Physical Properties of Soils

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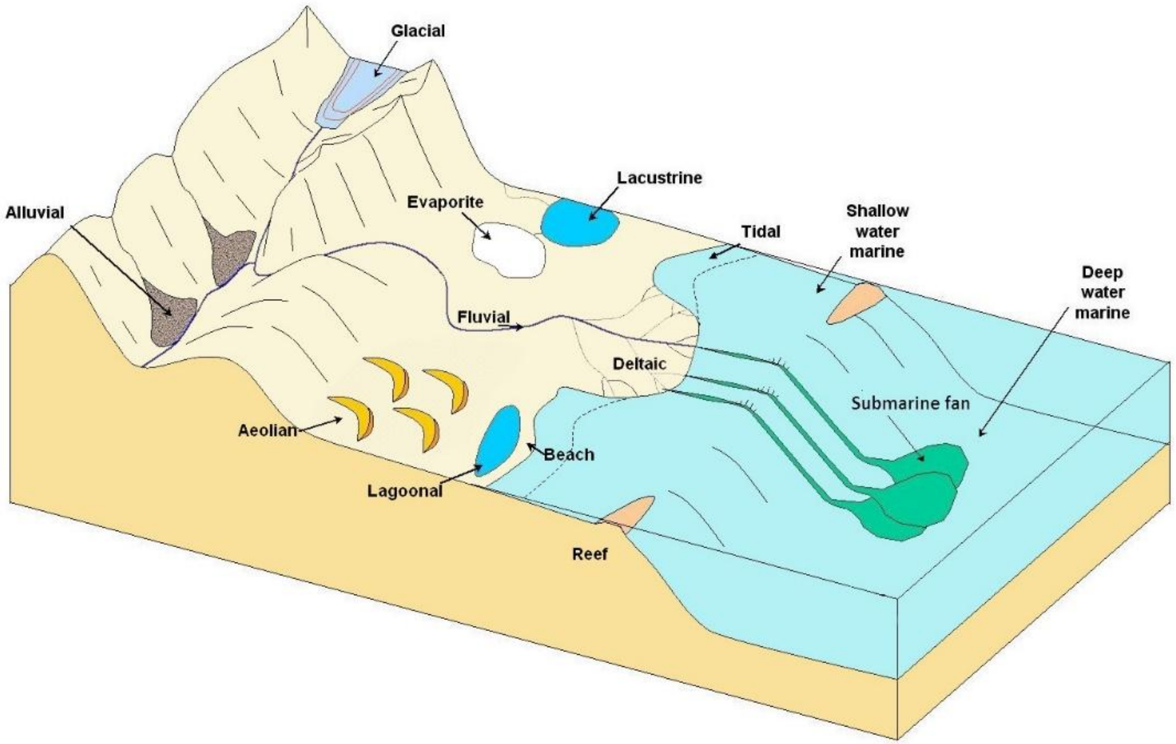
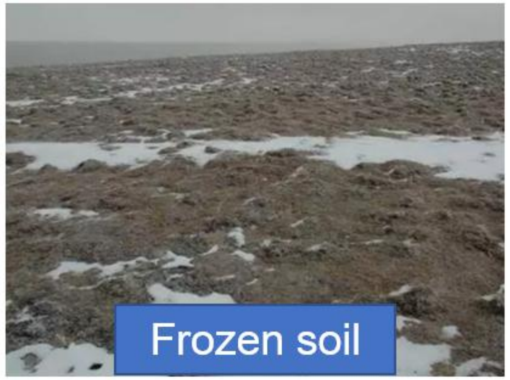
- Formation of soils
- Constitution of soils
- Structure of soils
- Physical property indices of sols
- Relative density, consistency and compaction

Formation of soils

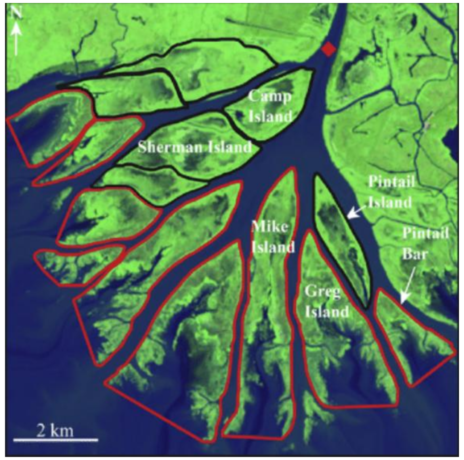


Various deposition environmental



Types of soil in different deposition environments

Formation of soils



Water deposited soil: The flowing water is capable of displacing particle. The size of particles ranges from boulders to clay. The carrying capacity highly depends on the velocity of the moving water, which means coarser particles are dropped when water velocity decreases, which usually occurs as the river deepens, widens, or changes direction. Fine particles still remain in suspension and get deposited in quieter waters downstream.

Formation of soils

Wind transported soil: The transportation process by wind is almost the same as that of by water except that it occurs in arid regions. This kind of soil has low density and is highly compressible. Loess is typical wind transported soil.

Formation of soils

Glacier deposited soil: The extremely slow moving glacier on earth also has the capacity to carry soils of various sizes ranging from clay to boulders. When the glacier melts, large volume particles deposit. Normally, this kind of deposit possess high shear strength.

Formation of soils

Gravity deposited soil the soil can be move under the action of gravity or short-term water flow (rainfall, melting of snow or ice). Particles can be moved only a very small distance in this case. Deposit at the toe of the slop is a typical gravity deposited soil, which is the mixture of particles with distinctive variation size and accordingly the strength is uniform.

Constitution of soils

- Solid phase
  - Inorganic matters
  - Organic matters
- Liquid phase
  - Adsorbed water
  - Free water
- Gaseous phase
  - Free air
  - Entrapped air

Constitution of soils – solid phase

Inorganic components come from the weathering of various rock types. The particle size range in size from tiny colloids (< 2μm) to large gravels (>2mm) and rocks. Inorganic components mainly consist of 2 minerals, primary and secondary. Inorganic components usually control soil properties and its suitability as a plant growth medium.

Organic particles are the result of both plants and animals. Although the content of organic particles are small relative to the inorganic component, they can significantly alter soil properties.

Constitution of soils – solid phase

Minerals

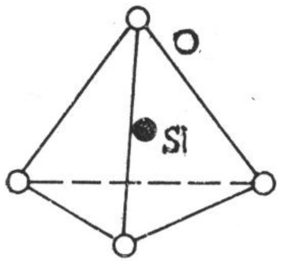
Primary minerals: pieces usually broken from parent rock (**physical weathering**); relatively large (>0.002mm in diameter); cohesionless; angular or rounded in shape; weak water adsorption capacity; no plasticity. **The representative are quartz, feldspar, mica.**

Secondary minerals: **chemical weathering of primary minerals**. Relative small (<0.002mm in diameter); commonly in flat shape, unstable; high water adsorption capacity; swell; with plasticity. The representative are kaolinite, Montmorillonite, illite

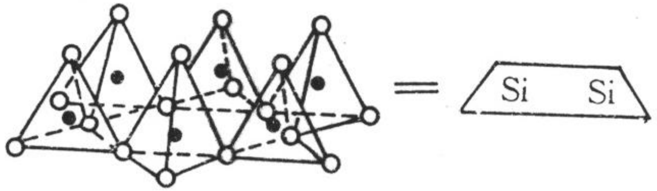
Constitution of soils – solid phase

The major second minerals in soils are clay minerals. The higher content of clay minerals, the more complex of the soil properties.

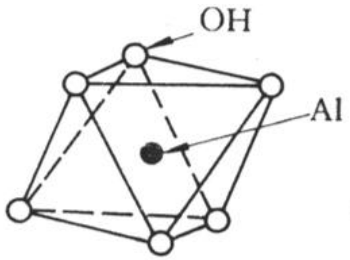
Clay minerals are fundamentally built of tetrahedral silicate sheet and octahedral hydroxide sheet, which are the periodically arrangement of tetrahedral silicate and octahedral hydroxide in space



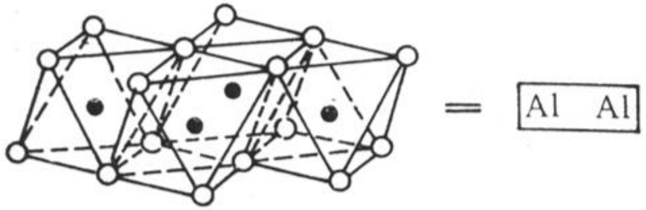
Tetrahedral silicate



Tetrahedral silicate sheet

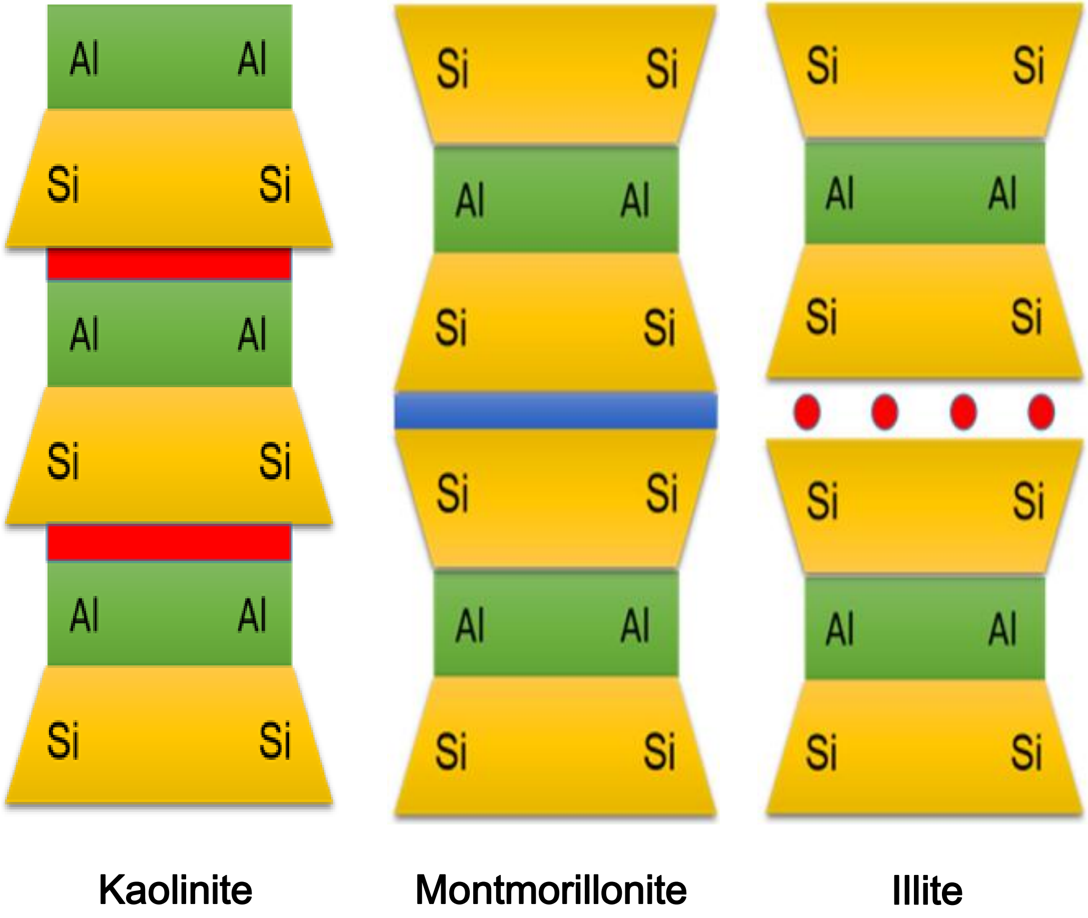


Octahedral hydroxide



Octahedral hydroxide sheet

Constitution of soils – solid phase

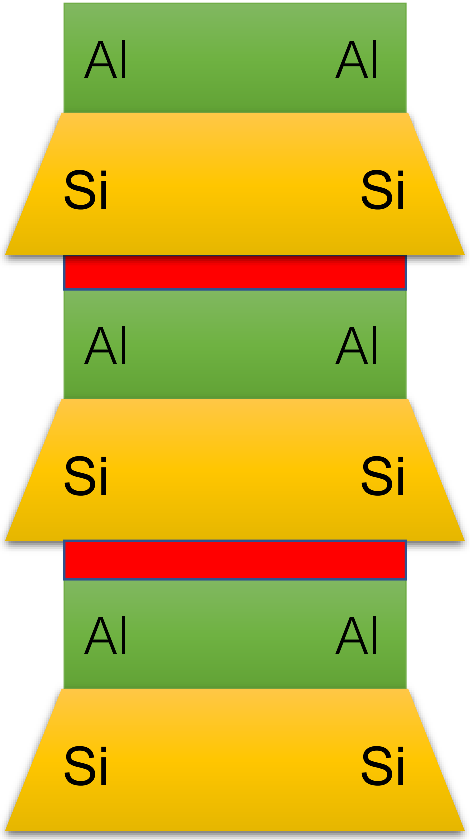


Clay minerals are distinctive to each other according to the number and sequence of tetrahedral silicate sheet and octahedral hydroxide sheet (1:1, 2:1) , as well as the interlayer bonds (hydrogen bonds, Van der Waals force potassium ions).

Constitution of soils – solid phase

Kaolinite

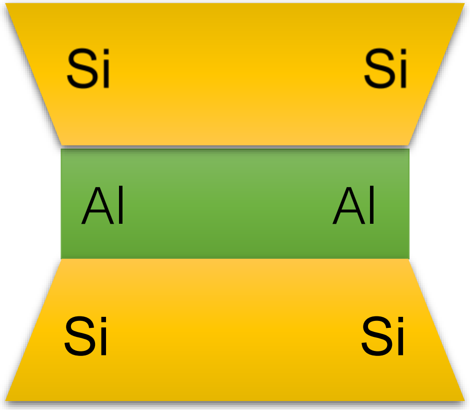
- Basic unit (1:1): one tetrahedron silicate sheet plus one octahedral hydroxide sheet
- Basic units are tied together by **hydrogen bonds,** which has high strength. Crystal lattice can not freely slide, which hinders the penetration of water
- A particle of kaolinite normally consists of hundreds of stacks, which measures 1.0 micron in diameter and 0.05 micron thick
- Large particle, no expansion and contraction after water adsorption

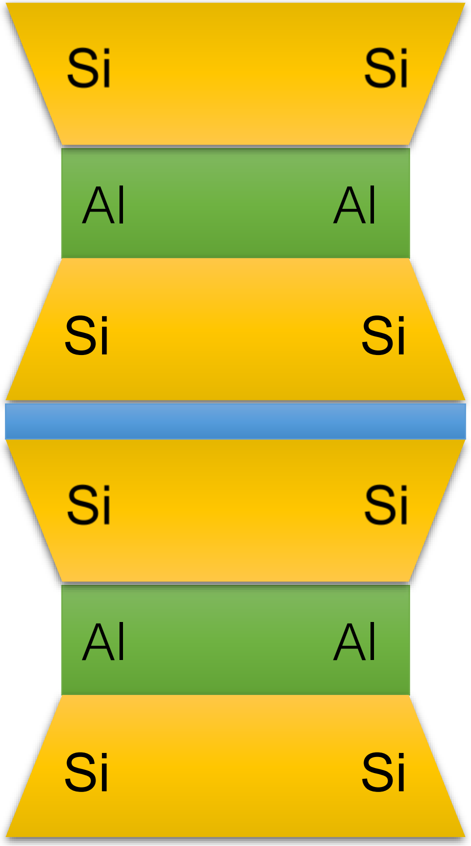


Constitution of soils – solid phase

Montmorillonite

- Basic unit (2:1): two tetrahedron silicate sheets plus one octahedral hydroxide sheet
- Basic units are tied together by **Van der Waals force**, which has low strength. Water can easily access
- A particle of montmorillonite normally has several stacks, which measures 0.1~1.0 micron in diameter and 0.001~0.01 micron thick
- Small particle, expansion and contraction after water adsorption

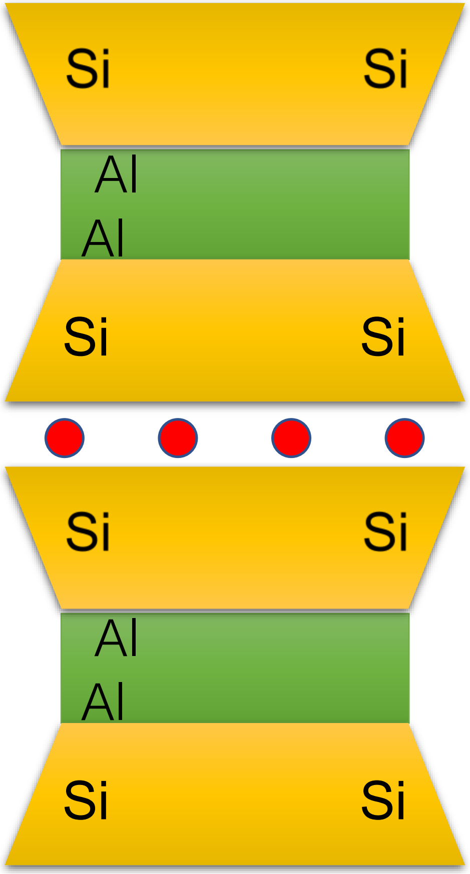


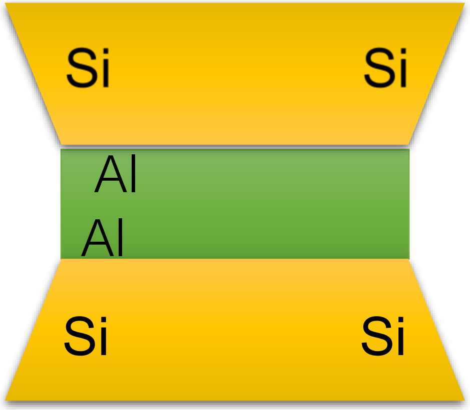


Constitution of soils – solid phase

Illite

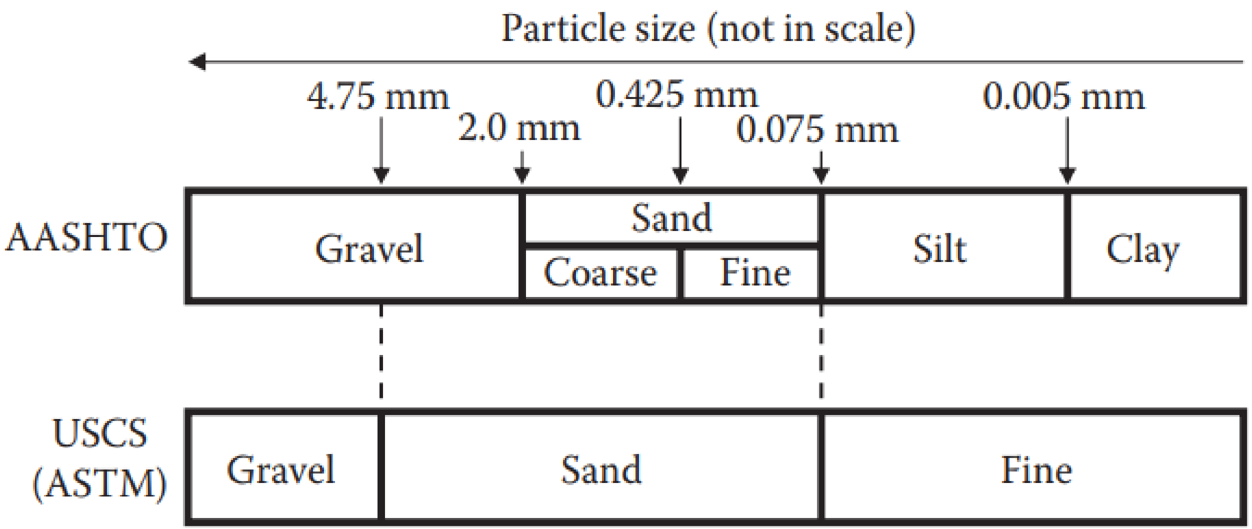
- Basic unit (2:1): two tetrahedron silicate sheets plus one octahedral hydroxide sheet
- Basic units are tied together by potassium ions (K^+), whose strength is larger than Van der Waals force, but smaller than hydrogen bond.
- The characteristics fall in between kaolinite and montmorillonite





Constitution of soils – solid phase

Soils are classified according to **equivalent particle diameter (D)**. Different codes may have different definitions.



AASHTO and USCS codes

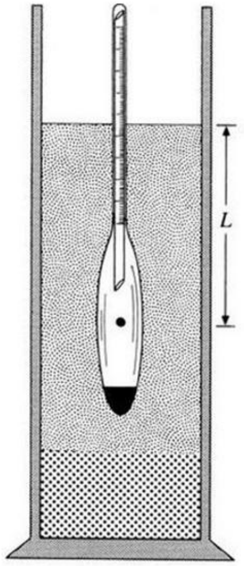
General grain grade	Grain grade		Nominal diameter (mm)
Giant-grained soil	Boulder		d > 200
	Cobble		200 ≥ d > 60
Coarse-grained soil	Gravel	Coarse	60 ≥ d > 20
		Medium	20 ≥ d > 5
		Fine	5 ≥ d > 2
	Sand	Coarse	2 ≥ d > 0.5
		Medium	0.5 ≥ d > 0.25
		Fine	0.25 ≥ d > 0.075
Fine-grained soil	Silt		0.075 ≥ d > 0.005
	Clay		d ≤ 0.005

Chinese code

Constitution of soils – solid phase

Particle size analysis: sieve analysis method (D>0.075mm) and sedimentation analysis method (D<0.075mm)

Sieve shaker for sieve analysis



$$D = \sqrt{\frac{18\eta}{g(\rho_s - \rho_L)} \frac{L}{t}}$$

Hydrometer for sedimentation analysis

Constitution of soils – solid phase

Sieve shaker for sieve analysis

Procedures for sieve analysis (D>0.075mm)

1. Take a representative oven-dried sample that weighs approximately 500g.
2. If particles are lumped or conglomerated, crush the lumps but not the particles using the pestle and mortar.
3. Determine the mass of sample accurately.
4. Prepare a stack of test sieves. The sieves are stacked in order, with the largest aperture size at the top, and the smallest at the bottom. A pan is placed under all of the sieves to collect samples.
5. Weigh all the sieves and the pan separately
6. Pour the soil samples to the top sieve and switch on the sieve shaker. The shaking time needs to be 8~10 minutes.
7. Determine the mass of soil retained on each sieve and finish the corresponding table

Constitution of soils – solid phase

After the sieve analysis, the following table can be finished

Opening (mm)	Weight Retained (gf)	Weight Retained (%)	Cumulative Retained (%)	Percentage Finer
4.75	0	0.0	0.0	100
2.00	16.8	3.1	3.1	96.9
0.85	37.8	7.0	10.1	89.9
0.425	45.9	8.4	18.5	81.5
0.25	44.4	8.2	26.7	73.3
0.15	52.5	9.7	36.4	63.6
0.106	50.7	9.3	45.7	54.3
0.075	39.0	7.2	52.9	47.1
pan	255.6	47.1	100	0
summation	542.7	100		

Sedimentation analysis

Constitution of soils – solid phase

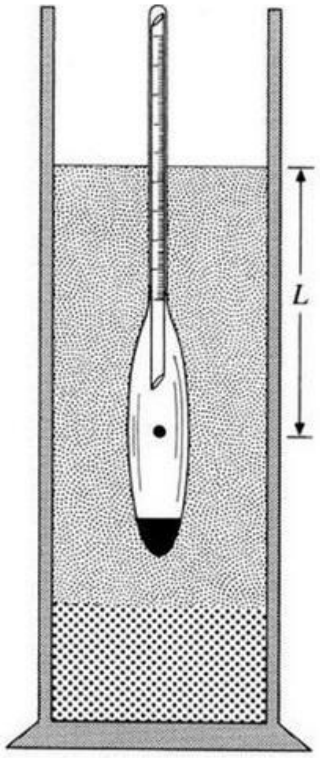
The soil specimen retained on pan（D<0.075） needs to be further analyzed by sedimentation analysis, which is based on Stoke's Law.

Stoke's Law states that the velocity of a particle falling through a fluid is proportional to the gravitational force (g), the difference between the density of the particle (ρ_s) and the density of the fluid (ρ_L), and the square of the effective particle diameter (D). Moreover, the velocity is also inversely proportional to the viscosity (η) of water as follows:

$$v = \frac{L}{t} = \frac{D^2 g\left(\rho_s - \rho_L\right)}{18\eta} \rightarrow D = \sqrt{\frac{18\eta}{g\left(\rho_s - \rho_L\right)}\frac{L}{t}}$$

Time (t) of settlement to the depth (L)

Constitution of soils – solid phase



$$D=\sqrt{\frac{18\eta}{g\left(\rho_s-\rho_L\right)}\frac{L}{t}}$$

Hydrometer for method of sedimentation

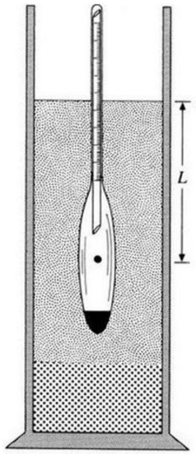
Procedures for method of sedimentation (D<0.075 mm)

1. The soil retained on the pan (W_s) is mixed with water thoroughly and placed in a flask. The volume of the suspension is V
2. At any time (t), the hydrometer is installed at certain depth (L). The equivalent particle diameter (D) can be calculated according to Stoke's Law
3. The mass percentage of soil (x%) with particle size small than (D) (percentage finer) can be calculated as

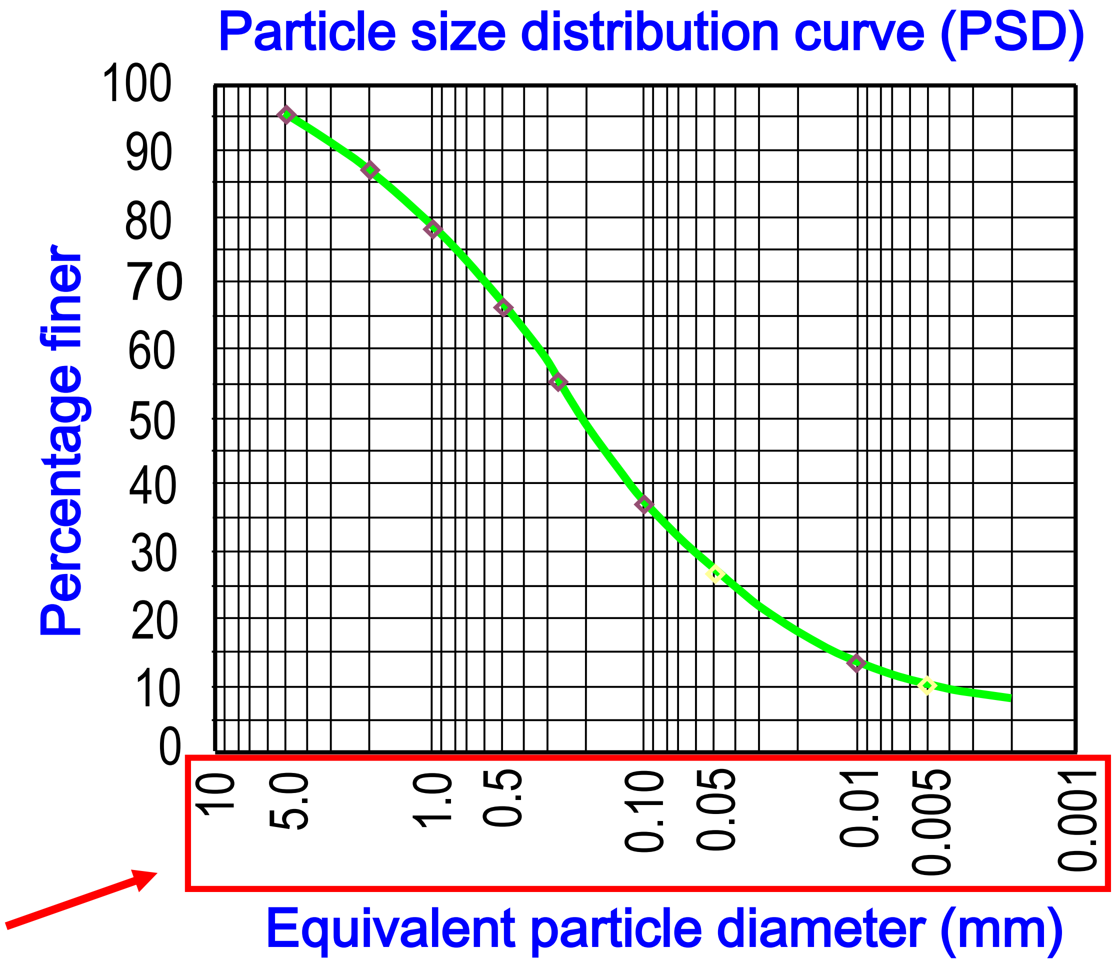
$$x(\%)=\frac{\rho_s}{\rho_s-\rho_L}\frac{V}{W_s}\left[\rho_{sut}-\rho_L\right]\times 100$$

Density of suspension by hydrometer

Constitution of soils – solid phase



$$D = \sqrt{\frac{18\eta}{g\rho_L\left(G_s - 1\right)}\frac{L}{t}}$$

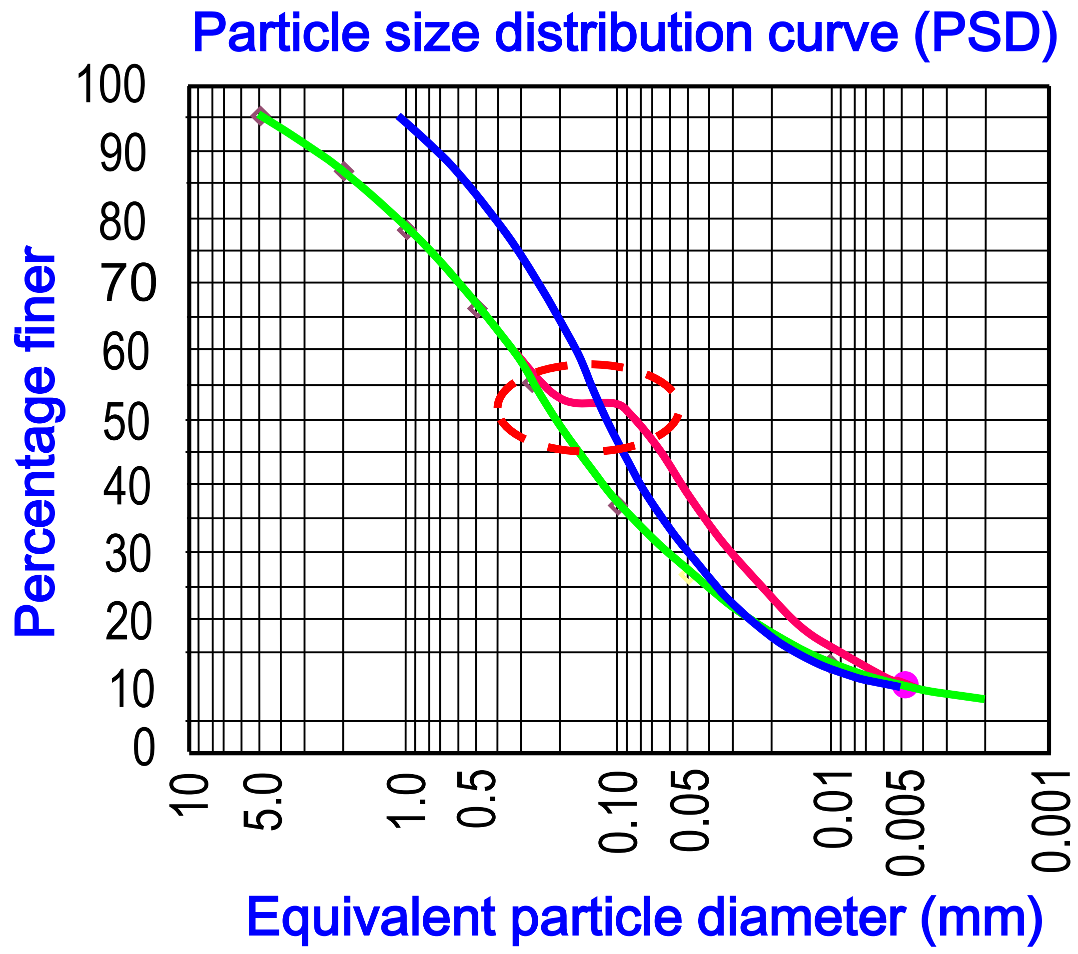


semilogarithmic

Constitution of soils – solid phase

Characteristics of PSD curve

- Steep slop (blue): concentrated distribution
- Gentle slop (green): Wide range distribution of particle size
- Platform (green): absence of certain particle size

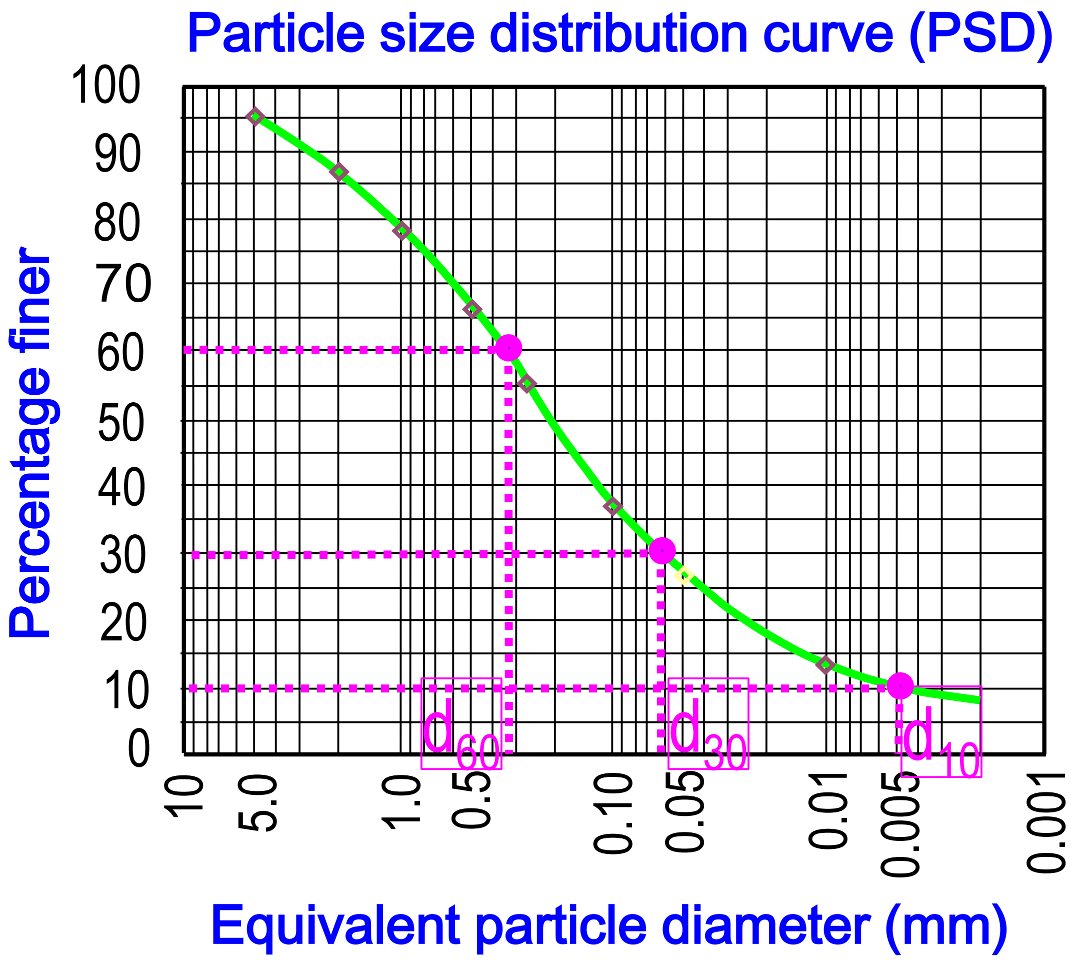


Constitution of soils – solid phase

Key nominal diameter

- d_{60} : diameter corresponding to **60% finer**
- d_{10}: diameter corresponding to **10% finer**
- d_{30} : diameter corresponding to **30% finer**

d_{60}	d_{10}	d_{30}
0.33	0.005	0.063



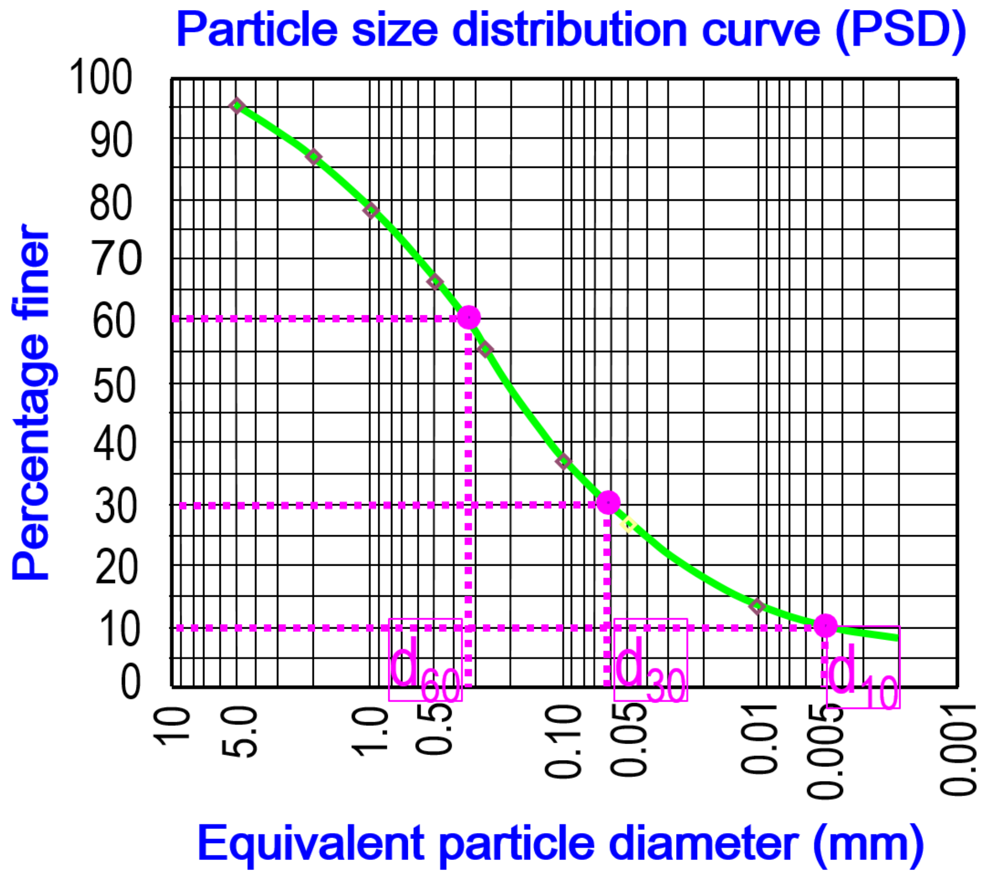
Constitution of soils – solid phase

Coefficient of uniformity

$$C_u = d_{60}/d_{10}$$

In Chinese code:

Cu<=5, soils are considered as uniformly graded (or poorly graded) soil, while for Cu>5, soils are considered well graded



Constitution of soils – solid phase

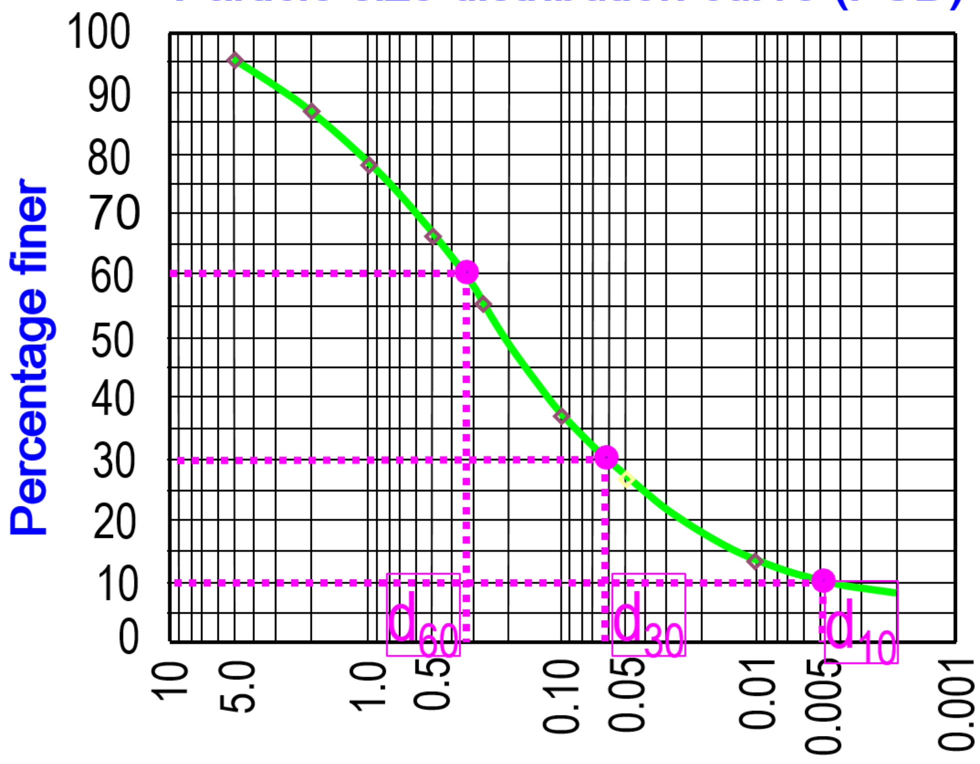
Coefficient of gradation (curvature)

$$C_c = d_{30}^{\ 2}/(d_{10} \times d_{60})$$

In Chinese code:

Cc<=1 or Cc >= 3, the soil sample is **gap-graded soil,** while for **1<Cc<3,** the soil sample is **well graded**

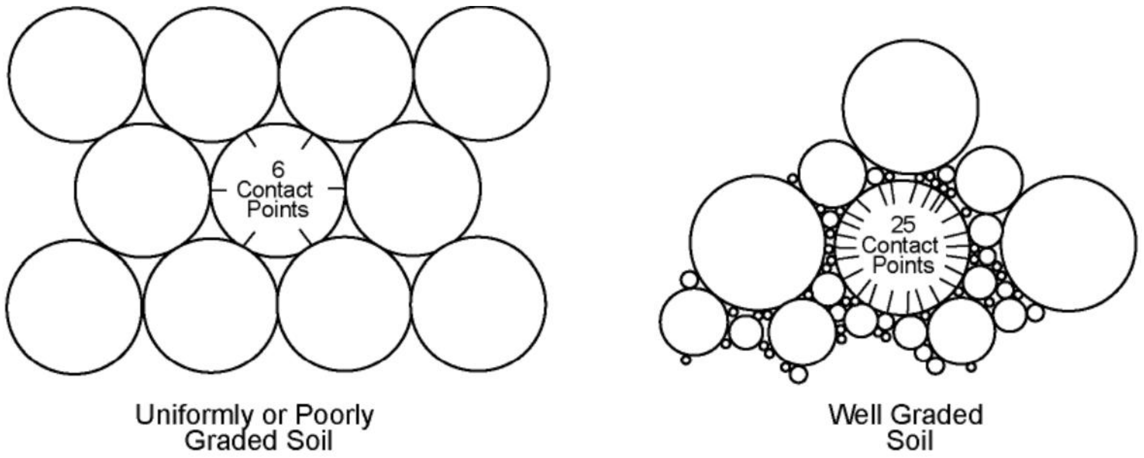
Particle size distribution curve (PSD)



Equivalent particle diameter (mm)

Constitution of soils – solid phase

The coefficient of uniformity (Cu) and the coefficient of gradation (Cc) affect the soil packing arrangement. Well-graded soils make more stable packing since finer particles fill voids made by larger particle assemblages. On the other hand, uniformly graded soils make rather ordinary arrangement of packing and thus less interlocking mechanisms. To evaluate soil gradation, both Cc and Cu are necessary.

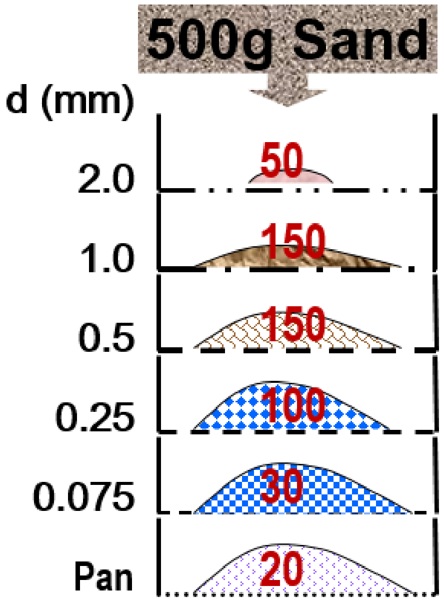


In Chinese code:

$Cu>=5$ and $1<Cc<3$, soils are considered as well graded, while others are considered as poor-graded.

Exercises

Determine the particle distribution curve according to the data of sieve analysis



Exercises

Table 1 shows a data set from a sieve analysis.

1) Complete the rest of Table 1

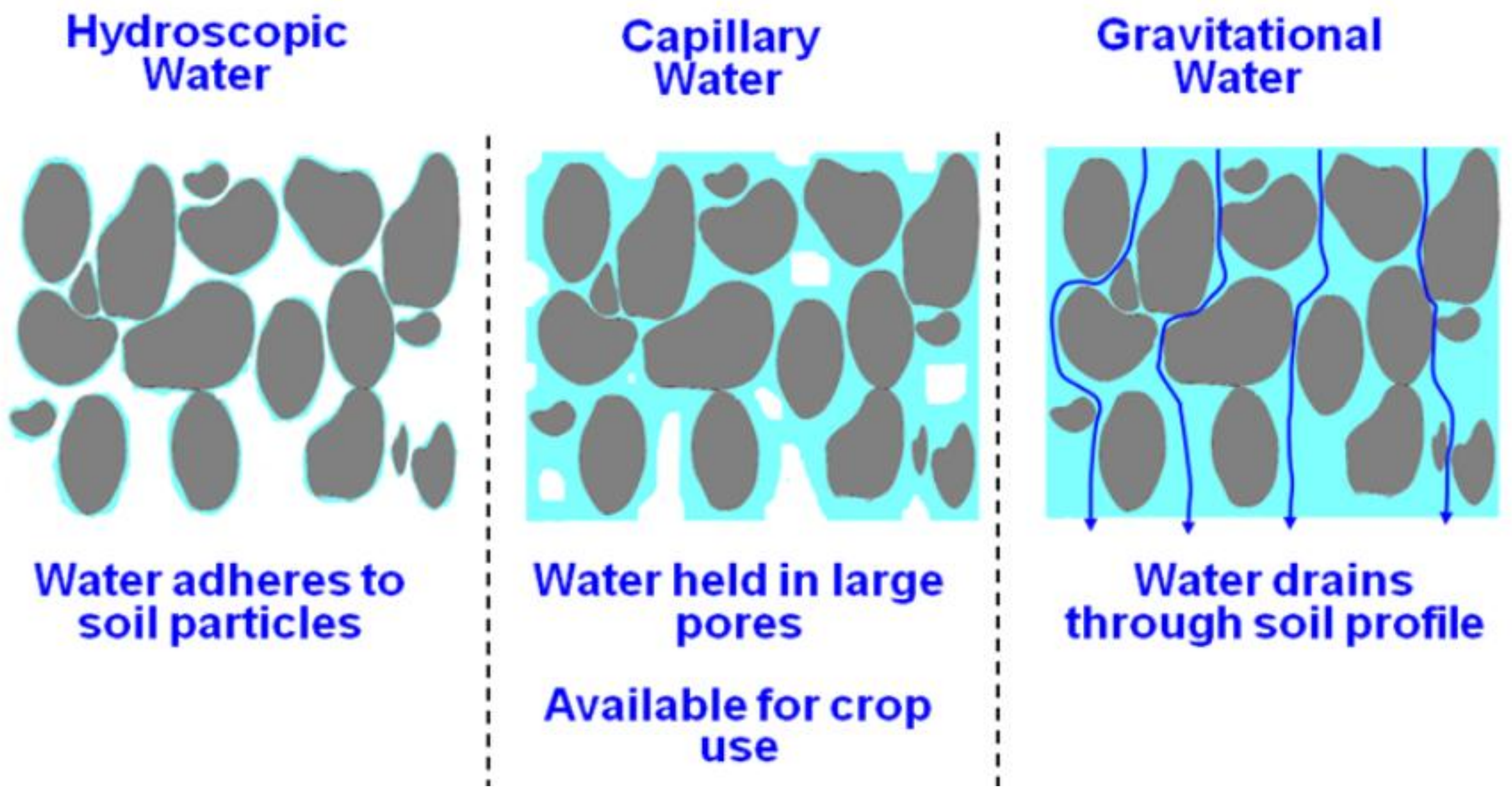
2) Plot the grain size distribution curve

3) Evaluate the gradation of the soil sample

Table 1 Data of sieve analysis

Sieve No.	Opening (mm)	Weight Retained (g)	Weight Retained (%)	Cumulative Retained (%)	Percentage Finer (%)
1	2.0	100			
2	1.0	100			
3	0.5	250			
4	0.25	300			
5	0.15	100			
6	0.075	50			
Pan	0	100			

Constitution of soil



Types of water in soils

Constitution of soil – liquid phase

Hydroscopic water

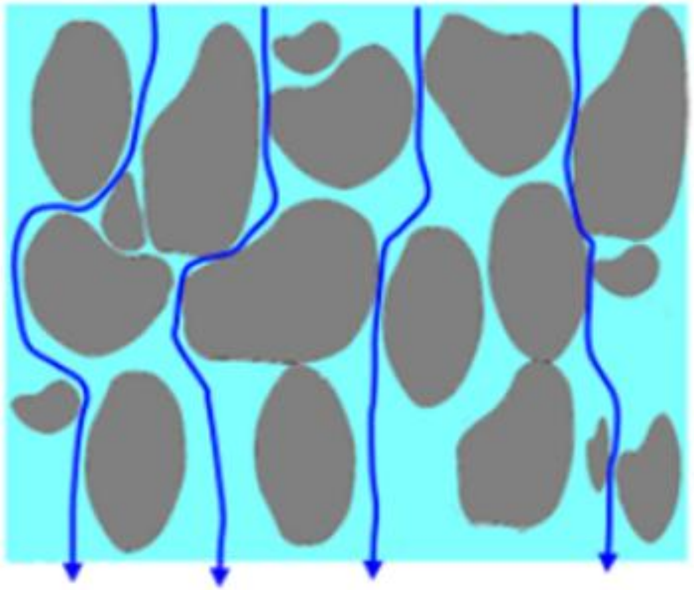
- It is the water which is absorbed by the particles of dry soil from the atmosphere and is held as a very thin film on the surface of the soil due to adhesion or attraction between the surface of particle and water molecules
- The adhesion or attraction is inversely proportionally to particle size
- In general, it is not available for the use of plants

Schematic diagram of hydroscopic water

Constitution of soil – liquid phase

Gravitational water

- This is a free form of water which is held loosely in soil. This water could be easily lost due to gravitational force.
- Water move through a soil in large pores
- Plants are not able to use this water as much as they move rapidly out of the soil

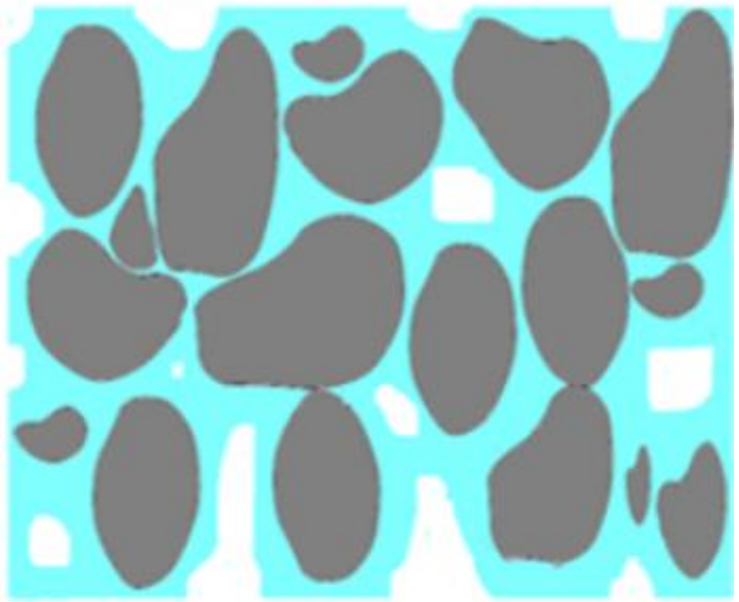


Schematic diagram of gravitational water

Constitution of soil – liquid phase

Capillary water

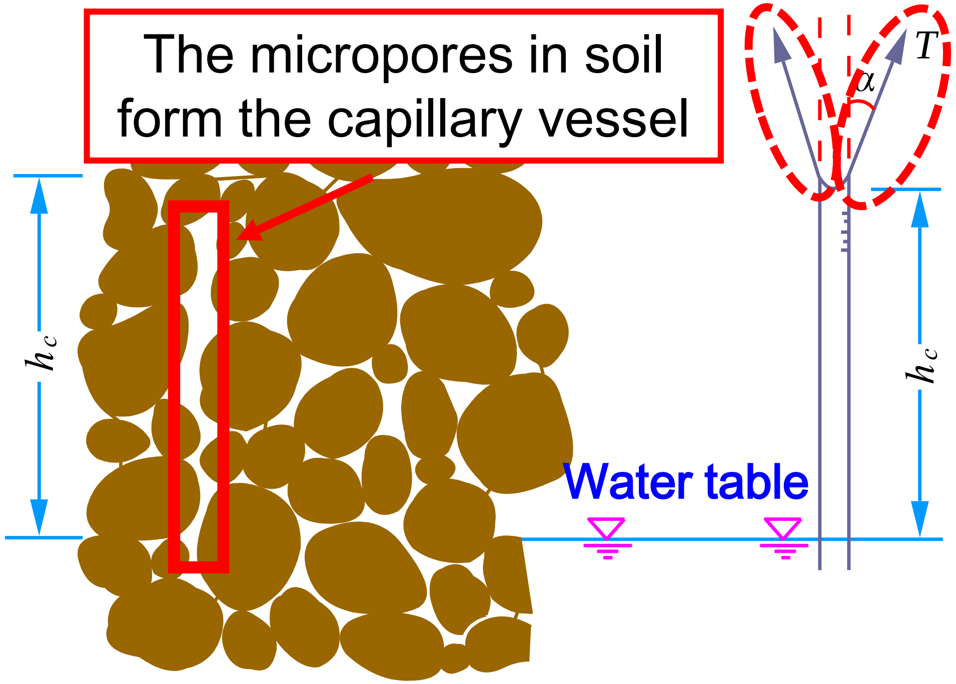
- This water is retained in the soil by capillary action (force) which is less than the atmospheric pressure.
- This water contains in the micropores of soils
- It is the main water available to plants



Schematic diagram of capillary water

Constitution of soil – liquid phase

Capillary action: the ability of a liquid to flow in narrow spaces without the assistance of external forces; rather, the liquid's movement is aided by intermolecular forces present in between the liquid and solid surface(s)



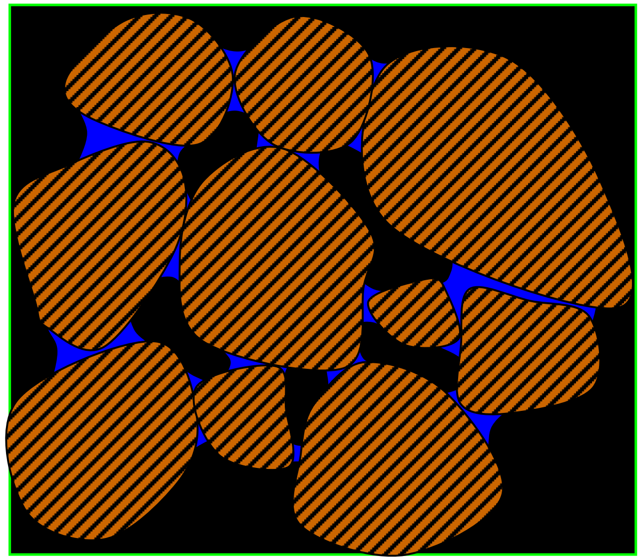
Height of capillary water

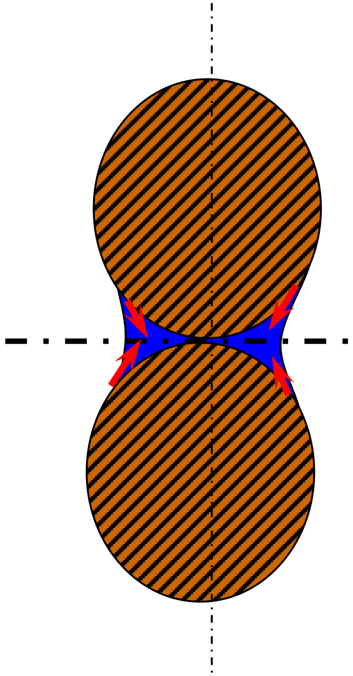
$$\pi r^2 h_c \gamma_w = 2\pi r T \cos\alpha$$

Clay > fine sand > coarse sand > gravel

Exercises

Why the sculpture could be built by wet sand ?

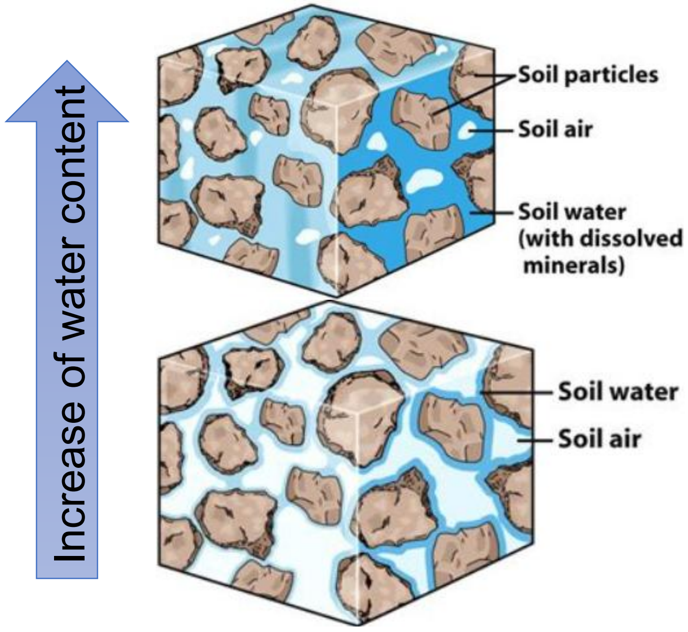




Capillary action gone with the water content increase !!!

Constitution of soil – gaseous phase

The gaseous phase plays an important role in plant growth and the activity of soil organisms. Soil pores are filled with air and water, and there is a dynamic equilibrium between water and air content within a soil. When water enters the soil, it displaces air from some of the pores; hence, the air content of a soil is inversely related to its water content.



Constitution of soil – gaseous phase

Characteristics of air in soils

- **The air in soils is not uniform throughout the soil** because there can be localized pockets of air
- **The relative humidity of soil air is close to 100%, unlike** most atmospheric humidity
- Air in soils often contains **several hundred times** more carbon dioxide.

Comparison between air in soil and in atmosphere

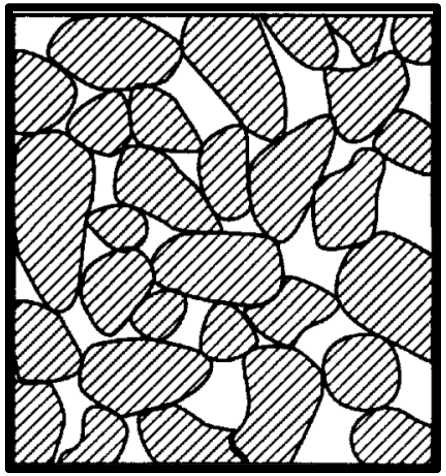
Component	Soil air (%)	Atmosphere (%)
N_2	79.2	79.0
O_2	20.6	20.9
CO_2	0.25	0.03

Source: Russel, E. J., and Appleyard, A. 1915. The atmosphere of the soil, its composition and causes of variation. *J. Agr. Sci.* 7:1–48.

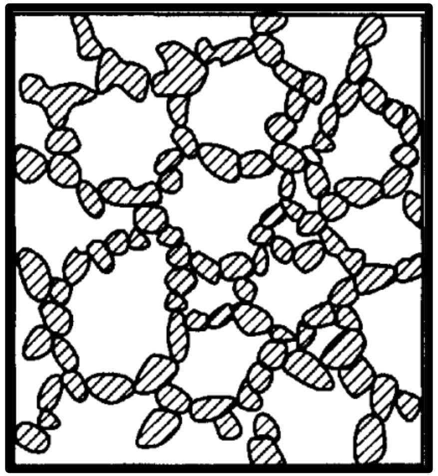
Structure of soil

Soil structure refers to the way soil particles grouped together to form the skeleton of soils. **Corse particles are susceptible to form single grain structure; while flocculent structure and honeycomb structure are formed by fine particles.**

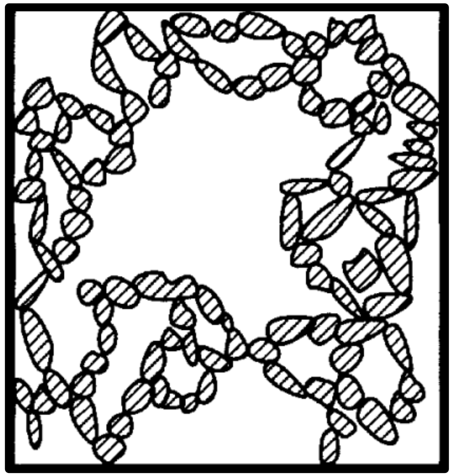
The structure of soils can be altered by external force. Honeycomb structure is formed by the disintegration of a flocculent structure under a superimposed load



Single grain structure



Flocculent structure



Honeycomb structure

Structure of soil

Thixotropy and sensitivity

When naturally formed clays are disturbed or remolded, their original clay structures will be destroyed and the strength is lost. The degree of recovery (**gain of strength**) with passage of time is called **thixotropy.**

Sensitivity (St) is defined as the clay's **shear strength** before remolding to that after remolding

$$S_t = \frac{q_u}{\bar{q}_u}$$

q_u: unconfined compressive strength of original soil

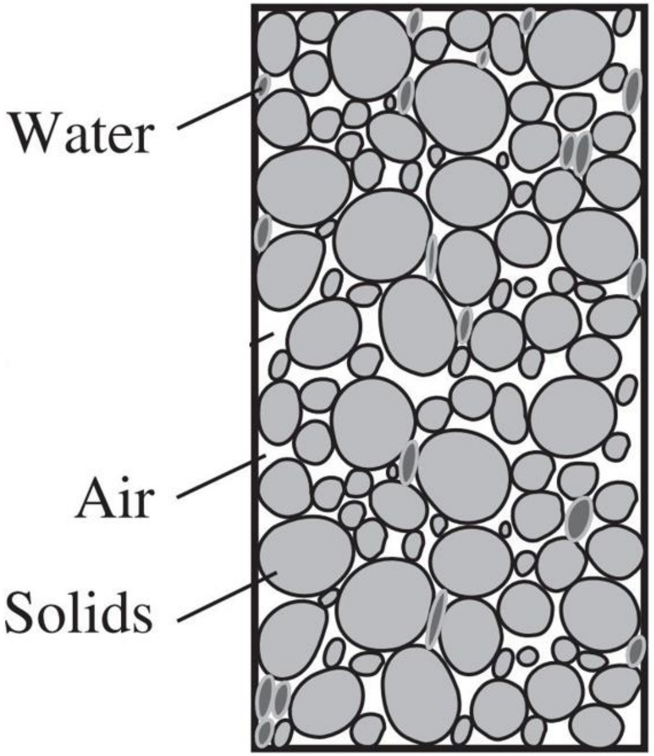
$\bar{q}_u$: unconfined compressive strength of remolded soil

S_t	Degree of sensitivity
<1	Insensitive
1-2	Low sensitivity
2-4	Medium sensitivity
4-8	With sensitivity
8-16	High sensitivity
>16	Flow

Exercises

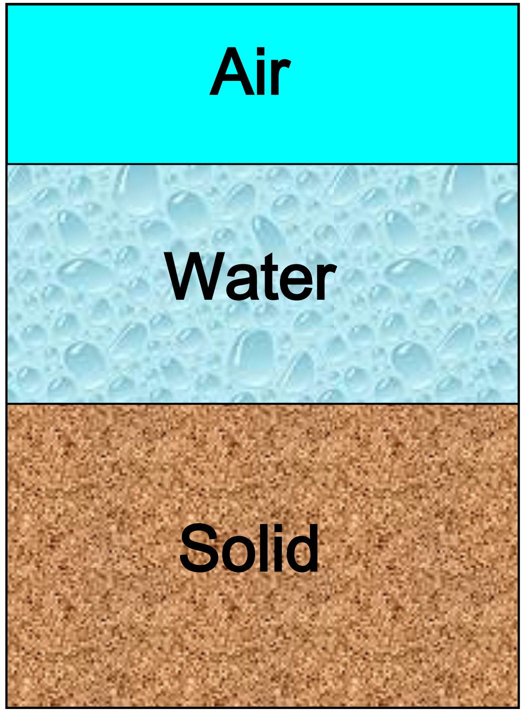
Why does pile driving process
should be continuous in clay soil?

Physical indices of soil



Schematic diagram of soil

To better understand the soil behavior and derive its properties, the constituents are imaged as occupying separate spaces

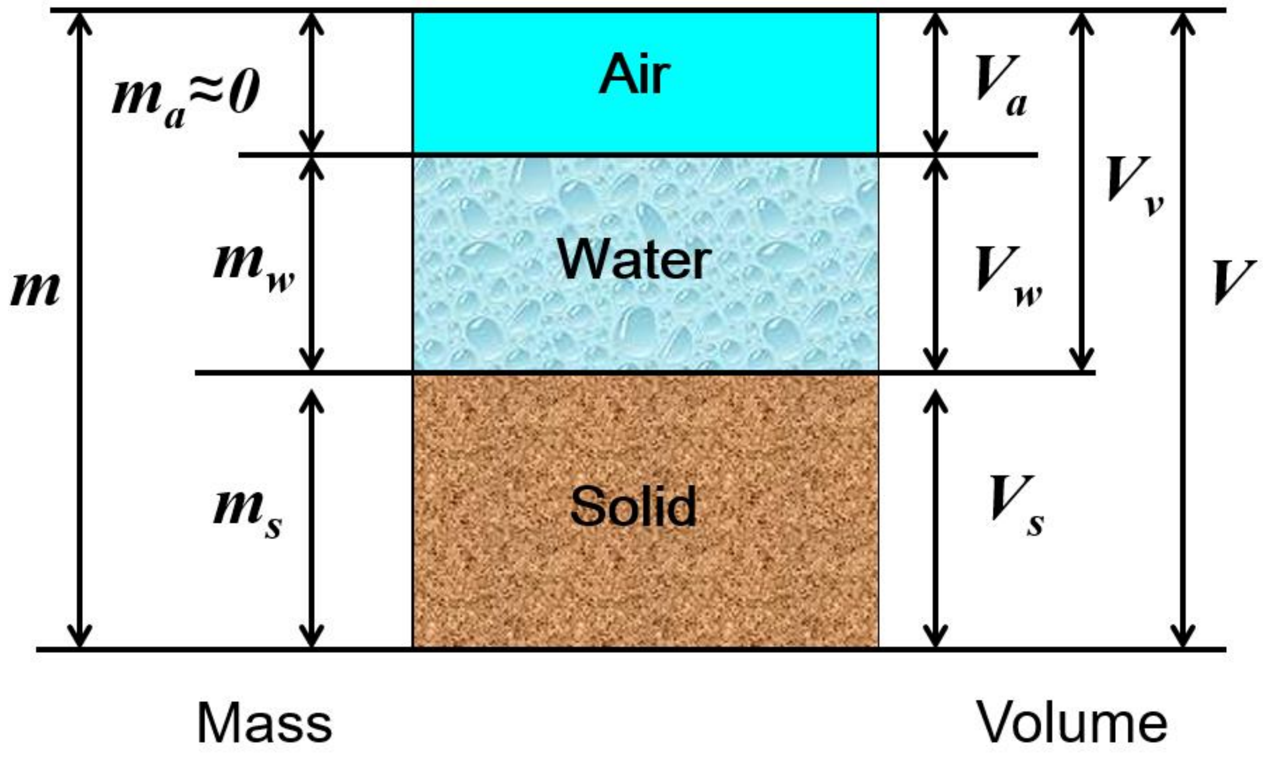


Three phase diagram

Physical indices of soil

Basic relationships:

- $V=V_s+V_a+V_\omega$
- $V_v=V_a+V_\omega$
- $m_a \approx 0$
- $m_\omega=\rho_\omega V_\omega$
- $m=m_s+m_\omega+m_a \approx m_s+m_\omega$



Three phase diagram and associated variables

Physical indices of soil

Three independent indices:

- Bulk density (ρ)
- Specific gravity (Gs)
- Water content (w)

Six derived indices:

- void ratio (e), porosity (n)
- Degree of saturation (Sr)
- dry density (ρ_d), buoyant density (ρ’), saturated density (ρ_{sat})

Physical indices of soil

Bulk unit weight (γ, kN/m³): the weight of a soil sample per unit volume

$$\gamma = \rho \boxed{g}$$

acceleration of gravity constant : 20 N/kg

Dry unit weight

$$\gamma_d = \rho_d g$$

Buoyant unit weight

$$\gamma' = \rho' g$$

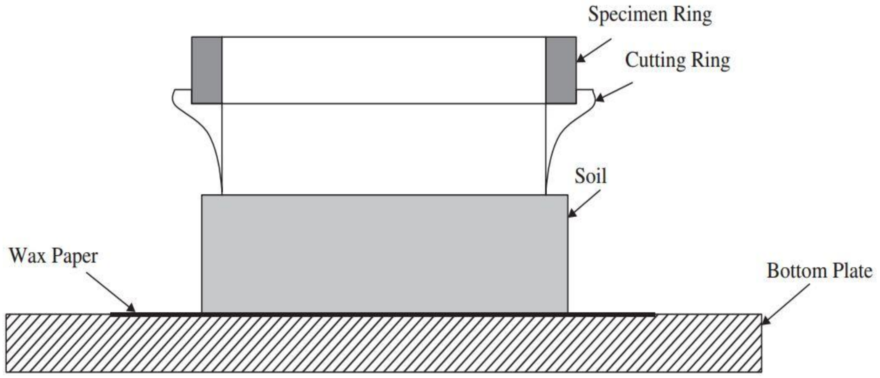
Saturated unit weight

$$\gamma_{sat} = \rho_{sat} g$$

Physical indices of soil

Bulk density (ρ, kg/m^3): mass of soil per unit volume

$$\rho = \frac{m}{V}$$



Cutting ring method

Procedures of cutting ring method

1) Measure the mass of cutting ring with fixed volume
2) Drive the cutting ring into the carefully prepared soil sample. Remove excess soil from the sample with a flat bladed knife and weigh the total mass (cutting ring and soil sample)
3) Determine the mass of soil sample
4) Determine the bulk density

Physical indices of soil

Specific gravity of the soil particle (Gs): ratio of the mass of particles to the mass of an equal volume of water at 4°C

$$G_s = \frac{m_s}{m_w} = \frac{\rho_s}{\rho_w(4^\circ C)}$$

Pycnometer Method

Procedures for determining specific gravity

1) Clean and dry the pycnometer bottle and weigh its mass m_1;
2) Put a small portion (about 300 g) of dry soil sample in pycnometer bottle and weigh the total mass m_2;
3) Fill the pycnometer bottle with de-aired water and weigh the total mass m_3;
4) Clean the pycnometer bottle and fill it with de-aired water. Weigh the total mass m_4;
5) Determine the specific gravity according to the following relation:

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

Physical indices of soil

Water content (w): ratio of weight of water in soil to the weight of the solid matter. It is usually expressed in percentage form

$$\boldsymbol{w = \frac{m_w}{m_s} \times 100\% = \frac{m - m_s}{m_s} \times 100\%}$$

Oven drying method

Procedures for determining water content

1. Clean the container and weigh its mass
2. Place a certain quantity of wet soil in the container and weigh the total mass
3. Keep the container in the oven and dry it for at least 24 hrs under the temperature of 110˚C untill the mass remains constant
4. Cool the container and determine the mass of dry soil (m_s)
5. Determine the water constant

Physical indices of soil

void ratio (e): ratio of volume of void to the volume of solid

$$e = \frac{volume\ of\ void}{volume\ of\ solid} = \frac{V_v}{V_s} \Rightarrow e = \frac{G_S(1+w)}{\rho} - 1$$

porosity (n): ratio of volume of void to the volume of soil

$$n = \frac{volume\ of\ void}{volume\ of\ soil} = \frac{V_v}{V} \Rightarrow n = \frac{V_v}{V} = \frac{V_v}{V_s + V_v} = \frac{e}{1+e}$$

Degree of saturation (S_r): ratio of volume of water to the volume of void

$$S_r = \frac{volume\ of\ water}{volume\ of\ void} = \frac{V_w}{V_v} \Rightarrow S_r = \frac{G_s w}{e}$$

Physical indices of soil

dry density(ρ_d): mass of solid per unit volume

$$\rho_d = \frac{m_s}{V} \Rightarrow \rho_d = \frac{m_s}{V} = \frac{m}{V(1+w)} = \frac{\rho}{1+w}$$

saturated density(ρ_{sat}): mass of saturated soil per unit volume

$$\rho_{sat} = \frac{m_s + V_v \rho_w}{V} \Rightarrow \rho_{sat} = \frac{G_s + e}{1+e}\rho_w$$

buoyant density(ρ'): mass of soil under water table per unit volume

$$\rho' = \frac{m_s - V_s \rho_w}{V} \Rightarrow \rho' = \frac{G_s - 1}{1+e}\rho_w = \rho_{sat} - \rho_w$$

Exercises

1) The volume of a soil specimen is $60\ \mathrm{cm}^3$, and its mass is $108\ \mathrm{g}$. After being dried, the mass of the sample is $96.43\ \mathrm{g}$. The value of G_s is 2.7. Determine: 1) bulk density; 2) dry density, 3) water content; 4) porosity; 5) the degree of saturation.

Exercises

A sample of wet silly clay soil has a mass of 126 kg. The following data were obtained from a series of laboratory tests on the sample: bulk density ρ=2.1 g/cm^3, specific gravity $G_s = 2.7$, water content $w = 15\%$. Determine 1) dry density; 2) porosity; 3) void ratio; 4) degree of saturation.

Relative density, consistency and compaction

Relative density (Dr) is the measure of compactness of **cohesionless soil**

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

e: void ratio of cohesionless soil in natural state

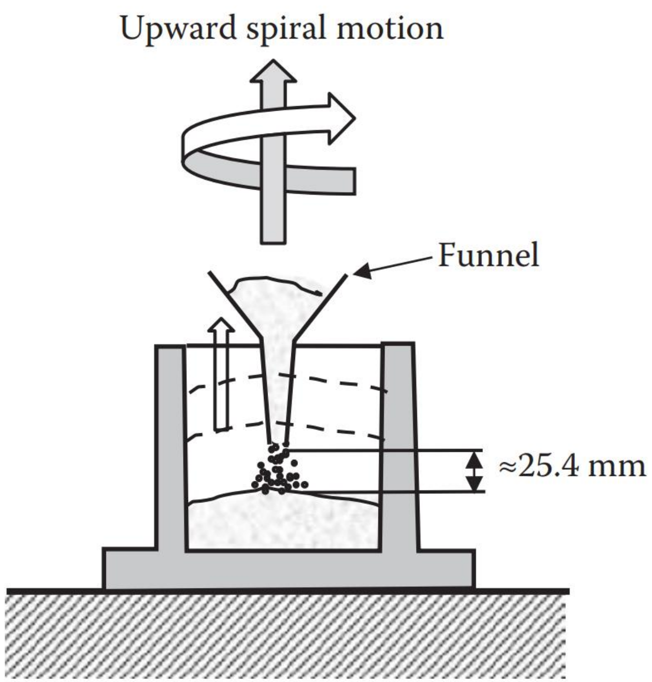
e_{min}: minimum void ratio of cohesionless soil

e_{max}: maximum void ratio of cohesionless soil

D_r	compactness
0~0.33	Loose
0.33~0.67	Medium tight
0.67~1	Tight

Relative density, consistency and compaction

Maximum void ratio



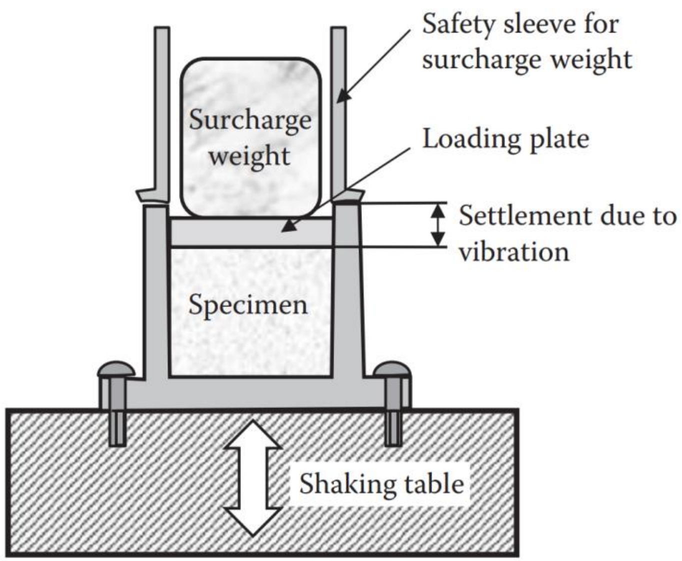
Maximum void ratio determination

$$e_{max} = \frac{G_s \rho_w}{\rho_{dmin}} - 1$$

General steps: The dry soil is dumped to the container through a funnel. With the rise of the cross section of the soil sample, the funnel **makes an upward spiral** but keep its bottom opening almost **25.4mm** above the section. After the filling, the density (ρ_{dmin}) is calculated from the mass and volume of dry soil. With the known density and zero water content (**dry soil**), the corresponding maximum void ratio are determined.

Minimum void ratio

$$e_{min} = \frac{G_s \rho_w}{\rho_{dmax}} - 1$$



Minimum void ratio determination

General steps: the soil used to calculate the maximum void ratio, is utilized. The soil is firstly surcharged and then vertically shaken for a certain period of time. After the procedure, the settlement of the soil is carefully measured. The density of the densified soil (ρ_{dmax}) is calculated from the mass and varied volume. The corresponding minimum void ratio are determined

Exercises

The water content of natural cohesionless soil is 11%, the bulk density is 1.7g/cm^3, the minimum dry density is 1.41g/cm^3 and the maximum dry density is 1.75g/cm^3, determine the compactness of the cohesionless soil.

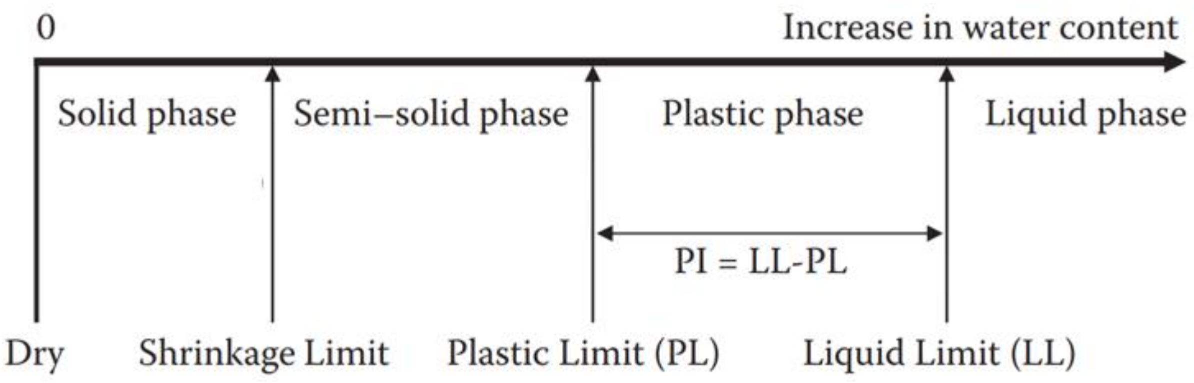
(Hints: with the definition of e_{max} and e_{min} , the relative density could be further written as:

$$\boldsymbol{D_r = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{\rho_d - \rho_{dmin}}{\rho_{dmax} - \rho_{dmin}} \frac{\rho_{dmax}}{\rho_d}}$$

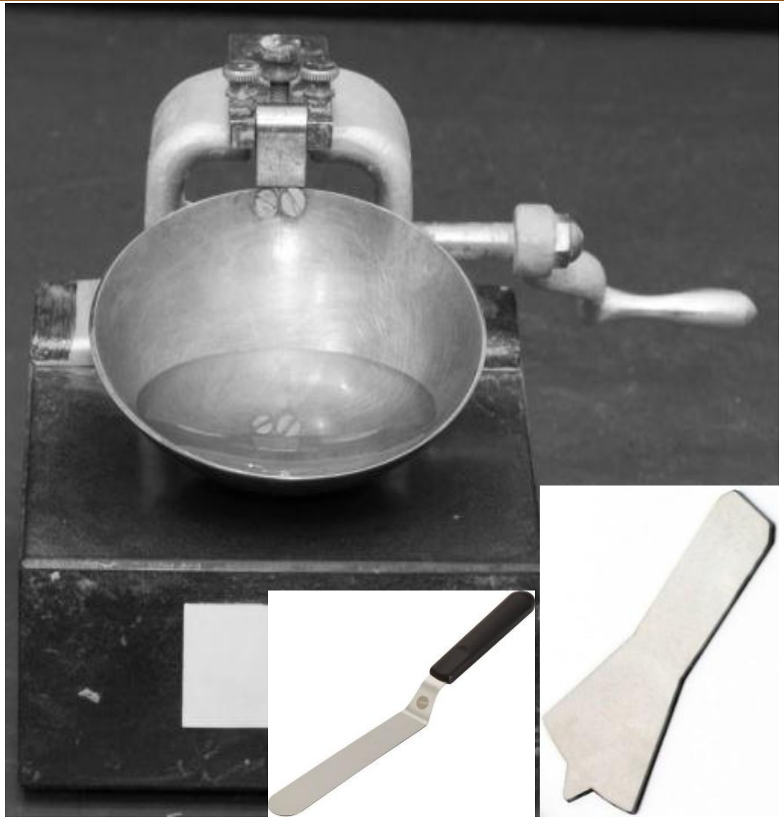
Relative density, consistency and compaction

Consistency is a term to used to describe the ability of the cohesive soil to resist rupture and deformation.

Consistency limits (Atterberg limit): The **water content** at which soil changes from one state to the other. With increase of water, soils experience **four states: solid phase, semi-solid phase, plastic phase, liquid phase**. These four stages are separated by **Shrinkage Limit (SL), Plastic Limit (PL), Liquid Limit (LL)**



Relative density, consistency and compaction



Casagrande device method

Procedures for the Liquid Limit (LL) determination:

1. Prepare a uniform soil paste
2. Place a portion of the paste in the front of cup and spread it with a spatula. Make sure the depth approximates 10mm
3. Make a clean, sharp groove by a grooving tool
4. Turn the crank to closure the groove for a length of 13mm. Plot the blow count and measure the water content

Relative density, consistency and compaction

Hand rolling method

Procedures for the Plastic Limit (PL) determination:

1) Rolling a portion of soil on a glass plate to a 3 mm diameter thread, if cracks and crumbling happen, the water content at that point is the desired PL
2) Repeat this procedure three times and take the average value as the plastic limit

Relative density, consistency and compaction

Liquid limit (LL) and Plastic limit (PL) depend upon the amount and type of clay present in the soil:

- A soil with a high clay content usually has high LL and PL
- Colloidal clays have higher LL and PL than non-colloidal clays
- Sand, gravel and peat have no plasticity, namely PL= 0;

Relative density, consistency and compaction

Plasticity index (P_I): is a term indicate the size of the range of the water content where the soil exhibits plastic properties. **In general, the plasticity index depends only on the amount of clay present.**

$$P_I = L_L - P_L$$

For calculation, the limits are used without percent sign. For example, LL=40% and PL=20%, then PI=40-20=20

PI	Classification
3~10	Silt
10~17	Silty clay
≥17	Clay

Relative density, consistency and compaction

Liquidity index (L_I): is defined as a ratio of the difference between the natural water content of soil and plastic limit to the plastic index

$$L_I = \frac{w - P_L}{L_L - P_L} = \frac{w - P_L}{P_I}$$

LI < 0: semi-plastic or solid state

0< LI <1: plastic state

LI > 1: liquid state (quick clays or ultra sensitive clays)

Exercises

The liquid limit, plastic limit, and natural water content of a cohesive soil sample are 47%, 18% and 40%, respectively. Determine the state of the soil sample.

Relative density, consistency and compaction

In certain practical engineering, .e.g. earth fill dam, ground of foundations for structure and pavement, **backfilling with soil are necessary.**

The coarse grains (gravel and sand) and fine grains (silt and clay) have completely different compaction characteristics. For fine grains, roller compaction is commonly used. During compaction, the water content should be strictly controlled. **For coarse grains, vibration compaction** is preferred and the water content should as high as possible.

Relative density, consistency and compaction

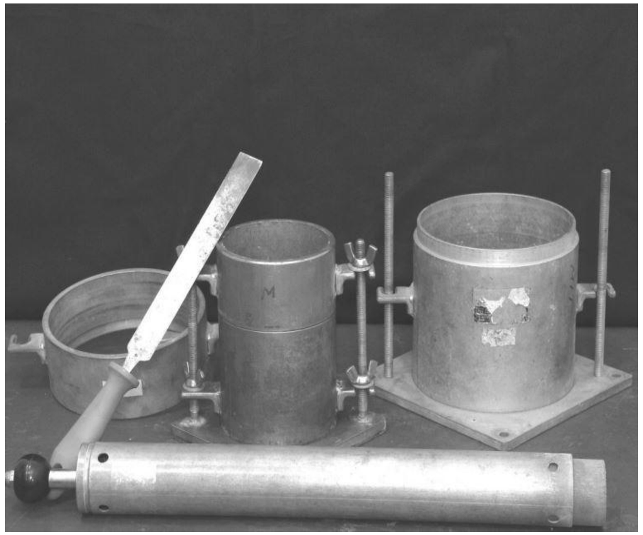
Why compaction necessary !

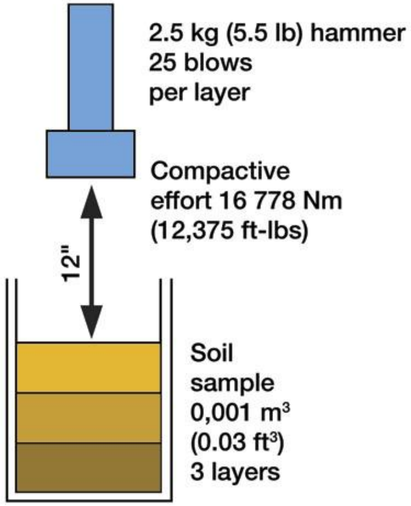
The soil's shear strength, bearing capacity, compressibility and permeability, **all depends on how well the soil is compacted.**

Compaction could destroy the structure of certain special soils. The collapsibility of loess, swelling and shrinkage of expansive soil, or freeze-thaw susceptibility could be controlled. For sand, the densification due to compaction of void may reduce the possibility of liquefaction.

Relative density, consistency and compaction

Compaction of cohesive soils: soil compaction is the process in which a stress applied to a soil causes densification as **air (not water)** is displaced from the pores between the soil grains.





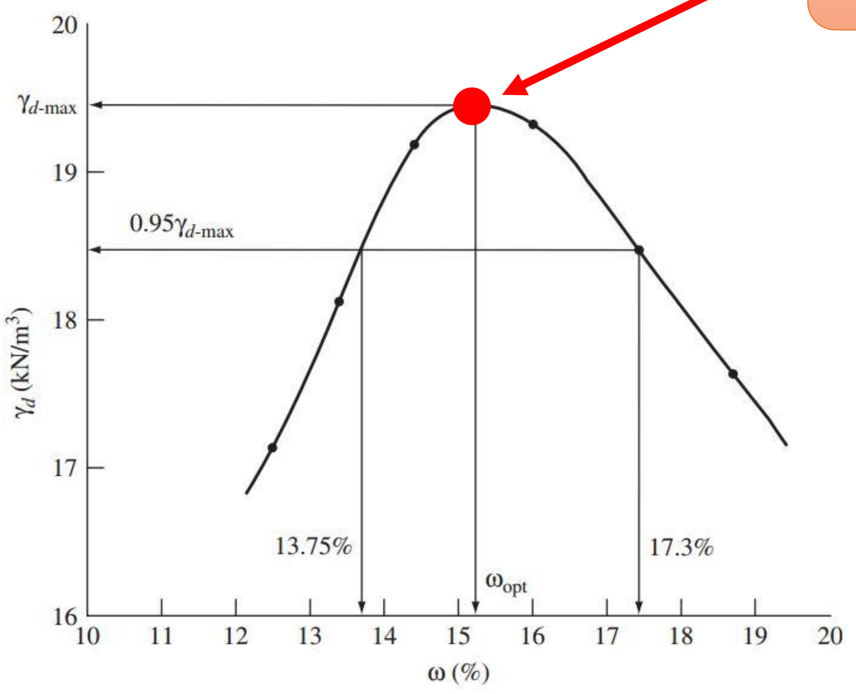
Proctor compaction test

Procedures to conduct proctor compaction test

1. Prepare the 4~6 soil samples with different water contents
2. The soil is then placed and compacted in the **proctor compaction mold** in three different layers where each layer receives 25 blows of the standard hammer.
3. Determine the water content and bulk density

Relative density, consistency and compaction

Optimal water content (w_{opt}): the water content at which soil can reach its maximum dry density

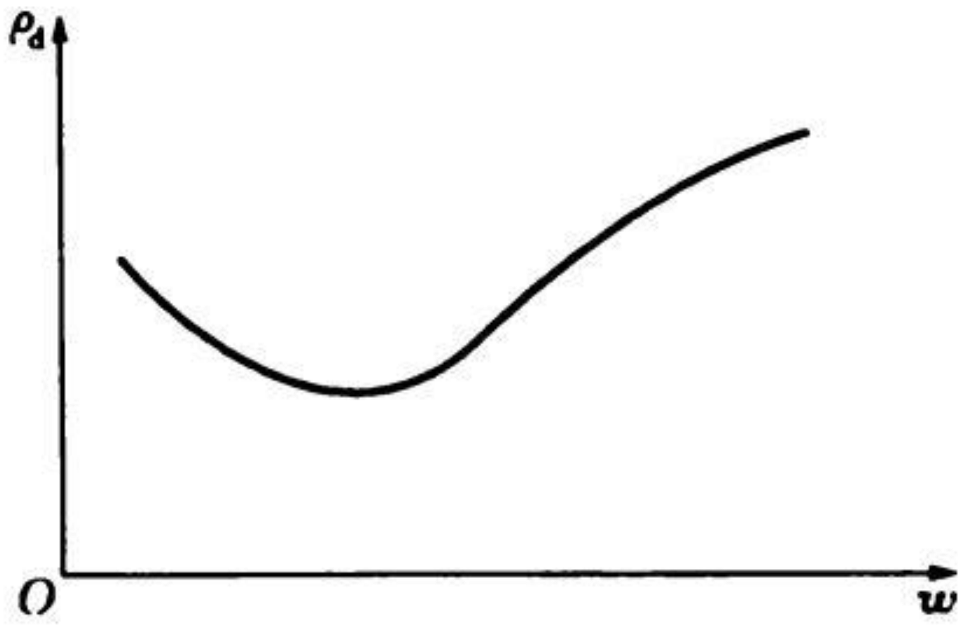


Compaction curve

Why optimal water content (w_{opt}) exists?

1) w <w_{opt}: At the beginning, the addition of water works as a lubricant between particles to reduce the void and then to increase the dry unit weight.
2) w >w_{opt}: The effect of lubrication decreases with the increase the water. This is due to: 1) the decrease of connected air; 2) The gaseous left is entrapped air which works as a cushion against compaction energy.

Relative density, consistency and compaction



Compaction curve

Similar to the cohesive soil, water content also plays an important role in compaction. However, there is no optimum water content for cohesionless soil. Accordingly to the compaction curve, it could attain maximum dry density either under very low or high water content. The minimum dry density is mainly due to the capillary force, which enhances the attraction force between particles. However, as long as the water content increases, the capillary force disappear and the dry density increases.

Relative density, consistency and compaction

Why is watering required before compaction?

Watering before compaction

The End