Standard Test Method for Maximum Media Density for Dead Load Analysis of Vegetative (Green) Roof Systems[1]

This standard is issued under the fixed designation E2399/E2399M; 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 a procedure for determining the maximum media density for purposes of estimating the maximum dead load for green roof assemblies. The method also provides a measure of the moisture content, the air-filled porosity, and the water permeability measured at the maximum media density.

1.2 This procedure is suitable for green roof media that contain no more than 30 % organic material as measured using the loss on ignition, as described in Test Methods E177, Test Method C. The test specimen should be a bulk oven-dried sample prepared according to Test Methods E177, Test Method A.

1.3 The maximum media density and associated moisture content measured in this procedure applies to drained conditions near the saturation point.

1.4 The test method is intended to emulate vertical percolation rates for water in green roofs.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the 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 and health practices and to determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))

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

D2325 Test Method for Capillary-Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-Plate Apparatus (Withdrawn 2007)[3]

D2947 Test Method for Screen Analysis of Asbestos Fibers

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E631 Terminology of Building Constructions

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E2114 Terminology for Sustainability Relative to the Performance of Buildings

3. Terminology

3.1 *Definitions:*

3.1.1 For terms related to building construction, refer to Terminology E631.

3.1.2 For terms related to sustainability relative to the performance of buildings, refer to Terminology E2114.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air-filled porosity*—the air-filled porosity, also known as void ratio or non-capillary porosity, is a measure of the air volume remaining in a sample after it has been compacted to

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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.

the maximum media density and when the moisture content equals the maximum media water retention. In this method, the air-filled porosity does not include closed-cell particle porosity or porosity that is unavailable to be filled by water when the sample is immersed.

3.2.1.1 *Discussion*—This property has two important applications:

(*1*) It is an indicator of the viability of media to support plants when it is wet. Materials with low air-filled porosity may tend toward anoxic conditions when wet, and

(*2*) This is the volume available for water to fill after the maximum media water retention is satisfied. This volume of water may contribute to the live load of the green roof system.

3.2.2 *maximum media density*—the density of a mixed media material determined after it has been subjected to a specific amount of compaction and hydrated by immersion to simulate prolonged exposure to both foot traffic and rainfall.

3.2.2.1 *Discussion*—The maximum media density applies to drained conditions.

3.2.3 *maximum media water retention*—the quantity of water held in a media at the maximum media density, measured in volume percent.

3.2.3.1 *Discussion*—This is useful measure of the capacity of a media to hold water under drained conditions.

3.2.4 *saturation point*—the moisture content at which the soil tension in the mixed media is zero, but a free water surface has not developed.

3.2.4.1 *Discussion*—The saturation point represents the theoretical maximum moisture content that a material can contain in a drained state.

3.2.5 *water permeability*—the coefficient, which when multiplied by the hydraulic gradient will yield the apparent velocity with which water, at 68°F [20°C] will move through a cross-section of media.

3.2.5.1 *Discussion*—The conditions created in this method apply to freely-drained media where the free water surface is level with the upper surface of the media layer (such as, impending accumulation of water above the surface of the media).

4. Summary of Test Method

4.1 This test method involves compressing a moist sample of a media into a perforated mold using specified compaction developed using a Proctor hammer. The sample is subsequently immersed in a water bath for 24 hours to promote full hydration of the material. After allowing the sample to drain briefly, its density and moisture content are determined using standard gravimetric procedures. This procedure also includes methods for estimating: (*1*) the water permeability using a pseudo-constant head procedure, and (*2*) the air-filled porosity.

4.2 This test method involves measuring the density of the media after the sample has been allowed to drain for 2 h. This measurement is the maximum media density. The 2-h measurement is valuable to the green roof designer, since it is directly comparable to media densities determined using the most common international procedures for establishing green roof dead load values.

5. Significance and Use

5.1 This test method describes simple laboratory methods that provide reproducible measurements of critical media properties, and permit direct comparisons to be made between different media materials.

5.2 The density of mixed media materials will vary depending on the degree to which they are subjected to compaction and the length of time that the material is allowed to hydrate and subsequently drain. Most green roof media materials have a large capacity to absorb and retain moisture. Furthermore, moisture will drain gradually from the media following a hydration cycle. The maximum media density measured in this procedure approaches the density at the theoretical saturation point.

5.3 Existing methods for measuring the capillary-moisture relationship for soils (Test Method D2325) rely on sample preparation procedures (Test Methods D698) that are not consistent with the conditions associated with the placement of green roof media materials. This procedure is intended to provide a reproducible laboratory procedure for predicting the maximum media density, moisture content, air-filled porosity, and water permeability under conditions that more closely replicate field conditions on green roofs.

5.4 The value of this test method to the green roof designer is that it provides an objective measure of maximum probable media density (under drained conditions) for estimating structural loads. It also provides a method for estimating the lower limit for the water permeability of the in-place media. This latter value is important when considering drainage conditions in green roofs. Finally, the maximum media water retention has been shown to be a useful indicator of the moisture retention properties of green roof media.

6. Apparatus

6.1 *Apparatus*—contains the following:

6.1.1 Cylindrical stainless steel container: inside dimensions 6.5 in. [16.5 cm] high with a 6-in. [15.2 cm] inside diameter and 125 3⁄16-in. [4.75-mm] perforations in the bottom. The hole pattern is not significant, provided the holes are distributed evenly across the bottom of the cylinder. The tolerance for the cylinder dimensions shall be plus or minus 0.1 in. [2.5 mm].

6.1.2 U.S. #30 [0.6 mm] sieve disc, 5.8-in. [14.7-cm] diameter.

6.1.3 Steel disk plate, 5.8-in. [14.7-cm] diameter.

6.1.4 Proctor hammer: 10 lb [4.54 kg], with fall height of 18 in. [45.7 cm].

6.1.5 Scale, accurate to 0.0035 oz [0.1 g] and capacity of at least 11 lb [5 kg].

6.1.6 Drying dish.

6.1.7 Plastic water immersion bath with minimum immersion depth of 8 in. [20.3 cm].

6.1.8 Drain stand.

6.1.9 Filter fabric disk, 5.8-in. [14.7-cm] diameter, for covering the upper surface of the sample within the test cylinder.

6.1.10 4-in. [10-cm] concrete cubes (for use as weights).

6.1.11 Measuring scale, supported by a circular wire stand, with marks at 1.5 and 2.0 in. [3.8 and 5.0 cm].

6.1.12 Thermometer.

6.1.13 Calibrated 8 fluid oz [250 mL] volumetric flask with wide neck.

6.1.14 Hot plate.

6.1.15 Hot mitts.

7. Conditioning

7.1 The procedure requires a damp sample. If the sample is received in a dry condition, it must be moistened. The initial moisture content, M_i, of the sample shall be not less than 10 % and not more than 25 %, by weight.

7.2 Determine the as-received moisture content of the sample according to Test Method E691.

7.3 If the as-received moisture content of the sample is less than 10% moisture content by weight, adjust by adding water and incorporate by gently mixing. If the as-received moisture content of the sample is greater than 25 % moisture content by weight, allow the sample to air-dry until the moisture content is reduced to within the appropriate range. After moistening or air-drying, allow the sample to stand in an airtight container for 3 hours before continuing the procedure. Re-measure the percent moisture content (Test Method E691) to confirm that the appropriate moisture range has been achieved and record as M_i .

8. Procedure

8.1 *General:*

8.1.1 Place one of the sieve discs inside the cylinder to cover the perforations. Weigh the cylinder and disc together, and record. Fill the cylinder with the sample material to a height of 4.75 to 5.5 in. [12 to 14 cm]. The quantity of material added should be sufficient to produce a sample height of approximately 4 in. [10 cm] after being compressed.

8.1.2 Cover the contained material with the steel plate and compress with 6 blows of the Proctor hammer. Remove the steel plate. Determine the sample thickness, H_i, by measuring the height from the top of the upper cylinder edge to the upper surface of the sample and subtracting this from the inside cylinder height. If the sample surface is not level, four cross-wise measurements of the sample height should be taken and averaged. Compute the initial sample volume, V_i.

8.1.3 Determine the weight of the container together with the contained sample. Compute the initial sample weight, W_i, by subtracting the combined weight of the container and bottom sieve (see above).

8.1.4 The sample volume and the sample weight must be established initially, before the sample is immersed. Any change in sample volume during subsequent immersion should be reported with the test results. A determination of the sample density in the dry condition is undertaken after determination of the maximum media density capacity.

8.1.5 Cover the upper surface of the sample with the filter fabric disc. Cover the fabric with the sieve disc and place the stone weights on top in order to minimize swelling of the sample during immersion.

8.1.6 Place the cylinder in the immersion bath and slowly fill with water to a depth of 0.5 in. [1.25 cm] over the top of the sample. As required, fill to maintain the water level. Maintain the temperature of the bath at 68°F ± 5°F [20 ± 2.75°C].

8.1.7 Remove the cylinder after 24 hours of immersion. Place on the drain stand and allow to drain for 120 min. Wipe the outside of the container dry and remove the blocks and upper sieve disc. Do not remove the fabric. Weigh the cylinder with the contained sample.

8.1.8 Compute the sample weight, W_{120}, by subtracting the combined weight of the container and bottom sieve disc. Check the final sample thickness, H, and record changes from the initial height. This thickness will be used in the subsequent determination of water permeability and maximum media density. Compute the final sample volume, V, and record.

8.1.9 Return the cylinder to the drain stand. Place the measuring scale on the upper surface of the sample.

8.1.10 Using water from the bath, at a temperature of 68 ± 5°F [20 ± 2.75°C], fill the cylinder so that the water stands to a depth of 0.5 to 1 in. [1.25 to 2.50 cm] over the top of the sample. Add water continually to keep the water level approximately constant.

8.1.11 Begin the measurement as soon as a steady flow of water issues from the holes at the bottom of the cylinder. Fill the cylinder to a depth greater than the upper mark (2.0-in. [5.0-cm] mark). As the water level declines, note the time that at which the water level first reaches the 2.0-in. [5.0-cm] mark. Determine the elapsed time, T, in seconds, required for the water level to fall to the final water level (1.5-in. [3.8-cm] mark). Repeat 3 times and average the results. Record the temperature of the water that is collected from the bottom of the cylinder.

8.1.12 Place the sample in a drying dish of known weight and dry at 220° ≠ 5°F [104° ± 2.75°C] for four hours. Weigh the drying dish and sample. Continue drying until subsequent measurements made 15 min apart differ by 2 %, or less. Compute the weight of the dry sample, W_{dry}, by subtracting the weight of the dish.

8.1.13 Weigh clean dry volumetric flask, W_a.

8.1.14 Add 0.1 to 0.22 lb [50 to 100 g] of the conditioned sample to the flask and weigh. Record as W_s.

8.1.15 Fill the flask with approximately 5 fluid oz [150 mL] of distilled water, taking care to rinse sample particles into the suspension.

8.1.16 To remove entrapped air, place the flask on a hot plate and boil gently for 3 min. Agitate content, as necessary, to avoid foaming and sample loss. Remove the flask from the hot plate and cool to room temperature. Room temperature is 68°F [20°C], plus or minus 5°F [2.75°C].

8.1.17 Fill the flask to the 8 fluid oz [250 mL] calibration line with boiled distilled water at room temperature. Weigh the flask and contents. Record as W_{sw}.

8.1.18 Remove the content of the flask and rinse thoroughly. Fill the flask to the 8 fluid oz [250 mL] calibration line with distilled water at room temperature. Weigh the flask and contents. Records as W_w.

8.1.19 Conduct all tests in duplicate. If the results of two tests differ by more than 5 %, repeat a third time. Report all results.

9. Calculation of Results

9.1 *Initial Sample Volume:*

$$V_i = 0.0164 * H_i \quad (\text{in.} - \text{lb}) \tag{1}$$

$$V_i = 1.82 \times 10^{-7} * H_i \quad (\text{SI})$$

where:

V_i = initial volume, ft^3 $[m^3]$, and
Hi_i = initial sample thickness, in [cm].

9.2 *Final Sample Volume:*

$$V = 0.0164 * H \quad (\text{in.} - \text{lb}) \tag{2}$$

$$V = 1.82 \times 10^{-7} * H \quad (\text{SI})$$

where:

V = initial volume, ft^3 $[m^3]$, and
Hi = initial sample thickness, in [cm].

9.3 *Initial Media Density:*

$$D_i = W_i / V_i \tag{3}$$

where:

D_i = initial media density, lb/ft^3 $[kg/m^3]$,
W_i = initial sample weight, lb [kg], and
V_i = initial sample volume, ft^3 $[m^3]$.

9.4 *Maximum Media Density:*

$$MMD = W_{120} / V_i \tag{4}$$

where:

MMD = maximum media density, lb/ft^3 $[kg/m^3]$, and
W_{120} = Sample weight after draining for 120 min, lb [kg].

9.5 *Dry Media Density:*

$$D_{dry} = W_{dry} / V_i \tag{5}$$

where:

D_{dry} = dry media density, lb/ft^3 $[kg/m^3]$, and
W_{dry} = Sample weight after drying at 220°F [104°C], lb [kg].

9.6 *Maximum Media Water Retention*:

$$MMWR = 100 * (MMD - D_{dry}) / 62.4 \quad (\text{in.} - \text{lb}) \tag{6}$$

$$(MMWR = (MMD - D_{dry}) / 10) \quad (\text{SI})$$

where:

$MMWR$ = moisture content at the maximum media density [volume %].

9.7 *Water Permeability*:

$$K_{MMD} = 30 * H / (T * (1.75 + H)) \ (\text{in.} - \text{lb}) \tag{7}$$

$$K_{MMD} = 1.2 * H / (T * (4.4 + H)) \ (\text{SI})$$

where:

K_{MMD} = water permeability measured at the maximum media density, in./min [cm/s],
T = Elapsed time for the water level to fall by 0.5 in. [1.2 cm], s, and
H = height of the sample in the cylinder, measured after immersion, in. [cm].

9.8 *Particle Density:*

$$D_p = D_w * (S_w * (100 - M_i) / 100) / ((S_w * (100 - M_i) / 100) - (W_{sw} - W_w)) \tag{8}$$

where:

D_p = particle density, lb/ft^3 $[kg/m^3]$.
D_w = density of water at room temperature, lb/ft^3 $[kg/m^3]$,
S_w = sample weight at moisture content M_i,
W_{sw} = weight of flask plus sample and water, lb [kg],
W_w = weight of flask filled with water, lb [kg], and
M_i = as-received moisture content, weight %.

9.9 *Total Porosity:*

$$TP = 100 * (1 - (D_{dry} / D_p)) \tag{9}$$

where:

TP = total porosity, volume %.

9.10 *Air-Filled Porosity:*

$$AFP = TP - MMWR \tag{10}$$

where:

AFP = Air-filled porosity, volume %.

10. Report

10.1 The report shall contain the following information for each test. At a minimum, two tests shall be conducted. Additional tests are required if the results of the first two tests differ by more than 5 %.

10.1.1 As-received moisture, M_i, as adjusted according to 7.3.

10.1.2 Initial sample weight for each test, W_i,

10.1.3 Initial volume for each test, V_i,

10.1.4 Initial sample height for each test, H_i,

10.1.5 Final sample height for each test, H, after immersion for 24 h. Indicate percentage change, if any,

10.1.6 Sample weight after draining for 120 min for each test, W_{120},

10.1.7 Initial media density measurements and average for the duplicate tests, D_i,

10.1.8 Maximum media density measurements and average for the duplicate tests, *MMD*,

10.1.9 Moisture content at maximum media density measurements and average for the duplicate tests, *MMWR*,

10.1.10 Water permeability measurements and average for the duplicate tests, *KMMD*,

10.1.11 Air-filled porosity measurements and average for the duplicate tests, *AFP*, and

10.1.12 Dry media density measurements and average for the duplicate tests, D_{dry}.

11. Precision and Bias

11.1 The precision of this test method is based on an interlaboratory study of this test method, conducted in 2009. A single laboratory tested a total of 254 different materials in duplicate. Every "test result" represents an individual determination. Practice E691 was followed for the analysis of the data.[4]

11.1.1 *Repeatability Limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "r" value for that material; "r" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

11.1.1.1 Repeatability limits are listed in Table 1.

11.1.2 *Reproducibility Limit (R)*—Two test results shall be judged not equivalent if they differ by more than the "R" value for that material; "R" is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

11.1.2.1 Reproducibility limits could not be determined from this single laboratory study.

11.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

11.1.4 Any judgment in accordance with statements 11.1.1 would have an approximate 95 % probability of being correct.

11.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

11.3 The precision statement was determined through statistical examination of 3048 results, produced by a single laboratory, reporting the results of six measured parameters, on multiple materials, in duplicate.

TABLE 1 Precision Statistics

Parameter	Average, $\bar{X}$	Standard Deviation,[A] S_r	RSD[A]	Repeatability Limit, r
Bulk Density (dry weight basis) g/cm^3	0.83784	0.01023	1.26	0.029
Bulk Density (at saturation) g/cm^3	1.26826	0.01616	1.34	0.045
Water holding capacity (% volume)	44.37641	0.77690	1.90	2.175
Particle density	2.0082	0.03345	1.69	0.094
Total porosity from particle density (% volume)	58.29242	0.51287	0.93	1.436
K factor (cm/sec)	0.12824	0.01170	14.57	0.033

[A] These numbers represent the average of the standard deviations on 254 samples run in duplicate (in a single laboratory) for the tests specified.

12. Keywords

12.1 air-filled porosity; green roof; green roof system; maximum density; media; non-capillary porosity; vegetative roofing system; water permeability; water retention

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E60-1000.