



Designation: E3331 – 22a

Standard Test Method for Measuring Target Modulus Using Light Weight Deflectometer (LWD) on Compacted Proctor Mold Samples¹

This standard is issued under the fixed designation E3331; 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 describes the procedure to determine the target modulus (or deflection) required for compaction quality control of geomaterials using light weight deflectometer (LWD) drops on a compacted proctor mold in the laboratory.²

1.2 The same LWD type in terms of brand name, buffer stiffness, and deflection measurement location (on top of the plate or on top of the soil layer) used for the laboratory target modulus testing must be used during the field testing. This is to eliminate differences between measurements from different devices.

1.3 This procedure shall be performed in the laboratory on representative soil samples before the field compaction operations.

1.4 Gradation, moisture content inconsistency, and surface texture on the mold can affect the material moduli results.

1.5 The target surface modulus values can be compared to the field-measured modulus for compaction quality control/quality assurance purposes.

1.6 This test method covers the determination of the relationship between moisture content and modulus of unbound granular material using the light weight deflectometer (LWD) on laboratory compaction samples.

1.7 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. The values given in parentheses are for information only.

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

1.9 *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:³

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))

D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))

E2583 Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)

E2835 Test Method for Measuring Deflections Using a Portable Impulse Plate Load Test Device

2.2 AASHTO Standards:⁴

T 99 Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop

T 180 Standard Method of Test for Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18-in.) Drop

T 265 Standard Method of Test for Laboratory Determination of Moisture Content of Soils

3. Terminology

3.1 Definitions:

3.1.1 *light weight deflectometer (LWD)*, *n*—a testing apparatus that conforms to the general requirements of either Test

¹ This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.41 on Pavement Testing and Evaluation.

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² Afsharikia, Z., “Modulus Based Compaction Quality Assurance for Unbound Materials Using Lightweight Deflectometer,” Doctoral dissertation, University of Maryland, College Park, 2019.

³ 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.

⁴ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, <http://www.transportation.org>.

Method **E2583** for LWDs with load cells or Test Method **E2835** for LWDs without load cells.

3.1.2 *mold, n*—solid-wall, metal cylinders with dimensions and specifications conforming to AASHTO T 99 or T 180. Only 152.4 mm (6 in.) diameter molds conforming to AASHTO T 99 or T 180 shall be used.

3.1.3 *rammer, n*—a metal rammer conforming to AASHTO T 99 for standard compaction energy or AASHTO T 180 for modified compaction energy.

4. Summary of Test Method

4.1 This test is to be conducted as an add-on to the proctor method of moisture-density relations of soils. Refer to AASHTO T 99 or T 180, Method B or D, for the compaction of the specimen with three to five different water contents.

4.2 Perform LWD tests on the proctor mold samples, record the deflections and modulus values.

4.3 This test method is a type of plate-bearing test. The load is a force pulse generated by a falling mass dropped onto a spring assembly that transmits the load pulse to a plate resting on the material under test. This test method is performed on compacted mold samples of Test Method **D698** or **D1557** (AASHTO T 99 or T 180). The material under test must be in 152.4 mm (6 in.) diameter molds.

4.4 The desired load force is imparted by dropping the falling weight (mass) from a predetermined height established by the manufacturer. The weight is dropped and the resulting deflection is measured. Multiple drops from the same preset drop height may be performed on the same compacted sample.

4.5 The peak deflection is measured for each compacted mold sample. The deflection is measured in millimeters.

4.6 The peak force imparted by the falling weight is recorded in kN or lbf. In cases where the force is not recorded, the assumed value from the known drop height and mass is used.

4.7 The results from the laboratory tests on samples in a mold are used to set target modulus values for tests conducted on similar material in the field and at a similar stress level.

5. Significance and Use

5.1 LWDs are intended to be used as a tool to ensure adequate compaction of unbound materials. Adequate soil compaction of infrastructure projects will provide load capacity, stability of the soil, decrease permeability, and prevent or reduce the settlement of supported pavements and structures. The target modulus or deflections are used to establish QA/QC acceptance criteria for the LWD tests in the field.

5.2 This test method covers the determination of target acceptance modulus values of unbound materials based on measuring LWD deflections on laboratory proctor mold samples at varying moisture contents.

5.3 This standard test method provides a target modulus calculation that accounts for the constrained conditions (in the compaction mold) of the test sample. The intent is to be able to

compare the results from the laboratory samples to those of similar materials in the field at similar stress levels.⁵

5.4 The target modulus or deflections may be either correlated directly to pavement or structure performance or used to determine *in situ* material characteristics of the pavement or structure foundation layers.⁶

6. Apparatus

6.1 The LWD device is a force-generating device. The device shall use a mass capable of being raised and dropped from predetermined heights. The drop weight impacts a load plate resting on top of the proctor mold. The resulting force pulse is transmitted to the molded sample.

6.2 The resulting force pulse shall be capable of providing a half-sine or haversine-shaped load pulse, with a loading time conforming to Test Methods **E2835** and **E2583**.

6.3 The load plate shall be rigid and capable of transferring the force pulse to the sample in the mold. It is acceptable to use a proctor mold extension collar that prevents the load plate from slipping off of the mold. The outside diameter of the LWD load plate must be 150 mm in diameter for testing on a 152.4 mm (6 in.) diameter proctor mold and extension collar to allow friction-free, unencumbered contact with the compacted sample in the mold.

6.4 The deflection measurement is performed by a sensor capable of measuring the maximum vertical displacements of the downward and rebound movements of the load plate or sample. The deflection sensor shall be mounted so that the angular rotation is minimized with the measuring plane at the maximum expected deflection. The instrument shall be constructed to measure the vertical deflection at the center of the load plate. Sensors may be of several types such as displacement sensors, velocity sensors, or accelerometers.

6.5 For LWD devices (Test Method **E2583**) equipped with load cells or force transducers, the sensor shall be capable of measuring the applied load of each impact. The sensor shall be resistant to mechanical shock from impacts during testing and transport.

6.6 For LWD devices (Test Method **E2835**) that do not have a load cell or force transducer, the magnitude of the peak load for the lower drop heights is estimated as proportional to the square root of the drop height. Alternatively, the load values can be determined by calibrating the device for reduced drop heights.

6.7 Using a data processing and storage system, deflection measurements shall be displayed and recorded, along with the force.

⁵ Schwartz, C. W., Afsharikia, Z., Khosravifar, S., "Standardizing Lightweight Deflectometer Modulus Measurements for Compaction Quality Assurance," Final Report by University of Maryland, College Park, for Maryland State Highway Administration (Report No. MD-17-SHA-UM-3-20) and Federal Highway Administration (TPF-5(285)/SP409B4P), 2017.

⁶ Schwartz, C. W., and Afsharikia, Z., "Implementation of Lightweight Deflectometer (LWD) for Modulus Based Compaction Quality Assurance of Unbound Materials," Final Report by University of Maryland, College Park, for Project SHA/UM/4-51 for the Maryland Department of Transportation State Highway Administration, 2018.

6.8 The configuration for laboratory compaction characteristics testing shall match the applied pressure on the laboratory sample to be similar to that applied in the field for the various load plate sizes. This pressure matching ($\pm 10\%$) shall be accomplished by varying the falling mass weight and drop height.

6.9 The signal conditioning and recording of the LWD testing apparatus should conform to either Test Method **E2583** or **E2835**.

7. Reagents and Materials

7.1 This test method is applicable to any unbound material that is used in the proctor method of moisture-density relationships. It is typically used to determine field moisture and compaction requirements for the construction of highway or airfield pavements.

8. Hazards

8.1 Carefully follow the manufacturer's instructions on the LWD device assembly and operation. To prevent any damage to the device, make sure all the parts are firmly attached before dropping the load.

8.2 Injury can occur when lifting or dropping the falling mass. Keep back straight and lift with leg muscles when elevating the mass or lifting the LWD device.

8.3 Make sure hands and extremities are not positioned beneath the elevated mass or loading plate.

8.4 Secure falling mass into the lower locked position before and during transport.

9. Calibration and Standardization

9.1 LWD shall be calibrated in accordance with the applicable ASTM standard.

9.1.1 LWD devices with load cells shall be calibrated in accordance with Test Method **E2583**.

9.1.2 LWD devices without load cells shall be calibrated in accordance with Test Method **E2835**.

10. Procedure

10.1 *Mold Preparation*—Prepare the specimen as per the applicable ASTM standard, either Test Method **D698** or **D1557**. Position the compacted mold specimen on a rigid, flat, horizontal surface such as concrete. The extension collar of the mold shall be installed before the measurements are taken.

10.2 Position the LWD device on the compacted mold test setup. Follow the LWD manufacturer's recommendations for performing measurements on compaction mold samples. Make sure the loading plate is free to move without restriction in the mold collar. See **Fig. X1.1** in **Appendix X1**.

10.3 Rotate load plate 45° clockwise and counterclockwise to seat the plate. Any lateral movement of the plate with successive drops shall be minimized.

10.4 Perform six (6) falling mass drops. Use the first three as seating drops and the second three for analysis. Use the following procedure for each of the six falling mass drops heights:

10.4.1 Raise the mass to the predetermined drop height and latch into the release mechanism.

10.4.2 Release the mass to fall freely.

10.4.3 Catch the mass after rebound if required by the manufacturer.

10.4.4 Record the average peak deflection, device calculated modulus, force, and moisture content of test sample (if known prior to performing the tests).

10.5 Drops from reduced heights are used to permit interpolation/extrapolation to be approximately the same as the field stress state in LWD testing. Accordingly, drop weight height/force should be selected by taking account of the 150 mm diameter base plate area such that the peak LWD lab testing stress is approximately the same level of peak stress that is estimated/measured for the field LWD tests of the same compaction materials. Note that some LWD manufacturers have lighter drop weights for laboratory testing in a 150 mm (6 in.) diameter proctor mold versus the standard 10 kg drop weight typically used in field LWD testing.

10.6 After the LWD data is acquired and recorded, perform the required moisture and density relationship analysis for each moisture/density test point on the proctor compaction curve per the appropriate ASTM test method, such as **D698** or **D1557** (or AASHTO T 265).

11. Calculation or Interpretation of Results

11.1 Plot the moisture-density relationship and determine the optimum moisture content and maximum density following the procedures in AASHTO T 99 or T 180. Determine the acceptable moisture content (MC_{field}) range according to the agency requirements.

11.2 The modulus of the soil in the mold is derived from the theory of elasticity for a cylinder of elastic material with constrained lateral movement (assumed to be zero lateral strain):

$$E = \left(1 - \frac{2\nu^2}{1 - \nu} \right) \frac{4H}{\pi D^2} k \quad (1)$$

where:

ν = Poisson's ratio (refer to **Table X1.1** for suggested values),

H = height of the mold,

D = diameter of the plate or mold,

k = soil stiffness = F/δ as measured by the LWD device,

F = average maximum applied load by the LWD during the three measurement drops, and

δ = average maximum deflection measured by the LWD during the three measurement drops.

11.3 Each drop height on the mold corresponds to an applied pressure (P_{mold}).

$$P_{mold} = \frac{F}{\pi \left(\frac{D}{2} \right)^2} \quad (2)$$

11.4 It is optional to normalize the applied pressure to the atmospheric pressure ($P_a = 101.325$ kPa or 14.69 psi) for the analysis (P/P_a).