Designation: D4395 – 17

Standard Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Flexible Plate Loading Method[1]

This standard is issued under the fixed designation D4395; 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 covers the preparation, equipment, test procedure, and data reduction for determining in situ modulus of deformation of a rock mass using the flexible plate loading method.

1.2 This test method is designed to be conducted in an adit or small underground chamber; however, with suitable modifications it could be conducted at the surface.

1.3 This test method is usually conducted parallel or perpendicular to the anticipated axis of thrust, as dictated by the design load and to diametrically opposite surfaces.

1.4 Both instantaneous deformation and primary creep can be obtained from this test method.

1.5 Time-dependent tests not covered by this standard can be performed but are to be reported in another standard.

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

1.6.1 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.

1.7 The values stated in inch-pound units are to be regarded as standard, except as noted below. The values given in parentheses are mathematical conversions to SI units that 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 test method.

1.8 The references appended to this standard contain further information on this test method.

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 and health practices and determine the applicability of regulatory limitations prior to use.* For specific precaution statements, see Section 8.

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]

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
D4394 Test Method for Determining In Situ Modulus of Deformation of Rock Mass Using Rigid Plate Loading Method
D4403 Practice for Extensometers Used in Rock
D4879 Guide for Geotechnical Mapping of Large Underground Openings in Rock (Withdrawn 2017)[3]
D5079 Practices for Preserving and Transporting Rock Core Samples (Withdrawn 2017)[3]
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D6026 Practice for Using Significant Digits in Geotechnical Data
D6032 Test Method for Determining Rock Quality Designation (RQD) of Rock Core

3. Terminology

3.1 *Definitions:*

[1] This test method 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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[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.

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

3.1.1 For terminology used in this test method, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *deflection, n*—movement of the plate, mortar pad, or rock in response to and in the same direction as the applied load.

3.2.2 *flexible plate, n*—theoretically, a plate having no stiffness.

3.2.3 *peak-to-peak modulus of deformation, n*—the slope of stress - strain curve line connecting the peaks of the curves obtained from successive pressure cycles (see Fig. 1).

3.2.4 *recovery modulus of deformation, n*—the tangent modulus of the unloading stress - strain curve. This modulus is usually higher than the other moduli and is used in calculations where unloading conditions exist. The difference between the tangent and recovery moduli indicates the material's capacity of hysteresis or energy dissipation capabilities (see Fig. 2).

3.2.5 *secant modulus of deformation, n*—the slope of the stress - strain curve between zero stress and any specified stress. This modulus should be used for complete load steps from zero to the desired load (see Fig. 2).

3.2.6 *tangent modulus of deformation, n*—the slope of the stress - strain curve obtained over the segment of the loading curve judged as the most representative of elastic response by the investigator. It neglects the end effects of the curve and is better suited to small stress changes. The ratio between the secant modulus and the tangent modulus can be used as a means of measuring the stress damage of the material (see Fig. 2).

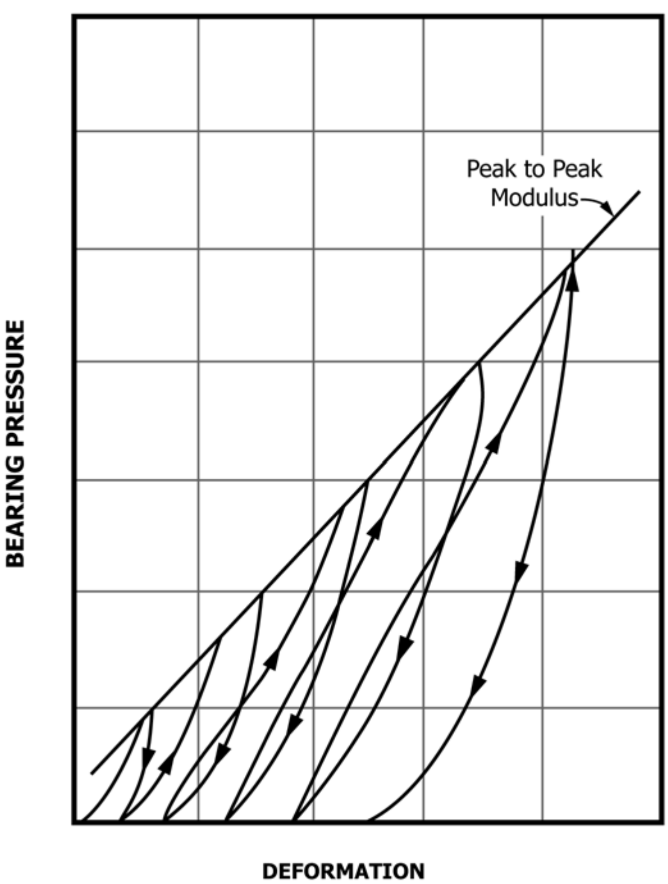

FIG. 1 Rock Surface Deformation as a Function of Bearing Pressure and Increasing Loading Cycles Plot—Arrows show up and down direction of loading cycles line shows Peak to Peak Modulus.

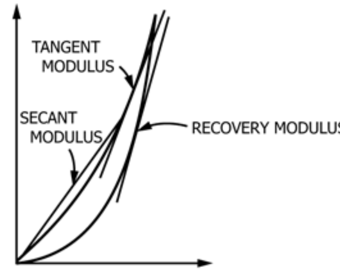

FIG. 2 Relationship Between Tangent, Secant, and Recovery Moduli for a Single Loading and Unloading Cycle

4. Summary of Test Method

4.1 Areas on two opposing sides of a test adit or underground chamber are made parallel and then flattened and smoothed.

4.2 A hydraulic loading system consisting of flat jacks, reaction members, and associated hardware is constructed between the two faces and a mortar pad is placed on each face.

4.3 If deflection is to be measured within the rock mass, install extensometer instruments in the rock in accordance with Practice D4403.

4.4 The two faces are loaded and unloaded incrementally and the deformations of the rock mass at the surfaces and, if desired, within the rock, are measured after each load and unload increment. The modulus of deformation (Secant, Tangent and/or Recovery) is then calculated on those segments of the data plot pertinent to the data acquisition program.

5. Significance and Use

5.1 Results of this type of test method are used to predict displacements in rock mass caused by loads from a structure or from underground construction. It is one of several tests that should be performed. The resulting in situ elastic modulus is commonly less than the elastic modulus determined in the laboratory.

5.2 The modulus is determined using an elastic solution for a uniformly distributed load (uniform stress) over a circular area acting on a semi-infinite elastic medium.

5.3 This test method is normally performed at ambient temperature, but equipment can be modified or substituted for operations at other temperatures.

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. Interferences

6.1 The rock under the loaded area is generally not homogeneous, as assumed in theory. Rock will respond to the load according to its local deformational characteristics. Therefore, deflection measurements at discrete points on the rock surface tend to be heavily influenced by the deformational characteristics of the rock mass at that location and may give results that are unrepresentative of the rock mass. The use of the average plate deflection will mitigate this problem.

6.2 Measurement of the deflection within the rock mass can utilize a finite gauge length to reflect the average rock mass deformation properties between the measuring points. This approach entails three drawbacks, however. First, the rock mass is tested at very low stress levels unless the measurement points are very close to the rock surface and because of this, the same problems as with surface measurements occur. Tests at low stress levels may give unrealistic modulus values because microfractures, joints, and other discontinuities in the rock are open. Secondly, the disturbance caused by implanting the deflection transducer in the rock mass is difficult to evaluate. The techniques in this test method are designed to produce minimal disturbance. Thirdly, in rocks with very high modulus, the accuracy of the instruments may be insufficient to provide reliable results.

6.3 Time-rate of loading has negligible influence on the modulus.

6.4 Calculations neglect the stress history of the rock.

6.5 This test method is insensitive to Poisson's ratio, which must be assumed or obtained from laboratory testing.

7. Apparatus

7.1 Equipment necessary for accomplishing this test method includes items for: preparing the test site, drilling and logging the instrumentation holes, measuring the rock deformation, applying and restraining test loads, recording test data, and transporting various components to the test site.

7.2 *Test Site Preparation Equipment*—This should include an assortment of excavation tools, such as drills, drill bits and chipping hammers. Blasting should not be allowed during final preparation of the test site. The drill for the instrumentation holes should, if possible, have the capability of retrieving cores from depths of at least 30 ft (10 m).

7.3 *Borehole Viewing Device*—Some type of device is desirable for examination of the instrumentation holes to compare and verify geologic features observed in the core if core recovery is poor or if it is not feasible to retrieve oriented cores.

7.4 *Deformation Measuring Instruments*—Instruments for measuring deformations should include a reliable multiple position borehole extensometer (MPBX) for each instrumentation hole and a tunnel diameter gauge. For surface measurements, dial gages, or linear variable differential transformers (LVDTs) are generally used. An accuracy of at least ± 0.0001 in. (0.0025 mm), including the error of the readout equipment, and a sensitivity of at least 0.00005 in. (0.0013 mm) is recommended. Errors in excess of 0.0004 in. (0.01 mm) can invalidate test results when the modulus of rock mass exceeds 5×10^6 psi (3.5×10^4 MPa).

7.5 *Loading Equipment*—The loading equipment includes the device for applying the load and the reaction members (usually thick-walled aluminum or steel pipes) which transmit the load of sufficient capacity for the intended test program. Flat jacks at each rock face should be used to apply the load and should have sufficient range to allow for deflection of the rock and maintain pressure to within 3 %. They should be constructed so that the two main plates move apart in a parallel manner over the usable portion of the range. A spherical bearing of suitable capacity should be incorporated in the reaction members.

7.6 *Load Measuring Instruments*—A pressure gauge/transducer or load cell should be used to measure the pressure in the flat jacks. The pressure gauge or transducer should have an accuracy of at least ±20 psi (0.14 MPa), including error introduced by readout equipment, and a sensitivity of at least 10 psi (0.069 MPa). The load cell should have an accuracy of at least ±1000 lbf (4.4 kN) including errors introduced by the readout system, and a sensitivity of at least 500 lbf (2.22 kN) is recommended.

7.7 *Bearing Pads*—The bearing pad material shall have a modulus no greater than the modulus of the rock being tested, as determined from an intact test sample. Generally, a neat cement grout is satisfactory if the curing time does not exceed several days. Fly ash or other suitable materials may be added to reduce the stiffness, if necessary.

8. Safety Precautions

8.1 Enforce safety by applicable safety standards.

8.2 Pressure lines must be bled of air to preclude violent failure of the pressure system.

8.3 Total deformation should not exceed the expansion capabilities of the flat jacks; normally this is approximately 3 % of the diameter of a metal flat jack.

9. In Situ Conditions

NOTE 2—The guidelines presented in this section are the domain of the agency or organization requesting the testing and are intended to facilitate definition of the scope and development of site-specific requirements for the testing program as a whole.

9.1 Test each structurally distinctive zone of rock mass selecting areas that are geologically representative of the mass. Test those portions of the rock mass with features such as faults, fracture zones, cavities, inclusions, and the like to evaluate their effects. Design the testing program so that effects of local geology can be clearly distinguished.

9.2 The size of the plate will be determined by local geology, pressures to be applied, and the size of the adit to be tested. These parameters should be considered prior to excavation of the adit. Optimum adit dimensions are approximately six times the plate diameter; recommended plate diameter is commonly 1½ to 3¼ ft (0.5 to 1 m). Other sizes are used depending upon site specifics.