Soil Mechanics
Unit 3 - Classification and Description of Soils

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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	Compaction	Tutorial		
22/05/25	Groundwater	Tutorial	LAB	LAB
23/05/25	Groundwater	Tutorial		
26/05/25	Effective Str.	Tutorial	Stress Incr.	Tutorial
27/05/25	Compressib.	Tutorial	LAB	LAB
28/05/25	Consolidation	Tutorial		
29/05/25	Shear Str.	Tutorial	Shear.Str.	Tutorial
30/05/25	Shear Str.	Review		

Overview

Why is this lecture important?

Any geotechnical structure will be located on or within a certain soil. Before geotechnical design is performed you need to have an idea of the shear strength (i.e. how much load it will resist) and the compressibility (i.e. how much it will deform. This is possible if you can classify and describe the soil that you find in the filed in a successful way.

Also note that usually soil descriptions may be performed by staff which are not responsible for the final design. Unless a soil description (and classification) is made rigorously and appropriately, the designer has little to infer from. You should always provide a soil description that accurately captures everything you observe in-situ.

Soil classification

Soils are normally classified according to their particle size, rather than by origin or mineralogy. There are two major subdivisions:

Cohesionless or coarse-grained soils which are particles held together by gravitational forces, e.g. *sands* and *gravels*.

Cohesive soils, or fine-grained soils which are small particles, frequently bound together by surface or inter-particle forces, e.g. *clays* and *silts*.

The classification of soils into fine-grained and coarse-grained is important as significant differences in their mechanical behaviour can be observed. The difference in behaviour is related to the size of the inter-particle pore spaces, evidenced by their respective hydraulic conductivities (permeability), and thus the time over which certain behaviours occur.

Particle size distribution (PSD)

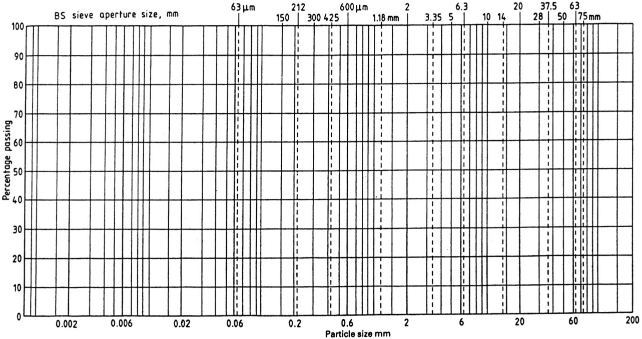
In addition to the definition of size ranges of the four main soil particle sizes, as shown in the Table below, the range of soil particle sizes can be defined using a particle size distribution curve or chart. The engineering size scale according to the British Standards is as follows:

Class	**Upper size (mm)**	**Lower size (mm)**
Gravel	60	2
Sand	2	0.06
Silt	0.06	0.02
Clay	0.002	-

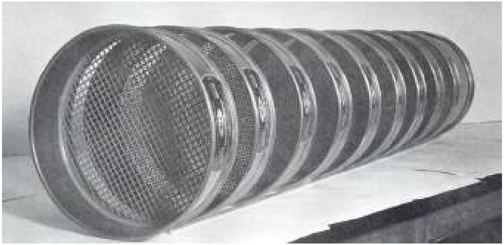
Particle size distribution (PSD)

Gravels can be subdivided into coarse (60-20 mm), medium (20-6 mm) and fine (6-2 mm). Similar subdivisions are made for sands and silts.

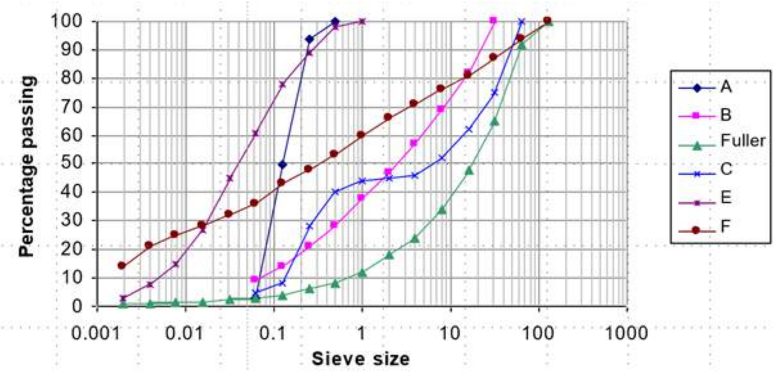
The sizes down to about fine sand/coarse silt (0.063 μm) can be separated by a nest of stacked sieves. The aperture size of each succeeding sieve is smaller than the one above. By weighing the mass of soil retained on each sieve, we obtain the particle size distribution (PSD) for the soil.



Particle size distribution (PSD)



Particle size distribution (PSD) - Examples



Mean particle diameter, d_{50}

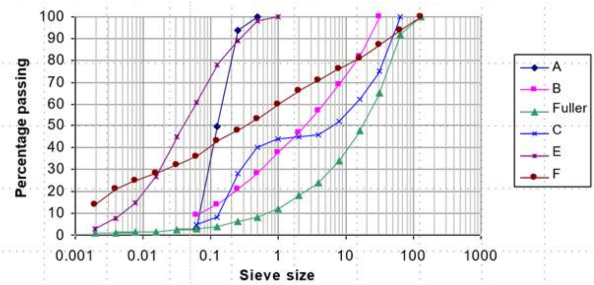
Coefficient of uniformity, $C_u = \frac{d_{60}}{d_{10}}$

Coefficient of curvature, $C_c = \frac{d_{30}^2}{d_{60}\,d_{10}}$

Soils with a C_u of less than about 6 are regarded as uniformly graded.

Greater values are regarded as well-graded.

Particle size distribution (PSD) - Examples



Soil	Description	d_{10}	d_{60}	C_u
A	Uniformly or narrowly graded fine SAND	0.12	0.18	1.5
B	Well-graded silty SAND and GRAVEL	0.07	4.5	64
Fuller	Theoretically densest/ideal	0.66	24	36
C	Gap graded medium SAND and GRAVEL	0.14	15	107
E	Well graded sandy SILT	0.0051	0.06	12
F	Boulder clay	0.001	1	1000

Particle size distribution (PSD) - Calculation Example

A particle size distribution analysis on a 241 g sample of soil returned the following results. Plot the particle size distribution, calculate the coefficient of uniformity and describe the grading of the soil.

Sieve size μm	Mass retained (g)
3350	0
2000	3
1180	15
600	32
212	105
150	70
63	11
$<$63	15

Particle size distribution (PSD) - Calculation Example

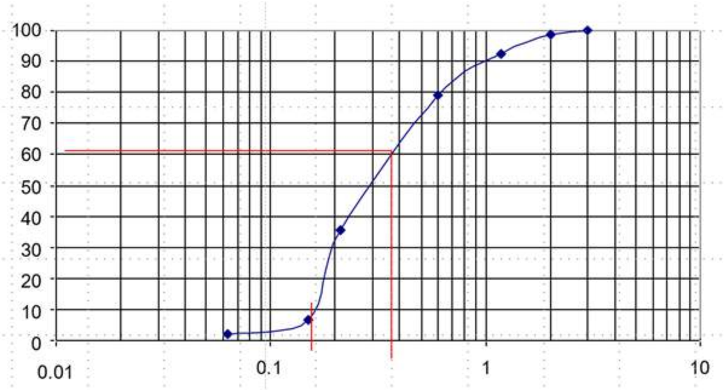
Solution procedure

1. Calculate total mass (sum of "Mass retained (g)")
2. Calculate percentage retained (mass retained/total mass)
3. Calculate cumulative percentage passing (sum of percentage retained successively)
4. Calculate percentage passing (100% - cumulative percentage passing)
5. Plot sieve size vs percentage passing
6. Calculate C_u
7. Classify the soil

Particle size distribution (PSD) - Calculation Example

Sieve size μm	Mass retained (g)	% retained	% passing
3350	0	0	100.0
2000	3	1.2	98.8
1180	15	6.2	92.6
600	32	13.3	79.3
212	105	43.6	35.7
150	70	29.0	6.7
63	11	4.6	2.1
$<$63	15	2.1	0.0

Particle size distribution (PSD) - Calculation Example



Gravel = 1.2%, Sand (0.063 mm – 2 mm) = 96.7%, Fines = 2.1%

$\rightarrow$ Slightly gravelly SAND

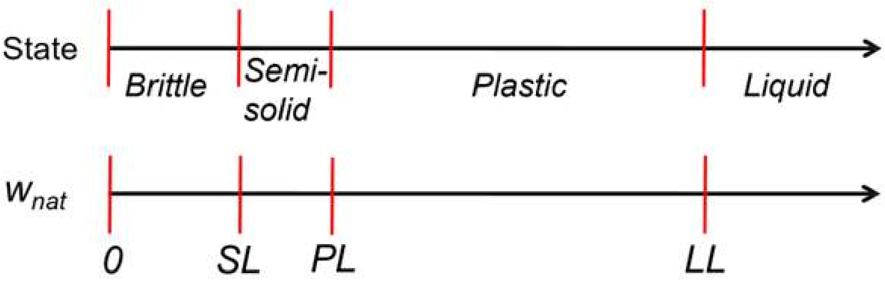
$C_u = \frac{d_{60}}{d_{10}} = \frac{0.36}{0.18} = 2$

Soil is uniformly graded.

Hence, **uniformly graded slightly gravely SAND**

Consistency limits

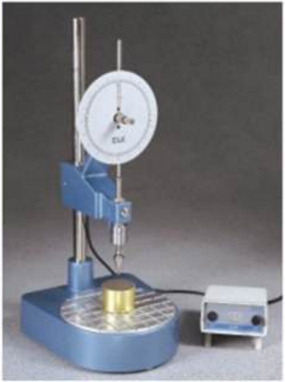
The index tests (consistency limits, Atterberg limits) describe the water contents in a fine-grained (clayey) soil at which different forms of material behaviour occur, i.e. the transitions between brittle, semi-solid, plastic and liquid behaviours.



SL – Shrinkage limit
PL – Plastic limit
LL – Liquid limit

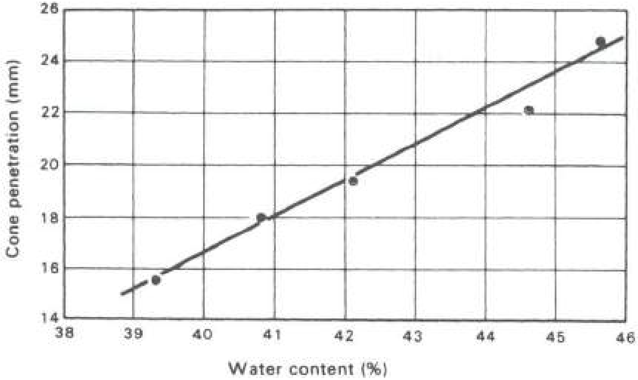
Liquid limit equipment

Two methods, the Casagrande or cup method and the falling cone method. The cone method has a direct relation with the shear strength of the soil and yields results that are less dependent on the operators' skill than is the case with the Casagrande method.



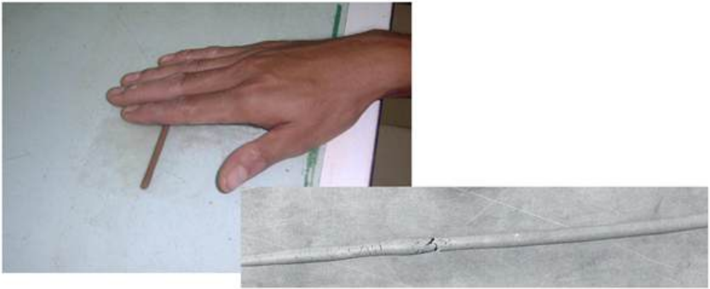
Liquid limit equipment

The resulting data is analysed by plotting penetration against moisture content and fixing a best-fit line. The liquid limit of the soil is the moisture content at which the penetration of the cone into the soil is 20 mm, as read off the graph.



Plastic limit

In **Europe** and the **United States**, the plastic limit is defined rather more arbitrarily and is defined as the water content at which a thread of soil with 3 mm diameter just crumbles when it is carefully rolled out.



In **China**, the cone penetrometer has mass 76 g and when used to determine liquid limit, targets a penetration depth of 17 mm. It is also used for the plastic limit with penetration depth of 2 mm.

Consistency indices

The difference between LL and PL limits is defined as the **plasticity index** (PI), and calculated as:

$$PI = LL – PL \text{ or } I_P = w_L - w_P$$

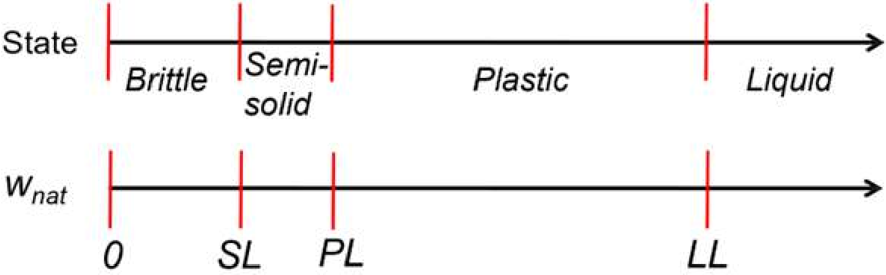
The PI, when plotted against the liquid limit (LL) on the plasticity chart, enables the classification of fine-grained soils.

The **liquidity index** (LI) is also a useful indicator. It gives a ready comparison of the soil's plasticity with its natural moisture content:

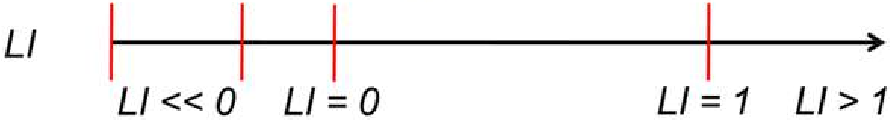
$$LI = \frac{w - w_P}{I_P}$$

If $LI = 1.0$, the soil is at its liquid limit. If $LI = 0.0$, the soil is at its plastic limit

Applicability of consistency indices



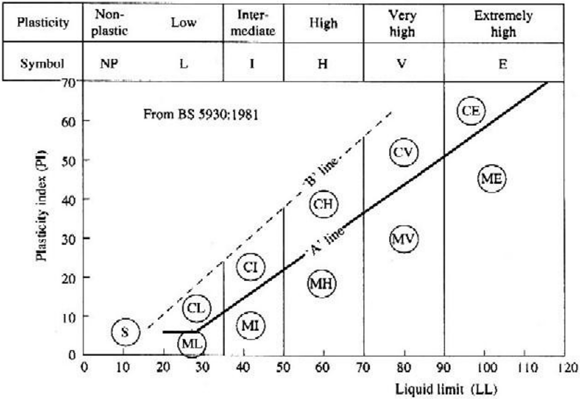
$$LI = \frac{w_{nat} - PL}{LL - PL} = \frac{w_{nat} - PL}{PI}$$



Classification of fine-grained soils

The plasticity index in conjunction with the liquid limit is used to classify the plasticity of fine-grained soils and the dominant particle size, i.e. clay/silt.

The A-line, after Atterberg, separates the clays (= C) from silts (= M).



Activity and mineralogy of clays

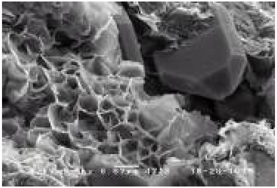
Atterberg limits are related to mineralogy and the amount of clay minerals present. A high plasticity index might be due to

1. large amount of a clay mineral with a relatively low moisture holding capability, or
2. a smaller amount of a clay mineral that can hold a lot of moisture.

The ability of a clay mineral to hold water is related to its surface area. A relatively large clay mineral with a low specific surface area is kaolinite. In contrast, montmorillonite is a very small clay mineral with large specific surface area.

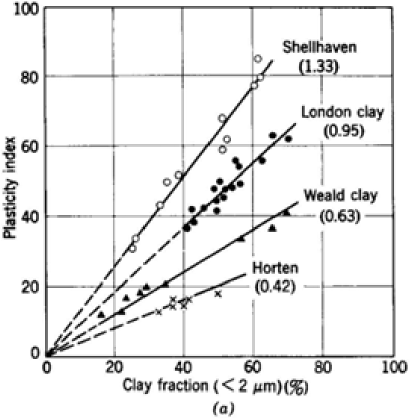
In order to distinguish between these two conditions, Skempton (1953) proposed a quantity he called the activity,

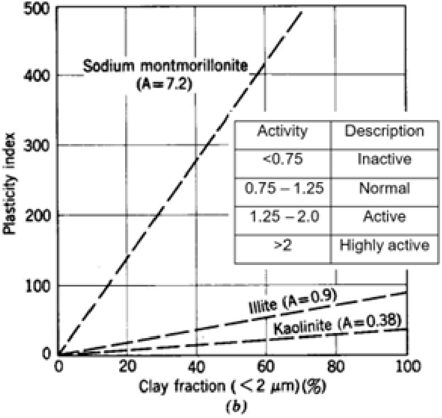
$$Activity = plasticity\ index\ /\ \%\ by\ mass\ of\ sample\ finer\ than\ 2\ \mu m$$



Activity and mineralogy of clays

The activity of a clay indicates something of its susceptibility to moisture content changes, i.e. to volume change or shrink-swell behaviour. Values of activity and the corresponding behavioural description are given below (Skempton, 1953)





Activity	Description
<0.75	Inactive
0.75 – 1.25	Normal
1.25 – 2.0	Active
>2	Highly active

Description of soils

CLASSIFICATION: A soil is allocated to one of a limited number of groups based on the material characteristics only.

DESCRIPTION: Includes details of the *material* and *mass* characteristics. Any two soils are not likely to have the same description

Material characteristics

- Particle size distribution
- Plasticity
- Colour
- Shape
- Structure
- Texture
- Composition

Mass characteristics

- Compactive state
- Bedding
- Discontinuities
- Weathering
- Macro-fabric

Should be obtained from undisturbed samples

MCCSSOOW approach for soil description

An approach suggested by Prof. John Burland.

M C C S S O O W

M C C So Wonderful!
M C C So What?

Any other ideas?

M - Moisture conditions

1. Dry (Desiccated)
2. Slightly moist
3. Moist
4. Very moist
5. Wet

Moisture conditions hves a fundamental influence on the mechanical properties of a soil. Two obvious examples of this are the swelling of desiccated clays and the collapse of sandy soils or loose fills on wetting.

Have you built a sand castle?

C - Colour

Bright colours: pink, red, purple, orange, yellow

Dark colours: olive, green, blue

Shades of grey

Intermediate colours are described by combining terms (e.g. pale reddish orange, or dark bluish green, etc.)

Colour is an indicator of chemical and mineralogical processes mainly associated with iron compounds and can give valuable information about weathering processes.

Consider description of colour for joints and fissures (it may indicate seepage)

C - Consistency

Consistency is a measure of stiffness and strength. It is important to assess the influence of vigorous remoulding on the consistency.

Fine-grained soils: very soft, soft, firm, stiff, very stiff (hard)

Coarse-grained soils: very loose, loose, medium dense, dense, very dense

C - Consistency (fine-grained soils)

Descriptor	Test	Approximate undrained shear strength (kN/m^2)
Very soft	Exudes between fingers when squeezed	< 20
Soft	Moulded by light finger pressure. Easy to pick	20 – 40
Firm	Moulded by strong finger pressure. Fairly easy to pick	40 – 75
Stiff	Cannot be moulded by fingers. Difficult to pick	75 – 150
Very stiff	Very tough and difficult to pick	> 150

C - Consistency (coarse-grained soils)

Descriptor	Test	SPT
Very loose	Very easy to excavate with spade	< 4
Loose	Fairly easy to excavate with spade or penetrate with handbar	4 – 10
Medium dense	Difficult to excavate with spade or penetrate with handbar	10 – 30
Dense	Very difficult to penetrate with handbar. Requires pick for excavation	30 – 50
Very dense	Difficult to pick	> 50

S - Structure

Structure means the presence or absence of discontinuities within the soil mass and not the particle arrangement within the soil skeleton. The structure of the soil mass is a vital feature since it can play a dominant role in controlling its behaviour, in particular its strength and permeability.

S - Soil type

The importance of grain size lies primarily in the drainage of the soil thereby influencing the permeability and the rate at which the strength and volume change respond to changes in loading.

Note:
You know this already (i.e. clay, silt, sand, gravel, etc.)

O - Other features

Roots? Man-made features? Animal-made features?

O - Origin

Think about geology... What do geological maps tell you about the soil for a given site? Soil types, parent rock, etc.

W - Water conditions

The most important descriptor...
If there is no water... write it down!

Recap

- What is the difference between a cohesive and a cohesionless soil? How can you differentiate/classify them?
- How do you perform and calculate the particle size distribution of a particular soil?
- How do you define C_u? What does it tell you?
- What are the Atterberg limits? How do you measure them?
- How do they relate to the consistency indices and what these indices tell you about possible soil behaviour?
- How do you classify a soil based on Atterberg's limit tests? What is the A- line?
- What is clay activity and why is it so important?
- List the meaning of each character for MCCSSOOW and provide brief comments on why each of these characters is important.

Before the break...

Are there any questions?