GEOTECHNICAL ENGINEERING

Historical Background of Soil Mechanics and Geotechnical Engineering

Lecture Outline:

1. Introduction
2. Pre-classical Period of Soil Mechanics
3. Classical Soil Mechanics
4. Modern Soil Mechanics
5. Geotechnical Engineering

Textbook:** Braja M. Das, "Principles of Geotechnical Engineering", 7^{th} E. **(Chapter 1).

Introduction

Soil is used as a construction material in various civil engineering projects, and it supports structural foundations . Thus, civil engineers must study the properties of soil, such as its origin, grain-size distribution, ability to drain water, compressibility, shear strength, and load-bearing capacity.

*"**Soil Mechanics** is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituent. "* Terzaghi (1948).

Geotechnical Engineering is a broader term for Soil Mechanics. It is the branch of Civil Engineering concerned with the engineering behavior of earth materials. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures, and earth structures.

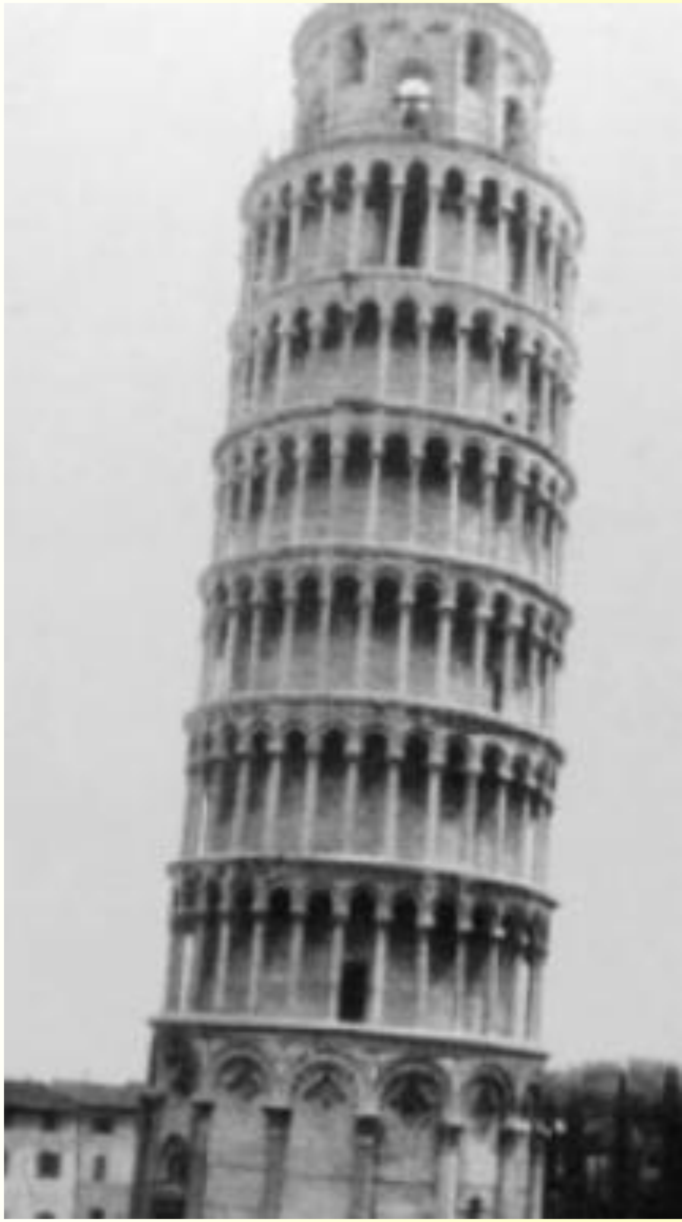
Geotechnical Engineering Prior to the 18th Century

The record of the first use of soil as a construction material by mankind is lost in antiquity. In true engineering sense, there is no 'Geotechnical Engineering' prior to the 18th Century.

For years, the art of geotechnical engineering was based on only past experiences through a succession of experimentation without any real scientific character. Based on those experimentations, many structures were built—some of which have crumbled, while others are still standing.

Geotechnical Engineering Prior to the 18th Century

One of the most famous examples of problems related to **soil-bearing capacity** in the construction of structures prior to the 18th century is the Leaning **Tower of Pisa in Italy.** Construction of the tower began in 1173 A.D. when the Republic of Pisa was flourishing and continued in various stages for over 200 years. The structure weighs about 15,700 metric tons and is supported by a circular base having a diameter of 20 m (66 ft). *The tower has tilted in the past to the east, north, west and, finally, to the south.*



Based on the emphasis and the nature of study in the area of geotechnical engineering, the time span extending from 1700 to 1927 can be divided into **four major periods** (Skempton, 1985):

1. Pre-classical (1700 to 1776 A.D.)
2. Classical soil mechanics-Phase I (1776 to 1856 A.D.)
3. Classical soil mechanics-Phase II (1856 to 1910 A.D.)
4. Modern soil mechanics (1910 to 1927 A.D.)

•Pre-classical Period of Soil Mechanics (1700 –1776)

This period concentrated on studies relating to natural slope and unit weights of various types of soils, as well as the semiempirical earth pressure theories.

Henri Gautier (1660–1737), studied the natural slopes of soils when tipped in a heap for formulating the design procedures of retaining walls. Bernard

Forest de Belidor (1671–1761) published a textbook for military and civil engineers in France. In the book, he proposed a theory for lateral earth pressure on retaining walls and specified a soil classification system.

Francois Gadroy (1705–1759), who observed the existence of slip planes in the soil at failure.

Classical Soil Mechanics

Classical Soil Mechanics began in 1736 with **Charles Coulomb's** (a physicist, 1736–1806) introduction of mechanics to soil problems. using the laws of friction and cohesion to determine the true sliding surface in soil behind a retaining wall, Coulomb defined the failure criteria for soil. By combining Coulomb's theory with Christian Otto Mohr's theory of a 2D stress state, the Mohr-Coulomb theory was developed.

Henry Darcy(1803–1858) defined the hydraulic conductivity.

Joseph Boussinesq, a mathematician and physicist (1842–1929), developed the theory of stress distribution.

William Rankines (1820–1872) simplified Coulomb's earth pressure theory.

Osborne Reynolds (1842–1912) demonstrated the phenomenon of dilatency in sand.

Modern Soil Mechanics (1910 -1927)

This period was marked by a series of important studies and publications related to the mechanic behavior of clays:

Albert Atterberg (1846–1916), a Swedish chemist and soil scientist, explained the consistency of cohesive soils by defining liquid, plastic, and shrinkage limits.

Arthur Bell (1874–1956), a civil engineer from England, developed relationships for lateral pressure and resistance in clay as well as bearing capacity of shallow foundations in clay.

Wolmar Fellenius (1876–1957), an engineer from Sweden, developed the stability analysis of saturated clay slopes.

Karl Terzaghi (1883–1963), a civil engineer and geologist from Austria, developed the theory of consolidation for clays as we know today.

Geotechnical Engineering after 1927

The development of modern Geotechnical Engineering as a branch of Civil Engineering is absolutely impacted by one single professional individual – Karl Terzaghi.

Generally recognized as the father of modern soil mechanics and geotechnical engineering.

He started modern soil mechanics with his theories of consolidation, lateral earth pressures, bearing capacity, and stability.

His contribution has spread to almost every topic in soil mechanics and geotechnical engineering covered by the test book: Effective stress (Ch. 8); Elastic stress distribution (Ch. 9); Consolidation settlement (Ch. 10); Shear strength (Ch. 11); in situ testing (Ch. 17).

Geotechnical Engineering

Geotechnical Engineering is the branch of Civil Engineering concerned with the engineering behavior of earth materials. It includes investigating existing subsurface conditions and materials; determining their physical/mechanical and chemical properties; assessing risks posed by site conditions; designing earthworks and structure foundations; and monitoring site conditions. It includes:

- Soil Mechanics (Soil Properties and Behavior).
- Rock Mechanics (Rock Stability and Tunneling).
- Foundation Engineering (Shallow & Deep Foundations).
- Soil Dynamics (Dynamic Properties of Soils, Earthquake Engineering).
- Earthworks Engineering (Embankments, Slops Stability, Dams).
- Earth Retaining Structures.
- Pavement Engineering (Flexible & Rigid Pavements).
- Ground Improvement (Soil Reinforcement, Geosynthetics).
- Cosatal and Ocean Engineering.

Introduction of Soil Mechanics

Lecture Outline

Original Topics

1. Phase Relationship
2. Physical Properties
3. Clay Minerals
4. Compaction

Modified Topics

1. Soil Formations

   (Phase Relationship)
2. Physical Properties
3. Soil Classification
4. Clay Minerals and Soil Structure
5. Compaction

Suggested Textbooks

Das, B.M. (2009). ***Principles of Geotechnical Engineering*****, 7th edition.**

Holtz, R.D. and Kovacs, W.D. (1981). ***An Introduction to Geotechnical Engineering*****, Prentice Hall.**

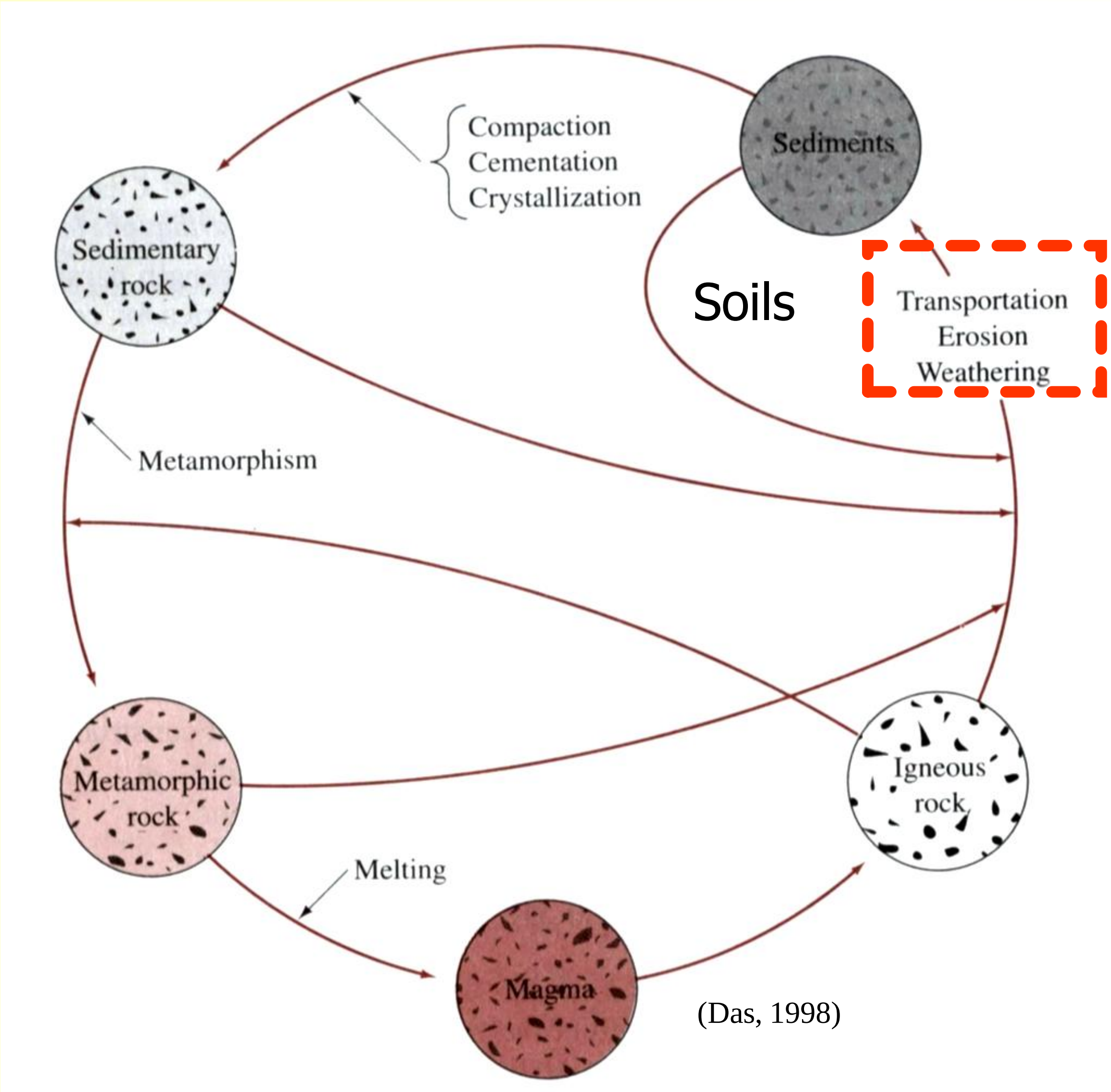
I. Soil Formations

Outline of the First Topic

1. Soil Formations and Deposits
2. **Residual Soils**
3. **Phase Relations**
4. Some Thoughts about the Specific Gravity Measurements
5. Suggested Homework

1. Soil Formations and Deposits

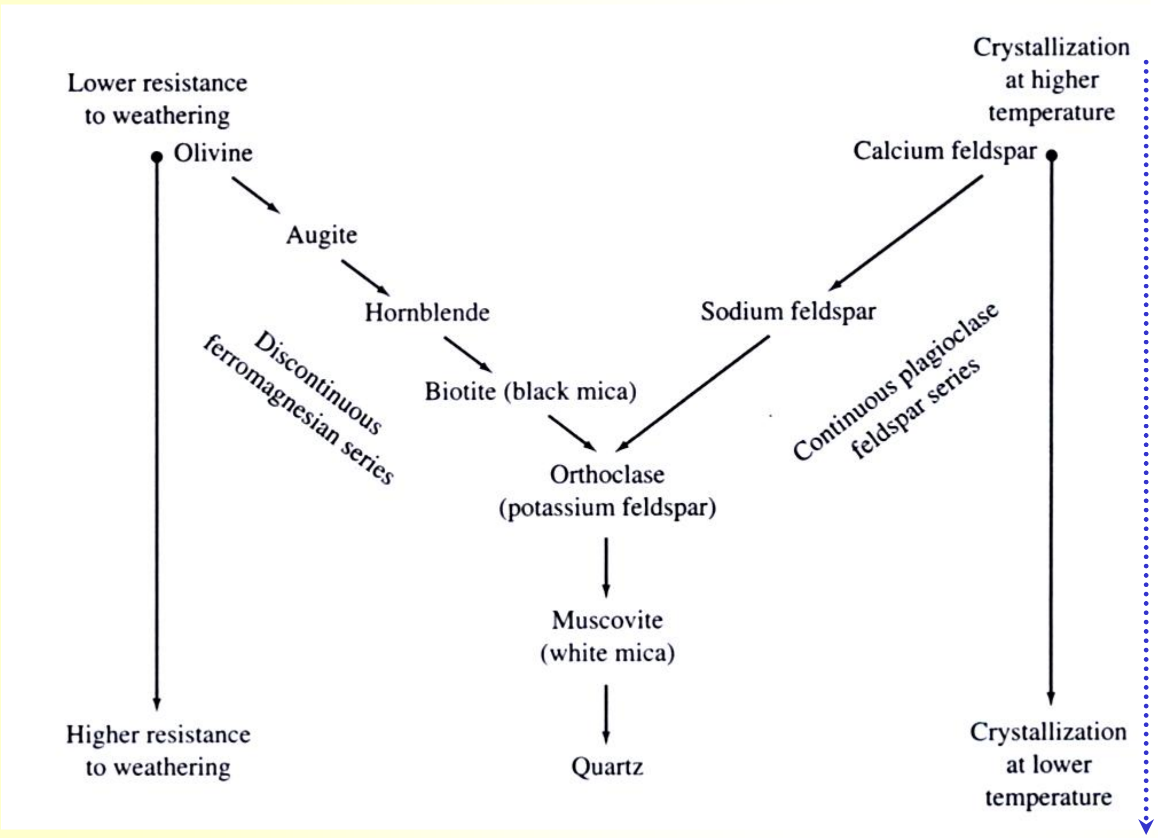
1.1 Rock Cycles



The final products due to weathering are ***soils***

1.2 Bowen's Reaction Series

- The reaction series are similar to the weathering stability series.



Mineral	Composition
Olivine	$(Mg, Fe)_2SiO_4$
Augite	$Ca, Na(Mg, Fe, Al)(Al, Si_2O_6)$
Hornblende	Complex ferromagnesian silicate of Ca, Na, Mg, Ti, and Al
Biotite (black mica)	$K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$
Plagioclase { calcium feldspar	$Ca(Al_2Si_2O_8)$
Plagioclase { sodium feldspar	$Na(AlSi_3O_8)$
Orthoclase (potassium feldspar)	$K(AlSi_3O_8)$
Muscovite (white mica)	$KAl_3Si_3O_{10}(OH)_2$
Quartz	SiO_2

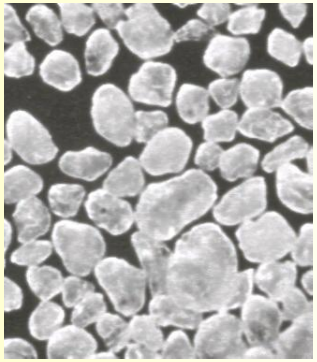
•More stable

•Higher weathering resistance

(Das, 1998)

Question

What is the main mineral of the sand particles in general?



Quartz

1.3 Weathering

1.3.1 Physical processes of weathering

- Unloading
  - e.g. uplift, erosion, or change in fluid pressure.
- Thermal expansion and contraction
- Alternate wetting and drying
- Crystal growth, including frost action
- Organic activity
  - e.g. the growth of plant roots.

1.3.2 Chemical Process of weathering

- Hydrolysis
  - is the reaction with water
  - will not continue in the static water.
  - involves solubility of silica and alumina
- Chelation
  - Involves the complexing and removal of metal ions .
- Cation exchange
  - is important to the formation of clay minerals
- Oxidation and reduction.
- Carbonation
  - is the combination of carbonate ions such as the reaction with CO_2

1.3.3 Factors affect weathering

- Many factors can affect the weathering process such as **climate, topography, features of parent rocks, biological reactions, and others.**
- Climate determines the amount of water and the temperature.

(Mitchell, 1993)

1.4 Transportation of Weathering Products

1.4.1 Residual soils-

to remain at the original place

- In Hong Kong areas, the top layer of rock is decomposed into residual soils due to the warm climate and abundant rainfall .
- Engineering properties of residual soils are different with those of transported soils
- The knowledge of "classical" geotechnical engineering is mostly based on behavior of transported soils. The understanding of residual soils is insufficient in general.

1.4.2 Transported soils-

to be moved and deposited to other places.

- The particle sizes of transported soils are selected by the transportation agents such as **streams, wind,** etc.
  - Interstratification of silts and clays.
- The transported soils can be categorize based on the mode of transportation and deposition
- **(six types).**

1.4.2 Transported Soils (Cont.)

(1) **Glacial soils**: formed by transportation and deposition of glaciers.

(2) **Alluvial soils**: transported by running water and deposited along streams （Bangladesh）

(3) **Lacustrine soils**: formed by deposition in quiet lakes (e.g. soils in Taipei basin).

(4) **Marine soils**: formed by deposition in the seas (Hong Kong, Japan).

(5) **Aeolian soils**: transported and deposited by the wind (e.g. soils in the loess plateau, China).

(6) **Colluvial soils**: formed by movement of soil from its original place by gravity, such as during landslide (*Hong Kong*). (from Das, 1998)

2.1 Decomposition Grades (Rock)

Common weathering processes in Hong Kong (Irfan, 1996).

- The most important chemical processes of weathering are hydrolysis and solution.
- The two important physical processes of weathering are the alternate wetting and drying, and the exfoliation (sheeting).

Saprolite: rock fabric is retained.

Residual soil: rock fabric is completely destroyed.

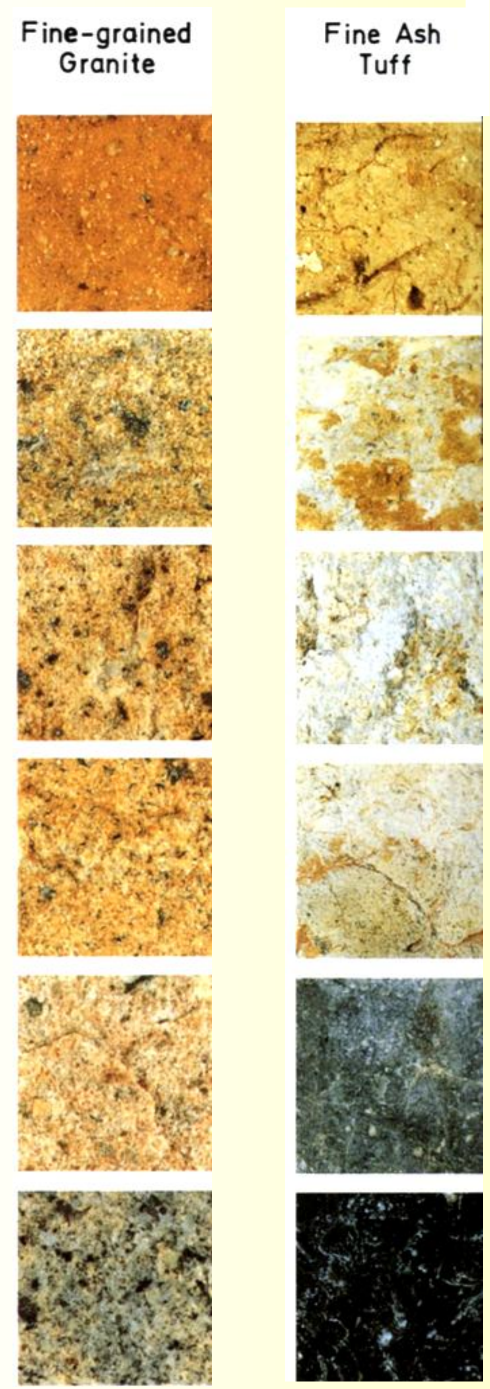
Descriptive Term	Grade Symbol	General Characteristics for Granitic & Volcanic Rocks & Other Rocks of Equivalent Strength in the Fresh State
Residual Soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains
Completely Decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily indented by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock
Highly Decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock
Moderately Decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout
Slightly Decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)

(Guide, 1988)

2.1 Cont.

- Most of the residual soils in Hong Kong are in-situ decomposed from igneous rocks
- The red or yellow color is due to the presence of iron oxides.

VI	Residual soils
V	Completely decomposed
IV	Highly decomposed
III	Moderately decomposed
II	Slightly decomposed
I	Fresh

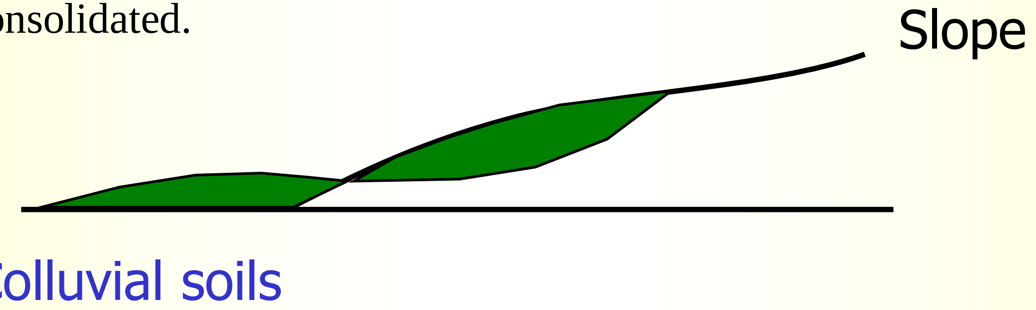


2.2 Soils in Hong Kong

Three important types of soils in Hong Kong

1. Residual soils
2. Saprolites (soil-like, contain relict joint of parent rocks)
3. Colluvial soils

The colluvial soils mainly originate from the landslide and they are usually poorly consolidated.

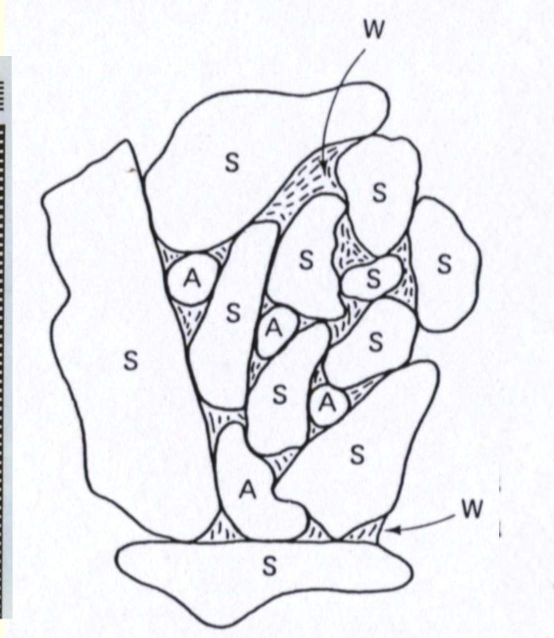


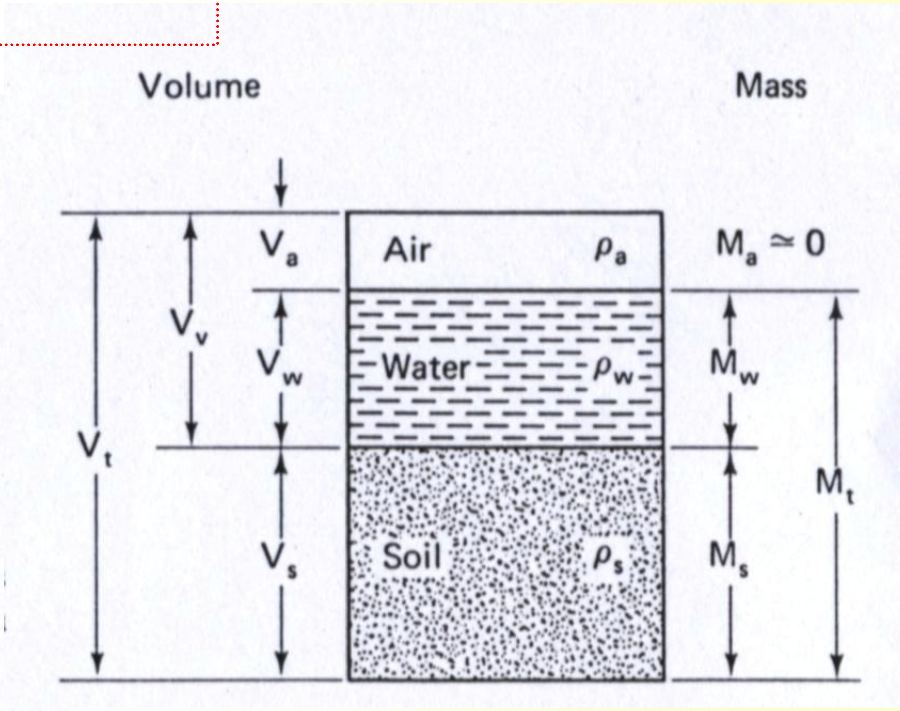
- **Alluvial soils- Bangladesh**

3. Phase Relations

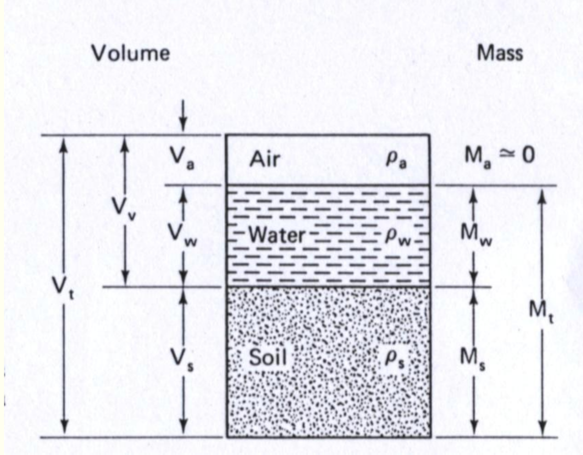
3.1 Three Phases in Soils

S :	Solid	Soil particle
W:	Liquid	Water (electrolytes)
A:	Air	Air





3.2 Three Volumetric Ratios



(1) **Void ratio *e* (given in decimal, 0.65)**

$$e = \frac{\text{Volume of voids}\,(V_v)}{\text{Volume of solids}\,(V_s)}$$

(2) **Porosity *n* (given in percent 100%, 65%)**

$$n = \frac{V_s e}{V_s(1+e)} = \frac{e}{1+e} \qquad n = \frac{\text{Volume of voids}\,(V_v)}{\text{Total volume of soil sample}\,(V_t)}$$

(3) **Degree of Saturation *S* (given in percent 100%, 65%)**

$$S = \frac{\text{Total volume of voids contains water}\,(V_w)}{\text{Total volume of voids}\,(V_v)} \times 100\%$$

3.2.1 Engineering Applications (e)

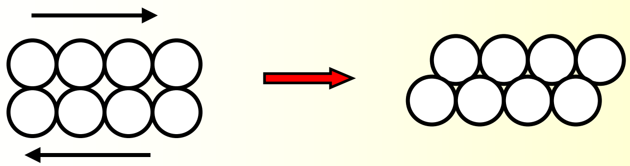
Typical values

Description	Void Ratio		Porosity (%)		Dry Unit Weight (kN/m³)	
	e_{max}	e_{min}	n_{max}	n_{min}	$\gamma_{d\,min}$	$\gamma_{d\,max}$
Uniform spheres	0.92	0.35	47.6	26.0	—	—
Standard Ottawa sand	0.80	0.50	44	33	14.5	17.3
Clean uniform sand	1.0	0.40	50	29	13.0	18.5
Uniform inorganic silt	1.1	0.40	52	29	12.6	18.5
Silty sand	0.90	0.30	47	23	13.7	20.0
Fine to coarse sand	0.95	0.20	49	17	13.4	21.7
Micaceous sand	1.2	0.40	55	29	11.9	18.9
Silty sand and gravel	0.85	0.14	46	12	14.0	22.9

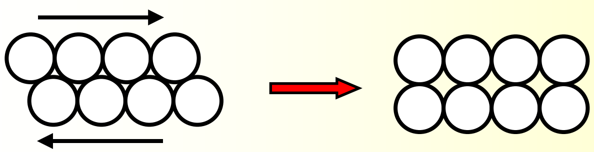
(Lambe and Whitman, 1979)

Engineering applications:

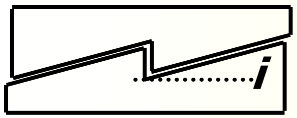
Simple cubic (SC), e = 0.91, ***Contract***



Cubic-tetrahedral (CT), e = 0.65, ***Dilate***



- Volume change tendency
- Strength

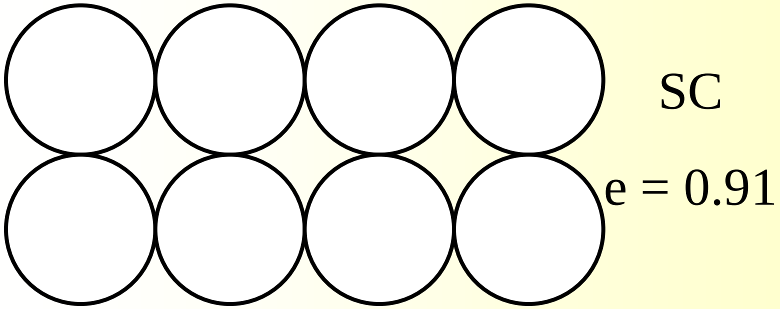


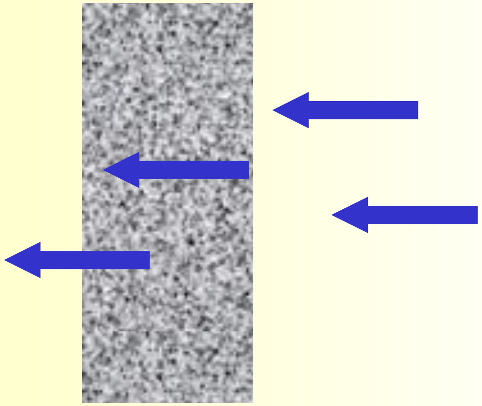
Link: the strength of rock joint

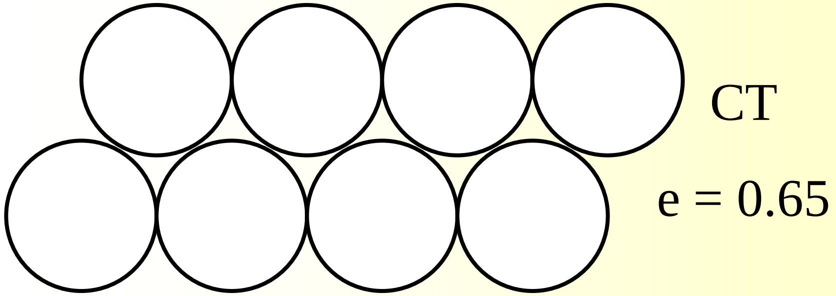
$$\text{Shear strength} = \sigma_n \tan(\phi + i)$$

3.2.1 Engineering Implications (e)(Cont.)

- Hydraulic conductivity
  - **Which packing (SC or CT) has higher hydraulic conductivity?**

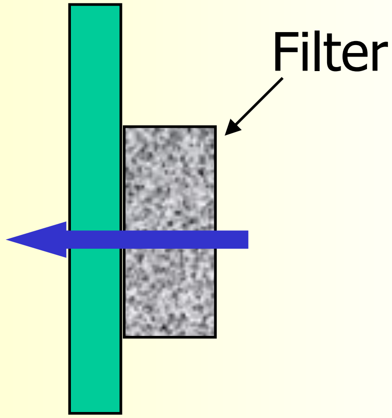


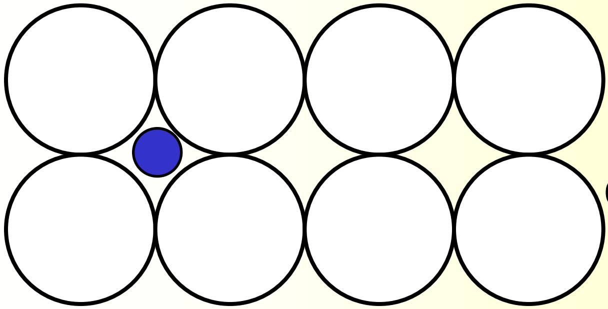




The fluid (water) can flow more easily through the soil with higher hydraulic conductivity

3.2.1 Engineering Applications (e)(Cont.)



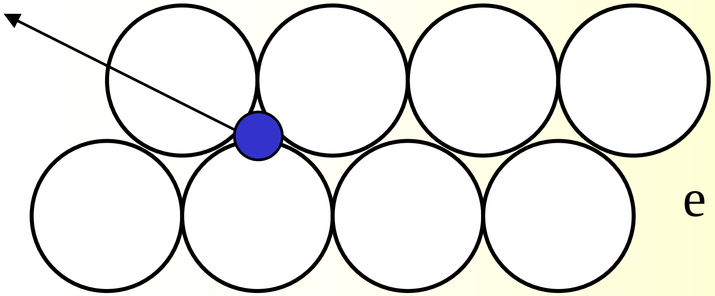


SC

e = 0.91

- Clogging

The finer particle cannot pass through the void



CT

e = 0.65

- Critical state soil mechanics

3.2.2 Engineering Applications (S)

Completely dry soil S = 0 %

Completely saturated soil S = 100%

Unsaturated soil (partially saturated soil) $0\% < S < 100\%$

$$S = \frac{\text{Total volume of voids contains water}\,(V_w)}{\text{Total volume of voids}\,(V_v)} \times 100\%$$

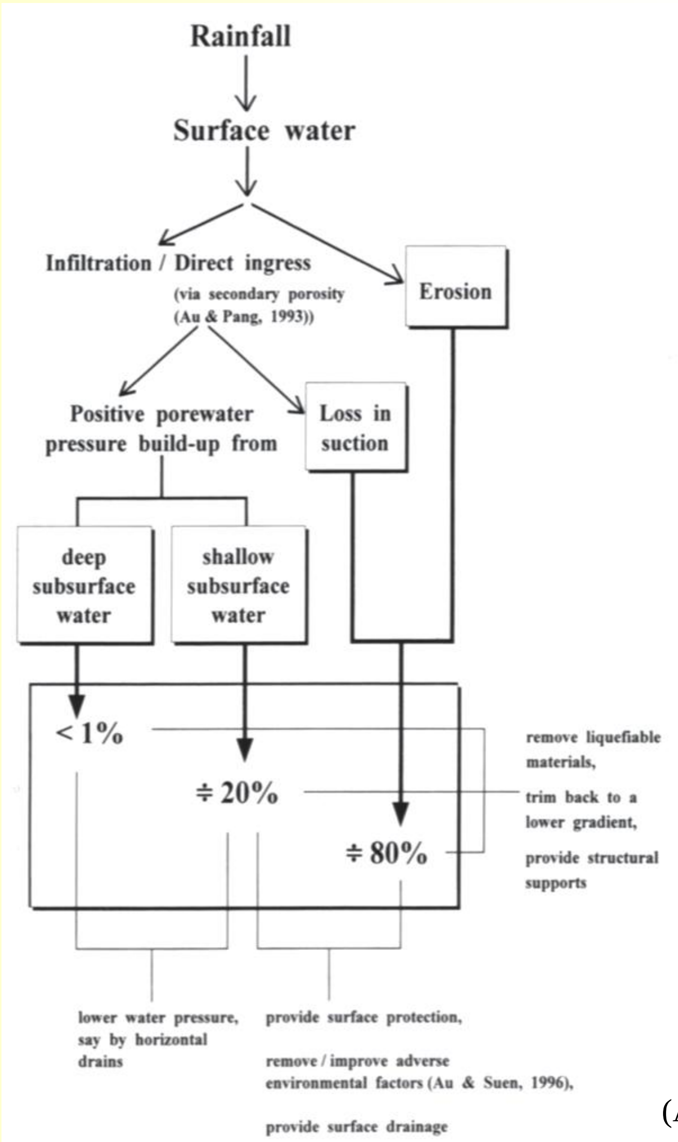
Demonstration:

Effects of capillary forces

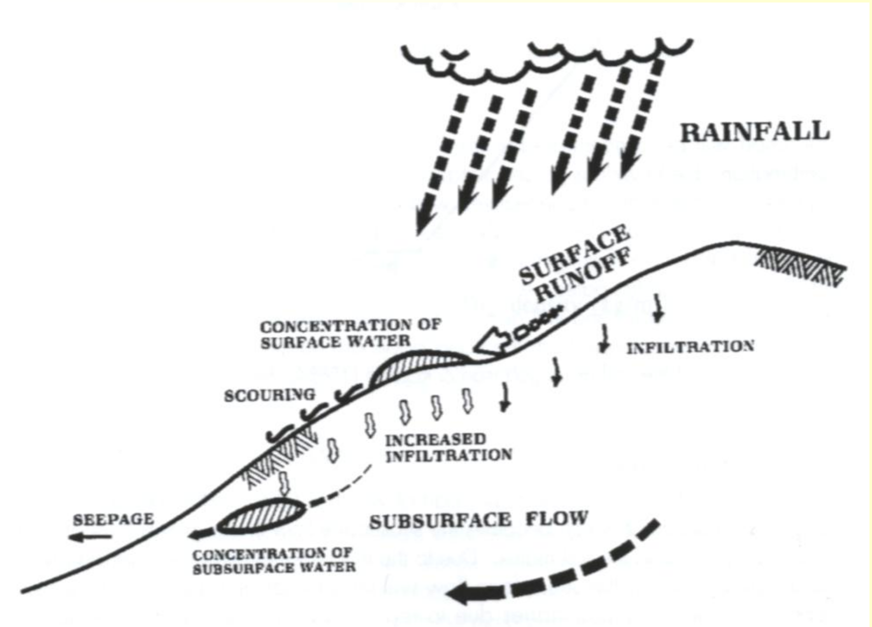
Engineering implications:

- **Slope stability**
- **Underground excavation**

3.2.2 Engineering Applications (S) (Cont.)



- **80 % of landslides are due to erosion and "*loss in suction*" .**
- **The slope stability is significantly affected by the surface water.**



(Au, 2001)

3.3 Density and Unit Weight

- **Mass is a measure of a body's inertia, or its "quantity of matter". Mass is not changed at different places.**

$$Density,\ \rho = \frac{Mass}{Volume}$$

$$Unit\ weight,\ \gamma = \frac{Weight}{Volume} = \frac{Mass \cdot g}{Volume}$$

- **Weight is force, the force of gravity acting on a body. The value is different at various places (Newton's second law F = ma) (Giancoli, 1998)**

$$g : acceleration\ due\ to\ gravity$$

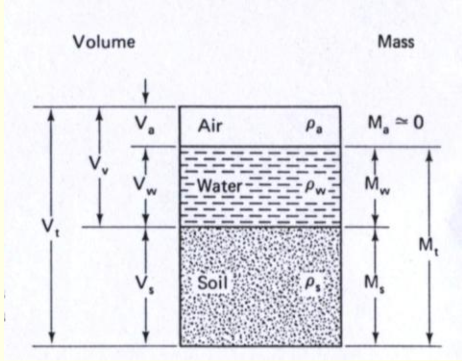
$$\gamma = \rho \cdot g = \rho \cdot 9.8\ m/\sec^2$$

$$Water,\ \gamma = 9.8\ kN/m^3$$

- **The unit weight is frequently used than the density is (e.g. in calculating the overburden pressure).**

$$G_s = \frac{\rho_s}{\rho_w} = \frac{\rho_s \cdot g}{\rho_w \cdot g} = \frac{\gamma_s}{\gamma_w}$$

3.4 Weight Relationships



(1)Water Content *w* (100%)

$$w = \frac{Mass\ of\ water\ (M_w)}{Mass\ of\ soil\ solids\ (M_s)} \cdot 100\%$$

For some organic soils *w*>100%, up to 500 %

For quick clays, *w*>100%

(2)Density of water (slightly varied with temperatures)

$$\rho_w = 1 g/cm^3 = 1000 kg/m^3 = 1 Mg/m^3$$

(3) Density of soil

a. Dry density

$$\rho_d = \frac{\text{Mass of soil solids}(M_s)}{\text{Total volume of soil sample}(V_t)}$$

b. Total, Wet, or Moist density
(0%<S<100%, Unsaturated)

$$\rho = \frac{\text{Mass of soil sample}(M_s + M_w)}{\text{Total volume of soil sample}(V_t)}$$

c. Saturated density (S=100%, V_a =0)

$$\rho_{sat} = \frac{\text{Mass of soil solids + water}(M_s + M_w)}{\text{Total volume of soil sample}(V_t)}$$

d. Submerged density (Buoyant density)

$$\rho' = \rho_{sat} - \rho_w$$

3.4 Weight Relationships (Cont.)

Submerged unit weight: $\gamma' = \gamma_{sat} - \gamma_w$

Consider the buoyant force acting on the soil solids:

$$\frac{W_s - V_s \cdot \gamma_w}{V_t} = \frac{W_s - (V_t - V_w) \cdot \gamma_w}{V_t} \quad (S = 100\%)$$

$$= \frac{W_s - V_t \cdot \gamma_w + W_w}{V_t}$$

$$= \frac{W_s + W_w - V_t \cdot \gamma_w}{V_t}$$

$$= \gamma_{sat} - \gamma_w$$

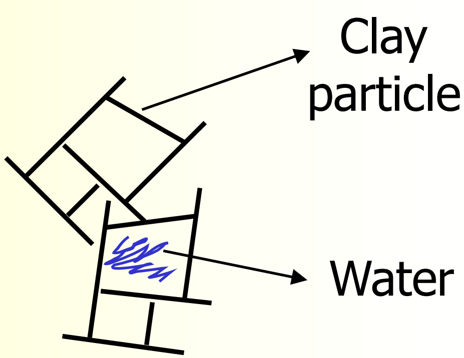
***Archimede's principle*:**

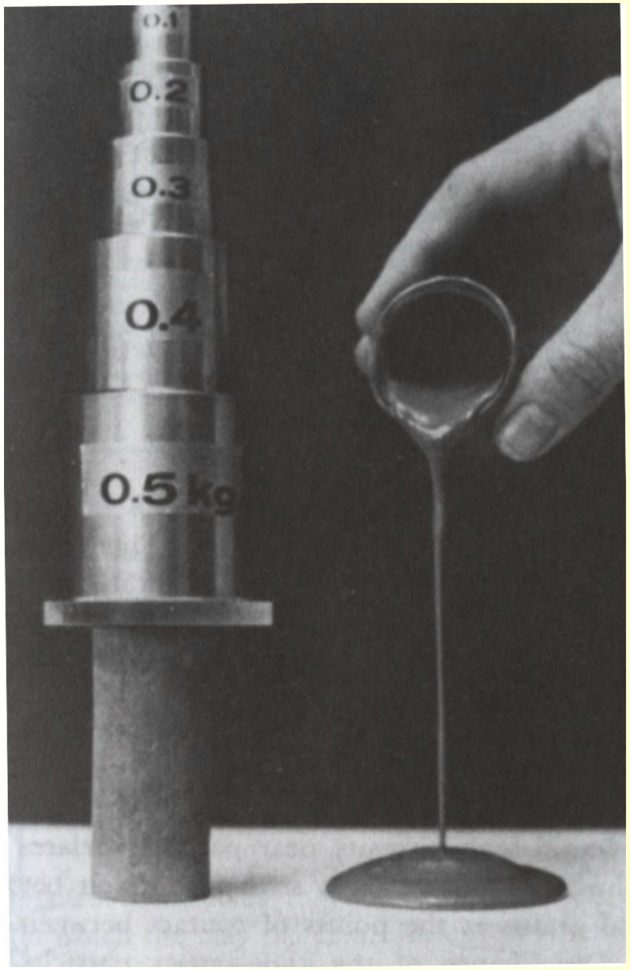
The buoyant force on a body immersed in a fluid is equal to the weight of the fluid displaced by that object.

3.4.1 Engineering Applications (*w*)

- **For fine-grained soils, water plays a critical role to their engineering properties (discussed in the next topic).**
- ***For example,***

The quick clay usually has a water content *w* greater than 100 % and a card house structure. It will behave like a viscous fluid after it is fully disturbed.





(Mitchell, 1993)

3.5 Other Relationships

(1) Specific gravity

$$G_s = \frac{\rho_s}{\rho_w} = \frac{\gamma_s}{\gamma_w}$$

Proof:

$$S \cdot e = w \cdot G_s$$

$$S \cdot e = \frac{V_w}{V_v} \cdot \frac{V_v}{V_s} = \frac{V_w}{V_s}$$

$$w \cdot G_s = \frac{M_w}{M_s} \cdot \frac{\rho_s}{\rho_w} = \frac{M_w}{M_s} \cdot \frac{M_s / V_s}{M_w / V_w} = \frac{V_w}{V_s}$$

(2)

$$\rho_w \cdot S \cdot e = w \cdot \rho_s$$

$$S \cdot e = w \cdot G_s$$

3.6 Typical Values of Specific Gravity

Table 3.1 Specific Gravities of Minerals

Quartz	2.65
K-Feldspars	2.54–2.57
Na–Ca-Feldspars	2.62–2.76
Calcite	2.72
Dolomite	2.85
Muscovite	2.7–3.1
Biotite	2.8–3.2
Chlorite	2.6–2.9
Pyrophyllite	2.84
Serpentine	2.2–2.7
Kaolinite	2.61[a]
	2.64 ± 0.02
Halloysite (2 H_2O)	2.55
Illite	2.84[a]
	2.60–2.86
Montmorillonite	2.74[a]
	2.75–2.78
Attapulgite	2.30

[a] Calculated from crystal structure.

(Lambe and Whitman, 1979)

Table 2.2 Specific Gravities of Common Minerals[a]

Mineral	*G*
Halite	2.1–2.6
Gypsum	2.3–2.4
Serpentine	2.3–2.6
Orthoclase	2.5–2.6
Chalcedony	2.6–2.64
Quartz	2.65
Plagioclase	2.6–2.8
Chlorite and illite	2.6–3.0
Calcite	2.7
Muscovite	2.7–3.0
Biotite	2.8–3.1
Dolomite	2.8–3.1
Anhydrite	2.9–3.0
Pyroxene	3.2–3.6
Olivine	3.2–3.6
Barite	4.3–4.6
Magnetite	4.4–5.2
Pyrite	4.9–5.2
Galena	7.4–7.6

[a] A. N. Winchell (1942).

(Goodman, 1989)

3.7 Solution of Phase Problems

Remember the following simple rules **(Holtz and Kovacs, 1981):**

1. **Remember the basic definitions of w, e, ρ_s, S, etc.**
2. **Draw a phase diagram.**
3. **Assume either V_s=1 or V_t=1, *if not given.***
4. **Often use $\rho_w Se = w\rho_s$, $Se = wG_s$**

Example

4. Some Thoughts about the Specific Gravity (G_s) Measurement

4.1 Standards

Standards

- ASTM D854-92 Standard Test Method for Specific Gravity of Soils

- ASTM C127-88 (Reapproved 1993) Test Methods for Specific Gravity and Absorption of Coarse Aggregate.

- BS 1377: Part 2:1990

4.2 Alternatives

- If the soil contains **soluble salts or can react with water**, an alternative liquid should be used such as kerosene (paraffin) or white spirit. **Note that the density of oil is not equal to 1 g/cm^3, $\rho_L \neq 1$ g/cm^3 (Head, 1992).**

$$G_s = \frac{(m_2 - m_1)}{\dfrac{(m_4 - m_1) - (m_3 - m_2)}{\rho_L}}$$

← Weight of liquid displaced by the soil solid.

$$= \frac{\rho_L (m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$$

4.2 Alternatives (Cont.)

- **If the particle density is likely to be changed owing to dehydration at 100°C, a lower drying temperature (e.g. 80 °C) and longer drying time should be adopted. Note that the modification must be recorded. However, for some clay minerals the dehydration is almost inevitable. For example, halloysite will lose its interlayer water at 50 °C or at relative humidity RH ≤ 50 %) (Irfan, 1996).**

4.3 Your Test Results

G_s for some minerals

Quartz,	2.65
Kaolinite,	2.65
K-feldspar,	2.54-2.57
Halloysite,	2.55

Hints:

Primary minerals:

Quartz, Kaolinite, K-feldspar, Halloysite

Note:

The specific gravity of solids of light-colored sand, which is mostly made of quartz, maybe estimated to be about 2.65; for clayed and silty soils, it may vary from 2.6 to 2.9 (from Das, 1998).

→

The G_s of soils is typically estimated as 2.65 if not given.

4.4 Average Specific Gravity Values

For example,

For soil particles larger than 2mm, the weight is W_1 and the volume is V_1.

For soil particles smaller than 2mm, the weight is W_2 and the volume is V_2.

$$G_{s-avg} = \frac{(W_1 + W_2)}{(V_1 + V_2)} = \frac{1}{\frac{(V_1 + V_2)}{(W_1 + W_2)}}$$

$$\cancel{\frac{G_{s1} + G_{s2}}{2}}$$

$$G_{s-avg} = \frac{1}{\frac{W_1}{(W_1 + W_2)}\frac{V_1}{W_1} + \frac{W_2}{(W_1 + W_2)}\frac{V_2}{W_2}}$$

$$G_{s-avg} = \frac{1}{P_1 \frac{1}{G_{s1}} + P_2 \frac{1}{G_{s2}}}$$

P is the weight fraction

• The term **Relative Density** is commonly used to indicate the in–situ denseness or looseness of **granular soil.** It is defined as

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

where D_r relative density, usually given as a percentage

e in situ void ratio of the soil

e_{max} void ratio of the soil in the loosest state

e_{min} void ratio of the soil in the densest state

The values of D_r may vary from a minimum of **0% for very loose soil** to maximum of **100% for very dense soils.** Soils engineers qualitative describe the granular soil deposits according to their relative densities, a shown in Table below

Table 3.3 Qualitative Description of Granular Soil Deposits

Relative density (%)	Description of soil deposit
0–15	Very loose
15–50	Loose
50–70	Medium
70–85	Dense
85–100	Very dense

- In-place soils seldom have relative densities less than 20 to 30%. Compacting a granular soil to a relative density greater than about 85% is difficult.

D_r also represented as follows;

$$D_r = \frac{(1 - n_{min})(n_{max} - n)}{(n_{max} - n_{min})(1 - n)}$$

By using the definition of dry unit weight given in Eq. (3.16), we can express relative density in terms of maximum and minimum possible dry unit weights. Thus,

$$D_r = \frac{\left[\frac{1}{\gamma_{d(min)}}\right] - \left[\frac{1}{\gamma_d}\right]}{\left[\frac{1}{\gamma_{d(min)}}\right] - \left[\frac{1}{\gamma_{d(max)}}\right]} = \left[\frac{\gamma_d - \gamma_{d(min)}}{\gamma_{d(max)} - \gamma_{d(min)}}\right]\left[\frac{\gamma_{d(max)}}{\gamma_d}\right]$$

where $\gamma_{d(min)}$ = dry unit weight in the loosest condition (at a void ratio of e_{max})
γ_d = *in situ* dry unit weight (at a void ratio of e)
$\gamma_{d(max)}$ = dry unit weight in the densest condition (at a void ratio of e_{min})

A sample of saturated clay from a consolidometer test has a total weight of 3.36 lb and a dry weight of 2.32 lb: the specific gravity of the solid particles is 2.7. For this sample, determine the water content, void ratio, porosity and total unit weight.

Solution

$$w = \frac{W_w}{W_s} \times 100\% = \frac{3.36 - 2.32}{2.32} = 44.9\% \approx 45\%$$

$$e = \frac{wG_s}{S} = \frac{0.45 \times 2.7}{1} = 1.215$$

$$n = \frac{e}{1+e} = \frac{1.215}{1+1.215} = 0.548 \text{ or } 54.8\%$$

$$\gamma_t = \frac{\gamma_w (G_s + e)}{1+e} = \frac{62.4(2.7+1.215)}{1+1.215} = 110.3 \text{ lb/ft}^3$$

A soil sample in its natural state has, when fully saturated, a water content of 32.5%. Determine the void ratio, dry and total unit weights. Calculate the total weight of water required to saturate a soil mass of volume 10 m^3. Assume $G_s = 2.69$.

Solution

Void ratio (Eq. 3.14a)

$$e = \frac{wG_s}{S} = \frac{32.5 \times 2.69}{(1) \times 100} = 0.874$$

Total unit weight (Eq. 3.15a)

$$\gamma_t = \frac{G_s \gamma_w (1+w)}{1+e} = \frac{2.69\ (9.81)\ (1+0.325)}{1+0.874} = 18.7\ \text{kN/m}^3$$

Dry unit weight (Eq. 3.18a)

$$\gamma_d = \frac{\gamma_w G_s}{1+e} = \frac{2.69 \times 9.81}{1+0.874} = 14.08\ \text{kN/m}^3$$

From Eq. (3.6a), $W = \gamma_t V = 18.66 \times 10 = 186.6$ kN

From Eq. (3.7a), $W_s = \gamma_d V = 14.08 \times 10 = 140.8$ kN

Weight of water = $W - W_s = 186.6 - 140.8 = 45.8$ kN

5. Suggested works

1.Please try to find the standard and read it.

ASTM:

Remember where you can find useful references!!

2. Please go over examples in **TEXT books.**