INTERNATIONAL

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Standard Practice for
Measurement of the Kinetic Energy of Simulated Rainfall[1]

This standard is issued under the fixed designation D8326; 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 practice is used to measure the kinetic energy of rainfall simulators used by laboratories to evaluate soil erosion. The kinetic energy of raindrops is an important factor that should be considered when conducting soil erosion studies. Using the data collected from determining the raindrop size, this practice provides a method to uniformly calculate the kinetic energy which can be used to compare results from different laboratories.

1.2 Many types of Erosion Control Products (ECPs) are evaluated for their ability to reduce soil erosion in laboratory and field settings using rainfall simulators. Rainfall simulators are used with test plots to simulate a specific condition that is or may be expected in the field. Rainfall simulators typically use drop emitters, sprinklers, or nozzles to create the raindrops. Each device produces different drops and since the rainfall simulators can be configured to produce different raindrop sizes and fall heights, the kinetic energy will be different. Therefore, the kinetic energy must be calculated for a given set of conditions in order to properly understand the impact of erosion for bare soil and the ECP.

1.3 The upper limit of the size of a raindrop is generally accepted to be 7 mm. While it is possible to get a raindrop size between 6 and 7 mm occasionally, it is not common to get raindrop sizes above 6 mm.

1.4 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

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

1.5.1 The procedures used to specify how data are collected/recorded or calculated in the standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.6 This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

1.7 *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.*

1.8 *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

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D6026 Practice for Using Significant Digits in Geotechnical Data

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.25 on Erosion and Sediment Control Technology.

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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.

D8151 Practice for Obtaining Rainfall Runoff from Unvegetated Rolled and Hydraulic Erosion Control Products (RECPs and HECPs) for Acute Ecotoxicity Testing

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

4. Summary of Practice

4.1 Before the kinetic energy can be measured, the raindrop size and drop height must be determined (Note 1). The fall velocities are also determined based on the drop height and the diameters as shown in Table A1.1. The fall velocities are either interpolated or selected directly from the table and then the raindrop diameter versus fall velocity is graphed and fitted with a third degree (cubic) polynomial regression trend line to obtain the regression equation. The constant values from the regression equation are used to calculate the ground velocities for each of the average raindrop diameters as measured. Once the ground velocity is determined, the various kinetic energy values are calculated, including the kinetic energy of the simulated event.

NOTE 1—Subcommittee D18.25 is currently developing a standard method for determining the raindrop size independent of any other type of testing. Until that standard is approved, Practice D8151 provides the information on how to obtain the raindrop size.

5. Significance and Use

5.1 When a raindrop impacts the surface of a soil, it expends its energy and begins the impact-induced soil erosion process. This kinetic energy of the raindrop is one factor influencing soil erosion. This practice provides a method to quantify the kinetic energy produced by rainfall simulators.

5.2 Soil erosion is a concern that affects many industries. The highway and road construction industry is particularly interested in slope protection. There are many ECP manufacturers that rely on testing of their products using rainfall simulators to meet certain specifications set forth by different agencies.

5.3 Laboratories that offer testing of ECPs use rainfall simulators. Many laboratories are able to adjust their rainfall simulators, the drop height of the raindrops, and even the slopes of the test plots they use to model expected, anticipated, or actual field conditions. The kinetic energy associated with the specific configuration of the simulator should be measured.

5.4 Knowing the kinetic energy for the given simulator configuration will provide a way to set minimum and upper limit values so that comparisons between laboratories can be made as well as having a way to account for the differences between the laboratories. If there are minimum and upper limit values and the raindrop size is in the same range between laboratories, the kinetic energy between the laboratories should be similar. Once the kinetic energy is established for a given rainfall simulator configuration according to a specific standard, comparisons of the results for those specific standards can be made.

NOTE 2—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. Apparatus

6.1 *Raindrop Size*—See Practice D8151 for the apparatus needed to measure the raindrop size.

6.2 *Measuring Device*—A surveyor's rod, tape measure, or similar with enough length and divisions of 5 mm or better to measure the rainfall distance (drop height) and the test plot width (cross slope) and length (down slope).

7. Procedure

7.1 *Raindrop Size*—Determine and record the range of raindrop sizes to the nearest 0.001 mm of the rainfall simulator configuration used following the procedure in 8.4 of Practice D8151.

7.2 *Drop Height*—Determine and record the drop height of the raindrops to the nearest 0.1 m of the rainfall simulator configuration used. For inclined structures, the drop height is taken to be from the rainfall simulator to the lowest point of the incline structure.

7.3 *Test Plot Dimensions*—Determine and record the width (cross slope) and length (downslope) of the test plot to the nearest 0.1 m. Determine and record the area of the test plot, A_{tp}, to the nearest 0.1 m^2.

7.4 *Cake Pan Dimensions*—Determine and record the width and length of each cake pan used to capture the raindrops to the nearest 5 mm. Determine and record the area of each cake pan, A_{cp}, to the nearest 0.001 m^2. Determine and record the total area of the cake pans, A_{pan}, to the nearest 0.001 m^2.

7.5 *Fall Velocity*—Determine and record the fall velocities to the nearest 0.01 m/s based on the drop height using raindrop diameters of 1.25, 2, 3, 4, 5, and 6 mm and Table A1.1 (See Annex A1). Graph the raindrop size (abscissa) versus the fall velocities (ordinate) and fit a third degree (cubic) polynomial trend line to the data and record the regression equation. Table 1 provides the cubic regression data for commonly used drop

TABLE 1 Cubic Regression Data for Commonly Used Drop Heights

Drop Height (m)[A]	a	b	c	d
2.4	0.0282	-0.4071	2.0914	2.3807
3.4	0.0324	-0.4794	2.5539	2.1783
3.7	0.0320	-0.4803	2.6169	2.1715
4.0	0.0313	-0.4796	2.6731	2.1715
4.3	0.0324	-0.5007	2.8028	2.0595
4.6	0.0343	-0.5310	2.9686	1.9051
6.1	0.0397	-0.6330	3.5798	1.3095

[A] The drop height in meters corresponds to the drop height in feet as follows: 2.4 m = 8 ft; 3.4 m = 11 ft; 3.7 m = 12 ft; 4.0 m = 13 ft; 4.3 m = 14 ft, 4.6 m = 15; and 6.1 m = 20 ft. For drop heights greater than 6.1 m, the velocity is considered terminal.

heights. For drop heights not listed in Table 1, refer to Annex A1 for instructions on obtaining the cubic regression data.

8. Calculation[3]

8.1 Calculate the ground velocity, *GV*, for each average raindrop, D_r, using the values from the cubic regression equation based on the drop height to the nearest 0.01 m/s.

$$GV_i = aD_{ri}^3 + bD_{ri}^2 + cD_{ri} + d \quad (1)$$

where:

GV_i = ground velocity of each average raindrop, nearest 0.01 m/s,
D_{ri} = diameter of average raindrop, nearest 0.001 mm, and
i = subscript indicating the sieve size.

8.2 Calculate the kinetic energy, *KE*, for each of the average raindrop, D_r, using the following equation to the nearest 0.0001 J.

$$KE_i = 0.5\left(\frac{M_{pi}}{1000} \times GV_i^2\right) \quad (2)$$

where:

KE_i = ground velocity of each average raindrop, nearest 0.01 m/s and
M_{pi} = mass of pellets retained on each sieve, nearest 0.0001 g.

8.3 Calculate the kinetic energy per area, KE_a, for each of the average raindrop sizes, D_r, using the following equation to the nearest 0.0001 J per m^2.

$$KE_{ai} = \frac{KE_i}{A_{pan}} \quad (3)$$

where:

KE_{ai} = kinetic energy per area of each average raindrop, nearest 0.0001 J per m^2 and
A_{pan} = total area of the cake pans (Acp_1 +Acp_2 +Acp_3), nearest 0.001 m^2.

8.4 Calculate the total kinetic energy per area, KE_t to the nearest 0.0001 J per m^2:

$$KE_t = \Sigma KE_{ai} \quad (4)$$

8.5 Calculate the kinetic energy of the simulated event, KE_{se}, using the following equation to the nearest 0.0001 J.

$$KE_{se} = KE_t \times T \times A_{tp} \quad (5)$$

where:

KE_{se} = kinetic energy of the simulated event, nearest 0.0001 J,
T = total test time, nearest 1 s, and
A_{tp} = area of the test plot, nearest 0.1 m^2.

8.6 *Optional*—If desired, calculate the percent kinetic energy per average raindrop using the following equation to the nearest 0.1 %.

$$\%KE = \frac{KE_a}{KE_t} \times 100 \quad (6)$$

9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.5 and in Practice D6026.

9.2 Record as a minimum the following general information (data):

9.2.1 Raindrop diameter and the associated data collected to determine the diameter as stated and as applicable in Practice D8151 report section.

9.2.2 Test number, if any, testing dates and the initials of the person(s) who performed the testing and the calculations.

9.2.3 Drop height

9.2.4 Test plot dimensions and area.

9.2.5 Cake pan dimensions and area for each pan and the total area.

9.2.6 Fall velocities; including the associated data needed to calculate the fall velocities and the cubic regression values.

9.2.7 If using a drop height not included in Table 1, graph of the fall velocity verses drop height.

9.2.8 Ground velocity.

9.2.9 The following kinetic energy values: kinetic energy for each average raindrop (*KE*), kinetic energy per area (KE_a), total kinetic energy per area (KE_t), kinetic energy of the simulated event (KE_{se}). If calculated (optional), the percent kinetic energy per average raindrop.

10. Keywords

10.1 erosion control; kinetic energy; raindrop; raindrop size; rainfall simulator; simulated rainfall

[3] For an excel file to enter your data please navigate to the D18 public page (https://www.astm.org/COMMITTEE/D18.htm) (hard copy users should go to www.astm.org, type D18 technical committee in the search bar and then navigate to the page) and under Additional Information click on the link titled D8326 Supplemental Spreadsheet.

ANNEX

A1. FALL VELOCITY VERSUS DROP HEIGHT EQUATION DEVELOPMENT

(Mandatory Information)

A1.1 The drop height of the raindrops is an important factor when calculating the kinetic energy. This section provides the information for determining the cubic regression equations used in the calculation of the ground velocity. The equations are derived from the data collected and reported by Laws in 1941. The curves from the Laws paper are assumed to be representative. The data in Table 1 presents the most common drop heights for simulators being used; however, there may be instances where a common drop height is not used. In these cases, the fall velocity versus drop height must be determined and graphed to produce the cubic regression needed to calculate the ground velocity.

A1.2 Measure the drop height as stated in 7.2. Use Table A1.1 to determine the fall velocity for the following raindrop sizes: 1.25, 2, 3, 4, 5, and 6 mm. When the drop height is not one of the increments shown in Table A1.1, the fall velocity must be interpolated. Use Eq A1.1 to interpolate the fall velocity.

A1.3 After the fall velocities have been calculated for the range of raindrop sizes, create a graph of the raindrop size (abscissa) versus the fall velocities (ordinate). Fit a third degree (cubic) polynomial trend line to the data and record the regression equation.

A1.4 *Fall Velocity Interpolation*—Use the following equation and the values in Table A1.1 to interpolate the fall velocity when the drop height is not shown in Table A1.1. Select the upper and lower values that bracket the actual drop height.

$$FV = UV - \left[\frac{((UV - LV) \times (UFH - DH))}{(UFH - LFH)} \right] \quad (A1.1)$$

where:

FV = interpolated fall velocity at drop height, nearest 0.01 m/s,
UV = upper velocity from Table A1.1, nearest 0.01 m/s,
LV = lower velocity from Table A1.1, nearest 0.01 m/s,
UFH = upper fall height from Table A1.1, 2 significant digits, m,
DH = drop height, 2 significant digits, m, and
LFH = lower fall height from Table A1.1, 2 significant digits, m.

A1.4.1 *Example Interpolation Calculation*—This example uses a raindrop size of 1.50 mm from a rainfall simulator with a drop height of 4.9 m. From Table A1.1, the upper velocity corresponding to 5.0 m is 5.39 m/s, lower velocity corresponding to 4.0 m is 5.25 m/s, upper fall height is 5.0 m, and lower fall height is 4.0 m. Therefore, the interpolated fall velocity is calculated to be 5.38 m/s as shown below:

$$5.38 \ m/s = FV = 5.39 - \left[\frac{((5.39 - 5.25) \times (5.0 - 4.9))}{(5.0 - 4.0)} \right] \quad (A1.2)$$

A1.5 *Example Data*—Table A1.2 provides an example of tabulated data using a drop height of 4.3 m for raindrop sizes of 1.25, 2, 3, 4, 5, and 6 mm. From the graph in Fig. A1.1, the constants used in the ground velocity equation are: a = 0.0324; b = -0.5007; c = 2.8028; d = 2.0595

TABLE A1.2 Data Example

Variables	DH: 4.3 m		UFH: 5.0 m		LFH: 4.0	
Diameter (mm):	1.25	2.0	3.0	4.0	5.0	6.0
UV (m/s):	4.85	6.15	7.08	7.65	8.00	8.20
LV (m/s):	4.80	5.91	6.68	7.17	7.50	7.69
FV (m/s):	4.82	5.98	6.80	7.31	7.65	7.84

TABLE A1.1 Raindrop Fall Velocity vs. Drop Height (Laws 1941)[4]

Raindrop Diameter (mm)	Fall Velocity Values (m/s), Drop Height (m): 0.5	0.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	8.0	20
1.25	2.65	3.15	3.52	3.97	4.21	4.43	4.56	4.80	4.85	4.85	4.85	4.85
1.50	2.76	3.26	3.64	4.18	4.50	4.82	4.99	5.25	5.39	5.47	5.51	5.51
1.75	2.84	3.34	3.74	4.34	4.73	5.10	5.31	5.64	5.80	5.92	6.08	6.08
2.00	2.89	3.40	3.83	4.47	4.92	5.29	5.55	5.91	6.15	6.30	6.53	6.58
2.25	2.93	3.45	3.91	4.57	5.07	5.44	5.74	6.14	6.42	6.63	6.90	7.02
2.50	2.96	3.50	3.98	4.65	5.19	5.57	5.89	6.34	6.67	6.92	7.22	7.41
2.75	2.98	3.54	4.04	4.72	5.28	5.69	6.02	6.52	6.89	7.16	7.50	7.76
3.00	3.00	3.58	4.09	4.79	5.37	5.80	6.14	6.68	7.08	7.37	7.75	8.06
3.25	3.02	3.61	4.12	4.85	5.45	5.89	6.25	6.82	7.25	7.56	7.96	8.31
3.50	3.03	3.64	4.15	4.90	5.52	5.98	6.35	6.95	7.40	7.73	8.15	8.52
3.75	3.04	3.66	4.18	4.95	5.58	6.06	6.44	7.07	7.53	7.88	8.31	8.71
4.00	3.05	3.67	4.21	4.98	5.63	6.12	6.52	7.17	7.65	8.00	8.46	8.86
4.50	3.07	3.70	4.24	5.05	5.72	6.24	6.66	7.36	7.85	8.21	8.70	9.10
5.00	3.09	3.72	4.27	5.11	5.79	6.33	6.77	7.50	8.00	8.36	8.86	9.25
5.50	3.10	3.74	4.29	5.16	5.85	6.40	6.86	7.61	8.11	8.47	8.97	9.30
6.00	3.10	3.75	4.31	5.20	5.90	6.46	6.94	7.69	8.20	8.55	9.01	9.30