Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft$^3$)

D 698-91

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SCOPE

This test method covers laboratory compaction procedures used to determine the relationship between water content and dry unit weight of soils (compaction curve) compacted in a 4 of 6 in. diameter mold with a 5.5 lbf rammer dropped from a height of 12 in. producing a compactive effort of 12,400 ft-lbf/ft$^3$.

This test method applies only to soils that have 30% or less by weight of particles retained on the ¾ in. sieve.

Three alternative procedures are provided. The procedure used shall be as indicated in the specification for the material being tested. If no procedure is specified, the choice shall be based on the material gradation.

Procedure A:
- Mold – 4 in. diameter
- Material – passing No. 4 sieve
- Layers – Three
- Blows per layer – 25
- Use – May be used if 20% or less by weight of the material is retained on the No. 4 sieve.

Procedure B
- Mold – 4 in. diameter
- Material – Passing 3/8 in. sieve
- Layers – Three
- Blows per layer – 25
- Use – Shall be used if more that 20% by weight of the material is retained on the 3/8 in. sieve.

Procedure C
- Mold – 6 in diameter
- Material – passing ¾ in sieve
- Layers – three
- Blows per layer – 56
- Use – Shall be used if more than 20% by weight of the material is retained on the 3/8 in sieve and less that 30% by weight of the material is retained on the ¾ in. sieve.

If the test specimen contains more than 5% by weight oversized fraction (coarse fraction) and the material will not be included in the test, correction must be made
to the unit weight and water content of the specimen or to the appropriate field in place density test specimen using Practice D 4718.

**Terminology**

Oversized fraction (coarse fraction) \( P_C \) in % - the portion of total sample not used in performing the compaction test. It may be the portion of total sample retained on the No. 4, 3/8 in., or ¾ in. sieve.

Standard effort – the term for the 12,400 ft \( \text{lbf/ft}^3 \) compactive effort applied by the equipment and procedure of this test.

Standard maximum dry weight, \( \gamma_{d_{\text{max}}} \) in \( \text{lbf/ft}^3 \) – the maximum value defined by the compaction curve for a compaction test using standard effort.

Standard optimum water content \( w_o \) in % - the water content at which a soil can be compacted to the maximum dry unit weight using standard compactive effort.

Test fraction (finer fraction) \( P_F \) in % - The portion of the total sample used in performing the compaction test; it is the fraction passing the No. 4 sieve in a procedure A, minus 3/8 in. sieve in procedure B or minus ¾ in. sieve in procedure C.

**Summary of Test Method**

A soil at a selected water content is placed in three layers into a mold of given dimensions, with each layer compacted by 25 or 56 blows of a 5.5 lbf rammer dropped from a distance of 12 in., subjecting the soil to a total compactive effort of about 12,400 ft \( \text{lbf/ft}^3 \). The resulting dry unit weight is determined. The procedure is repeated for sufficient number of water contents to establish a relationship between the dry unit weight and the water content for the soil. This data, when plotted, represents a curvilinear relationship known as the compaction curve. The values of optimum water content and standard maximum dry unit weight are determined from the compaction curve.

**Significance of Use**

Soil placed as engineering fill (embankments, foundation pads, and road base) is compacted to a dense to obtain satisfactory engineering properties such as, shear strength, compressibility, or permeability. Also, foundation soils are often compacted to improve their engineering properties. Laboratory compacted test provided the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling the construction to assure that the required compaction and water content are achieved.
During design of an engineering fill, shear, consolidation, permeability, or other test require preparation of test specimens by compacting at some water content to some unit weight. It is common practice to first determine the optimum water content \((w_o)\) and the maximum dry unit weight \((\gamma_{d_{\text{max}}})\) by means of a compaction test. Test specimens are compacted at a selected water content \((w)\), either wet or dry of optimum \((w_o)\), and at a selected dry unit weight related to a percentage of maximum dry unit weight \((\gamma_{d_{\text{max}}})\). The selection of water content \((w_o)\), either wet or dry of optimum \((w_o)\) or at optimum \((w_o)\) and dry unit weight \((\gamma_{d_{\text{max}}})\) may be based on past experience, or a range of values may be investigated to determine the necessary percent of compaction.

**Apparatus**

Mold – The mold shall be a cylindrical in shape, made a rigid metal. 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.

- **4 in. Mold** – a mold having a 4.000 ± 0.016 in. average inside diameter and height of 4584 ± 0.018 in a volume of 0.075 ± 0.0009 ft³.
- **Manual Rammer** – The rammer shall fall freely though a distance of 12 ± 0.05 in. from the surface of the specimen. The mass of the rammer shall be 5.5 ± 0.02 lbm. The striking face of the rammer shall be planar and circular with a diameter of 2.000 ± 0.005 in.
- **Straight Edge** – a stiff metal straight edge of sample trimming will be required.
- **Missing Tools** – tools for mixing soil samples.

**Test Sample**

The required sample mass for Procedure A is approximately 35 lbm.

**Preparation of Apparatus**

Select the proper compaction mold in accordance with the procedure (A,B, or C) being used. Determine and record the mass of the mold to the nearest gram. Assemble the mold, base and extension collar. Check the alignment of the inner wall of the mold and mold extension collar.

Check that the rammer assembly is in good working condition and that parts are not loose or worn.
Procedure

1. Soils – Do not reuse soil that has been previously laboratory compacted.
2. Prepare five specimens having water content such that they bracket the estimated optimum water content. A specimen having a water content close to optimum should be prepared first by trial addition of water and mixing. Select water content for the rest of the specimens to provide two specimens wet and two specimens dry of the optimum, and water contents varying by about 2%. At least two water contents are necessary on the wet and dry side of optimum to accurately define the dry unit weight compaction curve. Some soils with very high optimum or a relatively flat compaction dry unit weight. Water content increments should not exceed 4%.
3. Use approximately 5 lbm of sieved soil for each specimen to be compacted using procedure A or B or 13 lbm using procedure C. To obtain the specimen water contents selected above add or remove the required amount 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. Thoroughly mix each specimen to ensure even distribution of water throughout and place a separate covered container and allow to stand in accordance with the table below.
4. Compaction – Determine and record the mass of the mold or the mold and base plate.
5. Assemble and secure the mold and collar to the base plate. The mold shall rest on a uniform rigid foundation.
6. Compact the specimen in three layer of equal thickness. Lightly tamp the soil prior to compaction until it is not fluffy or loose. The total amount of soil used shall be such that the third compacted layer extends about ¼ in. into the extension collar. If the last blow or the rammer on the third layer is below the extension collar the specimen shall be discarded.
7. Compact each of the three layers with 25 blows for the 4 in. mold or with 56 blows for the 6 in. mold.
8. In operating the rammer, take care to avoid lifting the guide sleeve during the upstroke. Hold the guide sleeve steady and vertical. Apply the blows at a uniform rate of approximately 25 blow/min. and in such a manner as to provide complete, uniform coverage of the specimen surface.
9. Following compaction of the last layer remove the collar and carefully trim the sample flush with the top of the mold. Fill any holes in the top surface with unused or trimmed soil from specimen.
10. Remove the mold from the base plate and determine and record the mass of the specimen and mold.
11. Remove the specimen from the mold and obtain a sample for determination of water content.
12. Repeat the process until five unit weights and five water contents can be determined.
**Required Standing Time of Moisturized Specimens**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum Standing Time, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW, GP, SW, SP</td>
<td>No Requirement</td>
</tr>
<tr>
<td>GM, SM</td>
<td>3</td>
</tr>
<tr>
<td><strong>All other soils</strong></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

**Calculations**

Calculate the dry unit weight and water content of each compacted specimen.

Plot the values and draw the compaction curve as a smooth curve through the points. Plot dry unit weight to the nearest 0.1 lbf/ft$^3$ and water content to the nearest 0.1%. From the compaction curve, determine the optimum water content and the maximum dry unit weight.

Plot the 100% saturation line curve. Values of water content for the condition of 100% saturation can be calculated from the relationship below.

Calculate water content in accordance with test method D 2216.

**Dry Unit Weight**

Calculate the moist density as follows:

$$\rho_m = \frac{M_t - M_{md}}{V}$$

where

- $\rho_m$ = moist density,
- $M_t$ = mass of moist specimen and mold,
- $M_{md}$ = mass of compaction mold, and
- $V$ = volume of compaction mold.

Calculate dry density as follows:

$$\rho_d = 1 + \frac{w}{100}$$

where:

- $\rho_d$ = dry density of compacted specimen, and
- $w$ = water content in %.

Calculate the points for the 100% saturation line:

$$w_{sat} = \frac{\gamma_w G_s - \gamma_d}{\gamma_d G_s} \times 100\%$$
where:
\( w_{\text{sat}} \) = water content for complete saturation, \( \% \),
\( \gamma_w \) = unit weight of water,
\( \gamma_d \) = dry unit of soil, and
\( G_s \) = specific gravity of soil.

Report

The report shall contain the following information.
1. Procedure used (A, B, or C)
2. Standard optimum water content to the nearest 0.5%
3. Standard maximum unit weight
4. Description of soil used in test by Practice D 2488.
5. Compaction curve plot showing compaction points used to establish compaction curve, and 100% saturation curve, point of maximum dry unit eight and optimum water content.

Test Method for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft\(^3\))

D 1557 – 91

Procedure

1. Soils – Do not reuse soil that has been previously laboratory compacted.
2. Prepare five specimens having water content such that they bracket the estimated optimum water content. A specimen having a water content close to optimum should be prepared first by trial addition of water and mixing. Select water content for the rest of the specimens to provide two specimens wet and two specimens dry of the optimum, and water contents varying by about 2%. At least two water contents are necessary on the wet and dry side of optimum to accurately define the dry unit weight compaction curve. Some soils with very high optimum or a relatively flat compaction curve may require larger water content increment to obtain a well defined maximum dry unit weight. Water content increments should not exceed 4%.
3. Use approximately 5 lbm of sieved soil for each specimen to be compacted using procedure A or B or 13 lbm using procedure C. To obtain the specimen water contents selected above add or remove the required amount of water as follows: to add water, spray it into the soil during mixing; to remove water allow soil to dry in air at ambient temperature. Thoroughly mix each specimen to ensure even distribution of water throughout and place in a separate covered container and allow to stand in accordance with the table below.
4. Compaction – Determine and record the mass of the mold or the mold and base plate.
5. Assemble and secure the mold and collar to the base plate. The mold shall rest on a uniform rigid foundation.

6. **Compact the specimen in five layers of equal thickness.** Lightly tamp the soil prior to compaction until it is not fluffy or loose. The total amount of soil used shall such that the third compacted layer extends about ¼ in. into the extension collar. If the last blow of the rammer on the third layer is below the extension collar the specimen shall be discarded.

7. **Compact each of the five layers with 25 blows for the 4 in. mold or with 56 blows for the 6 in. mold.**

8. In operating the rammer, take care to avoid lifting the guide sleeve during the upstroke. Hold the guide sleeve steady and vertical. Apply the blows at a uniform rate of approximately 25 blow/min and in such a manner as to provide complete, uniform coverage of the specimen surface.

9. Following compaction of the last layer remove the collar and carefully trim the sample flush with the top of the mold. Fill any holes in the top surface with unused or trimmed soil from specimen.

10. Remove the mold from the base plate and determine and record the mass of the specimen and mold.

11. Remove the specimen from the mold and obtain a sample for determination of water content.

12. Repeat the process until five unit weights and five water contents can be determined.