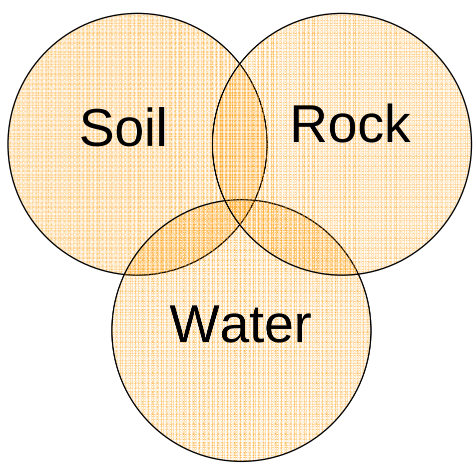
Soil Structure

Das Chapter 2

Geotechnical Engineering



Key Soil Engineering Properties

- Compressibility
  - Settlement
- Strength
  - Ability to carry load
- Permeability (hydraulic conductivity)
  - Flow of water through soils

Settlement Failure

Shear Failure

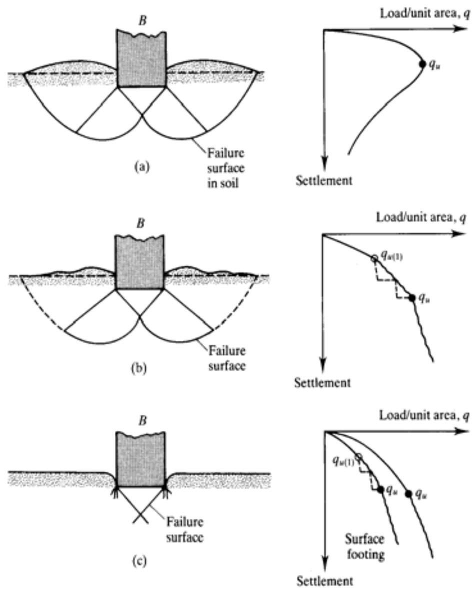
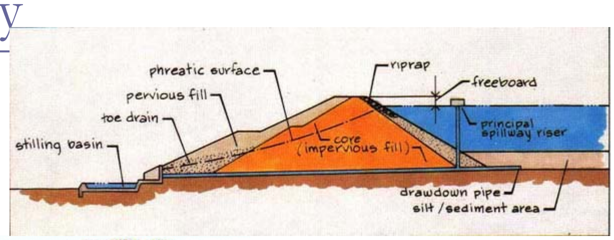


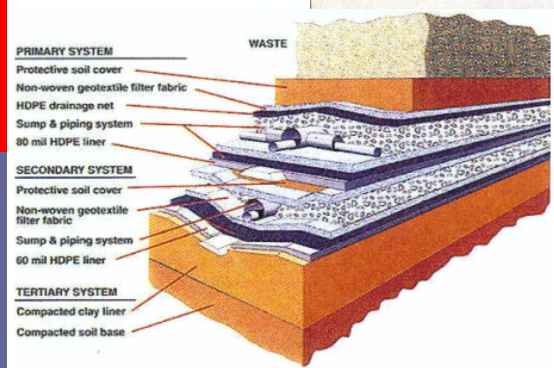
Figure 12.1 Nature of bearing capacity failure in soil: (a) general shear failure; (b) local shear failure; (c) punching shear failure

Palace of Fine Arts, Mexico

- A strange case of Palace of Fine Arts in the Alameda area of Mexico City. Built sometime between 1900 and 1934, it was a magnificent and strongly built structure. It was built on grade, level with the square and other buildings nearby. But because of loose sand permeated with water in the subsurface, the massive structure sunk 6 ft into the ground! (Luckily, it settled evenly minimizing structural damage.) Believe it or not, in the 1960's the building moved again. This time it moved 12 ft up! The weight of skyscrapers being built around the Palace had pushed the subsurface water and soil around sufficiently to raise the building.
  (Source: *Why Buildings Fall Down*, M. Levy and M. Salvadori, WW Norton & Company, 1992)

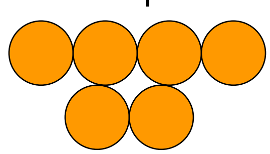
Permeability



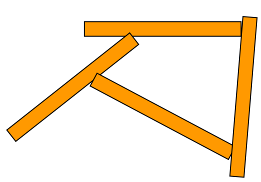


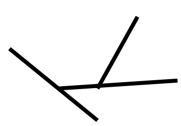
Soil Structure

- Assemblage of individual particles
  - Bulky particles



  - Plate particles
    - (Includes flaky or needle particles)
    - Card house structure





Bulky Particles

- Spherical particles
  - Boulders, cobbles, gravel, sand, and silt
- Coarse, granular or cohesionless soils
- Small surface area large mass
- Gravity forces dominate behaviour

$$F_g = m * a = m * g$$

g is earth's gravitation constant ($9.81 m/s^2$)

Particle Shape and Classification

- Engineering response impacted by:
  - Particle shape
    - (Angular, round, etc)
  - Range of particle sizes (distribution)
    - Percent gravel, sand, and silt particle shape description usually made based on visual classification
  - Rounded, sub-rounded, angular, sub-angular

Bulky Particles

- Shape depends on deposition environment and particle composition
  - Quartz, gold, feldspar, etc
- Shape good indication of how soil formed
- Particle size classification
  - Many different systems
    - (USCS, ASTM, AASHTO, MIT, British, etc)

Soil Classification Systems

Table 2.1 Soil-separate-size limits

Name of organization	Grain size (mm) Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unified Soil Classification System (U.S. Army Corps of Engineers; U.S. Bureau of Reclamation; American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

UNIFIED Soil Classification System (USCS)

	Soil	Particle diameter (mm)	
Cohesionless	Boulder	> 300	Bulky Particles
	Cobble	76.2 - 300	
	Gravel	4.75 – 76.2	
	Sand	0.075 – 4.75	
	Silt	.005 – 0.075	
Cohesive	Clay	0.002 - .005	Plate/Needle Particles
	Colloid	< 0.002	

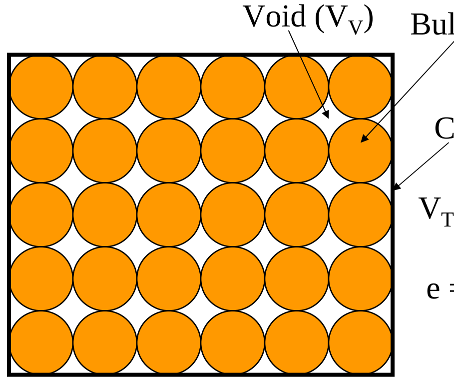
Bulky Particle Packing

- Stacking of marbles or balls
- Space between particles is called void

  Void ratio = volume of voids/volume of soil solids

$$e = V_v/V_s$$

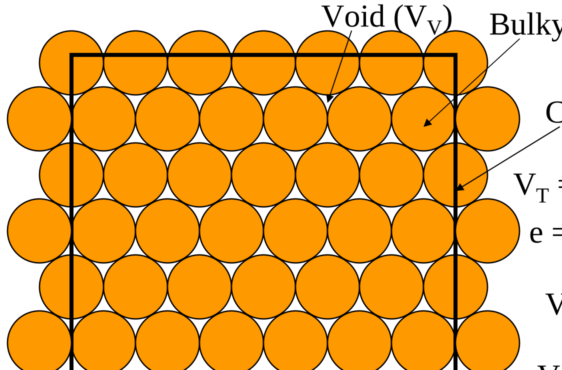
Loose Bulky Soil



$V_T = V_V + V_S$

$e = V_V/V_S$

Dense Bulky Soil



$V_T = V_V + V_S$

$e = V_V/V_S$

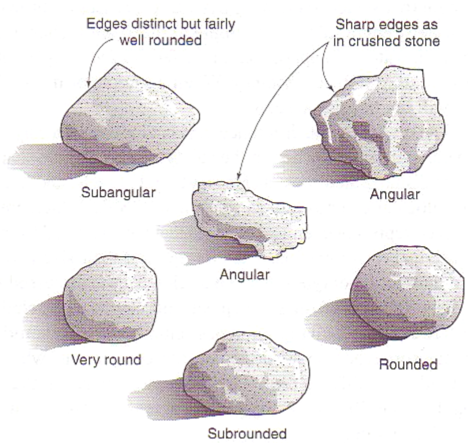
$V_v \downarrow = e \downarrow$

$V_s \uparrow = e \downarrow$

Bulky Soil Packing

- Most soils contain variety of particle sizes
- In general the greater the range of soil particles the lower the void ratio
  - Fill voids with smaller particles
- Soil strength also depends on particle interloc
  - Greater interloc higher shear strength
- Interloc function of: particle shape and amount of inter particle contact

Shape of Granular Soil Particles



Angular short transport distance

Round large transport

Bulky Soil Engineering Properties

- Compressibility
  - Relatively small in loose and dense state
  - Loose greater than dense
- Strength
  - Relatively high in loose and dense state
  - Dense greater than loose
  - High for angular particles
  - Low round particles
- Permeability (hydraulic conductivity)
  - Relatively high in loose and dense state
  - Loose greater than dense

Bulky Soil Consistency

- Very loose
- Loose
- Compact
- Dense
- Very dense

high void ratio (e)

Low strength, compressible

↓

Low void ratio (e)

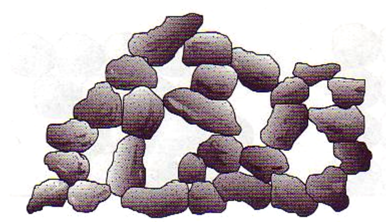
High strength, incompressible

Bulky Loose Soil

- High V_v low V_s therefore high e
  - May be prone to quick volume reduction or loss of strength of subjected to shocks or vibrations (loess)
  - Can get very loose or honeycombed silts and fine sand deposited in low energy environment (quiet water) or loosely dumped soils
  - Very large void ratio

Bulky Loose Soil

- Honeycomb soil structure in granular soil
- Loess (wind) deposit
- Good compressive strength
- Unstable if loaded sideways (shear)



Bulky Dense Soil

- Dense soil
  - Low V_v, high V_s therefore low e
  - Lower the soil void ratio the more dense,
    - less settlement and higher strength

Bulky Soil Properties

- Most soils have some water in voids
  - Voids filled then soil is 100 percent saturated
  - Portion of voids filled then soil is partially saturated

- Due to varying amount of water in a soil it density and void ratio will vary

Other Bulky Particles

- Organics
  - Peat
  - Decaying plant fragments
- Municipal solid waste
  - Paper, plastic, metal, etc
  - Not particulate materials
- Soil mechanic principles apply only to particulate materials

Soil Structure

- Soil - mineral aggregate that is weakly or loosely held together
- Assemblage of individual particles
  - Bulky particles
  - Plate particles
    - (Includes flaky or needle particles)

Plate Like Particles

- Flat thin particles
  - Clays and colloids
- Fine grained and cohesive soils
- Large surface area with small mass

Plate Like Particles

- Specific surface = surface area/mass
  - Sand = 0.001 to 0.4 m^2/gram
  - Silt = 0.4 to 1.0 m^2/gram
  - Clay = 5 to 800 m^2/gram
- Electrical forces dominate behaviour
  - No mass for gravity forces

Plate Like Mineral Formation

- Secondary minerals formed by weathering or oxidation of aluminous minerals or volcanic glass

Clay Mineral Formation

Micas, feldspar& feldspathoids → kaolinite

Siltstone/claystone/mudstone/shale → illite

Basalt, other mafic rocks → montmorillonite

Tuffs & volcanic ash → bentonite

Biotite → vermiculite (hydro-thermal alteration)

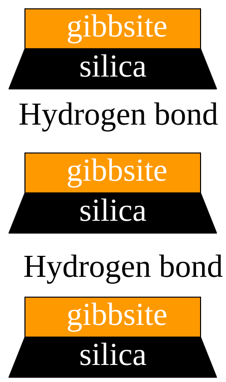
Structures of Most Clays

- Two main units
  - Silica tetrahedron (silica sheet)
  - alumina octahedron (alumina or gibbsite sheet)
- Silica tetrahedron
  - Four oxygen atoms surrounding a silicon atom
  - Combination of tetrahedrons gives a silica sheet
  - Black part of an OREO cookie

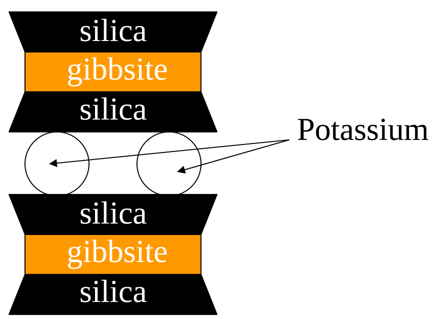
Structures of Most Clays

- Alumina octahedron
  - Six hydroxyls surrounding a silica atom
  - Combination of octahedrons gives a alumina or gibbsite sheet
  - When alumina is replaced with magnesium the sheet is known as a brucite sheet

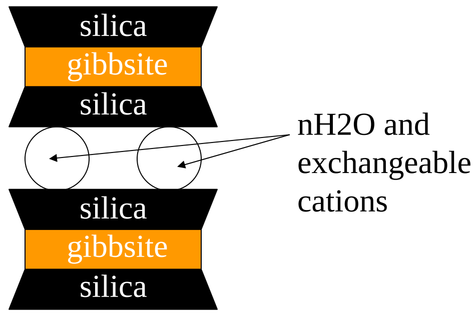
Kaolinite



Illite

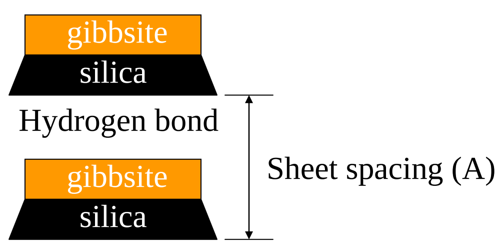


Montmorillonite



Clay Mineral Sheet Spacing

- Distance between sheet measured in angstroms (A)

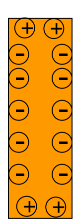


Clay Mineral Spacing

- Kaolinite = 7.2 A
- Illite = 10 A
- Montmorillonite = variable from 9.6 A to complete separation

Clay Mineral behaviour

- Charge particles
- Strong electrical forces on the particle surfaces
  - Negative charge on flat surface



Negative charge attracts positive cations:

•H+ from water

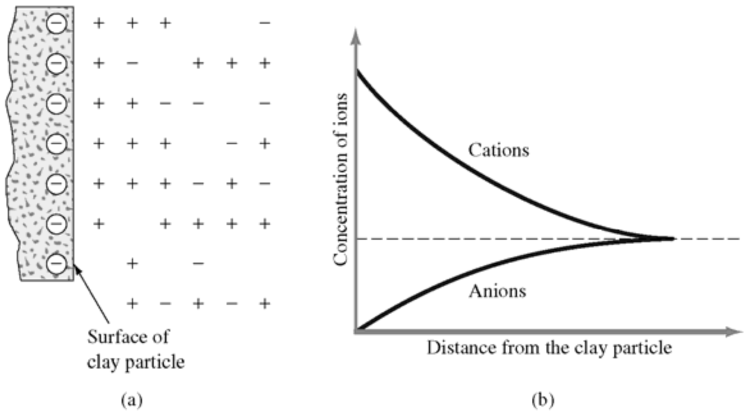


Figure 2.3 Diffuse double layer

Clay Mineral behaviour

- Cations adsorb to clay mineral surface
  - Absorb - within (sponge)
  - Adsorb - on surface
- Ability of clay mineral to adsorb cations is known as cation exchange
- Differs widely for different types of clays

Cation Exchange

- Cation exchange = # positive ions adsorbed per 100 gm of clay
- Depends on strength of negative charge
  - Montmorillonite = 360 to 500 $x10^{-20}$
  - Illite = 120 to 240 $x10^{-20}$
  - Kaolinite = 20 to 90 $x10^{-20}$

Cation Exchange

- Cations adsorbed may not be permanently attached

  Example:

  Clay with adsorbed Na++ washed with KCL. K+ will replaced Na++

Clays and Water

- Water adsorbed to clay mineral is called double layer water - strongly held
- Some weakly held
- Water outside double layer called free water
- Adsorbed water gives clay plasticity
  - Ability to roll out into 1/8th inch diameter thread

Clays

- Presence of clay minerals in soil will greatly impact engineering behavior
- For practical purposes when clay content in soil is >50% soil particles will float in clay
- High void ratio (>1 is typical)
- Water sensitive
- Water adsorb to surface - tightly held low hydraulic conductivity

Clay Consistency State

- Very soft
- Soft
- Firm
- Compact
- Stiff
- Very stiff

high void ratio (e)
high water content

↓

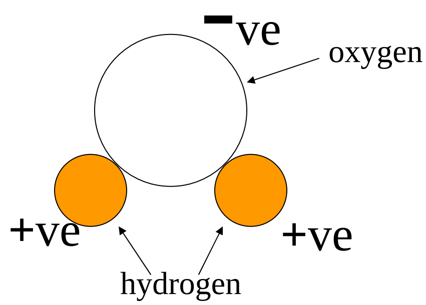
Low void ratio (e)
Low water content

Clay Engineering Properties

- Compressibility
  - Soft high and time dependant
  - Stiff low and time dependant
- Strength
  - low in soft state
  - High compact to stiff state
- Permeability
  - Very low in soft and stiff state (10^{-5} to 10^{-9}cm/s)

Clays and Water

- Water attracted to clay by two mechanisms:
  - Hydrogen bonding
  - di-polar water molecules



Water & Clay

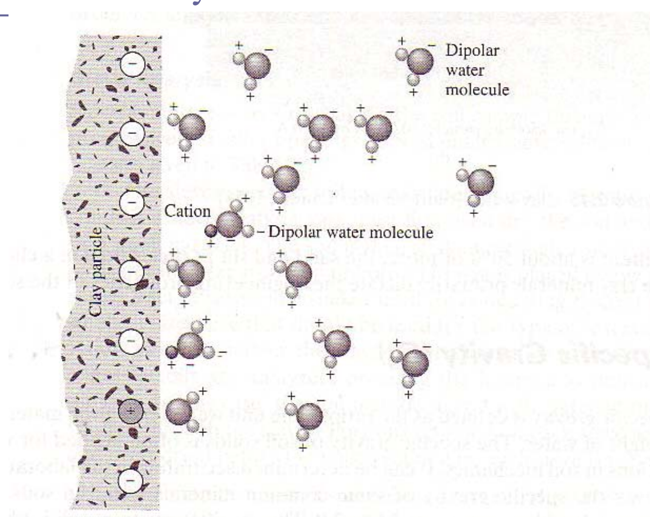


Figure 2.12 Attraction of dipolar molecules in diffuse double layer

Clays and Water

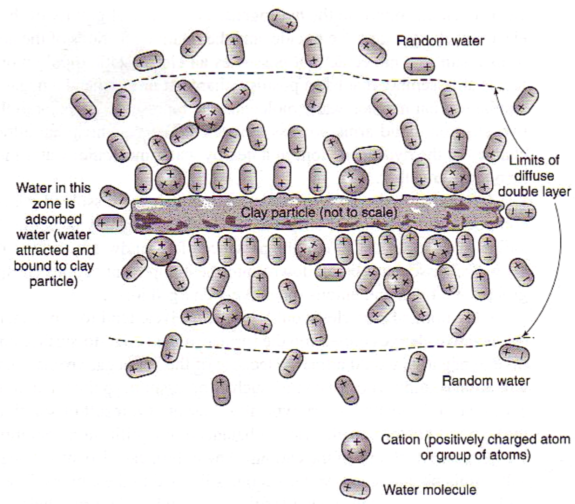


Figure 3-5 Adsorbed water and cations in diffuse double layer surrounding clay particle.

Clay Double Layer

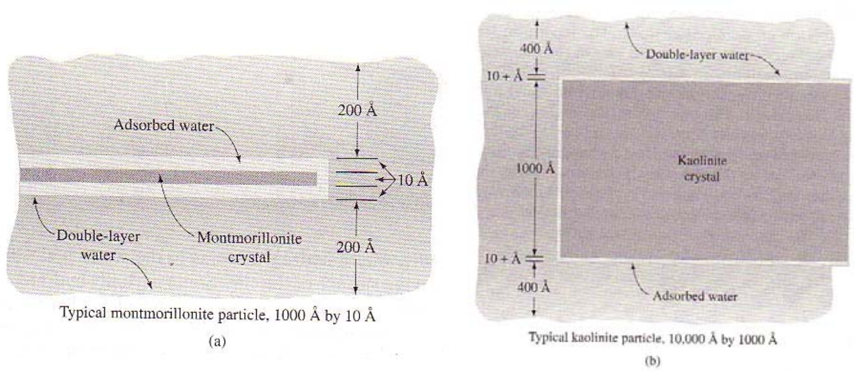
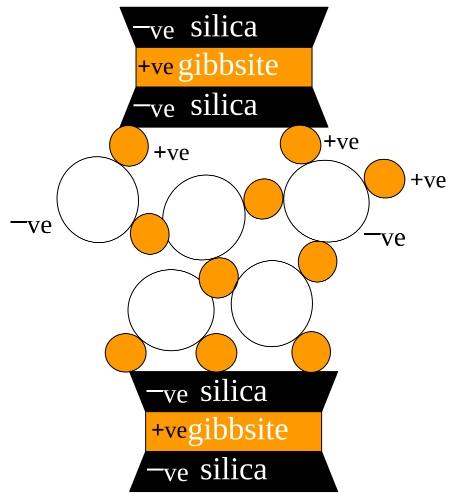


Figure 2.13 Clay water (redrawn after Lambe, 1958)

Bentonite & Water

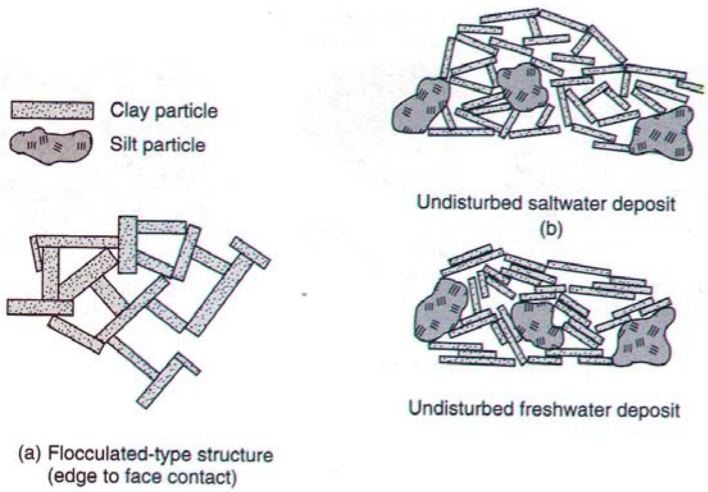
Dry Power



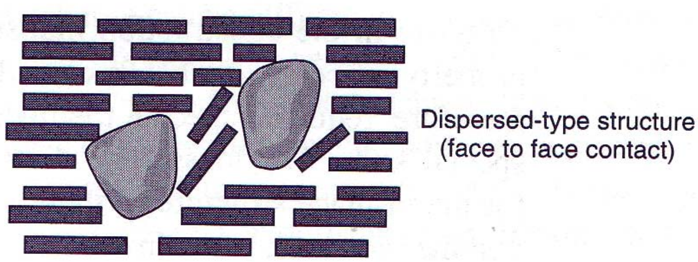
Clay Structure

- Due to electrical forces and deposition in very low energy environments develop loose structures (high e)
- Flocculated clay - particles attract each other then settle out due to gravity
- Dispersed - particles repel each other (negative to negative charge)

Clay Structure

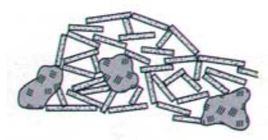


Clay Structure



Special Types of Clays

- Sensitive clay
  - Structure changes substantially due to disturbance (kneading or re-working)
  - Therefore engineering properties change
- Quick clay
  - After disturbance clay changes from solid to flowable fluid
  - Marine clays - leached out Na++ due to fresh water



Undisturbed saltwater deposit

Canada Quick Clays

- Leda Clay – Ottawa river valley
- Quebec – St Lawrence River valley
- NORWAY Quick Clay Movie