Period #3: Particle Characteristics and Size Effects

A. Motivation:

- In the presence of water, some clay soils in pure form can greatly increase in volume (expand, or swell).

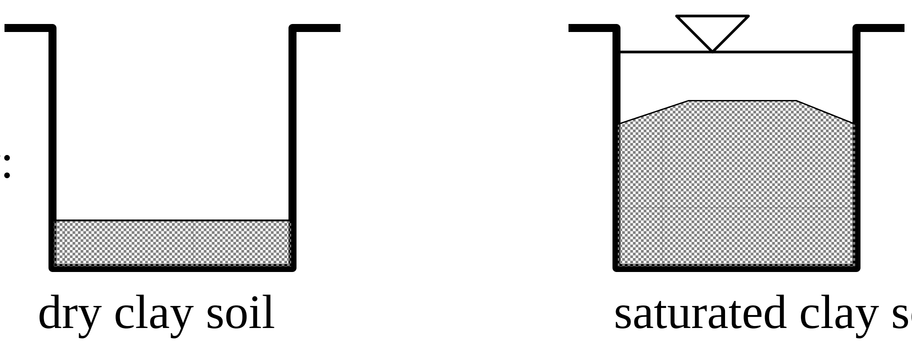
- When water is removed from a clay soil (by drying), the volume can be significantly reduced due to shrinkage. This leads to widespread cracking in the soil.

- In *pure* form, the most *active* clay soils can increase or decrease in volume by a factor of over 15! But since pure clays rarely exist naturally, most soils are not nearly that expansive or active.

- Nevertheless, active clay soils can potentially wreak havoc on engineered structures by expanding and shrinking somewhat.

Visualization:

In the laboratory:



Note the expansion of the clay soil with the introduction of water.

In this class period, we will begin to explore why clays expand and shrink.

The expansive and contractive characteristics of clay soils raise some fundamental questions:

(i) What is the nature of clay particles?
(ii) Why do clay soils expand when exposed to water?
(iii) What simple tests can be used to identify the most *active* or *expansive* soils?

B. Grain Size and Specific Surface Area

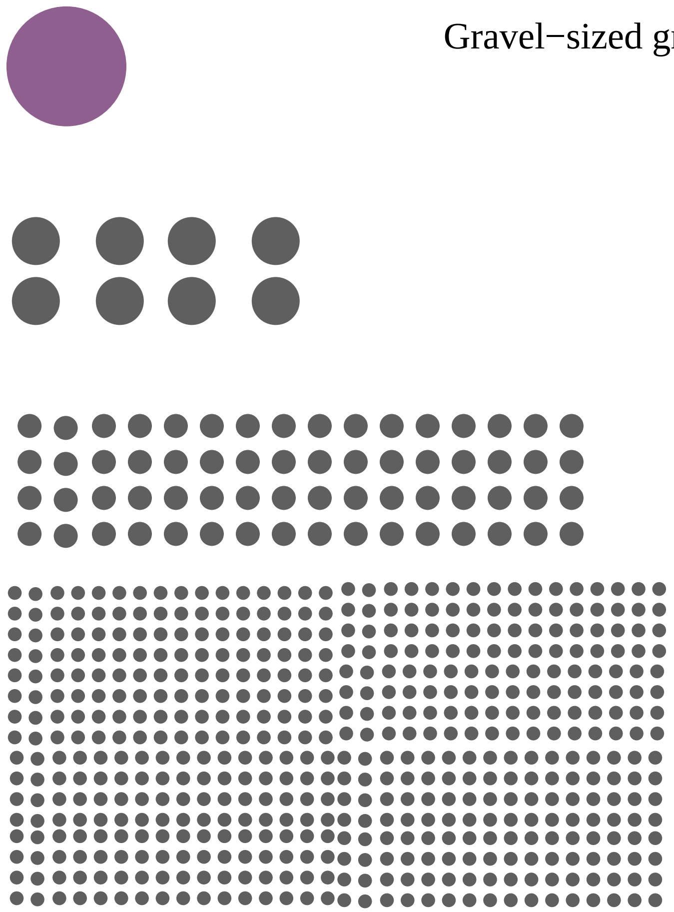
From previous discussions and readings you know that clay soils are those containing grains with $D \leq 2\mu m$.

As soil grain sizes decrease, the specific surface area (SSA) of the soil, which is simply the total surface area of the individual grains per dry mass of the grains, increases exponentially.

This can be demonstrated quite dramatically by considering the following conceptual experiment:

We take a gravel sized single grain of soil and successively breaking it up into smaller and smaller grains of equal size, until we achieve clay−sized grains.

i=0, N=1
r=1 cm = 10^4 μm
V=(4/3)π cm^3
S = 4π cm^2



Gravel−sized grains

i=1, N=8
r=1/2 cm
V=(4/3)π cm^3
S = 8π cm^2

i=2, N=64
r=1/4 cm
V=(4/3)π cm^3
S = 16π cm^2

i=3, N=512
r=1/8 cm
V=(4/3)π cm^3
S = 32π cm^2

⋮

i=14, N=4.4*10^{12}
r=1/(16,384) cm = 0.61 μm
V=(4/3)π cm^3
S = 65,536π cm^2

Clay−sized grains (Note that SSA increases by a factor of 2^{14}!)

- Thus, it is shown that for a given mass of soil grains, as the individual grain become smaller, the collective surface area of the mass of soils increases dramatically!

- As the total surface area of soils as measured by SSA increases, the surface propertiesand characteristics of the individual grains becomes increasingly significant.

- In fact, the high SSA of clay soils together with the surface properties of clay grains, can help to explain most all of the observed engineering behaviors of these soils.

Most Active (Expansive) Types of Clay Soils

Type	SSA (m^2/g)	thickness (Å)	lateral dimensions (Å)
Kaolinite	15	100−1,000	1,000−20,000
Illite	80	50−500	1,000−5,000
Montmorillonite	800	10−50	1,000−5,000

To better understand the surface properties of clay soils, we switch here to usage of a few diagrams from Section 2.3 of the textbook.

Summary of Important Points About Clay Soils

1. Fine−grained soils have much higher SSA's than coarse−grained soils.

2. As SSA's increase, the surface properties of individual soil grains assume greater importance.

3. Clay soils have electrical surface charges:

   a. predominantly negative;

   b. dipolar water molecules are attracted to charged clay particles;

   c. when water is added to clay soils, grains spread out allowing more water into the expanded void space.

      explains expansion of clays in going from dry to saturated state.

   d. when water leaves clay soils, spacing between grains decreases.

      explains shrinkage and cracking.

4. There are many different types of clay soils.

   The primary difference among clays has to do with the minerals and/or elements present in the soil:

   high aluminum content –> kaolinite clays

   high potassium content –> illite clays

   high iron and magnesium contents –> montmorillonite clays.

5. As we shall see later on, clay soils can be very unsound choices for many construction and engineering applications:

   Their significant expansion/contraction with appreciable changes in water content can lead to lifting and dropping of structural levels.

   This can be very damaging to structures.

6. Because water molecules are attracted to clay soil grains, and because of the very high SSA of clay soils, it is difficult for water to flow through clay soils. Thus clay soils have very low hydraulic permeabilities.