Introduction to Soil Mechanics

Courtesy of Hong Kong Geological Survey

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. (1998). ***Principles of Geotechnical Engineering*****, 4th edition, PWS Publishing Company.**

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

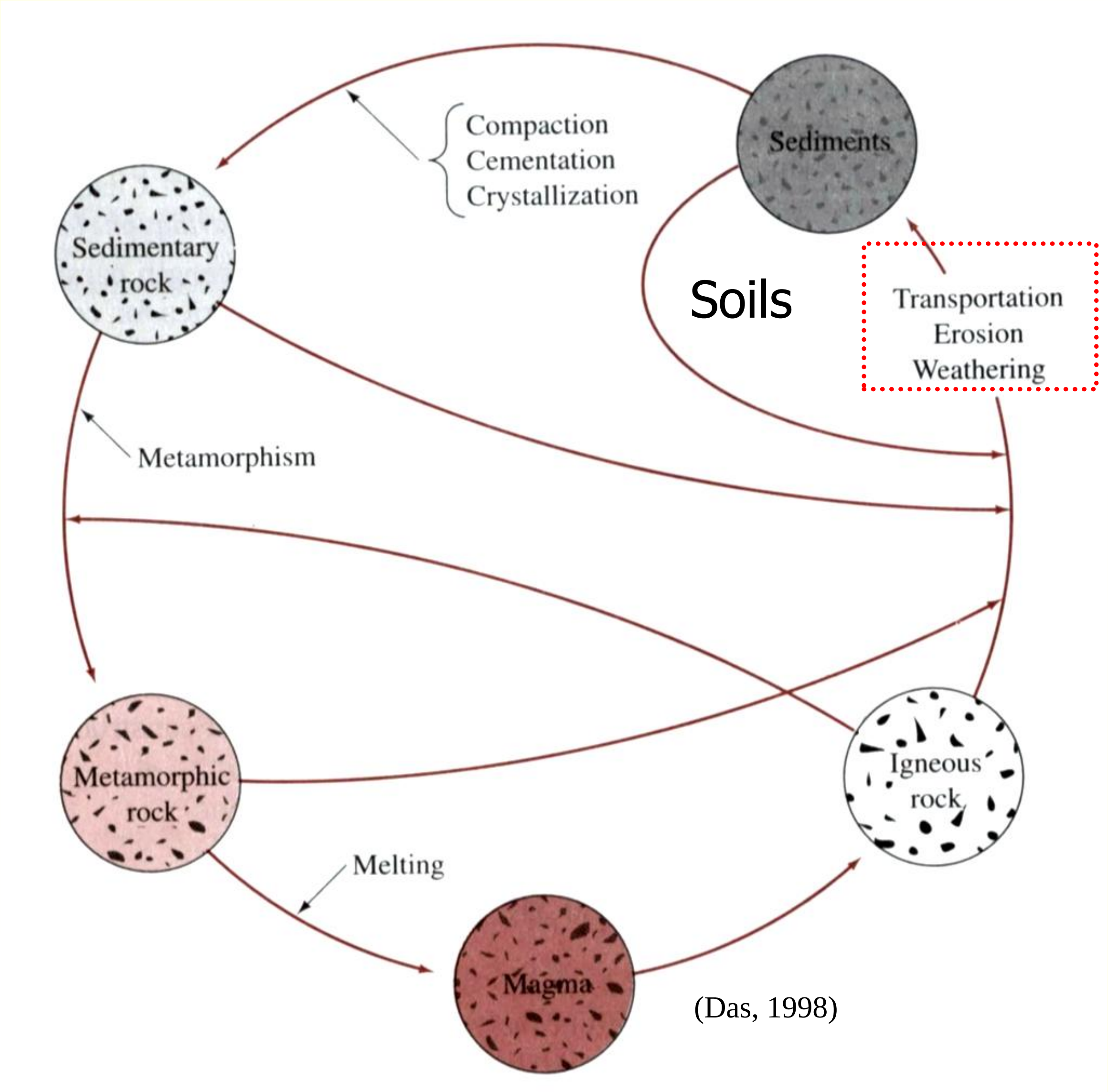
I. Soil Formations

Outline of the First Topic

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

1. Soil Formations and Deposits

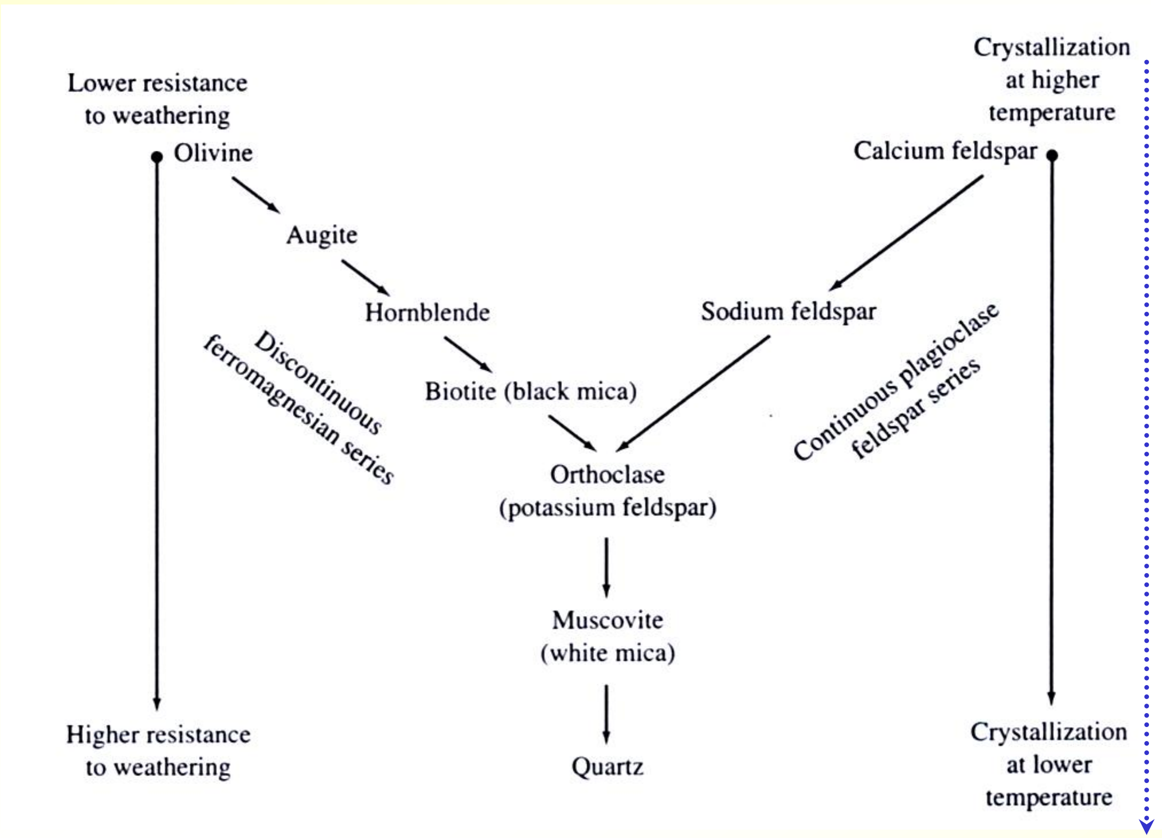
1.1 Rock Cycles



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

1.2 Bowen's Reaction Series

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



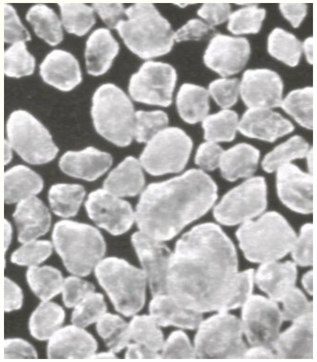
Mineral		Composition
Olivine		$(Mg, Fe)_2SiO_4$
Augite		$Ca, Na(Mg, Fe, Al)(Al, Si_2O_6)$
Hornblende		Complex ferromagnesian silicate of Ca, Na, Mg, Ti, and Al
Biotite (black mica)		$K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$
Plagioclase	calcium feldspar	$Ca(Al_2Si_2O_8)$
	sodium feldspar	$Na(AlSi_3O_8)$
Orthoclase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

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

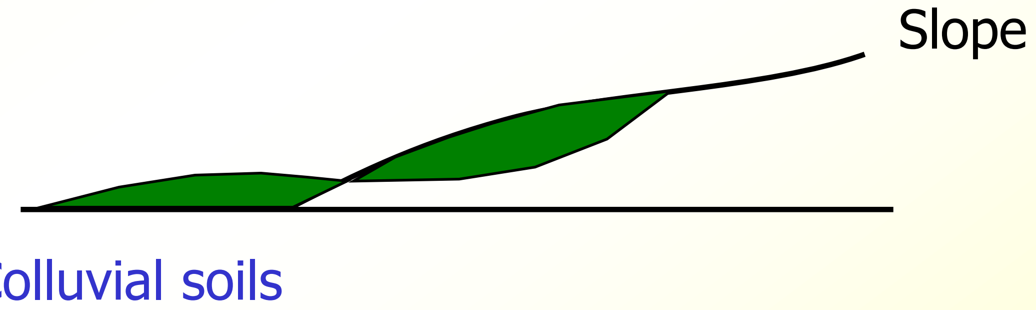
(4) **Marine soils**: formed by deposition in the seas (Hong Kong, Singapore, Taiwan, Japan).

(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)

Colluvial soils

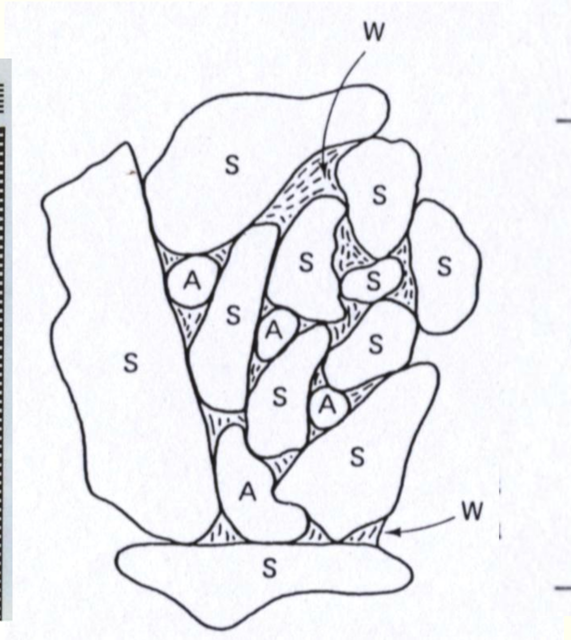
The colluvial soils mainly originate from the landslide and they are usually poorly consolidated.

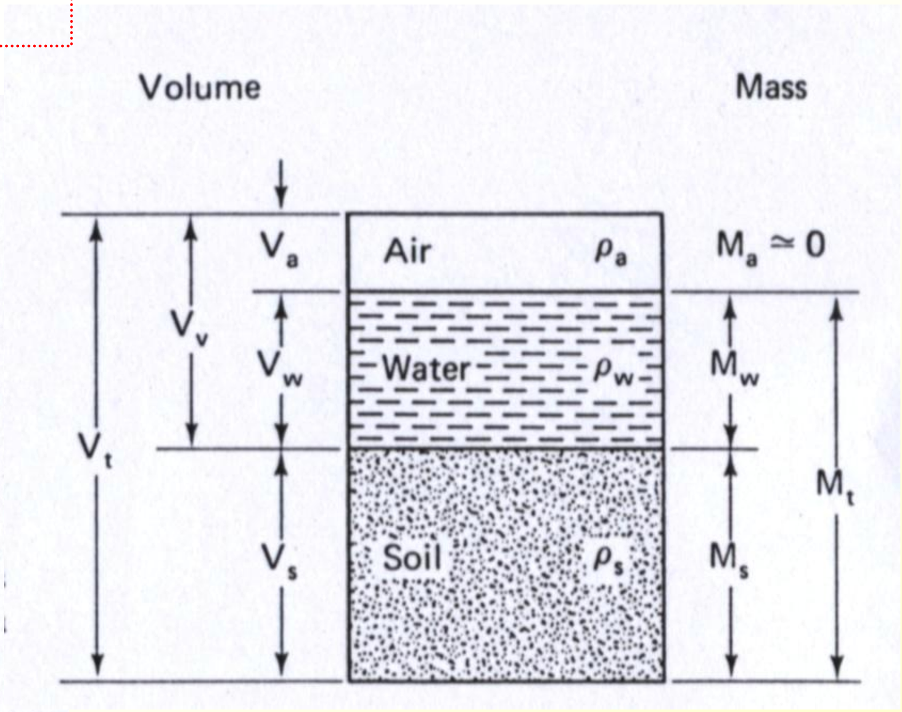


2. Phase Relations

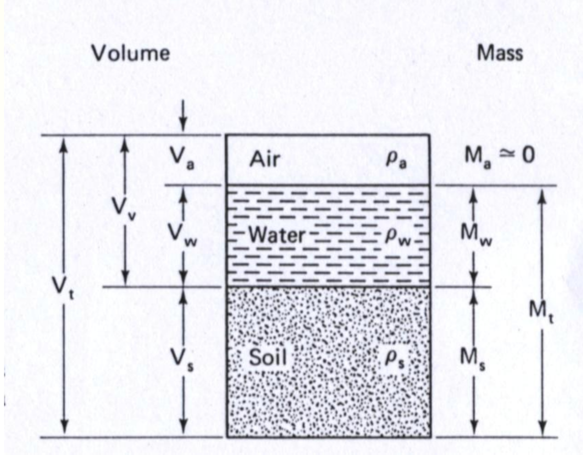
2.1 Three Phases in Soils

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





2.2 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%)**

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

2.2.1 Engineering Applications (e)

Typical values

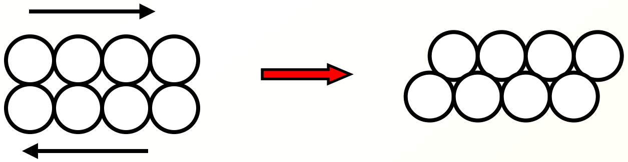
Description	Void Ratio e_{max}	Void Ratio e_{min}	Porosity (%) n_{max}	Porosity (%) n_{min}	Dry Unit Weight (kN/m³) $\gamma_{d\,min}$	Dry Unit Weight (kN/m³) $\gamma_{d\,max}$
Uniform spheres	0.92	0.35	47.6	26.0	—	—
Standard Ottawa sand	0.80	0.50	44	33	14.5	17.3
Clean uniform sand	1.0	0.40	50	29	13.0	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

After B. K. Hough, *Basic Soils Engineering*. Copyright © 1957, The Ronald Press Company, New York.

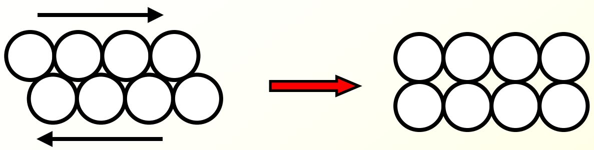
(Lambe and Whitman, 1979)

Engineering applications:

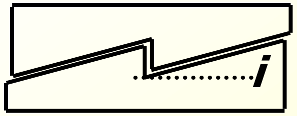
Simple cubic (SC), e = 0.91, ***Contract***



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



- Volume change tendency
- Strength

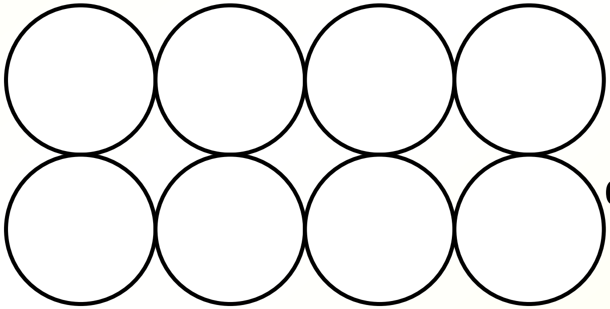


Link: the strength of rock joint

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

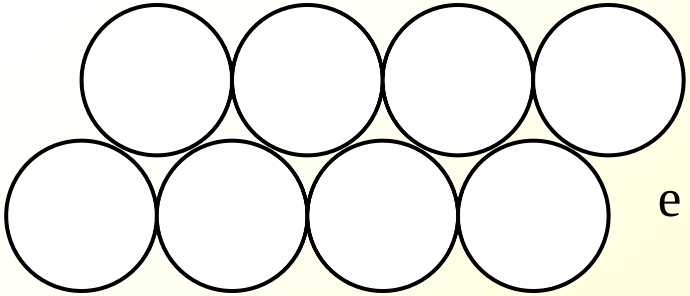
2.2.1 Engineering Implications (e)(Cont.)

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



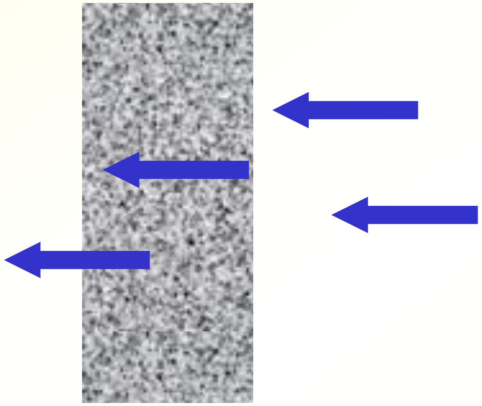
SC

e = 0.91



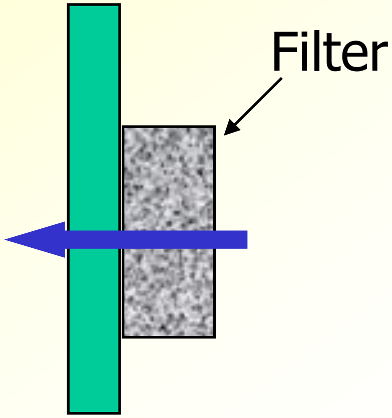
CT

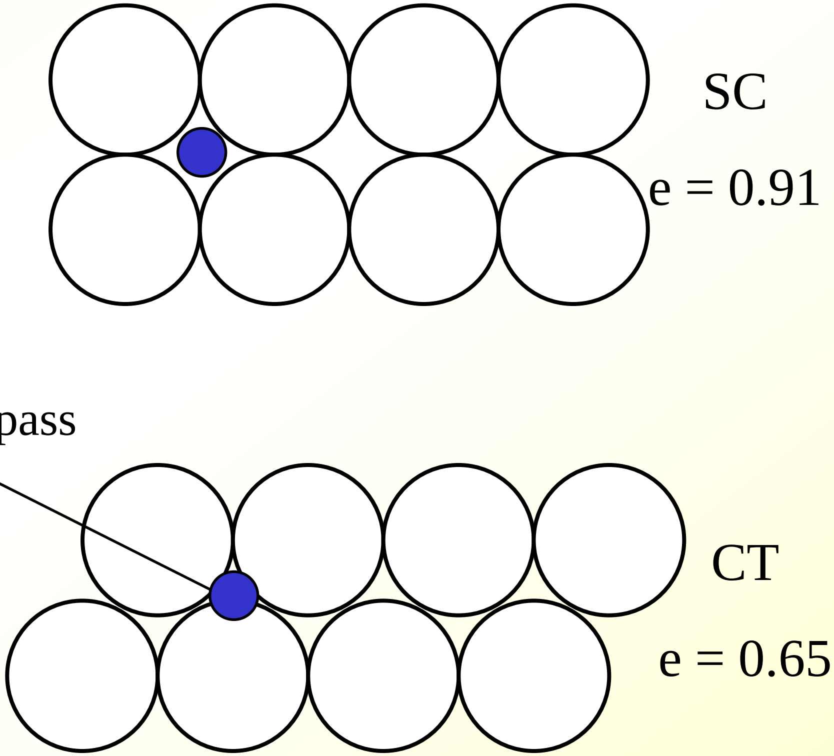
e = 0.65



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

2.2.1 Engineering Applications (e)(Cont.)





- Clogging

The finer particle cannot pass through the void

- Critical state soil mechanics

2.2.2 Engineering Applications (S)

Completely dry soil S = 0 %

Completely saturated soil S = 100%

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

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

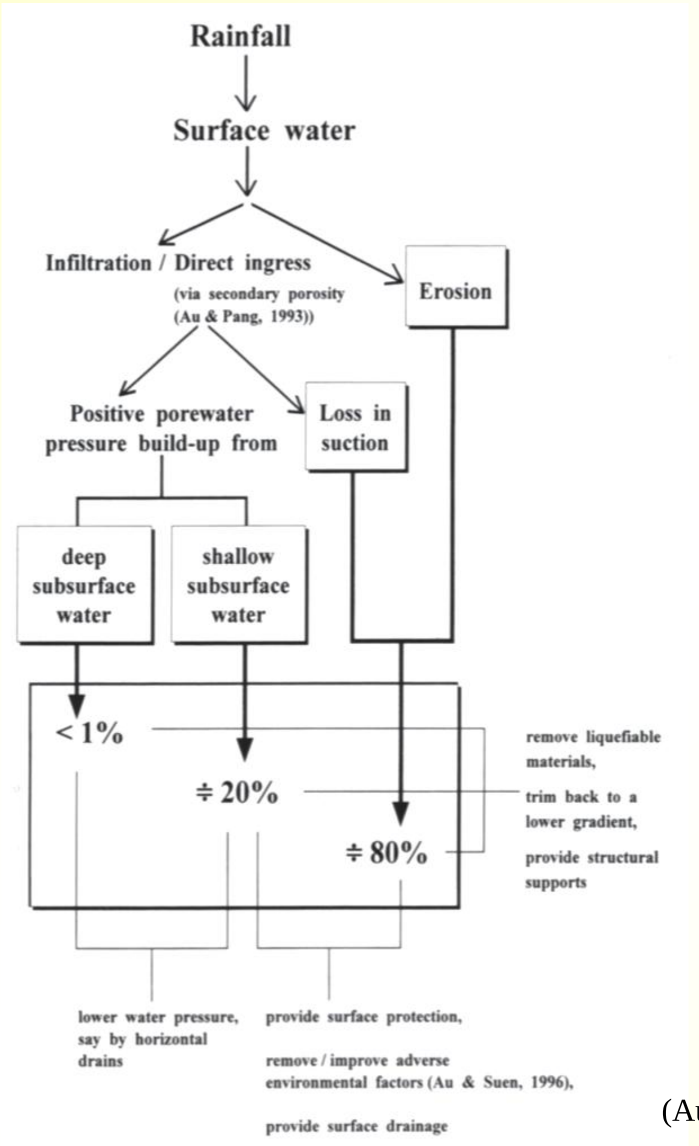
Demonstration:

Effects of capillary forces

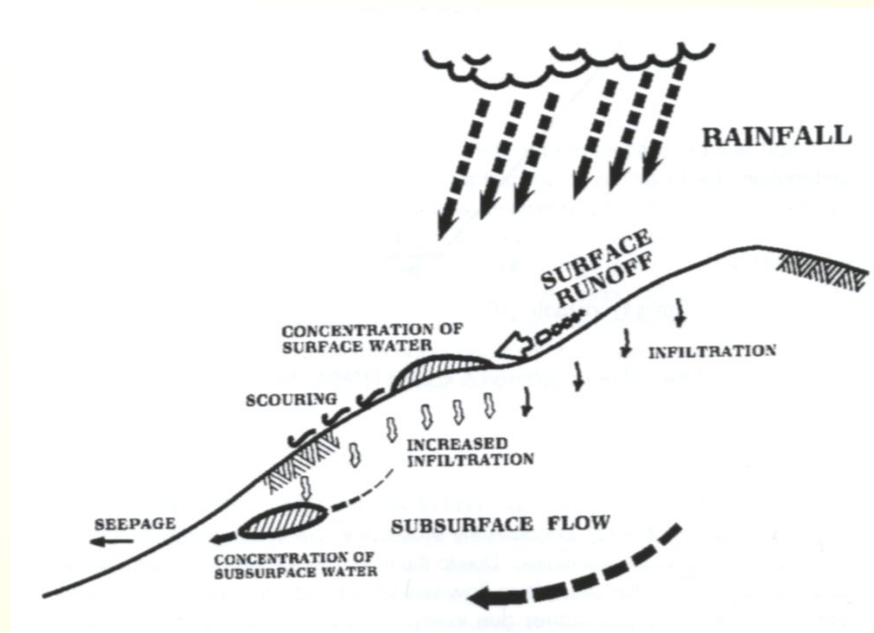
Engineering implications:

- Slope stability
- Underground excavation

2.2.2 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)

2.3 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.
- 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)
- The unit weight is frequently used than the density is (e.g. in calculating the overburden pressure).

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

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

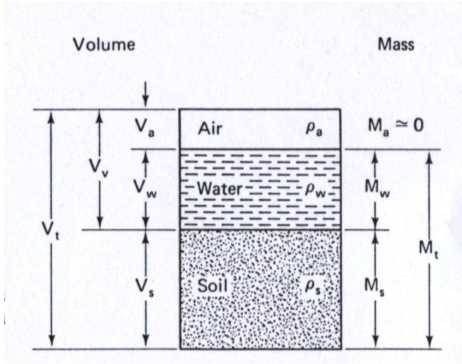
g : acceleration due to gravity

$$\gamma = \rho \cdot g = \rho \cdot 9.8 \, {}^{\text{m}}\!/\!{}_{\text{sec}^2}$$

$$\text{Water, } \gamma = 9.8 \, {}^{\text{kN}}\!/\!{}_{\text{m}^3}$$

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

2.4 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)

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

2.4 Weight Relationships (Cont.)

Submerged unit weight:

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

Consider the buoyant force acting on the soil solids:

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

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

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

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

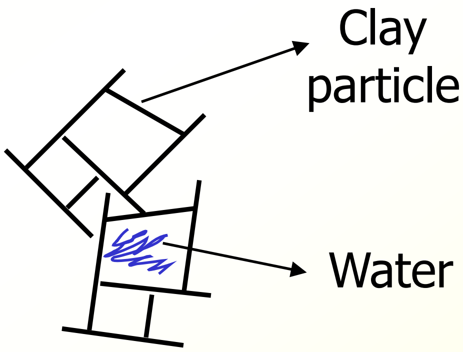
Archimede's principle:

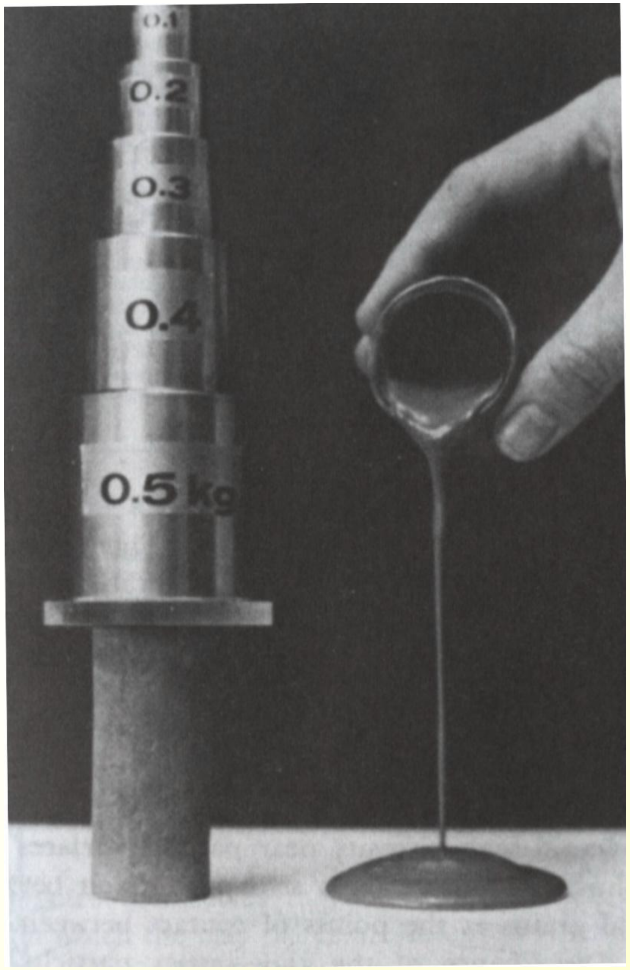
The buoyant force on a body immersed in a fluid is equal to the weight of the fluid displaced by that object.

2.4.1 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

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

3.1 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

3.2 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.

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

3.2 Alternatives (Cont.)

- If the particle density is likely to be changed owing to dehydration at 100ºC, a lower drying temperature (e.g. 80 ºC) 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 ºC or at relative humidity RH $\leq$ 50 %)(Irfan, 1996).

3.3 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.

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

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

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

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

P is the weight fraction

5. Suggested Homework

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

ASTM:

Call number TA401, A653 1997

(reference area)

Remember where you can find useful references!!

2. Please go over example 2-2 to 2-6 in your notes.

There will be some similar questions in the final exam.

6. References

Main References:

Das, B.M. (1998). *Principles of Geotechnical Engineering*, 4th edition, PWS Publishing Company. (Chapter 2)

Holtz, R.D. and Kovacs, W.D. (1981). *An Introduction to Geotechnical Engineering*, Prentice Hall. (Chapter 2)

Others:

Geological Landscapes of Hong Kong, Hong Kong Geological Survey.

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Head, K. H. (1992). *Manual of Soil Laboratory Testing, Volume 1: Soil Classification and Compaction Test*, 2nd edition, John Wiley and Sons.

Ifran, T. Y. (1996). Mineralogy, Fabric Properties and Classification of Weathered Granites in Hong Kong, *Quarterly Journal of Engineering Geology*, vol. 29, pp. 5-35.

Irfan, T.Y. (1999). Characterization of Weathered Volcanic Rocks in Hong Kong, *Quarterly Journal of Engineering Geology*, vol. 32, pp. 317-348.

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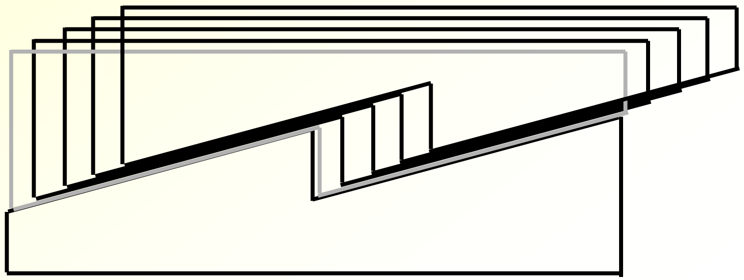
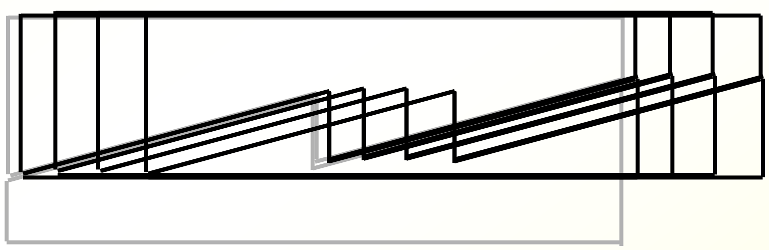
Shear Strength of Rock Joints



Low normal force

Dilate



High normal force

Shear off