Designation: D8359 – 21

Standard Test Method for Determining the In Situ Rock Deformation Modulus and Other Associated Rock Properties Using a Flexible Volumetric Dilatometer[1]

This standard is issued under the fixed designation D8359; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method establishes the guidelines, requirements, procedure, and analyses for determining the in situ deformation modulus of a rock mass and other ancillary data using a flexible volumetric dilatometer in an N-size, 75.7 mm (2.98 in.) drill hole (Fig. 1 and Fig. 2). Cyclic, creep, and unloading cycles are not covered in detail in this standard but may be added in the future or with a separate test standard, practice, or guide.

NOTE 1—Other rock mass deformability tests are radial jack tests, flat jack tests, flexible plate tests, and borehole jack tests.

1.2 This test method applies mainly to a commercially available flexible, volumetric dilatometer for an N-size, (75.7-mm (2.98-in.) I.D.) borehole that is inflated and deflated hydraulically in the borehole. However, the test method could apply to other dilatometers, including pneumatically inflated, or for different borehole sizes as well as covered under the British Standards Institute EN ISO 22476-5 (https://geotechnicaldesign.info). Use of a different diameter or type of volumetric dilatometer is up to the owner or project manager and shall not be regarded as nonconformance with this standard.

1.3 *Purpose, Application, Range of Uses, and Limitations:*

1.3.1 This designation is described in the context of obtaining data for the design, construction, or maintenance of structures on or in rock. This method can be conducted in any orientation but is usually conducted in a vertical or horizontal borehole as dictated by the design consideration.

1.3.2 The test has no depth limits other than those imposed by the limitations of the test equipment, drill hole quality, testing personnel, and equipment to drill the holes and position the testing assembly.

1.3.3 Since this is a volumetric test, only the average deformation is obtained around the borehole. If the rock properties, for any reason, including the in situ stress field or fracture density, are significantly anisotropic, then this device cannot detect that difference.

1.3.4 A large expansion of the probe in a test zone can occur due to either an oversized drill hole, weathering, lithology, or discontinuities. As a result, the maximum pressure and expansion of the dilatometer would be limited. For example, for one particular dilatometer to avoid damaging the membrane in a preferred N-size, 75.7 mm (2.98 in.) I.D., borehole, the maximum working pressure of 30,000 kPa (4,350 lbf/in.^{2}) might be possible. In contrast, at 82.5 mm (3.25 in.), the maximum working pressure would drop to only 20,680 kPa (3000 lbf/in.^{2}). Furthermore, regardless of if it an oversized drill hole or a low modulus test interval, the maximum diameter (inflated) of only 85.5 mm (3.37 in.) is allowed.

1.3.5 The radial displacements of the borehole walls during pressurization are calculated from the total volume change of the dilatometer. As such, the test results from a volumetric dilatometer indicates only the averaged value of the modulus of deformation.

1.3.6 The volumetric dilatometer test does not provide the anisotropic properties of the rock mass because it measures the average deformation and not the deformation in specific directions. However, by conducting dilatometer tests in boreholes oriented in different directions or taking impression packer data in any test intervals that had developed a hydraulic type fracture, some aspects of the in situ anisotropic conditions could be obtained.

1.4 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only and are not considered standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.4.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In the system, the pound (lbf) represents a unit of force (weight), while the units for mass is slugs. The slug unit is not given, unless dynamic (F = ma) calculations are involved.

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

[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.

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*A Summary of Changes section appears at the end of this standard

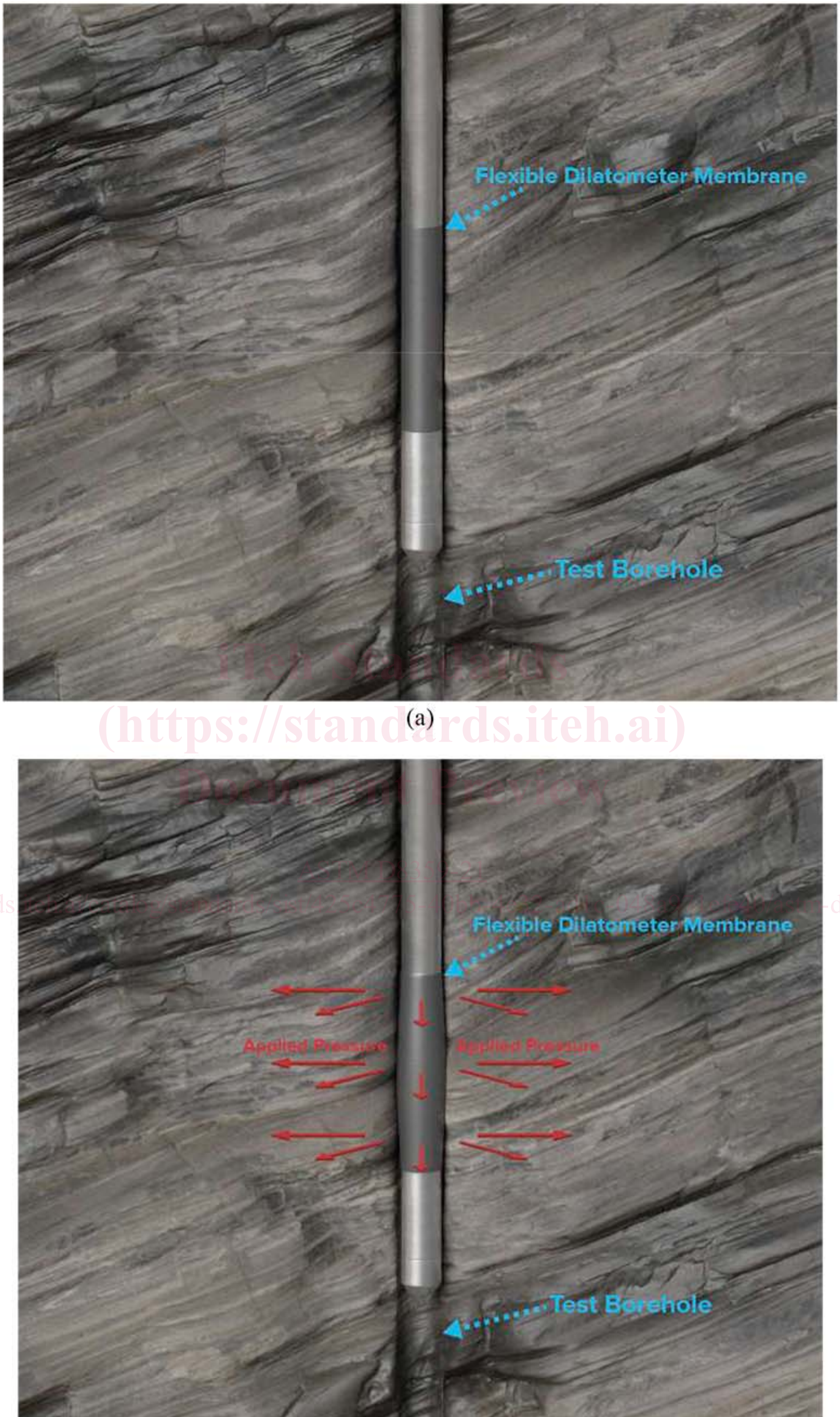

FIG. 1 General Depiction of a Flexible Dilatometer, Deflated (a) and Inflated (b) in a Borehole

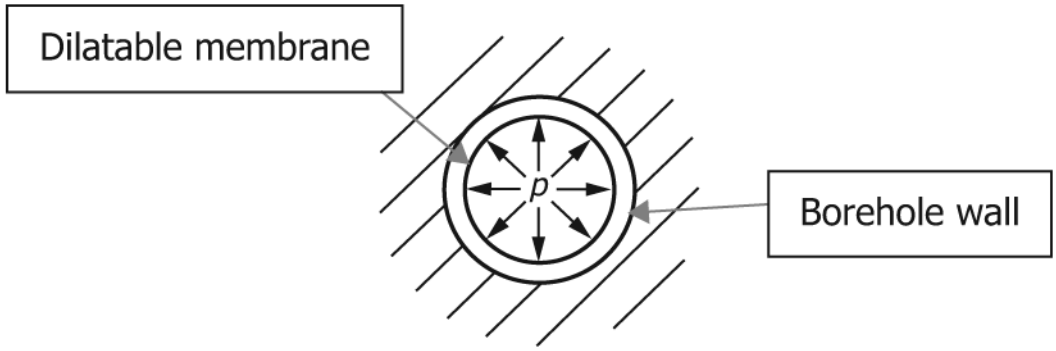

FIG. 2 Cross-Sections of the Borehole and Dilatable Membrane Portion of the Dilatometer in the Uninflated, r = 0, Starting Position

1.5.1 The procedures used to specify how data are collected/recorded or calculated in the 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, a 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.

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

1.7 *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

D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration

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

D4645 Test Method for Determination of In-Situ Stress in Rock Using Hydraulic Fracturing Method (Withdrawn 2017)[3]

D4719 Test Methods for Prebored Pressuremeter Testing in Soils

D6026 Practice for Using Significant Digits and Data Records in Geotechnical Data

D6032/D6032M Test Method for Determining Rock Quality Designation (RQD) of Rock Core

3. Terminology

3.1 *Definitions:*

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

3.1.2 *material certifications, n*—certifies a material's chemical and, in some cases, physical properties and states a product made of metal is in compliance with specific standards of international standards organizations such as ANSI, ASME, and alike, and bears the heat number from the cast from which the material was created.

3.1.2.1 *Discussion*—Also, known as a Material Test Report (MTR).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *borehole wall contact, n*—during the expansion of the dilatometer the pressure and volume at which the dilatable membrane contacts the borehole wall.

3.2.2 *correction factor "a", n*—sum of the intrinsic volumetric expansion of the dilatometer system and expansion of the thick-walled metallic calibration tube during pressurization.

3.2.3 *dilatometric modulus (E_d), n*—a average modulus of deformation based on the application of a uniform radial pressure on a cylindrical cavity in a medium assumed elastic, isotropic and homogeneous.

3.2.3.1 *Discussion*—The dilatometric modulus is a Young's modulus to the extent that the test would yield a Young's modulus of the medium if it were elastic and uniform (seamless, stress-free); since it provides a deformation modulus of the rock mass including the effects of all its peculiarities and defects adapted to the volumetric flexible dilatometer (using a formula expressed in terms of volumetric deformations). It represents an average deformation modulus in a zone of a rock mass directly affected by the loading pattern and strain.

3.2.4 *pressure correction factor (P_c), n*—a correction for the stiffness of the membrane at corresponding volume, determined from a pressure calibration at atmospheric pressure.

[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] The last approved version of this historical standard is referenced on www.astm.org.

3.2.5 *volume correction factor (V_c), n*—the intrinsic volumetric expansion of the probe, and the hydraulic module, which is the small difference between the injected volume and the actual volume increase caused by the deformation of the rock tested.

4. Summary of Test Method

4.1 A borehole, specified by the engineer and that meets the test equipment specification criteria, is drilled at one or more locations and to the depths for which test data is needed and following Practice D2113, including the collection of any ancillary data such as RQD (D6032/D6032M) or test samples. If the borehole requires support, cementing, grouting, or casing, proper methods are employed as needed; including the use of interval or staged drilling and testing, to obtain satisfactory borehole intervals in the rock mass for testing and for the type and diameter of the dilatometer available for testing.

4.2 Caliper logs of the borehole diameter and, if practicable, a visual inspection using an optical or acoustic televiewer of the borehole are run to assure the selected test interval is suitable for testing.

4.3 The rock cores and any other pertinent data are examined to determine which intervals of the borehole to targeted that are within the objectives of the testing program.

4.4 A calibrated flexible dilatometer is connected to electrical and hydraulic cables for the readout and hydraulic equipment at the surface and inserted into a borehole. The membrane section of the dilatometer is placed at the targeted test interval in the borehole and secured from moving. A seating pressure is applied to the dilatometer and then allowed time to stabilize to the temperature in the borehole.

4.5 The dilatometer is expanded, by increasing the hydraulic pressure in predetermined steps, and the applied pressures and corresponding volume changes recorded to the nearest one on the digital display. Depending on the geology in the test interval, the application of the pressure may be modified or repeated to obtain data for unloading, creep as well as tensile strength, and in situ stress.

4.6 From the recorded volume and pressure values, calculate the in situ modulus of deformation of the rock mass. Any variations in the loading sequence or additional data collected for a test interval for any other rock mechanics properties would be recorded and calculated as well.

4.7 After testing a section of the borehole, the dilatometer is completely deflated and moved to the next test interval or removed from the borehole if all testing was completed or if the borehole conditions require sequential drilling and testing.

5. Significance and Use

5.1 The dilatometer test is usually performed in vertical boreholes. It can be used in inclined or horizontal holes, but the probe would drag along the borehole wall.

5.2 Deformation modulus of rock, creep characteristics, rebound, and permanent set data is obtained and is useful for engineering designs.

5.3 The rock mass discontinuities, in situ stresses, geologic history, crystallography, texture, fabric, and other factors will determine the rock mass properties that laboratory size tests alone may not be able to measure and that the dilatometer test may be better able to measure.

5.4 Determination of rock mass deformability yields a critical parameter in the design of foundations of dams, support of underground excavations, piers, caissons, and stability of rock slopes.

NOTE 2—Although a rock mass behaves in an anisotropic and inhomogeneous manner, the calculations for a rock mass deformation modulus are based on assumptions of elasticity and homogeneity. However, they still render results that are practical, simple, usable, and not significantly different from those obtained using inhomogeneity and inelasticity.

NOTE 3—The existing in situ stresses can only be estimated by in situ tests on the rock mass, such as this or other tests.

5.5 In situ tests such as this one provides general information regarding rock mass behavior. Dilatometer tests are advised when designing and constructing specific structures.

5.6 Dilatometer tests can be performed at a reasonable cost and effort. Dilatometer tests are also less expensive and time-consuming compared to other deformability tests like radial jack or flexible plate tests that require underground excavation and access too.

5.7 Dilatometer modulus can be correlated with the moduli obtained by other methods (for example, the plate loading or radial jacking methods). The correlated dilatometer modulus can then be used instead of other more expensive in situ modulus tests.

5.8 Dilatometer tests can provide a qualitative evaluation of a rock mass deformability before performing a large scale deformability test such as a radial jack test.

5.9 Dilatometers are valuable for rapid index logging of boreholes in jointed rocks that yield poor core recovery and inadequate specimens for laboratory testing.

5.10 Pressurization and depressurization of the dilatable membrane in this standard are unique. This is done immediately upstream of the dilatable membrane by a dual-action piston actuated from a manual pump at the surface. This configuration allows the use of the dilatometer at substantial depths and eliminates the parasitic expansion of the tubing and pumping system and forces the membrane to collapse completely regardless of if the drill hole column has fluid or not.

5.11 The results of dilatometer tests may be used to check against the serviceability limit state of spread foundations on rocks through a deformation analysis.

5.12 When performing a deformation analysis the Young's modulus, E, may be taken equal to E_d on the assumption that the rock is linearly elastic and isotropic.

NOTE 4—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/sampling/inspection/etc. 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 The inside diameter of the borehole and rock properties of the borehole controls both range and maximum pressure applied to the borehole wall for a given dilatometer design. High-quality drilling and borehole caliper measurements are advised to avoid damage to the membrane and permit the highest practicable test pressures, especially in high strength, stiff materials.

6.2 The in situ stress field around the borehole may need to be included in the report and when collecting and analyzing the data. As the dilatometer membrane expands against the borehole wall, it will simulate in some ways a hydraulic fracturing test. The expansion of the membrane in the borehole will be resisted by the water head in the borehole, in situ stresses around the borehole wall, rock mechanic properties, which include the tensile strength and discontinuities.

6.3 Calibrations of the dilatometer in one material type or diameter of a calibration tube are not sufficient for stiffer rock types and can result in significantly lower deformation values. If a more accurate calibration is advised, then a borehole in a quarry site with known rock parameters may need to be utilized.

6.4 The dilatometer can be used in hard rock, but special precautions are necessary. First, the standard loading sequence provided by the supplier is recommended. The test interval in the borehole needs to be very tight. De-aired water should be used for reducing the deformation of the probe. Additional information can be found in references (**1, 2**)[4].

6.5 The modulus of deformation determined by the dilatometer is perpendicular to the borehole axis. Whereas, most typical mechanical properties tests on any drill cores will be parallel to the core axis or 90 degrees from the direction of the dilatometer tests. Only the indirect tensile strength test results on any drill cores would be in the same direction, provided the dilatometer creates a borehole wall fracture similar to a hydraulic fracture.

6.6 *Time for Setting the Probe in Place*—One purpose of the volume calibration is to knead the flexible membrane to ensure its repeatable behavior. The effect of this kneading starts to decay after about two hours. After this delay, this kneading should be repeated, or air will start to get into the rubber cavities, and the probe performance will be affected. Consequently, if it takes more than two hours to put the probe at testing elevation, it is suggested to knead the membrane by pressurizing it a couple of times against a casing or borehole walls.

7. Apparatus

7.1 *Borehole Drilling Apparatus*—This equipment includes an assortment of excavation tools, such as drills, drilling rods, drill casings, hoists, pumps, and auxiliary tools for drilling and sampling N-sized, 75.7-mm (2.98-in.), I.D. test boreholes at designated locations and depths. If the boreholes need to be supported, the necessary equipment needed so the boreholes may be cemented or grouted and re-drilled or cased to prepare the test sections in the rock mass for dilatometer tests.

7.2 *Borehole Logging Equipment:*

7.2.1 *Borehole Caliper*—Borehole device lowered into a borehole with a hoist that continuously measures the borehole diameter as it hoisted up the borehole, and accurate to 0.25-mm (0.01-in.). These devices come in single and multiple arm configurations. A six-arm configuration device is preferred.

7.2.2 *Borehole Imaging*—Some type of borehole TV camera, optical or acoustic televiewer for the observation of the borehole wall and to compare and verify geologic features observed in the core when the core recovery is poor or when retrieving oriented cores is advised but is not feasible.

7.3 *Dilatometer System*—The dilatometer is a cylindrical probe basically composed of an expandable dilatometer probe, a dual-action hydraulic module operated with a hydraulic pump, and a measuring module (see Fig. 3 and Fig. 4).

NOTE 5—The following explains one type of dilatometer system but, in general, pertains to most other systems currently being used. Therefore, the following component specifications are not absolute and may vary from dilatometer to dilatometer.

7.3.1 *Expandable Dilatometer Probe*—The dilatometer probe shown in Fig. 3 is mounted on a steel core (C) and saturated via a plugged port at its downstream extremity. Saturation of the system fills the annular space between the dilatable membrane and the steel core as well as cylinder (E) with fluid. The manual hydraulic pump (see 7.5) operates the dual-action hydraulic module (7.3.2) to inflate or deflate the dilatometer probe.

NOTE 6—In order to use or temporarily store the dilatometer at temperatures below 0°C, water in the probe should be replaced by an antifreeze solution. An ethylene-glycol-based antifreeze (regularly used in engine antifreeze liquid) is recommended as it is less corrosive for the equipment. A 50-50 solution of water-ethylene glycol by volume will allow using the equipment down to –25°C.

7.3.2 *Dual Action Hydraulic Module*—The module (see Fig. 3) contains two cylinders in which the ends of the piston travel. The dual piston identified by letters (F), (G), and (H) is the moving part responsible for inflation or deflation of the probe. When the piston is fully, retracted, as shown in Fig. 3, cylinder (E), is filled with fluid. When the oil is pumped immediately behind the inflation piston (F), the whole piston moves downstream, pushing water into the dilatable membrane (C). When the manual pump is in the deflation mode, oil is pumped on the downhole side of deflation piston (H), water is suctioned from the dilatable membrane (C) back into cylinder (E). Cylinder (E) has precise dimensions so that the known volume of fluid injected or returned from the dilatable member relative to the position of inflation piston (F) can be determined.

NOTE 7—This dual-action and that the expandable membrane pressurization is immediately upstream from the membrane by the movement of a piston actuated from a manual pump at the surface is an important attribute of this module design. The fluid in the dilatable membrane (C) is removed by negative pressure and just upstream of the membrane. As a result, this assures the collapse of the membrane back to the original diameter without any reliance on external water pressure in the borehole column, and any pressure in the hydraulic lines from the probe to the borehole collar is a non-issue. As a result, this allows the use of the

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

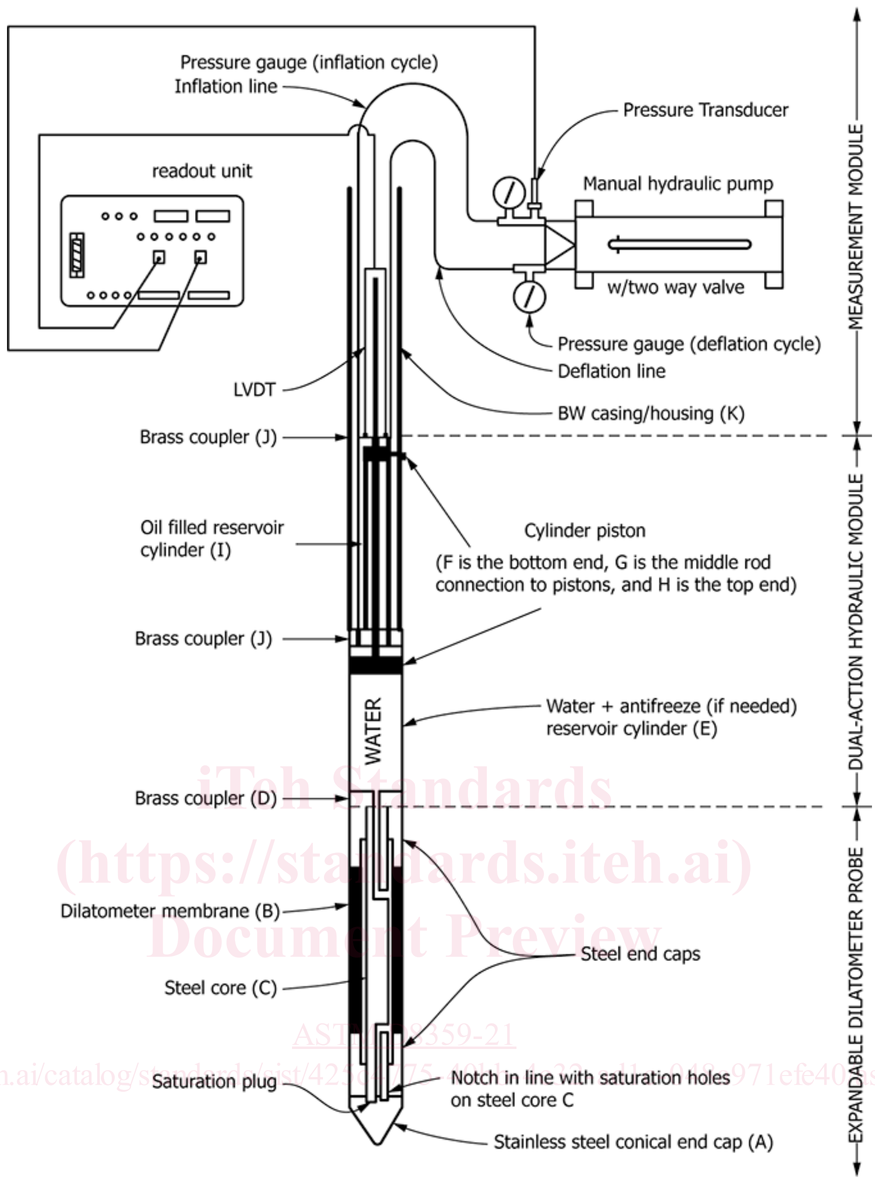

FIG. 3 Schematic Representation of One Variation of a Flexible Volumetric Hydraulically Inflatable Dilatometer—See text for description. (Courtesy of Roctest)

dilatometer at great depths and eliminates the parasitic expansion of the tubing and pumping system.

7.3.3 *Measuring Module*—The measuring module of the dilatometer (see Fig. 3) consists of an LVDT (linear variable differential transformer). It is fixed to the upstream end of the dual piston and follows piston displacement throughout the inflation and deflation of the membrane process. The LVDT output is read by the readout unit or other data acquisition system, which displays a reading corresponding to the axial position of the piston inside the cylinder.

7.3.4 *Readout Unit or Data Acquisition Interface*—A two-channel portable readout unit or other data acquisition interface that can indicate the volume change of the probe by reading the measuring module as well as the oil pressure delivered by the pump. Readings are recorded manually or electronically by the data acquisition system. The unit should have an accuracy of no less than 0.015 percent. The readout unit or data acquisition interface can run on a line voltage or rechargeable batteries with a low battery indicator.

7.3.5 *Hydraulic Pump*—A manually operated hydraulic pump with a reservoir capacity of 2.294 L (140 in.^{3}), and a pressure rating of 0 to 70 MPa (0 to 10,000 lbf/in.^{2}) with a two-way control valve to inflate or deflate the dilatometer flexible membrane.

7.3.6 *Dial Pressure Gages*—Two pressure gages are mounted on the hydraulic pump. The gage controlling the test pressure is fixed on a metal block mounted on the inflation circuit and has a pressure range of 0 to 35 MPa (0 to 5,000 lbf/in.^{2}), readable to a minimum of 50 kPa (10 lbf/in.^{2}) and an accuracy of 0.25 percent at full scale. A second gage is also fixed to a metal block mounted on the deflation circuit and has a pressure range of 0 to 14 MPa (0 to 2,000 lbf/in.^{2}) and readable to a minimum of 200 kPa (25 lbf/in.^{2}).

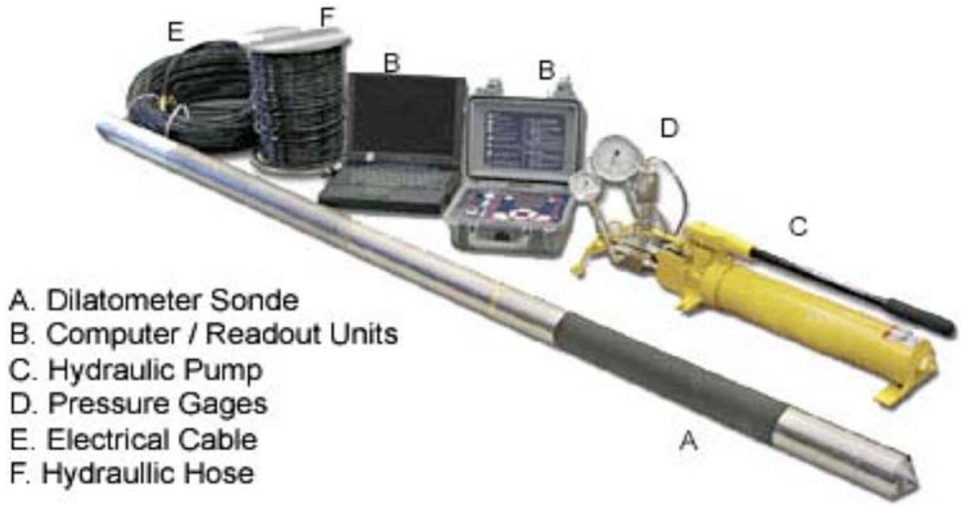

FIG. 4 Example of One Type of Volumetric Dilatometer Shown in Fig. 3.

NOTE 8—The second gage on the deflation side of the pump is a safety feature to monitor the pressure and prevent over pressurization and damage to the deflation piston.

7.3.7 *Pressure Transducer*—An electronic pressure transducer fixed on a metal block mounted on the inflation circuit and has a pressure range of 0 to 35 MPa (0 to 5,000 lbf/in.^{2}), readable to 5 kPa (1 lbf/in.^{2}) and an accuracy of 0.25 percent full scale.

7.3.8 *Hydraulic Hoses*—High-pressure hydraulic lines connect the hydraulic pump to the dilatometer and the readout unit. The inflation line has a working pressure of 70 MPa (10,000 lbf/in.^{2}), and the deflation line has a maximum working pressure of 32 MPa (4,700 lbf/in.^{2}). The outside diameters of the hoses are 8 mm (5⁄16 in.).

NOTE 9—Two optional short hydraulic lines can be used for speeding up the preparation and calibration process.

7.3.9 *Electrical Cables*—Standard electrical cables capable of sustaining 220-volt, 50-hertz operations are used for the dilatometer test.

7.4 *Cable Reel, (optional)*—Any reel with ample capacity that can handle the hydraulic hose and electrical cable while entering or exiting the dilatometer from the drill hole. The deeper the hole, the more likely a cable reel would be needed.

7.5 *Timing Device*—An analog, or digital clock, stopwatch, timer, or comparable device-readable to 1 second or better.

7.6 *Thermometric Device*—Digital or manually readable to 0.5°C or better and having an accuracy of at least ±0.5°C and capable of measuring the temperature range within which the test will be performed or the device calibrations.

7.7 *Digital or Mechanical Caliper Gage or Pi Tape,* to measure the diameter of the dilatometer membrane readable to 0.25-mm (0.01-in.).

7.8 *Calibration Tubes*—Thick-walled pipes, with a length appropriately greater than the expanding length of the instrument, with a 76.2-mm (3-in.) ID and wall thickness and alloy of any type adequate to withstand the calibration pressure range. Several calibration tubes of significantly different elastic moduli (that is, steel and aluminum) and different wall thicknesses are recommended. Material certificates (MC) for each calibration tube shall be obtained and retained for each calibration tube. Material certificate values shall be used in any calculations.

NOTE 10—Thick-walled pipe for calibration tubes, cold-rolled steel tubes have dimensions and tolerances that are more accurate than hot-rolled steel tubes.

7.9 *Recommended Ancillary Apparatus*—Borehole caliper and some type of borehole TV camera, optical or acoustic televiewer is recommended to determine the internal diameter and condition of borehole. See 9.3.3.3.

7.10 *Miscellaneous Items*—Measuring tape for determining length of dilatometer components, funnel for filling the membrane, clipboard for manually recording data, bucket, hydraulic oil for the pump, wrenches, screwdrivers, and hammer.

8. Reagents and Materials

8.1 *Inflation Fluid for Membrane*—Distilled, demineralized, and de-aired water is the only permissible fluid for the membrane except as noted in 8.2. The use of tap water is not permitted.

8.2 *Ethylene-Glycol-Based Antifreeze*—A 50-50 solution of water - ethylene glycol by volume would allow using the equipment down to –25°C, a 70-30 solution can be used down to –10°C.

NOTE 11—Ethylene glycol is not environment-friendly and should be used and disposed of accordingly and is less corrosive for the equipment than other antifreeze reagents.

9. Sampling and Test Specimens

9.1 While this test method involves samples and tests specimens that are in situ, it does not collect an actual sample or specimen, it still requires the use of drill core samples for planning tests or creates a drill hole that reaches the sample or test specimen interval. Therefore, any requirements for samples or specimens for the dilatometer testing may also have