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## Standard Method of Test for

# Bulk Density (“Unit Weight”) and Voids in Aggregate

AASHTO Designation: T 19M/T 19-14

ASTM Designation: C29/C29M-09



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## 1. SCOPE

1.1. This test method covers the determination of bulk density (“unit weight”) of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. This test method is applicable to aggregates not exceeding 125 mm [5 in.] in nominal maximum size.

**Note 1**—Unit weight is the traditional terminology used to describe the property determined by this test method, which is weight per unit volume (more correctly, mass per unit volume or density).

1.2. The values stated in either inch-pound units or acceptable metric units are to be regarded separately as standard, as appropriate for a specification with which this test method is used. An exception is with regard to sieve sizes and nominal size of aggregate, in which the metric values are the standard as stated in ASTM E11. Within the text, inch-pound units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other, without combining values in any way.

1.3. *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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## 2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*

- M 92, Wire-Cloth Sieves for Testing Purposes
- M 231, Weighing Devices Used in the Testing of Materials
- T 2, Sampling of Aggregates
- T 84, Specific Gravity and Absorption of Fine Aggregate
- T 85, Specific Gravity and Absorption of Coarse Aggregate
- T 121M/T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 248, Reducing Samples of Aggregate to Testing Size

2.2. *ASTM Standards:*

- C29/C29M, Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate
- C125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

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- D123, Standard Terminology Relating to Textiles
- E11, Standard Specification for Woven Wire Test Sieve Cloth and Test Sieves

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### 3. TERMINOLOGY

- 3.1. *definitions*—definitions are in accordance with ASTM C125 unless otherwise indicated.
- 3.1.1. *bulk density, n*—of aggregate, the mass of a unit volume of bulk aggregate material, in which the volume includes the volume of the individual particles and the volume of the voids between the particles. Expressed in  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ ).
- 3.1.1.1. *discussion*—units of mass are the kilogram (kg), the pound (lb), or units derived from these. Mass may also be visualized as equivalent to inertia, or the resistance offered by a body to change of motion (acceleration). Masses are compared by weighing the bodies, which amounts to comparing the forces of gravitation acting on them. ASTM D123.
- 3.1.2. *unit weight, n*—weight (mass) per unit volume. (Deprecated term—use preferred term “bulk density.”)
- 3.1.2.1. *discussion*—the term “weight” means the force of gravity acting on the mass.
- 3.1.3. *weight, n*—the force exerted on a body by gravity. (See also mass.)
- 3.1.3.1. *discussion*—weight is equal to the mass of the body multiplied by the acceleration due to gravity. Weight may be expressed in absolute units (newtons, poundals) or in gravitational units (kgf, lbf), for example: on the surface of the earth, a body with a mass of 1 kg has a weight of 1 kgf (approximately 9.81 N), or a body with a mass of 1 lb has a weight of 1 lbf (approximately 4.45 N or 32.2 poundals). Because weight is equal to mass times the acceleration due to gravity, the weight of a body will vary with the location where the weight is determined, while the mass of the body remains constant. On the surface of the earth, the force of gravity imparts to a body that is free to fall an acceleration of approximately  $9.81 \text{ m/s}^2$  [ $32.2 \text{ ft/s}^2$ ] (ASTM D123).
- 3.2. *Descriptions of Terms:*
- 3.2.1. *voids, n*—in unit volume of aggregate, the space between particles in an aggregate mass not occupied by solid mineral matter.
- 3.2.1.1. *discussion*—voids within particles, either permeable or impermeable, are not included in voids as determined by T 19M/T 19.

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### 4. SIGNIFICANCE AND USE

- 4.1. This test method is often used to determine bulk density values that are necessary for use for many methods of selecting proportions for concrete mixtures.
- 4.2. The bulk density also may be used for determining mass/volume relationships for conversions in purchase agreements. However, the relationship between degree of compaction of aggregates in a hauling unit or stockpile and that achieved in this method is unknown. Further, aggregates in hauling units and stockpiles usually contain absorbed and surface moisture (the latter affecting bulking), while this method determines the bulk density on a dry basis.
- 4.3. A procedure is included for computing the percentage of voids between the aggregate particles based on the bulk density determined by this method.

## 5. APPARATUS

- 5.1. *Balance*—The balance shall have sufficient capacity, be readable to 0.1 percent of the sample mass, or better, and conform to the requirements of M 231.
- 5.2. *Tamping Rod*—A round, straight steel rod, 16 mm [ $\frac{5}{8}$  in.] in diameter and approximately 600 mm [24 in.] in length, having one end rounded to a hemispherical tip of the same diameter as the rod.
- 5.3. *Measure*—A cylindrical metal measure, preferably provided with handles. It shall be watertight, with the top and bottom true and even, and sufficiently rigid to retain its form under rough usage. The measure should have a height approximately equal to the diameter, but in no case shall the height be less than 80 percent nor more than 150 percent of the diameter. The capacity of the measure shall conform to the limits in Table 1 for the aggregate size to be tested. The thickness of metal in the measure shall be as described in Table 2. The top rim shall be smooth and plane within 0.25 mm [0.01 in.] and shall be parallel to the bottom within 0.5 degrees (Note 2). The interior wall of the measure shall be a smooth and continuous surface.

**Table 1**—Capacity of Measures

Nominal Maximum Size of Aggregate		Capacity of Measure <sup>a</sup>	
mm	in.	L (m <sup>3</sup> )	ft <sup>3</sup>
12.5	$\frac{1}{2}$	2.8 (0.0028)	$\frac{1}{10}$
25.0	1	9.3 (0.0093)	$\frac{1}{3}$
37.5	$1\frac{1}{2}$	14 (0.014)	$\frac{1}{2}$
75	3	28 (0.028)	1
100	4	70 (0.070)	$2\frac{1}{2}$
125	5	100 (0.100)	$3\frac{1}{2}$

<sup>a</sup> The indicated size of measure shall be used to test aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 percent of the nominal volume listed.

**Note 2**—The top rim is satisfactorily plane if a 0.25 mm [0.01 in.] feeler gauge cannot be inserted between the rim and a piece of 6 mm [ $\frac{1}{4}$  in.] or thicker plate glass laid over the measure. The top and bottom are satisfactorily parallel if the slope between pieces of plate glass in contact with the top and bottom does not exceed 0.87 percent in any direction.

- 5.3.1. If the measure also is to be used for testing for bulk density of freshly mixed concrete according to T 121M/T 121, the measure shall be made of steel or other suitable metal not readily subject to attack by cement. Reactive materials such as aluminum alloys are permitted, where as a consequence of an initial reaction, a surface film is formed that protects the metal against further corrosion.
- 5.3.2. Measures larger than nominal 28-L [1-ft<sup>3</sup>] capacity shall be made of steel for rigidity, or the minimum thicknesses of metal listed in Table 2 should be suitably increased.

**Table 2**—Requirements for Measures

Capacity of Measure	Thickness of Metal, Min		
	Bottom	Upper 1 $\frac{1}{2}$ in. or 38 mm of Wall <sup>a</sup>	Remainder of Wall
Less than 11 L	5.0 mm	2.5 mm	2.5 mm
11 to 42 L, incl.	5.0 mm	5.0 mm	3.0 mm
Over 42 to 80 L, incl.	10.0 mm	6.4 mm	3.8 mm
Over 80 to 133 L, incl.	13.0 mm	7.6 mm	5.0 mm
Less than 0.4 ft <sup>3</sup>	0.20 in.	0.10 in.	0.10 in.
0.4 ft <sup>3</sup> to 1.5 ft <sup>3</sup> , incl.	0.20 in.	0.20 in.	0.12 in.
Over 1.5 to 2.8 ft <sup>3</sup> , incl.	0.40 in.	0.25 in.	0.15 in.
Over 2.8 to 4.0 ft <sup>3</sup> , incl.	0.50 in.	0.30 in.	0.20 in.

<sup>a</sup> The added thickness in the upper portion of the wall may be obtained by placing a reinforcing band around the top of the measure.

5.4. *Shovel or Scoop*—A shovel or scoop of convenient size for filling the measure with aggregate.

5.5. *Calibration Equipment*

5.5.1. *Plate Glass*—A piece of plate glass, at least 6 mm [ $\frac{1}{4}$  in.] thick and at least 25 mm [1 in.] larger than the diameter of the measure to be calibrated.

5.5.2. *Grease*—A supply of water insoluble grease.

**Note 3**—Petroleum jelly, vacuum grease, water pump grease, or chassis grease are examples of suitable material used to form a seal between the glass plate and measure.

5.5.3. *Thermometer*—A thermometer having a range of at least 10 to 32°C [50 to 90°F] and that is readable to at least 0.5°C [1°F].

5.5.4. *Balance*—A balance as described in Section 5.1.

## 6. SAMPLING

6.1. Obtain the sample in accordance with T 2, and reduce to test sample size in accordance with T 248.

## 7. SAMPLE

7.1. The size of sample shall be approximately 125 to 200 percent of the quantity required to fill the measure and shall be handled in a manner to avoid segregation. Dry the sample of aggregate to constant mass, preferably in an oven at 110 ± 5°C [230 ± 9°F].

## 8. CALIBRATION OF MEASURE

8.1. Measures shall be recalibrated at least once a year or whenever there is reason to question the accuracy of the calibration.

8.2. Place a thin layer of grease on the rim of the measure to prevent leakage of water from the measure.

8.3. Determine the mass of the plate glass and measure to the nearest 0.05 kg [0.1 lb].

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- 8.4. Fill the measure with water that is at room temperature and cover with the plate glass in such a way as to eliminate bubbles and excess water. Remove any water that may have overflowed onto the measure or plate glass.
- 8.5. Determine the mass of the water, plate glass, and measure to the nearest 0.05 kg [0.1 lb].
- 8.6. Measure the temperature of the water to the nearest 0.5°C [1°F] and determine its density from Table 3, interpolating if necessary.

**Table 3**—Density of Water

Temperature		kg/m <sup>3</sup>	lb/ft <sup>3</sup>
°C	°F		
15.6	60	999.01	62.366
18.3	65	998.54	62.336
21.1	70	997.97	62.301
(23.0)	(73.4)	(997.54)	(62.274)
23.9	75	997.32	62.261
26.7	80	996.59	62.216
29.4	85	995.83	62.166

- 8.7. Calculate the volume,  $V$ , of the measure. Alternatively, calculate the factor,  $F$ , for the measure.
- $$V = (B - C)/D \quad (1)$$
- $$F = D/(B - C) \quad (2)$$

where:

- $V$  = volume of the measure, m<sup>3</sup> (ft<sup>3</sup>);
- $B$  = mass of the water, plate glass, and measure, kg (lb);
- $C$  = mass of the plate glass and measure, kg (lb);
- $D$  = density of the water for the measured kg/m<sup>3</sup> (lb/ft<sup>3</sup>); and
- $F$  = factor for the measure, 1/m<sup>3</sup> (1/ft<sup>3</sup>).

**Note 4**—For the calculation of bulk density, the volume of the measure in acceptable metric units should be expressed in cubic meters, or the factor as 1/m<sup>3</sup>. However, for convenience, the size of the measure may be expressed in liters (equal to m<sup>3</sup>/1000).

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## 9. SELECTION OF PROCEDURE

- 9.1. The shoveling procedure for loose bulk density shall be used only when specifically stipulated. Otherwise, the compact bulk density shall be determined by the rodding procedure for aggregates having a nominal maximum size of 37.5 mm [1½ in.] or less, or by the jiggling procedure for aggregates having a nominal maximum size greater than 37.5 mm [1½ in.] and not exceeding 125 mm [5 in.].

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## 10. RODDING PROCEDURE

- 10.1. Fill the measure one-third full and level the surface with the fingers. Rod the layer of aggregate with 25 strokes of the tamping rod evenly distributed over the surface. Fill the measure two-thirds full and again level and rod as above. Finally, fill the measure to overflowing and rod again in the manner previously mentioned. Level the surface of the aggregate with the fingers or a straightedge

in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

- 10.2. In rodding the first layer, do not allow the rod to strike the bottom of the measure forcibly. In rodding the second and third layers, use vigorous effort, but not more force than to cause the tamping rod to penetrate to the previous layer of aggregate.

**Note 5**—In rodding the larger sizes of coarse aggregate, it may not be possible to penetrate the layer being consolidated, especially with angular aggregates. The intent of the procedure will be accomplished if vigorous effort is used.

- 10.3. Determine the mass of the measure plus contents, and the mass of the measure alone and record the values to the nearest 0.05 kg [0.1 lb].

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## 11. JIGGING PROCEDURE

- 11.1. Fill the measure in three approximately equal layers as described in Section 10.1, compacting each layer by placing the measure on a firm base, such as a cement-concrete floor, raising the opposite sides alternately about 50 mm [2 in.], and allowing the measure to drop in such a manner as to hit with a sharp, slapping blow. The aggregate particles, by this procedure, will arrange themselves in a densely compacted condition. Compact each layer by dropping the measure 50 times in the manner described, 25 times on each side. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

- 11.2. Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.05 kg [0.1 lb].

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## 12. SHOVELING PROCEDURE

- 12.1. Fill the measure to overflowing by means of a shovel or scoop, discharging the aggregate from a height not to exceed 50 mm [2 in.] above the top of the measure. Exercise care to prevent, so far as possible, segregation of the particle sizes of which the sample is composed. Level the surface of the aggregate with the fingers or a straightedge in such a way that any slight projections of the larger pieces of the coarse aggregate approximately balance the larger voids in the surface below the top of the measure.

- 12.2. Determine the mass of the measure plus contents, and the mass of the measure alone, and record the values to the nearest 0.05 kg [0.1 lb].

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## 13. CALCULATION OF RESULTS

- 13.1. *Bulk Density*—Calculate the bulk density for the rodding, jiggling, or shoveling procedure as follows:

$$M = (G - T) / V \quad (3)$$

or,

$$M = (G - T) \times F \quad (4)$$

where:

- $M$  = bulk density of aggregate,  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ );  
 $G$  = mass of aggregate plus the measure, kg (lb);  
 $T$  = mass of the measure, kg (lb);  
 $V$  = volume of measure,  $\text{m}^3$  ( $\text{ft}^3$ ); and  
 $F$  = factor for measure,  $\text{m}^{-3}$  ( $\text{ft}^{-3}$ ).

- 13.1.1. The bulk density determined by this method is for aggregate in an oven-dry condition. If the bulk density in terms of saturated surface-dry (SSD) condition is desired, use the exact procedure in this method, and then calculate the SSD bulk density by the following formula:

$$M_{SSD} = M [1 + (A/100)] \quad (5)$$

where:

- $M_{SSD}$  = bulk density in SSD condition,  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ ); and  
 $A$  = absorption, percent, determined in accordance with T 84 or T 85.

- 13.2. *Void Content*—Calculate the void content in the aggregate using the bulk density determined by either the rodding, jiggling, or shoveling procedure, as follows:

$$\text{voids \%} = \frac{100[(S \times W) - M]}{S \times W} \quad (6)$$

where:

- $M$  = bulk density of aggregate,  $\text{kg/m}^3$  ( $\text{lb/ft}^3$ );  
 $S$  = bulk specific gravity (dry basis) as determined in accordance with T 84 or T 85; and  
 $W$  = density of water,  $998 \text{ kg/m}^3$  [ $62.3 \text{ lb/ft}^3$ ].

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## 14. REPORT

- 14.1. Report the results for bulk density to the nearest  $10 \text{ kg/m}^3$  [ $1 \text{ lb/ft}^3$ ] as follows:

- 14.1.1. Bulk density by rodding,  
 14.1.2. Bulk density by jiggling, or  
 14.1.3. Loose bulk density.

- 14.2. Report the results for void content to the nearest one percent as follows:

- 14.2.1. Voids in aggregate compacted by rodding, percent,  
 14.2.2. Voids in aggregate compacted by jiggling, percent, or  
 14.2.3. Voids in loose aggregate, percent.

- 14.3. Indicate the procedure used.

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## 15. PRECISION AND BIAS

- 15.1. The following estimates of precision for this method are based on results from the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program, with testing conducted by this method and ASTM C29/C29M. There are no significant differences between the two

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methods. The data are based on the analyses of more than 100 paired test results from 40 to 100 laboratories.

15.2. *Coarse Aggregate (Bulk Density):*

15.2.1. *Single-Operator Precision*—The single-operator standard deviation has been found to be  $14 \text{ kg/m}^3$  [ $0.88 \text{ lb/ft}^3$ ] (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than  $40 \text{ kg/m}^3$  [ $2.5 \text{ lb/ft}^3$ ] (d2s).

15.2.2. *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be  $30 \text{ kg/m}^3$  [ $1.87 \text{ lb/ft}^3$ ] (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than  $85 \text{ kg/m}^3$  [ $5.3 \text{ lb/ft}^3$ ] (d2s).

15.2.3. These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for bulk density by rodding of normal-weight aggregates having a nominal maximum aggregate size of  $25.0 \text{ mm}$  [ $1 \text{ in.}$ ], and using a  $14\text{-L}$  [ $1/2\text{-ft}^3$ ] measure.

15.3. *Fine Aggregate (Bulk Density):*

15.3.1. *Single-Operator Precision*—The single-operator standard deviation has been found to be  $14 \text{ kg/m}^3$  [ $0.88 \text{ lb/ft}^3$ ] (1s). Therefore, results of two properly conducted tests by the same operator on similar material should not differ by more than  $40 \text{ kg/m}^3$  [ $2.5 \text{ lb/ft}^3$ ] (d2s).

15.3.2. *Multilaboratory Precision*—The multilaboratory standard deviation has been found to be  $44 \text{ kg/m}^3$  [ $2.76 \text{ lb/ft}^3$ ] (1s). Therefore, results of two properly conducted tests from two different laboratories on similar material should not differ by more than  $125 \text{ kg/m}^3$  [ $7.8 \text{ lb/ft}^3$ ] (d2s).

15.3.3. These numbers represent, respectively, the (1s) and (d2s) limits as described in ASTM C670. The precision estimates were obtained from the analysis of AMRL proficiency sample data for loose bulk density from laboratories using a  $2.8\text{-L}$  [ $1/10\text{-ft}^3$ ] measure.

15.4. No precision data on void content are available. However, as the void content in aggregate is calculated from bulk density and bulk specific gravity, the precision of the voids content reflects the precision of these measured parameters given in Sections 15.2 and 15.3 of this method and in T 84 and T 85.

15.5. *Bias*—The procedure in this test method for measuring bulk density and void content has no bias because the values for bulk density and void content can be defined only in terms of a test method.