INTERNATIONAL

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Standard Test Methods for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus[1]

This standard is issued under the fixed designation D3999/D3999M; 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—Designation was editorially corrected to match units information in October 2013.

1. Scope*

1.1 These test methods cover the determination of the modulus and damping properties of soils in either intact or reconstituted states by either load or stroke controlled cyclic triaxial techniques. The standard is focused on determining these properties for soils in hydrostatically consolidated, undrained conditions.

1.2 The cyclic triaxial properties of initially saturated or unsaturated soil specimens are evaluated relative to a number of factors including: strain level, density, number of cycles, material type, and effective stress.

1.3 These test methods are applicable to both fine-grained and coarse-grained soils as defined by the unified soil classification system or by Practice D2487. Test specimens may be intact or reconstituted by compaction in the laboratory.

1.4 Two test methods are provided for using a cyclic loader to determine the secant Young's modulus (*E*) and damping coefficient (*D*) for a soil specimen. The first test method (A) permits the determination of *E* and *D* using a constant load apparatus. The second test method (B) permits the determination of *E* and *D* using a constant stroke apparatus. The test methods are as follows:

1.4.1 *Test Method A*—This test method requires the application of a constant cyclic load to the test specimen. It is used for determining the secant Young's modulus and damping coefficient under a constant load condition.

1.4.2 *Test Method B*—This test method requires the application of a constant cyclic deformation to the test specimen. It is used for determining the secant Young's modulus and damping coefficient under a constant stroke condition.

1.5 The development of relationships to aid in interpreting and evaluating test results are left to the engineer or office requesting the test.

1.6 *Limitations*—There are certain limitations inherent in using cyclic triaxial tests to simulate the stress and strain conditions of a soil element in the field during an earthquake, with several summarized in the following sections. With due consideration for the factors affecting test results, carefully conducted cyclic triaxial tests can provide data on the cyclic behavior of soils with a degree of accuracy adequate for meaningful evaluations of modulus and damping coefficient below a shearing strain level of 0.5 %.

1.6.1 Nonuniform stress conditions within the test specimen are imposed by the specimen end platens.

1.6.2 A 90° change in the direction of the major principal stress occurs during the two halves of the loading cycle on isotropically confined specimens.

1.6.3 The maximum cyclic axial stress that can be applied to a saturated specimen is controlled by the stress conditions at the end of confining stress application and the pore-water pressures generated during undrained compression. For an isotropically confined specimen tested in cyclic compression, the maximum cyclic axial stress that can be applied to the specimen is equal to the effective confining pressure. Since cohesionless soils cannot resist tension, cyclic axial stresses greater than this value tend to lift the top platen from the soil specimen. Also, as the pore-water pressure increases during tests performed on isotropically confined specimens, the effective confining pressure is reduced, contributing to the tendency of the specimen to neck during the extension portion of the load cycle, invalidating test results beyond that point.

1.6.4 While it is advised that the best possible intact specimens be obtained for cyclic testing, it is sometimes necessary to reconstitute soil specimens. It has been shown that different methods of reconstituting specimens to the same density may result in significantly different cyclic behavior. Also, intact specimens will almost always be stronger and stiffer than reconstituted specimens of the same density.

1.6.5 The interaction between the specimen, membrane, and confining fluid has an influence on cyclic behavior. Membrane compliance effects cannot be readily accounted for in the test procedure or in interpretation of test results. Changes in

[1] These test methods are under the jurisdiction of ASTM Committee D18 on Soil and Rock and are the direct responsibility of Subcommittee D18.09 on Cyclic and Dynamic Properties of Soils.

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

pore-water pressure can cause changes in membrane penetration in specimens of cohesionless soils. These changes can significantly influence the test results.

1.7 The values stated in either SI units or inch-pound units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this test method.

1.8 All observed and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026. The procedures in Practice D6026 that are used to specify how data are collected, recorded, and calculated are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the objectives of the user. Increasing or reducing the significant digits of reported data to be commensurate with these considerations is common practice. Consideration of the significant digits to be used in analysis methods for engineering design is beyond the scope of this standard.

1.8.1 The method used to specify how data are collected, calculated, or recorded in this standard is not directly related to the accuracy to which the data can be applied in design or other uses, or both. How one applies the results obtained using this standard is beyond its scope.

1.9 *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.*

1.10 *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]

D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes

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

D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)

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

D4220 Practices for Preserving and Transporting Soil Samples

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils

D6026 Practice for Using Significant Digits in Geotechnical Data

2.2 *USBR Standard:*[4]

USBR 5210 Practice for Preparing Compacted Soil Specimens for Laboratory Use

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of terms used in these test methods shall be in accordance with Terminology D653.

3.1.2 *back pressure*—a pressure applied to the specimen pore-water to cause air in the pore space to pass into solution in the pore-water, that is, to saturate the specimen.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cycle duration*—the time interval between successive applications of a deviator stress.

3.2.2 *deviator stress* [FL^{-2}]—the difference between the major and minor principal stresses in a triaxial test.

3.2.3 *effective confining stress*—the confining pressure (the difference between the cell pressure and the pore-water pressure) prior to shearing the specimen.

3.2.4 *effective force, (F)*—the force transmitted through a soil or rock mass by intergranular pressures.

3.2.5 *hysteresis loop*—a trace of load versus deformation resulting from the application of one complete cycle of either a cyclic load or deformation. The area within the resulting loop is due to energy dissipated by the specimen and apparatus, see Fig. 1.

3.2.6 *load duration*—the time interval the specimen is subjected to a cyclic deviator stress.

4. Summary of Test Method

4.1 The cyclic triaxial test consists of imposing either a cyclic axial deviator stress of fixed magnitude (load control) or cyclic axial deformation (stroke control) on a cylindrical,

[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.

[4] Available from U.S. Department of the Interior, Bureau of Reclamation, 1849 C St NW Washington, DC 20240, http://www.doi.gov.

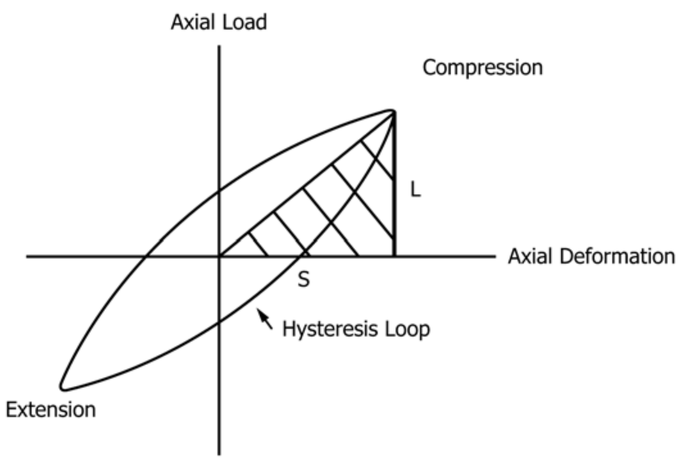

FIG. 1 Schematic of Typical Hysteresis Loop Generated by Cyclic Triaxial Apparatus

hydrostatically consolidated soil specimen in undrained conditions. The resulting axial strain and axial stress are measured and used to calculate either stress-dependent or stroke-dependent secant modulus and damping coefficient.

5. Significance and Use

5.1 The cyclic triaxial test permits determination of the secant modulus and damping coefficient for cyclic axial loading of a prismatic soil specimen in hydrostatically consolidated, undrained conditions. The secant modulus and damping coefficient from this test may be different from those obtained from a torsional shear type of test on the same material.

5.2 The secant modulus and damping coefficient are important parameters used in dynamic, performance evaluation of both natural and engineered structures under dynamic or cyclic loads such as caused by earthquakes, ocean wave, or blasts. These parameters can be used in dynamic response analyses including, finite elements, finite difference, and linear or non-linear analytical methods.

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/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. Apparatus

6.1 *General*—In many ways, triaxial equipment suitable for cyclic triaxial tests is similar to equipment used for the consolidated-undrained triaxial compression test (see Test Method D4767). However, there are special features described in the following sections that are required to perform acceptable cyclic triaxial tests. A schematic representation of the various components comprising a cyclic triaxial test setup is shown in Fig. 2.

6.2 *Cyclic Loading Equipment:*

6.2.1 Cyclic loading equipment used for load controlled cyclic triaxial tests must be capable of applying a uniform sinusoidal load at a frequency within the range of 0.1 to 2 Hz.

6.2.2 The equipment must be able to apply the cyclic load about an initial static load on the loading piston.

6.2.3 The loading device must be able to maintain uniform cyclic loadings to at least 0.5 % of the double amplitude stress,

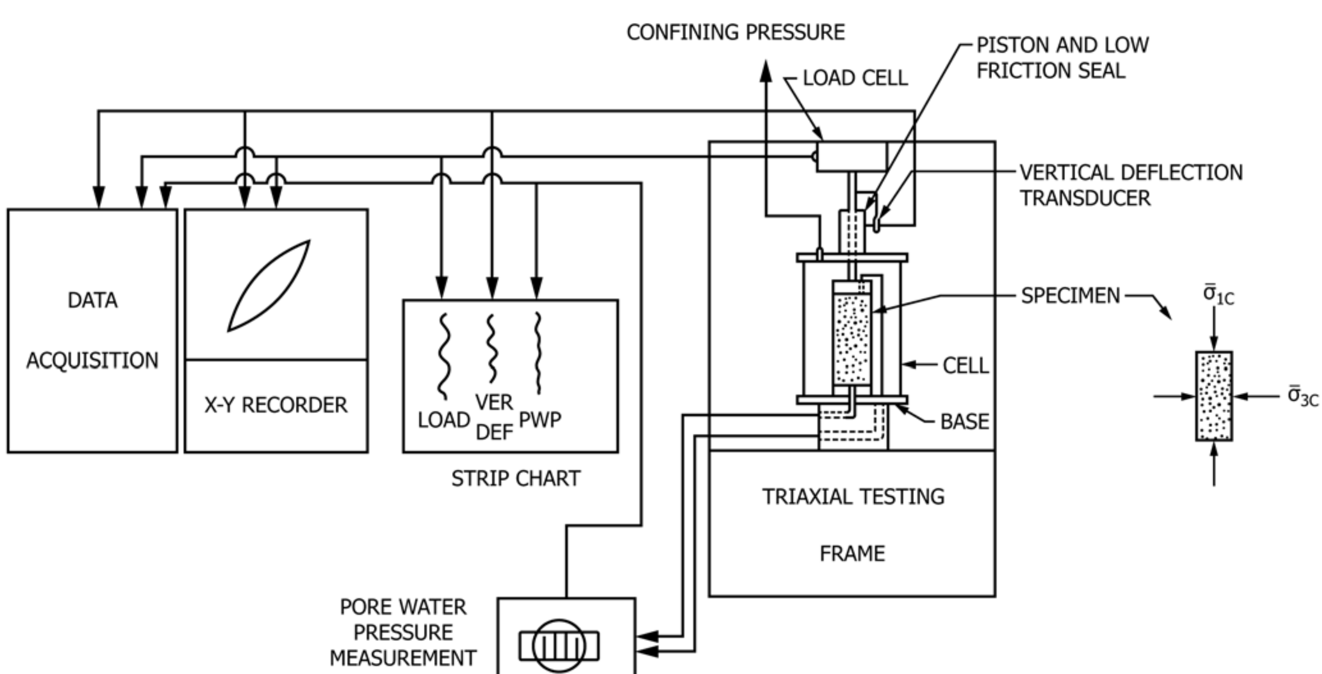

FIG. 2 Schematic Representation of Load or Stroke-Controlled Cyclic Triaxial Test Setup