Standard Test Method for Stiffness Based, In-Place Evaluation of Compacted Granular Materials[i]

This standard is issued under the fixed designation X XXXX; 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 method covers the in-place evaluation of compacted granular materials by an electro-mechanical means of in-place stiffness measurements. This method provides for an index of relative compaction. At the same time, it provides for an index of in-place modulus, structural uniformity and structural pavement design validation.

1.2. This method meets the in-place quality control test needs of Federal and state modulus based mechanistic pavement design and performance specifications. This method is intended to support the transition from evaluating material quality in terms of density to evaluating it in terms of modulus.

1.3. The test method provides a rapid means of testing so as to minimize interference and delay of construction. Testing proceeds at rate that keeps up with the rate of compaction, providing for real-time feedback to the construction process.

1.4. This method is intended for the quality control testing of granular materials used in earthworks and roadways. This method may also be applicable to other roadways materials. The stiffness measured with this method is influenced by boundary conditions, specifically the support offered by underlying layers as well as the thickness

[i] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.08 on Special and Construction Control Tests.

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of the layer and the modulus of the material being tested. The specific apparatus making the measurement will also influence the stiffness measured. Since this method approximates the material being evaluated as a half-space, then the modulus that might be inferred from the measurements is also approximate.

1.5. The stiffness of granular materials may be significantly influenced by changes in moisture content. This method should be used in conjunction with moisture content measurements where the effect of moisture on the stiffness values measured is a concern.

1.6. All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

1.7. The values tested in SI units are to be regarded as the standard. The inch-pound equivalents may be approximate.

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

2. Referenced Documents

2.1. *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock and Contained Fluids[ii]

D 698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort[ii]

[ii] Annual Book of ASTM Standards, Vol. 04.08

D 1557 Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort[ii]

D 2216 Test Method for Laboratory Determination of Water Content of Soil and Rock by Mass[ii]

D1556 Test Method for Density and Unit Weight of Soil in Place by the Sand Cone Method[ii]

D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[ii]

D2922 Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods[ii]

D2937 Test Method for Soil in Place by the Drive-Cylinder Method[ii]

D3017 Test Method for Water Content of Soil and Rock in Place by Nuclear Methods[ii]

D4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method[ii]

D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Method[ii]

D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating Method[ii]

D6026 Standard Practice for Using Significant Digits in Geotechnical Data[ii]

D 6758 Standard Test Method for Measuring Stiffness and Apparent Modulus of Soil and Soil-Aggregate In-Place by an Electro-Mechanical Method[iii]

3. Terminology

[iii] Annual Book of ASTM Standards, Vol. 04.09

3.1. *Definitions:*

3.1.1. For common definitions of terms in this standard, refer to terminology standard D 653.

3.1.2. *kilo-pounds force per inch, klbf/in*, n •

3.1.3. *mega-newton per meter, MN/m*, n •

3.1.4. *stiffness*, n • The ratio of change of force to the corresponding change in deflection.

3.1.5. *relative compaction,* n • The ratio, expressed as a percentage, of dry unit weight of a soil to a relative maximum dry unit weight obtained by a laboratory compaction test. **D 653**

3.1.6. *modulus*, n • The ratio of stress to strain for a material under given loading conditions; numerically equal to the slope of the tangent or the secant of the stress-strain curve. **D 653**

3.1.7. *quality control test*, n • A test that is conducted by the constructor to determine whether a product is in accordance with the appropriate specification(s).

3.1.8. *quality assurance test*, n • A test that is conducted by the Engineer to determine whether a product is in accordance with the appropriate specification(s).

3.1.9. *Engineer,* n • The person, firm, corporation or government agency acting for the owner as the duly authorized agent in the design or management of a project.

3.2. *Definitions Specific to this Standard:*

3.2.1. *site*, n • The general area where compaction occurs and measurements are made.

3.2.2. *test location*, n • A specific location on the surface of the ground where a measurement is made.

3.2.3. *resilient modulus*, n • The ratio of stress to recoverable elastic strain under repeated loading.

3.2.4. *control strip*, n • A section of in-place material, a single lift or layer, compacted to the required relative compaction and used as a reference for determining required values of stiffness for that compacted material.

4. Significance and Use

4.1. This method is useful for monitoring compaction quality in terms of relative compaction[2]. This method provides a means of relating layer stiffness to density for a particular material, range of water content and compaction procedure. This relationship is used to also relate stiffness to relative compaction, allowing this method to be used in connection with density based compaction specifications, (e.g. to meet the job specific requirements established by D 698 using standard effort or D 1557 using modified effort).

4.2. This method is useful for monitoring compaction quality in terms of achieved stiffness or modulus. The in-place layer stiffness measured in this method has been shown to be an index of roadway design parameters such as resilient modulus[1]. This method can thereby provide be useful in providing the in-place data required to validate and implement modulus based pavement design methods, including mechanistic-empirical design.

4.3. This method is useful in the construction of roadway subgrades or embankments. This method may not apply to silty and clayey materials containing significant fines. In such cases, the compactive effort and water content form a more critical relationship regarding the quality of compaction from stiffness and therefore water content should be measured (e.g., D 2216) at the time of the stiffness measurements

5. Apparatus

5.1. *Stiffness Gauge* An electro-mechanical instrument capable of being seated on the surface of the compacted material under test and which provides a means of determining force and displacement as well as calculating stiffness. This can be the same Apparatus as in D 6758. This standard takes precedence over D 6758 in the event of a conflict.

5.1.1. Stiffness measurements should be made over the range of at least 3 to 70 MN/ m (17 to 400 klbf/in).

5.1.2. A sufficiently short period of time should be required for a single measurement at any given test location so as to not interfere with or delay construction (e.g., ~ 2 minutes).

5.1.3. The depth of influence of the measurement should be approximately the top 20 cm (8”) to 30 cm (12”) of the material being tested. The depth of influence can be confirmed by measuring the stiffness of a layer of material in a confined bin per this method and comparing it to the stiffness of the layer as calculated from the measured void ratio, the estimated mean effective stress applied by the Apparatus and the estimated Poisson's ratio. This confirmation is intended as a one-time event of any given Apparatus and can come from the industry literature.[3]

5.1.4. The Apparatus should be used in a manner such that construction site noise and vibration do not interfere with the test. The Apparatus should be immune to construction noise and vibration as much as is practical.

5.1.5. An Apparatus static weight should be sufficient to produce a design relevant stress on the ground (e.g., 20.6 to 27.6 kPa (3 to 5 psi)).

5.1.6. The measurement should not significantly densify the material being measured or otherwise change its material properties.

5.1.7. The Apparatus should achieve the required precision and bias.

6. Calibration

6.1. Calibration pertains to the stiffness measurement. It draws from D 6758. This standard takes precedence over D 6758 in the event of a conflict. The recommendations of the Apparatus manufacturer regarding calibration always take precedence.

6.2. Calibration of the Apparatus is required at least every 12 months. The user should have the option of performing the calibration or having the Apparatus manufacturer or its authorized agent perform it.

6.3. To Calibrate the apparatus, place it on a 10 kg mass of a shape factor similar to that of the Apparatus. The mass should be inertially isolated over the Apparatus operating frequency range. The Apparatus should be mechanically attached to the mass to assure intimate contact between the Apparatus surface that contacts the ground and the mass. Repeated stiffness measurements are made in this configuration. The Apparatus is removed and reattached to the mass between measurements. The mean measurement result should be between –9.0 MN/m and –9.2 MN/m[5]. If it is not, a multiplier should be entered into Apparatus firmware to achieve the expected result. This calibration method will work for any apparatus that imparts a steady state low strain vibration to the ground over frequency. It will not work for a stiffness measuring apparatus that imparts a relatively high strain impact to or penetrates the ground.

6.4. A rough field check of the calibration may be needed. A mass similar to that used for calibration should be used for this purpose. As with the calibration mass, this verification mass should have an established value of stiffness for the Apparatus to measure. Note that field conditions may not allow the precision of a laboratory calibration and so an appropriate tolerance should be assigned to the check (e.g., the mean stiffness measured on the mass should be within +/- 5% of the value expected stiffness).

7. Procedure

7.1. *Verify Apparatus Operation* (daily)

7.1.1. Perform a field check of the Apparatus calibration. Make 3 measurements.

7.1.2. The Apparatus is operating properly if the mean stiffness is within +/- 5% of the expected value.

7.2. *Establish Apparatus Precision* (daily)

7.2.1. Locate some compacted material that is representative of what is to be measured that test day. Make a minimum of 3 measurements at or about the same test location per D 6758.

7.2.2. Apparatus precision is sufficient if the coefficient of variation of the measurements is less than approximately 10%.

7.3. *Establish Number Of Compactor Passes & Target Stiffness* (once per material per job)

7.3.1. Place a thickness of material specified by the Engineer over a prepared area and layout a 49 m x 3 m (~160' x 10') control strip (optimum). Ensure that the material's water content is within the targets defined by the Engineer. Begin compaction.

7.3.2. Measure stiffness with the Apparatus per D 6758 after every compactor pass at an optimum of 10 and a minimum of 6 well spaced test locations. Determine dry density and water content after every 2 passes within approximately 0.6 m (~ 2 ft.) of two (2) of the Apparatus test locations. Stop compaction when the relative compaction specified by the Engineer is reached. Record stiffness, density and water content vs. compactor passes for all test locations. Water content should be maintained within the target range defined by the Engineer during compaction and

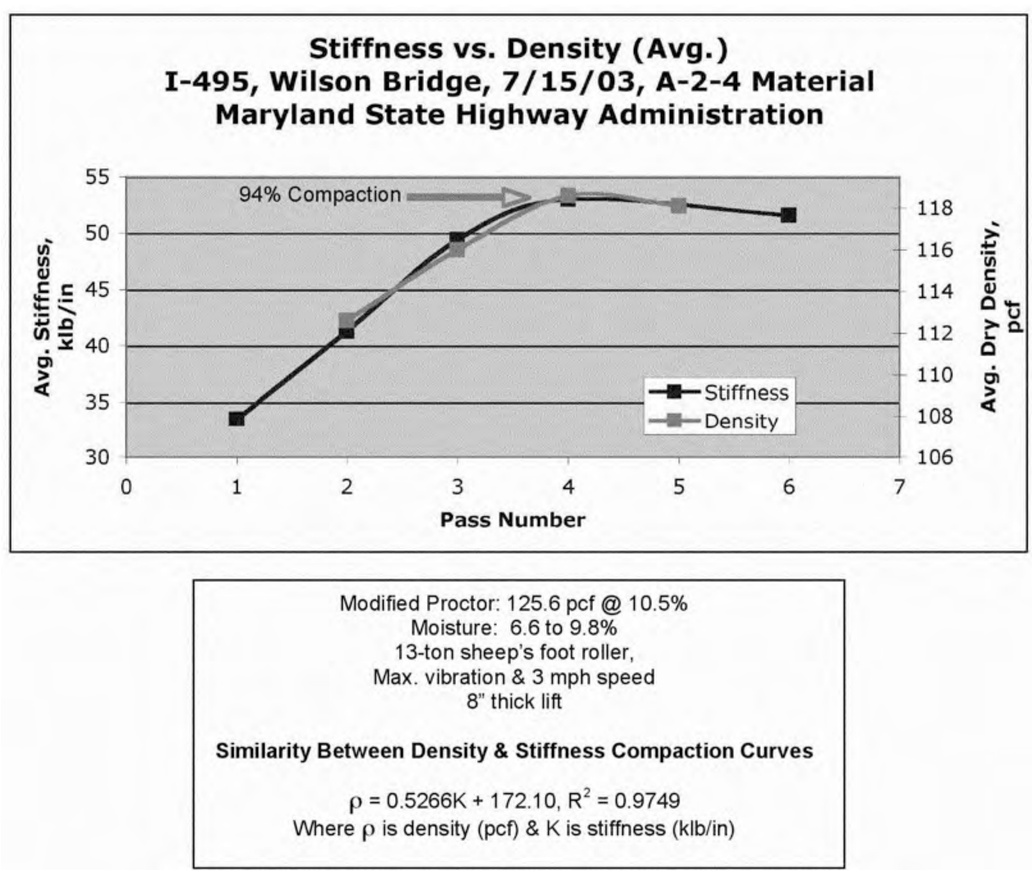

Figure 1: Example of Control Strip Data

during measurements. Density shall be determined by test methods D1556, D2167, D2922, or D2937. Water content shall be determined by test methods D2216, D3017, D4643, D4944, or D4959. Figure 1 is an example of the type of control strip data expected.

7.3.3. Calculate the stiffness mean and coefficient of variation over all locations within the control strip for the pass number that is coincident with the specified relative compaction. The resulting mean stiffness should define target stiffness over a range of water content. A tolerance on this target should be defined by 2 times the coefficient of variation.

7.3.4. With the use of this method, the measurement of density may be eliminated. Empirical relationships between stiffness and relative compaction can be built as data is accumulated on various classes of material. The Engineer may thereby be able to estimate an expected stiffness for a specified relative compaction as a function of material type, lift thickness, water content and construction methods. The control strip would be used to refine the estimate into the target stiffness on a job-by-job, material-by-material basis.

7.3.5. With further use and the availability of practical modulus based mechanistic roadway design, modulus may replace relative compaction as a specified requirement. Stiffness would then be used as an in-place index of modulus[1].

7.4. *Compaction Evaluation*

7.4.1. Compact the remainder of this material on the job using the number of compactor passes established in 7.3. Stiffness measurements per D 6758 should be made every 30 m to 150 m (~ 100 ft. to 500 ft.). Water content measurements may or may not be made at the discretion of the Engineer. The target stiffness will be reached only if water content is near that of the control strip and stiffness measurements are made very soon after compaction. Therefore, all measurements should be made within 1 hour after compaction is complete.

7.4.2. The locations for measuring stiffness should provide for an adequate spatial evaluation of the structural uniformity of the compacted material. Figure 2 presents an example of a useful stiffness measurement pattern. With continued use of this method the sampling frequency may be reduced to a minimum number of measurements per lane mile that shares the same statistical variance with the maximum sampling frequency initially used (e.g., every 30m (~ 100 ft.) per lane mile to every 150 m (~ 500 ft.))[2].

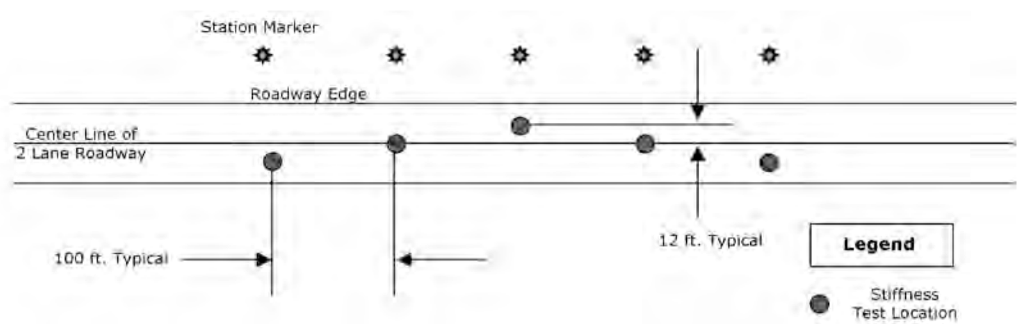

Figure 2: Example of Stiffness Measurement Pattern

8. Interpretation of Results

8.1. Nine out of ten stiffness measurements should be within the tolerance of the target stiffness as established in 7.3.

9. Report

9.1. The report shall contain the following as a minimum:

9.1.1. At least a visual classification of the materials as well as a visual description of the materials and the site conditions.

9.1.2. A sketch showing and numerically recording the position of test locations relative to site stations.

9.1.3. All stiffness, water content and density measurements identified by test location, time and date. Stiffness data shall be rounded and recorded to one decimal place (i.e., 14.3 MN/m). All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D 6026.

9.1.4. The make(s), model(s) and serial number(s) of the test equipment used.

9.1.5. The name(s) of the operator(s).

9.1.6. Identification of the project, the site and test locations.

10. Precision and Bias

10.1. Precision

10.1.1. Precision as defined below pertains to the stiffness measurement. It draws from D 6758. This standard takes precedence over D 6758 in the event of a conflict. Due to the nature of the soil or rock materials tested by the method in general it is either not feasible or too costly at this time to produce the multiple roadway sections having the uniform physical properties necessary to establish the precision of this method. A significant portion of the variation observed in the data is just as likely to be due to material and construction variation as to operator or Apparatus variation. Subcommittee D18-08 welcomes proposals that would allow for the development of a valid precision statement for the method in general.

10.1.2. Data should be collected for the determination of the precision of measurements made with each Apparatus used under this method.

10.1.3. In this standard, precision is defined as the coefficient of variation of a set of repeated measurements as follows:

$$P = \frac{\sigma}{\overline{S}} * 100 \quad (7)$$

where:

P = instrument precision in %
$\overline{S}$ = the mean stiffness of repeated measurements made at one test location, MN/m (klbf/in)
σ = one standard deviation of the stiffness

10.1.3 Typically, the precision of a stiffness measurement used under this method is represented by a coefficient of variation of less than approximately 10 %[4]. This value represents repeated measurements for three Apparatus and three operators on the same location.

10.1.4 Each Apparatus used to measure stiffness under this method should have its precision documented.

10.2.Bias

10.2.1. . Due to the nature of the soil or rock materials tested by the method in general, there is no accepted reference value and bias therefore cannot be determined.

11. Keywords

11.1. Compacted granular material, in-place evaluation, stiffness, modulus, quality control, stiffness gauge

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