Designation: D 3017 – 96$^{\epsilon 1}$

Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)[1]

This standard is issued under the fixed designation D 3017; 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.

ϵ^1 NOTE—Table 1 was corrected editorially in December 1997.

1. Scope

1.1 This test method covers the determination of water content of soil and rock by the thermalization or slowing of fast neutrons where the neutron source and the thermal neutron detector both remain at the surface.

1.2 The water content in mass per unit volume of the material under test is determined by comparing the detection rate of thermalized or slow neutrons with previously established calibration data.

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

1.3.1 It is common practice in the engineering profession to concurrently use pounds to represent both a unit of mass (lbm) and of force (lbf). This implicitly combines two systems of units, that is, the absolute system and the gravitational system. This standard has been written using the absolute system for water content (kilograms per cubic metre) in SI units. Conversion to the gravitational system of unit weight in lbf/ft^3 may be made by multiplying by 0.06243 or in kN/m^3 by multiplying by 9.807. The recording of water content in pound-force per cubic foot should not be regarded as non-conformance with this standard although the use is scientifically incorrect.

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:*

D 1556 Test Method for Density of Soil in Place by the Sand-Cone Method[2]

D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method[2]

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[2]

D 2922 Test Methods for Density of Soil and Soil Aggregate and Rock in Place by Nuclear Methods (Shallow Depth)[2]

D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method[2]

D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method[2]

D 4718 Practice for Correction of Unit Weight and Water Content for Soils Containing Oversize Particles[2]

3. Significance and Use

3.1 The test method described is useful as a rapid, nondestructive technique for the in-place determination of water content of soil and rock.

3.2 The test method is used for quality control and acceptance testing of compacted soil and rock for construction and for research and development. The non-destructive nature allows repetitive measurements at a single test location and statistical analysis of the results.

3.3 The fundamental assumptions inherent in the test method are that the hydrogen present is in the form of water as defined by Test Method D 2216, and that the material under test is homogeneous.

3.4 Test results may be affected by chemical composition, sample heterogeneity, and, to a lesser degree, material density and the surface texture of the material being tested. The technique also exhibits spatial bias in that the apparatus is more sensitive to water contained in the material in close proximity to the surface and less sensitive to water at deeper levels.

4. Interferences

4.1 The chemical composition of the sample may dramatically affect the measurement and adjustments may be necessary. Hydrogen in forms other than water, as defined by Test Method D 2216, and carbon will cause measurements in excess of the true value. Some chemical elements such as boron, chlorine, and minute quantities of cadmium will cause measurements lower than the true value.

4.2 The water content determined by this test method is not

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

necessarily the average water within the volume of the sample involved in the measurement. The measurement is heavily influenced by the water content of the material closest to the surface. The volume of soil and rock represented in the measurement is indeterminate and will vary with the water content of the material. In general, the greater the water content of the material, the smaller the volume involved in the measurement. At 160 kg/m^3 (10 lbf/ft^3), approximately 50 % of the typical measurement results from the water content of the upper 50 to 75 mm (2 to 3 in.).

4.2.1 If samples of the measured material are to be taken for purposes of correlation with other test methods or rock correction, the volume measured can be approximated by a 200-mm (8 in.) diameter cylinder located directly under the center line of the fast neutron source and thermal neutron detector. The height of the cylinder to be excavated is approximated by:

Moisture Content		Cylinder Height		Volume	
kg/m^3	lbf/ft^3	mm	in.	m^3	ft^3
80	5	250	10	0.0079	0.29
160	10	200	8	0.0063	0.23
240	15	150	6	0.0047	0.17
320	20	125	5	0.0039	0.15
400	25	112	4.5	0.0035	0.13
480	30	100	4	0.0031	0.12

NOTE 1—The volume of field compacted material sampled by the test can effectively be increased by repeating the test at immediately adjacent (vertically or horizontally) locations and averaging the results.

4.3 Other neutron sources must not be within 8 m (25 ft) of equipment in operation.

5. Apparatus

5.1 While exact details of construction of the apparatus may vary, the system shall consist of:

5.1.1 *Fast Neutron Source*—A sealed mixture of a radioactive material such as americium or radium and a target material such as beryllium.

5.1.2 *Slow Neutron Detector*—Any type of slow neutron detector such as boron trifluoride or helium-3 proportional counter.

5.1.3 *Readout Device*—A suitably timed scaler(s). Usually the readout device will contain the high-voltage supply necessary to operate the detector, and low-voltage power supply to operate the readout and accessory devices.

5.1.4 *Housing*—The source, detector, readout device, and power supply shall be in housings of rugged construction which shall be water and dust resistant.

5.1.5 *Reference Standard*—A block of hydrogeneous material for checking equipment operation and to establish conditions for a reproducible count rate.

5.1.6 *Site Preparation Device*—A steel plate, straightedge, or other suitable leveling tools which may be used to plane the test site to the required smoothness.

5.2 Calibrate apparatus in accordance with Annex A1.

5.3 Determine the precision of the apparatus in accordance with Annex A2.

6. Hazards

6.1 This equipment utilizes radioactive materials which may be hazardous to the health of the users unless proper precautions are taken.

6.2 Effective operator instruction together with routine safety procedures such as source leak tests, recording and evaluation of film badge data, use of survey meters, etc., are a recommended part of the operation of equipment of this type.

7. Standardization

7.1 All nuclear water content instruments are subject to long-term aging of the radioactive source, detectors, and electronic systems, which may change the relationship between count rate and water content. To offset this aging, instruments are calibrated as a ratio of the measurement count rate to a count rate made on a reference standard. The reference count rate should be in the same or higher order of magnitude than the range of measurement count rates over the useful water range of the equipment.

7.2 Standardization of equipment on the reference standard is required at the start of each day's use and a permanent record of these data shall be retained. The standardization shall be performed with the equipment located at least 8 m (25 ft) away from other gages and clear of large masses of water or other items which may affect the gage readings.

7.2.1 Turn on the instrument and allow for stabilization in accordance with the manufacturer's recommendations. If the instrument is to be used either continuously or intermittently during the day, it is generally best to leave it in the "power on" condition to prevent having to repeat the stabilization. This will provide more stable, consistent results.

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

7.2.3 If the value obtained above is within the limits stated below, the equipment is considered to be in satisfactory condition and the value may be used to determine the count ratios for the day of use. If the value obtained is outside these limits, another standardization check should be made. If the second standardization check is within the limits, the equipment may be used, but if it also fails the test, the equipment shall be adjusted or repaired as recommended by the manufacturer.

$$N_s \leq N_o + \frac{2.0\sqrt{N_o}}{\sqrt{F}} \quad (1)$$

and

$$N_s \geq N_o - \frac{2.0\sqrt{N_o}}{\sqrt{F}} \quad (2)$$

where:

N_s = value of current standardization check (7.2.2) on the reference standard,

N_o = average of the past four values of N_s taken for prior usage, and

F = value of prescale (A2.2.1).

7.3 The value of N_s will be used to determine the count ratios for the current day's use of the equipment. If, for any reason, measured water content becomes suspect during the day's use, perform another standardization.

8. Procedure

8.1 Standardize the instrument (Section 7).

8.2 Select a location for test where the instrument in test position will be at least 250 mm (10 in.) away from any vertical projection.

8.3 Prepare the test site in the following manner:

8.3.1 Remove all loose and disturbed material, and remove additional material as necessary to reach the top of the vertical interval to be tested. Surface drying and the spatial bias should be considered in determining the depth at which the instrument is to be seated.

8.3.2 Prepare a horizontal area, sufficient in size to accommodate the instrument, by planing to a smooth condition so as to obtain maximum contact between the instrument and material being tested. If the instrument base is to be placed below the surrounding surface, the horizontal area shall be at least twice the area of the base of the instrument. If the depression is greater than 25 mm (1 in.), the condition in 8.2 must be met by clearing a larger area.

8.3.3 The placement of the instrument on the surface of the material to be tested is critical to the successful determination of water. The optimum condition is total contact between the bottom surface of the instrument and the surface of the material being tested. The maximum void beneath the instrument shall not exceed approximately 3 mm (⅛ in.). Use native fines of similar water content or dry quartz sand to fill voids and level the excess with a rigid plate or other suitable tool. The total area filled shall not exceed 10 % of the bottom area of the instrument.

8.4 Proceed with the test in the following manner:

8.4.1 Seat the instrument firmly, place the source in the proper position and take a count for the normal measurement period.

8.4.2 Determine the ratio of the reading to the standard count (Section 7). From this ratio and the calibration and adjustment data, determine the in-place water content per unit volume (Note 2).

NOTE 2—Some instruments have built-in provisions to compute the ratio, the water content per unit volume with adjustments, the dry density, and the water content in percent of dry density (or dry unit weight).

8.5 If the volume tested as defined in 4.2.1 is insufficient for the size of rock contained in the soil (refer to Practice D 4718), take additional tests at adjacent locations and average the results (Note 3).

NOTE 3—The water content value obtained should be compared to other water contents obtained for similar soils and conditions. The presence of a large rock particle or void in the soil being tested may give an unrepresentative value of water content. If the value is unusually high or low, another determination of water content should be performed. To avoid preparation of another test site, the gage may be repositioned (such as rotating the gage 90°) at the original site.

9. Calculation

9.1 Calculate the water content, w, in percent of dry density (or dry unit weight) of soil as follows:

$$w = \frac{M_m \times 100}{\rho_d} \quad (3)$$

or

$$w = \frac{M_m \times 100}{\rho - M_m} \quad (4)$$

where:

w = water content, percent of dry density,
M_m = water content, kg/m^3(lbf/ft^3),
ρ_d = dry density of soil (kg/m^3) or dry unit weight (lbf/ft^3), and
ρ = wet (total) density of soil (kg/m^3) or wet unit weight (lbf/ft^3).

10. Report

10.1 Report the following information:

10.1.1 Make, model, and serial number of the test device,

10.1.2 Standard count and adjustment data for the date of the tests,

10.1.3 Name of the operator,

10.1.4 Test site identification,

10.1.5 Visual description of material tested,

10.1.6 Count rate for each reading, if applicable,

10.1.7 Water content in kg/m^3 or lbf/ft ^{3},

10.1.8 Wet and dry densities in kg/m^3 or unit weights in lbf/ft^3,

10.1.9 Water content in percent of dry density or dry unit weight.

11. Precision and Bias

11.1 *Precision*—Criteria for judging the acceptability of the water content results obtained by this test method are given in Table 1. The value in column two is in the units actually measured by the nuclear gage. The figures in column three represent the standard deviations that have been found to be appropriate for the materials tested in column one. The figures given in column four are the limits that should not be exceeded by the difference between the results of two properly conducted tests. The figures given are based upon an interlaboratory study in which five test sites containing soils, with water content as shown in column two, were tested by eight different devices and operators. The water content of each test site was determined three times by each device.[3]

11.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

TABLE 1 Results of Statistical Analysis

Precision and Soil Type	Average kg/m^3(lb/ft^3)	Standard Deviation, kg/m^3(lb/ft^3)	Acceptable Range of Two Results kg/m^3(lb/ft^3)
Single Operator Precision:			
CL	194 (12.1)	5.6 (0.35)	15.5 (0.97)
SP	300 (18.7)	7.4 (0.46)	20.7 (1.29)
ML	314 (19.6)	5.6 (0.35)	15.8 (0.99)
Multilaboratory Precision:			
CL	194 (12.1)	8.3 (0.52)	23.1 (1.44)
SP	300 (18.7)	12.0 (0.75)	33.6 (2.10)
ML	314 (19.6)	9.3 (0.58)	26.1 (1.63)

12. Keywords

12.1 compaction test; construction control; density; field

[3] Details of the study are contained in a Research Report available from ASTM Headquarters. Request RR:D18-1005.

control; inspection; moisture content; moisture control; nuclear methods; nuclear moisture; quality control; soil moisture; test procedure; water content

ANNEXES

(Mandatory Information)

A1. CALIBRATION

A1.1 *Calibration Curves*—Calibration curves, tables, or equations shall be established or verified once each year by determining by test the nuclear count rate of at least two samples of different known water content. This data may be plotted or equations determined to create tables or computer programs for conversion of count data to water content. The method and test procedures used in obtaining the count rate (or ratio as defined in Section 7) to establish the calibration relationship must be the same as those used for measuring the water content of the material to be tested. The water content of materials used to establish the calibration must vary through a range to include the water content of materials to be tested and be in the density range of 1600 to 2240 kg/m^3 (100 to 140 lbf/ft^3). Due to the effect of chemical composition, the calibration supplied by the manufacturer with the apparatus will not be applicable to all materials. It shall be accurate for mixes of silica sand and water; therefore, the calibration must be checked and adjusted, if necessary, in accordance with A1.3.

A1.2 *Calibration Standards*—Calibration standards may be established using any of the following methods. Prepared containers or standards must be large enough to not change the observed count rate (or ratio as defined in Section 7) if made larger in any dimension.

NOTE A1.1—Dimensions of approximately 610 mm long by 460 mm wide by 360 mm deep (approximately 24 by 18 by 14 in.) have proven satisfactory.

A1.2.1 Prepare a homogeneous standard of hydrogenous materials having an equivalent water content determined by comparison (using a nuclear instrument) with a saturated silica sand standard prepared in accordance with A1.2.2. A metallic density standard as defined in Test Methods D 2922 is a convenient zero water content standard.

A1.2.2 Prepare containers of compacted material with a percent water content determined by oven dry (Test Method D 2216) and a wet density calculated from the mass of the material and the inside dimensions of the container. The water content may be calculated as follows:

$$M_m = \frac{\rho \times w}{100 + w} \quad \text{(A1.1)}$$

where:

M_m = water content, kg/m^3 or lbf/ft^3,
w = water content, percent of dry mass, and
ρ = wet (total) density, kg/m^3 or lbf/ft^3.

A1.2.3 Where neither of the previous calibration standards are available, the instrument may be calibrated by using a minimum of four selected test sites in an area of a compaction project where a homogenous material has been placed at several different water contents. The test sites shall represent the range of water contents over which the calibration is to be used. At least four replicate nuclear measurements shall be made at each test site. The density at each site shall be measured by making four closely spaced determinations with calibrated equipment in accordance with Test Methods D 2922, Test Method D 1566, Test Method D 2167, or Test Method D 2937. The water content of each of the density tests shall be determined by Test Method D 2216. Use the mean value of the replicate readings as the calibration point value for each site.

A1.3 *Calibration Adjustments:*

A1.3.1 The calibration of newly acquired or repaired instruments shall be verified and adjusted prior to use. Calibration curves shall be checked prior to performing tests on materials that are distinctly different from material types previously used in obtaining or adjusting the calibration. Sample materials may be selected by either A1.3.1.1 or A1.3.1.2. The amount of water shall be within ±2 % of the water content established as optimum for compaction. Determine the water content in kg/m^3 or lbf/ft^3 by Eq A1.1. A microwave oven or direct heater may be utilized for drying materials which are not sensitive to temperature, in addition to the methods listed in A1.2.3. A minimum of four comparisons is required and the mean of the observed differences used as the correction factor.

A1.3.1.1 Container(s) of compacted material taken from the test site may be prepared in accordance with A1.2.2.

A1.3.1.2 Test site(s) on the compacted material may be selected in accordance with A1.2.3.

A1.3.2 The method and test procedures used in obtaining the count rate (or ratio as defined in Section 7) to establish the error must be the same as those used for measuring the water content of the material to be tested.

A1.3.3 The mean value of the difference between the moisture content of the test samples as determined in A1.3.1.1 or A1.3.1.2 and the values measured with the instrument shall be used as a correction to measurements made in the field. Some instruments utilizing a microprocessor may have provision to input a correction factor that is established by the relative values of water content as a percentage of dry density, thus eliminating the need to determine the difference in mass units of water.

A2. DETERMINING PRECISION OF APPARATUS

A2.1 The precision of the apparatus at a water content of 160 kg/m^3 (10 lbf/ft^3) shall be better than 4 kg/m^3 (0.25 lbf/ft^3) at the manufacturer's stated period of time for the measurement (Note A2.1). Other timing periods may be available (usually multiples of four of the normal period) which may be used where higher or lower precisions are desired for statistical purposes. The precision shall be determined by the procedure defined in 5.2.1 or 5.2.2.

NOTE A2.1—While 1 min is the usual timing period and may be used for the comparison of various apparatus, the intent of the test method is to require a measurement period that produces the stated precision for all acceptance testing.

A2.2 The precision of the apparatus is determined from the slope of the calibration response and the statistical deviation of the count (detected neutrons) for the period of measurement, as follows:

$$P = \frac{\sigma}{S} \tag{A2.1}$$

where:
P = apparatus precision in water content (kg/m^3 or lbf/ft^3),
σ = standard deviation in counts per measurement period, and
S = slope in change in counts per measurement period divided by the change in water content (kg/m^3 or lbf/ft^3).

A2.2.1 The count per measurement period shall be the total number of thermal neutrons detected during the timed period. The displayed value must be corrected for any prescaling which is built into the apparatus. 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.

A2.2.2 The standard deviation in counts per measurement period shall be obtained as follows:

$$\sigma = \frac{\sqrt{C}}{\sqrt{F}} \tag{A2.2}$$

where:
σ = standard deviation in counts per measurement period,
C = counts per measurement period (before prescale correction) at a water content of 160 kg/m^3 (10 lbf/ft^3), and
F = value of prescale (A2.2.1).

A2.2.3 The counts per measurement period (before prescale correction) shall be obtained form the calibration curve, tables or equation.

A2.2.4 The slope of calibration response in counts per measurement period (before prescale correction) at a water content of 160 kg/m^3 (10 lbf/ft^3) shall be determined from the calibration curve, tables, or equation.

A2.3 The precision shall be computed by determining the standard deviation of at least 20 repetitive measurements (instrument not moved after the first measurement) on material having a water content of 130 to 190 kg/m^3 (8.1 to 11.9 lbf/ft^3). In order to perform this procedure, the resolution of the count display, calibration response, or other method of displaying water content must be equal to or better than $\pm$1 kg/m^3 or 0.1 lbf/ft^3.