Standard Practice for Extensometers Used in Rock[1]

This standard is issued under the fixed designation D 4403; 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 changes were made throughout in December 2000.

1. Scope *

1.1 This practice covers the description, application, selection, installation, data collecting, and data reduction of the various types of extensometers used in the field of rock mechanics.

1.2 Limitations of each type of extensometer system are covered in Section 3.

1.3 The values stated in inch-pound units are to be regarded as the standard. The SI values given in parentheses are provided for information purposes only.

1.4 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.

1.5 *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 judgement. 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.*

1.6 *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 determine the applicability of regulatory limitations prior to use.*

2. Significance and Use

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

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

2.3 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.

2.4 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 installation. No single instrument is suitable for all applications.

3. Apparatus

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

3.1.1 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. Where measurements are used to determine rock properties (such as in plate-jack tests), accurate measurements involving a high degree of precision are required. For in-situ rock testing, instrument sensitivity better than 0.0012 in. (0.02 mm) is necessary for proper interpretation.

3.1.2 Most field measurements related to construction in rock do not require the precision of in-situ testing. Precision in the range of 0.001 to 0.01 in. (0.025 to 0.25 mm) is typically required and is readily obtainable by several instruments.

3.1.3 As the physical size of an underground structure or slope increases, the need for highly precise measurements diminishes. A precision of 0.01 to 0.04 in. (0.25 to 1.0 mm) is often sufficient. This range of precision is applicable to underground construction in soil or weak rock. In most hard rock applications, however, an instrument sensitivity on the order of 0.001 in. (0.025 mm) is preferred.

3.1.4 The least precision is required for very large excavations, such as open pit mines and large moving landslides. In such cases, the deformations are large before failure and, thus, relatively coarse precision is required, on the order of 1 % of the range where the range may be 3 ft. (1 m) or more.

3.1.5 For long-term monitoring, displacements are typically smaller than those that occur during construction. Therefore, greater precision may be required for the long-term measurements.

3.2 *Extensometers*:

[1] This practice 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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*A Summary of Changes section appears at the end of this standard.

3.2.1 *Rod Extensometers*—A large variety of rod extensometers are manufactured. They range from simple single-point units to complicated multipoint systems with electrical readout. 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 microswitches have been used where remote or continuous readings are required (as shown in Fig. 1). Another type of readout recently developed is a noncontact removable sonic probe digital readout system which is interchangeable with the depth micrometer type. Multipoint rod extensometers have up to eight measuring points. Reduced rod diameters are required for multipoint instruments and have been used effectively to depths of at least 150 ft (45 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.

3.2.2 *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 100-mm) 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.

3.2.3 *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 or a vernier, 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.

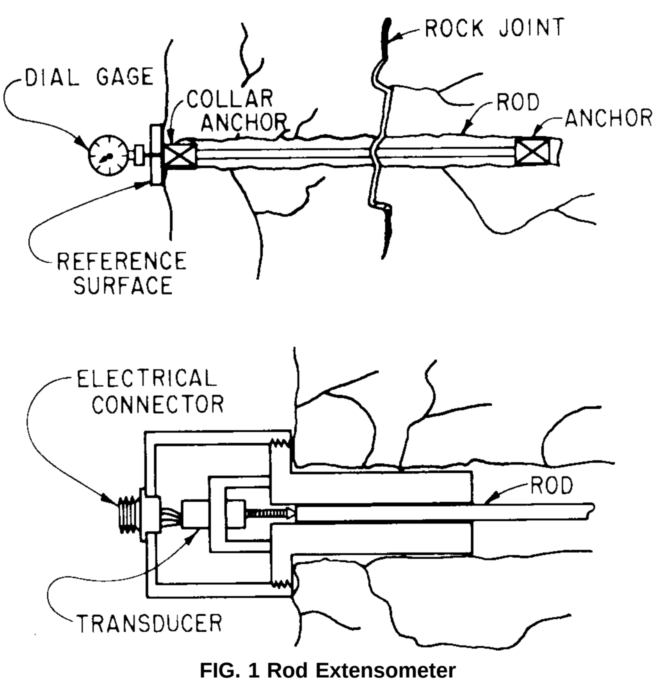


FIG. 1 Rod Extensometer

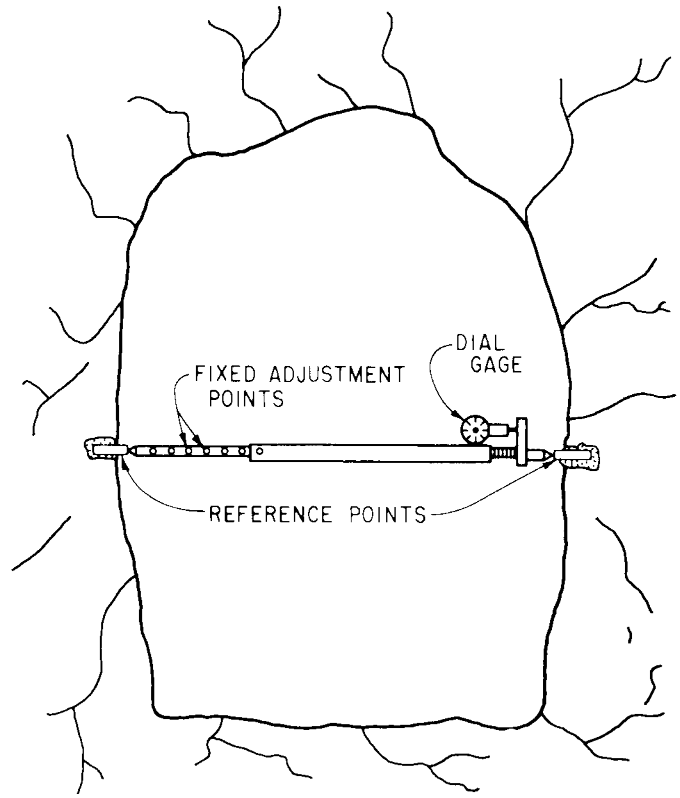


FIG. 2 Bar Extensometer

3.2.4 *Joint Meters*—Normally, joint meters consist of an extensometer fixed across the exposed surface of a joint (as demonstrated in Fig. 5), and are used to measure displacements along or across joints. 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 meters with both ends fixed across the joint. Preset limit switches are often mounted on the joint meter to serve as a warning device in problem areas such as slopes and foundations.

3.2.5 *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

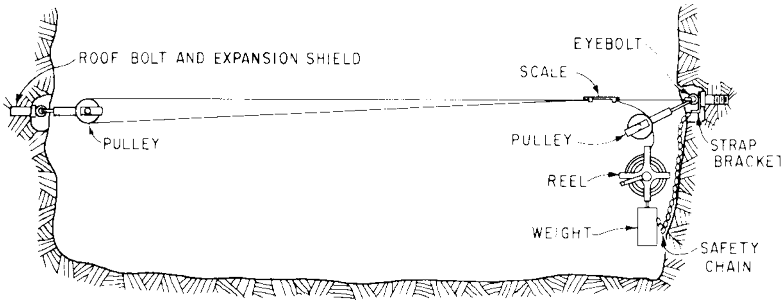


FIG. 3 Tape Extensometer with Vernier Readout and Deadweight

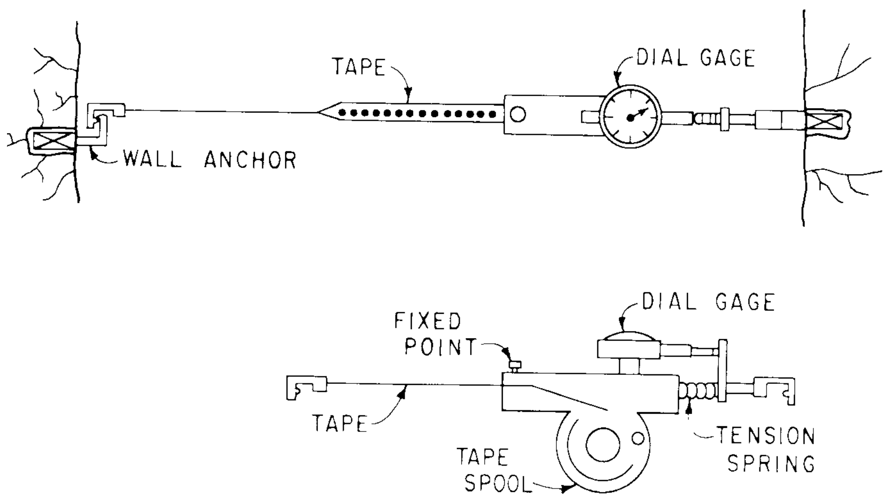


FIG. 4 Tape Extensometer with Dial Gage and Tension Spring

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.

3.3 *Anchor Systems*:

3.3.1 *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 often collapsed the PVC tubing. 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). As an alternative to this system, liquid-tight flexible steel conduit is used to replace the PVC pipe. This alternative system seems to work well and can be used in most applications. Resin anchors fall in this category and are very successful.

3.3.2 *Wedge-Type Anchors*—These consist of a mechanical anchor that has been widely used for short-term anchoring applications in hard rock. Fig. 8 shows the two basic types of wedge anchors: (*1*) the self-locking spring-loaded anchor, and

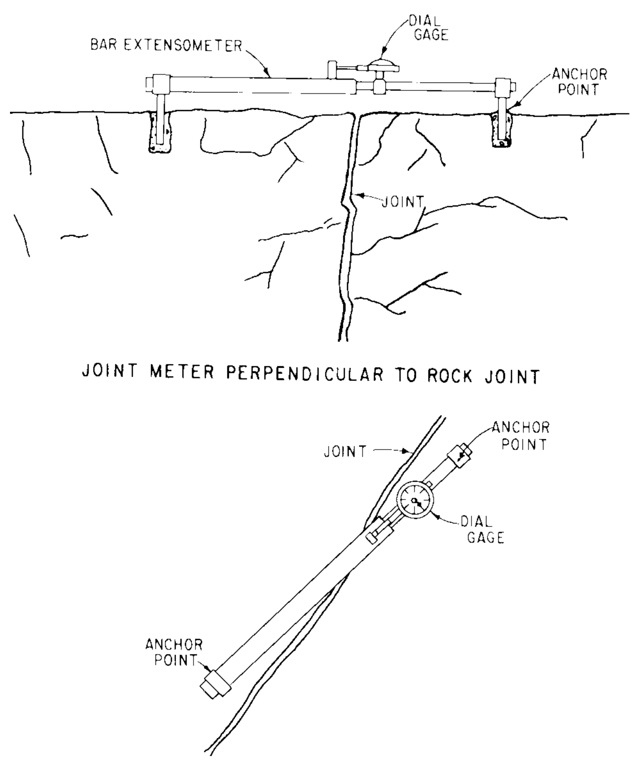


FIG. 5 Joint Meters

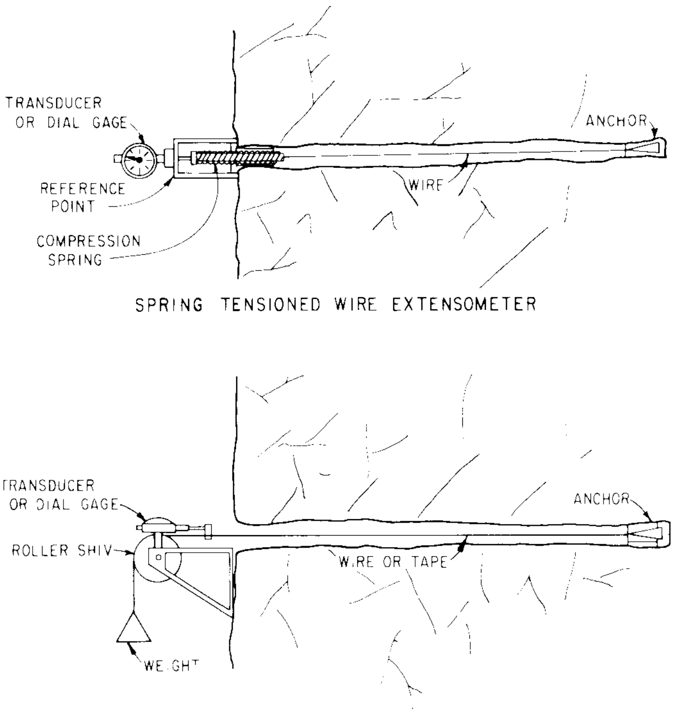


FIG. 6 Wire Extensometers

(*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.

3.3.3 *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 rather costly. 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 have been other specialized anchor systems developed, however, these systems have proven to be too costly and unsuccesful for most applications.

3.4 *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.

3.4.1 *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.

3.4.2 *Electrical Transducers*—For remote or continuous readings, electrical transducers are used rather than dial gages. LVDTs are often used because of their accuracy, small size, and availability. 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.

3.4.3 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 calibrated in the field after installation shall be used. In all cases, the accuracy of extensometers, either determined through calibration or estimation, should be given in addition to the sensitivity of the transducers. The strain-gaged cantilever extensometer (shown in Fig. 10) has been used successfully for many years. The strain-gaged cantilever operates on the principles of the linear strain produced across a given area of a spring material when flexed. This type of extensometer readout is normally used when rock movements of 0.5 in. (12.5 mm) or less are expected. Strain gages produce a linear change in resistance of 1 to 3% of their initial resistance, over their total measurement range. Because of this small change in resistance, it is absolutely necessary to provide extremely good electrical connections and cable insulation when using this type of transducer. Standard strain-gage readout equipment can be used with this type of extensometer, however, care must be taken to protect this equipment from the hostile environments found in most field applications. Vibrating wire and sonic readouts are also reliable and are becoming more common than strain-gage readouts. Provision should always be made for mechanical readout capability.

4. Procedure

4.1 *Preparatory Investigations*:

4.1.1 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 2½ tunnel diameters beyond the perimeter of the tunnel.

4.1.2 Displacement measurements are most valuable when extensometers are installed at, or before, the beginning of excavation, and when measurements have been taken regularly throughout the entire excavation period at several locations so

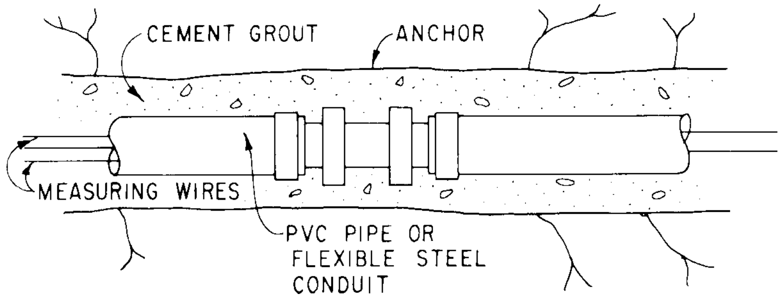


FIG. 7 Grouted Anchor System

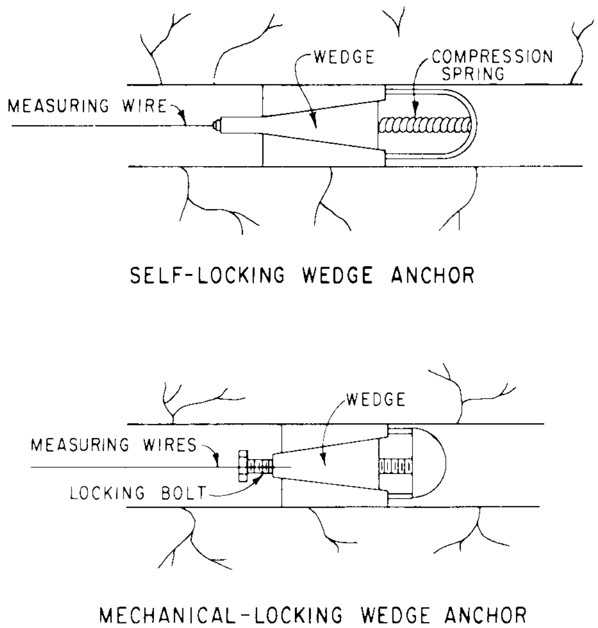


FIG. 8 Wedge Anchors

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.

4.2 *Drilling*:

4.2.1 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.

4.2.2 The method of drilling used depends upon the nature of the rock, the available equipment, the cost of each method, 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. 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 major discontinuties.

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

4.2.4 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.

4.2.5 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 degree of weathering. For both percussion-drilled and cored holes, note the location of water bearing seams or joints and water flows.

4.2.6 Immediately prior to installing the anchor assembly, thoroughly clean the completed borehole by washing with a pressure water hose. Holes in which instruments are not installed for a lengthy time after drilling (a day or more) shall be carefully cleaned immediately prior to installing the anchor. If hole caving or other blocking in zones of poor rock is suspected, verify the openness of the hole by inserting a pipe or wooden dowel the full length of the hole. In very poor ground conditions, special procedures involving grouting and temporary casing may be required to keep the borehole open sufficiently long to allow installation.

4.3 *Installation*:

4.3.1 Installation of the anchor assembly and connection of the displacement sensor to the anchor assembly shall be performed by a suitably qualified instrumentation specialist. This specialist may be the manufacturer's representative or an individual who, through previous experience and training, is qualified to perform the task.

4.3.2 Whenever possible, adjust the position of the anchors to maximize the information obtained by the extensometer. For instance, it is desirable to have one anchor to each side of a shear zone or filled joint. If not determined from rock cores, discontinuities can be located by borehole television or borehole periscope surveys (Fig. 11 illustrates a typical extensometer installation in a tunnel).

4.3.3 For grouted anchor assemblies, allow sufficient time for setting and hardening of the grout before installation of the extensometer sensor unit. During this time, keep notes on any blasting or other construction activities in the vicinity of the instrument. The strength and compressibility of the grout should somewhat match the surrounding soil or rock.

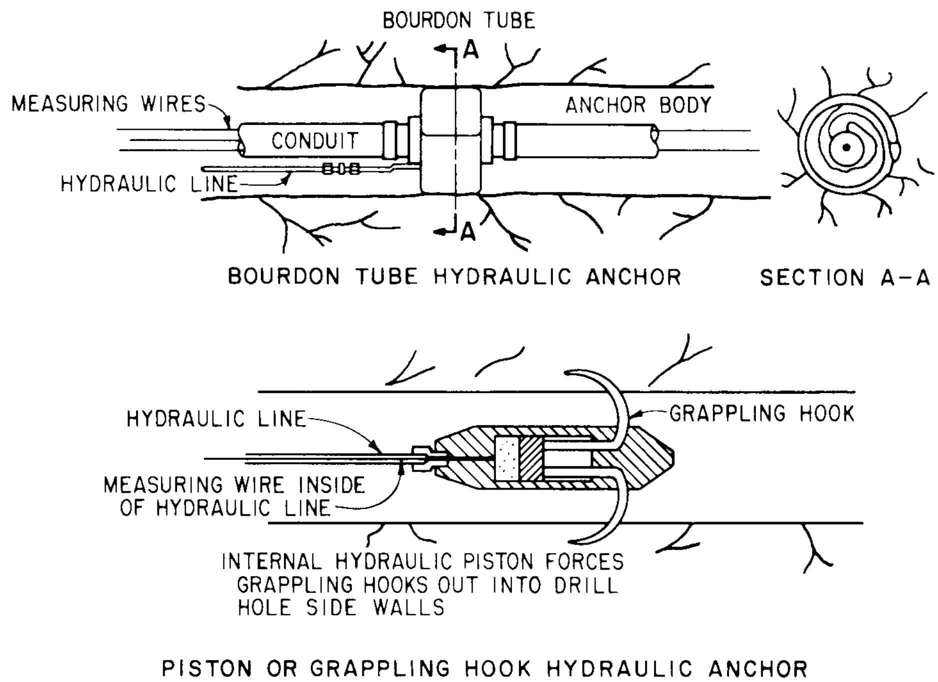


FIG. 9 Hydraulic Anchors

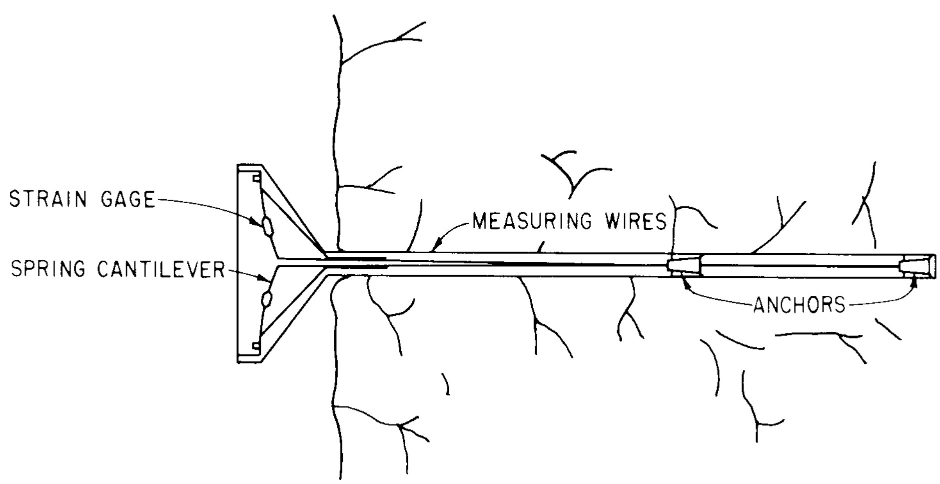


FIG. 10 Extensometer Using Strain-Gaged Spring Cantilevers

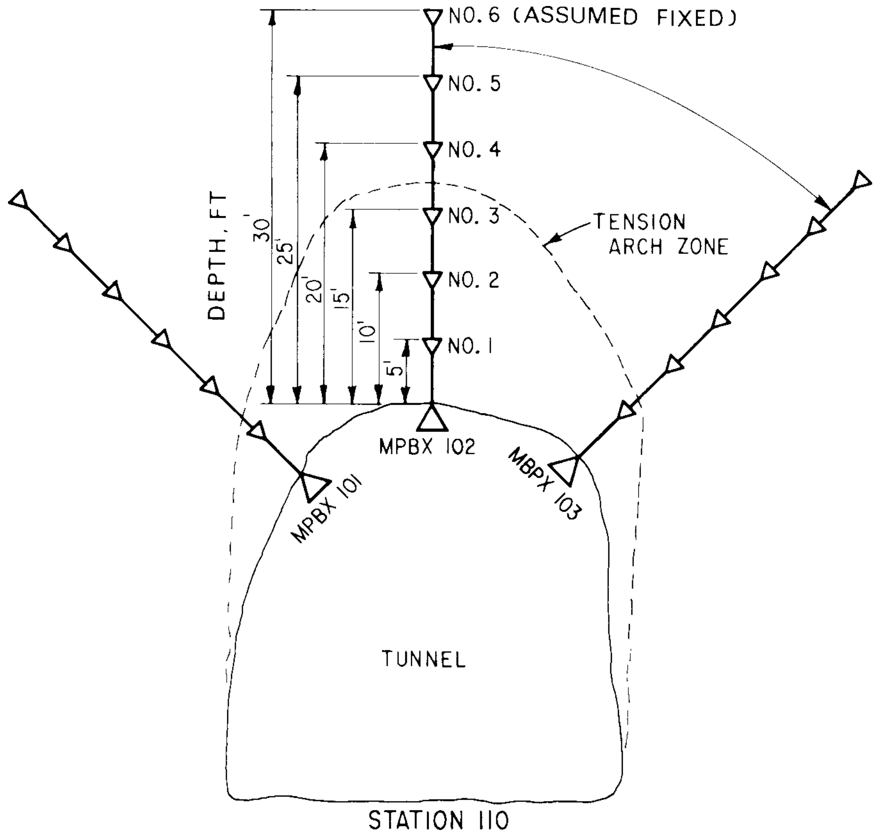
4.3.4 Install a protective cover if the instrument does not have an inherently rugged protective cover or is not recessed within a borehole. The protective cover must provide full protection from damage due to workmen, equipment, and fly rock from blasting. For installations in blast-damaged areas, it is preferable to initially install the instrument with a mechanical sensor only. After the risks of damage have been reduced, an electrical, remotely read sensor can be installed. If an instrument is an electrical, remotely read type, suitably protect the electrical cable (such as by armored cable or steel pipe) to prevent damage during the intended period of use. Instruments installed at the ground surface shall be installed below the depth of frost penetration. Manholes shall be watertight in cold climates to prevent icing.

4.3.5 Verify zero readings of each extensometer at least two times prior to the start of construction, or at the time of installation or resetting if construction is in progress. Instruments installed several weeks or months in advance of construction should be monitored to detect equipment malfunctions and reading variations due to temperature or operation. Two calibrations are required per extensometer, one following installation and one following the conclusion of the test series. Additional calibrations are required only where: (*1*) a transducer is replaced or rewired, (*2*) the power supply is changed, (*3*) the instrument head is damaged, or (*4*) a transducer is moved or reset to change its zero point.

4.3.6 Completion of installation of the sensing unit requires a thorough check for electrical or mechanical malfunctions. For future reference, keep notes of any measurements, in-situ calibrations, or settings performed during this final checkout.

4.4 *Readings*:

4.4.1 Readings shall be taken by a person familiar with the equipment and trained to recognize critical measurements and their relevance to the particular project.



NOTE 1—Include such features as shear zones, rock bolts, and the like.

FIG. 11 Typical Extensometer Installation for a Tunnel Using Three 6-Point Extensometers with Anchors Spaced at 5-ft (1.5m)

4.4.2 The mechanical or electrical device used to read an extensometer shall be checked on site both before and after each day's use. For instance, verify zero settings on dial gages, and compare readouts for resistance or vibrating-wire gages to standards.

4.4.3 Electrical readout equipment shall undergo full-range calibration by the manufacturer, or an appropriately qualified commercial calibration service, on a routine basis. This calibration shall take place before and after times of critical measurement, or periodically for long-term measurements.

4.4.4 For those instruments having such a feature, a periodic in-situ calibration shall be performed to determine changes in the behavior of the instrument. The calibration may be done at times of critical measurements or during regular maintenance.

4.4.5 After reading the extensometer, record the data in a field notebook or data sheet that contains a record of previous readings. When a reading is taken, check it immediately with the previous reading to determine if any significant displacements have taken place since the last reading, or to determine if the reading is in error. If a reading is in question (that is, unanticipated displacements are indicated), the observer shall take additional readings. The observer shall also check to see if the extensometer is dirty or has been damaged, or if any construction events have taken place that would explain the change in the readings. For all readings, record construction conditions and temperature.

4.4.6 Several observations will aid the interpretation of displacement measured by borehole extensometers and shall be noted in a" remarks" column on the data sheet or field book. Examples of these observations are as follows:

4.4.6.1 Opening of joints or movement of rock blocks.

4.4.6.2 Mapping of joints, shear zones, and other geologic features that could be related to movement. Observations of overbreak and rock loosening along the joints and shear zones will aid in evaluating the significance of these features.

4.4.6.3 Crack surveys in shotcrete. The width, length, and relative movement of the crack shall be measured with time, and the thickness of the shotcrete in the vicinity of the crack determined.

4.4.6.4 In tunnels, evidence of distress or displacement of steel ribs and timber blocking.

4.4.6.5 Evidence of distress or loosening of rock bolts.

4.4.6.6 The increase of waterflow in the drainage system of dams that can reflect the opening of joints in the upstream part of a rock foundation. This is also helpful in tunnels to indicate loosening and opening of rock mass.

5. Calculation

5.1 Unless otherwise specified, process all data as soon as possible, but within 24 h of the reading.

5.2 Again scrutinize the field data in the office and clearly mark obvious errors in the field book. Supposedly erroneous readings shall be replaced by additional readings and shall not be discarded or obliterated from the field records.

5.3 If not entered on a special data sheet at the time of the reading, the field data shall be transferred to a computation and data summary sheet, such as shown in Fig. 12.

5.4 The method of calculating displacements from the field data depends on the particular instrument. The procedure recommended by the manufacturer shall be followed unless an alternative method is proven acceptable. Thermal displacement corrections to extensometer output are made by interpolating the change in measuring rod or wire temperature between the depths where thermocouples are able to directly measure temperature change, integrating the interpolation function (a cubic spine) over each length and multiplying this quantity by the thermal expansion coefficient of the wire or rod.

5.5 A plot of displacement versus time is the best means of summarizing current data and should be kept up to date. Interpretation of the measurements is facilitated by considering not only displacement, but the rate of displacement and the rate of change of displacement with time. Rate of displacement is equal to the slope of the displacement curve.

5.6 Periodically, prepare displacement-depth plots, as illustrated for a tunnel in Fig. 11 and Fig. 13. The deepest anchor (No. 6) has been assumed a fixed point of reference for all anchors. The rock movements can be correlated with the position of supports.

6. Report

6.1 *General*—Present results, unless otherwise specified, in two forms: (*1*) an installation report giving basic data on the instrumentation system at the time of installation, and (*2*) a monitoring report that presents periodically the results of routine observations. The monitoring reports will generally be required at frequent intervals to minimize delay between the detection of adverse behavior and the implementation of any remedial measures that may be necessary.

6.2 Installation reports shall include the following:

6.2.1 A description, with diagrams, of all components of the extensometer (anchor assembly, displacement-sensing unit, readout equipment), including detailed performance specifications.

6.2.2 Type and details of drilling equipment used.

6.2.3 Log of drilling—For cored holes, a summary log including the log of drilling and a log of the core. Also include summaries of borehole television or periscope investigations when undertaken.

6.2.4 Details and methods of installation, calibration, and monitoring; reference may be made to this practice, stating only departures from the recommended procedures.

6.2.5 A borehole location diagram that relates the specific instrument to the entire project and other instrumentation. This diagram shall include (*1*) the station or coordinates and elevation of the head of instrument, (*2*) depth, orientation, and diameter of borehole, (*3*) distances between anchors and the reference head, and (*4*) the relative position of the instrument to present and future structures and other construction.

6.2.6 A plan and section of the installation that illustrates present and anticipated construction and geology.

6.3 Monitoring reports shall include the following:

6.3.1 A set of tabulated field monitoring results (containing information in the manner shown in Fig. 12), including all

DOUBLE-POSITION MECHANICAL EXTENSOMETER

EXTENSOMETER NO. DX4 STATION 66+03 LOCATION CROWN

DATE	TIME	DEPTH 30 FT.		DEPTH 6 FT.		COMMENTS
		READING 0.001 INCHES	DISPLACEMENT INCHES	READING 0.001 INCHES	DISPLACEMENT INCHES	
7/11/72	10:30	2.252	—	2.460	—	INITIAL READING
10/24	11:00	2.264	+.012	2.459	-.001	STAGE I -65+66
10/27	15:30	2.270	+.018	2.464	+.004	STAGE I -65+76
10/31	21:30	2.283	+.031	2.471	+.011	STAGE I -65+86
11/3	18:20	2.240		2.374		NEW ZERO STAGE I - 66+06
11/6	13:52	2.281	+.072	2.392	+.029	STAGE I -66+11
11/6	22:00	2.353	+.094	2.398	+.035	STAGE I -66+16
11/7	22:00	2.323	+.114	2.400	+.037	STAGE I -66+21
11/8	10:00	2.329	+.120	2.400	+.037	STAGE I -66+21
11/9	9:45	2.349	+.140	2.402	+.039	STAGE I -66+26
11/10	10:30	2.366	+.157	2.406	+.043	STAGE I -66+31
11/13	17:00	—	—	2.408	+.045	STAGE I -66+36
11/14	10:00	2.381	+.172	2.409	+.046	STAGE I -66+36
11/14	18:00	2.388	+.179	2.409	+.046	STAGE I - 65+41 2b-65+32

FIG. 12 Sample Computation and Data Summary Sheet for a Double-Position Mechanical Extensometer

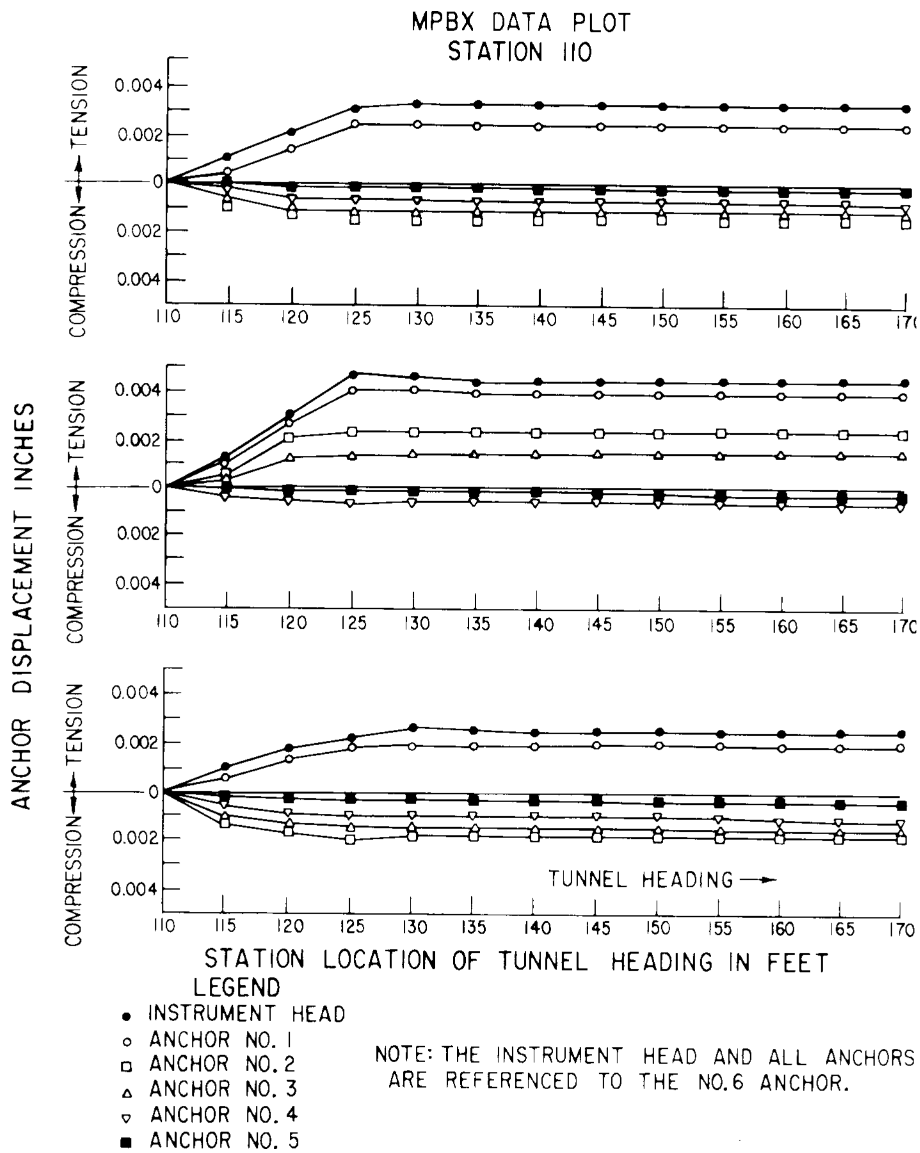


FIG. 13 Hypothetical Extensometer Data Plot

observations since the preceding report.

6.3.2 Updated diagrams of displacement of all individual sensing points with respect to time.

6.3.3 For selected instruments and locations, a diagram of displacement versus depth for various times. The reading times shall be correlated to the construction activity and shall emphasize the development or progressive nature of displacements that might be taking place.

6.3.4 A brief summary of the most significant displacements and all instrument malfunctions since the preceding report.

7. Keywords

7.1 convergence; data analysts; deformation; displacement; extensometers; field testing; installation; monitoring; rock; settlement; tunnels; underground environments

SUMMARY OF CHANGES

This section identifies the location of changes to this practice that have been incorporated since the last issue.

(1) Added paragrahos1.5, 1.3, and 1.4 as caveats. Added Summary of Changes.