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American Association State Highway and Transportation Officials Standard
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Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete[1]

This standard is issued under the fixed designation C138/C138M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers determination of the density (see Note 1) of freshly mixed concrete and gives formulas for calculating the yield, cement content, and air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

1.2 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.

NOTE 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

1.3 The text of this test method refers to notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

1.4 *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.*(**Warning—**Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

1.5 *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]

C29/C29M Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate
C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C125 Terminology Relating to Concrete and Concrete Aggregates
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C150/C150M Specification for Portland Cement
C172/C172M Practice for Sampling Freshly Mixed Concrete
C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
C188 Test Method for Density of Hydraulic Cement
C231/C231M Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
C1758/C1758M Practice for Fabricating Test Specimens with Self-Consolidating Concrete

3. Terminology

3.1 *Definitions*—For definitions of terms used in this standard, refer to Terminology C125.

3.2 *Symbols:*

A = air content (percentage of voids) in the concrete
C = actual cement content, kg/m^3 [lb/yd^3]
C_b = mass of cement in the batch, kg [lb]
D = density (unit weight) of concrete, kg/m^3 [lb/ft^3]
M = total mass of all materials batched, kg [lb] (see Note 3)
M_c = mass of the measure filled with concrete, kg [lb] or

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete.

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[2] See section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

[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.

*A Summary of Changes section appears at the end of this standard

M_m = mass of the measure, kg [lb]
R_y = relative yield
T = theoretical density of the concrete computed on an airfree basis, kg/m^3 [lb/ft^3] (see Note 2)
Y = yield, volume of concrete produced per batch, m^3 [yd^3]
Y_d = volume of concrete which the batch was designed to produce, m^3 [yd^3]
Y_f = volume of concrete produced per batch, m^3 [ft^3]
V = total absolute volume of the component ingredients in the batch, m^3 [ft^3]
V_m = volume of the measure, m^3 [ft^3]

NOTE 2—The theoretical density is, customarily, a laboratory determination, the value for which is assumed to remain constant for all batches made using identical component ingredients and proportions.

NOTE 3—The total mass of all materials batched is the sum of the masses of the cement, the fine aggregate in the condition used, the coarse aggregate in the condition used, the mixing water added to the batch, and any other solid or liquid materials used.

4. Apparatus

4.1 *Balance*—A balance or scale accurate to 45 g [0.1 lb] or to within 0.3 % of the test load, whichever is greater, at any point within the range of use. The range of use shall be considered to extend from the mass of the measure empty to the mass of the measure plus its contents at 2600 kg/m^3 [160 lb/ft^3].

4.2 *Tamping Rod*—A round, smooth, straight steel rod, with a 16 mm [⅝ in.] ± 2 mm [1⁄16 in.] diameter. The length of the tamping rod shall be at least 100 mm [4 in.] greater than the depth of the measure in which rodding is being performed, but not greater than 600 mm [24 in.] in overall length (see Note 4). The rod shall have the tamping end or both ends rounded to a hemispherical tip of the same diameter as the rod.

NOTE 4—A rod length of 400 mm [16 in.] to 600 mm [24 in.] meets the requirements of the following: Practice C31/C31M, Test Method C138/C138M, Test Method C143/C143M, Test Method C173/C173M and Test Method C231/C231M.

4.3 *Internal Vibrator*—The vibrator frequency shall be at least 9000 vibrations per minute [150 Hz] while the vibrator is operating in the concrete. The outside diameter or the side dimension of the vibrating element shall be at least 19 mm [0.75 in.] and not greater than 38 mm [1.50 in.]. The combined length of the vibrator shaft and vibrating element shall exceed the depth of the section being vibrated by at least 75 mm [3 in.]. The vibrator frequency shall be checked with a vibrating reed tachometer at an interval not to exceed two years. If the vibrator manufacturer recommends a shorter verification interval, a verification procedure, or other verification device, the manufacturer's recommendation shall be followed.

4.4 *Measure*—A cylindrical container made of steel or other suitable metal (see Note 5). The minimum capacity of the measure shall conform to the requirements of Table 1 based on the nominal size of aggregate in the concrete to be tested. All measures, except for measuring bowls of air meters which are also used for Test Method C138/C138M tests, shall conform to the requirements of Test Method C29/C29M. When measuring bowls of air meters are used, they shall conform to the requirements of Test Method C231/C231M, and shall be calibrated for volume as described in Test Method C29/C29M. The top rim of the air meter bowls shall be smooth and plane within 0.01 in. [0.3 mm] (see Note 6).

TABLE 1 Capacity of Measures

Nominal Maximum Size of Coarse Aggregate		Capacity of Measure[A]	
mm	[in.]	L	[ft^3]
25.0	[1]	6	[0.2]
37.5	[1½]	11	[0.4]
50	[2]	14	[0.5]
75	[3]	28	[1.0]
112	[4½]	70	[2.5]
150	[6]	100	[3.5]

[A] The indicated size of measure shall be used to test concrete containing aggregates of a nominal maximum size equal to or smaller than that listed. The actual volume of the measure shall be at least 95 % of the nominal volume listed.

NOTE 5—The metal should not be readily subject to attack by cement paste. However, reactive materials such as aluminum alloys may be used in instances where as a consequence of an initial reaction, a surface film is rapidly formed which protects the metal against further corrosion.

NOTE 6—The top rim is satisfactorily plane if a 0.3-mm [0.01-in.] feeler gage cannot be inserted between the rim and a piece of 6-mm [¼-in.] or thicker plate glass laid over the top of the measure.

4.5 *Strike-Off Plate*—A flat rectangular metal plate at least 6 mm [¼ in.] thick or a glass or acrylic plate at least 12 mm [½ in.] thick with a length and width at least 50 mm [2 in.] greater than the diameter of the measure with which it is to be used. The edges of the plate shall be straight and smooth within a tolerance of 2 mm [1⁄16 in.].

4.6 *Mallet*—A mallet (with a rubber or rawhide head) having a mass of 600 ± 200 g [1.25 ± 0.50 lb] for use with measures of 14 L [0.5 ft^3] or smaller, and a mallet having a mass of 1000 ± 200 g [2.25 ± 0.50 lb] for use with measures larger than 14 L [0.5 ft^3].

4.7 *Scoop*—of a size large enough so each amount of concrete obtained from the sampling receptacle is representative and small enough so it is not spilled during placement in the measure.

5. Sample

5.1 Obtain the sample of freshly mixed concrete in accordance with Practice C172/C172M.

6. Procedure

6.1 Dampen the interior of the measure and remove any standing water from the bottom. Determine the mass of the empty measure to an accuracy consistent with the requirements of 4.1. Place the measure on a flat, level, firm surface.

6.2 If self-consolidating concrete is being tested, follow the procedures in Practice C1758/C1758M for filling the measure. Upon completion of the filling process, proceed to Strike-Off (6.8).

NOTE 7—Practice C1758/C1758M covers the procedure for filling the specimen container in one layer and without using any additional consolidation method.

6.3 Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. The methods of consolidation are rodding and internal vibration. Rod concretes with a slump greater than 75 mm [3 in.]. Rod or vibrate concrete with a slump of 25 to 75 mm [1 to 3 in.]. Consolidate concretes with a slump less than 25 mm [1 in.] by vibration.

NOTE 8—Nonplastic concrete, such as is commonly used in the manufacture of pipe and unit masonry, is not covered by this test method.

6.4 Place the concrete in the measure using the scoop described in 4.7. Move the scoop around the perimeter of the measure opening to ensure an even distribution of the concrete with minimal segregation. Fill the measure in the number of layers required by the consolidation method (6.5 or 6.6).

6.5 *Rodding*—Place the concrete in the measure in three layers of approximately equal volume. Rod each layer with 25 strokes of the tamping rod when nominal 14-L [0.5-ft^3] or smaller measures are used, 50 strokes when nominal 28-L [1-ft^3] measures are used, and one stroke per 20 cm^2 [3 $in.^2$] of surface for larger measures. Rod each layer uniformly over the cross section with the rounded end of the rod using the required number of strokes. Rod the bottom layer throughout its depth. In rodding this layer, use care not to damage the bottom of the measure. For each upper layer, allow the rod to penetrate through the layer being rodded and into the layer below approximately 25 mm [1 in.]. After each layer is rodded, tap the sides of the measure 10 to 15 times with the appropriate mallet (see 4.6) using such force so as to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Add the final layer so as to avoid overfilling.

6.6 *Internal Vibration*—Fill and vibrate the measure in two approximately equal layers. Place all of the concrete for each layer in the measure before starting vibration of that layer. Insert the vibrator at three different points for each layer. In compacting the bottom layer, do not allow the vibrator to rest on or touch the bottom or sides of the measure. In compacting the final layer, the vibrator shall penetrate into the underlying layer approximately 25 mm [1 in.] . Take care that the vibrator is withdrawn in such a manner that no air pockets are left in the specimen. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator (see Note 9). Continue vibration only long enough to achieve proper consolidation of the concrete (see Note 10). Observe a constant duration of vibration for the particular kind of concrete, vibrator, and measure involved.

NOTE 9—Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth.

NOTE 10—Overvibration may cause segregation and loss of appreciable quantities of intentionally entrained air.

6.7 On completion of consolidation the measure must not contain a substantial excess or deficiency of concrete. An excess of concrete protruding approximately 3 mm [⅛ in.] above the top of the mold is optimum. A small quantity of concrete may be added to correct a deficiency. If the measure contains a great excess of concrete at completion of consolidation, remove a representative portion of the excess concrete with a trowel or scoop immediately following completion of consolidation and before the measure is struck-off.

6.8 *Strike-Off*—After consolidation, strike-off the top surface of the concrete and finish it smoothly using the flat strike-off plate so that the measure is level full. Strike-off the measure by pressing the strike-off plate on the top surface of the measure to cover about two thirds of the surface and withdraw the plate with a sawing motion to finish only the area originally covered. Then place the plate on the top of the measure to cover the original two thirds of the surface and advance it with a vertical pressure and a sawing motion to cover the whole surface of the measure and continue to advance it until it slides completely off the measure. Incline the plate and perform final strokes with the edge of the plate to produce a smooth surface.

6.9 *Cleaning and Weighing*—After strike-off, clean all excess concrete from the exterior of the measure and determine the mass of the concrete and measure to an accuracy consistent with the requirements of 4.1.

7. Calculation

7.1 *Density (Unit Weight)*—Calculate the net mass of the concrete in pounds or kilograms by subtracting the mass of the measure, M_m, from the mass of the measure filled with concrete, M_c. Calculate the density, D, kg/m^3 [lb/ft^3] , by dividing the net mass of concrete by the volume of the measure, V_m as follows:

$$D = (M_c - M_m) / V_m \tag{1}$$

7.2 *Theoretical Density*—Calculate the theoretical density as follows:

$$T = M / V \tag{2}$$

7.2.1 The absolute volume of each ingredient in cubic meters is equal to the mass of the ingredient in kilograms divided by 1000 times its relative density (specific gravity). The absolute volume of each ingredient in cubic feet is equal to the quotient of the mass of that ingredient divided by the product of its relative density times 62.4 lb/ft^3. For the aggregate components, base the relative density and mass on the saturated, surface-dry condition. For cement, determine the actual relative density using Test Method C188. It is permitted to use a value of 3.15 for the relative density of portland cements that conform to Specification C150/C150M. The relative density used for other cements and supplementary cementitous material shall be as determined by testing or as supplied by the material's manufacturer.

7.3 *Yield*—Calculate the yield as follows:

$$Y(yd^3) = M / (D \times 27) \tag{3}$$

or

$$Y(m^3) = M / D \tag{4}$$

7.4 *Relative Yield*—Relative yield is the ratio of the actual volume of concrete obtained to the volume as designed for the batch (see Note 11) calculated as follows:

$$R_y = Y / Y_d \tag{5}$$

NOTE 11—A value for R_y greater than 1.00 indicates an excess of concrete being produced whereas a value less than 1.00 indicates the batch to be "short" of its designed volume. In the inch-pound system, a ratio of yield in cubic feet per cubic yard of design concrete mixture is frequently used, for example, 27.3 ft^3/yd^3.

7.5 *Cement Content*—Calculate the actual cement content as follows:

$$C = C_b / Y \quad (6)$$

7.6 *Air Content*—Calculate the air content as follows:

$$A = [(T - D) / T] \times 100 \quad (7)$$

or

$$A = [(Y - V) / Y] \times 100 \text{ (SI units)} \quad (8)$$

or

$$A = [(Y_f - V) / Y_f] \times 100 [\text{inch - pound units}] \quad (9)$$

8. Report

8.1 Report the following information:

8.1.1 Identification of concrete represented by the sample.

8.1.2 Date of test.

8.1.3 Volume of density measure to the nearest 0.01 L [0.001 ft^3].

8.1.4 Density (unit weight) to the nearest 1.0 kg/m^3 [0.1 lb/ft^3].

8.1.5 Theoretical density, when requested, to the nearest 1.0 kg/m^3 [0.1 lb/ft^3].

8.1.6 Yield, when requested, to the nearest 0.1 m^3 [0.1 yd^3].

8.1.7 Relative yield, when requested, to the nearest 0.01.

8.1.8 Cement content, when requested, to the nearest 0.5 kg [1.0 lb].

8.1.9 Air content, when requested, to the nearest 0.1 percent.

9. Precision and Bias

9.1 The following estimates of precision for this test method are based on a collection of data from various locations by the National Ready Mixed Concrete Association.[4] The data represent concrete mixtures with slump ranging from 75 to 150 mm [3 to 6 in.] and density ranging from 1842 to 2483 kg/m^3 [115 to 155 lb/ft^3] and included air-entrained and non air-entrained concrete. The study was conducted using 7-L [0.25 ft^3] and 14-L [0.5 ft^3] measures.

9.1.1 *Single-Operator Precision*—The single operator standard deviation of density of freshly mixed concrete has been found to be 0.65 lb/ft^3 [10.4 kg/m^3] (1s). Therefore, results of two properly conducted by the same operator on the same sample of concrete should not differ by more than 1.85 lb/ft^3 [29.6 kg/m^3] (d2s).

9.1.2 *Multi-Operator Precision*—The multi-operator standard deviation of density of freshly mixed concrete has been found to be 13.1 kg/m^3 [0.82 lb/ft^3] (1s). Therefore, results of two properly conducted tests by the two operators on the same sample of concrete should not differ by more than 37.0 kg/m^3 [2.31 lb/ft^3] (d2s).

9.2 *Bias*—This test method has no bias since the density is defined only in terms of this test method.

10. Keywords

10.1 air content; cement content; concrete; relative yield; unit weight; yield

[4] Mullings, G. M., NRMCA/NAA Joint Research Lab Study "Series D324 Accuracy of Concrete Density Test," Feb. 17, 2000.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATIONS (SI UNITS)

X1.1 Concrete Mix Data:

X1.1.1 The following quantities are batched for a designed 10 m^3 load:

Cement	3560 kg
Coarse Aggregate	10 975 kg
Fine Aggregate	8070 kg
Added Water	1216 kg
Total Mass of Materials Batched (*M*)	23 821 kg

X1.1.2 The following are the properties of the aggregates:

Coarse Aggregate	(Moisture content = 2.0%; Absorption = 0.8%; Relative Density (Specific Gravity) SSD = 2.72)
Fine Aggregate	(Moisture content = 4.0%; Absorption = 1.1%; Relative Density (Specific Gravity) SSD = 2.63)

X1.1.3 The following fresh concrete properties were measured at the job site:

Slump	=	115 mm
Air content	=	5.0 %
Density (unit weight)	=	2335 kg/m^3

X1.2 Calculate the Yield (Y):

$$Y = M / D = (\text{Total Mass of Materials Batched}) / (\text{Density of Concrete})$$

$$Y = 23821 / 2355 = 10.2 m^3 \quad (X1.1)$$

X1.3 Calculate the Relative Yield (R_Y):

$$R_y = Y / Y_d = (\text{Yield}) / (\text{Design Yield})$$

$$R_y = 10.2 / 10.0 = 1.02 \quad (X1.2)$$

X1.4 Convert the batch mixture proportions of the fine and coarse aggregates to a saturated-surface-dry (SSD) basis, by first dividing the batch quantity of the aggregate by [1 + the moisture content (expressed as a decimal)] to determine the mass of the dry aggregate. Then multiply the mass of the dry aggregate by [1 + the absorption (expressed as a decimal)] to calculate the mass of the SSD aggregate.

Mass of dry coarse aggregate	=	10 975 / 1.02 = 10 760 kg
Mass of coarse aggregate (SSD)	=	10 760 × 1.008 = 10 846 kg
Mixing water contributed by coarse aggregate	=	(2.0 % – 0.8 %) = 1.2 % × 10 760 = 129 kg