

Soil Structure

Text: Das, 2010. Principles of Geotechnical Engineering Ch 4.8

Soil structure is defined as the geometric arrangement of soil particles with respect to one another.

Among the many factors that affect the structure of the shape, size, and mineralogical composition of soil particles, and the nature and composition of soil water.

Soils can be placed into two groups; cohesionless and cohesive.

http://blog.sewserendipity.com/2011_05_01_archive.html



Soil nailing to increase the stability of a cohesive soil

<http://www.sulit.com.ph/index.php/view+classifieds/id/19143980/Gravel+and+Sand,+Coco+Lumber>



Wetting can increase the stability of a cohesionless soil

Structures in Cohesionless Soil

Single-grained and Honeycombed:

The structures generally encountered in cohesionless soils can be divided into two major categories: single-grained and honeycombed.

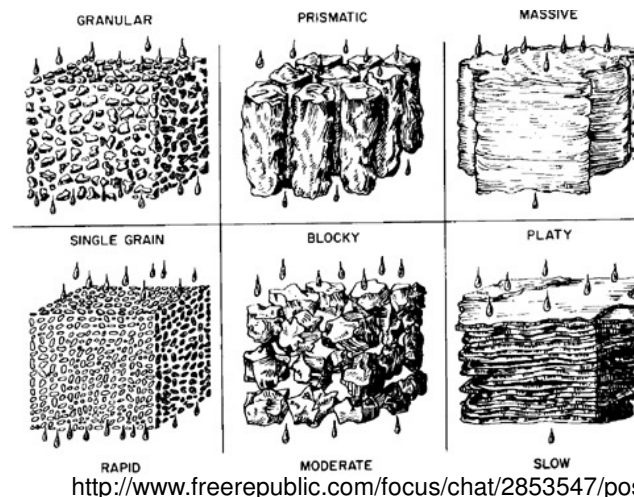
In single-grained structures, soil particles are in stable positions, with each particle in contact with the surrounding ones. A wide range of porosities from low to high are possible.

In honeycombed structures (rare), fine sand and silt cement arches of larger particles. These soils have large porosities and are generally low in shear strength with a risk of collapse and excess settlement under load.

<http://www.excessnyc.org/2013/09/looking-at-soil-under-the-microscope/>

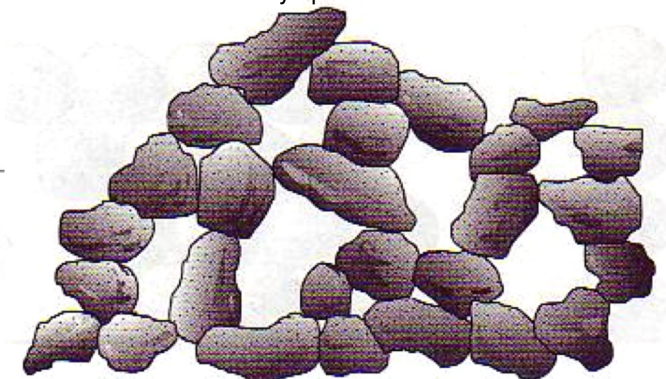


There are far more types of cohesive than cohesionless soils



<http://www.freerepublic.com/focus/chat/2853547/posts>

<http://www.amazon.com/Generic-Keyboard-Silicone-Aluminum-Unibody/dp/B0052CGEOM>



Cohesionless Honeycomb

Structures in Cohesionless Soil

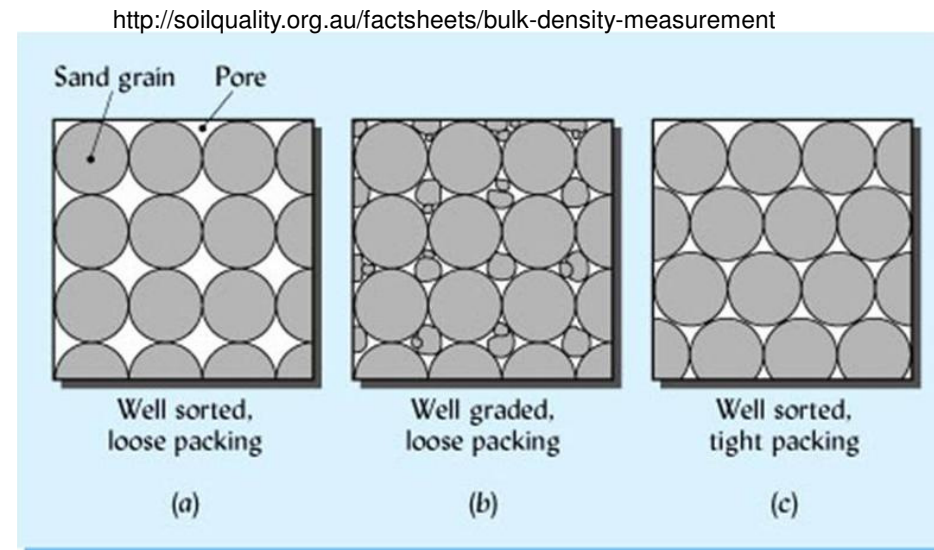
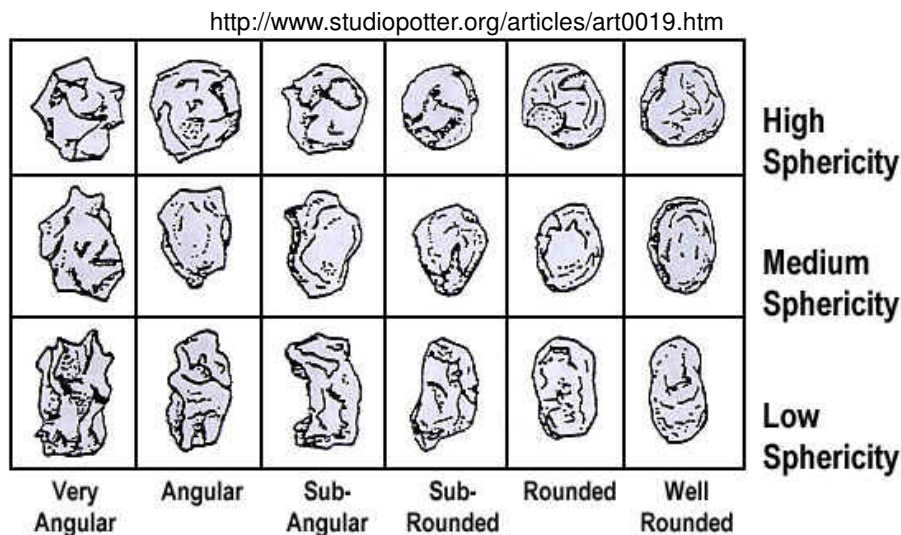
Grain Angularity, Sphericity and Grading

The interlocking of cohesionless soil grains into stable and strong structures depends on their shape, and the grading of particle sizes.

Grains with rough edges (high angularity) tend to interlock more effectively.

Grains with a round shape (high sphericity) can fit together with more efficient packing ratios, giving higher density and lower porosity.

Well-graded soils with a wide mixture of grain sizes are both more efficiently packed and more effectively interlocked, as every particle is supported by neighbouring particles within a matrix of smaller particles that fill the pore space.



Structures in Cohesive Soil

Dispersion and Flocculation (saline and non-saline)

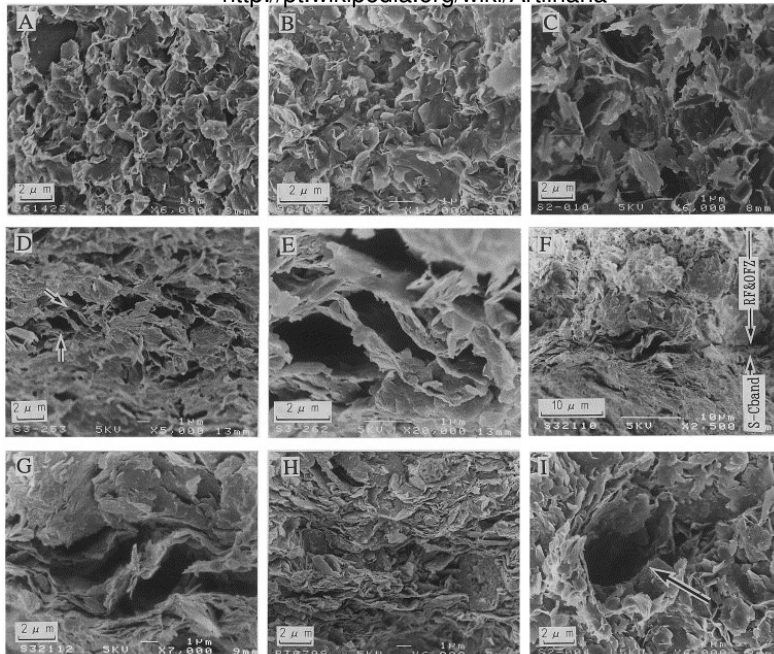
To understand the basic structures in cohesive soils we need to know the types of forces that act between clay particles suspended in water.

When two clay particles in suspension come close to each other, the tendency for interpenetration of the diffuse double layers results in combinations of repulsion and attraction between the particles.

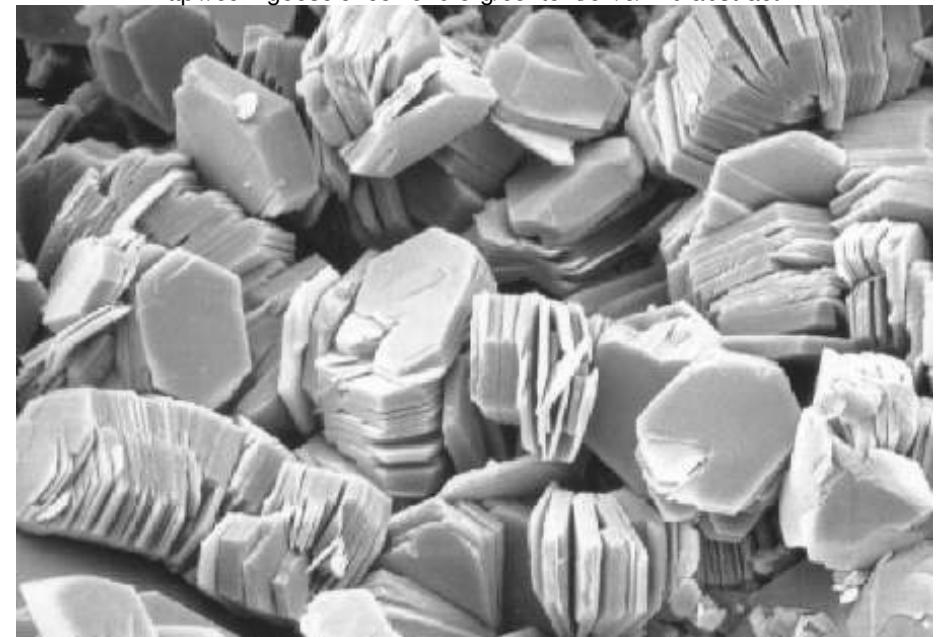
The edges of clay particles are positively charged, while the faces are negatively charged. This gives a tendency for honeycombed structures of all kinds as edges attach to faces.

When the spacing between particle faces is very small, the force of attraction is greater than the force of repulsion so that the plate-like crystals can aggregate into *domains*.

<http://pt.wikipedia.org/wiki/Artilharia>



<http://ccm.geoscienceworld.org/content/52/6/749.abstract>

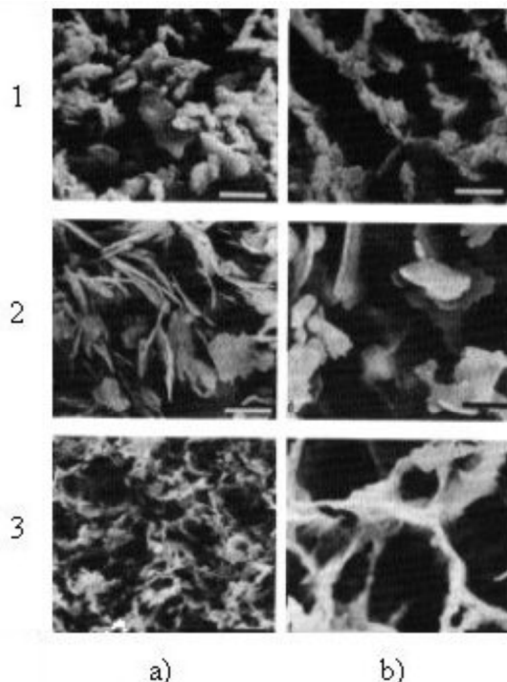


Structures in Cohesive Soil

Dispersion and Flocculation (saline and non-saline)

The formation of clay structures depends on the chemical composition and in particular the salinity of the soil water.

In saline water, the double layer is partly suppressed, reducing interparticle repulsion so that faces are more likely to bind: more and larger domains develop and the particles settle more quickly out of suspension.



http://echo2.epfl.ch/VICAIRE/mod_3/chapt_1/main.htm

Figure 1.8. Comparative image of the structure of kaolinite (1), illite (2) and montmorillonite (3) resulted from: a) sedimentation in distilled water and b) 0.5N NaCl solution (from Mitchell, 1993 after Osipov and Sokolov, 1978)

http://echo2.epfl.ch/VICAIRE/mod_3/chapt_1/main.htm

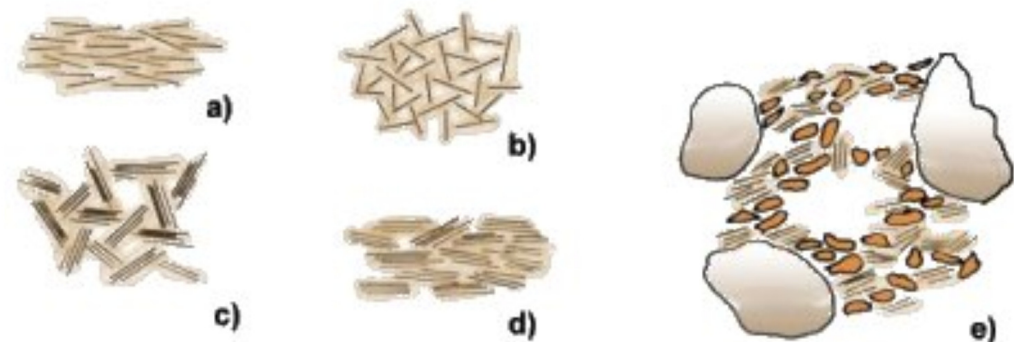


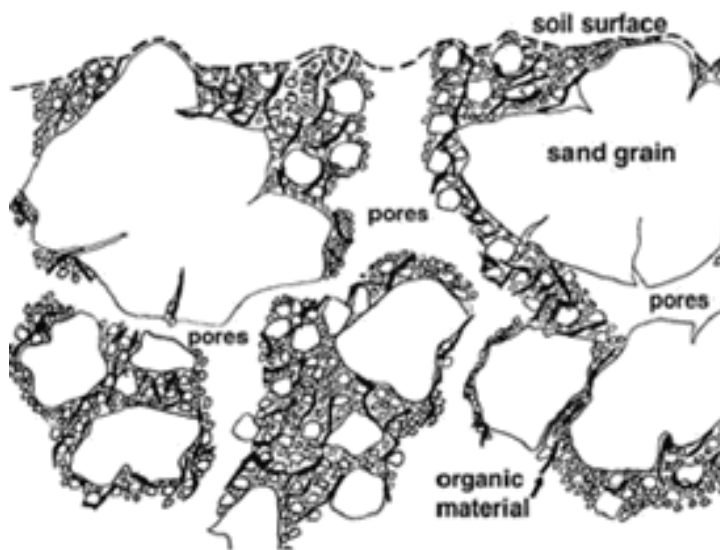
Figure 1.9. Clay structures: dispersed (a), flocculated (b), bookhouse (c), turbostratic (d) and the natural structure of clay (after Craig, 1990)

Structures in Native and Engineered Soils

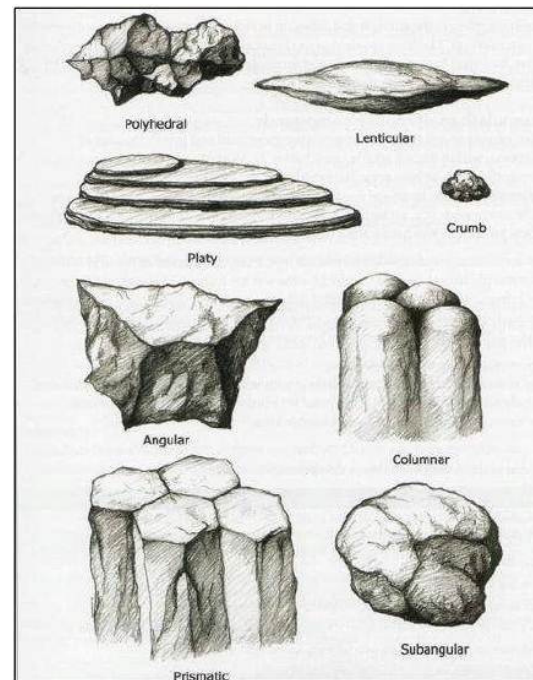
Pore-particle distributions and Peds

The clay structures in a natural setting are extremely complex at all scales from the microscopic to the landscape. A wide range of aggregate structures, forming structural units known as peds, can be identified.

To a limited extent the purpose-reliability of a soil can be improved by importing specifically engineered cohesionless or cohesive soils.



<http://quizlet.com/5451986/soil-structure-flash-cards/>



<http://fhrfarms1.com/blog/bio-farming-bulletin-august-september-2013/>



<http://www.forestbulgaria.com/?>

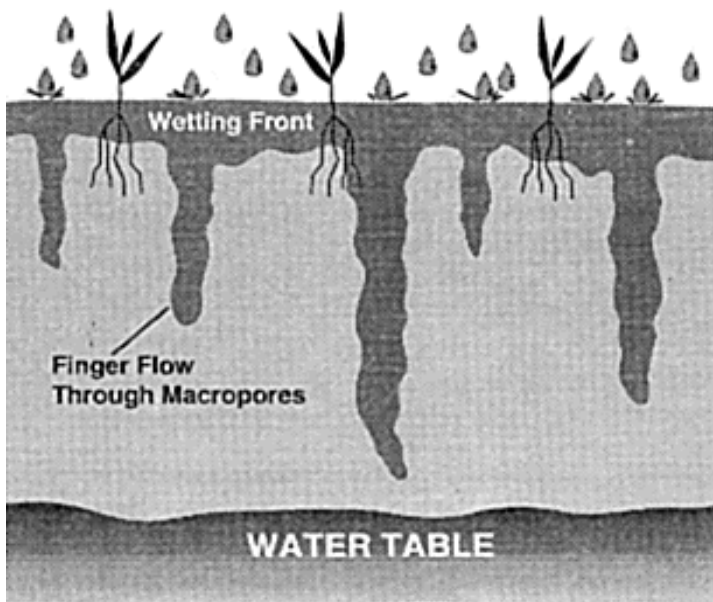
Structure of the Soil Matrix

Pore-particle distributions and Peds

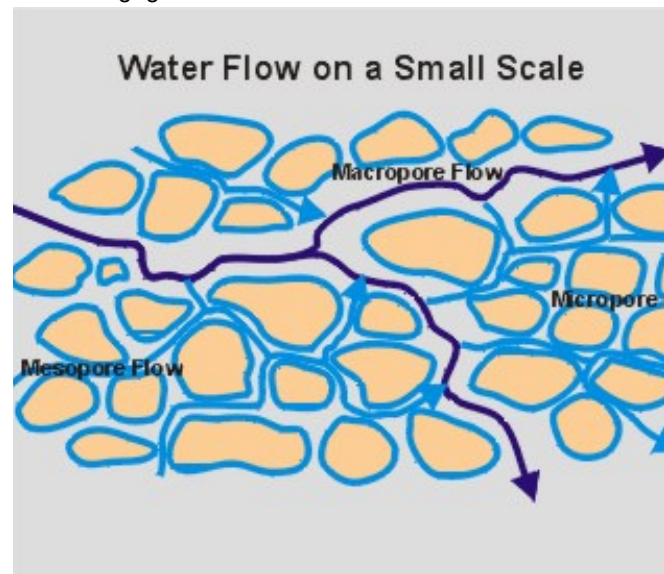
The fundamental distribution of particles within pores is of a *discontinuous array* of particles within a *continuous capillary structure* of pores.

Pores can be subdivided into two overall scales:

- *Macropores*, which surround the aggregate ped structures and provide high drainage, aeration or infiltration rates, and
- *Micropores* which surround the smaller aggregates, grains and particles.



http://www.geocaching.com/geocache/GC4HNCM_dla2013-fizzy-3-5-2-5-fen-or-bog?guid=e827e357-3fce-4f9a-a89f-497d9de75a20

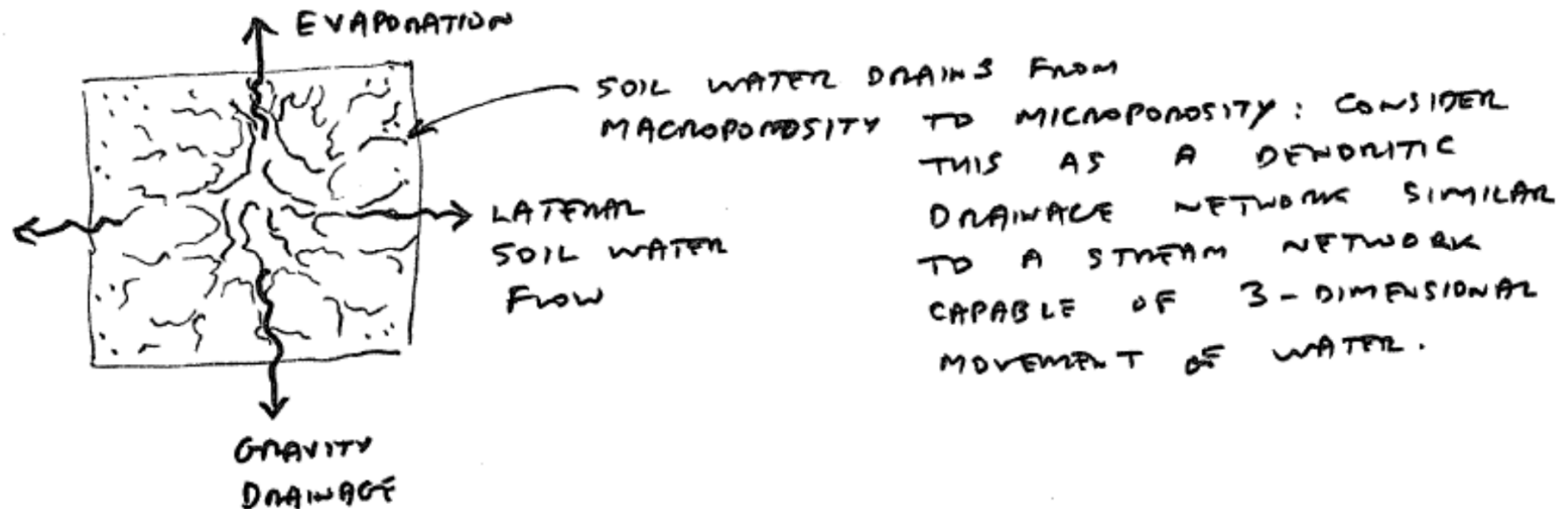


Structure of the Soil Matrix

Capillary Model of Porosity

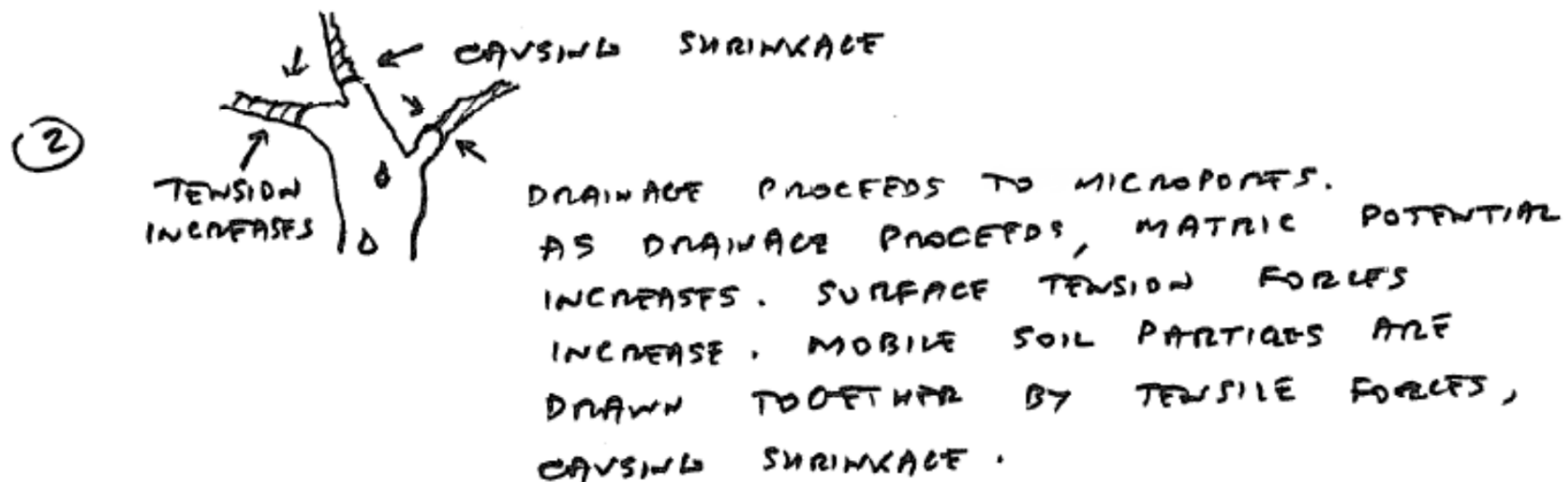
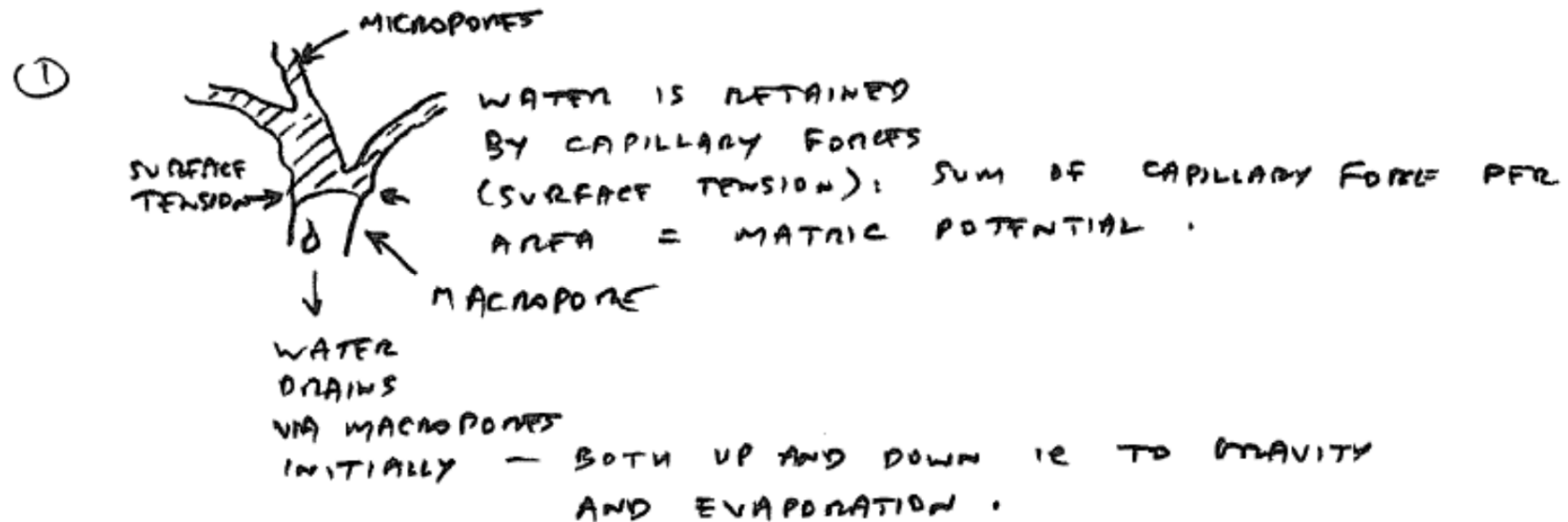
Pore space is an effectively continuous volume of capillary macropores and micropores at all scales down to the smallest particles ($<2\ \mu\text{m}$)

This connected structure resembles a dendritic drainage network leading from the gravity-draining macropores to clay crystal sized micropores where the drying process is governed by intermolecular forces.

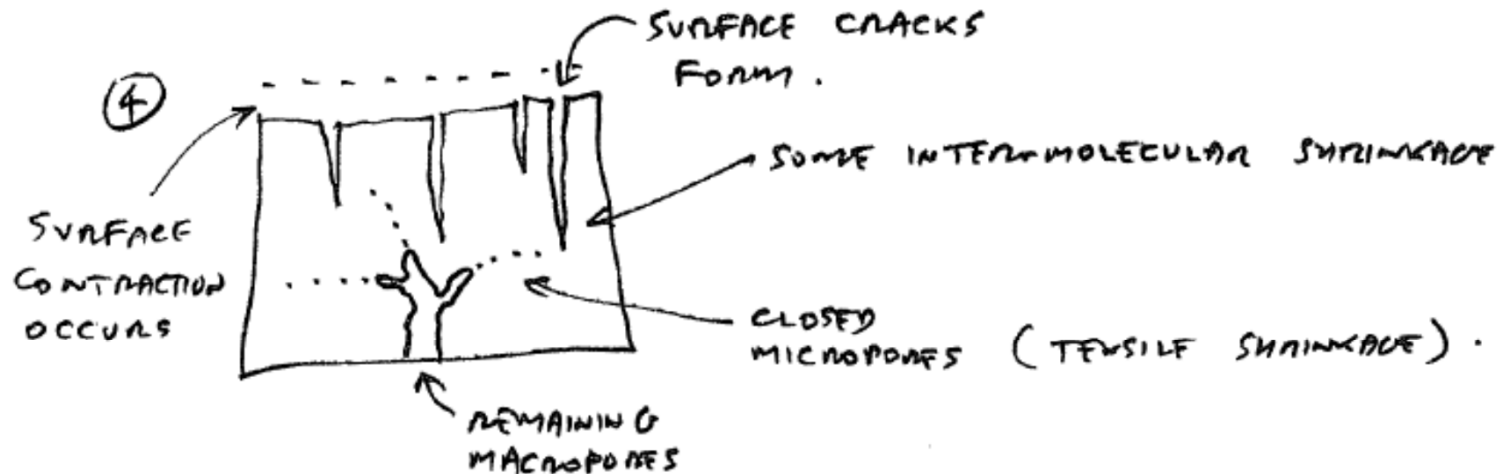
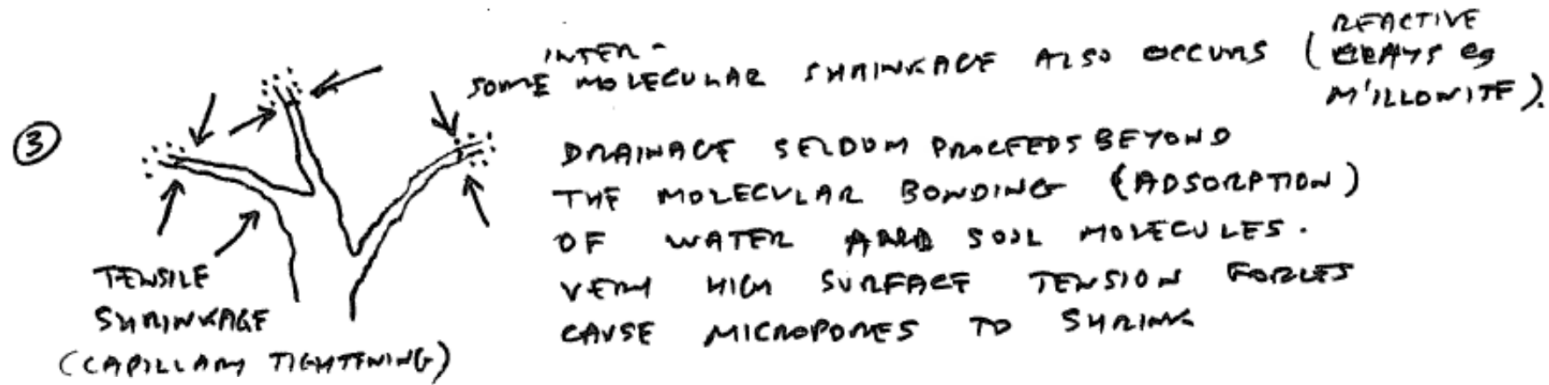


Capillary Model of Drying Shrinkage

Looking closely at the junctions between macropore and micropore capillaries we can see the mechanism for drying shrinkage:



Capillary Model of Drying Shrinkage



Most clays do not shrink beyond capillary tightening, even as water is lost from hygroscopic surfaces. Reactive clays such as montmorillonite are an exception, as adsorbed water contributes to intermolecular spacing of clay domains. All fine-grained soils shrink on drying, but reactive clays have very large expansion and shrinkage due to this extra mechanism.

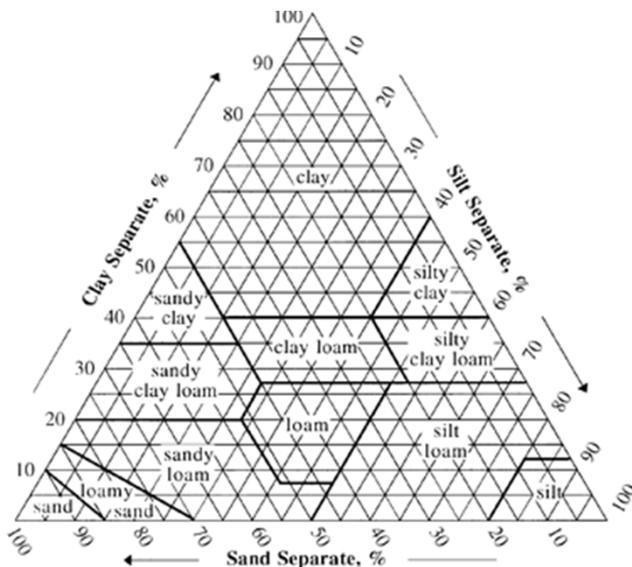
The capillary model tends to agree with the constant air volume model of shrinkage (Dexter, 1988)

Soil Classification

We are now in a position to combine various types of soil descriptions to classify soils for engineering purposes.

Most of the soil classification systems that have been developed for engineering purposes are based on simple index properties such as particle size distribution and plasticity.

Although several classification systems exist, none is totally definitive of any soil for all possible applications because of the wide diversity of soil properties.



<http://ecode360.com/12583121>

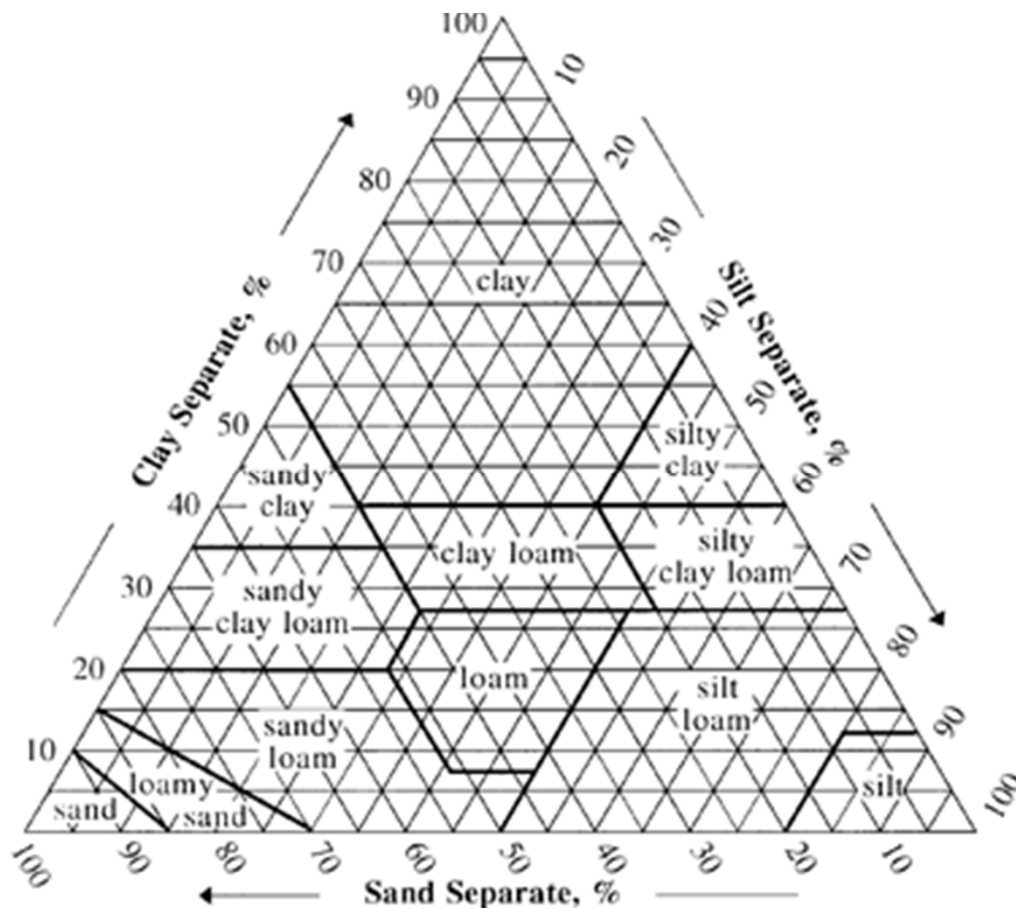
Classification System	Grain Size (mm)					
	100	10	1	0.1	0.01	0.001
Unified	Cobbles Gravel Sand Fines (silt and clay)					
AASHTO	Cobbles Gravel Sand Silt Clay					
MIT	Gravel Sand Silt Clay					
ASTM	Gravel Sand Silt Clay					
USDA	Cobbles Gravel Sand Silt Clay					

http://www.scielo.org.co/scielo.php?pid=S0120-02832008000200003&script=sci_arttext

Textural Classification

A number of textural classification systems were developed by different organisations and several of those are in use today.

eg The USDA system:



Sand 2.0 - 0.05 mm

Silt 0.05 - 0.002 mm

Clay < 0.002 mm

For example, an analysis showing 30% sand, 40% silt and 30% clay would be classified as a *clay loam* in this system.

Engineering Classification

or Behavioral Classification

Because textural classification systems do not take plasticity into account and are not totally indicative of many important soil properties they are inadequate for most engineering purposes.

Currently two more elaborate classification systems are commonly used by soils engineers. Both systems take into consideration the particle size distribution and Atterberg limits of consistency.

- AASHTO System (1929)
- Unified Soil Classification System USCS (originally Casagrande 1942, developed to 1952)

The USCS has been adopted by the Australian Institution of Engineers. ENGT350 will focus on this system.

Unified Soil Classification System

USCS: Two Main Categories

- Coarse-grained soils that are gravelly (G) and/or sandy (S), with less than 50% passing through the 75 μm sieve.
- Fine-grained soils of silt (M) or clay (C) with 50% or more passing through the 75 μm sieve.

Other symbols used in the classification are:

- W - Well-graded
- P - Poorly graded
- L - Low plasticity
- H - High plasticity

For example a well-graded, predominantly clay soil of low plasticity, would be classified as **WCL**. A poorly-graded gravel with no significant fines would be **GP**, the L or H suffix not applying to the cohesionless soil.

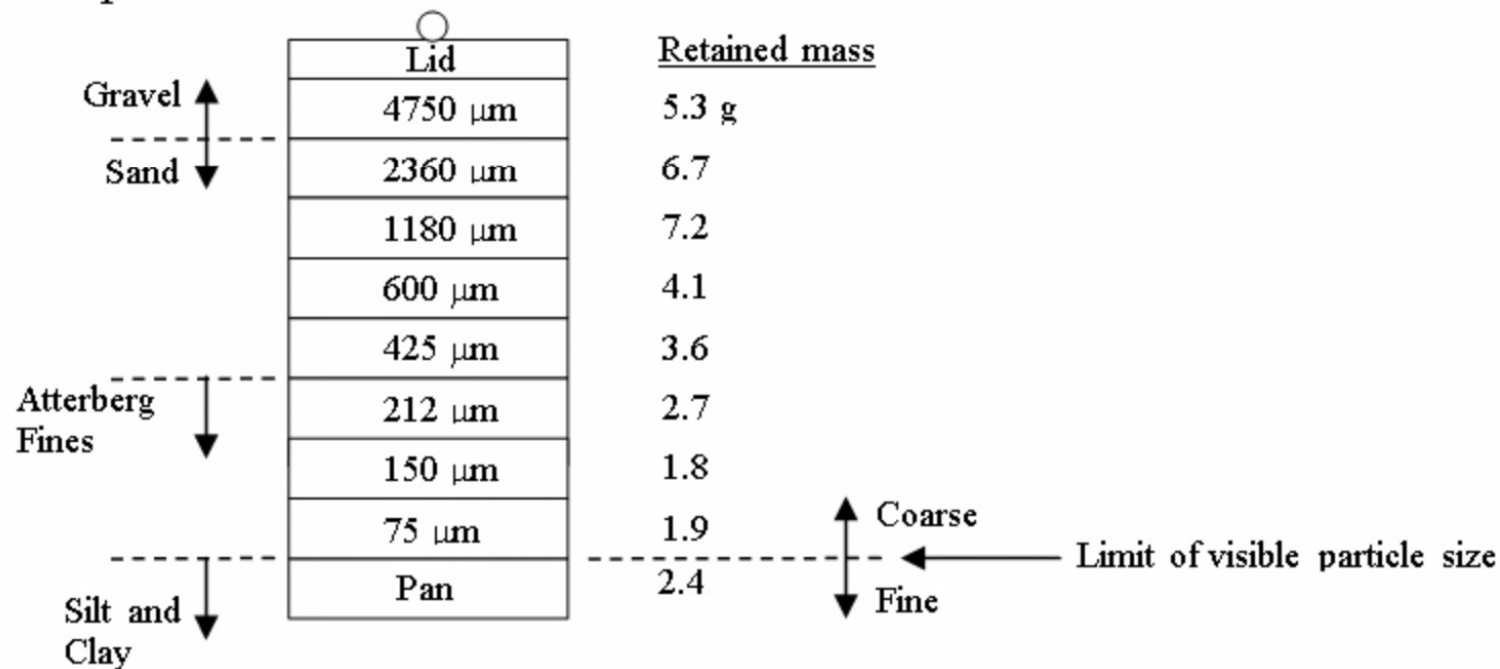
Unified Soil Classification System

Laboratory Method

1. Classify Inorganic Soils as Coarse- or Fine-Grained

- 1.1 Remove (by sieve or hand) particles larger than 75 mm
- 1.2 Sieve from at least 4.75 mm to at least 0.075 mm (standard sieve sizes 4750 and 75 μm)
- 1.3 Weigh soil masses retained on each sieve:

Example:



Unified Soil Classification System

Laboratory Method

1.4 Calculate mass percentages passing each sieve:

Sieve Size	(1) Mass Retained	(2) Cumulative Mass Retained	(3) Mass Passing	(4) Percent Passing	
μm	g	g	g	%	
4750	5.3	5.3	30.4	85.2%	
2360	6.7	12	23.7	66.4%	
1180	7.2	19.2	16.5	46.2%	
600	4.1	23.3	12.4	34.7%	
425	3.6	26.9	8.8	24.6%	
212	2.7	29.6	6.1	17.1%	
150	1.8	31.4	4.3	12.0%	
75	1.9	33.3	2.4	6.7%	
pan	2.4	35.7	0	0.0%	
		(2)= Σ (1)	(3)=35.7-(2)	(4)=(3)/35.7 x100%	

1.5 Classify as Coarse- or Fine-Grained Soil:

- If Percent Passing 75 μm < 50% : Coarse-Grained Soil
- If Percent Passing 75 μm > 50% : Fine-Grained Soil

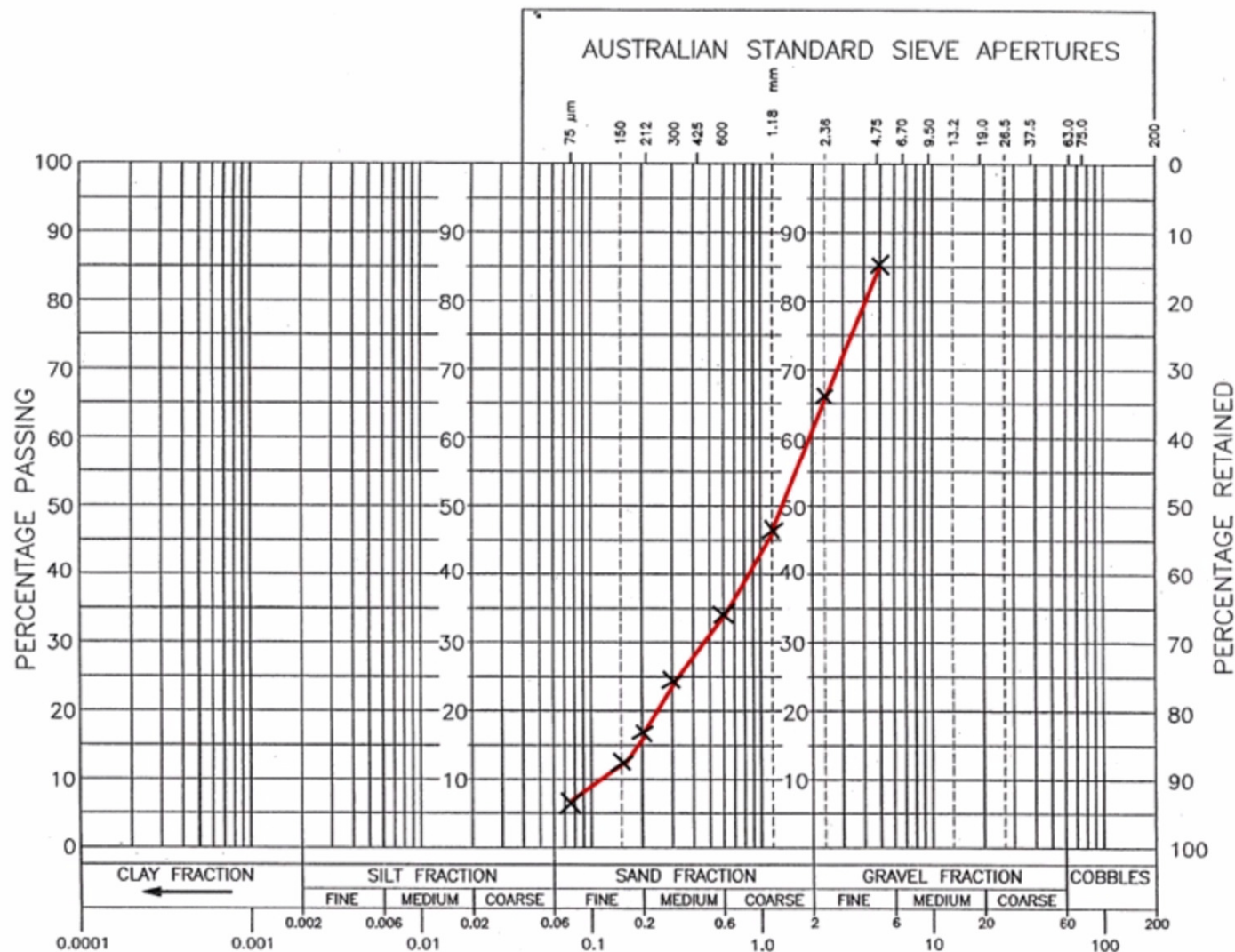
Mixed classifications are allowed: Thus if the percent passing 75 μm is approximately 50%, classify as a well graded coarse to fine grained soil (a “loam” in agricultural terms not often used in engineering).

Example: The sieve data indicate a Coarse-Grained Soil

Unified Soil Classification System

Laboratory Method

All Soils: Plot the % passing Grading Curve on standard sieve paper. Example:



Unified Soil Classification System

Laboratory Method

2. Coarse-Grained Soils:

2.1 Classify as Gravel or Sand

- If Percent Passing $4750\ \mu\text{m}$ $< 50\%$: Gravel Denoted G
- If Percent Passing $4750\ \mu\text{m}$ $> 50\%$: Sand Denoted S

Example: Sieve data indicate a Sand soil

2.2 Gravel or Sand: Classify as Clean (no significant fines) or Dirty (with significant fines)

- If Percent Passing $75\ \mu\text{m}$ $< 5\%$: Clean
- If Percent Passing $75\ \mu\text{m}$ $> 12\%$: Dirty
- If Percent Passing $75\ \mu\text{m}$ range from 5 – 12% : Intermediate, use mixed classifications

Example: Sieve data indicate a Intermediate Clean Sand Soil with some fines.

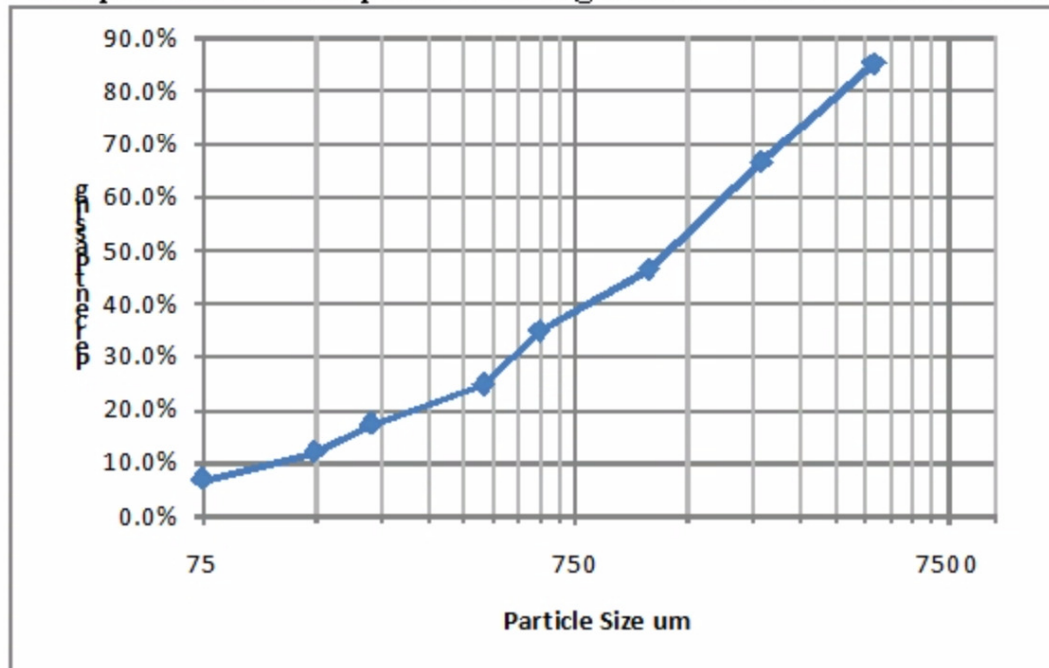
Unified Soil Classification System

Laboratory Method

2.3 Clean Soils: Classify as Well-Graded or Poorly Graded

- 2.3.1 Examine the Grading Curve for the range of particle sizes. Well graded soils (GW or SW) show a smooth or uniform gradation from coarse to fine particles on a log scale, with roughly equal proportions of particle sizes. Poorly Graded or Gap-Graded soils (GP or SP) show stepped sections due to zero mass retained at those sizes.

Example: Sieve data plotted on log scale: Well Graded Sand SW + fines



Unified Soil Classification System

Laboratory Method

2.3.2 If in doubt, calculate the coefficients of uniformity and curvature.

- Obtain approximate particle sizes at 60%, 30% and 10% passing.

Example: $D_{60} \sim 2 \text{ mm}$, $D_{30} \sim 0.5 \text{ mm}$, $D_{10} \sim 0.15 \text{ mm}$

- Calculate:

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{Coefficient of Uniformity}$$

$$C_c = \frac{D_{30}^2}{D_{60} D_{10}} \quad \text{Coefficient of Curvature}$$

Example: $C_u = 2.0/0.15 = 13.3$, $C_c = 0.5^2/(2.0 \times 0.15) = 0.83$

- Gravels: If $C_u > 4$ and $1 < C_c < 2$: GW ; otherwise GP
- Sands: If $C_u > 6$ and $1 < C_c < 2$: SW ; otherwise SP

Example: $C_u = 13.3$, $C_c = 0.83$: Well Graded to Intermediate SW with some fines

Unified Soil Classification System

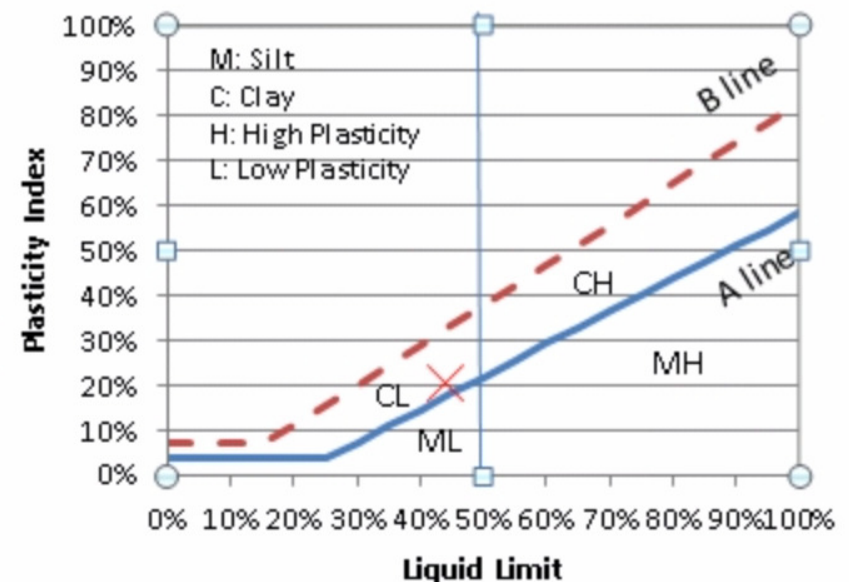
Laboratory Method

2.4 Dirty Soils: Classify as with Silt or Clay Fines of High or Low Plasticity

2.4.1 Combine all sieve fractions $< 425 \mu\text{m}$ (Atterberg Fines).

2.4.2 Process fines as per Atterberg limits (see separate notes)

- Clay Fines: Fines test above “A” line with high plasticity index per liquid limit:
Denote fines as C (clay)
- Silt Fines: Fines test below “A” Line with low plasticity index per liquid limit:
Denote fines as M (silt)
- High Plasticity: Liquid Limit $> 50\%$: Denote as H (High Plasticity)
- Low Plasticity: Liquid Limit $< 50\%$: Denote as L (Low Plasticity)



Unified Soil Classification System

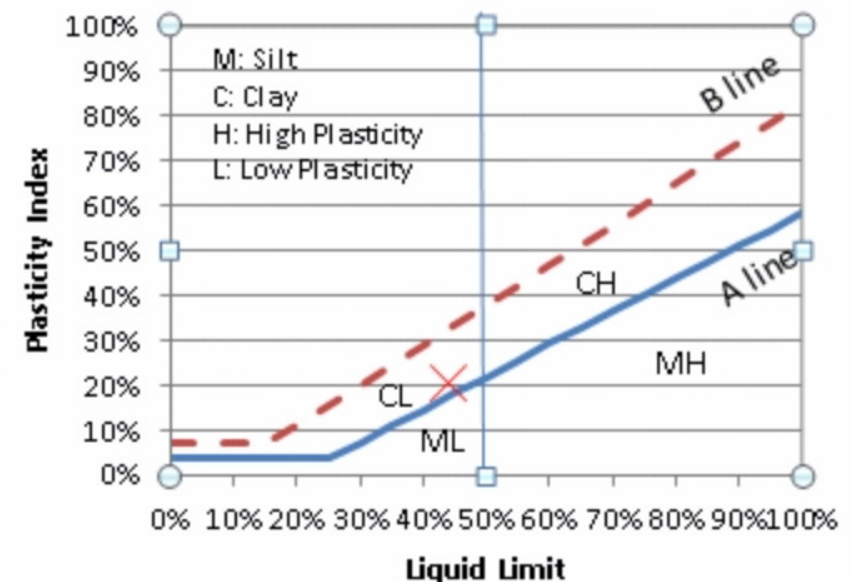
Laboratory Method

3. Classify Fine-Grained Soils as Silt or Clay, with High or Low Plasticity

- 3.1 Combine all sieve fractions $< 425 \mu\text{m}$ (Atterberg Fines).
- 3.2 Process fines as per Atterberg limits (as above)

4. Classify Organic Soils as Peat or Organic with High or Low Plasticity

- 4.1 Visual and Odour inspection of bulk soil for high organic content: Denote Pt (Peat or predominantly organic) or O (with organic fines)
- 4.2 Atterberg tests of fines $< 425 \mu\text{m}$: Denote as OL or OH for Organic fines of Low or High Plasticity



Unified Soil Classification System

Field Method

1. Classify Inorganic Soils as Coarse- or Fine-Grained
 - 1.1 Estimate proportion of particles that can be seen (equivalent to % passing 75 μm)
 - > 50% visible: Coarse-Grained
 - < 50% visible: Fine-Grained
2. Coarse-Grained Soils: Classify as Gravel or Sand
 - 2.1 Estimate proportion of particles > 5 mm diameter (equivalent to % passing 4750 μm)
 - > 50% > 5 mm: Gravel: Denote G
 - < 50% > 5 mm: Sand: Denote S
 - 2.2 Classify as Clean or Dirty
 - Clean: Does not stain a wet palm
 - Dirty: Leaves a stain on a wet palm
 - 2.3 Classify Clean Soils as Well-Graded or Poorly-Graded
 - Well-Graded: Substantial amounts of all grain sizes. Denote GW or SW
 - Poorly-Graded: Predominantly one size or with some sizes missing: Denote GP or SP

Unified Soil Classification System

Field Method

2.4 Dirty Soils: Classify as with Silt or Clay Fines of High or Low Plasticity

- Remove particles greater than 425 μm by eye
- Add enough water to make a soft but not sticky 10 ml pat.
- Shake the pat firmly from hand to hand several times. Dilatancy reaction characteristic of silt is for water to form on the surface, which develops a glossy appearance. Denote with reaction as M (Silt fines) or without reaction as C (Clay fines)
- Roll-dry the pat on a smooth hard surface until a 3 mm thread just crumbles (at Plastic Limit PL). Form into a bolus and test its toughness by crumbling. Strong bolus indicates high plasticity, weak indicates low plasticity: Denote as H (High) or L (Low). Thus CL or CH or ML or MH fines.

3. Classify Fine-Grained Soils as Silt or Clay, with High or Low Plasticity

- As per 2.4

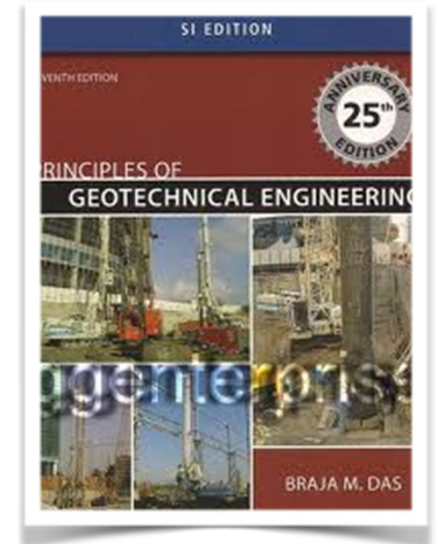
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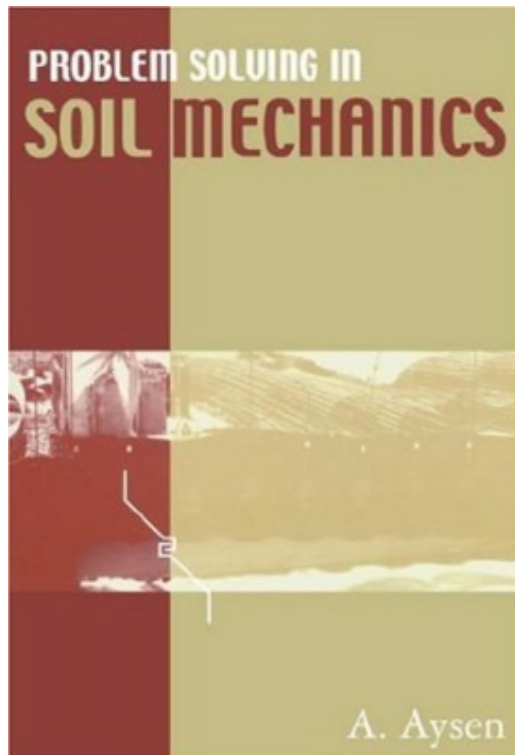
Readings

Chapter 4.8 - 5.5 Das

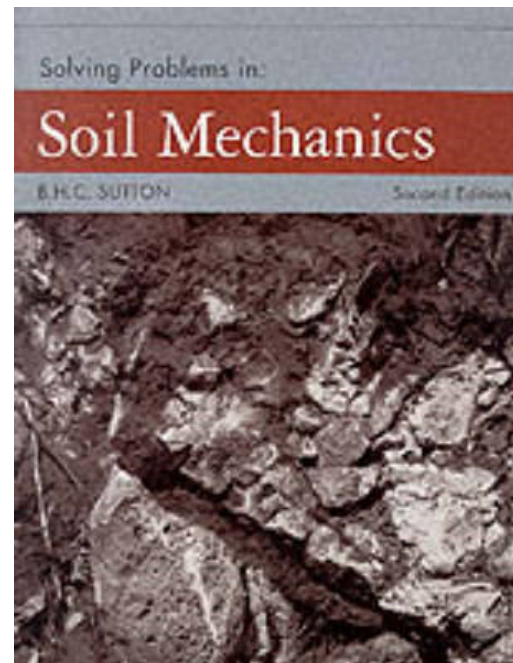
Internet keywords: Soil structure, pedology, soil classification, USCS.



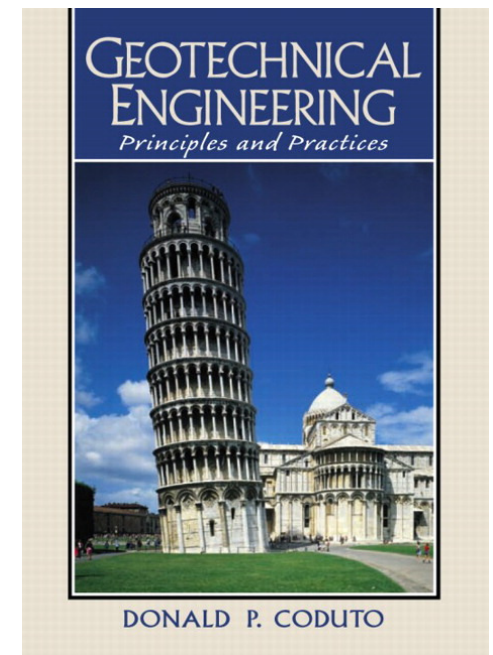
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<http://www.tower.com/foundation-design-principles-practices-donald-p-coduto-hardcover/wapi/100501083>