Soil Mechanics

Soil is the most misunderstood term in the field. The problem arises in the reasons for which different groups or professions study soils.

Soil scientists are interested in soils as a medium for plant growth. So soil scientists focus on the organic rich part of the soils horizon and refer to the sediments below the weathered zone as parent material. Classification is based on physical, chemical, and biological properties that can be observed and measured.

Soils engineers think of a soil as any material that can be excavated with a shovel (no heavy equipment). Classification is based on the particle size, distribution, and the plasticity of the material. These classification criteria more relate to the behavior of soils under the application of load - the area where we will concentrate.

Soil Mechanics

Most geologists fall somewhere in between. Geologists are interested in soils and weathering processes as indicators of past climatic conditions and in relation to the geologic formation of useful materials ranging from clay to metallic ore deposits. Geologists usually refer to any loose material below the plant growth zone as sediment or unconsolidated material.

The term ***unconsolidated*** is also confusing to engineers because ***consolidation*** specifically refers to the compression of saturated soils in soils engineering.

Soil Mechanics

Engineering Properties of Soil
The engineering approach to the study of soil focuses on the characteristics of soils as construction materials and the suitability of soils to withstand the load applied by structures of various types.

Weight-Volume Relationship
Earth materials are three-phase systems. In most applications, the phases include solid particles, water, and air. Water and air occupy voids between the solid particles. For soils in particular, the physical relationship between these phases must be examined. A mass of soil can be conveniently represented as a block diagram, with each phase shown as a separate block.

Soil Mechanics

The relationship between weight and volume can be expressed as:

$$\mathbf{W_m = V_m G_m \gamma_w}$$

where: $\mathbf{W_m}$ is the weight of the material (solid, liquid or gas),
$\mathbf{V_m}$ is the volume of the material,
$\mathbf{G_m}$ is the specific gravity of the material (weight of a material relative to the weight of an equal volume of water - dimensionless) and
γ_w is the unit weight of water (mass * gravity - 62.4 lb/ft^3 , 1.0 g/cm^3 and 9800 N/m^3).

Also

$$\mathbf{W_s = V_s G_s \gamma_w}$$

and the weight of water is:

$$\mathbf{W_w = V_w G_w \gamma_w = V_w \gamma_w}$$

(since the specific gravity of water is = 1)

Soil Mechanics

When dealing with a soil sample from the field that contains both water and soil particles, the unit weight can be expressed both with and without the water contained in the soil. The **unit wet weight** is given by:

$$\gamma_{wet} = W_T / V_T$$

(total weight over total volume in kg/m^3, g/cm^3 or lbs/ft^3)

and is determined by weighing a known volume of soil without allowing any drainage or evaporation of water from the voids.

Alternatively, the **unit dry weight** is expressed as:

$$\gamma_{dry} = W_s / V_T$$

(weight of solids over total volume)

Unit dry weight is determined by oven drying a known volume of soil. The resulting weight will be the weight of solids (W_s). Both unit wet and dry weights are expressed in pcf or g/cm^3.

Soil Mechanics

The weight of water in a soil sample that was oven dried is the difference between the weight before drying and the weight of solids measured after drying.

The water content (w) of a soil, which is expressed as a decimal or percent, is defined as:

$$w = W_w / W_s \times 100\%$$

where - w – water content
W_w – weight of water
W_s – weight of solids

Soil Mechanics

Relationships between volumes of soil and voids are described by the void ratio (e) and porosity (n).

The void ratio is the ratio of the volume of voids to the volume of solids: (expressed as a decimal):

$$e = V_v / V_s$$

whereas the porosity is the ratio of void volume to total volume: (expressed as a percent)

$$n = V_v / V_T \times 100\%$$

These terms are related and it is possible to show that

$$e = n / 1 - n$$

The term degree of saturation (S) relates the volume of water in the void space to total void volume:

$$S = V_w / V_v \times 100\%$$

problem

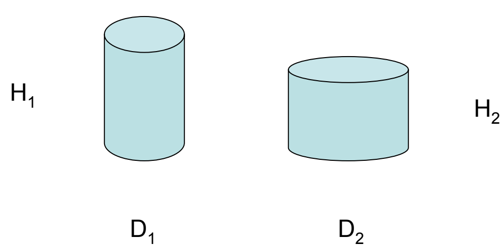
Soil Mechanics

Poisson's Ratio

$$\mathbf{V = E_1 / E}$$

where E_1 = lateral strain
E = is axial strain

ASSUMING there is no change in volume



$E_1 = \Delta D / D_1$

$E = \Delta H / H_1$

Soil Mechanics

Index Properties and Classification
Particles size and distribution, type of particle, density and water content relate to the shear strength, compressibility, and other aspects of soil behavior. These index properties are used to form engineering classifications of soil and can be measured by simple lab or field tests called classification tests.

Index Properties of Soils

Soil type	Index Property
Coarse-grained (cohesionless)	Particle-size distribution Shape of particle Clay content In-place density Relative density
Fine-grained (cohesive)	Consistency Water content Atterberg limits Type and amount of clay Sensitivity

Soil Mechanics

Index Properties and Classification
An important division of soils for engineering purposes is the separation of coarse-grained, or cohesionless soils, from fine-grained, or cohesive soils. Cohesive soils, which contain silt and clay, behave much differently from cohesionless materials.

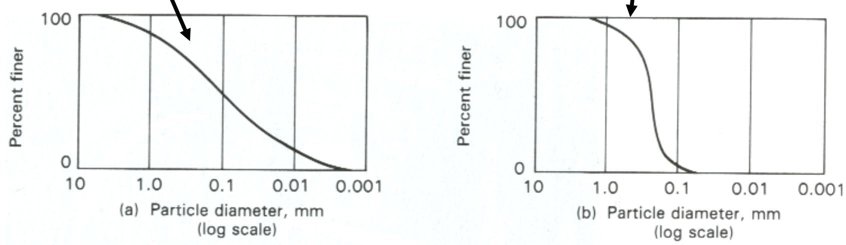
The term cohesion refers to the attractive forces between individual clay particles in a soils.

The index properties that apply to cohesionless soils refer to the size and distribution of particles in the soil. These characteristics are evaluated by mechanical analysis, a laboratory procedure that consists of passing the soil through a set of sieves with successively smaller openings. The size of the sieve openings determines the size of the particles that can pass through them. After the test, the particles retained on each sieve are converted to a weight percentage of the total and then plotted against particle diameter as determined by the known sieve opening size. The result is a grain-size distribution curve.

Soil Mechanics

Index Properties and Classification
The shape of the grain-size distribution curve is a very important soil characteristic. A curve that covers several log cycles of the graph contains a variety of particle sizes. This type of soil would be called well-graded.

The opposite type of soil, composed of a very narrow range of particle sizes, would be classified as poorly graded.



Soil Mechanics

Index Properties and Classification
For a soil to be truly described as well-graded, it must also meet certain criteria.

The coefficient of uniformity, C_u, must be greater than 4 for gravel, and greater than 6 for sand, and the coefficient of curvature, C_c, must be between 1 and 3.

The coefficient of uniformity is calculated from the graph by the following formulas:

$$C_u = D_{60} / D_{10}$$

where D_{60} is the particle-size diameter for which 60 percent of the sample was finer, and,
D_{10} is the particle-size diameter for which 10 percent of the sample was finer.

These same diameters are used in computing the coefficient of curvature according to the formula:

$$C_c = (D_{30})^2 / (D_{10} * D_{60})$$

grain-size distribution curve.

Soil Mechanics

Index Properties and Classification
These terms can be easily confused with the term sorting, the geological designation for grain-size distribution.

Geologists would refer to a ***poorly graded*** soil with a narrow range of sizes as ***well sorted***.

The opposite, a ***well graded*** soil, would be considered ***poorly sorted*** by geologists.

To determine whether a material is sand or gravel note where the D_{50} value lies on the grain-size distribution curve and extrapolate straight down to the grain-size. If the D_{50} value is less than 5 mm in diameter it is considered to be sand (fine, medium or coarse) and if the D_{50} value is greater than 5 mm than the material is considered to be a gravel.

Soil Mechanics

Index Properties and Classification
The other index properties describing cohesionless soils include ***particle shape***, ***in-place density***, and ***relative density (D_r)***. These properties are related because particle shape influences how closely particles can be packed together. The in-place density refers to the actual density of the soil at its particular depth in the field. It is measured by weighing an oven-dried sample taken from a known volume. The relative density is the ratio of the actual density to the maximum possible density of the soil. It is expressed in terms of void ratio:

$$\frac{\text{void ratio in loose}}{\text{void ratio in natural setting,}}$$

$$\mathbf{D_R = (e_{max} - e_0)/(e_{max} - e_{min}) * 100\%}$$

where e_{max} is the void ratio of the soil in its loosest condition,
e_0 is the void ratio in its natural condition, and
e_{min} is the void ratio in its densest condition.

Both e_{max} and e_{min} can be measured in lab tests. Relative density is a good indication of possible increases in density, or compaction, that may occur if load is applied to the soil.

Soil Mechanics

Index Properties and Classification
The index properties of fine-grained, or cohesive, soils are somewhat more complicated than the index properties of cohesionless soils because of the influence of **clay minerals**. The type and amount of clay minerals are, therefore, very significant.

Clay size versus Clay mineral
The concept of clay size versus clay mineral has plagued soils workers for many years. **Clay minerals** are fine-sized platy silicates that have the property of plasticity, that is, they can be rolled into a thin thread which adheres together at low moisture levels.

Clay size, by contrast, is a small particle size designation that does not always ensure that its constituents will be plastic. In actual fact, some fine-sized quartz and feldspar grains can occur in the range of 0.005 mm and it is these non-plastic materials that complicate the problem. However, very few feldspar and quartz grains occur at 0.002 mm and below, so by placing the clay boundary at this lower value, the clay size and clay mineral designations coincide quite well.

Soil Mechanics

Index Properties and Classification
With respect to engineering behavior, **consistency** is the most important characteristics of cohesive soils. It refers to the strength and resistance to penetration of the soil in its in-place condition.

Consistency is determined by the arrangement of soil particles, particularly clay particles, in the soil, which is called the soil's *fabric*. Although many types of fabric are possible, soils in which edge-to-face contact of clay particles exists or soils which have **flocculated fabrics**, are much stronger than soils which have the parallel arrangement of particles found in **dispersed fabrics**.

Flocculated fabrics change to dispersed fabrics during remolding, which involves disturbance and alteration of the soil by natural processes or during various lab tests.

Flocculated — Dispersed

Soil Mechanics

Index Properties and Classification

The consistency of a soil can be determined by field tests in which the soil is evaluated in place, or by lab tests on samples that have been carefully handled to avoid remolding. The unconfined compression test is often used as an indication of consistency. In practice, the relative terms soft, medium, stiff, very stiff, and hard are applied to describe consistency.

Consistency	Shear Strength N/m^2	Unc. Comp Strength N/m^2	Feel or Touch
Soft	<24,500	< 49,000	Easily penetrated several inches with thumb
Medium stiff	24,500 – 49,000	49,000 – 98,000	Moderate effort penetrates several inches with thumb
Stiff	49,000 – 98,000	98,000 – 196,000	Readily indented with thumb but penetrated only with great effort
Very stiff	98,000 – 196,000	196,000 – 392,000	Readily indented by thumbnail only
Hard	> 196,000	> 392,000	Indented with difficulty by thumbnail

Soil Mechanics

Index Properties and Classification

The ratio of unconfined compressive strength in the undisturbed state to strength in the remolded state defines the index property called **sensitivity**.

The ***sensitivity***, S_t can be expressed as:

S_t = (strength in the undisturbed conditions) / (strength in remolded condition)

Sensitivity of clays

Type	Sensitivity value
Non-sensitive	2-4
Sensitive	4-8
Highly sensitive	8-16
Quick	>16

Soils with high sensitivity are highly unstable and can be converted to a remolded or dispersed state very rapidly, with an accompanying drastic loss of strength. Disastrous slope movements generally follow these transformations.

Soil Mechanics

Index Properties and Classification
The water content is an important influence upon the bulk properties and the behavior of a soil. In the remolded state, the consistency of the soil is defined by the water content.

Four consistency states are separated by the water content at which the soil passes from one state to another. These water content values are known as the Atterberg limits. For example, the **liquid limit** is the water content at which the soil-water mixture changes from a liquid to a plastic state. As the water content decreases, the soil passes into a semisolid state at the **plastic limit**, and a solid state at the **shrinkage limit**. The **shrinkage limit** defines the point at which the volume of the soil becomes nearly constant with further decreases in water content.

The Atterberg limits can be determined with simple laboratory tests. The use of the Atterberg limits in predicting the behavior of natural, in-place soil is limited by the fact that they are conducted on remolded soils. The relationship between moisture content and consistency defined by the Atterberg limits may not be the same in soils in the undisturbed state. Therefore, the Atterberg limits are mainly used for classification rather than for the prediction of soil behavior under field conditions.

Soil Mechanics

Index Properties and Classification
Various agencies and professional organizations have devised classifications that provide subdivision which are the most useful for specific applications in their specialty.

Unified Soil Classification System
The most useful engineering classification of soils is the Unified Soil Classification System.

This classification gives each soil type a two-letter designation. For coarse-grained soils, the first letter, either G for gravel or S for sand, refers to the dominant particle size in the soil. The second letter is either W, for well graded or P, for poorly graded or M (silt) or C (clay) for coarse-grained soils with more than 12% of silt or clay.

The first letter of the designation for fine-grained soils is M or C (silt or clay). The second letter, either H (high) or L (low), refers to the plasticity of the soil as defined by the plasticity index.

Soil Mechanics

Unified Soil Classification System
The **plasticity index** is defined as:

PI = LL – PL

The difference between the liquid and plastic limits (PI) is a measure of the range in water contents over which the soil remains in a plastic state.

The plotted position of a soil with respect to the A-line on the plasticity chart determines whether the soil receives the letter H for high plasticity or the letter L for low plasticity.

Highly organic soils, which form a final category in the classification, are also subdivided into high- and low-plasticity types. Once a soil has been classified by the Unified system, predictions can be made of the soil's permeability, strength, compressibility, and other properties.

Soil Mechanics

Clay size versus Clay mineral
Remember our previous discussion on this issue… Clay size does not mean the same as clay minerals. Clay minerals generate cohesion while clay sizes can be cohesionless.

In the USC approach the problem is faced in a different way. Because the silt-clay size boundary for the ASTM classification (0.005 mm) does not ensure that finer material will consist of clay materials (and be plastic) and coarser materials will be non-plastic, the entire size group below 0.074 mm is collectively referred to as fines. If the fines are plastic, then the material is considered to be clay and, in like manner, if the fines are not plastic then they are silt. This leads to the distinction of plastic fines and non-plastic fines replacing the decision based on particle size.

Soil Mechanics

Shear strength
The strength of a soil determines its ability to support the load of a structure or remain stable upon a hillside. Engineers must therefore incorporate soil strength into the design of embankments, road cuts, buildings, and other projects.

The strength of a soil is often determined by its ability to withstand shearing stresses. The Mohr-Columb equation relates normal stress, cohesion, pore pressure, and friction angle to the shear strength of rock or soil:

$$\tau = c + (\sigma - \mu) \tan \phi$$

where: τ is shear stress,
c is cohesion,
σ is normal stress,
μ is hydrostatic stress (pore pressure),
ϕ is the angle of internal friction

Soil Mechanics

Shear strength
Mohr-Columb

$$\tau = c + (\sigma - \mu) \tan \phi$$

In many engineering geologic problems, such as landslides and earthquakes, **fluid pressure** is an important consideration because it affects the normal stress.

Hydrostatic Stress (σ' = effective stress = $(\sigma - \mu)$) of entrapped fluids counteracts the normal pressure.

$$\tau = c + (\sigma - \mu) \tan \phi$$

$$\tau = c + \sigma' \tan \phi$$

where: τ is shear stress,
c is cohesion,
σ' is effective stress,
μ is hydrostatic stress,
ϕ is the angle of internal friction

Soil Mechanics

Shear strength
In the Mohr-Coulomb theory of failure, shear strength has two components:

- one for inherent strength due to bonds or attractive forces between particles, and
- the other produced by frictional resistance to shearing movement

The shear strength of cohesionless soils is limited to the frictional component.

When the direct shear test is used to investigate a cohesionless soil, successive tests with increasing normal stress will establish a straight line that passes through the origin.

The angle of inclination of the line with respect to the horizontal axis is the angle of internal friction.

Soil Mechanics

Shear strength
Values of the angle of internal friction are given in the following table. If the soil is dense when tested, initially higher values for the angle of internal friction will be measured, but with increasing amounts of strain, the angle will decline to the approximate ranges seen in the Table.

SOIL TYPE	ANGLE ϕ, DEGREES
Sand and gravel mixture	33 – 36
Well-graded sand	32 – 35
Fine to medium sand	29 – 32
Silty sand	27 – 32
Silt (non-plastic)	26 – 30

Soil Mechanics

Shear strength

The shear strength of a cohesive soil is more complicated than a cohesionless material.

The differences are due to the role of pore water in a cohesive soil. Most cohesive soils in field conditions are at or near saturation because of their tendency to hold moisture and their low permeability.

When load is applied to a soil of this type, the load is supported by an increase in the pore-water pressure until pore-water can drain into regions of lower pressure.

At that point, soil particles are forced closer together and the strength increases, just like a cohesionless soil. Time is an important factor however, because it takes longer for water to move out of a low permeability material.

Soil Mechanics

Shear strength

Strength tests for cohesive soils are usually made in tri-axial cells in which the drainage of the sample can be controlled. Test conditions can allow

1. no drainage of the soil during loading,
2. drainage during an initial phase of loading, followed by failure in an un-drained condition, and
3. complete drainage during very slow loading to failure

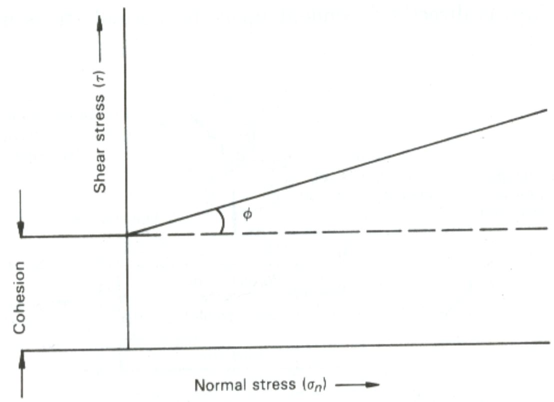
The response of the sample is different in each case.

For the most basic case, in which the sample is un-drained throughout the test, the results will yield a straight line on a plot of normal stress versus shear stress. The reason for this consequence is that the soil particles cannot be forced close together without drainage of pore water, and thus cannot develop greater resistance to shear failure.

Soil Mechanics

Shear strength

Strength tests of soils that are mixtures of cohesive and cohesionless material yield failure envelopes similar to the following illustration:



problem

Soil Mechanics

Settlement and Consolidation

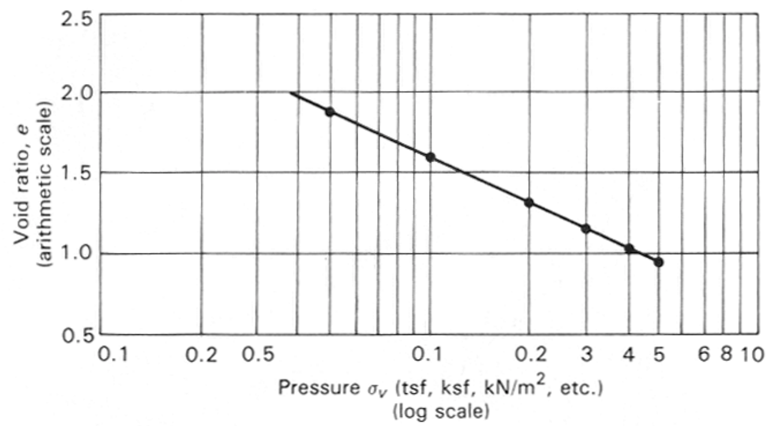
When a landslide occurs, it is an indication that the stress within the soil mass exceeded the shear strength of the soil at the time of failure. the load imposed by buildings and other structures on most soils is rarely great enough to overcome the ultimate shear strength or **bearing capacity** of the soil.

Despite the lack of large-scale bearing capacity failures caused by the load upon the soil exerted by structures, the soil does deform under the load applied. The usual response is a volume decrease in the soil beneath the foundation. **Settlement** is the vertical subsidence of the building as the soil is compresses. Excessive settlement, particularly when it is unevenly distributed beneath the foundation, can result in serious damage to the structure.

The tendency of a soil to decrease in volume under load is called **compressibility**. This property is evaluated in the consolidation test, in which a soil sample is subjected to an increasing load. The change in thickness is measured after the application of each load increment.

Soil Mechanics

Settlement and Consolidation
During the consolidation test, soil particles are forced closer together as in strength tests. Thus compression of the soil causes a decrease in void ratio. Data from the consolidation test are plotted as void ratio against the log of vertical pressure applied to the sample. The slope of the resulting straight line is called the **compression index**, $\mathbf{C_c}$.



Soil Mechanics

Settlement and Consolidation
The compression index is an important property of soil because it can be used to predict the amount of settlement that will occur from the load of a building or other structure. Clay-rich soils and soils high in organic content have the highest compressibility.

The compression of a saturated clay soil is a slightly different process from the compression of an unsaturated material. When the pores of a soils are filled with water compression is impossible because the void volume is totally occupied. The increase in load upon the saturated clay during a consolidation test or actual field situation is initially balanced by an increase in fluid pressure in the pores of the soil.

Higher fluid pressure in the clay causes the pore water to flow out of the clay toward any direction where fluid pressure is lower. Only after pore fluid is removed, can the soil compress to a lower void ratio. This process is called **consolidation**.

Soil Mechanics

Settlement and Consolidation
Settlement is calculated as follows:

$$S = \sigma_v * R / E * 2(1-V^2)$$

Where: σ_v **= vertical stress**
R = radius of the loaded area
E = modulus of elasticity
V = poisson's ratio

Soil Mechanics

Settlement and Consolidation
Consolidation is an important phenomenon to consider when constructing a building on a saturated clay because consolidation is very slow.

The movement of pore water out of the soil is a function of the permeability, and clay has the lowest permeability of any soil. Therefore, it may take years for the soil to reach equilibrium under the load imposed. The settlement occurring during this period can be dangerous to the building.

A famous example of consolidation is the Leaning Tower of Pisa. Titling of the tower is the result of non-uniform consolidation (differential in a clay layer beneath the structure. This ongoing process may eventually lead to the failure of the tower.

finis

Links

problem

Example:
A 110 cm^3 sample of wet soil has a mass of 212 g and a degree of saturation of 100%. When oven-dried, the mass is 162 g. Determine the unit dry weight (dry density in this case because of the units used), water content, void ratio, and specific gravity of the soil particles.

Solution:
Given: V_{total} – 110 cm^3
W_{total} – 212 g
W_{solid} – 162 g
S – 100%

Unit dry weight

$$\gamma_{dry} = W_s/V_T = 162 \text{ g} / 110 \text{ cm}^3 = 1.47 \text{ g/cm}^3$$

Water content

$$w = W_w/W_s * 100 = (212 \text{ g} - 162 \text{ g}) / 162 \text{ g} = 0.309 = 30.9\%$$

problem

Example:
A 110 cm^3 sample of wet soil has a mass of 212 g and a degree of saturation of 100%. When oven-dried, the mass is 162 g. Determine the unit dry weight (dry density in this case because of the units used), water content, void ratio, and specific gravity of the soil particles.

Solution:
Given: V_{total} – 110 cm^3
W_{total} – 212 g
W_{solid} – 162 g
S – 100%

For void ratio (V_v / V_s) , first find the volume of water:

$$V_w = W_w / G_w \gamma_w = (212 \text{ g} - 162 \text{ g})/1.0 * 1.0 \text{ g/cm}^3) = 50 \text{ cm}^3$$

Since S = 100%, $V_w = V_v$ (If S = 50%, then Vw = 0.5Vv)

$$V_s = V_T - V_w = 110 \text{ cm}^3 - 50 \text{ cm}^3 = 60 \text{ cm}^3$$

problem

Example:
A 110 cm^3 sample of wet soil has a mass of 212 g and a degree of saturation of 100%. When oven-dried, the mass is 162 g. Determine the unit dry weight (dry density in this case because of the units used), water content, void ratio, and specific gravity of the soil particles.

Solution:
Given: V_{total} – 110 cm^3
W_{total} – 212 g
W_{solid} – 162 g
S – 100%

to find void ratio:

$$e = V_v / V_s = 50\ cm^3 / 60\ cm^3 = 0.83$$

to find the specific gravity ($W_s = V_s G_s \gamma_w$)

solving for $G_s = W_s / V_s\ \gamma_w$ = 162 g / (60 cm^3) (1.0 g/cm^3) = 2.70 of the soil particles

problem

Example:
A saturate cohesive soil is tested in a triaxial cell. During the test, no drainage is allowed from the sample. At failure, the major and minor principal stresses are 2600 and 1000 psf respectively. What is the cohesion of the sample?

Because the sample is undrained, increases in the normal stress will have no effect on the strength, and the failure envelope will be a straight line. σ_1 and σ_3 are plotted on the horizontal axis to form a diameter of a Mohr's circle plot. The failure envelope will be tangent to the top of the circle at a distance from the origin on the vertical axis equal to the radius of the circle. Thus

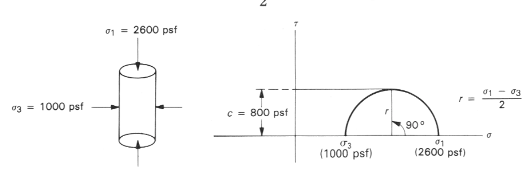
$c = r = (\sigma_1 - \sigma_3) / 2$

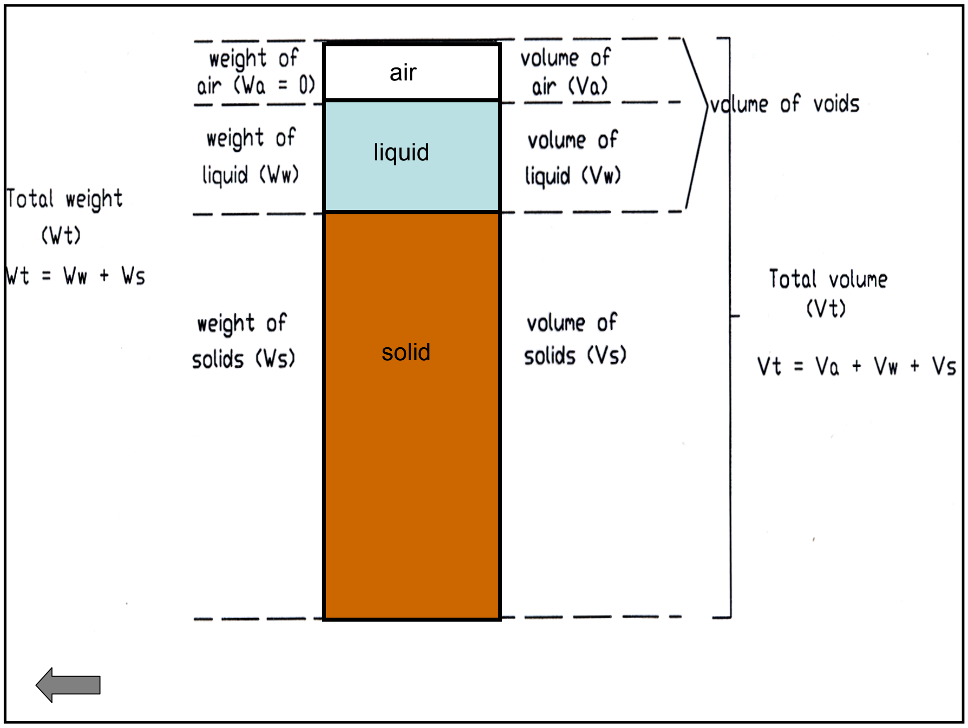
c = (2600 psf - 1000 psf) / 2

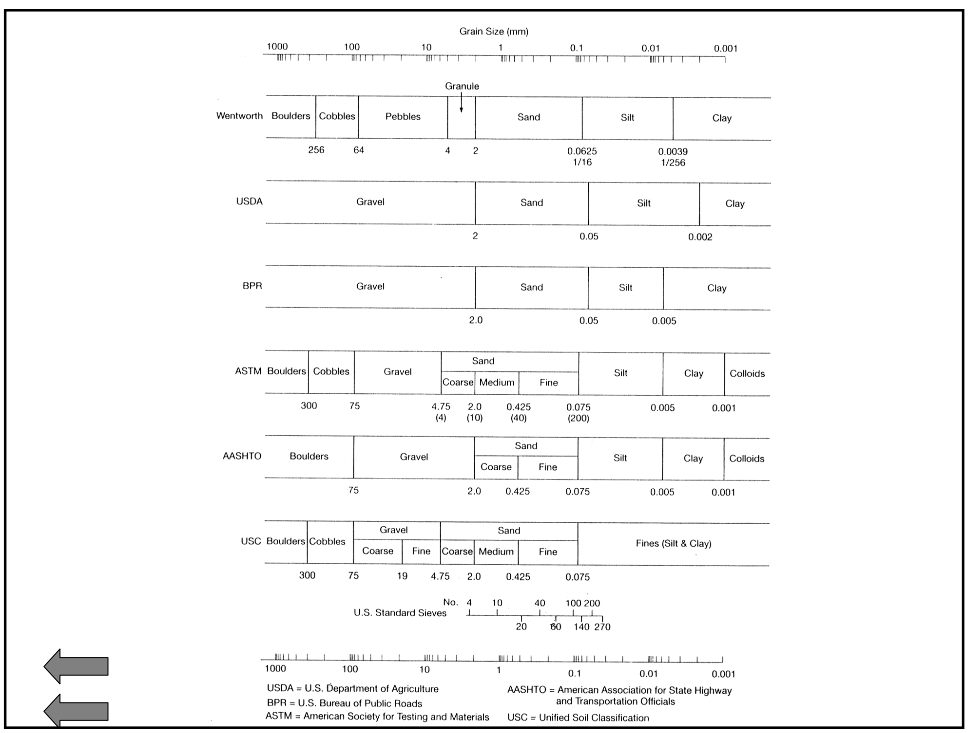
= 800 psf

$$c = r = \frac{\sigma_1 - \sigma_3}{2}$$

$$c = \frac{2600\ \text{psf} - 1000\ \text{psf}}{2} = 800\ \text{psf}$$

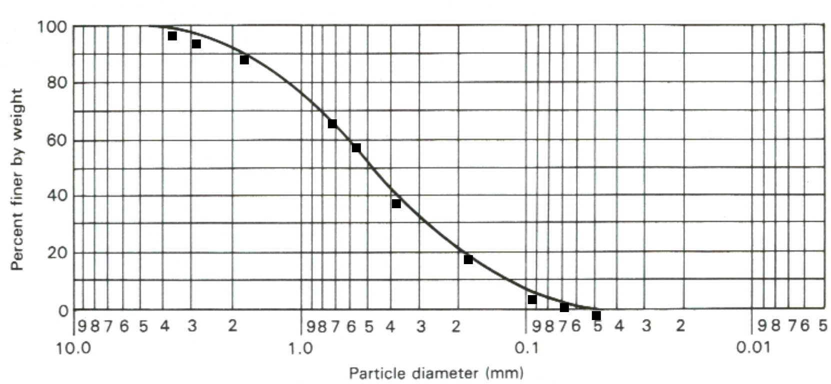



weight of air (Wa = 0)
air
volume of air (Va)
volume of voids
weight of liquid (Ww)
liquid
volume of liquid (Vw)
Total weight (Wt)
Wt = Ww + Ws
Total volume (Vt)
Vt = Va + Vw + Vs
weight of solids (Ws)
solid
volume of solids (Vs)

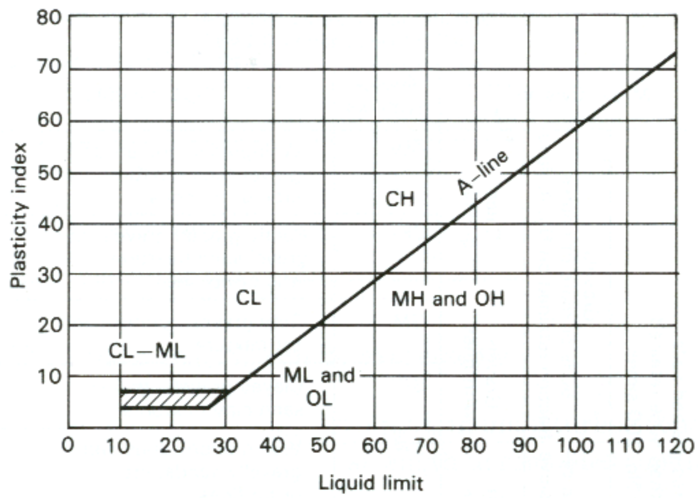

Grain Size (mm)
1000 100 10 1 0.1 0.01 0.001
Granule
Wentworth Boulders Cobbles Pebbles Sand Silt Clay
256 64 4 2 0.0625 1/16 0.0039 1/256
USDA Gravel Sand Silt Clay
2 0.05 0.002
BPR Gravel Sand Silt Clay
2.0 0.05 0.005
ASTM Boulders Cobbles Gravel Sand Coarse Medium Fine Silt Clay Colloids
300 75 4.75 (4) 2.0 (10) 0.425 (40) 0.075 (200) 0.005 0.001
AASHTO Boulders Gravel Sand Coarse Fine Silt Clay Colloids
75 2.0 0.425 0.075 0.005 0.001
USC Boulders Cobbles Gravel Coarse Fine Sand Coarse Medium Fine Fines (Silt & Clay)
300 75 19 4.75 2.0 0.425 0.075
U.S. Standard Sieves
No. 4 10 40 100 200
20 60 140 270
1000 100 10 1 0.1 0.01 0.001
USDA = U.S. Department of Agriculture
BPR = U.S. Bureau of Public Roads
ASTM = American Society for Testing and Materials
AASHTO = American Association for State Highway and Transportation Officials
USC = Unified Soil Classification

Unified Soil Classification System
(ASTM Designation D-2487)

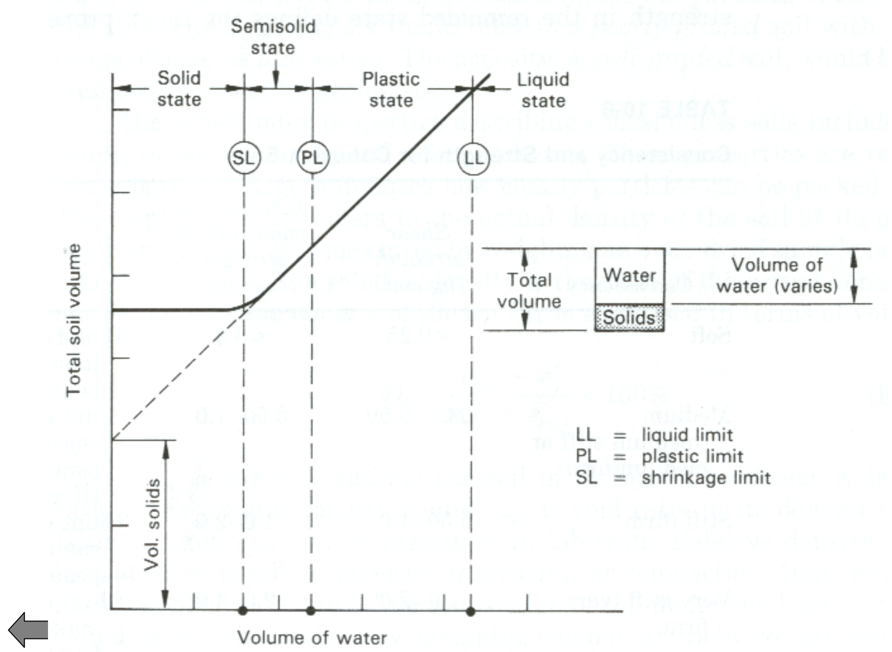
Major division			Group symbols	Typical names
Coarse-grained soils More than 50% retained on No. 200 sieve	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with fines	GM	Silty gravels, gravel-sand-silt mixture
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands More than 50% of coarse fraction passes No. 4 sieve	Clean sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Sands with fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-grained soils 50% or more passes No. 200 sieve	Silts and clays Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and clays Liquid limit greater than 50%		MH	Inorganic silts, micaceous, or diatomaceous fine sand or silts, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly organic soils			Pt	Peat, muck, and other highly organic soils

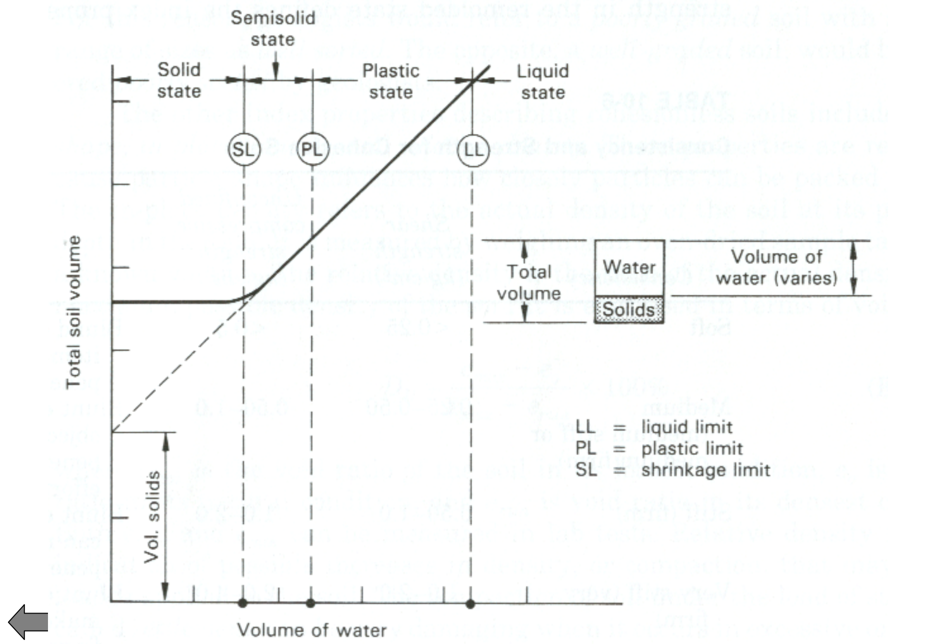


Cu

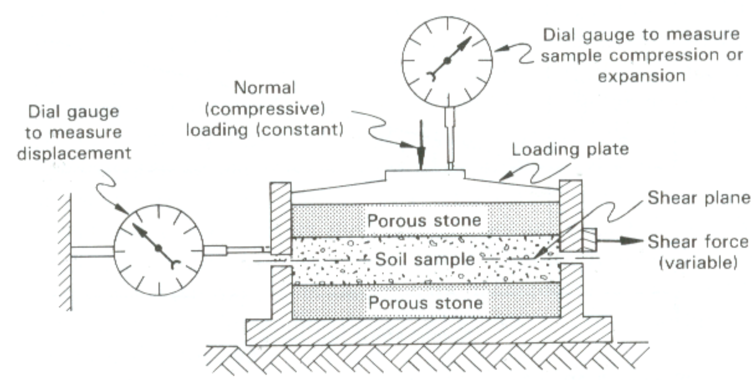


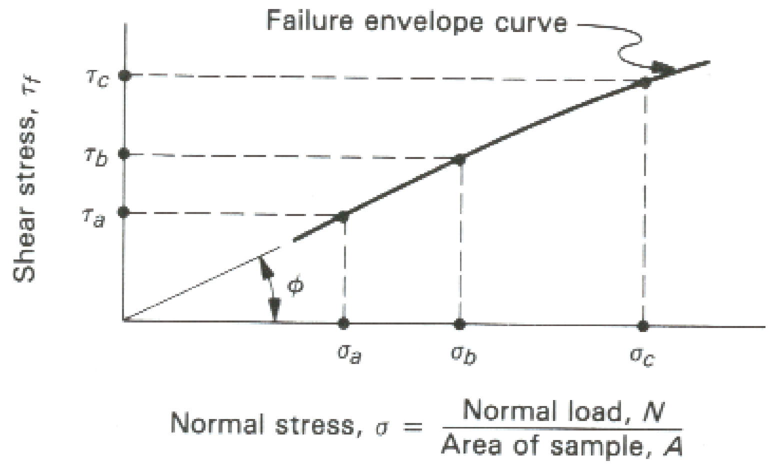
The chart is a plot of ***plasticity index (PI)*** against ***liquid limit (LL***).
The plasticity index is defined as: **PI = LL - PL**





Direct shear test





Tri-axial shear test