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Standard Test Method for Density of Bituminous Concrete in Place by Nuclear Methods[1]

This standard is issued under the fixed designation D 2950; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

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

1. Scope

1.1 This test method describes a test procedure for determining the density of bituminous concrete by the attenuation of gamma radiation, where the source and detector(s) remain on the surface (Backscatter Method) or the source or detector is placed at a known depth up to 300 mm (12 in.) while the detector or source remains on the surface (Direct Transmission Method).

1.2 The density, in mass per unit volume of the material under test, is determined by comparing the detected rate of gamma emissions with previously established calibration data.

1.3 *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.* For specific warning statements see Section 6 and Note 4.

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

2. Referenced Documents

2.1 *ASTM Standards:*

D 1188 Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Paraffin-Coated Specimens[2]

D 1559 Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus[2]

D 2041 Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures[2]

D 2726 Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures[2]

D 3665 Practice for Random Sampling of Construction Materials[2]

3. Significance and Use

3.1 The test method described is useful as a rapid, nondestructive technique for determining the in-place density of compacted bituminous mixtures.

3.2 With proper calibration and confirmation testing, the test method is suitable for quality control and acceptance testing of compacted bituminous concrete.

3.3 The test method can be used to establish the proper rolling effort and pattern to achieve the required density.

3.4 The non-destructive nature of the test allows repetitive measurements to be made at a single test location between roller passes and to monitor changes in density.

3.5 The density results obtained by this test method are relative. Correlation with other test methods such as D 1188 or D 2726 are required to convert the results obtained using this method to actual density. It is recommended that at least seven core densities and seven nuclear densities be used to establish a conversion factor. A new factor must be established at any time a change is made in the paving mixture or in the construction process.

4. Interferences

4.1 The chemical composition of the material being tested may significantly affect the measurement and adjustments may be necessary. Certain elements with atomic numbers greater than 20 may cause erroneously high test values.

4.2 The test method exhibits spatial bias in that the instrument is most sensitive to the density of the material in closest proximity to the nuclear source.

4.2.1 When measuring the density of an overlay, it may be necessary to employ a correction factor if the underlying material varies in thickness, mineral composition or degree of consolidation at different points within the project. (See Annex A3.)

4.2.2 The surface roughness of the material being tested may cause lower than actual density determination.

4.3 Oversize aggregate particles in the source-detector path may cause higher than actual density determination.

4.4 The sample volume being tested is approximately 0.0028 m^3 (0.0989 ft^3) for the Backscatter Method and 0.0056 m^3 (0.198 ft^3) for the Direct Transmission Method. The actual sample volume varies with the apparatus and the density of the material. In general, the higher the density the smaller the volume (Note 1).

NOTE 1—The volume of field compacted material represented by a test

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[1] This test method is under the jurisdiction of ASTM Committee D-4 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.21 on Specific Gravity and Density of Bituminous Mixtures.

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[2] *Annual Book of ASTM Standards*, Vol 04.03.

can be effectively increased by repeating the test at adjacent locations and averaging the results.

4.5 If samples of the measured material are to be taken for purposes of correlation with other test methods such as D 1188 or D 2726, the volume measured can be approximated by a 200 mm (8 in.) diameter cylinder located directly under the center line of the radioactive source and detector(s). The height of the cylinder to be excavated will be the depth setting of the source rod when using the Direct Transmission Method or approximately 75 mm (3 in.) when using the Backscatter Method (Note 2).

NOTE 2—If the layer of bituminous concrete to be measured is less than the depth of measurement of the instrument, corrections must be made to the measurements to obtain accurate results due to the influence of the density of the underlying material. (See Annex A3. for the method used.)

5. Apparatus

5.1 *Nuclear Device*— An electronic counting instrument, capable of being seated on the surface of the material under test, and which contains:

5.1.1 *Gamma Source*— A sealed high energy gamma source such as cesium or radium, and

5.1.2 *Gamma Detector*— Any type of gamma detector such as a Geiger-Mueller tube(s).

5.2 *Reference Standard*—A block of dense material used for checking instrument operation and to establish conditions for a reproducible reference-count rate.

5.3 *Site Preparation Device*—A metal plate, straightedge, or other suitable leveling tool which may be used to level the test site to the required smoothness using fine sand or similar material.

5.4 *Drive Pin*—A steel rod of slightly larger diameter than the rod in the Direct Transmission Instrument, to prepare a perpendicular hole in the material under test for inserting the rod. A drill may also be used.

6. Hazards

6.1 This equipment utilizes radioactive materials which may be hazardous to the health of the users unless proper precautions are taken. Users of this equipment must become familiar with applicable safety procedures and government regulations.

6.2 Effective user instructions together with routine safety procedures, such as source leak tests, recording and evaluation of film badge data, etc. are a recommended part of the operational guidelines for the use of this instrument.

6.3 A regulatory agency radioactive materials license may be required to possess this equipment.

7. Calibration

7.1 Calibrate the instrument in accordance with Annex A1. at least once each year. Adjust the calibrations as necessary in accordance with Annex A2.

8. Standardization and Reference Check

8.1 Nuclear test devices are subject to long-term aging of the radioactive source, detectors, and electronic systems, which may change the relationship between count rate and material density. To offset this aging, the apparatus may be standardized as the ratio of the measured count rate to a count rate made on a reference standard. The reference count rate should be of the same order of magnitude as the measured count rate over the useful density range of the apparatus.

8.2 Standardization of equipment should be performed at the start of each day's work, and a permanent record of this data retained.

8.2.1 Perform the standardization with the apparatus located at least 8 m (25 ft) away from other sources of radioactivity and clear of large masses or other items which may affect the reference count rate.

8.2.2 Turn on the apparatus prior to standardization and allow it to stabilize. Follow the manufacturer's recommendations in order to provide the most stable and consistent results.

8.2.3 Using the reference standard, take at least four repetitive readings at the normal measurement period and determine the mean. If available on the apparatus, one measurement period of four or more times the normal period is acceptable. This constitutes one standardization check.

8.2.4 If the value obtained in 8.2.3 is within the following stated limits, the apparatus is considered to be in satisfactory operating condition and the value may be used to determine the count ratios for the day of use. If the value is outside these limits, allow additional time for the apparatus to stabilize, make sure the area is clear of sources of interference and then conduct another standardization check. If the second standardization check is within the limits, the apparatus may be used, but if it also fails the test, the apparatus shall be adjusted or repaired as recommended by the manufacturer. The limits are as follows:

$$|N_s - N_o| \leq 2.0\sqrt{N_o/F} \quad (1)$$

where:

N_s = value of current standardization count,
N_o = average of the past four values of N_s taken previously, and
F = value of any prescale.

NOTE 3—The count per measurement periods shall be the total number of gammas detected during the timed period. The displayed value must be corrected for any prescaling which is built into the instrument. The prescale value (F) is a divisor which reduces the actual value for the purpose of display. The manufacturer will supply this value if other than 1.0.

8.3 Use the value of N_s to determine the count ratios for the current day's use of the instrument. If for any reason the measured density becomes suspect during the day's use, perform another standardization check.

9. Procedure

9.1 In order to provide more stable and consistent results: (*1*) Turn the instrument on prior to use to allow it to stabilize, and (*2*) Leave the power on druing the day's testing.

9.2 Standardize the apparatus.

9.3 Select a test location in accordance wtih the project specifications, or, if not otherwise specified, in accordance with Practice D 3665. If the instrument will be closer than 250 mm (10 in.) to any vertical mass that may influence the result, follow the instrument manufacturer's correction procedure.

9.4 Maximum contact between the base of the instrument and the surface of the material under test is critical. The maximum void shall not exceed 6 mm (¼ in.). Use native fines or fine sand to fill the voids and level with the guide/scraper plate.

9.5 For the Direct Transmission Method use the guide/scraper plate and drive the steel rod to a depth of at least 25 mm (1 in.) deeper than the desired measurement depth.

NOTE 4—**Caution:** Extreme care must be taken when driving the rod into compacted bituminous concrete as it may cause a disturbance of the material which could cause errors in the measurement. Drilling may be more suitable.

9.6 Place the source in the proper position. For the Direct Transmission Method measurements move the instrument so that the rod is firmly against the side of the hole in the gamma measurement path.

9.7 Take a count for the normal measurement period. If the Backscatter Method using the Air Gap Technique is used take an additional measurement in the air-gap position as recommended by the manufacturer. (See Note 2)

9.8 Determine the ratio of the reading to the standard count or the air-gap count. From this ratio and the calibration and adjustment data, determine the in-place density. (See Note 5 and Note 6)

NOTE 5—Some instruments have built-in provisions to compute the ratio, bulk (or wet) density, and allow an adjustment bias.

NOTE 6—If the depth of the bituminous concrete layer under test is less than the depth of measurement of the instrument, the value obtained in 9.8 must be adjusted. (See Annex A3.)

NOTE 7—Do not leave the gage on a hot surface for an extended period of time. Prolonged high temperatures may adversely affect the instrument's electronics. The gage should be allowed to cool between measurements.

10. Calculation of Results

10.1 Using the calibration chart, calibration tables, or equation, and coefficients, or instrument direct readout feature, with appropriate calibration adjustments, determine the in-place density. This is the bulk (or wet) density.

10.1.1 An adjustment bias can be calculated by comparing the results from a number of instrument measurements to the results obtained using Test Method D 2726.

10.2 Compare the results obtained to samples compacted by Test Method D 1559 or with the results of test methods such as D 2041 to determine acceptability (percentage of compaction).

11. Report

11.1 Report the following information:

11.1.1 Make, model, and serial number of the test apparatus,

11.1.2 Date and source of calibration data,

11.1.3 Date of test,

11.1.4 Standard count for the day of the test,

11.1.5 Test site description including project identification number, location and mixture type(s),

11.1.6 Thickness of layer tested and any adjustment bias,

11.1.7 Method of measurement (backscatter or direct transmission), depth, count rate, calculated density of each measurement and any adjustment data, and

11.1.8 Percentage of compaction, if required.

12. Precision and Bias

12.1 *Precision*:

12.1.1 While an instrument count precision of 10 kg/m ^{3} (0.62 lbf/ft^3) for the Backscatter Method and 5 kg/m ^{3} (0.31 lbf/ft^3) for the Direct Transmission Method is typical on a material of approximately 2.25 mg/m^3 (140 lbf/ft^3) density, with a measurement time of one minute, it only applies to the instrument for repetitive measurements at the same location.

12.1.2 Instrument count precision is defined as the change in density that occurs corresponding to a one standard deviation change in the count due to the random decay of the radioactive source. The density of the material should be in the approximate range of 2150 and 2350 kg/m ^{3} (135 to 145 lbf/ft^3). Both the density of the material and the time period of the count must be stated. It may be determined from a series of 20 or more counts taken without moving the instrument, or alternately from the calibration data using the assumption that σ is equal to the $\sqrt{\text{count}}$ at that density. The count must be the true instrument count corrected for any pre-scaling.

$$P = \frac{\sigma}{S} \tag{2}$$

where:
P = apparatus precision in density (kg/m^3 or lbf/ft^3),
σ = one standard deviation of the count, and
S = the slope of the calibration curve at the defined density value.

12.2 *Bias*:

12.2.1 Due to the variability in materials and construction practices, no methods are presently available that provide sufficiently accurate values of density of bituminous concrete against which this test can be compared. Accordingly, a statement of method bias cannot be made.

13. Keywords

13.1 bituminous-concrete density; density; in-place density; nuclear test method

ANNEXES

(Mandatory Information)

A1. CALIBRATION

A1.1 Calibration of the apparatus shall be in accordance with the manufacturer's recommended procedures for the instrument.

A1.2 At least once each year and after all major repairs which may affect the instrument geometry, the calibration curves, tables, or equation coefficients shall be verified or reestablished.

A1.3 The instrument shall be calibrated in such a way as to produce a calibration response within $\pm$ 16 kg/m^3 ($\pm$1.0 lbf/ft^3) on blocks of materials (standards) of established densities. Because nuclear instrument response is influenced by the chemical composition of measured material, the chemical composition of the standard blocks must be taken into account in establishing the standard density. The densities of materials used to establish or verify the calibration should extend through a range wide enough to include the types and density of the in-place materials to be tested.

A1.4 Sufficient data shall be taken on each density standard to ensure an instrument count precision of at least one-half the instrument count precision required for field use. The data may be presented in the form of a graph, table, equation coefficients, or stored in the apparatus to allow converting the count-rate data to material density.

A1.5 The method and test procedures used in establishing the count-rate data shall be the same as those used for obtaining the count-rate data for in-place material.

A1.6 The material type, density, and calculated material equivalent density of each calibration standard used to establish or verify the instrument calibration shall be stated as part of the calibration data.

A1.7 *Calibration Standards:*

A1.7.1 Calibration standards may be established using one of the following methods. The standards shall be of sufficient size to not change the count rate if enlarged in any dimension (Note A1.1).

NOTE A1.1—Minimum surface dimensions of approximately 610 mm long by 430 mm wide (24 by 17 in.) have proven satisfactory. For the Backscatter Method a minimum depth of 230 mm (9 in.) is adequate. For the Direct Transmission Method the depth shall be at least 50 mm (2 in.) deeper than the deepest rod depth. A larger surface area may be required for the Backscatter Method using the Air-Gap technique. Minimum surface dimensions may be reduced slightly if the standards are adjacent to a dense material.

A1.7.1.1 Prepare standards of soil and rock compacted to a range of densities. In building the standards, place the material in lifts whose thickness depends upon the compaction equipment available. Each lift is to receive equal compactive effort. Calculate the density of each standard based on the measured volume and mass of the standard.

A1.7.1.2 Prepare standards of in-place concrete using different aggregates and aggregate mixes to obtain a range of densities. The concrete shall be placed in a way that will ensure a uniform mixture and uniform densities of the standards. Calculate the density of each standard based on the measured volume and mass of the standard.

A1.7.1.3 Prepare standards of stable non-soil materials. Determine the soil and rock equivalent density of each standard based on the measured volume and mass of the standard.

NOTE A1.2—Standards prepared using magnesium, aluminum or laminated blocks of magnesium/aluminum sheets of equal thickness (maximum 1.0 mm) as well as solid blocks of granite and limestone have been used successfully for years in establishing and verifying calibrations.

A1.7.1.4 The density of these standards shall be determined to an accuracy of $\pm$0.3 %.

A2. CALIBRATION ADJUSTMENTS

A2.1 The calibration response shall be checked by the user prior to performing tests on materials that are distinctly different from the material types used in establishing the calibration. The calibration response shall also be checked on newly acquired or repaired apparatus.

A2.2 Take a sufficient number of measurements and compare them to other accepted methods such as volumetric sampling (Test Method D 2726) to establish a correlation between the apparatus calibration and the other method(s).

A3. DETERMINATION OF DEPTH OF MEASUREMENT

A3.1 The depth of measurement is characteristic of a particular instrument design and may be defined as that depth, measured from the surface, at which a significant change in density will not result in change in the measurement.

A3.1.1 Determine the depth by measuring the apparent density of top layers of uniform density but varying thicknesses placed over a base layer having a highly different density. Vary the thickness of the top layer until a constant density as determined by the instrument is reached (Note A3.2).

NOTE A3.1—For lift thicknesses of 51 mm (2 in.) or less, the backscatter mode is suggested; for lift thicknesses greater than 51 mm (2 in.) the direct transmission mode is suggested. Thin lift gages can be used for lift thicknesses up to 102 mm (4 in.).

NOTE A3.2—Materials such as magnesium and aluminum in sheet form have proven to be satisfactory for the top layer. Blocks of magnesium and aluminum used as calibration standards are useful as the base material.

A3.1.2 Plot the results on graph paper and determine the depth at which the apparent measured density is equal to the calculated density. This determination should be made for both a lower density material and a higher density material as the top layer. The depth of measurement is the average of the two results.