FUNDAMENTALS OF GEOTECHNICAL ENGINEERING

Lesson 3. Soil and rock classification.

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3. SOIL AND ROCK CLASSIFICATION.

LESSON OVERVIEW

In this lesson identification tests and classification systems for soils and rocks are explained. First, the different particles that constitute a soil are presented. Then, the particle-size distribution test is introduced. After that, it is necessary to explain thoroughly some specific characteristics of clay particles that come from the electric charges on its surface, as, for example, plasticity and cohesion. Then, Atterberg limits and Casagrande's plasticity chart can be explained and also the Unified Soil Classification System (USCS). Finally, the main classification systems for intact rocks and rock masses are presented. Along this lesson, the international standards of application are continuously referenced.

LEARNING OUTCOMES

On completion this lesson, the student will be able to:

- ✓ Identify the different particles in a soil according their size.
- ✓ Determine the particle-size distribution curve of a soil and the properties related.
- ✓ Know and understand the specific characteristics of clay particles due to the electrical charge on surface.
- ✓ Determine de Atterberg limits of a soil.
- ✓ Classify a soil according to the Unified Soil Classification System (USCS).
- ✓ Classify a rock mass according its weathering grade, RQD and RMR.

3. SOIL AND ROCK CLASSIFICATION.

CONTENTS

1. Particles in a soil.
2. Particle size distribution analysis.
3. Properties of clays.
4. Atterberg limits.
5. Casagrande's plasticity chart.
6. Unified Soil Classification System (USCS).
7. Rock and rock mass classification.

PARTICLES IN A SOIL (I)

Coarse particles ⟷ Fines

USCS

	Gravel		Sand			
Cobbles	Coarse	Fine	Coarse	Medium	Fine	Silt and clay

(mm) 75 19 4.75 2 0.425 0.075 (mm)

Cohesive soils

TBC

BS

	Gravel			Sand			Silt			
Cobbles	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	Clay

(mm) 60 20 6 2 0.6 0.2 0.060 0.020 0.006 0.002 (mm)

Granular soils

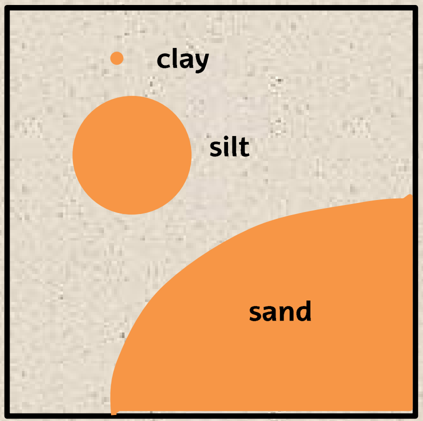
Coarse particles ⟷ Fines

Mechanical weathering

Chemical weathering

PARTICLES IN A SOIL (II). Differences.

- Gravel and sand: different behaviour with water.
- Silt:
  - Cannot be remoulded.
  - Poor-practically impervious.
  - Dried ⇨ Little strength.
  - Warning! Some of them behave as clay ⇨ Plastic silt.
- Clay (< 0.002 mm):
  - Can be remoulded over a range of water content.
  - Swelling when wet and shrinking when dry.
  - Practically impervious.
  - Dried ⇨ high strength.

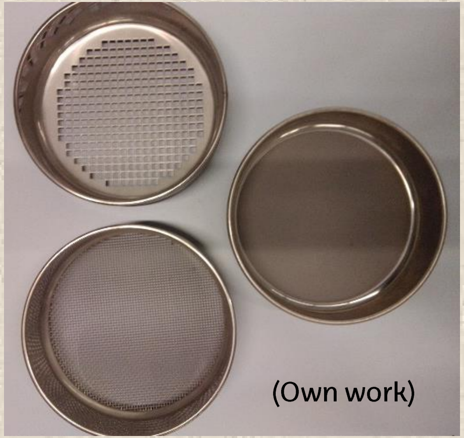


PARTICLE SIZE DISTRIBUTION ANALYSIS (I)

- **Objectives:**

  To determine: 1) the range of size of particles in the soil, and 2) the percentage of particles in each of the sizes between the maximum and the minimum.

- **Methods:**
  - Sieving.
    - UNE 103101:1995 and ASTM D422-63(2007).
    - Coarse-grained soils.
    - Dry soil and wet soil.
  - Sedimentation. UNE 103102:1995 and ASTM D422-63(2007).
    - Fine-grained soils.
    - It is not necessary to evaluate the significant engineering properties of these soils.



(Own work)

PARTICLE SIZE DISTRIBUTION ANALYSIS (II)

Procedure

- A soil sample is dried and clumps are broken.
- A column of sieves having different openings is selected, with the larger sizes over the smaller and a pan at the bottom.
- The soil sample is passed through the series of sieves by shaking, and particles are retained on a particular sieve according to their size.
- The weight of material retained on each sieve is presented graphically as a particle-size distribution curve.

(Own work)

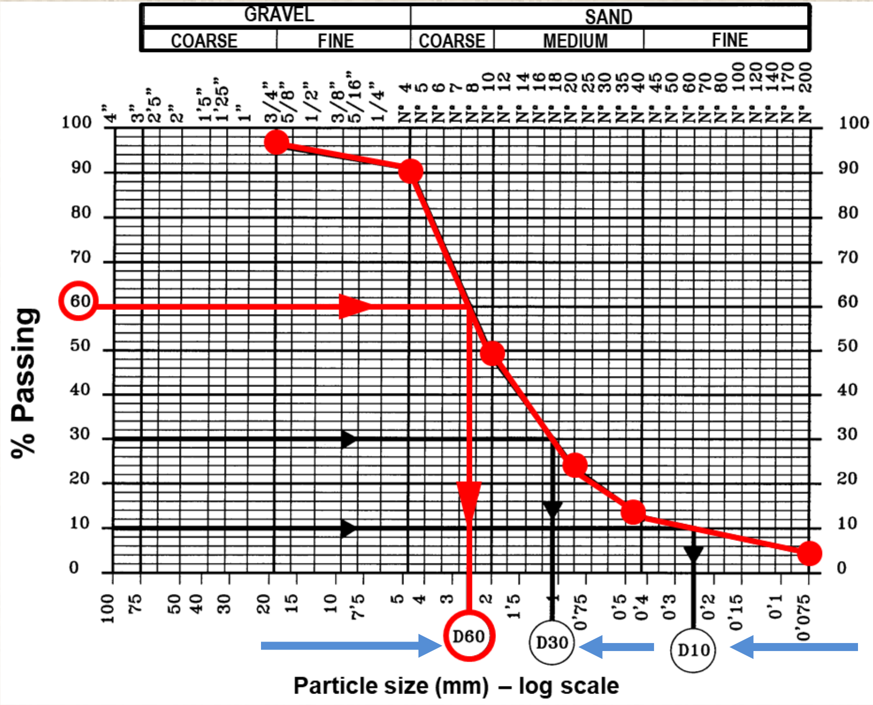
PARTICLE SIZE DISTRIBUTION ANALYSIS (III)

Data obtained from a sieve analysis

Mass of the soil sample = 2028,0
Water content = 18,4%
Mass of the dry soil = 1712,8

	ASTM sieve	Opening (mm)	Retained (g)	Passing (g)	% passing
Convenient	3/4"	19,0	70,25	1642,55	95,90%
Necessary	Nº 4	4,75	82,68	1559,87	91,07%
Convenient	Nº 10	2,00	733,4	826,47	48,25%
	Nº 20	0,850	421,48	404,99	23,64%
Convenient	Nº 40	0,425	189,46	215,53	12,58%
Necessary	Nº 200	0,075	139,13	76,40	4,46%
	Pan		76,40		

These data are presented as a particle-size distribution curve



Particle-size distribution curve and parameters (D_{10}, D_{30}, D_{60})

PARTICLE SIZE DISTRIBUTION ANALYSIS (IV)

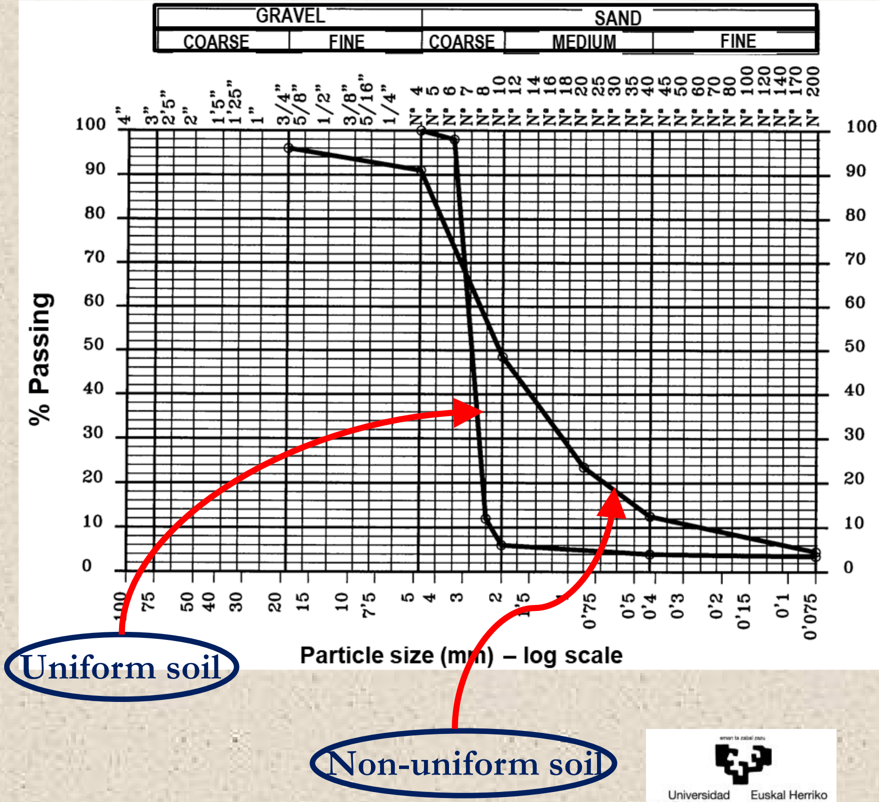
Parameters from the particle-size distribution curve

- D_{10}: effective size.
  - It is related to hydraulic conductivity in sand.

- C_U: coefficient of uniformity. $C_U = \frac{D_{60}}{D_{10}}$

$C_U > 10 \Rightarrow$ Non-uniform soil $\Rightarrow$ Wide range of particle sizes.
$C_U < 2 \Rightarrow$ Uniform soil $\Rightarrow$ Narrow range of particle sizes.

- C_C: coefficient of curvature. $C_C = \frac{D_{30}^2}{D_{60} \cdot D_{10}}$



PARTICLE SIZE DISTRIBUTION ANALYSIS (V)

ASTM sieves and openings

In addition, european standards have other sieves (with different openings)

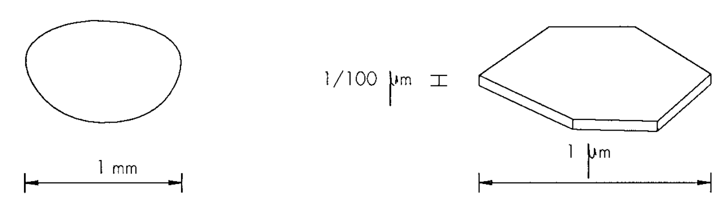
ASTM sieve	Opening (mm)
4"	100
3'5”	90
3”	75
2'5"	63
2'12”	53
2"	50
1'75”	45
1'5"	37.5
1'25"	31.5
1'06”	26.5
1"	25.0
7/8”	22.4
3/4"	19.0
5/8"	16.0
0'530”	13.2
1/2"	12.5
7/16”	11.2

ASTM sieve	Opening (mm)
3/8"	9.5
5/16"	8.0
0'265”	6.7
1/4"	6.3
Nº 3½	5.6
Nº 4	4.75
Nº 5	4.00
Nº 6	3.35
Nº 7	2.80
Nº 8	2.36
Nº 10	2.00
Nº 12	1.70
Nº 14	1.40
Nº 16	1.18
Nº 18	1.00
Nº 20	0.850
Nº 25	0.710

ASTM sieve	Opening (mm)
Nº 30	0.600
Nº 35	0.500
Nº 40	0.425
Nº 45	0.355
Nº 50	0.300
Nº 60	0.250
Nº 70	0.212
Nº 80	0.180
Nº 100	0.150
Nº 120	0.125
Nº 140	0.106
Nº 170	0.090
Nº 200	0.075
Nº 230	0.063
Nº 270	0.053
Nº 325	0.045
Nº 400	0.038

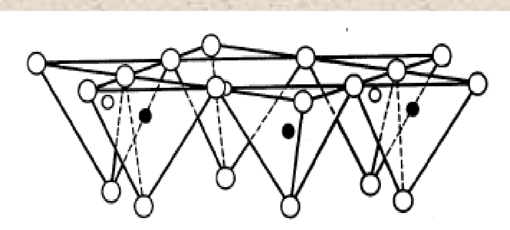
PROPERTIES OF CLAYS (I). Clay minerals.

Silt particles are granular materials coming from mechanical weathering.

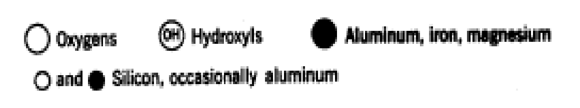


Clay particles come from chemical weathering. Flaky shape.

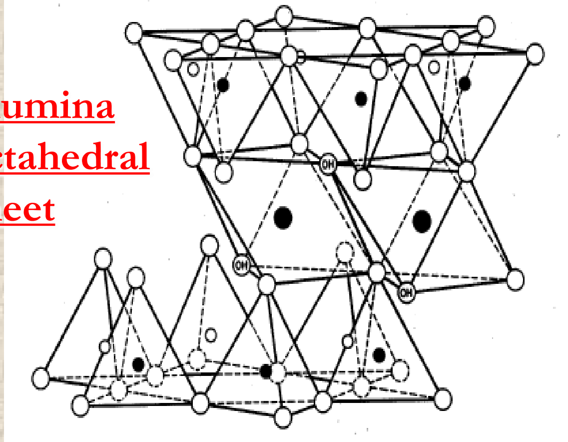
➔ Clay particles (< 0.002 mm). Clay minerals, consisting of an orderly and repetitious arrangement of molecules to produce a sheet-like structure (5A thick). Clay particles may be made of many sheets.



Silica tetrahedral sheet



Alumina octahedral sheet

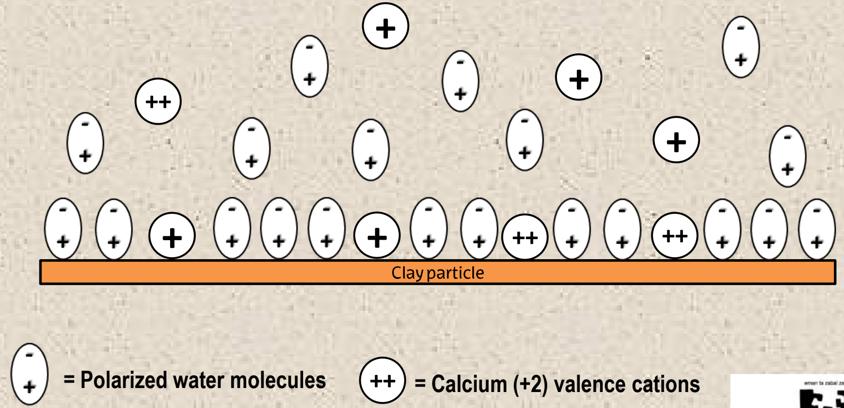


PROPERTIES OF CLAYS (II). Clay and water.

➔ The surfaces of clay mineral particles have a net electrical charge that is negative, while the edges have positive charges. Hence, the particles will attract water, due to its dipole structure, and cations.

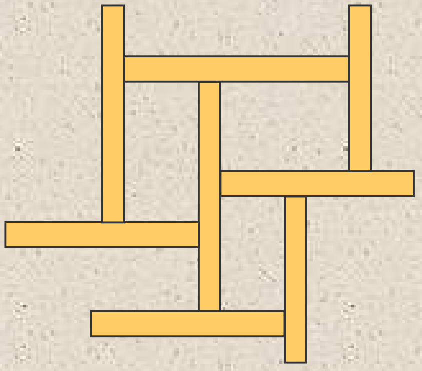
➔ A significant amount of water becomes "bonded" to the clay. The distance from the clay particle surface to the limit of attraction is termed the "diffuse double layer" (10A thick).

➔ The plasticity that clay soils posses occurs because of the unusual molecular structure and the common presence of water in soil deposits.



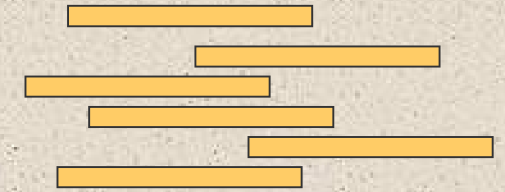
PROPERTIES OF CLAYS (III). Particle arrangements.

➔ Flocculated structure, edge-to-face arrangement. ⇒ High void ratios, low density, high water content, strong and resistant to external forces because of the attraction between particles.



COHESION

➔ Dispersed structure, face-to-face arrangement. It occurs after reworking or remoulding.



NO COHESION

ATTERBERG LIMITS (I)

Consistency	SOLID	SEMISOLID (brittle)	PLASTIC (mouldable)	LIQUID (viscous)
Behaviour as	Hard candy	Cheese	Soft butter	Pea soup
Limits	Shrinkage	Plastic	Liquid	
Designations	w_S or SL	w_P or PL	w_L or LL	

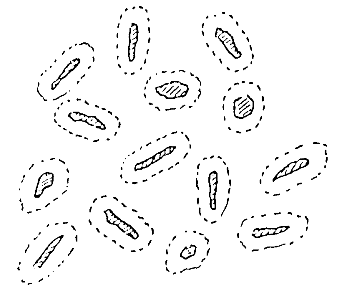
→ Increasing water content

Atterberg limits

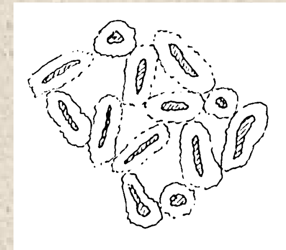
- ➔ Atterberg limits are quantified in terms of water content of a soil (see figure).
- ➔ Standard laboratory test procedures are available to determine them.
- ➔ Limit tests are somewhat arbitrary. Hence, Atterberg limit values have little direct meaning.
- ➔ Atterberg limits are necessary to classify fine-grained soils ⇒ Silt and clay

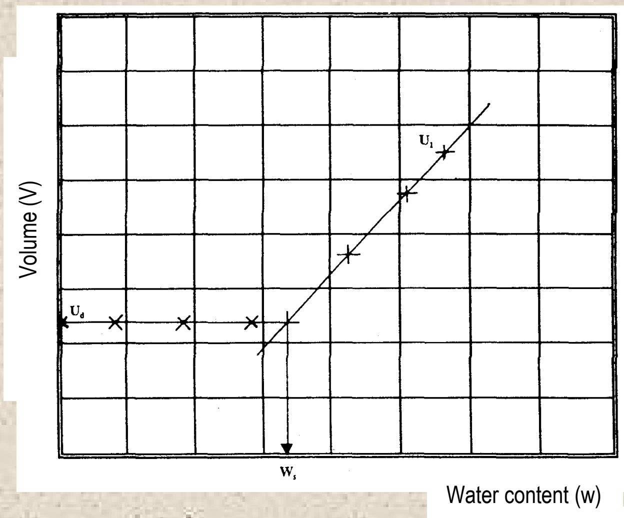
ATTERBERG LIMITS (II). Shrinkage limit (w_S or SL)

The shrinkage limit is quantified for a given soil as a specific water content. It is the water content that is just sufficient to fill the voids when the soil is at the minimum volume it will attain on drying. Also, it can be defined as the smallest water content at which a soil can be completely saturated. UNE 103108:1996 and ASTM D427-04.



drying





The SL test is rarely performed because it is not necessary to classify soils.

ATTERBERG LIMITS (III). Plastic limit (w_P or PL)

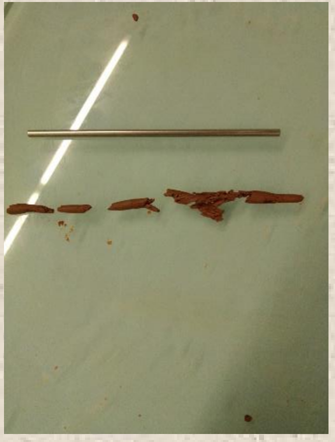
It is the minimum water content in which soil remains in a plastic state. If that soil goes on drying, it will pass from a plastic (mouldable) state to a semisolid (brittle) state. UNE 103104:1993 and ASTM D4318-17.

Procedure

(Own work)

(Own work)

(Own work)



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ATTERBERG LIMITS (IV). Liquid limit (w_L or LL)

Liquid limit is taken as the water content at which the soil flows (i.e. the condition where a very viscous liquid shears). If that soil goes on drying, it will pass from a liquid (viscous) state to a plastic (mouldable) state. UNE 103104:1993 and ASTM D4318-17.

Procedure

(Own work)

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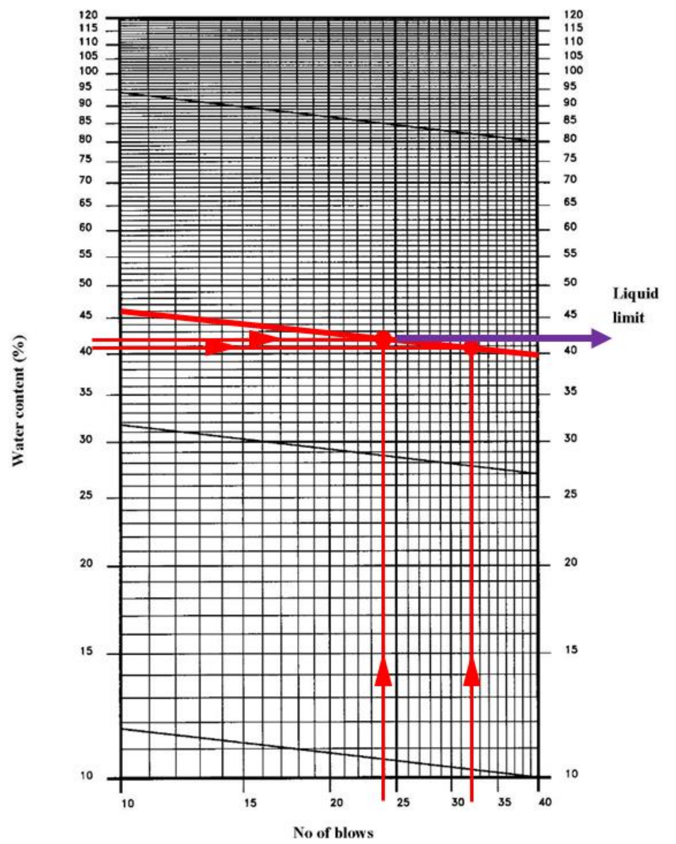
ATTERBERG LIMITS (V). Liquid limit (w_L or LL)



Calculation

Two valid tests are required: one of them between 15 and 25 blows and the other one between 25 and 35 blows.

For each valid test, determine the water content.

Plot on the chart the points representing each test (No of blows vs water content).

Draw a line parallel to those on the chart, passing through the points.

Intersection between that line and the vertical line at 25 blows provides us a new point. Its ordinate is the liquid limit of the soil.

ATTERBERG LIMITS (VI). Liquid limit (w_L or LL)

Calculation. Alternative method.

Instead of using the chart, the mathematical expression below can be used.

Two valid tests are also required. The first one between 20 and 30 blows (N1). In the second one (N1 – 2) ≤ N2 ≤ (N1 + 2).

For each valid test, determine the water content.

Using the expression below, determine the corresponding w_L for each test.

The liquid limit of the soil will be the average.

$$w_L = w \cdot \left(\frac{N}{25}\right)^{0.121}$$

ATTERBERG LIMITS (VII). Plasticity index (I_P or PI)

It is a measure of the range of water content that encompasses the plastic state. In this state, the soil can be easily moulded without cracking or breaking.

$$I_P = w_L - w_P$$

ATTERBERG LIMITS (VII). Consistency index (I_C or CI) and liquidity index (I_L or LI)

It is an indicator of where the natural water content w lies in relation to Atterberg limits.

Table D.3 Consistency and strength for clays

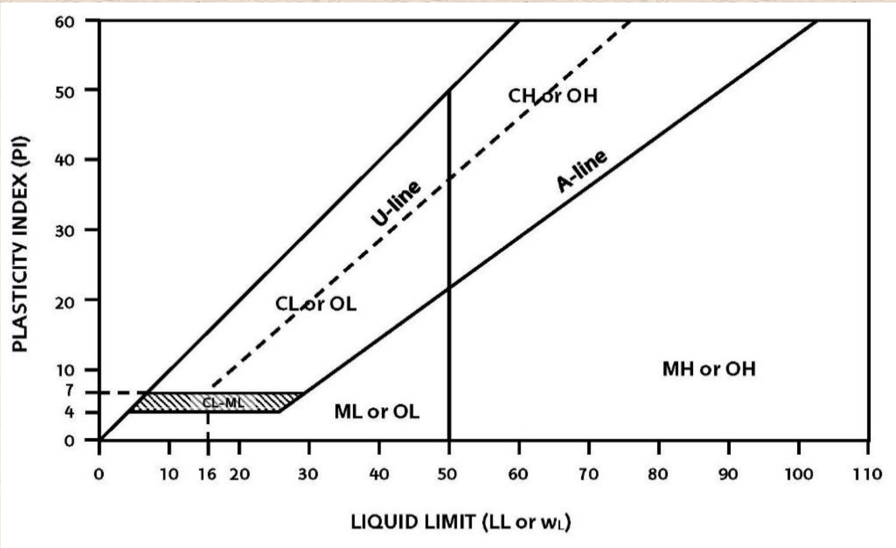
Consistency	CI	Unconfined compressive strength (kPa)
Very soft	0 - 0.25	0 - 25
Soft	0.25 - 0.50	25 - 50
Medium	0.50 - 0.75	50 - 100
Stiff (firm)	0.75 - 1	100 - 200
Very stiff	1 - 1.5	200 - 400
Hard	> 1.5	> 400

Technical Building Code. Foundations.

$$\boxed{I_C = \frac{w_L - w}{w_L - w_P}} \qquad I_L = \frac{w - w_P}{w_L - w_P}$$

In cohesive soils, I_C expression is analogous to that of density index, I_D

CASAGRANDE'S PLASTICITY CHART



Using this chart it is possible to classify the fine particles of a soil. Two data are necessary: the liquid limit and the plasticity index. According to these input data, a name will be assigned to the soil, depending on the area it is placed.

Equation of A-line:

Horizontal at PI = 4 to LL = 25.5, then PI = 0.73·(LL - 20)

Equation of U-line:

Vertical at LL = 16 to PI = 7, then PI = 0.9·(LL – 8)

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

- The Unified Soil Classification System (USCS) is the most common classification system all over the world. It is an all-purpose system and is standardized in ASTM D2487-11.
- Classifications are on the basis of coarse- and fine-grained soils, and retain the four common groupings of soil: gravel, sand, silt and clay.
- The USCS includes the use of a plasticity chart for aiding the classification of fine-grained soils.
- In this course, an Annex is included to classify soils according the USCS.

ROCK AND ROCK MASS CLASSIFICATION (I)

Rock classification systems for engineering purposes

- Geological: sedimentary, igneous and metamorphic.
- According to the unconfined compressive strength: from extremely soft to very hard (lesson 8).
- According to the weathering grade.

Table D.5 Weathering grade of rocks (ISRM)

Grade	Term	Description
I	Fresh rock	No visible sign of matrix weathering; some rock discoloration may be present along main discontinuities.
II	Slightly weathered rock	Discolouration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering and may be somewhat weaker externally than in its fresh conditions.
III	Moderately weathered rock	Slight discoloration extends through the greater part of the rock mass. Discontinuities are stained and/or contain a filling comprising altered materials. Less than half the rock material is decomposed and/or disintegrated to a soil.
IV	Highly weathered rock	More than half of rock matrix is decomposed or disintegrated to soil condition. Fresh or discolored rock is present either as a discontinuous framework or as core stones.
V	Completely weathered rock	All rock material is completely discoloured and converted to soil, but the original mass structure is still visible.
VI	Residual soil	All rocks are transformed into soil. Geological structure of rock mass is destroyed. There is a great volume variation but no significant soil transport is present.

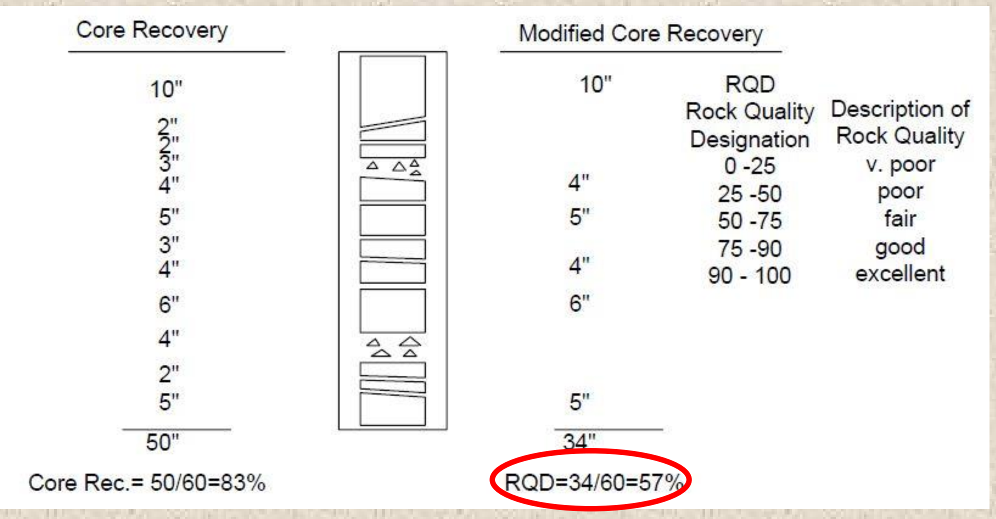
Table from International Society for Rock Mechanics and Rock Engineering (ISRM).

ROCK AND ROCK MASS CLASSIFICATION (II)

Rock mass classifications (I)

❖ Depend on many variables: intact rock properties, characteristics of discontinuities, weathering grade, in situ stresses, groundwater conditions, etc.

❖ Classification according RQD (Rock Quality Designation). ASTM D6032-17.



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ROCK AND ROCK MASS CLASSIFICATION (III)

Rock mass classifications (II)

Geomechanics classifications: Bienawski's RMR (it is used to characterize rock masses and, hence, to apply in the design and construction of any excavation in rock), and Q-system, which is used to estimate tunnel support.

RMR: parameters (Tables D.9 to D.17 TBC.Foundations)

- Uniaxial compressive strength of intact rock (Table D.9).
- RQD (Table D.16).
- Spacing of discontinuities (Table D.13).
- Condition of discontinuities: length or persistence (Table D.15), separation or aperture (Table D.10), roughness (Table D.11), infilling (Table D.12) and weathering (Table D.14).
- Groundwater conditions (Table D.17).
- Orientation of discontinuities.

RMR: input parameters and support table.

By Dr. Arild Palmström MSc and PhD www.rockmass.net.