# MOISTURE-DENSITY RELATIONSHIP OF SOILS USING 2.5 kg RAMMER AND 305 mm DROP

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## LS 1. SCOPE

1.1 This method covers the determination of the relationship between the moisture content and density of soils using a mould of given size with a 2.5 kg rammer dropped from a height of 305 mm.........._______

1.2 Test Method ASTM D 698 shall be followed, except as noted................................................._______

1.3 System International (SI) units are to be regarded as standard................................................_______

## 2. TEST PROCEDURE

2.1 Bulk density (specific gravity), $G_M$, of the oversize fraction, may be determined per MTO LS-604 or estimated based on previous test data........................................................................................_______

2.2 ASTM Practice D 4718 shall be used to correct maximum dry unit weight and optimum moisture content if more than 5% by mass of oversize material is removed from the test sample................_______

## ASTM 1. Scope

1.2 These test methods apply only to soils (materials) that have 30 % or less by mass of particles retained on the 3⁄4-in. (19.0-mm) sieve and have not been previously compacted in the laboratory; that is, **do not reuse compacted soil**........................................................................................._______

1.2.1 For relationships between unit weights and molding water contents of soils with 30 % or less by mass of material retained on the 3⁄4-in. (19.0-mm) sieve to unit weights and molding water contents of the fraction passing 3⁄4-in. (19.0-mm) sieve, see Practice D4718..................................................._______

## 5. Significance and Use

5.1 Soil placed as engineering fill (embankments, foundation pads, road bases) is compacted to a dense state to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. In addition, foundation soils are often compacted to improve their engineering properties. Laboratory compaction tests provide the basis for determining the percent compaction and molding water content needed to achieve the required engineering properties, and for controlling construction to assure that the required compaction and water contents are achieved.

## 6. Apparatus

6.1 *Mold Assembly*—The molds shall be cylindrical in shape, made of rigid metal and be within the capacity and dimensions indicated in 6.1.1 or 6.1.2 and Figs. 1 and 2 of the ASTM. See also Table 1 of the ASTM........................................................................................................................._______

The walls of the mold may be solid, split, or tapered. The "split" type may consist of two half-round sections, or a section of pipe split along one element, which can be securely locked together to form a cylinder meeting the requirements of this section..........................................................................._______

The "tapered" type shall have an internal diameter taper that is uniform and not more than 0.200 in./ft (16.7 mm/m) of mold height........................................................................................................._______

Each mold shall have a base plate and an extension collar assembly, both made of rigid metal and constructed so they can be securely attached and easily detached from the mold........................._______

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The extension collar assembly shall have a height extending above the top of the mold of at least 2.0 in. (51 mm) which may include an upper section that flares out to form a funnel, provided there is at least a 0.75 in. (19 mm) straight cylindrical section beneath it. The extension collar shall align with the inside of the mold..........______

The bottom of the base plate and bottom of the centrally recessed area that accepts the cylindrical mold shall be planar within 60.005 in. (60.1 mm) ..........______

6.1.1 *Mold, 4 in.*—A mold having a 4.000 ± 0.016-in. (101.6 ± 0.4-mm) average inside diameter..........______

A height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm) ..........______

And a volume of 0.0333 ± 0.0005 $ft^3$ (943.0 6 14 $cm^3$) ..........______

A mold assembly having the minimum required features is shown in Fig. 1 of the ASTM..........______

6.1.2 *Mold, 6 in.*—A mold having a 6.000 ± 0.026-in. (152.4 ± 0.7-mm) average inside diameter..........______

A height of 4.584 ± 0.018 in. (116.4 ± 0.5 mm) ..........______

And a volume of 0.0750 ± 0.0009 $ft^3$ (2124 ± 25 $cm^3$) ..........______

A mold assembly having the minimum required features is shown in Fig. 2 of the ASTM..........______

6.2 *Rammer*—A rammer, either manually operated as described further in 6.2.1 or mechanically operated as described in 6.2.2..........______

The rammer shall fall freely through a distance of 12.00 ± 0.05 in. (304.8 ± 1 mm) from the surface of the specimen..........______

The weight of the rammer shall be 5.50 ± 0.02 lbf (24.47 ± 0.09 N, or mass of 2.495 ± 0.009 kg), except that the weight of the mechanical rammers may be adjusted as described in Practices D2168; see Note 5..........______

The striking face of the rammer shall be planar and circular, except as noted in 6.2.2.1, with a diameter when new of 2.000 ± 0.005 in. (50.80 ± 0.13 mm). The rammer shall be replaced if the striking face becomes worn or bellied to the extent that the diameter exceeds 2.000 ± 0.01 in. (50.80 ± 0.25 mm) ..........______

NOTE 5—It is a common and acceptable practice to determine the weight of the rammer using either a kilogram or pound balance and assume 1 lbf is equivalent to 0.4536 kg, 1 lbf is equivalent to 1 lbm, or 1 N is equivalent to 0.2248 lbf or 0.1020 kg.

6.2.1 *Manual Rammer*—The rammer shall be equipped with a guide sleeve that has sufficient clearance that the free fall of the rammer shaft and head is not restricted..........______

The guide sleeve shall have at least four vent holes at each end (eight holes total) located with centers 3⁄4 ± 1⁄16 in. (19 ± 2 mm) from each end and spaced 90 degrees apart. The minimum diameter of the vent holes shall be 3⁄8 in. (9.5 mm). Additional holes or slots may be incorporated in the guide sleeve..........______

6.2.2 *Mechanical Rammer-Circular Face*—The rammer shall operate mechanically in such a manner as to provide uniform and complete coverage of the specimen surface..........______

There shall be 0.10 ± 0.03-in. (2.5 ± 0.8-mm) clearance between the rammer and the inside surface of the mold at its smallest diameter..........______

The mechanical rammer shall meet the standardization/calibration requirements of Practices D2168..........______

The mechanical rammer shall be equipped with a positive mechanical means to support the rammer when not in operation..........______

6.2.2.1 *Mechanical Rammer-Sector Face*—The sector face can be used with the 6-in. (152.4-mm) mold, as an alternative to the circular face mechanical rammer described in 6.2.2................................._______
The striking face shall have the shape of a sector of a circle of radius equal to 2.90 ± 0.02 in. (73.7 ± 0.5 mm) and an area about the same as the circular face, see 6.2......................................................_______
The rammer shall operate in such a manner that the vertex of the sector is positioned at the center of the specimen and follow the compaction pattern given in Fig. 3b of the ASTM.............................._______
6.3 *Sample Extruder (optional)*—A jack, with frame or other device adapted for the purpose of extruding compacted specimens from the mold..................................................................................._______
6.4 *Balance*—A Class GP5 balance meeting the requirements of Guide D4753 for a balance of 1-g readability................................................................................................................................_______
If the water content of the compacted specimens is determined using a representative portion of the specimen, rather than the whole specimen, and if the representative portion is less than 1000 g, a Class GP2 balance having a 0.1-g readability is needed in order to comply with Test Methods D2216 requirements for determining water content to 0.1 %................................................................._______
NOTE 6—Use of a balance having an equivalent capacity and a readability of 0.002 lbm as an alternative to a class GP5 balance should not be regarded as nonconformance to this standard.
6.5 *Drying Oven*—Thermostatically controlled oven, capable of maintaining a uniform temperature of 230 ± 9°F (110 ± 5°C) throughout the drying chamber. These requirements typically require the use of a forced-draft type oven. Preferably the oven should be vented outside the building......................_______
6.6 *Straightedge*—A stiff metal straightedge of any convenient length but not less than 10 in. (250 mm). The total length of the straightedge shall be machined straight to a tolerance of 60.005 in. (60.1 mm). The scraping edge shall be beveled if it is thicker than 1⁄8 in. (3 mm) ............................................._______
6.7 *Sieves*—3⁄4 in. (19.0 mm), 3⁄8 in. (9.5 mm), and No. 4 (4.75 mm), conforming to the requirements of Specification E11..............................................................................................................._______
6.8 *Mixing Tools*—Miscellaneous tools such as mixing pan, spoon, trowel, spatula, spraying device (to add water evenly), and (preferably, but optional) suitable mechanical device for thoroughly mixing the subspecimen of soil with increments of water..................................................................._______

## 7. Standardization/Calibration

7.1 Perform standardizations before initial use, after repairs or other occurrences that might affect the test results, at intervals not exceeding 1,000 test specimens, or annually, whichever occurs first, for the following apparatus: ........................................................................................................_______
7.1.1 *Balance*—Evaluate in accordance with Guide D4753........................................................_______
7.1.2 *Molds*—Determine the volume as described in Annex A1 of the ASTM................................_______
7.1.3 *Manual Rammer*—Verify the free fall distance, rammer weight, and rammer face are in accordance with 6.2. Verify the guide sleeve requirements are in accordance with 6.2.1................................_______
7.1.4 *Mechanical Rammer*—Verify and adjust if necessary that the mechanical rammer is in accordance with Practices D2168. In addition, the clearance between the rammer and the inside surface of the mold shall be verified in accordance with 6.2.2..........................................................................._______

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## 8. Test Specimen

8.1 The minimum specimen (test fraction) mass for Methods A and B is about 16 kg....................._______
And for Method C is about 29 kg of dry soil.........................................................................._______
Therefore, the field sample should have a moist mass of at least 23 kg and 45 kg, respectively......_______
Greater masses would be required if the oversize fraction is large (see 10.2 or 10.3) or an additional molding water content is taken during compaction of each point (see 10.4.2.1) ............................_______

8.2 If gradation data is not available, estimate the percentage of material (by mass) retained on the No. 4 (4.75-mm), 3⁄8-in. (9.5-mm), or 3⁄4-in. (19.0-mm) sieve as appropriate for selecting Method A, B, or C, respectively..........................................................................................................................._______
If it appears the percentage retained of interest is close to the allowable value for a given Method (A, B, or C), then either:

8.2.1 Select a Method that allows a higher percentage retained (B or C) ......................................_______

8.2.2 Using the Method of interest, process the specimen in accordance with 10.2 or 10.3, this determines the percentage retained for that method. If acceptable, proceed, if not go to the next Method (B or C) ..........................................................................................................................._______

8.2.3 Determine percentage retained values by using a representative portion from the total sample, and performing a simplified or complete gradation analysis using the sieve(s) of interest and Test Methods D6913 or C136. It is only necessary to calculate the retained percentage(s) for the sieve or sieves for which information is desired..........................................................................................._______

## 9. Preparation of Apparatus

9.1 Select the proper compaction mold(s), collar, and base plate in accordance with the Method (A, B, or C) being used..........................................................................................................................._______
Check that its volume is known and determined with or without base plate, free of nicks or dents, and will fit together properly..........................................................................................................._______
NOTE 7—Mass requirements are given in 10.4.

9.2 Check that the manual or mechanical rammer assembly is in good working condition and that parts are not loose or worn. Make any necessary adjustments or repairs. If adjustments or repairs are made, the rammer must be re-standardized..........................................................................................._______

## 10. Procedure

10.1 *Soils:*

10.1.1 Do not reuse soil that has been previously compacted in the laboratory............................._______
The reuse of previously compacted soil yields a significantly greater maximum dry unit weight (**1**, p. 13 of the ASTM) ..........................................................................................................................._______

10.1.2 When using this test method for soils containing hydrated halloysite, or in which past experience indicates that results will be altered by air-drying, use the moist preparation method (see 10.2) ..._______
In referee testing, each laboratory has to use the same method of preparation, either moist (preferred) or air-dried..........................................................................................................................._______

10.1.3 Prepare the soil specimens for testing in accordance with 10.2 (preferred) or with 10.3......_______

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10.2 *Moist Preparation Method (preferred)*—Without previously drying the sample/specimen, process it over a No. 4 (4.75-mm), ⅜-in. (9.5-mm), or ¾-in. (19.0-mm) sieve, depending on the Method (A, B, or C) being used or required as covered in 8.2. For additional processing details, see Test Methods D6913........................................................................................................................______

Determine and record the mass of both the retained and passing portions (oversize fraction and test fraction, respectively) to the nearest g...................................................................................______

Oven dry the oversize fraction and determine and record its dry mass to the nearest g.................______

If it appears more than 0.5 % of the total dry mass of the specimen is adhering to the oversize fraction, wash that fraction. Then determine and record its oven dry mass to the nearest g........................______

Determine and record the water content of the processed soil (test fraction) ...............................______

Using that water content, determine and record the oven dry mass of the test fraction to the nearest g.........................................................................................................................................______

Based on these oven dry masses, the percent oversize fraction, $P_C$, and test fraction, $P_F$, shall be determined and recorded, unless a gradation analysis has already been performed, see Section 11 on Calculations.......................................................................................................................______

10.2.1 From the test fraction, select and prepare at least four (preferably five) subspecimens having molding water contents such that they bracket the estimated optimum water content.................______

A subspecimen having a molding water content close to optimum should be prepared first by trial additions or removals of water and mixing (see Note 8) ..............................................................______

Select molding water contents for the rest of the subspecimens to provide at least two subspecimens wet and two subspecimens dry of optimum, and molding water contents varying by about 2 %.....______

At least two molding water contents are necessary on the wet and dry side of optimum to define the dry-unit-weight compaction curve (see 10.5) ........................................................................______

Some soils with very high optimum water content or a relatively flat compaction curve may require larger molding water content increments to obtain a well-defined maximum dry unit weight. Molding water content increments should not exceed about 4 %..............................................................______

NOTE 8—With practice it is usually possible to visually judge a point near optimum water content. Typically, cohesive soils at the optimum water content can be squeezed into a lump that sticks together when hand pressure is released, but will break cleanly into two sections when "bent." They tend to crumble at molding water contents dry of optimum; while, they tend to stick together in a sticky cohesive mass wet of optimum. The optimum water content is typically slightly less than the plastic limit. While for cohesionless soils, the optimum water content is typically close to zero or at the point where bleeding occurs.

10.2.2 Thoroughly mix the test fraction, then using a scoop select representative soil for each subspecimen (compaction point) ..........................................................................................______

Select about 2.3 kg when using Method A or B, or about 5.9 kg for Method C...............................______

Test Methods D6913 section on Specimen and Annex A2 gives additional details on obtaining representative soil using this procedure and why it is the preferred method................................______

To obtain the subspecimen's molding water contents selected in 10.2.1, add or remove the required amounts of water as follows..........................................................................................................______

To add water, spray it into the soil during mixing; ...........................................................................______

To remove water, allow the soil to dry in air at ambient temperature or in a drying apparatus such that the temperature of the sample does not exceed 140°F (60°C). Mix the soil frequently during drying to facilitate an even water content distribution. Thoroughly mix each subspecimen to facilitate even distribution of water throughout and then place in a separate covered container to stand (cure) in accordance with Table 2 prior to compaction..........................................................................._______

**TABLE 2 Required Standing Times of Moisturized Specimens**

| Classification | Minimum Standing Time, h |
|---|---|
| GW, GP, SW, SP | No Requirement |
| GM, SM | 3 |
| All other soils | 16 |

For selecting a standing time, the soil may be classified using Practice D2487, Practice D2488, or data on other samples from the same material source. For referee testing, classification shall be by Practice D2487.........................................................................................................................................._______

10.3 *Dry Preparation Method*—If the sample/specimen is too damp to be friable, reduce the water content by air drying until the material is friable..................................................................._______

Drying may be in air or by the use of drying apparatus such that the temperature of the sample does not exceed 140°F (60°C) ........................................................................................................._______

Thoroughly break up the aggregations in such a manner as to avoid breaking individual particles.._______

Process the material over the appropriate sieve: No. 4 (4.75-mm), 3⁄8-in. (9.5-mm), or 3⁄4-in. (19.0-mm) ..........................................................................................................................................._______

When preparing the material by passing over the 3⁄4-in. sieve for compaction in the 6-in. mold, break up aggregations sufficiently to at least pass the 3⁄8-in. sieve in order to facilitate the distribution of water throughout the soil in later mixing..........................................................................................._______

Determine and record the water content of the test fraction and all masses covered in 10.2, as applicable to determine the percent oversize fraction, $P_C$, and test fraction, $P_F$............................._______

10.3.1 From the test fraction, select and prepare at least four (preferably five) subspecimens in accordance with 10.2.1 and 10.2.2, except for the following: Use either a mechanical splitting or quartering process to obtain the subspecimens. As stated in Test Methods D6913, both of these processes will yield non-uniform subspecimens compared to the moist procedure. Typically, only the addition of water to each subspecimen will be required................................................................_______

10.4 *Compaction*—After standing (curing), if required, each subspecimen (compaction point) shall be compacted as follows: ..........................................................................................................._______

10.4.1 Determine and record the mass of the mold or mold and base plate, see 10.4.7................._______

10.4.2 Assemble and secure the mold and collar to the base plate. Check the alignment of the inner wall of the mold and mold extension collar. Adjust if necessary. The mold shall rest, without wobbling/rocking on a uniform rigid foundation, such as provided by a cylinder or cube of concrete with a weight or mass of not less than 200-lbf or 91-kg, respectively.................................................._______

Secure the base plate to the rigid foundation. The method of attachment to the rigid foundation shall allow easy removal of the assembled mold, collar and base plate after compaction is completed.._______

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10.4.2.1 During compaction, it is advantageous but not required to determine the water content of each subspecimen. This provides a check on the molding water content determined for each compaction point and the magnitude of bleeding, see 10.4.9. However, more soil will have to be selected for each subspecimen than stated in 10.2.2.........................................................................................._______

10.4.3 Compact the soil in three layers. After compaction, each layer should be approximately equal in thickness and extend into the collar..........................................................................................._______

Prior to compaction, place the loose soil into the mold and spread into a layer of uniform thickness_____

Lightly tamp the soil prior to compaction until it is not in a fluffy or loose state, using either the manual rammer or a 26-in. (506-mm) diameter cylinder..............................................................................._______

Following compaction of each of the first two layers, any soil that has not been compacted; such as adjacent to the mold walls or extends above the compacted surface (up the mold walls) shall be trimmed. The trimmed soil shall be discarded. A knife or other suitable device may be used........._______

The total amount of soil used shall be such that the third compacted layer slightly extends into the collar, but does not extend more than approximately 1⁄4-in. (6-mm) above the top of the mold....._______

If the third layer does extend above this limit, then the compaction point shall be discarded........_______

In addition, the compaction point shall be discarded when the last blow on the rammer for the third layer results in the bottom of the rammer extending below the top of the compaction mold; unless the soil is pliable enough, that this surface can easily be forced above the top of the compaction mold during trimming (see Note 9) ........................................................................................................._______

10.4.4 Compact each layer with 25 blows for the 4-in. (101.6-mm) mold or with 56 blows for the 6-in. (152.4-mm) mold. The manual rammer shall be used for referee testing......................................_______

10.4.5 In operating the manual rammer, take care to avoid lifting the guide sleeve during the rammer upstroke. Hold the guide sleeve steady and within 5° of vertical. Apply the blows at a uniform rate of about 25 blows/min and in such a manner as to provide complete, uniform coverage of the specimen surface......................................................................................................................................_______

When using a 4-in. (101.6-mm) mold and manual rammer, follow the blow pattern given in Fig. 3a and Fig. 3b of the ASTM......................................................................................................................._______

While for a mechanical rammer, follow the pattern in Fig. 3b of the ASTM..................................._______

When using a 6-in. (152.4-mm) mold and manual rammer, follow the blow pattern given in Fig. 4 of the ASTM up to the 9th blow, then systematically around the mold (Fig. 3b) and in the middle..........._______

When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a sector face, the mechanical rammer shall be designed to follow the compaction pattern given in Fig. 3b..............._______

When using a 6-in. (152.4-mm) mold and a mechanical rammer equipped with a circular face, the mechanical rammer shall be designed to distribute the blows uniformly over the surface of the specimen.................................................................................................................................._______

If the surface of the compacted soil becomes highly uneven (see Note 9), then adjust the pattern to follow the logic given in Fig. 3a or Fig. 4 of the ASTM. This will most likely void the use of a mechanical rammer for such compaction points.........................................................................................._______

NOTE 9—When compacting specimens wetter than optimum water content, uneven compacted surfaces can occur and operator judgement is required as to the average height of the specimen and rammer pattern during compaction.

10.4.6 Following compaction of the last layer, remove the collar and base plate (except as noted in 10.4.7) from the mold. A knife may be used to trim the soil adjacent to the collar to loosen the soil from the collar before removal to avoid disrupting the soil below the top of the mold. In addition, to prevent/reduce soil sticking to the collar or base plate, rotate them before removal....................._______

10.4.7 Carefully trim the compacted specimen even with the top of the mold by means of the straightedge scraped across the top of the mold to form a plane surface even with the top of the mold. Initial trimming of the specimen above the top of the mold with a knife may prevent the soil from tearing below the top of the mold........................................................................................._______

Fill any holes in the top surface with unused or trimmed soil from the specimen, press in with the fingers, and again scrape the straightedge across the top of the mold. If gravel size particles are encountered, trim around them or remove them, whichever is the easiest and reduces the disturbance of the compacted soil......................................................................................................................_______

The estimated volume of particles above the surface of the compacted soil and holes in that surface shall be equal, fill in remaining holes as mentioned above..........................................................._______

Repeat the appropriate preceding operations on the bottom of the specimen when the mold volume was determined without the base plate......................................................................................._______

For very wet or dry soils, soil or water may be lost if the base plate is removed. For these situations, leave the base plate attached to the mold. When the base plate is left attached, the volume of the mold must be calibrated with the base plate attached to the mold rather than a plastic or glass plate as noted in Annex A1, A1.4 of the ASTM........................................................................................................._______

10.4.8 Determine and record the mass of the specimen and mold to the nearest g......................._______

When the base plate is left attached, determine and record the mass of the specimen, mold and base plate to the nearest g......................................................................................................................._______

10.4.9 Remove the material from the mold..........................................................................................._______

Obtain a specimen for molding water content by using either the whole specimen (preferred method) or a representative portion..............................................................................................................._______

When the entire specimen is used, break it up to facilitate drying.................................................._______

Otherwise, obtain a representative portion of the three layers, removing enough material from the specimen to report the water content to 0.1 %..............................................................................._______

The mass of the representative portion of soil shall conform to the requirements of Table 1, Method B, of Test Methods D2216........................................................................................................................._______

Determine the molding water content in accordance with Test Methods D2216..........................._______

10.5 Following compaction of the last specimen, compare the wet unit weights to ensure that a desired pattern of obtaining data on each side of the optimum water content will be attained for the dry-unit-weight compaction curve......................................................................................................................._______

Plotting the wet unit weight and molding water content of each compacted specimen can be an aid in making the above evaluation. If the desired pattern is not obtained, additional compacted specimens will be required. Generally, for experienced plotters of compaction curves, one compaction point wet of the optimum water content is adequate to define the maximum wet unit weight, see 11.2..........._______

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## 11. Calculations and Plotting (Compaction Curve)

11.1 *Fraction Percentages*—If gradation data from Test Methods D6913 is not available, calculate the dry mass of the test fraction, percentage of oversize fraction and test fraction as covered below and using the data from 10.2 or 10.3: ........................................................................................._______

11.1.1 *Test Fraction*—Determine the dry mass of the test fraction as follows: ..............................._______

$$M_{d,tf} = \frac{M_{m,tf}}{1 + (w_{tf}/100)} \quad (1)$$

where:

$M_{d,tf}$ = dry mass of test fraction, nearest g or 0.001 kg,

$M_{m,tf}$ = moist mass of test fraction, nearest g or 0.001 kg,

$w_{tf}$ = water content of test fraction, nearest 0.1 %.

11.1.2 *Oversize Fraction Percentage*—Determine the oversize (coarse) fraction percentage as follows: ..............................................................................................................................................._______

$$P_C = \frac{M_{d,of}}{M_{d,of} + M_{d,tf}} \quad (2)$$

where:

$P_C$ = percentage of oversize (coarse) fraction, nearest %,

$M_{d,of}$ = dry mass of oversize fraction, nearest g or 0.001 kg,

11.1.3 *Test Fraction Percentage*—Determine the test (finer) fraction percentage as follows:.........._______

$$P_F = 100 - P_C \quad (3)$$

where:

$P_F$ = percentage of test (finer) fraction, nearest %.

11.2 *Density and Unit Weight*—Calculate the molding water content, moist density, dry density, and dry unit weight of each compacted specimen as explained below......................................................._______

11.2.1 *Molding Water Content, w*—Calculate in accordance with Test Methods D2216 to nearest 0.1 %__

11.2.2 *Density and Unit Weights*—Calculate the moist (total) density (Eq 4), the dry density (Eq 5), and then the dry unit weight (Eq 6) as follows: ..........................................................................................._______

11.2.2.1 *Moist Density:*

$$\rho_m = K \times \frac{(M_t - M_{md})}{V} \quad (4)$$

where:

$\rho_m$ = moist density of compacted subspecimen (compaction point), four significant digits, g/cm$^3$ or kg/m$^3$,

$M_t$ = mass of moist soil in mold and mold, nearest g,

$M_{md}$ = mass of compaction mold, nearest g,

$V$ = volume of compaction mold, $cm^3$ or $m^3$ (see Annex A1 of the ASTM),
$K$ = conversion constant, depending on density units and volume units.
Use 1 for $g/cm^3$ and volume in $cm^3$.
Use 1000 for $g/cm^3$ and volume in $m^3$.
Use 0.001 for $kg/cm^3$ and volume in $m^3$.
Use 1000 for $kg/m^3$ and volume in $cm^3$.

11.2.2.2 *Dry Density:* ........................................................................................................______

$$\rho d = \frac{\rho m}{1 + (w/100)} \qquad (5)$$

where:
$\rho_d$ = dry density of compaction point, four significant digits, $g/cm^3$ or $kg/m^3$,
$w$ = molding water content of compaction point, nearest 0.1 %.
11.2.2.3 *Dry Unit Weight:* ..................................................................................................______

$$\gamma d = K1 \text{ X } \rho d \text{ in lbf/ft}^3 \qquad (6)$$

or

$$\gamma d \ 5 \ K2 \text{ X } \rho d \text{ in kN/m}^3 \qquad (7)$$

where:
$\gamma_d$ = dry unit weight of compacted specimen, four significant digits, in $lbf/ft^3$ or $kN/m^3$,
$K_1$ = conversion constant, depending on density units,
Use 62.428 for density in $g/cm^3$, or
Use 0.062428 for density in $kg/m^3$,
$K_2$ = conversion constant, depending on density units,
Use 9.8066 for density in $g/cm^3$, or
Use 0.0098066 for density in $kg/m^3$.

11.3 *Compaction Curve*—Plot the dry unit weight and molding water content values, the saturation curve (see 11.3.2), and draw the compaction curve as a smooth curve through the points (see example, Fig. 5 of the ASTM) ........................................................................................................______
For each point on the compaction curve, calculate, record, and plot dry unit weight to the nearest 0.1 $lbf/ft^3$ (0.02 $kN/m^3$) and molding water content to the nearest 0.1 %............................................______
From the compaction curve, determine the compaction results: optimum water content, to nearest 0.1 % and maximum dry unit weight, to the nearest 0.1 $lbf/ft^3$ (0.02 $kN/m^3$) ......................................______
If more than 5 % by mass of oversize material was removed from the sample/specimen, calculate the corrected optimum water content and maximum dry unit weight of the total material using Practice D4718. This correction may be made to the appropriate field in-place density test specimen rather than to the laboratory compaction results.......................................................................................______

# MOISTURE-DENSITY RELATIONSHIP OF SOILS USING 2.5 kg RAMMER AND 305 mm DROP



11.3.1 In these plots, the scale sensitivities should remain the same, that is the change in molding water content or dry unit weight per division is constant between plots. Typically, the change in dry unit weight per division is twice that of molding water content's (2 lbf/ft$^3$ to 1 % *w* per major division). Therefore, any change in the shape of the compaction curve is a result of testing different material, not the plotting scale. However, a one to one ratio should be used for soils that have a relatively flat compaction curve (see 10.2.1), such as highly plastic soils or relatively free draining ones up to the point of bleeding..........................................................................................................................._______

11.3.1.1 The shape of the compaction curve on the wet side on optimum should typically follow that of the saturation curve..........................................................................................................._______

The shape of the compaction curve on the dry side of optimum may be relatively flat or up and down when testing some soils, such as relatively free draining ones or plastic soils prepared using the moist procedure and having molding water contents close to or less than the shrinkage limit................._______

11.3.2 Plot the 100 % saturation curve, based on either an estimated or a measured specific gravity. Values of water content for the condition of 100 % saturation can be calculated as explained in 11.4 (see example, Fig. 5 of the ASTM) ..........................................................................................._______

NOTE 10—The 100 % saturation curve is an aid in drawing the compaction curve. For soils containing more than about 10 % fines and molding water contents well above optimum, the two curves generally become roughly parallel with the wet side of the compaction curve between 92 to 95 % saturation. Theoretically, the compaction curve cannot plot to the right of the 100 % saturation curve. If it does, there is an error in specific gravity, in measurements, in calculations, in testing, or in plotting. The 100 % saturation curve is sometimes referred to as the zero air voids curve or the complete saturation curve.

11.4 *Saturation Points*—To calculate points for plotting the 100 % saturation curve or zero air voids curve, select values of dry unit weight, calculate corresponding values of water content corresponding to the condition of 100 % saturation as follows: ..............................................................................._______

$$W_{sat} = \frac{(\gamma w)(Gs) - \gamma d}{(\gamma d)(Gs)} \times 100 \qquad (8)$$

where:

$w_{sat}$ = water content for complete saturation, nearest 0.1 %,

$\gamma_w$ = unit weight of water, 62.32 lbf/ft$^3$ (9.789 kN/m$^3$) at 20°C,

$\gamma_d$ = dry unit weight of soil, lbf/ft$^3$ (kN /m$^3$), three significant digits,

$G_s$ = specific gravity of soil (estimated or measured), to nearest 0.01 value, see 11.4.1.

11.4.1 Specific gravity may be estimated for the test fraction based on test data from other soils having the same soil classification and source or experience. Otherwise, a specific gravity test (Test Methods C127 or D854, or both) is necessary........................................................................................._______

# MOISTURE-DENSITY RELATIONSHIP OF SOILS USING 2.5 kg RAMMER AND 305 mm DROP

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## 12. Report: Data Sheet(s)/Form(s)

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as described below, is covered in 1.6 of the ASTM............................................................................._______

12.2 The data sheet(s)/form(s) shall contain as a minimum the following information: ................._______

12.2.1 Method used (A, B, or C) ......................................................................................................._______

12.2.2 Preparation method used (moist or dry) ...................................................................._______

12.2.3 As received water content if determined, nearest 1 %......................................................_______

12.2.4 Standard optimum water content, Std-$w_{opt}$ to nearest 0.1 %............................................_______

12.2.5 Standard maximum dry unit weight, Std-$\gamma_{d,max}$ nearest 0.1 lbf/ft$^3$ or 0.02 kN/m$^3$.................._______

12.2.6 Type of rammer (manual or mechanical) ..........................................................................._______

12.2.7 Soil sieve data when applicable for selection of Method (A, B, or C) used............................_______

12.2.8 Description of sample used in test (as a minimum, color and group name and symbol), by Practice D2488, or classification by Practice D2487.........................................................................._______

12.2.9 Specific gravity and method of determination, nearest 0.01 value......................................_______

12.2.10 Identification of sample used in test; for example, project number/name, location, depth, and the like.........................................................................................................................._______

12.2.11 Compaction curve plot showing compaction points used to establish compaction curve, and 100 % saturation curve, value or point of maximum dry unit weight and optimum water content........._______

12.2.12 Percentages for the fractions retained ($P_C$) and passing ($P_F$) the sieve used in Method A, B, or C, nearest 1 %. In addition, if compaction data (Std-$w_{opt}$ and Std-$\gamma_{d,max}$) are corrected for the oversize fraction, include that data..............................................................................................._______

## LS 3. REPORTING OF RESULTS

3.1 Report all results in SI units. A laboratory compaction data sheet is provided in Figure 1 of the LS. The report shall include as a minimum the following: ..........................................................................._______

3.1.1 Method used (A, B, or C) ........................................................................................................_______

3.1.2 Sample preparation method used (dry or moist) ................................................................_______

3.1.3 Moisture content of sample as received, if determined........................................................_______

3.1.4 Percent of oversize fraction retained and sieve used............................................................_______

3.1.5 Description of test sample with applicable classification (CL, ML, SM, GM, etc.) ...................._______

3.1.6 Optimum moisture content determined..............................................................................._______

3.1.7 Maximum dry and wet densities determined........................................................................_______

3.1.8 Corrected maximum dry density and optimum moisture content of the combined sample if applicable..................................................................................................................................._______

3.1.9 Specific gravity values of oversize and fine fractions used for calculations and the method of determination (measured or assumed) ......................................................................................._______

3.2 Both uncorrected and corrected values for items 3.1.6, 3.1.7 and 3.1.8 shall be given and reported to the nearest 0.001 and 3.1.3 to the nearest 0.1 %.................................................................._______

# MOISTURE-DENSITY RELATIONSHIP OF SOILS USING 2.5 kg RAMMER AND 305 mm DROP



## 4. GENERAL NOTES AND PRECAUTIONS

4.1 The rammer should be held in a vertical position during compaction........................................_______

4.2 Rebound of the rammer from the top of the sleeve must be avoided otherwise the compactive effort will change.........................................................................................................................._______

4.3 Samples of heavy clays (CI - CH) should be cured at the initial water content for a minimum of 12 h in a plastic bag to ensure even moisture distribution..........................................................................._______

4.4 To avoid injury, keep fingers away from the ram of the hydraulic extruder or the rammer of the mechanical compactor.........................................................................................................._______

4.5 Obtaining an even surface on a compacted granular material with the straightedge is very difficult. An attempt should be made to balance voids in the surface with an approximately equal number of pieces of aggregate projecting from the surface of the sample, using a round steel rod as a gauge_______

4.6 Observe and note the presence and degree of free water........................................................_______

4.7 Ensure that the rammer is maintained in a clean condition and that no build-up of soil occurs on the rammer which would affect the compactive effort..........................................................................._______

## COMMENTS