



# Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method<sup>1</sup>

This standard is issued under the fixed designation C 231; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

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

## 1. Scope\*

1.1 This test method covers determination of the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

1.2 This test method is intended for use with concretes and mortars made with relatively dense aggregates for which the aggregate correction factor can be satisfactorily determined by the technique described in Section 6. It is not applicable to concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. In these cases, Test Method C 173/C 173M should be used. This test method is also not applicable to nonplastic concrete such as is commonly used in the manufacture of pipe and concrete masonry units.

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

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *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 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.)*<sup>2</sup>

## 2. Referenced Documents

### 2.1 ASTM Standards:

C 138/C 138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete<sup>3</sup>

C 172 Practice for Sampling Freshly Mixed Concrete<sup>3</sup>

C 173/C 173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method<sup>3</sup>

C 192/C 192M Practice for Making and Curing Concrete Test Specimens in the Laboratory<sup>3</sup>

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials<sup>3</sup>

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods<sup>4</sup>

## 3. Significance and Use

3.1 This test method covers the determination of the air content of freshly mixed concrete. The test determines the air content of freshly mixed concrete exclusive of any air that may exist inside voids within aggregate particles. For this reason, it is applicable to concrete made with relatively dense aggregate particles and requires determination of the aggregate correction factor (see 6.1 and 9.1).

3.2 This test method and Test Method C 138/C 138M and C 173/C 173M provide pressure, gravimetric, and volumetric procedures, respectively, for determining the air content of freshly mixed concrete. The pressure procedure of this test method gives substantially the same air contents as the other two test methods for concretes made with dense aggregates.

3.3 The air content of hardened concrete may be either higher or lower than that determined by this test method. This depends upon the methods and amount of consolidation effort applied to the concrete from which the hardened concrete specimen is taken; uniformity and stability of the air bubbles in the fresh and hardened concrete; accuracy of the microscopic examination, if used; time of comparison; environmental exposure; stage in the delivery, placement and consolidation processes at which the air content of the unhardened concrete is determined, that is, before or after the concrete goes through a pump; and other factors.

## 4. Apparatus

4.1 *Air Meters*—There are available satisfactory apparatus of two basic operational designs employing the principle of Boyle's law. For purposes of reference herein these are designated Meter Type A and Meter Type B.

<sup>1</sup> 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.

Current edition approved July 10, 2003. Published September 2003. Originally approved in 1949. Last previous edition approved in 1997 as C 231 – 97<sup>e1</sup>.

<sup>2</sup> Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 04.02.

<sup>4</sup> *Annual Book of ASTM Standards*, Vol 14.02.

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

4.1.1 *Meter Type A*—An air meter consisting of a measuring bowl and cover assembly (see Fig. 1) conforming to the requirements of 4.2 and 4.3. The operational principle of this meter consists of introducing water to a predetermined height above a sample of concrete of known volume, and the application of a predetermined air pressure over the water. The determination consists of the reduction in volume of the air in the concrete sample by observing the amount the water level is lowered under the applied pressure, the latter amount being calibrated in terms of percent of air in the concrete sample.

4.1.2 *Meter Type B*—An air meter consisting of a measuring bowl and cover assembly (see Fig. 2) conforming to the requirements of 4.2 and 4.3. The operational principle of this meter consists of equalizing a known volume of air at a known pressure in a sealed air chamber with the unknown volume of air in the concrete sample, the dial on the pressure gage being calibrated in terms of percent air for the observed pressure at which equalization takes place. Working pressures of 7.5 to 30.0 psi (51 to 207 kPa) have been used satisfactorily.

4.2 *Measuring Bowl*—The measuring bowl shall be essentially cylindrical in shape, made of steel, hard metal, or other hard material not readily attacked by the cement paste, having a minimum diameter equal to 0.75 to 1.25 times the height, and a capacity of at least 0.20 ft<sup>3</sup> (5.7 L). It shall be flanged or otherwise constructed to provide for a pressure tight fit between bowl and cover assembly. The interior surfaces of the bowl and surfaces of rims, flanges, and other component fitted parts shall be machined smooth. The measuring bowl and cover assembly shall be sufficiently rigid to limit the expansion factor, *D*, of the apparatus assembly (Annex A1.5) to not more than 0.1 % of air content on the indicator scale when under normal operating pressure.

4.3 *Cover Assembly:*

4.3.1 The cover assembly shall be made of steel, hard metal, or other hard material not readily attacked by the cement paste.

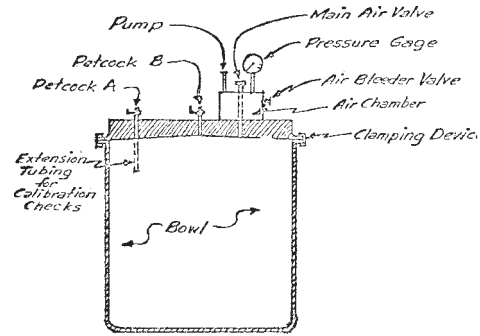
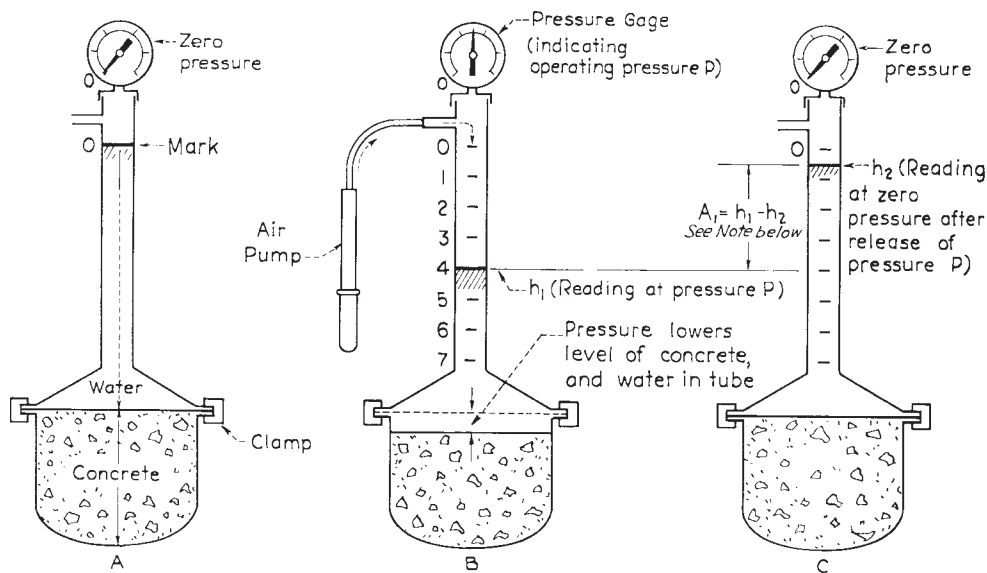


FIG. 2 Schematic Diagram—Type-B Meter

It shall be flanged or otherwise constructed to provide for a pressure-tight fit between bowl and cover assembly and shall have machined smooth interior surfaces contoured to provide an air space above the level of the top of the measuring bowl. The cover shall be sufficiently rigid to limit the expansion factor of the apparatus assembly as prescribed in 4.2.

4.3.2 The cover assembly shall be fitted with a means of direct reading of the air content. The cover for the Type A meter shall be fitted with a standpipe, made of a transparent graduated tube or a metal tube of uniform bore with a glass water gage attached. In the Type B meter, the dial of the pressure gage shall be calibrated to indicate the percent of air. Graduations shall be provided for a range in air content of at least 8 % readable to 0.1 % as determined by the proper air pressure calibration test.

4.3.3 The cover assembly shall be fitted with air valves, air bleeder valves, and petcocks for bleeding off or through which water may be introduced as necessary for the particular meter design. Suitable means for clamping the cover to the bowl shall be provided to make a pressure-tight seal without entrapping air at the joint between the flanges of the cover and bowl. A



Note:  $A_1 = h_1 - h_2$  when bowl contains concrete as shown in this figure; when bowl contains only aggregate and water,  $h_1 - h_2 = G$  (aggregate correction factor).  $A_1 - G = A$  (entrained air content of concrete)

FIG. 1 Illustration of the Pressure Method for Air Content—Type-A Meter

suitable hand pump shall be provided with the cover either as an attachment or as an accessory.

4.4 *Calibration Vessel*—A measure having an internal volume equal to a percent of the volume of the measuring bowl corresponding to the approximate percent of air in the concrete to be tested; or, if smaller, it shall be possible to check calibration of the meter indicator at the approximate percent of air in the concrete to be tested by repeated filling of the measure. When the design of the meter requires placing the calibration vessel within the measuring bowl to check calibration, the measure shall be cylindrical in shape and of an inside depth ½ in. (13 mm) less than that of the bowl.

NOTE 1—A satisfactory calibration vessel to place within the measuring bowl may be machined from No. 16 gage brass tubing, of a diameter to provide the volume desired, to which a brass disk ½ in. in thickness is soldered to form an end. When design of the meter requires withdrawing of water from the water-filled bowl and cover assembly, to check calibration, the measure may be an integral part of the cover assembly or may be a separate cylindrical measure similar to the above-described cylinder.

4.5 The designs of various available types of air meters are such that they differ in operating techniques; therefore, all of the items described in 4.6-4.16 may not be required. The items required shall be those necessary for use with the particular design of apparatus used to satisfactorily determine air content in accordance with the procedures prescribed herein.

4.6 *Coil Spring or Other Device for Holding Calibration Cylinder in Place*.

4.7 *Spray Tube*—A brass tube of appropriate diameter, which may be an integral part of the cover assembly, or which may be provided separately. It shall be so constructed that when water is added to the container, it is sprayed to the walls of the cover in such a manner as to flow down the sides causing a minimum of disturbance to the concrete.

4.8 *Trowel*—A standard brick mason's trowel.

4.9 *Tamping Rod*—The tamping rod shall be a round straight steel rod ⅝ in. (16 mm) in diameter and not less than 16 in. (400 mm) in length, having the tamping end rounded to a hemispherical tip the diameter of which is ⅝ in. (16 mm).

4.10 *Mallet*—A mallet (with a rubber or rawhide head) weighing approximately  $1.25 \pm 0.50$  lb ( $0.57 \pm 0.23$  kg) for use with measures of  $0.5 \text{ ft}^3$  (14 L) or smaller, and a mallet weighing approximately  $2.25 \pm 0.50$  lb ( $1.02 \pm 0.23$  kg) for use with measures larger than  $0.5 \text{ ft}^3$  (14 L).

4.11 *Strike-Off Bar*—A flat straight bar of steel or other suitable metal at least ⅛ in. (3 mm) thick and ¾ in. (20 mm) wide by 12 in. (300 mm) long.

4.12 *Strike-Off Plate*—A flat rectangular metal plate at least ¼ in. (6 mm) thick or a glass or acrylic plate at least ½ in. (12 mm) thick with a length and width at least 2 in. (50 mm) 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 ⅛ in. (1.5 mm).

4.13 *Funnel*, with the spout fitting into spray tube.

4.14 *Measure for Water*, having the necessary capacity to fill the indicator with water from the top of the concrete to the zero mark.

4.15 *Vibrator*, as described in Practice C 192/C 192M.

4.16 *Sieves*, 1½-in. (37.5-mm) with not less than  $2 \text{ ft}^2$  ( $0.19 \text{ m}^2$ ) of sieving area.

## 5. Calibration of Apparatus

5.1 Make calibration tests in accordance with procedures prescribed in the annex. Rough handling will affect the calibration of both Types A and B meters. Changes in barometric pressure will affect the calibration of Type A meter but not Type B meter. The steps described A1.2 to A1.6, as applicable to the meter type under consideration, are prerequisites for the final calibration test to determine the operating pressure,  $P$ , on the pressure gage of the Type A meter as described in A1.7, or to determine the accuracy of the graduations indicating air content on the dial face of the pressure gage of the Type B meter. The steps in A1.2 to A1.6 need be made only once (at the time of initial calibration), or only occasionally to check volume constancy of the calibration cylinder and measuring bowl. The calibration test described in A1.7 and A1.9, as applicable to the meter type being checked, must be made as frequently as necessary to ensure that the proper gage pressure,  $P$ , is being used for the Type A meter or that the correct air contents are being indicated on the pressure gage air content scale for the Type B meter. A change in elevation of more than 600 ft (183 m) from the location at which a Type-A meter was last calibrated will require recalibration in accordance with A1.7.

## 6. Determination of Aggregate Correction Factor

6.1 *Procedure*—Determine the aggregate correction factor on a combined sample of fine and coarse aggregate as directed in 6.2 to 6.4. It is determined independently by applying the calibrated pressure to a sample of inundated fine and coarse aggregate in approximately the same moisture condition, amount, and proportions occurring in the concrete sample under test.

6.2 *Aggregate Sample Size*—Calculate the weights of fine and coarse aggregate present in the sample of fresh concrete whose air content is to be determined, as follows:

$$F_s = (S/B) \times F_b \quad (1)$$

$$C_s = (S/B) \times C_b \quad (2)$$

where:

$F_s$  = weight of fine aggregate in concrete sample under test, lb (kg),

$S$  = volume of concrete sample (same as volume of measuring bowl),  $\text{ft}^3$  ( $\text{m}^3$ ),

$B$  = volume of concrete produced per batch (Note 2),  $\text{ft}^3$  ( $\text{m}^3$ ),

$F_b$  = total weight of fine aggregate in the moisture condition used in batch, lb (kg),

$C_s$  = weight of coarse aggregate in concrete sample under test, lb (kg), and

$C_b$  = total weight of coarse aggregate in the moisture condition used in batch, lb (kg).

NOTE 2—The volume of concrete produced per batch can be determined in accordance with applicable provisions of Test Method C 138/C 138M.

NOTE 3—The term “weight” is temporarily used in this test method because of established trade usage. The word is used to mean both “force”

and “mass,” and care must be taken to determine which is meant in each case (SI unit for force = newton and for mass = kilogram).

**6.3 Placement of Aggregate in Measuring Bowl**—Mix representative samples of fine aggregate  $F_s$  and coarse aggregate  $C_s$ , and place in the measuring bowl filled one-third full with water. Place the mixed aggregate, a small amount at a time, into the measuring bowl; if necessary, add additional water so as to inundate all of the aggregate. Add each scoopful in a manner that will entrap as little air as possible and remove accumulations of foam promptly. Tap the sides of the bowl and lightly rod the upper 1 in. (25 mm) of the aggregate eight to twelve times. Stir after each addition of aggregate to eliminate entrapped air.

**6.4 Aggregate Correction Factor Determination:**

**6.4.1 Initial Procedure for Types A and B Meters**—When all of the aggregate has been placed in the measuring bowl, remove excess foam and keep the aggregate inundated for a period of time approximately equal to the time between introduction of the water into the mixer and the time of performing the test for air content before proceeding with the determination as directed in 6.4.2 or 6.4.3.

**6.4.2 Type A Meter**—Complete the test as described in 8.2.1 and 8.2.2. The aggregate correction factor,  $G$ , is equal to  $h_1 - h_2$  (see Fig. 1) (Note 4).

**6.4.3 Type B Meter**—Perform the procedures as described in 8.3.1. Remove a volume of water from the assembled and filled apparatus approximately equivalent to the volume of air that would be contained in a typical concrete sample of a size equal to the volume of the bowl. Remove the water in the manner described in A1.9 for the calibration tests. Complete the test as described in 8.3.2. The aggregate correction factor,  $G$ , is equal to the reading on the air-content scale minus the volume of water removed from the bowl expressed as a percent of the volume of the bowl (see Fig. 1).

**NOTE 4**—The aggregate correction factor will vary with different aggregates. It can be determined only by test, since apparently it is not directly related to absorption of the particles. The test can be made easily. Ordinarily the factor will remain reasonably constant for given aggregates, but an occasional check test is recommended.

## 7. Preparation of Concrete Test Sample

**7.1** Obtain the sample of freshly mixed concrete in accordance with applicable procedures of Practice C 172. If the concrete contains coarse aggregate particles that would be retained on a 2-in. (50-mm) sieve, wet-sieve a sufficient amount of the representative sample over a 1½-in. (37.5-mm) sieve, as described in Practice C 172, to yield sufficient material to completely fill the measuring bowl of the size selected for use. Carry out the wet-sieving operation with the minimum practicable disturbance of the mortar. Make no attempt to wipe adhering mortar from coarse aggregate particles retained on the sieve.

## 8. Procedure for Determining Air Content of Concrete

**8.1 Placement and Consolidation of Sample:**

**8.1.1** Dampen the interior of the measuring bowl and place it on a flat, level, firm surface. Place a representative sample of the concrete, prepared as described in Section 7, in the measuring bowl in equal layers. Consolidate each layer by the

rodding procedure (8.1.2) or by vibration (8.1.3). Strike-off the finally consolidated layer (8.1.4). Rod concretes with a slump greater than 3 in. (75 mm). Rod or vibrate concrete with a slump of 1 to 3 in. (25 to 75 mm). Consolidate concretes with a slump less than 1 in. (25 mm) by vibration.

**8.1.2 Rodding**—Place the concrete in the measuring bowl in three layers of approximately equal volume. Consolidate each layer of concrete by 25 strokes of the tamping rod evenly distributed over the cross section. After each layer is rodded, tap the sides of the measure smartly 10 to 15 times with the mallet to close any voids left by the tamping rod and to release any large bubbles of air that may have been trapped. Rod the bottom layer throughout its depth, but the rod shall not forcibly strike the bottom of the measure. In rodding the second and final layers, use only enough force to cause the rod to penetrate the surface of the previous layer about 1 in. (25 mm). Add the final layer of concrete in a manner to avoid excessive overfilling (8.1.4).

**8.1.3 Vibration**—Place the concrete in the measuring bowl in two layers of approximately equal volume. Place all of the concrete for each layer before starting vibration of that layer. Consolidate each layer by three insertions of the vibrator evenly distributed over the cross section. Add the final layer in a manner to avoid excessive overfilling (8.1.4). In consolidating each layer, do not allow the vibrator to rest on or touch the measuring bowl. Take care in withdrawing the vibrator to ensure that no air pockets are left in the specimen. Observe a standard duration of vibration for the particular kind of concrete, vibrator, and measuring bowl involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Continue vibration until the concrete is properly consolidated. Never continue vibration long enough to cause escape of froth from the sample.

**NOTE 5**—Overvibration may cause segregation and loss of intentionally entrained air. Usually, sufficient vibration has been applied as soon as the surface of the concrete becomes relatively smooth and has a glazed appearance.

**8.1.4 Strike Off**—After consolidation of the concrete, strike off the top surface by sliding the strike-off bar across the top flange or rim of the measuring bowl with a sawing motion until the bowl is just level full. On completion of consolidation, the bowl must not contain an excess or deficiency of concrete. Removal of ⅛ in. (3 mm) during strike off is optimum. When a strike-off plate is used, strike off concrete as prescribed in Test Method C 138/C 138M.

**NOTE 6**—A small quantity of representative concrete may be added to correct a deficiency. If the measure contains a great excess, remove a representative portion of concrete with a trowel or scoop before the measure is struck off.

**NOTE 7**—The use of the strike-off plate on cast aluminum or other relatively soft metal air meter bases may cause rapid wear of the rim and require frequent maintenance, calibration, and ultimately, replacement.

**8.1.5 Application of Test Method**—Any portion of the test method not specifically designated as pertaining to Type A or Type B meter shall apply to both types.

**8.2 Procedure—Type A Meter:**



8.2.1 *Preparation for Test*—Thoroughly clean the flanges or rims of the bowl and of the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus and add water over the concrete by means of the tube until it rises to about the halfway mark in the standpipe. Incline the apparatus assembly about 30° from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the column, simultaneously tapping the cover lightly to remove any entrapped air bubbles above the concrete sample. Return the apparatus assembly to a vertical position and fill the water column slightly above the zero mark, while lightly tapping the sides of the bowl. Bring the water level to the zero mark of the graduated tube before closing the vent at the top of the water column (see Fig. 1 A).

NOTE 8—Some Type A meters have a calibrated starting fill mark above the zero mark. Generally, this starting mark should not be used since, as noted in 8.2.3, the apparent air content is the difference between the water level reading  $H$ , at pressure  $P$  and the water level  $h_2$  at zero pressure after release of pressure  $P$ .

8.2.2 The internal surface of the cover assembly shall be kept clean and free from oil or grease; the surface shall be wet to prevent adherence of air bubbles that might be difficult to dislodge after assembly of the apparatus.

8.2.3 *Test Procedure*—Apply more than the desired test pressure,  $P$ , (about 0.2 psi (1380 Pa) more) to the concrete by means of the small hand pump. To relieve local restraints, tap the sides of the measure sharply and, when the pressure gage indicates the exact test pressure,  $P$ , as determined in accordance with A1.7, read the water level,  $h_1$ , and record to the nearest division or half-division on the graduated precision-bore tube or gage glass of the standpipe (see Fig. 1 B). For extremely harsh mixes tap the bowl vigorously until further tapping produces no change in the indicated air content. Gradually release the air pressure through the vent at the top of the water column and tap the sides of the bowl lightly for about 1 min. Record the water level,  $h_2$ , to the nearest division or half-division (see Fig. 1 C). Calculate the apparent air content as follows:

$$A_1 = h_1 - h_2 \quad (3)$$

where:

$A_1$  = apparent air content,

$h_1$  = water level reading at pressure,  $P$  (see Note 9), and

$h_2$  = water level reading at zero pressure after release of pressure,  $P$ .

8.2.4 *Check Test*—Repeat the steps described in 8.2.3 without adding water to reestablish the water level at the zero mark. The two consecutive determinations of apparent air content should check within 0.2 % of air and shall be averaged to give the value  $A_1$  to be used in calculating the air content,  $A_s$ , in accordance with Section 9.

8.2.5 In the event the air content exceeds the range of the meter when it is operated at the normal test pressure  $P$ , reduce the test pressure to the alternative test pressure  $P_1$  and repeat the steps outlined in 8.2.2 and 8.2.3.

NOTE 9—See A1.7 for exact calibration procedures. An approximate value of the alternative pressure,  $P_1$ , such that the apparent air content will

equal twice the meter reading can be computed from the following relationship:

$$P_1 = P_a P / (2P_a + P) \quad (4)$$

where:

$P_1$  = alternative test pressure, psi (or kPa),

$P_a$  = atmospheric pressure, psi (approximately 14.7 psi (101 kPa) but will vary with altitude and weather conditions) (or kPa), and

$P$  = normal test or operating gage pressure, psi (or kPa).

### 8.3 Procedure—Type B Meter:

8.3.1 *Preparation for Test*—Thoroughly clean the flanges or rims of the bowl and the cover assembly so that when the cover is clamped in place a pressure-tight seal will be obtained. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open both petcocks on the holes through the cover. Using a rubber syringe, inject water through one petcock until water emerges from the opposite petcock. Jar the meter gently until all air is expelled from this same petcock.

8.3.2 *Test Procedure*—Close the airbleeder valve on the air chamber and pump air into the air chamber until the gage hand is on the initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gage hand at the initial pressure line by pumping or bleeding-off air as necessary, tapping the gage lightly by hand. Close both petcocks on the holes through the cover. Open the air valve between the air chamber and the measuring bowl. Tap the sides of the measuring bowl smartly with the mallet to relieve local restraints. Lightly tap the pressure gage by hand to stabilize the gage hand. Read the percentage of air on the dial of the pressure gage. Failure to close the main air valve before releasing the pressure from either the container or the air chamber will result in water being drawn into the air chamber, thus introducing error in subsequent measurements. In the event water enters the air chamber, it must be bled from the air chamber through the bleeder valve followed by several strokes of the pump to blow out the last traces of water. Release the pressure by opening both petcocks (Fig. 2) before removing the cover.

## 9. Calculation

9.1 *Air Content of Sample Tested*—Calculate the air content of the concrete in the measuring bowl as follows:

$$A_s = A_1 - G \quad (5)$$

where:

$A_s$  = air content of the sample tested, %,

$A_1$  = apparent air content of the sample tested, % (see 8.2.3 and 8.3.2), and

$G$  = aggregate correction factor, % (Section 6).

9.2 *Air Content of Full Mixture*—When the sample tested represents that portion of the mixture that is obtained by wet sieving to remove aggregate particles larger than a 1½-in. (37.5-mm) sieve, the air content of the full mixture is calculated as follows:

$$A_t = 100 A_s V_c / (100 V_t - A_s V_a) \quad (6)$$

where: (Note 10):

$A_t$  = air content of the full mixture, %,

- $V_c$  = absolute volume of the ingredients of the mixture passing a 1½-in. (37.5-mm) sieve, airfree, as determined from the original batch weights, ft<sup>3</sup>(m<sup>3</sup>),
- $V_t$  = absolute volume of all ingredients of the mixture, airfree, ft<sup>3</sup> (m<sup>3</sup>), and
- $V_a$  = absolute volume of the aggregate in the mixture coarser than a 1½-in. (37.5-mm) sieve, as determined from original batch weights, ft<sup>3</sup>(m<sup>3</sup>).

9.3 *Air Content of the Mortar Fraction*—When it is desired to know the air content of the mortar fraction of the mixture, calculate it as follows:

$$A_m = 100 A_s V_c / [100 V_m + A_s (V_c - V_m)] \quad (7)$$

where: (Note 10):

- $A_m$  = air content of the mortar fraction, %, and
- $V_m$  = absolute volume of the ingredients of the mortar fraction of the mixture, airfree, ft<sup>3</sup> (m<sup>3</sup>).

NOTE 10—The values for use in Eq 6 and Eq 7 are most conveniently obtained from data on the concrete mixture tabulated as follows for a batch of any size:

		Absolute Volume, ft <sup>3</sup> (m <sup>3</sup> )			
Cement	_____	}	$V_m$	}	$V_c$
Water	_____				
Fine aggregate	_____				
Coarse aggregate (No. 4 (4.75-mm) to 1½-in. (37.5-mm))	_____				
Coarse aggregate (1½-in. ) (37.5-mm)	_____				$V_a$
Total	_____				$V_t$

## 10. Precision and Bias

### 10.1 Precision:

10.1.1 *Single-Operator Precision*—The single-operator standard deviation cannot be established because the sampling

requirements for this test, as established in Practice C 172, do not allow a single operator time to conduct more than one test on a sample.

10.1.2 *Multilaboratory Precision*—The multilaboratory standard deviation has not been established.

10.1.3 *Multioperator Precision*—The multioperator standard deviation of a single test result has been found to be 0.28 % air by volume of concrete for Type A air meters as long as the air content does not exceed 7 %. Therefore results of two tests properly conducted by different operators but on the same material should not differ by more than 0.8 % air by volume of concrete (see Practice E 177, Note 11 and Note 12).

NOTE 11—These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C 670. The precision statements are based on the variations in tests on three different concretes, each tested by eleven different operators.<sup>5</sup>

NOTE 12—The precision of this test method using Type B air meters has not been determined.

10.2 *Bias*—This test method has no bias because the air content of freshly mixed concrete can only be defined in terms of the test methods.

## 11. Keywords

11.1 air content; calibration; concrete; correction factor; measuring bowl; meter; pressure; pump; unit weight

<sup>5</sup> Reidenour, D. R., and Howe, R. H., "Air Content of Plastic and Hardened Concrete," presented at the 2nd International Conference on "Durability of Building Materials and Components" Sept. 14–16, 1981. Reprints compiled by: G. Frohnsdorff and B. Horner, National Institute for Standards and Technology, Gaithersburg, MD 20899, formerly National Bureau of Standards, Washington, DC 20234.

# ANNEX

## (Mandatory Information)

### A1. CALIBRATION OF APPARATUS

A1.1 Calibration tests shall be performed in accordance with the following procedures as applicable to the meter type being employed.

A1.2 *Calibration of the Calibration Vessel*—Determine accurately the weight of water,  $w$ , required to fill the calibration vessel, using a scale accurate to 0.1 % of the weight of the vessel filled with water. This step shall be performed for Type A and B meters.

A1.3 *Calibration of the Measuring Bowl*—Determine the weight of water,  $W$ , required to fill the measuring bowl, using a scale accurate to 0.1 % of the weight of the bowl filled with water. Slide a glass plate carefully over the flange of the bowl in a manner to ensure that the bowl is completely filled with water. A thin film of cup grease smeared on the flange of the

bowl will make a watertight joint between the glass plate and the top of the bowl. This step shall be performed for Type A and B meters.

A1.4 *Effective Volume of the Calibration Vessel, R*—The constant  $R$  represents the effective volume of the calibration vessel expressed as a percentage of the volume of the measuring bowl.

A1.4.1 For meter Types A, calculate  $R$  as follows (Note A1.1):

$$R = 0.98 w/W \quad (A1.1)$$

where:

$w$  = weight of water required to fill the calibration vessel, and

$W$  = weight of water required to fill the measuring bowl.

NOTE A1.1—The factor 0.98 is used to correct for the reduction in the volume of air in the calibration vessel when it is compressed by a depth of water equal to the depth of the measuring bowl. This factor is approximately 0.98 for an 8-in. (203-mm) deep measuring bowl at sea level. Its value decreases to approximately 0.975 at 5000 ft (1524 m) above sea level and 0.970 at 13 000 ft (3962 m) above sea level. The value of this constant will decrease by about 0.01 for each 4-in. (102-mm) increase in bowl depth. The depth of the measuring bowl and atmospheric pressure do not affect the effective volume of the calibration vessel for meter Types B.

A1.4.2 For meter Types B calculate  $R$  as follows (Note A1.1):

$$R = w/W \quad (\text{A1.2})$$

A1.5 *Determination of, or Check of, Allowance for Expansion Factor,  $D$ :*

A1.5.1 For meter assemblies of Type A determine the expansion factor,  $D$  (Note A1.2) by filling the apparatus with water only (making certain that all entrapped air has been removed and the water level is exactly on the zero mark (Note A1.3) and applying an air pressure approximately equal to the operating pressure,  $P$ , determined by the calibration test described in A1.7. The amount the water column lowers will be the equivalent expansion factor,  $D$ , for that particular apparatus and pressure (Note A1.5).

NOTE A1.2—Although the bowl, cover, and clamping mechanism of the apparatus must of necessity be sturdily constructed so that it will be pressure-tight, the application of internal pressure will result in a small increase in volume. This expansion will not affect the test results because, with the procedure described in Sections 6 and 8, the amount of expansion is the same for the test for air in concrete as for the test for aggregate correction factor on combined fine and coarse aggregates, and is thereby automatically cancelled. However, it does enter into the calibration test to determine the air pressure to be used in testing fresh concrete.

NOTE A1.3—The water columns on some meters of Type-A design are marked with an initial water level and a zero mark, the difference between the two marks being the allowance for the expansion factor. This allowance should be checked in the same manner as for meters not so marked and in such a case, the expansion factor should be omitted in computing the calibration readings in A1.7.

NOTE A1.4—It will be sufficiently accurate for this purpose to use an approximate value for  $P$  determined by making a preliminary calibration test as described in A1.7 except that an approximate value for the calibration factor,  $K$ , should be used. For this test  $K = 0.98R$  which is the same as Eq A1.2 except that the expansion reading,  $D$ , as yet unknown, is assumed to be zero.

A1.5.2 For meters of Type B design, the allowance for the expansion factor,  $D$ , is included in the difference between the initial pressure indicated on the pressure gage and the zero percent mark on the air-content scale on the pressure gage. This allowance shall be checked by filling the apparatus with water (making certain that all entrapped air has been removed), pumping air into the air chamber until the gage hand is stabilized at the indicated initial pressure line, and then releasing the air to the measuring bowl (Note A1.5). If the initial pressure line is correctly positioned, the gage should read zero percent. The initial pressure line shall be adjusted if two or more determinations show the same variation from zero percent and the test repeated to check the adjusted initial pressure line.

NOTE A1.5—This procedure may be accomplished in conjunction with the calibration test described in A1.9.

A1.6 *Calibration Reading,  $K$* —The calibration reading,  $K$ , is the final meter reading to be obtained when the meter is operated at the correct calibration pressure.

A1.6.1 For meter Types A, the calibration reading,  $K$ , is as follows:

$$K = R + D \quad (\text{A1.3})$$

where:

$R$  = effective volume of the calibration vessel (A1.4.1),  
and

$D$  = expansion factor (A1.5.1, Note A1.6).

A1.6.2 For meter Types B the calibration reading,  $K$ , equals the effective volume of the calibration vessel (A4.2) as follows:

$$K = R \quad (\text{A1.4})$$

NOTE A1.6—If the water column indicator is graduated to include an initial water level and a zero mark, the difference between the two marks being equivalent to the expansion factor, the term  $D$  shall be omitted from Eq A1.3.

A1.7 *Calibration Test to Determine Operating Pressure,  $P$ , on Pressure Gage, Type A Meter*—If the rim of the calibration cylinder contains no recesses or projections, fit it with three or more spacers equally spaced around the circumference. Invert the cylinder and place it at the center of the dry bottom of the measuring bowl. The spacers will provide an opening for flow of water into the calibration cylinder when pressure is applied. Secure the inverted cylinder against displacement and carefully lower the cover assembly. After the cover is clamped in place, carefully adjust the apparatus assembly to a vertical position and add water at air temperature, by means of the tube and funnel, until it rises above the zero mark on the standpipe. Close the vent and pump air into the apparatus to the approximate operating pressure. Incline the assembly about 30° from vertical and, using the bottom of the bowl as a pivot, describe several complete circles with the upper end of the standpipe, simultaneously tapping the cover and sides of the bowl lightly to remove any entrapped air adhering to the inner surfaces of the apparatus. Return the apparatus to a vertical position, gradually release the pressure (to avoid loss of air from the calibration vessel), and open the vent. Bring the water level exactly to the zero mark by bleeding water through the petcock in the top of the conical cover. After closing the vent, apply pressure until the water level has dropped an amount equivalent to about 0.1 to 0.2 % of air more than the value of the calibration reading,  $K$ , determined as described in A1.6. To relieve local restraints, lightly tap the sides of the bowl, and when the water level is exactly at the value of the calibration reading,  $K$ , read the pressure,  $P$ , indicated by the gage and record to the nearest 0.1 psi (690 Pa). Gradually release the pressure and open the vent to determine whether the water level returns to the zero mark when the sides of the bowl are tapped lightly (failure to do so indicates loss of air from the calibration vessel or loss of water due to a leak in the assembly). If the water levels fails to return to within 0.05 % air of the zero mark and no leakage beyond a few drops of water is found, some air probably was lost from the calibration

cylinder. In this case, repeat the calibration procedure step by step from the beginning of this paragraph. If the leakage is more than a few drops of water, tighten the leaking joint before repeating the calibration procedure. Check the indicated pressure reading promptly by bringing the water level exactly to the zero mark, closing the vent, and applying the pressure,  $P$ , just determined. Tap the gage lightly with a finger. When the gage indicates the exact pressure,  $P$ , the water column should read the value of the calibration factor,  $K$ , used in the first pressure application within about 0.05 % of air.

A1.7.1 The apparatus assembly must not be moved from the vertical position until pressure has been applied, which will force water about one third of the way up into the calibration cylinder. Any loss of air from this cylinder will nullify the calibration.

A1.8 *Calibration Test to Determine Alternative Operating Pressure  $P_1$ —Meter Type A*—The range of air contents which can be measured with a given meter can be doubled by determining an alternative operating pressure  $P_1$  such that the meter reads half of the calibration reading,  $K$ , (Eq A1.3). Exact calibration will require determination of the expansion factor at the reduced pressure in A1.5. For most purposes the change in expansion factor can be disregarded and the alternative operating pressure determined during the determination of the regular operating pressure in A1.7.

A1.9 *Calibration Test to Check the Air Content Graduations on the Pressure Gage, Type B Meter*—Fill the measuring bowl with water as described in A1.3. Screw the short piece of tubing or pipe furnished with the apparatus into the threaded petcock hole on the underside of the cover assembly. Assemble the apparatus. Close the air valve between the air chamber and the measuring bowl and open the two petcocks on holes through the cover assembly. Add water through the petcock on the cover assembly having the extension below until all air is expelled from the second petcock. Pump air into the air chamber until the pressure reaches the indicated initial pressure line. Allow a few seconds for the compressed air to cool to normal temperature. Stabilize the gage hand at the initial pressure line by pumping or bleeding off air as necessary, tapping the gage lightly. Close the petcock not provided with the tube or pipe extension on the under side of the cover. Remove water from the assembly to the calibrating vessel controlling the flow, depending on the particular meter design,

by opening the petcock provided with the tube or pipe extension and cracking the air valve between the air chamber and the measuring bowl, or by opening the air valve and using the petcock to control flow. Perform the calibration at an air content which is within the normal range of use. If the calibration vessel (A1.2) has a capacity within the normal range of use, remove exactly that amount of water. With some meters the calibrating vessel is quite small and it will be necessary to remove several times that volume to obtain an air content within the normal range of use. In this instance, carefully collect the water in an auxiliary container and determine the amount removed by weighing to the nearest 0.1 %. Calculate the correct air content,  $R$ , by using Eq A1.2. Release the air from the apparatus at the petcock not used for filling the calibration vessel and if the apparatus employs an auxiliary tube for filling the calibration container, open the petcock to which the tube is connected to drain the tube back into the measuring bowl (see A1.7.1). At this point of procedure the measuring bowl contains the percentage of air determined by the calibration test of the calibrating vessel. Pump air into the air chamber until the pressure reaches the initial pressure line marked on the pressure gage, close both petcocks in the cover assembly, and then open the valve between the air chamber and the measuring bowl. The indicated air content on the pressure gage dial should correspond to the percentage of air determined to be in the measuring bowl. If two or more determinations show the same variation from the correct air content, the dial hand shall be reset to the correct air content and the test repeated until the gage reading corresponds to the calibrated air content within 0.1 %. If the dial hand was reset to obtain the correct air content, recheck the initial pressure mark as in A1.5.2. If a new initial pressure reading is required, repeat the calibration to check the accuracy of the graduation on the pressure gage described earlier in this section. If difficulty is encountered in obtaining consistent readings, check for leaks, for the presence of water inside the air chamber (see Fig. 2), or the presence of air bubbles clinging to the inside surfaces of the meter from the use of cool aerated water. In this latter instance use deaerated water which can be obtained by cooling hot water to room temperature.

NOTE A1.7—If the calibrating vessel is an integral part of the cover assembly, the petcock used in filling the vessel should be closed immediately after filling the calibration vessel and not opened until the test is complete.



**SUMMARY OF CHANGES**

Committee C09 has identified the location of selected changes to this standard since the last issue (C 231 – 97<sup>e1</sup>) that may impact the use of this standard. (Approved July 10, 2003.)

- (1) Revised 1.5 by adding warning, deleting reference to procedural note, and adding footnote.
- (2) Revised 2.1 to update referenced designations and correct titles.
- (3) Corrected reference to dual designations in 1.2, 3.2, 4.15, 8.1.4, and Note 2.
- (4) Changed Note A1.7 to section A1.7.1 and renumbered subsequent Note A1.8 to Note A1.7.
- (5) Revised reference to Note A1.7 to reference section A1.7.1 in section A1.9.
- (6) Editorially corrected spelling, punctuation, references, and SI unit equivalents in Note 1, 4.5, 4.7, 6.2, 8.2.3, 8.3.2, 9.1, 9.2, Note 10, 10.1.3, and A1.4.1.
- (7) Revised 3.1 and 8.1.3 to improve wording.
- (8) Note 4 altered to remove mandatory language.
- (9) Volumetric SI units in 4.2 and 4.10 changed to litres.

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