SOIL COMPACTION AND STABILITY

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It's difficult to stick with the basics if you can't remember them. Here's a brief review of the fundamentals of soil compaction and stability, along with advice about dealing with unstable subgrades.

Geotechnical engineers have to answer questions about soil compaction and stability on a regular basis. The questions often asked by architects, developers, contractors and civil engineers are "How can compaction results be obtained that are greater than 100 percent?" and "How can soil that meets compaction requirements be unstable?"

SOIL COMPACTION

To review some basics of soil mechanics, compaction is the process by which a mass of soil consisting of solid soil particles, air, and water is reduced in volume by the momentary application of loads, such as rolling, tamping, or vibration. Compaction involves an expulsion of air without a significant change in the amount of water in the soil mass. Thus, the moisture content of the soil, which is defined as the ratio of the weight of water to the weight of dry soil particles, is normally the same for loose, uncompacted soil as for the same soil after compaction. Since the amount of air is reduced without change in the amount of water in the soil mass, the degree of saturation (the ratio of the volume of water to the combined volume of air and water) increases.

When used as a construction material, the significant engineering properties of soil are its shear strength, its compressibility, and its permeability. Compaction of the soil generally increases its shear strength, decreases its compressibility, and decreases its permeability.

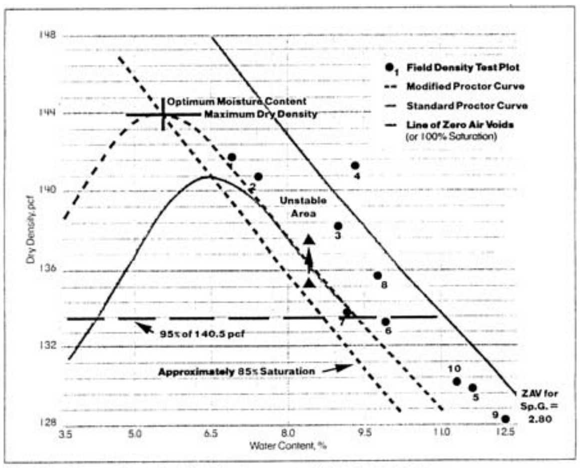
SOIL CLASSIFICATIONS

Considering soil compaction, the two broad classifications are cohesive soils and cohesionless, or noncohesive, soils. Cohesive soils are those that contain sufficient quantities of silt or clay to render soil mass virtually impermeable when properly compacted. Such soils are all varieties of clays, silts, and silty or clayey sands and gravels. By contrast, cohesionless soils are the relatively clean sands and gravels, which remain pervious even when well-compacted.

SOILS AND COMPACTION

An important characteristic of cohesive soils is that compaction improves their shear strength and compressibility properties. Such characteristics follow the principles stated by R.R. Proctor in 1933. The most recognizable development of his theory was a test now known as the "Standard Proctor," which is used to estimate the maximum density of soils. Today, there are several laboratory compaction standards and many construction methods to compact cohesive soils; however, the effect of the soil's water content on the resulting dry density is similar for all methods.

For each compaction procedure, there is an optimum moisture content, which results in the greatest dry density or state of compactness. At every other moisture content, the resulting dry density is less than this maximum. The figure below, which represents this principle, shows two moisture-density curves (a Standard Proctor Curve and a Modified Proctor Curve) for different amounts of compactive effort on the same soil. A different Proctor Curve is obtained for each compactive effort, but each curve has the same shape.



Plots of typical standard and modified Proctor curves with density test results.

For cohesionless soils, many well-graded sands and well-graded gravels can be tested for maximum density and optimum moisture content using Proctor methods. However, most poorly graded sands and gravels cannot be tested accurately using Proctor methods, so other methods, such as vibrating tables, are often used to estimate the maximum.

During the first half of the 20th Century, spectacular developments were made in the size and variety of field compaction equipment. The weight of available compaction equipment increased from approximately 5,000 pounds to 400,000 pounds. When Proctor developed his test, it seemed to be adequate. However, as the construction industry developed bigger and better equipment, engineers realized that specifying a compaction requirement of 90 percent of Standard Proctor was minimal and easily obtained with modern equipment. In fact, results greater than 100 percent compaction were becoming more common. Therefore, the “Modified Proctor test,” which imparts four and a half times more energy into the compactive effort than the Standard Proctor test, was developed.

The Standard Proctor test, which meets the requirements of ASTM D-698 Method A or AASHTO T-99, is performed in a 1/30-cubic-foot cylindrical mold using three layers. Each layer is compacted by 25 blows of a 5.5-pound hammer dropped 12 inches, which inputs 12, 375 foot-pounds per cubic foot of energy. The Modified Proctor meets the requirements of ASTM D-1557 Method A or AASHTO T-180. It is compacted in the same 1.30-cubic-foot mold, suing five layers; however, each layer is compacted by 25 blows of a 10-pound hammer dropped 18 inches, equaling 56, 520 foot-pounds per cubic foot.

The Modified Proctor usually results in a maximum density of three to six pounds per cubic foot more than the Standard Proctor and an optimum moisture content somewhat lower than the Standard Proctor. A line connecting the optimum moisture contents from the two methods is approximately 85 percent of the soil saturation for soils with specific gravities between 2.6 and 2.8, as shown in the figure above. Additionally, numbered circles show the dry densities obtained in the field. Note that two of the field points plot at or above 100 percent of the Standard Proctor. As described above, this is not unusual.

One point on the graph, Test 4, plots above the zero air void line; however, this is an impossible result. Either this data point is incorrect for this soil type, or it is an erroneous test. To be closer to achieving 100 percent accuracy for each density test, a soil sample would be obtained at each location, and a Proctor analysis would be performed for each field density test. Since this is prohibitively expensive on most commercial projects, one or more representative soil samples is chosen. Engineering technicians take additional samples if they observe different native soils on the site.

SOILS AND STABILITY

As stated previously, soil compaction involves a reduction in volume of the soil mass by the expulsion of air. As compaction increases, the degree of saturation increases. If the degree of saturation is less than about 90 percent, the soil is usually stable under dynamic loads. When the degree of saturation of a soil mass is between 90 percent and 100 percent, the soil exhibits instability, or pumping. Greater instability occurs at higher saturation levels. As can be seen in the figure to the left, Tests 1, 2, 3, 6, and 8 met the compaction requirement but are above the 90 percent line.

Soil can be compacted above the minimum compaction requirement but can still be unstable at the time of compaction. Soil can also be compacted and stable, and then become unstable later. For instance if a soil mass at a particular moisture content is compacted to a specific density and then recompacted by scrapers truck traffic, or other means, it could become more compacted but also unstable as the degree of saturation increases. This situation is shown by the triangles in the figure.

ACHIEVING STABILITY

The topic of how to deal with wet and pumping soil could fill a book. However, give such a subgrade, on or more of the following options might be useful to improve conditions:

1. If there is enough time, wait for the soil to dry sufficiently. This may or may not work
2. Rip or disk the soil, allow it to dry, and then recompact it. This may or may not work, based on the type of soil, the depth and severity of unstable soil, and the moisture content of the soil.
3. Use a geotextile or geogrid between the subgrade soil and the gravel base course.
4. Lime stabilize soil that contains a sufficient amount of soil passing the Number 200 sieve.
5. Mix Portland cement with a soil that is sufficiently sandy or gravelly. This is known as “cement treating” a soil.
6. Use a Class C fly ash to stabilize the soil.

Consult a geotechnical engineer to assess the best technique for dealing with wet or pumping soil. Also, be sure to seek recommendations for the most qualified contractors to deal with soil stabilization in your area.

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