
Test Procedure for

LABORATORY COMPACTION CHARACTERISTICS AND MOISTURE-DENSITY RELATIONSHIP OF SUBGRADE, EMBANKMENT SOILS, AND BACKFILL MATERIAL



TxDOT Designation: Tex-114-E

Effective Date: February 2011

1. SCOPE

- 1.1 Use this test method to determine the relationship between water content and the dry unit mass (density) of sub-grade and embankment materials.
 - 1.1.1 Part I is a subgrade or embankment sample, 4 in. (101.6 mm) in diameter and 6 in. (152.4 mm) high, is molded in four layers, using a 5.5 lb. (2.5 kg) hammer dropped 25 times per layer from a height of 12 in. (304.8 mm). This part is intended for plastic and fine-grain soils, such as silts and clays (ML, MH, CL, and CH classifications as determined by Tex-142-E.)
 - 1.1.2 Part II is a subgrade or embankment sample, 6 in. (152.4 mm) in diameter and 8 in. (203.2 mm) high, is molded in four layers using a 5.5 lb. (2.5 kg) hammer dropped 75 times per layer from a height of 12 in. (304.8 mm). This part is intended for plastic, and coarse-grain soils, such as sands and gravels with fines (GM, GC, SM, and SC classifications as determined by Tex-142-E.)
 - 1.1.3 Part III is a cohesionless backfill (sand/silt) sample, 4 in. (101.6 mm) in diameter and 6 in. (152.4 mm) in height, is molded in four layers, using a 10 lb. (4.54 kg) hammer dropped 61 times per layer from a height of 12 in. (304.8 mm). Perform the test in Part III on prepared materials passing the 1/4 in. (6.3 mm) sieve. This part is intended for clean, cohesionless sands used for MSE backfill (SW and SP classifications as determined by Tex-142-E.)
- 1.2 Follow Tex-113-E to determine moisture-density relationships of flexible base materials, coarse-grained materials containing particles larger than 7/8 in. (22.4 mm), and treated subgrade and embankment materials. Use of the Soil Compactor Analyzer (SCA) is required at this time for flexible base materials only.
- 1.3 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. DEFINITIONS

- 2.1 *Maximum Dry Density (D_a)*—Maximum dry density is the maximum value obtained by the compaction curve using the specified compactive effort.
- 2.2 *Optimum Water Content (W_{opt})*—Optimum water content is the water content at which the soil can be compacted to the D_a .
- 2.3 *Compactive Effort (C.E.)*—Compactive effort is the total energy, expressed as foot-pounds per cubic inch (kilo-Newton-meters per cubic meter) used to compact the specimen.

- C.E. is calculated as follows:

$$\frac{Ht. \text{ of Drop (ft or m)} \times Wt. \text{ of Hammer (kN or lb)} \times \# \text{ Drops} \times \# \text{ Layers}}{\text{Volume of Mold (m}^3 \text{ or in}^3\text{)}}$$

- This procedure requires, for Part I and Part II, 7.30 ft.-lb./in.³ (604 kN-m/m³) and, for Part III, 32.36 ft.-lb./in.³ (2677 kN-m/m³), equivalent to ASTM D 1557.

3. APPARATUS

- 3.1 *Automatic tamper (compaction) device*, with:
- Base plate to hold 4 in. (101.6 mm) or 6 in. (152.4 mm) inside diameter (ID) forming molds
 - 5.5 ± 0.02 lb. (2.5 ± 0.01 kg) sector-face rammer
 - 10 ± 0.02 lb. (4.55 ± 0.01 kg) sector-face rammer
 - Adjustable drop height
 - Striking face of the rammer conforming to a 43 ± 2° segment of a 2.9 ± 0.1 in. (74 ± 2.5 mm) radius circle
 - Rigid foundation, such as a concrete block, with a mass of not less than 200 lb. (91 kg) on which the base plate of the tamper is secured. (An alternate foundation support, such as a rigid stand or table, is allowed if the D_a produced is within 2% of that produced by an automatic tamper bolted to a concrete floor).
- 3.2 *Rigid metal compaction mold*, with 4 ± 1/64 in. (101.6 ± 0.4 mm) average ID and a height of 6 ± 0.0026 in. (152.4 ± 0.7 mm) with removable collar, and/or a 6 in., +1/16 or -1/64 in. (152.6 mm, +1.6 or -0.4 mm) average ID and a height of 8-1/2 ± 1/16 in. (215.9 ± 1.6 mm) with removable collar.
- 3.3 *Metal stand*, with a set of standard spacer blocks and a micrometer dial assembly, with 2 in. (50 mm) travel, for determining height of specimens. Spacer blocks 1, 4, 6, and 11 in. (25.4, 101.6, 152.4, and 279.4 mm) accurate to 0.001 in. (0.025 mm).

- 3.4 *Balance*, Class G2 in accordance with Tex-901-K, with a minimum capacity of 35 lb. (15 kg).
- 3.5 *Extra base plate*, secured on a rigid stand to hold the forming mold.
- 3.6 *Hydraulic press*, to extrude molded specimens.
- 3.7 *Drying oven*, maintained at $230 \pm 9^{\circ}\text{F}$ ($110 \pm 5^{\circ}\text{C}$).
- 3.8 *Metal pans*, wide and shallow for mixing and drying materials.
- 3.9 *Circular porous stones*, slightly less than 6 in. (152.4 mm) in diameter and 2 in. (51 mm) high.
- 3.10 *Supply of small tools*, including a 4–5 lb. (1.8–2.3 kg) rawhide hammer, level, finishing tool, and others.
- 3.11 *Standard U.S. sieves*, meeting the requirements of Tex-907-K, in the following sizes:
 - 1-3/4 in. (45 mm)
 - 7/8 in. (22.4 mm)
 - 3/8 in. (9.5 mm)
 - No. 4 (4.75 mm).

4. CALIBRATING EQUIPMENT

- 4.1 Calibrate equipment in accordance with Tex-198-E. In addition, calibrate equipment before initial use, after repair, or after any occurrence that might affect the test results.
- 4.2 Follow the steps outlined in Tex-113-E, Section 4.

PART I—MEASURING MOISTURE-DENSITY RELATIONSHIP OF SUBGRADE AND EMBANKMENT SOILS

5. SCOPE

- 5.1 Part I uses a 4-in. (102 mm) ID mold and applies only to soils with:
 - 100% passing the 3/8 in. (9.5 mm) sieve
 - $\geq 80\%$ passing the 1/4 in. (6.3 mm) sieve
 - ML, MH, CL, and CH soil classification as determined by Tex-142-E.

6. PREPARING SAMPLE

- 6.1 Prepare the material in accordance with Tex-101-E, Part II. Do not use materials that have been previously laboratory compacted.
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7. PROCEDURE

- 7.1 Determine the percent hygroscopic moisture of a representative sample of prepared material in accordance with Tex-103-E.
- 7.2 Separate sample on 7/8 in. (22.4 mm), 3/8 in. (9.5 mm), and 1/4 in. (6.3 mm) sieves and determine particle size distribution.
- 7.3 Estimate the mass of air-dried material that will fill the mold when wetted and compacted.
- 7.4 Using this estimated mass, and the percentages of the various sizes of particles obtained in Section 7.2, compute the cumulative masses of each size to combine to make a specimen.
- 7.5 Using the masses calculated in Section 7.3, recombine at least four specimens of approximately 7.7 lb. (3.5 kg) each.
- 7.6 Estimate the optimum percent moisture required to attain maximum density.
Note 1—The plastic limit is a good indicator of optimum moisture content, typically within 2%, or 3–4% higher for $PI > 35$ material.
- 7.7 Start the M-D curve using a sample with a moisture content of 2% below the estimated optimum moisture content. For soils with a low to moderate plasticity index ($PI < 35$), adjust the moisture content of the remaining samples in approximately 2% increments to attain two samples above and two samples below the optimum moisture content. For soils with high plasticity index ($PI \geq 35$), the moisture content may be adjusted in 4% increments to attain two samples above and two samples below the optimum moisture.
Note 2—After compacting the first two or three specimens, construct the initial M-D curve to aid in evaluation of the shape of the curve. If necessary, adjust the water content of the other prepared samples by adding additional water or air-drying to obtain a well-defined compaction curve.
- 7.8 Calculate the mass of the water to be added based on the air-dry mass of the material.
- 7.9 Weigh out this amount of water into a tared sprinkling jar.
- 7.10 Sprinkle water onto the soil during mixing, in increments.
- 7.11 Thoroughly mix each specimen to ensure even distribution of water throughout specimen.
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- 7.12 Cover the mixed sample and allow sample to stand and cure for at least 12 hr. before compacting. When the PI is less than 12, reduce the curing time to no less than 3 hr. Cure split or referee samples for the full 12 hr.
- 7.13 Assemble and secure the mold and collar to the base plate.
- 7.14 Thoroughly remix the cured sample.
- 7.15 Obtain approximately 1 lb. (453.6 g) of the sample and determine water content as described in Tex-103-E, Section 7.
- 7.16 Place loose soil into the mold and spread into a layer of uniform thickness.
- 7.17 Before compaction, use hand tools to tamp the soil lightly until it is not fluffy or loose.
- 7.18 Separate the material in the pan into four equal portions. Each portion must contain representative quantities of all sizes and adequate material to compact four 1.5-in. (38-mm) layers.
- 7.19 For each layer, dump the material into the mold. Spade and level the layer of material with a spatula to fill cavities around the edge and to ensure an even distribution of material in each layer before compacting. Do not push this layer down by hand or other means than that described above.
- 7.20 Compact each layer using 25 per lift with a drop height of 12 in. (304.88 mm).
- 7.21 Use the soil mass and compacted thickness of the first lift to adjust the mass and thickness of the subsequent lifts.
- 7.22 Upon completion of compacting each of the first three lifts, use a knife or other convenient tool to scarify the surface to a depth of 1/4 in. (6.3 mm). Dislodge uncompacted soils that extend above the compacted surface.
- 7.23 Upon completion of the fourth lift, the compacted specimen should extend above the top, but by no more than 1/4 in. (6.3 mm). Discard the compacted specimen if it does not extend above the top of the mold at any point.
- 7.24 After compaction of the last lift, remove the collar and use a straight edge or draw knife to carefully trim the compacted specimen even with the top of the mold.
- 7.25 Invert the mold and trim the bottom of the specimen even with the bottom of the mold.
- 7.26 Use trimmed soil from the specimen to fill holes on the trimmed surfaces. Trim again as needed to ensure a smooth, level surface.
- 7.27 Determine and record the mass of the specimen and mold as W_T to the nearest 0.001 lb. (0.5 g) under Tex-113-E, Section 9.
- 7.28 Record the data on [Form 113.4](#), "Moisture Density Relations of Base Material and Sand or Subgrade and Embankment Soils."

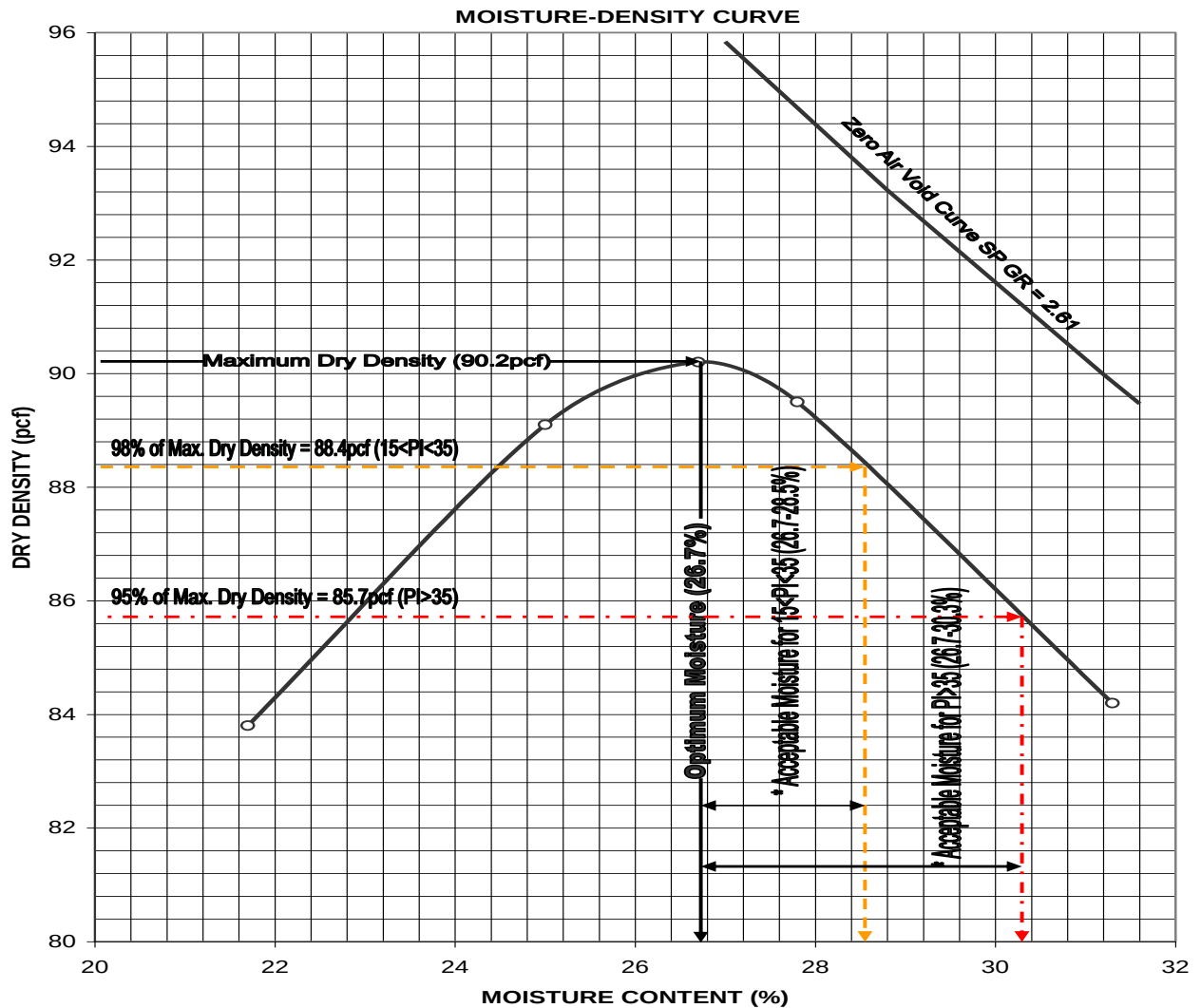
- 7.29 Use the hydraulic jack press to remove the specimen from the mold.
- 7.30 Place the compacted specimen and identification tag into a large pan and break into several pieces.
- 7.31 Obtain the mass of the drying pan and wet sample and record to 0.001 lb. (0.5 g).
- 7.32 Place the specimen in an oven at a temperature of $230 \pm 9^{\circ}\text{F}$ ($110 \pm 5^{\circ}\text{C}$) and dry to constant weight.
Note 3—Use a $140 \pm 9^{\circ}\text{F}$ ($60 \pm 5^{\circ}\text{C}$) oven for ML or MH soils (as determined by Tex-145-E).
- 7.33 Record the mass of the oven-dried material to the nearest 0.001 lb. (0.5 g) under Tex-113-E, Section 9.
- 7.34 Repeat Sections 7.8–7.33 for all samples.
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8. CALCULATIONS

- 8.1 Use the equations in Tex-113-E, Section 9.
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9. GRAPHS

- 9.1 Plot the molding moisture and dry density curve for D_a as shown in Figure 1.



PLOT OF SAMPLE MOISTURE-DENSITY CURVE
* Acceptance limits based on 2004 Item 132 Specifications

Figure 1—Plot of Sample Moisture-Density Curve

10. REPORTING TEST RESULTS

10.1 Report:

- D_a to the nearest 0.1 lbs/ft³ (1 kg/m³)
- W_{opt} to the nearest 0.1 %.

PART II—MEASURING MOISTURE-DENSITY RELATIONSHIP OF SUBGRADE AND EMBANKMENT SOILS

11. SCOPE

- 11.1 Part II uses a 6-in. (152.4-mm) diameter mold and applies only to soils with:
- 100% passing the 7/8-in. (22.4-mm) sieve
 - $\leq 20\%$ passing the 1/4-in. (6.3-mm) sieve
 - GM, GC, SM, or SC soil classifications as described by Tex-142-E
- 11.2 Use Tex-113-E for moisture-density curve determination of flexible base materials and coarse-grained materials containing particles larger than 7/8 in. (22.4 mm). Use of the Soil Compactor Analyzer (SCA) is required at this time for flexible base materials only.

12. PREPARING SAMPLE

- 12.1 Secure a representative sample of material and prepare approximately 132 lb. (60 kg) of moist soil as described in Tex-101-E, Part II for moisture-density test. Do not reuse soil that has been previously laboratory compacted.

13. PROCEDURE

- 13.1 Determine the percent hygroscopic moisture of a representative sample of prepared material in accordance with Tex-103-E.
- 13.2 Separate sample on 7/8 in. (22.4 mm), 3/8 in. (9.5 mm), and 1/4 in. (6.3 mm) sieves, and determine the particle size distribution.
- 13.3 Estimate the mass of air-dried material that will fill the mold when wetted and compacted.
- 13.4 Using this estimated mass and the percentages of the various sizes of particles obtained in Section 13.2, compute the cumulative masses of each size to combine to make a specimen.
- 13.5 Using the masses calculated in Section 13.3, recombine at least four specimens of approximately 22 lb. (10 kg) each.
- 13.6 Estimate the optimum percent moisture required to attain maximum density.
Note 4—The plastic limit is a good indicator of optimum moisture content, typically within 2%, or 3–4% higher for PI >35 material.
- 13.7 Start the M-D curve using a sample with a moisture content of 2% below the estimated optimum moisture content. For soils with a low to moderate plasticity index (PI < 35), adjust the moisture content of the remaining samples in approximately 2% increments to

attain two samples above and two samples below the optimum moisture content. For soils with high plasticity index ($PI \geq 35$), adjust the moisture content in 4% increments to attain two samples above and two samples below the optimum moisture.

Note 5—After compacting the first two or three specimens, the initial M-D curve can be constructed to aid in evaluation of the shape of the curve. If necessary, adjust the water content of the other prepared samples by adding additional water or air-drying to obtain a well-defined compaction curve.

- 13.8 Calculate the mass of the water to be added based on the air-dry mass of the material.
- 13.9 Weigh the required mass of water into a tared sprinkling jar.
- 13.10 Sprinkle water onto the soil during mixing, in increments.
- 13.11 Thoroughly mix each specimen to ensure an even distribution of water.
- 13.12 Cover the mixed sample and allow sample to stand and cure for at least 12 hr. before compacting. When the PI is less than 12, reduce the curing time to not less than 3 hr. Cure split or referee samples for the full 12 hr.
- 13.13 Assemble and secure the mold and collar to the base plate.
- 13.14 Thoroughly remix the cured sample.
- 13.15 Obtain approximately 1 lb. (453.6 kg) of the sample and determine water content as described in Tex-103-E, Section 7.
- 13.16 Place loose soil into the mold and spread into a layer of uniform thickness.
- 13.17 Use hand tools to tamp the soil lightly until it is not fluffy or loose.
- 13.18 Separate the material in the pan into four equal portions. Each portion must contain representative quantities of all sizes and adequate material to compact four 2-in. (50-mm) layers.
- 13.19 For each layer, dump the material into the mold. Spade and level the layer of material with a spatula to fill cavities around the edge and to ensure an even distribution of material in each layer before compacting. Do not push this layer down by hand or other means than that described above.
- 13.20 Compact each layer using 75 per lift with a drop height of 12 in. (304.88 mm).
- 13.21 Use the soil mass and compacted thickness of the first lift to adjust the mass and thickness of the subsequent lifts.
- 13.22 Upon completion of compacting each of the first three lifts, use a knife or other convenient tool to scarify the surface and dislodge the uncompacted soils that extend above the compacted surface.

- 13.23 Use the finishing tools outlined in Tex-113-E and four medium-firm blows of the 4–5 lb. (1.818–2.273 kg) rawhide hammer to level and finish the fourth lift.
- 13.24 Using the height-measuring stand, measure and record the specimen height to the nearest 0.001 in. (0.025 mm). The height of the finished specimen should be $8 \pm 1/4$ in. (2036.3 mm). Discard the specimen if it is too short or too tall.
- Note 6**—To adjust the molded height of specimen in Section 13.21, calculate as follows:
- Dry Weight of Specimen = (Dry Weight of Specimen $\times$ 8") / Height of Specimen*
- 13.25 Determine and record the mass of the specimen and mold as W_T to the nearest 0.001 lb. (0.5 g), under Tex-113-E, Section 9.
- 13.26 Record the data on [Form 113.4](#).
- 13.27 Use the hydraulic jack press to remove the specimen from the mold.
- 13.28 Place the compacted specimen and identification tag into a large pan and break into several pieces.
- 13.29 Obtain the mass of the drying pan and wet sample and record to 0.001 lb. (0.5 g).
- 13.30 Place the specimen in an oven at a temperature of $230 \pm 9^\circ\text{F}$ ($110 \pm 5^\circ\text{C}$) and dry to constant weight.
- Note 7**—Use a $140 \pm 9^\circ\text{F}$ ($60 \pm 5^\circ\text{C}$) oven for ML or MH soils (as determined by Tex-142-E) or soils with measurable sulfates (as determined by Tex-145-E).
- 13.31 Record the mass of the oven-dried material to the nearest 0.001 lb. (0.5 g) under Tex-113-E, Section 9.
- 13.32 Repeat Sections 13.8–13.31 for all samples.

14. CALCULATIONS

- 14.1 Use the equations under Tex-113-E, Section 9.

15. GRAPHS

- 15.1 Plot the molding moisture vs. the dry density curve for D_a shown in Figure 1.

16. REPORTING TEST RESULTS

- 16.1 Report test results as described in Part I.

PART III—MEASURING MOISTURE-DENSITY RELATIONSHIP OF COHESIONLESS BACKFILL

17. SCOPE

17.1 Part III uses a 4-in. (102-mm) ID mold and applies only to cohesionless soils and backfills as described below:

- 100% passing the 1/4 in. (9.5-mm) sieve
- $\geq 50\%$ passing the No. 4 (4.75-mm) sieve
- $\leq 25\%$ passing the No. 200 (75- μ m) sieve
- SW – SP classification.

18. PREPARING SAMPLES

18.1 Prepare the material in accordance with Tex-101-E, Part II.

19. PROCEDURE

19.1 Perform Part I, Sections 7.1–7.15, except for Section 7.12.

19.2 Mix the material thoroughly and separate into four equal portions. Each portion must contain representative quantities of all sizes and contain enough material to compact four 1.5-in. (38-mm) layers.

19.3 For each layer, dump the material into the mold. Spade and level the layer of material with a spatula to fill cavities around the edge and to ensure an even distribution of material in each layer before compacting. Do not push this layer down by hand or other means than that described above.

19.4 Compact each layer by applying 61 ram blows with a 10 lb. (4.55 kg.) rammer from a height of 12 in. (457.2 mm).

19.5 Stop the compactor as frequently as necessary to clean the ram face.

19.6 Use the soil mass and compacted thickness of the first layer to adjust the mass and thickness of the subsequent layers.

19.7 Each layer thickness should be approximately equal in height and mass. All material should be molded.

19.8 Upon completion of the fourth lift, the compacted specimen should extend above the top, but by no more than 1/4 in. (6.3 mm). Discard the compacted specimen if it does not extend above the top of the mold at any point.

- 19.9 Remove the collar and use a straight edge or draw knife to carefully trim the compacted specimen even with the top of the mold.
- 19.10 Use trimmed material from the specimen to fill holes on the trimmed surfaces. Trim again, as needed to ensure a smooth, level surface.
- 19.11 Determine and record the mass of the specimen and mold as W_T to the nearest 0.001 lb. (0.5 g) under Tex-113-E, Section 9.
- 19.12 Record the data on [Form 113.4](#).
- 19.13 Carefully center the specimen over a porous stone and place in the hydraulic press to extrude the specimen from the mold.
- 19.14 Place the compacted specimen and identification tag into a large pan and break into several pieces.
- 19.15 Obtain the mass of the drying pan and wet sample and record to 0.001 lb. (0.5 g).
- 19.16 Place the drying pan with wet material in an oven at a temperature of 230°F (110°C) and dry to constant weight.
- 19.17 Record the mass of the oven-dried material to the nearest 0.001 lb. (0.5 g) under Tex-113-E, Section 9.
- 19.18 Repeat Sections 19.2–19.17 for all samples.
- Note 8**—After compacting the first two or three specimens, the initial M-D curve can be constructed to aid in evaluation of the shape of the curve. If necessary, adjust the water content of the other prepared samples by adding additional water or air-drying to obtain a well-defined compaction curve.

20. CALCULATIONS

- 20.1 Use the equations under Tex-113-E, Section 9.

21. REPORTING TEST RESULTS

- 21.1 Report test results as described in Part I.

22. FAMILY OF CURVES

- 22.1 The materials used for subgrade and embankment construction are variable in color, texture, and moisture-density relationship.
- 22.2 To adequately control the compaction and field densities of these materials, it is necessary to have several compaction curves prepared and plotted on the same graph to

assist the inspector to make a sound judgment as to which curve is representative of the material being tested for field density.

- 22.3 The family of compaction curves shown in Figure 2 illustrates that, as the material's plasticity and fineness increase, the D_a will decrease with a corresponding increase in W_{opt} . The wet leg of the compaction curve is generally parallel with the 0% air void line.
- 22.4 To properly correlate the soil properties to a compaction curve, the soil properties presented in Table 1 should be provided along with the family of compaction curves.

Table 1—Soil Properties, Family of Curves, & One-Point Control

Curve No.	Max. Dry Density kg/m ³ (pcf)	Optimum Water Content %	Liquid Limit %	PI	Wet Gradation, % Retained			Material Description
					22.4 mm (7/8 in.)	9.5 mm (3/8 in.)	4.75 mm (No.4)	
1	93.6 (1499.5)	22.0	61	43	0	0	0	dark brown clay
2	96.6 (1547.5)	20.4	48	30	0	0	1.4	brown clay
3	100.3 (1606.8)	18.8	44	27	0	0	2.5	brown clay
4	104.6 (1675.7)	17.4	38	21	0	0	4.3	lt. brown clay

23. ONE-POINT CONTROL

- 23.1 In the event the material being tested for field density does not match the description and properties of any of the materials from the family of compaction curves, the one-point control method may be used to derive an adjusted D_a and W_{opt} by:
- air drying the field sample to a water content near the plastic limit of the material
 - molding one compaction specimen
 - using the one-point moisture-density data to construct a compaction curve which mimics the shape of the family of curves
- 23.2 The wet leg of the compaction curve is well defined by the 0% air void line; therefore, it is essential to air-dry the field sample to a water content near the plastic limit of the material and provide better definition of the dry side of the curve. Figure 2 shows an example of the one-point control method.

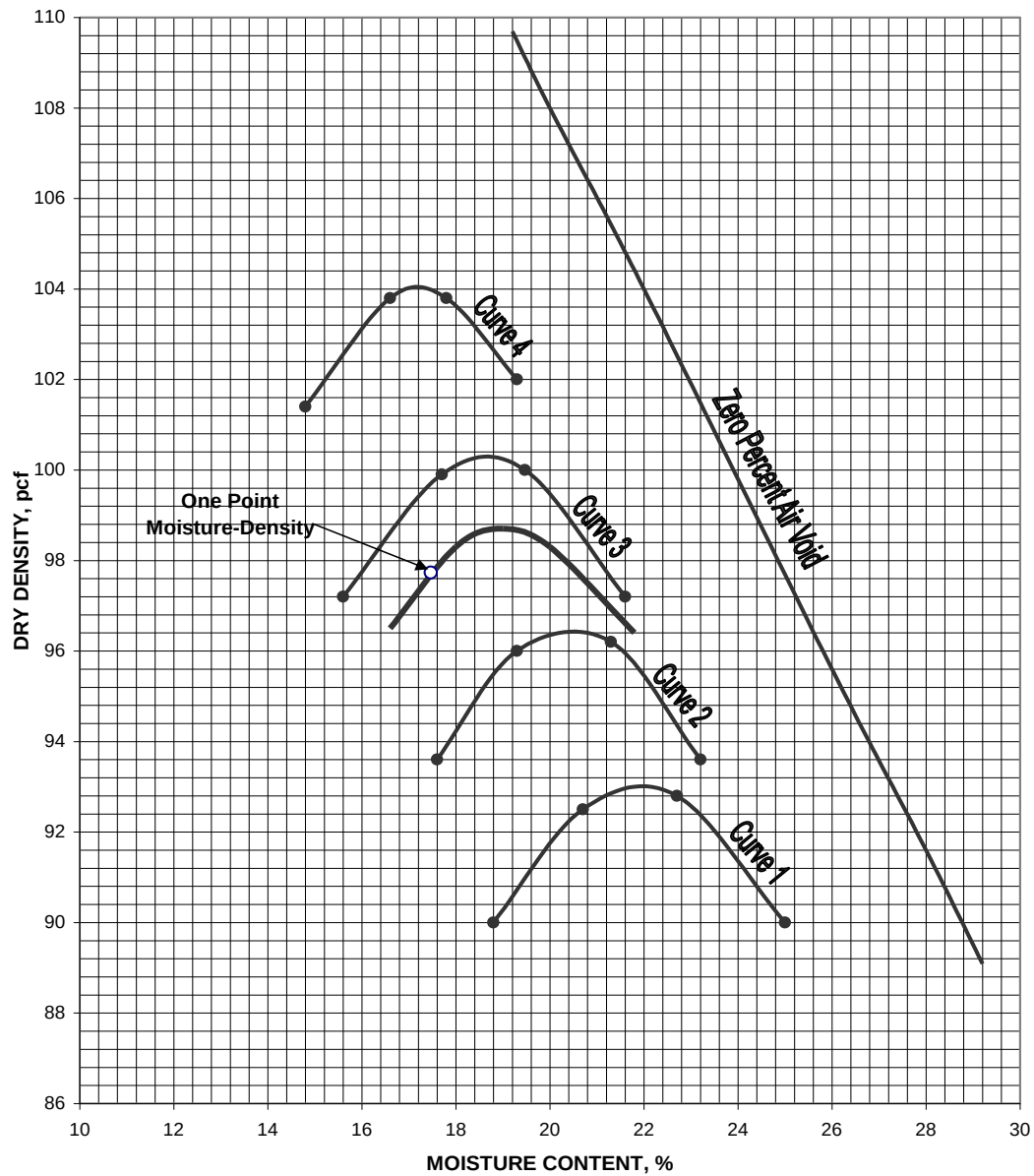


Figure 2—Family of Curves and One-Point Control (Example)

24. ARCHIVED VERSIONS

24.1 Archived versions are available.