MEASURING SOIL COMPACTION

SUMMARY
Out of all the various current expressions, only the term “percent compaction” should be used to evaluate compaction of a soil. “Percent compaction” compares the in-place dry density with a laboratory maximum dry density. There are different laboratory maximum density tests for cohesive soils and different laboratory maximum density tests for cohesionless soils. For most construction activities, compaction evaluation using “relative density” should not be used.

DEFINITIONS
Cohesive soil (ASTM D653) – A soil that when unconfined has considerable strength when air-dried and that has significant cohesion when submerged.
Typically, these soils are silts and clays. Some silts may fall into the cohesionless category.

Cohesionless soil (ASTM D653) – A soil that when unconfined has little or no strength when air-dried and that has little or no cohesion when submerged.
Typically, these soils are clean sands and gravels. Common materials would be beach sand, concrete aggregates, stream deposits, pea gravel, etc.

Density – Weight per unit volume. Usually expressed as lbs/ft³, pcf, pounds per cubic foot, etc.

Maximum particle size – The largest particle contained in a soil described by the smallest standard sieve opening which the particle would pass. Gravel sieves are typically 3, 1-1/2, 3/4, 3/8-inch. The maximum particle size for sands are typically described as coarse, medium, and fine.

PERCENT COMPACTION

Compaction increases the density of the soil by compressing all the soil particles closer together. Soils are compacted to improve their strength, reduce their compressibility, and decrease their permeability. To measure how much compaction has occurred, the term “percent compaction” is used.

The percent compaction is found by dividing the in-place density by a laboratory maximum density test, and expressing it as a percent. Normally, the percent compaction is expressed as a whole percent, e.g. 96%.
To calculate the **percent compaction**, the actual density of the soil in-place, or **field density** must be determined. There are various methods to measure the field density.

The **maximum density** is determined in a laboratory and there are several different ways to determine the maximum value. The laboratory test used depends on whether the soil is cohesive or cohesionless.

**FIELD DENSITY**

The in-place density, or field density, is determined by one of several different ways. The type of test depends on the cohesiveness of the in-place soil and the maximum particle size present in the material. The most familiar tests are the sand cone, the balloon density meter, and the nuclear gage. The various procedures, ASTM and AASHTO standards, and the advantages and disadvantages for each can be found in Chapter 10 of *Pipeline Installation* by Amster Howard.

The **percent compaction** is calculated by dividing the **field density** by the laboratory **maximum density** and expressing it as a percent, as follows:

\[
\text{percent compaction} = \frac{\text{field density}}{\text{laboratory maximum density}} \times 100
\]

ASTM recommends stating the percent compaction followed by the standard used to determine the maximum density.

The **percent compaction** is described in different terms, such as:

- Percent Compaction
- Percent Proctor
- Percent standard Proctor
- Percent modified Proctor
- Relative Compaction

Since various agencies and firms use various terms to describe percent compaction, contractors are often confused about what is required.

**PERCENT COMPACITION OF COHESIVE SOILS**
Maximum Density

The Proctor concept is a moisture-density relationship and is useful mainly for cohesive soils, such as silts and clays. As shown in Figure 1, as moisture increases, the compacted density increases up to a point and then decreases. The peak of the curve is the maximum density and it occurs at the optimum moisture content. The same soil in the field is compacted to a selected percent of the maximum value.

![Soil Moisture-Density Curve](image)

Figure 1 Typical “Proctor” Moisture-Density Curve

COHESIONLESS SOILS

A Proctor-type moisture-density curve can be determined for some fine and medium sands, however as the grains get larger, increasing the moisture does not have the same effect as with clays and silts. The laboratory test can still be performed, a density obtained but not a moisture density curve. While impact and kneading compaction can density sands and gravels, higher densities can be obtained from vibration. Since vibration is the best method to compact clean sands and gravels in the field, the laboratory test to measure the maximum density is based on vibration.

Clean, cohesionless soils such as gravel and sand are sometime evaluated, or specified, by “Relative Density.”

In the Relative Density (RD) procedure, laboratory tests are used to determine the minimum and maximum density of a clean sand/gravel. The in-place density is compared to both densities and calculated to be somewhere in between, such as “62 % RD.” The value 70% RD is considered to be roughly the equivalent of 95% standard Proctor.
Relative Density

Clean, cohesionless soils such as gravel and sand are sometime evaluated, or specified, by “Relative Density.”

There are two vibratory maximum density tests that can be used. ASTM D 4253 uses a vibratory table to densify a container of the soil. ASTM D 7382 uses a vibratory hammer on the surface of soil in a container.

The percent compaction is still calculated from:

\[
\text{percent compaction} = \frac{\text{field density}}{\text{laboratory maximum density}} \times 100
\]

Except the laboratory maximum density is determined using a different test.

In the Relative Density (RD) procedure, laboratory tests are used to determine the minimum and maximum density of a clean sand/gravel. The maximum density procedure is ASTM D 4253 or D 7382 and the minimum density procedure is ASTM 4254. The in-place density is compared to both densities and calculated to be somewhere in between, such as “62 % RD.” The value 70% RD is considered to be roughly the equivalent of 95% standard Proctor.

The Proctor compaction test cannot be performed on clean gravels and often gives misleading numbers for some clean sands. For these soils, a maximum density is determined by vibration, either on a shaking table or by a impact hammer. The ASTM Proctor tests (D-698 and D 1557) specifically say they are not applicable to clean, free-draining, cohesionless soils.

A percent compaction can be obtained on a clean, cohesionless soil just like the percent compaction for cohesive soils, except a different maximum test is used. In the Relative Density test procedure, a minimum density is obtained by carefully placing loose soil in a container. Typically the minimum density is 75% to 85% of the maximum density, with 80% being a good average.

There are two vibratory maximum density tests that can be used. ASTM D 4253 uses a vibratory table to densify a container of the soil. ASTM D 7382 uses a vibratory hammer on the surface of soil in a container.

This means that gravels/sands that are dumped in are at only 80% of their maximum density. Dumped crushed rock is about 85% of the maximum density. When the soil is loaded it can deform 15 to 20% before stabilizing. Damp sand is even worse because of the bulking moisture. At the typically moisture content in a stockpile (3-5%), sand can end up at a lower
density than the laboratory minimum density test. Specifying that gravel be compacted to 95 percent compaction based on a vibratory test will help prevent this.

Dumping from a height can densify some cohesionless soils. While not at the maximum density, the density will be higher than the minimum.

**References:**


ASTM D 4253, "Test Method for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table"

ASTM D 7382, "Determination of Maximum Dry Unit Weight and Water Content Range for Effective Compaction of Granular Soils Using a Vibratory Hammer,"
Compaction is mechanically making the soil denser. The method of compaction depends on the soil, some soils are compressed into a denser state and some are vibrated into a denser state.

In construction, we want the soil to support a structure, hold back water, and not settle when loaded. A dense soil is stronger, less permeable, and settles less.

We use percent compaction to determine how much the soil has been compacted. Sometimes the term “Relative Density” is used, but in this book, Relative Density will only be used to describe a special method of measuring the degree of compaction of clean sands and gravels. The term Relative Density should not be used to describe the compaction of soils that are not evaluated by this method.

While percent compaction can be use to determine compaction in sands and gravels, in some cases a different evaluation is done based on a minimum density and maximum density laboratory tests. Relative Density will be discussed in a later section “Relative Density.”

The in-place density of a soil at a particular spot is a set number, there are just many different ways to measure what that density is. However, the laboratory maximum density will vary depending on the test standard used. The different test standards are:

<table>
<thead>
<tr>
<th>Test Standard</th>
<th>ASTM Code</th>
<th>AASHTO Code</th>
</tr>
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<tbody>
<tr>
<td>Standard Proctor</td>
<td>D 698</td>
<td>T-99</td>
</tr>
<tr>
<td>Modified Proctor</td>
<td>D 1557</td>
<td>T-180</td>
</tr>
<tr>
<td>Maximum Index Density</td>
<td>D 4253</td>
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</tr>
<tr>
<td>Maximum Density (Vibrating Hammer)</td>
<td>D 7382</td>
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These tests are described later in the section “Laboratory Maximum Density.”