ASTM

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Standard Test Methods for
Density of Unhardened and Hardened Concrete In Place By Nuclear Methods[1]

1. Scope

1.1 These test methods cover the determination of the in-place density of unhardened and hardened concrete by gamma radiation. For notes on the nuclear test see Appendix X1.

1.2 Two test methods are described, as follows:

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Test Method A—Direct Transmission	7
Test Method B—Backscatter	8

1.3 The values stated in inch-pound units are to be regarded as the standard. The SI equivalents of inch-pound units may be approximate.

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:*
C 29/C 29M Test Method for Unit Weight and Voids in Aggregate[2]
C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]

3. Significance and Use

3.1 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.

3.2 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.

3.3 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.

4. Apparatus

4.1 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 10.1. The system shall consist of the following:

4.1.1 *Gamma Source*—An encapsulated and sealed radioisotopic source, such as cesium-137 (see X1.2).

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

4.1.3 *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 2 in. (50 mm) for tests with probe depths from 2 to 12 in. (50 to 300 mm). 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.

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

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

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

4.1.7 *Guide Plate and Hole-Forming-Device*—For direct

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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.

4.1.8 *Calibration Adjustment Container*— The container shall be rigid and watertight, with minimum inside dimensions large enough to allow the calibration curve adjustment procedure (5.2) 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 C 29/C 29M.

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

4.1.9 *Scale*—The scale shall be accurate to within 0.5 lb (0.2 kg) 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 160 lb/ft^3 (2600 kg/m^3).

4.1.10 *Strike-Off Plate or Bar*—This shall be a flat metal or glass plate or metal bar with a length at least 2 in. (50 mm) 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.

5. Calibration

5.1 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 3—Calibration curves are supplied by gage 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.

5.2 *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:

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

5.2.2 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 4—Consolidation may be achieved by the procedure used for unit weight testing (Test Method C 138) or by other methods, such as spading the concrete and then dropping the ends of the container alternately on a rigid surface.

5.2.3 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 5—A ¹⁄₁₆ in. (1.6 mm) average difference between the concrete surface and the container edges in a 6 in. (150 mm) deep container will produce a 1.0 % error in the weighed density of the concrete.

5.2.4 Weigh the concrete in the container to the nearest 0.5 lb (250 g) and determine the weighed density as follows:

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

where:
W = weighed density of concrete, lb/ft^3 (kg/m^3),
W_c = weight of the concrete, lb (kg), and
V = volume of the container, ft^3 (m^3).

5.2.5 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.

5.2.6 Using the applicable calibration curve, determine the density from the average of the 12 counts obtained in 5.2.5.

5.2.7 Determine the difference between the two density readings obtained in 5.2.4 and 5.2.6.

5.2.8 Repeat 5.2.2-5.2.7 on two additional concrete mixes of the same proportions. Determine the adjustment factor by averaging the three values obtained in 5.2.7 and 5.2.8. If one of the three values differs from the average by more than 1.5 lb/ft^3 (24 kg/m^3), discard it as a statistical outlier and recalculate the adjustment factor as the average of the remaining two values.

5.2.9 Use the adjustment factor determined in 5.2.8 to plot a corrected count-rate calibration curve which shall be parallel to the original calibration curve and offset by the amount indicated in 5.2.8. 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 6—In some circumstances, for example, where chemical composition changes are minimal, calibration curve adjustments may be established on permanent, uniform, hardened concrete blocks.

6. Standardization

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

NOTE 7—In some older instrument models, count rates are strongly influenced by the ambient temperature; frequent standardization may be necessary.

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

6.3 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.

6.4 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.

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

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:

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

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

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

6.4.3 If no malfunction is found, establish a new N_o equal to the average count found in 6.4.2.

6.5 If a new N_o differs by more than 10 % from the standard count at which the calibration curve (5.1) was established, recalibrate the instrument.

TEST METHOD A—DIRECT TRANSMISSION (FOR UNHARDENED CONCRETE)

7. Procedure

7.1 Select a test location such that, when the gage is placed in test position:

7.1.1 Any point on the source-detector axis shall be at least 9 in. (230 mm) from any pavement edge or object.

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

7.1.3 The test location shall contain concrete to a depth 1 in. (25 mm) 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 1 to 2 in. (25 to 50 mm) down over a small area before placement of the overlay.

7.2 Smooth the surface with a wood float. If necessary, use the guide plate and hole-forming device (4.1.7) 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.

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

NOTE 8—Thirty feet (10 m) is the recommended minimum distance from other nuclear density gages.

7.4 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 (5.2.9). If the instrument has a direct reading display which is not programmed to apply the calibration adjustment factor (5.2.8), correct the displayed density by applying that factor.

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

8. Procedure

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

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

8.1.2 No reinforcing steel with less than 3 in. (75 mm) of concrete cover shall lie directly under the source - detector axis, except as indicated in Note 9.

NOTE 9—The user may find that certain instrument models and operating modes allow gages to operate over steel with as little as 1½ in. (38 mm) of concrete cover.

8.2 Prepare the test site in the following manner:

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

8.2.2 For best results on hardened concrete, find as smooth a surface as possible. Remove all loose material. The maximum void beneath the gage shall not exceed ⅛in. (3 mm). Use fine sand to fill these voids and smooth the surface with a rigid plate or other suitable tool.

8.3 Seat the gage firmly. Keep all other radioactive sources at such a distance from the gage that the readings will not be affected (Note 8).

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 (5.2.9). 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 (5.2.8), correct the displayed density by applying that factor.

NOTE 10—On lifts less than 3 in. (75 mm) 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 gage models.

9. Report

9.1 Report the following information:
9.1.1 Test method (direct transmission or backscatter),
9.1.2 Nature of concrete (hardened or unhardened),
9.1.3 Depth of probe, if using direct transmission,
9.1.4 Thickness of layer tested,
9.1.5 Identification of raw materials,
9.1.6 Mixture proportions,

9.1.7 Count rate for standardization, and

9.1.8 Count rate for each test reading and the converted mean density value, or the corrected direct reading density value, in lb/ft ^{3} (kg/m^3).

10. Precision and Bias

10.1 *Precision*—The precision of the instrument is determined from the slope of the calibration curve and the statistical standard deviation of the count rate, as follows:

$$P = \sigma/S$$

where:
P = precision, lb/ft^3 (kg/m^3),
σ = standard deviation, cpm (counts/minute), and
S = slope, cpm/lb/ft^3 (cpm/kg/m^3).

10.1.1 The slope of the calibration curve is determined at the 140 lb/ft^3 (2240 kg/m^3) point and the standard deviation is calculated from ten individual automatically-timed readings taken on 140 $\pm$ 5 lb/ft^3 (2240 $\pm$ 80 kg/m^3) material. The gage is not moved after seating for the first count. For a direct reading gage, the precision, P, in lb/ft^3 (kg/m^3), is the standard deviation of 10 individual automatically-timed density readings. The value of P shall be less than 1.0 lb/ft^3 (16 kg/m^3) for backscatter and 0.5 lb/ft^3 (8 kg/m^3) for direct transmission measurements.

10.2 *Bias*—The bias of the procedure in these test methods has not been determined because there is no accepted method to which these test methods can be compared. Possible bias is minimized by adjusting the nuclear gage's calibration curve after comparing gage readings to the gravimetrically determined densities of concretes in fixed-volume containers (5.2).

11. Keywords

11.1 acceptance testing; backscatter measurement; concrete-density; density; direct transmission measurement; gamma radiation; in-place density; nuclear testing

APPENDIX

(Nonmandatory Information)

X1. NOTES ON THE NUCLEAR TEST

X1.1 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 gage readings are influenced by 3 to 5 in. (75 to 125 mm) of material; the top 1 in. (25 mm) of the material determines 50 to 70 % of the measured count rate, and the top 2 in. (50 mm) 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 gage 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.

X1.2 The use of cesium-137 and other radiosotope sources in density gages 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, gage 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.

X1.3 The determination of density in these test methods by the nuclear means is indirect. The relationship between nuclear gage 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.

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