Soil Mechanics and Geotechnical Analysis
Phase relationships

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Programme

Day	08:00-09:30	09:45-11:15	13:00-14:30	14:45-16:15
19/05/25	Introduction	Programming	Phase Rel.	Tutorial
20/05/25	Classification	Tutorial	LAB	LAB
21/05/25	Effective Str.	Tutorial		
22/05/25	Seepage	Tutorial	LAB	LAB
23/05/25	Str. Incr.	Tutorial		
26/05/25	Settl.	Tutorial	Settl.	Tutorial
27/05/25	Tutorial	Shear Str.	LAB	LAB
28/05/25	Shear Str.	Tutorial		
29/05/25	Footings	Tutorial	Piles	Piles
30/05/25	Tutorial	Review		

Overview

Why is thsi lecture important?

Any geotechnical design requires a profound knowledge of soil behaviour.

Soil behaviour (i.e. how soil responds to loads) is highly dependant on soil type.

Soil type is largely determined by its origin (geologically speaking).

This lecture introduces you to various soil types and the phase relationships which are necessary to describe, classify and understand soil behaviour.

Definitions

Soil is:

- an assembly of mineral particles
- with particle size varying across several orders of magnitude (i.e. 1×10^{-9} m for clays, about 0.06 m for gravels

Soil mechanics is:

- science at the heart of geotechnical engineering
- fundamental properties
- behaviour of the ground under load (compressibility and strength)
- behaviour during presence or flow of water (governed by permeability)

Geotechnical engineering is:

- the *design* of foundations, excavations, slopes, retaining walls, etc.
- the *analysis* of foundations, excavations, slopes, retaining walls, etc.

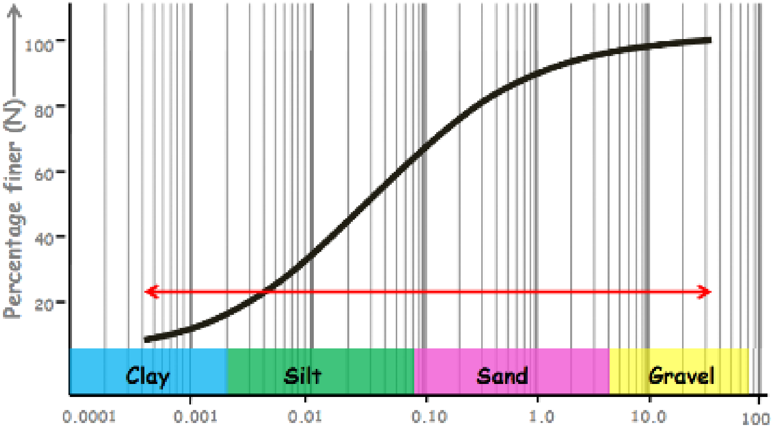
The nature of soils and their characterisation

Note:

- Particle sizes
- Particle shapes
- Inter- and intra-particle voids
- Particle assembly (structure)

Structure = Fabric + Bonding

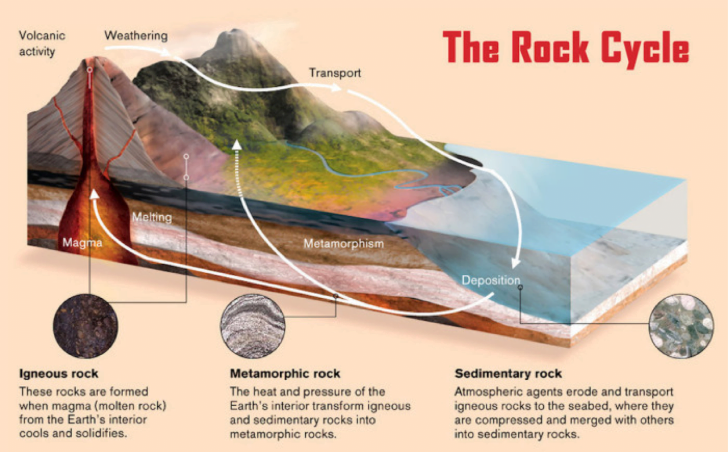
The nature of soils and their characterisation



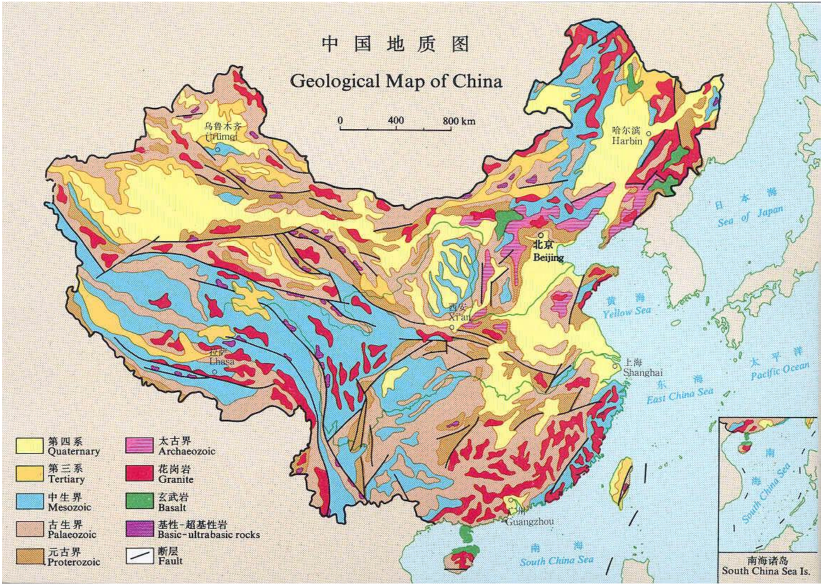
Particle diameter (mm)

Origin of soils

Soils are the result of geological events. The nature and structure of a given soil depends on the geological processes that formed it. These geological processes affect both the particles and the soil structure.

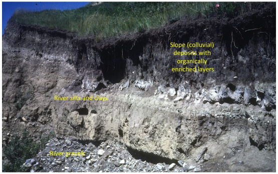


Geological history



Transported soils

Alluvial: Transported by water
Aoelian: Transported by wind
Glacial: Transported by ice




Can you match the definitions to the images?
What is a fluvio-glacial deposit? Where are you likely to find it?

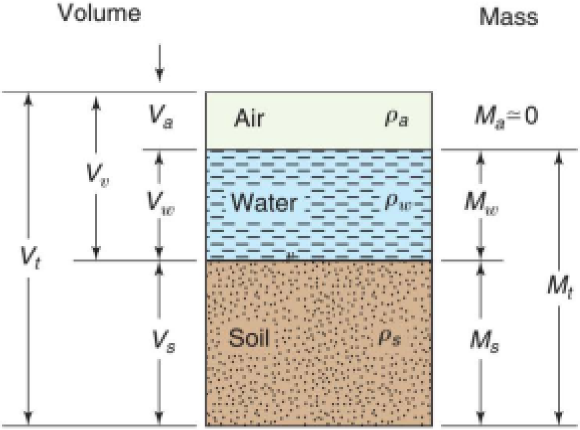
Residual soils

Formed by in-situ weathering. The mineralogy of particles varies widely (depending on the source material), especially with depth, and this influences engineering behaviour. Their fabric may change continuously due to weathering.

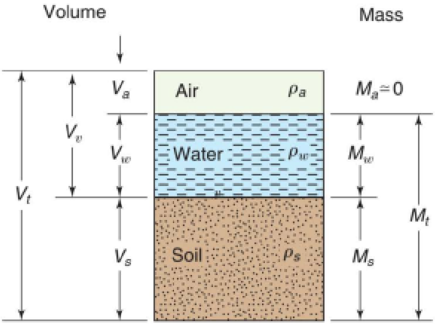
Fills

The behaviour of fills depends on both the soil nature and the method of deposition/compaction

Phase relationships - soil components



The phase model

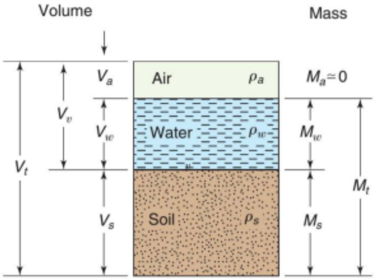


$$V_t = V_s + V_v$$

$$V_v = V_a + V_w$$

$$M_t = M_s + M_w$$

Phase relations



Void ratio (e)

$$e = \frac{V_v}{V_s}$$

Normally expressed as a decimal

Porosity (n)

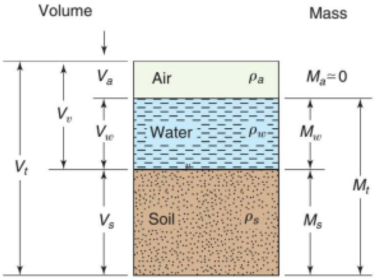
$$n = \frac{V_v}{V_t}$$

Normally expressed as a percentage

It can be shown that

$$n = \frac{e}{1+e} \text{ and } e = \frac{n}{1-n}$$

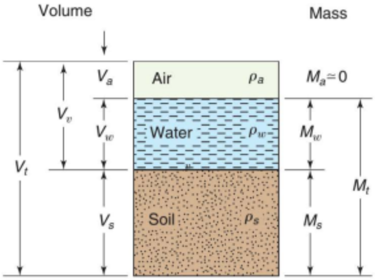
Phase relations



Degree of saturation (S)

$$S = \frac{V_w}{V_v}$$

$S = 0\%$ for dry soil.
$S = 100\%$ for fully saturated soil.



Water content (w)

$$w = \frac{M_w}{M_s}$$

The **most important** phase relationship

Example - Water content calculation

A sample of wet soil in a metallic tin has a mass of 450g. After drying in an oven overnight, the sample and thin have a mass of 368g. The mass of the empty tin is 24g. What is the water content (w) of the sample?

Answer:

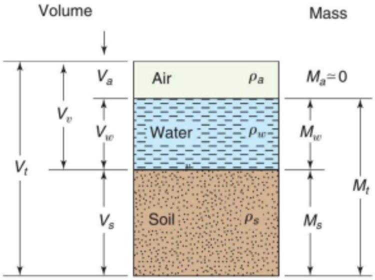
$w = \frac{M_w}{M_s}$ then

$M_w =$ *(mass of wet soil + tin)* - *(mass of dry soil + tin)*
$M_w = 50 - 368 = 82\text{g}$

$M_s =$ *(mass of dry soil + tin)* - *(mass of tin)*
$M_s = 368 - 24 = 344\text{g}$

$w = \frac{M_w}{M_s} = \frac{82}{344} \rightarrow w = 23.8\%$

Phase relations

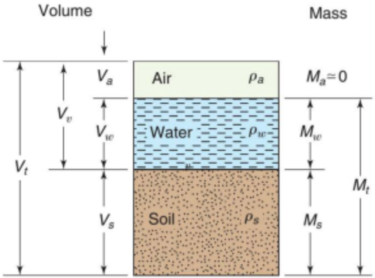


Bulk density (ρ)

$$\rho = \frac{M_t}{V_t} = \frac{M_s + M_w}{V_t}$$

Dry density (ρ_d)

$$\rho_d = \frac{M_s}{V_t}$$



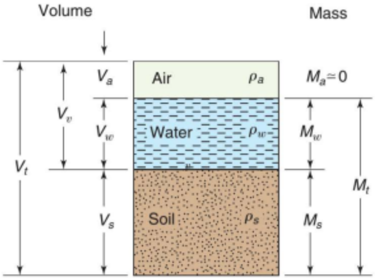
Solid (or particle) density (ρ_s)

$$\rho_s = \frac{M_s}{V_s}$$

Specific gravity (G_s)

$$G_s = \frac{\rho_s}{\rho_w} = \frac{M_s}{V_s \rho_w}$$

Phase relations



Submerged (buoyant) density (ρ')

$$\rho' = \rho - \rho_w$$

Unit weight (γ)

$$\gamma = \rho g$$

with $g = 9.81 m/s^2$

Example - Phase relationships

A sample of sand has a bulk density (ρ_t) of 1.8 Mg/m^3 and a water content (w) of 25%. Calculate e, n, S, ρ_d, ρ_{sat} and ρ'.

Solution strategy:

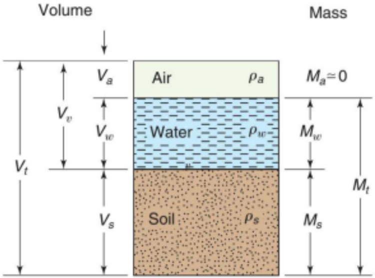
- Always draw a phase diagram first
- Assume an initial quantity (volume or mass)
- Use Mg and m^3 as units
- Complete phase diagram using logical derivations
- Calculate requested phase relationships

Example - Phase relationships

A sample of sand has a bulk density (ρ_t) of 1.8 Mg/m^3 and a water content (w) of 25%. Calculate e, n, S, ρ_d, ρ_{sat} and ρ'.

Given data: $\rho_t = 1.8\ Mg/m^3$ $w = 0.25$

Assume $V_t = 1.0\ m^3$

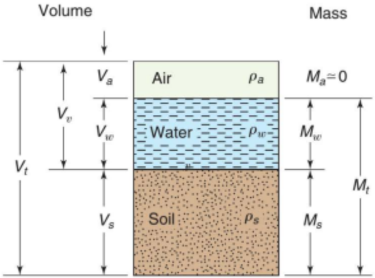


$$\rho_t = \frac{M_t}{V_t} = \frac{M_w + M_s}{V_t}$$

$$w = \frac{M_w}{M_s} = 0.25$$

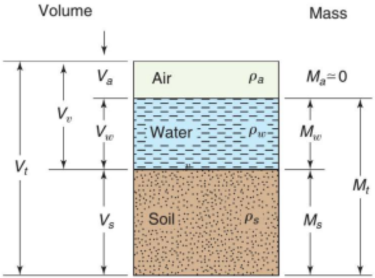
$$\rightarrow M_w = 0.25 M_s$$

Example - Phase relationships



$$\rho_t = \frac{0.25 M_s + M_s}{V_t}$$
$$1.8 = \frac{0.25 M_s + M_s}{1.0}$$
$$1.8 = 1.25 M_s$$

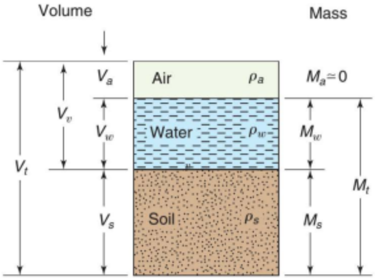
$$\rightarrow M_s = 1.44 \ Mg$$



$$M_w = 0.25 M_s$$
$$M_w = 0.25(1.4) = 0.36\ Mg$$

$$\rho_w = \frac{M_w}{V_w} = 1.0\ Mg/m^3$$
$$\rightarrow V_w = \frac{M_w}{\rho_w} = \frac{0.36}{1.0} = 0.36\ m^3$$

Example - Phase relationships

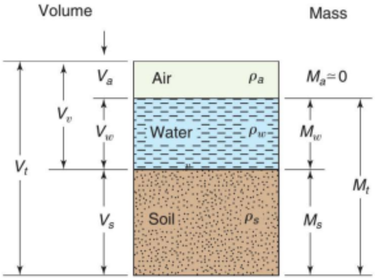


Assume $G_s = 2.65$

$$G_s = \frac{M_s}{V_s \rho_w} = \frac{\rho_s}{\rho_W} = 2.65$$
$$\rightarrow 2.65 = \frac{\rho_s}{1.0}$$
$$\rightarrow \rho_s = 2.65 \ Mg/m^3$$

$$\rho_s = \frac{M_s}{V_s} = 2.65 \ Mg/m^3$$
$$\rightarrow V_s = \frac{M_s}{\rho_s} = \frac{1.44}{2.65} = 0.54 \ m^3$$

Example - Phase relationships



$$V_t = V_a + V_w + V_s$$
$$1.0 = V_a + 0.36 + 0.54 = 0.10\ m^3$$
$$\rightarrow \rho_s = 2.65\ Mg/m^3$$

Now with the complete phase diagram, all phase relationships may be calculated. Verify your results with a Jupyter notebook!

Recap

- What is the difference between soil mechanics and geotechnical engineering?
- Can you list for examples of projects where the involvement of a geotechnical engineer may be required?
- What is soil fabric?
- What is soils structure?
- Can you explain the origin of soils on how it may affect soil properties?
- What is a phase diagram?
- Can you calculate phase relationships?

Before the break...

Are there any questions?