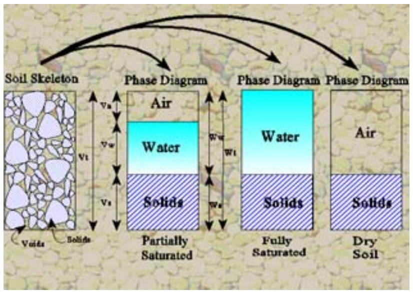
GEM Engineering, Inc.

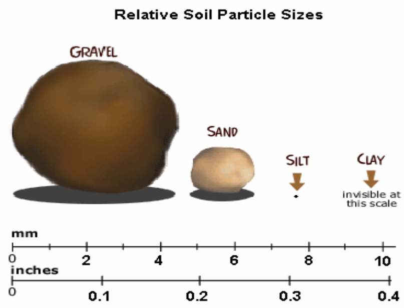
GEOTECHNICAL ENVIRONMENTAL & MATERIALS SERVICES

Soil Index Properties



Soil is composed of a wide variety of minerals combined with water, air, and other components such as organic matter. The diversity of soil types is virtually infinite, with countless combinations and proportions of the different components. Verbal descriptions of soil are subject to misunderstanding due to terminology that often is vague and not uniquely defined. For example, there are many different definitions and connotations for the term “clay”.

Geotechnical engineers have found that soils can be grouped into a small number of categories having similar engineering properties. The ability to properly identify and classify soils is an important initial method for predicting soil behavior. Soil classification is primarily cased on the results of certain laboratory tests. The results of these tests are called *index properties.* Soils having similar index properties are likely to have similar engineering behaviors.



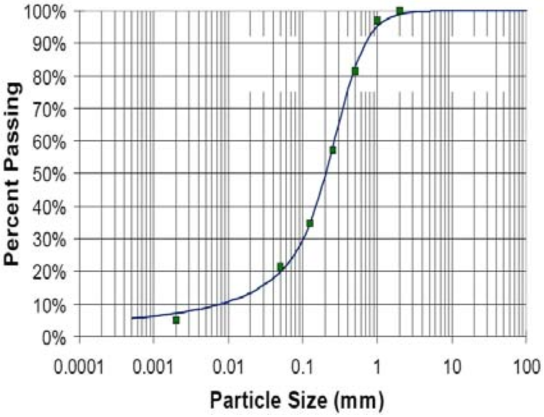
Index properties may be divided into two general types: soil *grain properties* and soil *aggregate properties*. Grain properties pertain to the individual particles that make up a soil mass. These properties are relatively constant for a given soil and generally are not significantly affected by disturbance. Particle size distribution and specific gravity are the most important grain properties of coarse-grained soils (sands and gravels). Mineral composition and specific gravity are the most important grain properties of fine-grained soils (silts and clays).

Aggregate properties depend on the structure and interactions between the individual particles. Since soil is malleable, the aggregate properties of undisturbed soil in the ground will differ from those of the same soil that has been excavated and placed in a loose pile. The aggregate properties of wet soil will differ from those of dry soil. Although grain properties are commonly used for identification purposes, the aggregate properties have a greater influence on the engineering behavior of the soil. Important aggregate properties include: density, moisture content, moisture density relationship, plasticity, and strength. (1)

Grain Property Tests

Particle-Size Analysis of Soils (ASTM D 422)

Particle size distribution is an indicator of many physical soil properties including: permeability, compactability, consolidation, shrink/swell potential, and liquefaction characteristics. The soil specimen is prepared and tested to determine the percentages of particles within a range of selected sizes. The measured cumulative quantities for each size are depicted on a graph that shows a distribution of gradations. The distribution of coarse-grained, sand and clay size particles (those retained on No. 200 / 75 micron sieve) is determined by sieving, while the smaller, fine-grained, silt and clay particle sizes are measured by a sedimentation process using a hydrometer. ASTM D 422 covers both methods.



A sieve analysis involves shaking a known weight of dry soil through a set of sieves arranged vertically with the largest sieve at the top to the smallest at the bottom. This process separates the soil according to the sieve opening sizes. The soil retained on each sieve is weighed. This data indicates the proportion of soil particles in each size range.

A hydrometer analysis involves filling a graduated cylinder with a well-mixed slurry of soil and water and observing the rate at which the soil particles fall out of suspension and settle to the bottom. The largest particles settle first, with more and more time required for settlement of the smaller particles. As the particles fall out of suspension, the density of the slurry decreases. The slurry density changes are measured with a calibrated hydrometer. The hydrometer readings and temperature of the slurry are directly related to the size of the settled particles. This method is based on Stokes's law, which expresses the velocity at which a particle falls through a fluid as a function of the diameter and specific gravity of the particle. By taking readings at various times, the particle size distribution can be determined.

Specific Gravity of Soils (ASTM D 854)

The specific gravity of a soil is the ratio of the soil density to density of water at a constant temperature. The specific gravity of a soil is used in calculating the phase relationships of soils (that is, the relative volumes of solids to water and air in a given volume of soil). It is applicable to many weight-volume relationships used in geotechnical engineering.

A specific gravity test involves determining the weight of a volumetric flask when filled with de-aired, distilled water, and again when the flask is filled with water mixed with 100 grams of air dry soil. The air must be removed from the soil-water mixture by applying a vacuum. This is an extremely important step. Most of the errors in the results of the test are due to entrapped air which is not removed. Finally, soil-water mixture is oven dried and the weight of the dry soil is determined. These values are used to calculate the average specific gravity of the soil particles.

The specific gravity of most soil particles lies within the range of 2.65 to 2.85. Soils containing organic matter or porous particles may have specific gravity values below 2.0. Soils containing metals may have specific gravity values above 3.0.

Aggregate Property Tests

Water (Moisture) Content of Soil (ASTM D 2216)

The soil moisture content is the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of soil to the mass of the solid soil. Moisture content samples are obtained during the field exploration phase of a project. Each sample is weighed, and then placed in an oven set to 110°C ± 5°. Each sample remains in the oven until the free moisture evaporates. Each dried sample is removed from the oven, allowed to cool, and then weighed. The moisture content is computed by dividing the weight of evaporated water by the weight of the dry sample.

Moisture content is a key index property used in predicting soil properties such as strength and compressibility. The moisture content, along with the liquid and plastic limits, is used to express the relative consistency or liquidity index of a soil. Higher moisture contents typically reflect lower strengths for a given soil.

Liquid Limit, Plastic Limit, and Plasticity Index of Soils (ASTM D-4318)

As a mixture of clay and water is progressively dried, it passes from a liquid state through a plastic state and finally to a solid state. The soil moisture content at each of these arbitrarily defined state changes is consistent for soils having similar physical properties. These moisture values, termed the Atterberg Limits, are perhaps the most important useful characteristics of fine-grained soils for basic geotechnical engineering classification and evaluation. A Swedish soil scientist, Albert Atterberg, developed tests to determine these values in the early 1900's. He was working in the ceramics industry and needed a method to evaluate the plasticity (malleability)of clay, which was important both in molding bricks and in reducing shrinkage and cracking during firing. He defined the term *plasticity index,* which is the range of water content where soil is plastic. He was the first to suggest that this property could be used for soil classification. In the 1920's, Karl Terzaghi and Arthur Casagrande, modified the test procedures for engineering classification purposes. (2)

The liquid limit (LL) is the minimum moisture content at which a soil will flow as a viscous fluid. It is determined using the liquid limit device invented by Casagrande (Figure 5). The liquid limit is defined as the moisture content at which the soil, when placed in the bowl shaped test device, makes a 1/2-inch closure in a groove cut through the soil after the bowl is dropped 25 times at a specified height and rate.

The plastic limit (PL) is the minimum moisture content at which the soil will exhibit plastic (semi-solid) behavior. This is determined by rolling the clay into 1/8" diameter threads until it begins to crumble (Figure 6) and determining the moisture content of the soil at that state.

The plasticity index (PI) is defined as the difference between the liquid limit and the plastic limit and is the range of moisture content over which a soil deforms as a plastic material.

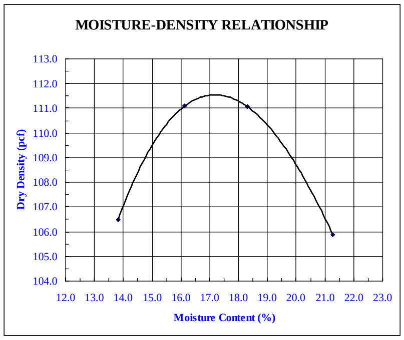
The LL, PL and PI are among the most useful index properties for classification of fine-grained soils. These values aid in predicting important soil behaviors of fine-grained soils including: compressibility, permeability, compactibility, shrink-swell, and shear strength.

Laboratory Compaction Characteristics of Soil Using Standard & Modified Effort (ASTM D 698/1557)

In general, the engineering behavior of soil improves with increased density. Soil placed as fill (embankments, building pads, backfill, pavement bases, dams, etc.) must be compacted to a dense state to obtain satisfactory engineering properties such as increased strength, reduced compressibility, and reduced permeability.

The ability to compact soil significantly depends on its water content. It the water content is low, the soil will be hard and difficult to compact. Water must be added to facilitate compaction. The water aids the compaction process by acting as a lubricant, allowing the soil particles to move closer together into a more compact, dense structure. However, if water content is too high, the soil particles will fall apart without an increase in density and the excess water will occupy space that otherwise would have been filled with soil particles, thereby decreasing the density. Between these extremes there is an optimum moisture content at which the effects of compaction are maximized.

The Proctor tests involve compacting the soil in either three or five equal layers, within either a 4-inch or 6-inch diameter mold. The compaction energy is applied by either 25 or 56 blows on each layer with a hammer of specified weight and drop height. The resulting dry unit weight and moisture content values are determined. The procedure is repeated for a sufficient number of moisture contents to establish a relationship (compaction curve) between the dry unit weight and moisture content for the soil. The values of optimum moisture content and maximum dry density are determined from the compaction curve.



The Proctor test is used to determine the maximum dry density and the optimum moisture content of a soil for a specified amount of compaction effort. The compaction energy applied to the soil with standard and modified effort approximately corresponds to that applied in the field with standard and heavy compactors, respectively. Proctor tests provide the basis for determining the percent compaction and water content needed to achieve the required engineering properties, and for controlling construction to assure that the required properties are achieved.

Unconfined Compressive Strength of Cohesive Soil (ASTM D 2166)

The primary purpose of this test is to obtain the approximate compressive strength of soils that possess sufficient cohesion to permit testing in the unconfined state. Tests are conducted on undisturbed, remolded, or compacted soil specimens, using strain controlled application of an axial load. Loading is increased until the sample fails (the load values begin to decrease with increasing strain) or until 15 percent strain is reached. The unconfined compressive strength is the maximum compressive stress, or the compressive stress at 15 percent strain, whichever is developed first.

Density of Soil in Place (ASTM D-2937)

The density of in place soil is a common property that directly indicates the degree of compaction and is indirectly related to a number of other soil properties including shear strength, compressibility, permeability and modulus. The test consists of driving or pushing a thin-walled cylinder into the soil and extracting a relatively undisturbed soil specimen. The sample is trimmed to a uniform size and the soil weight is determined. The specimen dimensions are measured to determine the volume of soil. A portion of the sample is tested in accordance with ASTM D 2216 to determine the soil water content. These values are then used to calculate the wet and dry density of the soil.

References

1. *Foundation Engineering*, Ralph B. Peck, Walter E. Hanson, Thomas H. Thornburn. John Wiley and Sons, Canada, 1974.

2. *An Introduction to Geotechnical Engineering*, Robert D. Holtz and William D Kovacs. Prentice Hall, Upper Saddle River, New Jersey 1981.

3. *Annual Book of ASTM Standards 2003,* ASTM International. Baltimore, MD, U.S.A. 2003.