Designation: C1040/C1040M – 16a

Standard Test Methods for In-Place Density of Unhardened and Hardened Concrete, Including Roller Compacted Concrete, By Nuclear Methods[1]

This standard is issued under the fixed designation C1040/C1040M; 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 These test methods cover the determination of the in-place density of unhardened and hardened concrete, including roller compacted concrete, by gamma radiation. For notes on the nuclear test see Appendix X1.

1.2 Two test methods are described, as follows:

	Section
Test Method A—Direct Transmission	8
Test Method B—Backscatter	9

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C29/C29M Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate

C125 Terminology Relating to Concrete and Concrete Aggregates

C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in these test methods, refer to Terminology C125.

4. Significance and Use

4.1 These test methods are useful as rapid, nondestructive techniques for the in-place determination of the density of unhardened concrete. The backscatter test method is also useful for the same purpose on hardened concrete. The fundamental assumptions inherent in the test methods are that Compton scattering is the dominant interaction and that the material under test is homogeneous.

4.2 These test methods are suitable for control and for assisting in acceptance testing during construction, for evaluation of concrete quality subsequent to construction, and for research and development.

NOTE 1—Care must be taken when using these test methods in monitoring the degree of consolidation, which is the ratio of the actual density achieved to the maximum density attainable with a particular concrete. The test methods presented here are used to determine the actual density. A density measurement, by any test method, is a function of the components of the concrete and may vary, to some extent, in response to the normal, acceptable variability of those components.

4.3 Test results may be affected by reinforcing steel, by the chemical composition of concrete constituents, and by sample heterogeneity. The variations resulting from these influences are minimized by instrument design and by the user's compliance with appropriate sections of the test procedure. Results of tests by the backscatter test method may also be affected by the density of underlying material. The backscatter test method exhibits spatial bias in that the apparatus's sensitivity to the material under it decreases with distance from the surface of the concrete.

NOTE 2—Typically, backscatter gauge readings represent the density in the top 75 to 100 mm [3 to 4 in.] of material.

5. Apparatus

5.1 The exact details of construction of the apparatus may vary, but the apparatus as a whole shall satisfy the requirements for system precision stated in Annex A1. The system shall consist of the following:

[1] These test methods are under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregatesand are the direct responsibility of Subcommittee C09.45 on Roller-Compacted Concrete.

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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.

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

5.1.1 *Gamma Source*—An encapsulated and sealed radioisotopic source, such as cesium-137 (see X1.3).

5.1.2 *Detector*—Any type of gamma detector, such as a Geiger-Müller tube, scintillation crystal, or proportional counter.

5.1.3 *Probe*—For direct transmission measurements, either the gamma source or the detector shall be housed in a probe for inserting in a preformed hole in the material to be tested. The probe shall be marked in increments of 50 mm [2 in.] for tests with probe depths from 50 to 300 mm [2 to 12 in.]. The probe shall be so made mechanically, that when moved manually to the marked depth desired, it will be held securely in position at that depth.

5.1.4 *Readout Instrument*—A suitable scaler or direct readout meter.

5.1.5 *Gauge Housing*—The source, detector, readout instrument and appropriate power supplies shall be in housings of rugged construction that are moisture and dust proof.

5.1.6 *Reference Standard*—A block of uniform, unchanging density provided for checking equipment operation, background count, and count-rate reproducibility.

5.1.7 *Guide Plate and Hole-Forming-Device*—For direct transmission measurements, a guide plate and a device, such as a pin or drill rod, having a nominal diameter slightly larger than the probe, for forming a hole normal to the concrete surface are required.

5.1.8 *Calibration Adjustment Container*—The container shall be rigid and watertight, with minimum inside dimensions large enough to allow the calibration curve adjustment procedure (6.2) to be followed with no effect of the finite size of the container on the instrument's responses. The volume of the container shall be established following the procedure outlined in Test Method C29/C29M.

NOTE 3—For backscatter measurements, a container 450 by 450 by 150 mm [18 by 18 by 6 in.] will meet this requirement for most equipment currently available commercially. For 50-mm [2-in.] depth direct transmission measurements, a container 600 by 600 by 100 mm [24 by 24 by 4 in.] will meet this requirement.

5.1.9 *Scale*—The scale shall be accurate to within 0.2 kg [0.5 lb] of the test load at any point within the range of use. The range of use shall be considered to extend from the weight of the calibration adjustment container empty, to the weight of the measure plus the contents at 2600 kg/m^3 [160 lb/ft^3].

5.1.10 *Strike-Off Plate or Bar*—This shall be a flat metal or glass plate or metal bar with a length at least 50 mm [2 in.] greater than the length, width, or diameter of the calibration adjustment container. The strike-off must be rigid, straight, and smooth enough to finish the concrete surface flat and flush with the edges of the calibration adjustment container.

6. Calibration

6.1 Calibration curves are established by determining the nuclear count rate of each of several materials at different and known densities, plotting the count rate (or count ratio) versus each known density, and placing a curve through the resulting points. The method used to establish the curve must be the same as that used to determine the density. The materials used for calibration must be of uniform density.

NOTE 4—Calibration curves are supplied by gauge manufacturers, or can be established using blocks of known density or prepared containers of uniform, unchanging material compacted to known densities. Materials considered satisfactory for use in blocks include granite, aluminum, chalk, limestone, and magnesium.

6.2 *Adjusting Calibration Curves*—Prior to use, adjust the instrument's calibration curve, if necessary, to compensate for chemical composition effects. Such an adjustment is necessary whenever the chemical composition of the concrete to be tested differs significantly from that for which the calibration curve was established. An adjustment is also necessary if the testing equipment has been changed. Adjustment is particularly important for backscatter test method measurements. Determine the necessary adjustments using the same mode of operation and at the same depth (if using direct transmission) as that intended for testing. A recommended procedure for making this adjustment is as follows:

6.2.1 Prepare a concrete mix similar in composition to the material to be tested subsequently.

6.2.2 Fill the calibration adjustment container with concrete and consolidate to produce a uniform, homogeneous material with approximately the density that will be achieved in the construction.

NOTE 5—Consolidation may be achieved by the procedure used for unit weight testing (Test Method C138/C138M) or by other methods, such as spading the concrete and then dropping the ends of the container alternately on a rigid surface.

6.2.3 Strike off the container with strike-off plate or bar. Take care to make the concrete surface flat and flush with the container edges.

NOTE 6—A2 mm [1⁄16 in.] average difference between the concrete surface and the container edges in a 150 mm [6 in.] deep container will produce a 1 to 2 % error in the weighed density of the concrete.

6.2.4 Weigh the concrete in the container to the nearest 0.2 kg [0.5 lb] and determine the weighed density as follows:

$$W = \frac{W_c}{V} \tag{1}$$

where:

W = weighed density of concrete, kg/m^3 [lb/ft^3],
W_c = mass of the concrete, kg [lb], and
V = volume of the container, m^3 [ft^3].

6.2.5 Immediately take three automatically timed direct transmission or backscatter readings with the instrument centered on the surface of the concrete in the container. Rotate the base of the instrument 90° around the vertical axis, with subsequent rotations of 180 and 270° from the original position. Obtain three additional automatically timed counts at each position. The instrument must be centered over the surface of the concrete in each rotated position to prevent edge effects on the instrument reading.

6.2.6 Using the applicable calibration curve, determine the density from the average of the 12 counts obtained in 6.2.5.

6.2.7 Determine the difference between the two density readings obtained in 6.2.4 and 6.2.6.

6.2.8 Repeat 6.2.2 – 6.2.7 on two additional concrete mixes of the same proportions. Determine the adjustment factor by averaging the three values obtained in 6.2.7 and 6.2.8. If one of the three values differs from the average by more than 25 kg/m^3 [1.5 lb/ft^3], discard it as a statistical outlier and recalculate the adjustment factor as the average of the remaining two values.

6.2.9 Use the adjustment factor determined in 6.2.8 to plot a corrected count-rate calibration curve which shall be parallel to the original calibration curve and offset by the amount indicated in 6.2.8. Alternatively, the value of the adjustment factor shall be attached to the instrument and applied to all density determinations arrived at from an original (unadjusted) calibration curve.

NOTE 7—In some circumstances, for example, where chemical composition changes are minimal, calibration curve adjustments may be established on permanent, uniform, hardened concrete blocks.

7. Standardization

7.1 Standardization of the equipment on the reference standard is required at the start of each day and whenever test measurements are suspect.

NOTE 8—In some older instrument models, count rates are strongly influenced by the ambient temperature; frequent standardization may be necessary.

7.2 Warm-up time shall be in accordance with the manufacturer's recommendations.

7.3 Take at least five readings on the reference standard, more if recommended by the manufacturer, or take one 4 min or longer count if the instrument is equipped with automatic standard count storage.

7.4 If more than one of the individual readings is outside the limit set by Eq 2, repeat the standardization. If the second attempt does not satisfy Eq 2, check the system for a malfunction. If no malfunction is found, establish a new N_o (average count) by taking the average of a minimum of 10 counts on the reference standard.

$$|N_s - N_o| < 1.96\sqrt{N_o} \quad (2)$$

where:

N_s = count currently measured in checking the instrument operation, and

N_o = average count previously established on the reference standard.

In instruments where the count has been prescaled, that is, divided by a constant factor k before it is displayed, Eq 2 shall be replaced by the following:

$$|N_s - N_o| < 1.96\sqrt{N_o/k} \quad (3)$$

7.4.1 If automatic standard count storage is used and the newly established count is outside the limit set by Eq 2, repeat the standardization.

7.4.2 If the second attempt does not satisfy Eq 2, check the system for a malfunction.

7.4.3 If no malfunction is found, establish a new N_o equal to the average count found in 7.4.2.

7.5 If a new N_o differs by more than 10 % from the standard count at which the calibration curve (6.1) was established, recalibrate the instrument.

TEST METHOD A—DIRECT TRANSMISSION (FOR UNHARDENED CONCRETE)

8. Procedure

8.1 Select a test location such that, when the gauge is placed in test position:

8.1.1 Any point on the source-detector axis shall be at least 230 mm [9 in.] from any pavement edge or object.

8.1.2 Reinforcing steel shall not be present in the volume bounded by the extended probe and the detector tubes.

8.1.3 The test location shall contain concrete to a depth 25 mm [1 in.] greater than that to which the probe will be inserted. In thin concrete overlay projects, this may require the removal of the underlying (original) concrete 25 to 50 mm [1 to 2 in.] down over a small area before placement of the overlay.

8.2 Smooth the surface with a wood float. If necessary, use the guide plate and hole-forming device (5.1.7) to make a hole slightly larger than the probe and perpendicular to the surface. In some concretes, the probe may be inserted directly into the concrete without the use of the guide plate and hole-forming device.

8.3 Insert the probe so that the side of the probe facing the center of the gauge is in intimate contact with the side of the hole. Keep all other radioactive sources at such a distance from the gauge that the readings will not be affected.

NOTE 9—The recommended minimum distance from other nuclear density gauges is 10 m [30 ft].

8.4 Use the same warm-up time as in standardization. Take automatically timed readings, for a minimum of 1 min, and determine the in-place density from the adjusted calibration curve. Alternatively, determine the in-place density from the unadjusted calibration curve and then apply the calibration adjustment factor (6.2.9). If the instrument has a direct reading display which is not programmed to apply the calibration adjustment factor (6.2.8), correct the displayed density by applying that factor.

TEST METHOD B—BACKSCATTER (FOR UNHARDENED OR HARDENED CONCRETE)

9. Procedure

9.1 Select a test location such that, when the gauge is placed in test position:

9.1.1 Any point on the source-detector axis shall be at least 230 mm [9 in.] from any pavement edge or object, and

9.1.2 No reinforcing steel with less than 75 mm [3 in.] of concrete cover shall lie directly under the source - detector axis, except as indicated in Note 10.

NOTE 10—The user may find that certain instrument models and operating modes allow gauges to operate over steel with as little as 40 mm [1½ in.] of concrete cover.

9.2 Prepare the test site in the following manner:

9.2.1 On unhardened concrete, smooth the surface with a wood float.

9.2.2 For best results on hardened concrete, find as smooth a surface as possible. Remove all loose material. The maximum void beneath the gauge shall not exceed 3 mm [⅛ in.].

Use fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool.

9.3 Seat the gauge firmly. Keep all other radioactive sources at such a distance from the gauge that the readings will not be affected (Note 9).

9.4 Use the same warm-up time as in standardization. Take automatically timed readings, for a minimum of 1 min, and determine the in-place density from the adjusted calibration curve (6.2.9). Alternatively, determine the in-place density from the unadjusted calibration curve and then apply the calibration adjustment factor. If the instrument has a direct reading display which is not programmed to apply the calibration adjustment factor (6.2.8), correct the displayed density by applying that factor.

NOTE 11—On lifts less than 75 mm [3 in.] thick, readings may be erroneous if the density of the underlying material differs significantly from that of the concrete being placed. Correction procedures are available for some gauge models.

10. Report

10.1 Report the following information:

10.1.1 Test method (direct transmission or backscatter),

10.1.2 Nature of concrete (hardened or unhardened),

10.1.3 Depth of probe, if using direct transmission,

10.1.4 Thickness of layer tested,

10.1.5 Identification of raw materials,

10.1.6 Mixture proportions,

10.1.7 Count rate for standardization, and

10.1.8 Count rate for each test reading and the converted mean density value, or the corrected direct reading density value, in kg/m^3 [lb/ft^3].

11. Precision and Bias

11.1 *Precision:*

11.1.1 *Round Robin Test Program*—A round robin program was executed involving five instruments and five operators. All tests were done on a single placement of RCC. Twelve sites were prepared for measurements, relying on the natural variation in the as-placed material among the sites to generate twelve different material properties. Each instrument-operator combination determined the density at each location three times. The instrument was removed and re-inserted before each new determination. The study resulted in 60 sets of three determinations. All instruments were of the same manufacture. A report of results and calculations is on file at ASTM.[3] The data used to develop the precision statement were obtained using the inch-pound version of this test method. The precision indices shown in SI units are exact conversions of the values in parentheses.

11.1.2 *Single-Operator, Single-Instrument Precision*—The single-instrument and single-operator standard deviation was found to be 8.0 kg/m^3 [0.5 lb/ft^3].[4] Therefore, results of two properly conducted tests by the same operator are not expected to differ by more than 22.4 kg/m^3 [1.4 lb/ft^3].[4]

11.1.3 *Multi-Operator, Multi-Instrument Precision*—The multi-operator and multi-instrument standard deviation was found to be 16.0 kg/m^3 [1.0 lb/ft^3].[4] Therefore, results of two properly conducted tests by the same operator are not expected to differ by more than 44.9 kg/m^3 [2.8 lb/ft^3].[4]

11.2 *Bias*—No statement on bias is being made because no standard reference concrete of known density is available.

12. Keywords

12.1 acceptance testing; backscatter measurement; concrete-density; density; direct transmission measurement; gamma radiation; in-place density; nuclear testing ; roller-compacted concrete

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:C09-1031.

[4] These numbers represent, respectively, the (1s) and (d2s) limits as described in Practice C670.

ANNEX

(Mandatory Information)

A1. DETERMINING PRECISION OF APPARATUS

A1.1 Instrument Count Precision:

A1.1.1 Instrument count precision is defined as the change in density that corresponds to a one standard deviation change in the count due to the random decay of the radioactive source. Instrument count precision is determined from the slope of the calibration curve and the statistical standard deviation of the count rate, as follows:

$$P = \sigma / S \quad \text{(A1.1)}$$

where:

P = instrument count precision, kg/m^3 [lb/ft^3],

σ = standard deviation, cpm (counts/minute), and

S = slope, cpm/kg/m^3 [cpm/lb/ft^3].

A1.1.2 The slope of the calibration curve is determined at the 2240 kg/m^3 [140 lb/ft^3] point and the standard deviation is calculated from ten individual automatically-timed readings taken on material with a density of 2240 ± 80 kg/m^3 [140 ± 5 lb/ft^3]. The gauge is not moved after seating for the first count. For a direct reading gauge, the instrument count precision, P, in kg/m^3 [lb/ft^3], is the standard deviation of ten individual automatically-timed density readings.

A1.1.3 The value of *P* shall be determined at least once every three months. The value of *P* shall be less than 16 kg/m^3 [1.0 lb/ft^3] for backscatter and less than 8 kg/m^3 [0.5 lb/ft^3] for direct transmission measurements.

APPENDIX

(Nonmandatory Information)

X1. NOTES ON THE NUCLEAR TEST

X1.1 Nuclear density gauges may use either the backscatter method or the direct transmission method to determine the density of the material. In the backscatter method for density, the source is lowered near the surface of the test material, in the same plane as the detectors. The gamma ray photons emitted from the source penetrate the test material and the scattered gamma ray photons are measured by the detectors. Measurements using the backscatter method are most effective to an approximate depth of 75 mm [3 in.] beneath the bottom of the gauge, with only approximately 7 % of the reading coming from below 75 mm [3 in.]. In the direct transmission method for density, the rod containing the source is lowered through the base of the gauge to the desired depth in a hole prepared using a drive pin. Gamma ray photons from the source travel through the test material, colliding with electrons present in the material, to the detectors in the gauge, where they are measured. Both methods involve the use of gamma radiation (gamma ray photons) which is high energy, short wavelength electromagnetic radiation that originates from the atomic nucleus. As stated in 4.1, one of the fundamental assumptions inherent in these test methods is that Compton scattering is the dominant interaction. Compton scattering is the interaction between a gamma ray photon and an orbital electron where the gamma ray photon loses energy and rebounds in a different direction.

X1.2 It should be noted that the volume of concrete represented in the measurements is indeterminate and will vary with (*1*) the source-detector geometry of the equipment used, and (*2*) with the characteristics of the material tested. In general, and with all other conditions constant, the denser the material, the smaller the volume involved in a backscatter measurement. The density so determined is not necessarily the average density within the volume involved in the measurement. Typically, backscatter gauge readings are influenced by 75 to 125 mm [3 to 5 in.] of material; the top 25 mm [1 in.] of the material determines 50 to 70 % of the measured count rate, and the top 50 mm [2 in.] determines 80 to 95 %. Where these materials are of uniform density, this characteristic of this test method is of no effect. However, reinforcing steel and underlying concrete are both often within the volume in which they may influence gauge readings. Also, the extent of the influence of vertical density variations, such as those caused by reinforcing steel, depends on the depth at which the steel is located.

X1.3 The use of cesium-137 and other radioisotope sources in density gauges is regulated and licensed by the U.S. Nuclear Regulatory Commission or, in agreement states, by state regulatory agencies. The primary objective of these regulations is the use of these materials in a manner safe to the operator, to other workers, and to the general public. While detailed safety procedures are beyond the scope of these test methods, the originating committee emphasized its support of these objectives. In order to meet regulatory agency requirements, gauge owners must establish effective operator instruction and use procedures, together with routine safety procedures, such as source leak tests, recording and evaluation of film badge data, the use of survey meters, etc., in connection with the operation of this type of equipment. Likewise, individual users of the equipment must complete a formal training program and must be familiar with possible safety hazards. Users should be particularly concerned about developing safe procedures for removing mortar while cleaning the source rod after direct transmission measurements.

X1.4 The determination of density in these test methods by the nuclear means is indirect. The relationship between nuclear gauge count rate and density necessarily is determined by correlation tests on materials at known average densities. Calibration curves established in this manner do not necessarily hold for all concretes because of differences in chemical composition. This effect is particularly significant for backscatter method measurements. Because of these considerations, provisions are included in these test methods for adjusting calibration curves on a project-by-project basis.

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to these test methods since the last issue, C1040/C1040M – 16, that may impact the use of these test methods. (Approved Dec. 15, 2016.)

(1) Revised X1.1 to clarify that this test method is referring to the measurement of density and that there are limitations to the depth of measurement in the backscatter method.