INTERNATIONAL

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Standard Test Methods for Modulus and Damping of Soils by Fixed-Base Resonant Column Devices[1]

This standard is issued under the fixed designation D4015; 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 These test methods cover the determination of shear modulus and shear damping as a function of shear strain amplitude for solid cylindrical specimens of soil in intact and reconstituted conditions by torsional vibration using resonant column devices. The vibration of the specimen may be superposed on a controlled static state of stress in the specimen. The vibration apparatus and specimen may be enclosed in a triaxial chamber and subjected to an all-around pressure and axial load. In addition, the specimen may be subjected to other controlled conditions (for example, pore-water pressure, degree of saturation, temperature). These test methods of modulus and damping determination are considered nondestructive when the shear strain amplitudes of vibration are less than 10^{-2} % (10^{-4} in./in.), and many measurements may be made on the same specimen and with various states of static stress.

1.2 Two device configurations are covered by these test methods: Device Type 1 where a known torque is applied to the top of the specimen and the resulting rotational motion is measured at the top of the specimen, and Device Type 2 where an uncalibrated torque is applied to the top of the specimen and the torque transmitted through the specimen is measured by a torque transducer at the base of the specimen. For both types of devices, the torque is applied to the active end (usually top) of the specimen and the rotational motion also is measured at the active end of the specimen.

1.3 These test methods are limited to the determination of the shear modulus and shear damping, the necessary vibration, and specimen preparation procedures related to the vibration, etc., and do not cover the application, measurement, or control of the axial and lateral static normal stresses. The latter procedures may be covered by, but are not limited to, Test Method D2850, D4767, or D7181.

1.4 *Significant Digits*—All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.4.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally 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.

1.4.2 Measurements made to more significant digits or better sensitivity than specified in this standard shall not be regarded a nonconformance with this standard.

1.5 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units, which 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 these test methods.

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

1.5.2 It is common practice in the engineering/construction profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two separate systems of units; that is, the absolute system and the gravitational system. It is scientifically undesirable to combine the use of two separate sets of inch-pound units within a single standard. As stated, this standard includes the gravitational system of inch-pound units and does not use/present the slug

[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**

unit for mass. However, the use of balances or scales recording pounds of mass (lbm) or recording density in lbm/ft^3 shall not be regarded as nonconformance with this standard.

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

D2166/D2166M Test Method for Unconfined Compressive Strength of Cohesive Soil

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

D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils

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

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

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

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

D7181 Test Method for Consolidated Drained Triaxial Compression Test for Soils

3. Terminology

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

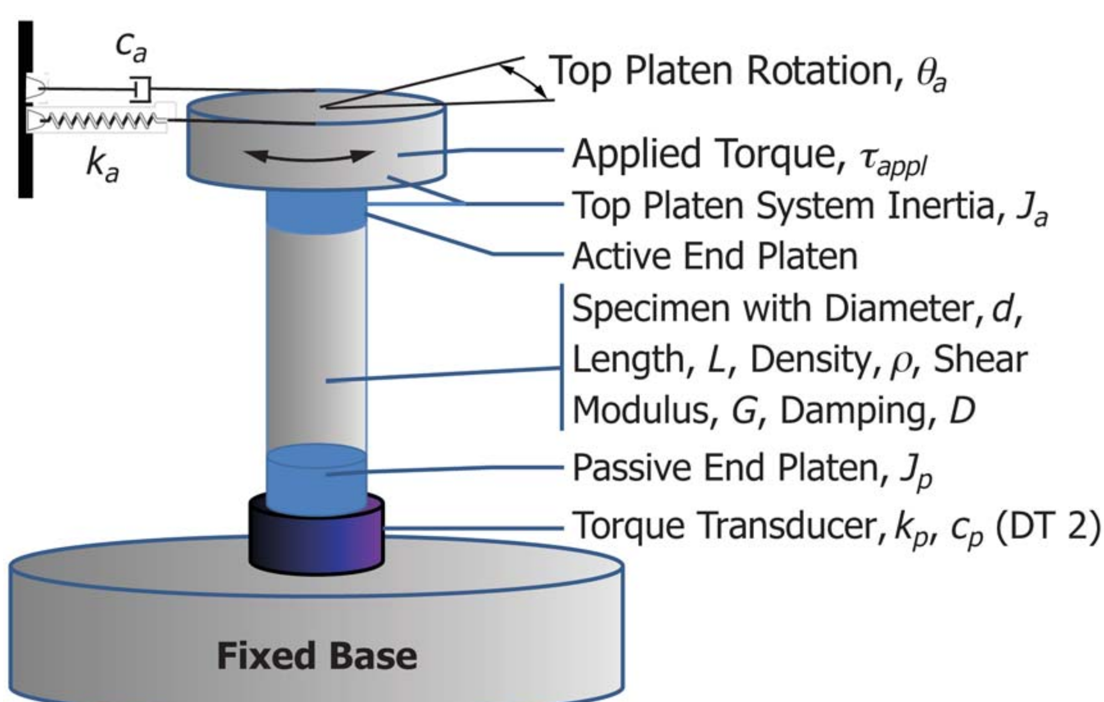
3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *damping capacity D* [unitless, typically expressed in %], *n—in resonant column systems*, is related to the component of the dynamic shear modulus that lags the applied shear stress by 90° degrees.

3.2.2 *Device Type 1, DT1, n—in resonant column systems*, a resonant column system as shown in Fig. 1 where the passive end platen is directly connected to the Fixed Base (no torque transducer), a calibrated vibratory torque is applied to the active end, and rotation is measured at the active end.

3.2.2.1 *Discussion*—The vibration excitation device may incorporate springs and dashpots connected to the active-end platen, where the spring constants and viscous damping coefficients must be known. The rotational inertia of the active-end

[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.



For Device Type 1, no torque transducer is needed and the Passive End Platen is connected to the Fixed Base.

FIG. 1 Resonant-Column Schematic for Both Device Types 1 and 2

platen and portions of the vibration excitation device moving with it must be known.

3.2.3 *Device Type 2, DT2, n—in resonant column systems*, a resonant column system as shown in Fig. 1 where the passive end platen is connected to a torque transducer, an uncalibrated torque is applied to the active end, torque is measured by the torque transducer at the passive end, and rotation is measured at the active end.

3.2.3.1 *Discussion*—The vibration excitation device may incorporate springs and dashpots connected to the active-end platen, but the spring constants and viscous damping coefficients are not needed. The rotational inertia of the active-end platen and portions of the vibration excitation device moving with it also are not needed.

3.2.4 *dimensionless specimen stiffness, DSS* [unitless], n—in resonant column systems*, is a complex number used to characterize the real and imaginary components of the specimen stiffness.

3.2.5 *dynamic shear modulus, G* [FL^{-2}], n—in resonant column systems*, is the ratio of shear stress to shear strain under vibratory conditions (also known as complex shear modulus).

3.2.6 *equivalent elastic shear modulus G [FL^{-2}], n—in resonant column systems*, is the component of the dynamic shear modulus that is in-phase with the applied shear stress.

3.2.7 *resonant-column system, n*—a system as shown in Fig. 1 consisting of a cylindrical specimen or column of soil enclosed with a flexible membrane that has platens attached to each end and where a sinusoidal vibration excitation device is attached to the active-end platen and where the other end is the passive-end platen that is rigidly fixed.

3.2.8 *specimen shear strain γ,* [unitless, frequently expressed as %]*, n*—in resonant column systems, is the average shear strain in the specimen where the shear strain in each cross section varies from zero along the axis of rotation to a maximum at the perimeter of the specimen.

3.2.8.1 *Discussion*—The radius for calculating average shear strains vary depending on soil type, strain level, confining stress, etc. The default value of the radius for calculating average strain is 0.4*diameter but values in the range of 0.33 to 0.40*diameter may be used if the value is documented in the report.

3.2.9 *system resonant frequency f_r*[s^{-1}]*, n—in resonant column systems*, for Device Type 1 is the lowest frequency at which the rotational velocity at the active end is in phase with the sinusoidal excitation torque and for Device Type 2, is the lowest frequency at which the rotational motion at the active end is a maximum.

4. Summary of Test Method

4.1 The resonant column device is shown schematically in Fig. 1. In the resonant column test, a cylindrical soil specimen, usually enclosed with a thin membrane, is subjected to an imposed static axial and lateral stress condition. Torsional sinusoidal vibrations are applied at the top of the soil specimen and the rotational response is measured. The frequency of excitation is varied until the system resonant frequency is achieved as described in 3.2.9. The devices may be operated at frequencies other than resonant frequencies. Given the geometry, mass and system parameters, the equivalent elastic shear modulus and damping capacity can be determined at a measured level of excitation vibration. The amplitude of vibration (which is related to shear strain) is typically varied to measure the variation of modulus and damping as a function of shear strain. The test is usually conducted at levels of shear strain between 0.00001 % and 0.2 %. (The upper limit of shear strain is dependent on the specimen stiffness and the maximum torque capability of the excitation system.) For specimens where the maximum shear strain measured is of the order of 0.01 %, the test is often conducted at several different sets of static axial and lateral stress conditions to measure the variation of moduli and damping with static stress states. The test results are dependent on sample quality/specimen disturbance which are beyond the scope of this standard.

5. Significance and Use

5.1 The equivalent elastic shear modulus and damping capacity of a given soil, as measured by the resonant column technique herein described, depend upon the strain amplitude of vibration, the state of effective stress, and the void ratio of the soil, temperature, time, etc. Since the application and control of the static axial and lateral stresses and the void ratio are not prescribed in these methods, the applicability of the results to field conditions will depend on the degree to which the application and control of the static axial and lateral stresses and the void ratio, as well as other parameters such as soil structure, duplicate field conditions. The techniques used to simulate field conditions depend on many factors and it is up to the engineer to decide on which techniques apply to a given situation and soil type. The results of these tests are useful for calculations involving soil-structure interaction and seismic response of soil deposits.

NOTE 1—The quality of the results produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities. 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*—The complete test apparatus is shown schematically in Fig. 1 and includes the platens for holding the specimen in the pressure cell, the vibration excitation device (torque motor), transducers for measuring the response, the control and readout instrumentation, and auxiliary equipment for specimen preparation. The theory for the resonant column is provided in Annex A1. The entire apparatus is generally enclosed within a pressure chamber (commonly referred to as a triaxial cell). For some apparatus that can apply an axial load to the specimen, the pressure chamber lid may be fitted with a piston passing through the top.

6.2 *Specimen Platens*—Both the active-end and passive-end platens shall be constructed of noncorrosive material having a modulus at least ten times the modulus of the material to be tested. Each platen shall have a circular cross section and a