SOIL COMPACTION

MOISTURE CONTENT/PROCTOR DENSITY CURVE

The importance of water to the process of soil compaction cannot be overstated. Every type of soil has physical characteristics that define how the soil reacts to moisture. For every soil material, there is a moisture content that maximizes the engineering properties of the material for a given compaction energy. Generally, the smaller the particle size, the greater the influence of water on compaction.

If a soil possesses too little moisture, the material will be difficult to work with because the particles will lack the lubrication necessary to rearrange them into a more dense state. And, the particles will not be cohesive enough to stay where they have settled.

Water is added to enhance cohesion and lubrication. Too much water can cause saturation. When the soil is saturated, voids fill with water, weakening the load-bearing capability of the structure. The particles will also be over-lubricated, allowing them to easily displace.

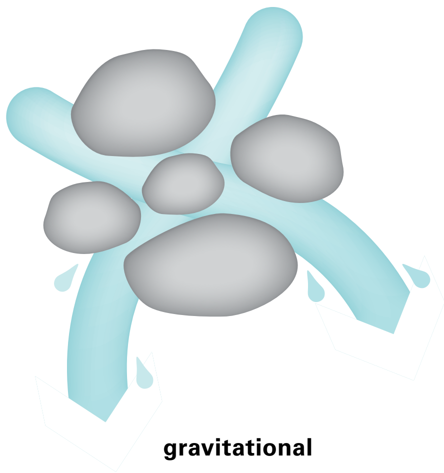
As a simple example of how water can affect the engineering properties of a soil, imagine trying to construct a sand castle on a beach. The water in the sand gives it enough cohesion to be molded into thick walls and tall towers. Now imagine trying to build the same sand castle in the desert. The arid desert soil lacks cohesion, so it would be difficult to manage more than a few low mounds of sand.

Water has other effects as well. Because it resists compression, it will displace soil materials, causing instability. Frozen water expands, displacing the soil around it. When the frozen water thaws, it occupies a smaller volume, creating space that will allow settling to occur.

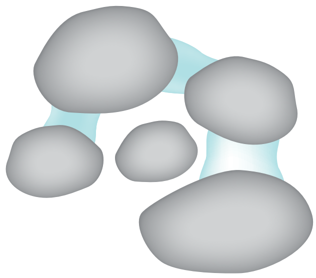
Water is present in all soils in their natural states. It appears in one of three ways.

1. Gravitational water is free to move downward due to the force of gravity. It can drain naturally from a soil.
2. Capillary water is held in a soil by small pores or voids. It is considered free water and can only be removed by lowering the water table or by evaporation.
3. Hygroscopic water is present in a soil after gravitational and capillary water are removed. Individual soil grains hold this water in the form of a very thin film having physical and chemical affinity for the soil grains. It is also called "air-dry" moisture content. This water would have to be removed by baking the soil in an oven to determine the true dry weight of the soil.

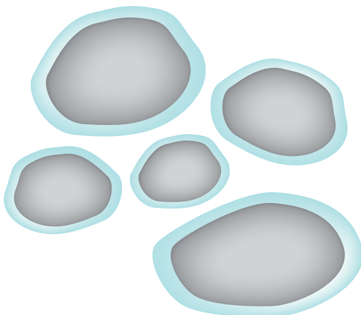
Too much moisture over-lubricates the soil and causes particle instability, while too little moisture reduces cohesion and prevents particles from reorienting easily into a denser state. For each soil type, there is an ideal moisture content at which maximum density can be reached with a given amount of compaction energy. The Proctor Test was developed as a way to help define this optimal moisture content for the selected compaction effort.



gravitational



capillary



hygroscopic

THE PROCTOR TEST

The value of compacting base and subbase soils has long been understood. But it was not until 1933 that Ralph R. Proctor of the Los Angeles Bureau of Water Works developed a standardized method for determining the optimum moisture content and the corresponding maximum dry density. The Proctor Test used a manually operated ram to compact three layers of the soil placed in a confined cylinder.

The Standard procedure determines the optimum moisture content of a material that will allow a given applied compaction force to obtain the maximum dry density of the material. This result is used to create a specification for compaction on the worksite. Because conditions in the field do not match the ideal conditions in a laboratory, the target compaction is scaled to a percentage of the dry density determined in the lab. This can range from 90 percent to over 100 percent.

Modified compaction tests have also been introduced in connection with structures requiring heavier bearing strength to support extremely heavy loads or to limit settlement. The Modified compaction test applies about four times more energy than the Standard compaction test and normally results in a lower "optimum" moisture content.

Proctor lab test kit

Surpassing 100 Percent Dry Density

How can the target density be over 100 percent? The maximum dry density established by the Proctor Test is not the maximum field density achievable on a particular soil. Proctor Dry Density of 100 percent represents the maximum density achieved in the lab with the particular sample using a specific amount of compaction force and ideal moisture content. Standard Proctor and Modified Proctor use different weights and will achieve different dry densities for the same sample. In the field, the "blows" are coming from a large soil compactor that applies a different amount of force than the hammers from the Proctor tests. It is not unusual to achieve field densities from 100 percent to 115 percent of Proctor maximum dry density. Geotechnical engineers may determine that due to load-bearing requirements and soil characteristics, compaction density over 100 percent of Proctor is warranted.

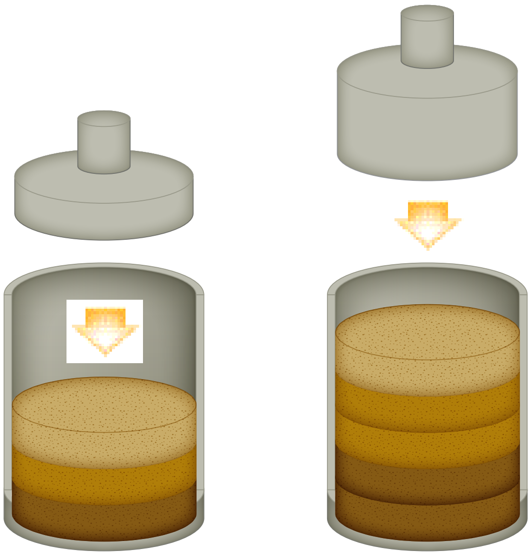
For a given soil sample, either the Standard or Modified Proctor is performed five times. The same procedure is used each time the test is run, but the moisture content is varied for each.

The series starts with the soil in a damp condition somewhat below the probable optimum moisture content. After the first sample is compacted into a cylindrical container, the wet weight is measured and a portion of the sample is placed in a drying oven. When the sample is completely dry, it is weighed again. The difference between the wet and dry weights yields the moisture content that is expressed as a percent of the dry weight.

A second sample with increased moisture content is compacted and the weighing and drying process is repeated. Additional samples with increasing moisture content are processed until the wet unit weight decreases or the soil becomes too wet to work.

Dry density and moisture content values for each sample are then plotted and a smooth curve is formed. The highest point on the curve represents the maximum dry density and the optimum moisture content for that soil sample.

PROCTOR TESTS



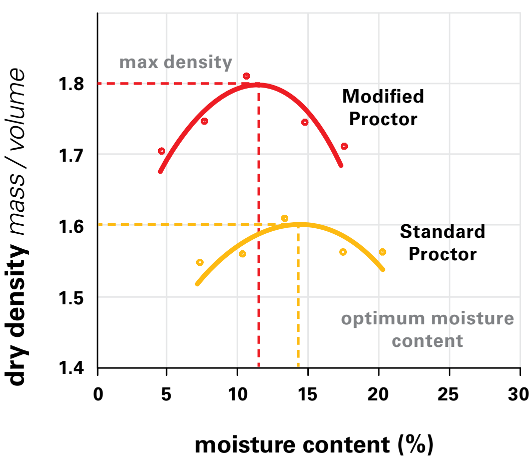
standard

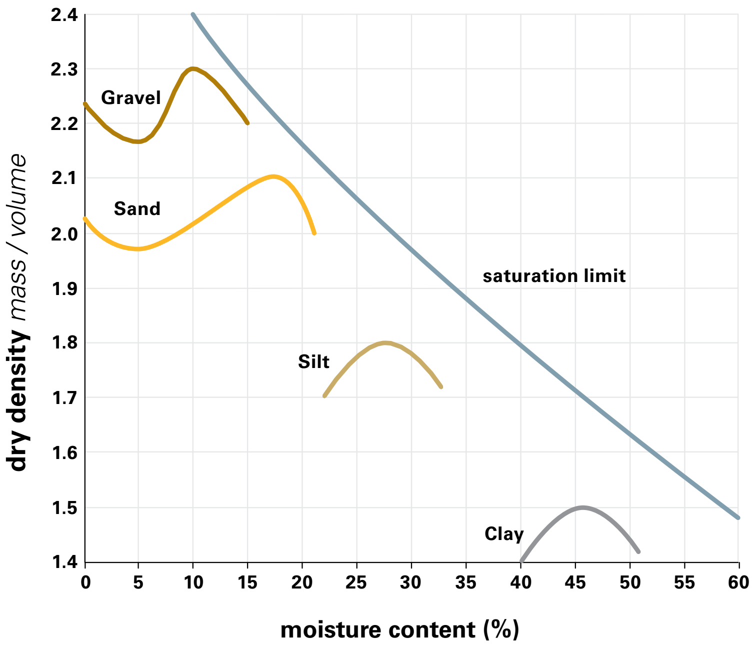
Each layer receives 25 blows from a 2.5 kg (5.5 lb) hammer at a distance of 305 mm (12 in)

modified

Each layer receives 25 blows from a 4.5 kg (10 lb) hammer at a distance of 457 mm (18 in)

PROCTOR CURVES

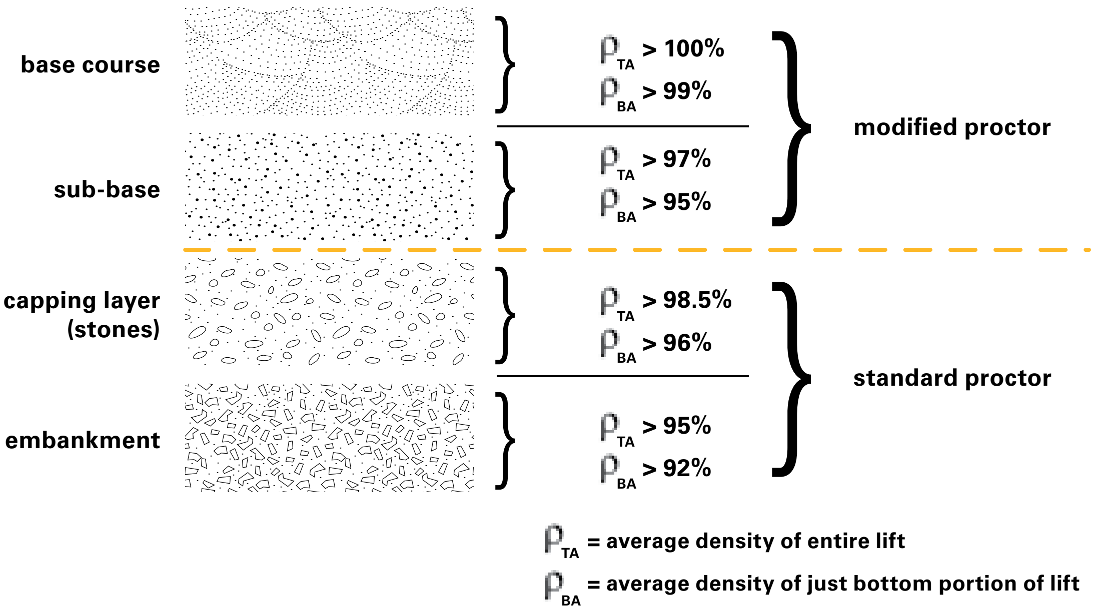




Laboratory tests determine the moisture content at which maximum density can be attained for that particular soil material. Field target densities are specified as a certain percent of the maximum laboratory dry density. Generally, required field densities will be 95 percent of Standard Proctor for embankments and up to 100 percent of Modified Proctor for roadway structures. Likewise, the moisture content must be within a range of the laboratory-determined, optimum moisture content.

DENSITY TARGETS

This example shows how the nearer the material is to the surface, the higher the density.



This illustration of the gradient of compaction compares the average density of the entire lift (ρ_{TA}) with the average density of just the bottom portion of the lift (ρ_{BA}).