Period #5: Soil Consistency and Structure

A. Motivation:

In geotechnical engineering, we need to determine the range of potential behaviors of a given soil type based on only *a few simple tests*. Typical concerns are the following:

i) soils might *shrink or expand excessively* in an uncontrolled manner after they've been placed in geotechnical structures (roadway subgrades, dams, levees, foundation materials, etc).
ii) soils might *lose their shear strength*, and ability to carry loads safely.

Tests used to detect potential problems for coarse−grained soils (gravels & sands) are different than those used to detect potential problems for fine−grained soils (silts & clays).

Coarse−Grained Soils:
water content is generally not a major factor
major factor leading to *shrinkage* is the *structure* of the soil skeleton.

Fine−Grained Soils:
water content is a *major factor*, especially when the soil contains so−called *active clays*.

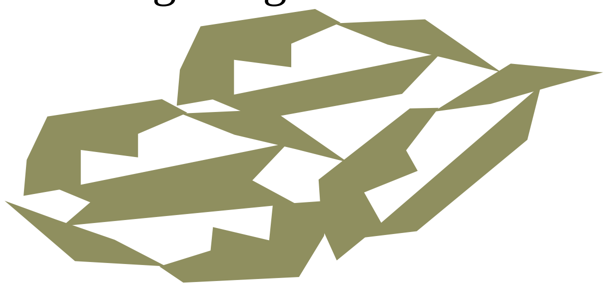
soils shrink
gain strength ⟵⟶ soils expand
lose strength

water content

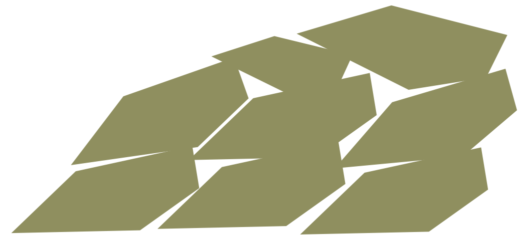
B. Structure of Cohesionless, Granular, Coarse−Grained Soils

When speaking of cohesionless, granular soils, there are many possibilities:

Soils with angular grains:

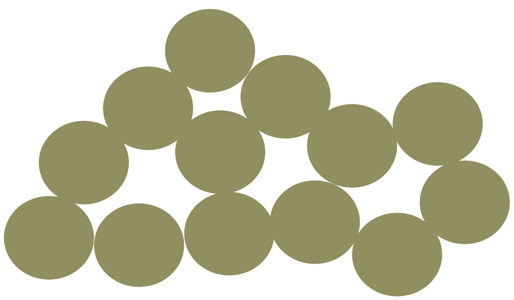


Loose, angular soil

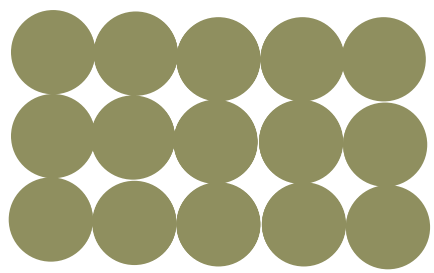


Dense, angular soil

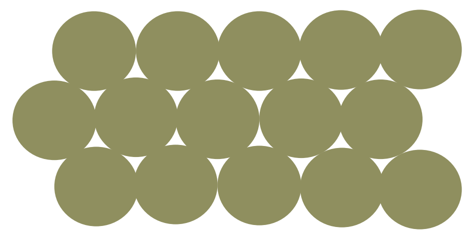
Soils with uniform, rounded grains:



Honey−combed soil
very loose (e > 0.90)

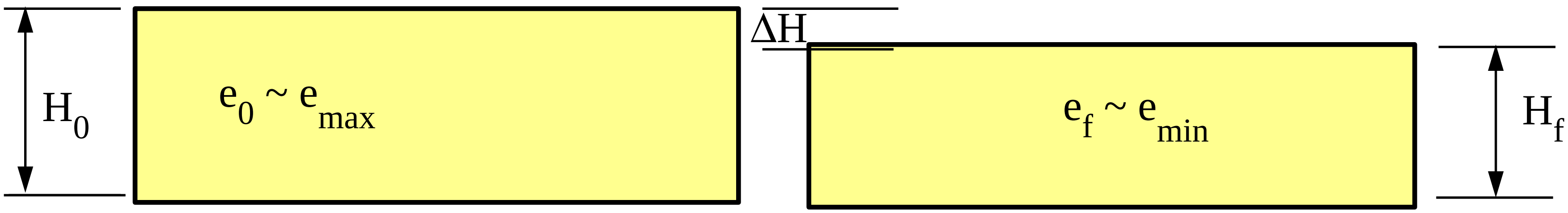


Square−packed grains
loose (e = 0.90)



Hexagonally packed grains
dense (e = 0.35)

- Soils in loose or honeycombed states are avoided, or compacted before being being built upon, since they are prone to densification when subjected to vibratory or shock loading (as from earthquakes or vibrating machinery).



$$\Delta H = H_0(e_0 - e_f) / (1 + e_0)$$

- The relative looseness of a soil in its natural, in−situ state is determined by measuring/ computing its relative density, D_r.
  [Recall that $D_r = (e_{max} - e) / (e_{max} - e_{min})$]

- The smaller D_r is for a given granular soil deposit, the more prone that soil deposit will be to densification and settlement.

- For uniform (poorly graded) spherical grained soils, the theoretical range of void ratios is $0.35 < e < 0.90$.

- For nonuniform, well−graded soils, the possible range of void ratios is much smaller.
  - well−graded, subangular sand: $0.35 < e < 0.75$
  - well−graded, silty sand: $0.25 < e < 0.65$

- Thus the range of void ratios for well−graded soils is less than that for uniform soils.

- This is why it is generally preferred to use well−graded soils in geotechnical applications as opposed to uniform soils.

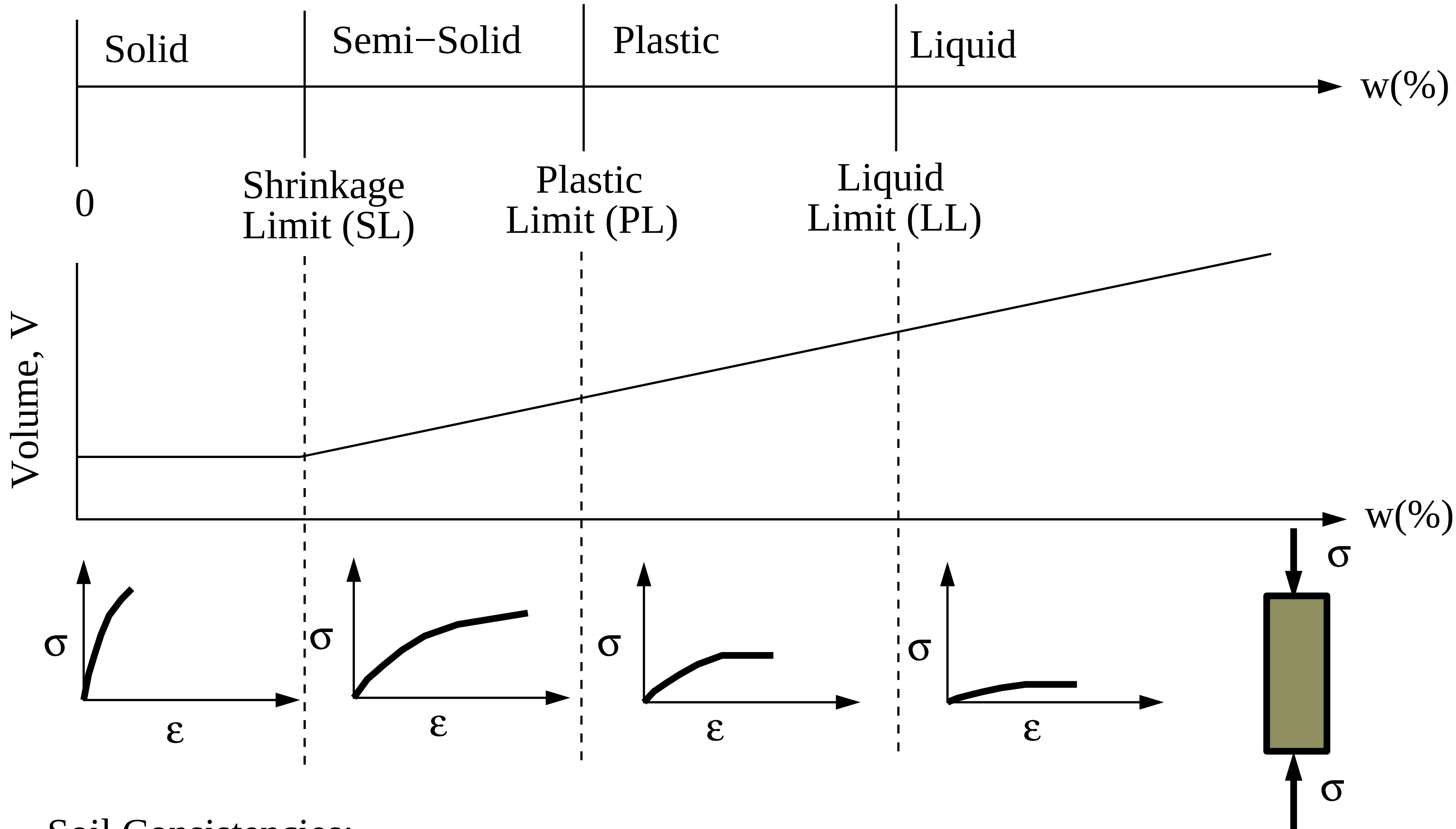
C. Consistency of Fine−Grained Soils

- In Period#3, it was discussed that fine−grained soils have high SSA's, and electrical charges on their grains. Because of this, fine−grained soils, and clays in particular can change their consistency quite dramatically with changes in water content.

- With increasing water content, fine−grained soils tend to expand and lose strength as shown in the diagram on the following page.

- Each soil type will generally have different water contents at which it behaves like a *solid, semi–solid, plastic, and liquid.* For a given soil, the water contents that mark the boundaries between these soil consistencies are the so−called *Atterberg Limits.*

- In Lab experiments 3 and 4, we will measure the Atterberg Limits of a given fine−grained soil type. In general, the *Atterberg Limits* of fine−grained soils provide a good deal of information on the *range of potential behaviors* a given soil might show in the field with variations of water content.



Soil Consistencies:

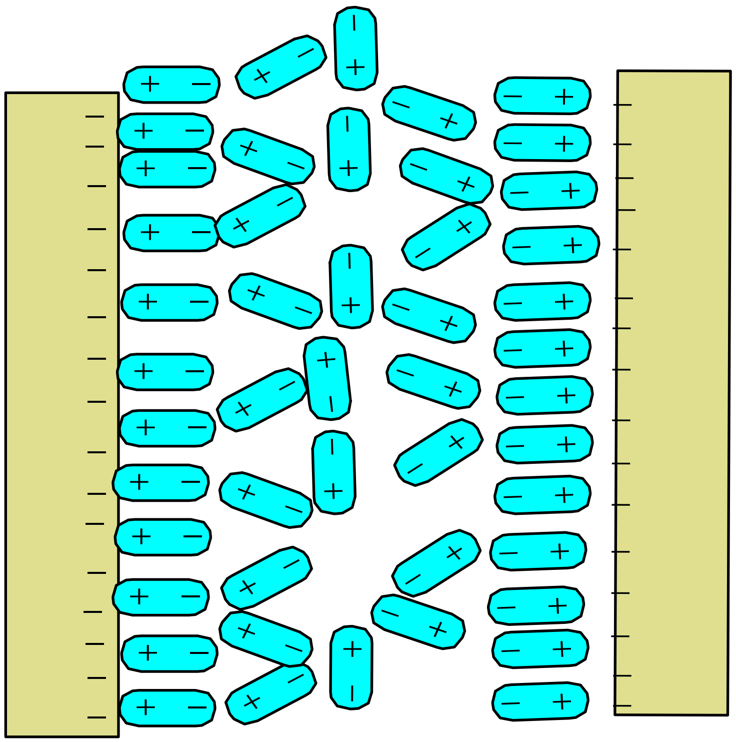
Solid:	soil is hard and brittle
Semi−Solid:	soil has combined brittle/ductile behavior (like stiff cheese)
Plastic:	soil has very ductile, malleable behavior (like Play−Doh)
Liquid:	soil behaves like a thick or thin viscous fluid

1. The Plasticity Index or PI.

--> Plasticity Index (PI) = LL − PL

--> This measures the range of water contents over which a given soil can pull water into its micro−structure, assimilate it, and still act like a solid.

--> Clay soils with high SSA's and charged particles will be able to hold a large amount of water between grains due to their charge field and the polar nature of water molecules.



Charged soil grains with polar water molecules between. Clay soils with high SSA's and charged surfaces are able to bind/ assimilate water molecules and the overall soil will still behave as a plastic solid. Such soils will have high plasticity indexes.

Soils with comparatively lower SSA's will not be able to bind/assimilate water molecules and thus will have much smaller PI values.

- The PI of a soil is thus a measure of the *activity* $\mathcal{A}$ of the soil grains.

  A = PI / (% clay−sized fraction of soil) , or alternatively,

  A = PI / (% clay−sized fraction − C'), where C' ~ 9.

- The activity A of a fine−grained soil can be useful in identifying the type of clay contained in a soil. For example:

	A
Montmorillonite	1 − 7
Illite	0.5 − 1
Kaolinite	0.5

2. The Liquidity Index: I_L:

- This is a useful index which can indicate potentially unstable fine−grained soil deposits.

$$I_L = (w - PL) / (LL - PL) = (w - PL) / PI$$

- In the field, an $I_L << 1$, indicates that the soil has a water content much smaller than LL. Therefore the danger of liquefaction is not immediate.
- In the field as $I_L \to 1$ the soil's water content is approaching LL. While soils with $I_L \to 1$ could appear stable., they are in danger of potential liquifaction if they are perturbed by disturbances they could easily liquify and "muddy".

  --> Clay soils are often thixotropic. They can "set" and appear stable. However, if they are perturbed, as by pile driving, or by construction equipment, or earthquake loading, they can liquify.

D. Conclusions

- For coarse−grained soils, low D_r values indicate potentially unstable soils.
- For fine−grained soils, high I_L values indicate potentially unstable soils.
- Note the similarity of purpose between these indices.