Percent Compaction

Soil compaction is an important aspect of underground pipeline installation. Unfortunately, confusing compaction terminology in contract documents can create delays, wasted efforts and conflicts on the job site. Not only is confusing language an issue, but the basic concepts of soil compaction are often not applied properly.

Some of the more common terminology problems are:
- Using an assortment of terms to describe the proper level of compaction.
- Specifying Percent Proctor for clean gravels and crushed rock even though the ASTM Proctor-type standards prohibit testing these materials.
- Requiring modified Proctor tests when standard Proctor tests would be more appropriate.
- Confusing the term relative density with relative compaction.
- Using the term consolidation incorrectly.

Proper compaction is critical for a buried pipeline because compaction prevents differential settlement and creates a soil-structure interaction that increases structural support for the pipe. Compaction is mechanically making the soil denser. In construction, compacted soil is used to support a structure, to hold back water and to reduce settlement. Increasing the density of the soil makes it stiffer, less permeable and less compressible. The bearing capacity and the stiffness, or modulus, is higher. The level of compaction achieved is evaluated by how the in-place density compares to a maximum density for that soil. The pipeline design assumes a certain percent compaction and this requires assurances that the proper support has been attained.

Percent compaction term recommended

Specifying a level of compaction is one of the more confusing areas of earthwork construction. For example, the following terms are often used in current specifications and literature to describe the required compaction of soil:

<table>
<thead>
<tr>
<th>Percent compaction</th>
<th>Percent dry density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Proctor</td>
<td>Percent density</td>
</tr>
<tr>
<td>Percent standard Proctor</td>
<td>Compaction level</td>
</tr>
<tr>
<td>Percent modified Proctor</td>
<td>Relative compaction</td>
</tr>
<tr>
<td>Percent maximum Proctor</td>
<td>Relative density</td>
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</tbody>
</table>

These terms all refer to a simple concept – the comparison of the in-place field density with a laboratory maximum density. Yet, we have successfully complicated the issue with myriad terms. While some terms attempt to refer to different tests for determining the maximum density, the type of test is not always reflected in the name. The terms do not indicate the different test standards used by various organizations or agencies.

ASTM proposes a simple solution. A single term, percent compaction, should be used to indicate the degree of compaction. ASTM recommends (D653, Manual 70) stating the desired percent compaction, followed by the reference test standard in parentheses (ASTM, AASHTO or state DOT). For example:

**Specifications/Installation Guides**
- The fill shall be compacted to at least 95 percent (D 698).
- Compact the subbases to a minimum of 98 percent (T-180).
- Compaction of 85 percent (Tex 114-E) is required.

**Figures and Tables**
- ≥ 95 percent (D 698)
- Compact embedment to 95 percent (D 7382)

Using this approach makes it clear what standard is to be used to determine the percent compaction.

Percent compaction for cohesionless soils

Percent compaction can apply to both cohesive and cohesionless soils by simply referring to the different methods used to obtain the maximum density. Different maximum density tests are necessary to reflect how the soil is compacted in the field, since the method of compaction depends on the type of soil. Cohesive soils (clayey or silty soils) are best compacted using impact or kneading, and cohesionless (clean sands and gravels) soils are best compacted using vibration.

Accordingly, the laboratory test for maximum density uses either impact or vibration. A Proctor test is an impact test similar to the method used to compact the soil in the field. Therefore, Proctor-type tests are appropriate for cohesive soils, but not for cohesionless soils. Proctor-type tests result in a parabolic moisture-density curve with a peak that is the maximum density. For cohesionless soils, the maximum density is best obtained using vibration. There are some clean sands that may have a moisture-density Proctor-type curve. These soils should also have a vibratory maximum density performed and then the higher value used for the maximum density.

ASTM D 4253 uses a vibratory table to obtain the maximum density, while ASTM D 7382 uses a vibratory hammer. These two vibratory tests are typically used along with a minimum density test to determine a relative density value, sometimes used to evaluate compaction. The percent compaction concept can be applied by using one of these maximum density tests. Generally, the percent compaction for cohesionless soils should be the same as for cohesive soils, i.e. if 95 percent (D 698) is required then 95 percent (D 7382) should be required. If there is a concern, geotechnical evaluation is advised.

Percent Proctor is sometimes specified for clean gravels and crushed rock. However, the ASTM Proctor-type standards prohibit testing these materials. These cohesionless soils do not generally exhibit a distinct moisture-density curve. Additionally, the vibratory methods typically result in a higher maximum density.

Standard versus Modified Proctor

Modified Proctor tests are frequently required for pipeline installation when standard Proctor tests would be more appropriate. The misunderstanding results from the fact that various versions of the Proctor-type test use different size cylinders, different weight rammer, different numbers of lifts, different heights of drop and different numbers of blows. Fortunately, there are only two versions that are primarily used (other varieties of the test are unique to certain agencies or to areas of the country). The two more common versions are the standard Proctor and the modified Proctor, which are described in ASTM and AASHTO standards. Compared to the standard method, the modified version uses four times the energy input to obtain the laboratory maximum density, resulting in a value that is significantly higher.

Some pipeline installation projects use both standard and modified Proctor tests for different applications. The compaction requirements can sometimes get blurred since specifications may list the test methods in one section, prescribe the tests to be used in another section and state the percent requirement in yet another section. As a consequence, the site compaction can end up either under-compacted or over-compacted.

Most of the pipeline installation standards, manuals and guides refer to standard Proctor rather than modified Proctor. Modified Proctor tests are typically used in road construction where large amounts of soil are moved and compacted with large, heavy equipment. In a pipe trench, smaller compaction equipment is used and the standard Proctor test is more appropriate.

Relative density versus relative compaction

Another confusing issue is the word “relative.” In geotechnical engineering, relative density refers to a comparison of the in-place density to both the min-
imum and maximum density, not just the maximum. In applications where relative density is the best measure, the compaction requirement is typically expressed as “70 percent relative density,” which is considered equivalent to about 95 percent Proctor. When engineers, inspectors, and contractors see 70 percent relative density in a specification or drawing, they sometimes incorrectly think the in-place density needs to be only 70 percent of the maximum density. Some states and agencies use the term relative compaction (meaning percent modified Proctor) and this adds to the confusion. Using the term percent compaction as defined earlier would provide relief from this problem.

Compaction or consolidation
In geotechnical applications, compaction and consolidation have very different meanings. Conceptually, compaction is the rapid reduction of air in the soil and consolidation is the reduction of water in the soil over time. Compaction removes the air by equipment pressure, impact, kneading or vibration. Consolidation is squeezing out the water by a steady pressure (such as backfill load).

Some of the confusion results from the use of consolidation in concrete work. Consolidation means removing the air in fresh concrete using vibration. As a result, some people refer to using vibrators to densify soils as consolidation.

However, during pipeline construction and in related contract documents, one only needs to use the term compaction for soils. Compaction is technically correct and covers all mechanical methods used to increase the soil density.

REFERENCES
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• ASTM (2011) Quality Control of Soil Compaction Using ASTM Standards, Manual 70, ASTM International
• D 653 Terminology Relating to Soil, Rock, and Contained Fluids
• D 698 Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft³ (600 kN-m/m³))
• D 1557 Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2700 kN-m/m³))
• ASTM D 4253 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
• AASHTO T-99 Test for the Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in (304.8-mm) Drop
• AASHTO T-180 Test for the Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54-kg) Rammer and 18-in (457-mm) Drop

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