure the temperature in the most critical or required places of the extensometer.

6. Procedure

6.1 *Preparatory Investigations:*

6.1.1 Select the location, orientation, length, and number of anchors for each extensometer on the basis of a thorough review of both the construction and geotechnical features of the project. Among the items to be considered are direction and magnitude of anticipated rock movements, location and nature of other instruments to be installed, and the procedures and timing of construction activities before, during, and after installation of the instrument. If the instrument is installed where rock bolts are used for support, the deepest extensometer anchor shall be located beyond the end of the rock bolt. The length of the extensometer shall depend upon the anticipated depth of rock influenced by excavation, expressed, for example, in terms of tunnel diameter or slope height. As a general rule, the deepest anchor (reference point for all subsequent anchors) shall be placed at least 2 ½ tunnel diameters beyond the perimeter of the tunnel.

6.1.2 Displacement measurements are most valuable when extensometers are installed at, or before, the beginning of the excavation, and when measurements have been taken regularly throughout the entire excavation period at several locations so that a complete history of movements is recorded. Documentation of the geologic conditions and construction events in the vicinity of the measurements is essential to the proper interpretation of the field data.

6.2 *Drilling:*

6.2.1 The size of borehole required for extensometers depends on the type, character, and number of anchors. The borehole size shall conform to the recommendations of the extensometer manufacturer.

6.2.2 The method of drilling used depends upon the nature of the rock, the available equipment, the cost of each method, depth, hole diameter, and the need for supplemental geologic data. Percussion drilling equipment of the type used for blast holes is usually available and is the least costly. Coring methods, like those used for subsurface exploration, are usually more expensive but provide important information on the presence and nature of rock discontinuities. However, with the improvements in optical and acoustical borehole logging, there is much geological information that can still be obtained about the drill hole even without drill core. On large projects, coring or close observation of the percussion hole is usually justified to better define the geology. In addition, coring affords the opportunity to position extensometers accurately in the vicinity of or as needed to major discontinuities.

6.2.3 Immediately prior to drilling, verify the location and orientation of the drill hole.

6.2.4 For percussion-drilled holes, maintain visual inspection of the drilling operation from start to completion of the hole. At all times, the operation shall be under the direct supervision of an individual familiar with drilling and knowledgeable in the peculiarities and intended use of the extensometer. For later use in summarizing the installation, keep notes on drilling rates, use of casing, soft zones, hole caving, plugging of drilling equipment, and any other drilling difficulties.

6.2.5 For cored holes, similar inspection and observation as that for percussion-drilled holes shall be recorded, giving particular attention to drilling techniques that may affect the quality of the rock core obtained. The core shall be logged, including rock lithology, joint orientation, joint roughness, and