ΠΑΝΕΠΙΣΤΗΜΙΟ
ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS

«ENGINEERING GEOLOGY»
Department of Geology
Laboratory of Engineering Geology

LABORATORY EXERCISES: Physical properties: Soil Classification

Exercise 4 : Grain Size Analysis (Sieve Method & Hydrometer Method)
Exercise 5 : Plasticity
Exercise 6 : Soil Classification

Engineering Geology Laboratory Notes

SOIL CLASSIFICATION

Why to classify soils;

1. Grouping of soils of similar composition and properties.
2. Provide typical symbology-nomenclature of every soil type (“common language”)
3. **Similar soil types are expected to have similar some physical and mechanical properties.**

Soil Classification Systems.

Group soils according to:

✓ Similar characteristics

Information about

The mechanical behavior of soil

SOIL CLASSIFICATION PROPERTIES

Soil grading

Soil Consistency

Grading

The process of separation of soil in distinct classification classes (grain size groups).
Every grain size group has a certain grain size range (in mm or inches) **Grain size analysis.**

Scope: To find the percent (%) per weight of every grain size group in respect to the total sample weigh.

Use of sieves with standard openings.

Soil Classification Systems

Unified Soil Classification System(USCS)

No.200 (0,075mm) **No.4 (4,75mm)**

Soil grain sizes(mm)		
Coarse soils	Gravel	4,75 - 75
	Sand	0,075 - 4,75
Fine soils	Silt	0,002 - 0,075
	Clay	<0,002

Sieve No. 4 (4,75mm)

+size ⟷ **- size**

Separates gravels from sands, silts and clays.

6,3mm **75mm**

Sive no No. 200 (0,075mm)

+size ⟷ **- size**

Separates gravels and sands from silts and clays

USCS Sieve range (ASTM)	
Sieve No	Sieve opening (mm)
	75,00
	6,30
4	4,75
8	2,36
10	2,00
16	1,18
20	0,85
30	0,60
40	0,43
50	0,30
80	0,18
100	0,15
200	0,075

Grain size analysis

Coarse soil fraction → **Sieve method**

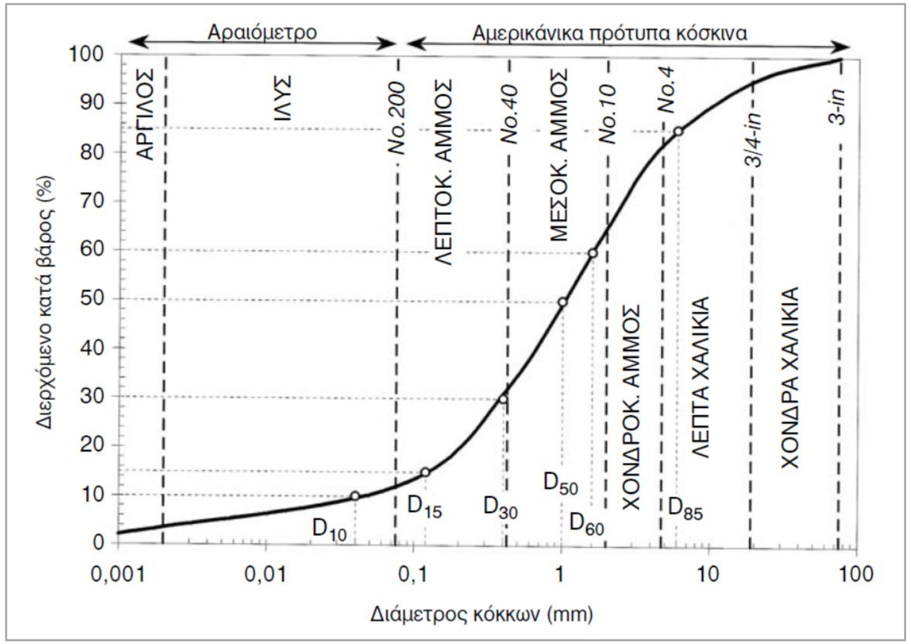
Fine soil fraction → **Hydrometer method**

Grain size curve

Cumulative plot (% passing per weight vs grain size

Semi-log plot

“Particle size – Distribution” curve



Grain size analysis with sieves

Scope

Determination of the Particle Size Distribution

Lab Equipment

Scale
(acc 0.1%)

mortar

Sieves
series

Oven

Test methodology

Lab Procedures - steps:

1. Obtaining – selecting representative soil sample (according to the lab test standard)
2. Drying of sample for 12-24hrs at 100°C
3. Breaking apart of soil clumps with the mortar
4. Accurate weight of the sample.
5. Passing of the sample from the sieve series (from the larger to the smaller opening).
6. The retained weight per sieve is being recorded.
7. Final weight of the weight passes from the smaller sieve (No. 200) (silt and clay)

Results are expressed as a percent in respect to the initial (total) dry weight of the sample

Test methodology

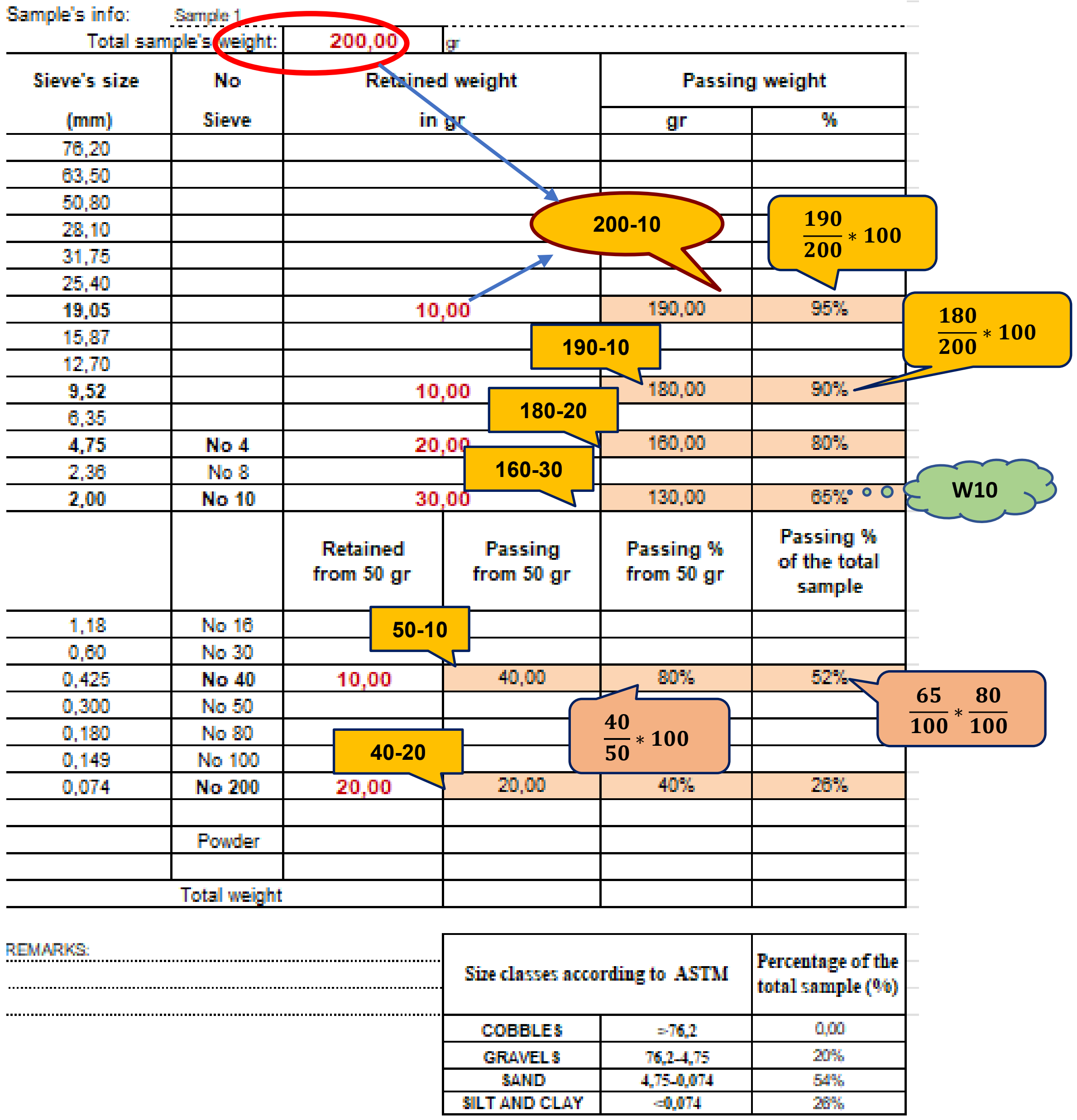
https://youtu.be/8vAeV5aWK3U

Calculations

1. Sample ID - info
2. Total dry weight (gr)
3. Record of the retained dry weight (gr) in 19.05, 9.52, No.4 and No.10 sieves and in % percent /total weight.
4. Record of the retained dry weight (gr) in the No.40 and No.200 sieves from 50gr of sample weight

- The weight passing from every sieve is calculated after subtracting the retained weight from the passing wight of the immediate largest sieve
- The % passing is calculated for both the 50gr of initial weight and after normalizing for the total initial weight.
- For the two smaller siever (No40 and No200) the percent in respect of the total weight is calculated :

$$\boxed{W10\ (\%) * \text{passing of 50gr}\ (\%)}$$



Sample's info: Sample 1
Total sample's weight: 200,00 gr

Sieve's size (mm)	No Sieve	Retained weight in gr	Passing weight gr	Passing weight %
76,20				
63,50				
50,80				
28,10				
31,75				
25,40				
19,05		10,00	190,00	95%
15,87				
12,70				
9,52		10,00	180,00	90%
6,35				
4,75	No 4	20,00	160,00	80%
2,36	No 8			
2,00	No 10	30,00	130,00	65%

		Retained from 50 gr	Passing from 50 gr	Passing % from 50 gr	Passing % of the total sample
1,18	No 16				
0,60	No 30				
0,425	No 40	10,00	40,00	80%	52%
0,300	No 50				
0,180	No 80				
0,149	No 100				
0,074	No 200	20,00	20,00	40%	26%
	Powder				
Total weight					

REMARKS:

Size classes according to ASTM		Percentage of the total sample (%)
COBBLES	>76,2	0,00
GRAVELS	76,2-4,75	20%
SAND	4,75-0,074	54%
SILT AND CLAY	<0,074	26%

Schematic example

Passed

76.2 mm — 100 %

Gravel

100 – 93 = 7% **Gravel**

No.4 4.75 mm — 93 %

Sand

93 – 62 = 31% **Sand**

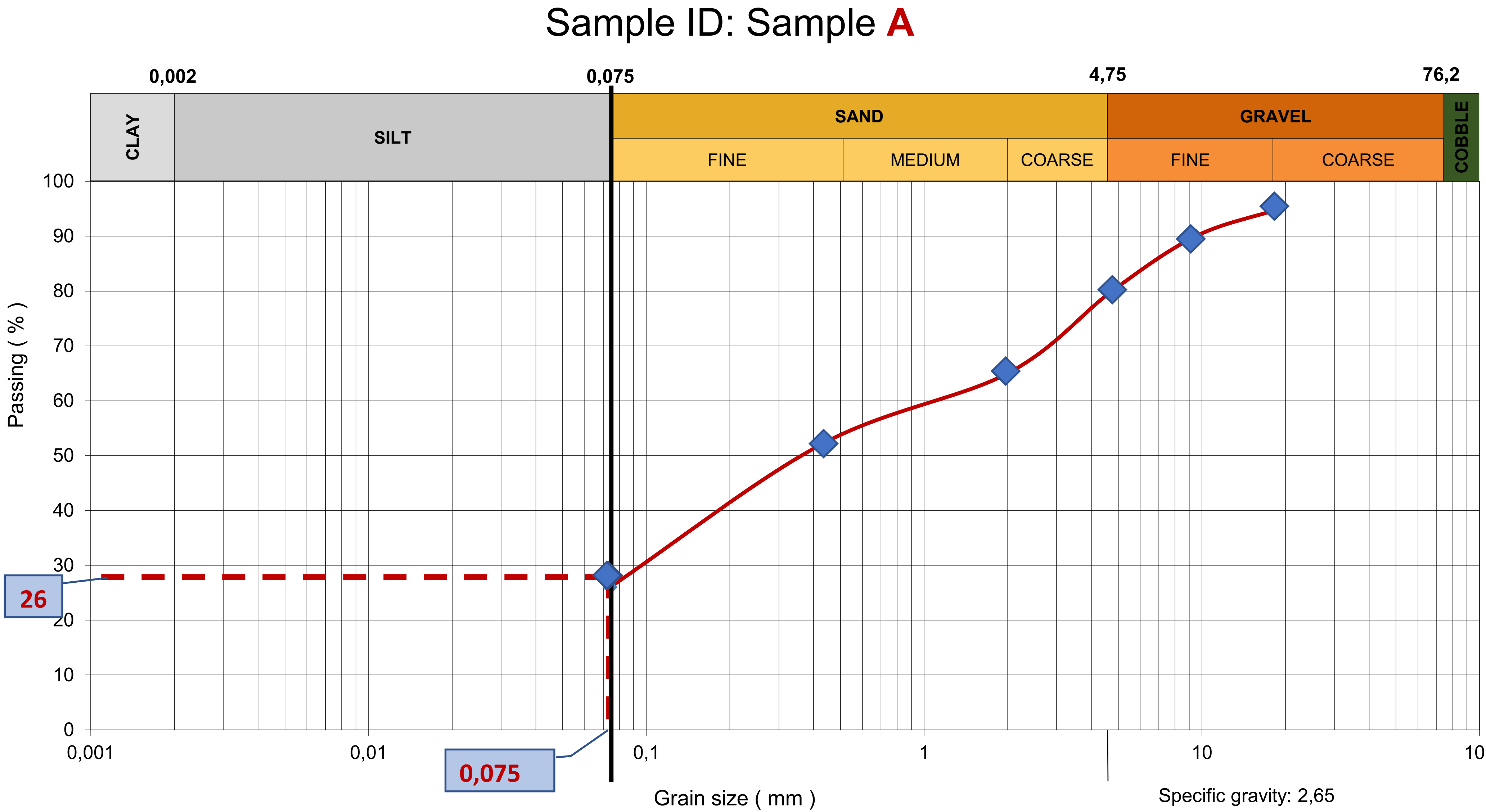
No.200 0.075 mm — 62 %

62 – 0 = 62% **Silt and Clay**

Silt and Clay — 0 %

Grain size distribution curve

%	mm
95	19.05
90	9.52
80	4.75
65	2
52	0.425
26	0.075



GRAIN SIZE ANALYSIS

Coarse soil fraction → **Sieve method**

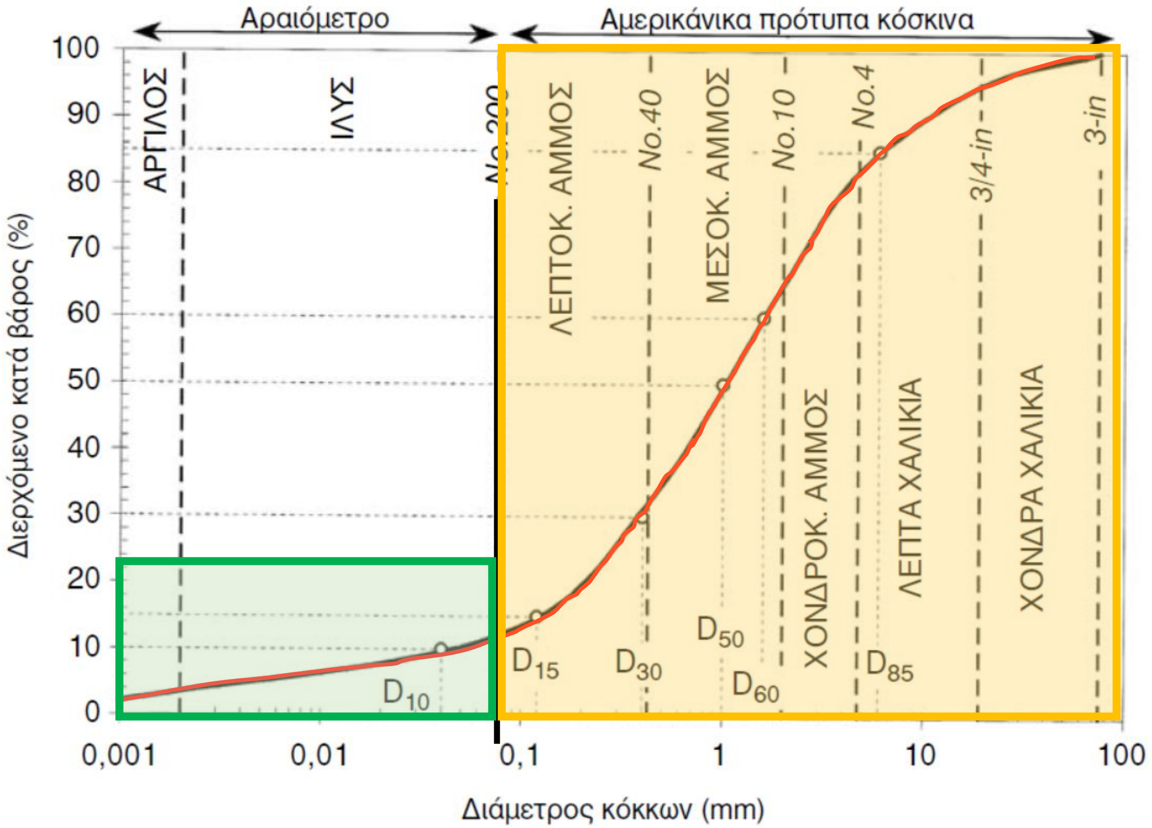
Fine soil fraction → **Hydrometer method**

Grain size distribution plot

Grain size <No200 (<0,075mm):

Cumumative frequency plot

Similar to sieve analysis plot (semi-log scale)



GRAIN SIZE ANALYSIS WITH HYDROMETER

Principe of dispersion: The sedimentation of soil grain in a water medium is being done with different velocities, depending on the shape, the size and the weight of the soil grains.

- Soil grains of the size range **0,0002 – 0,2mm**
- Records are done with a **hydrometer**

Stokes Law

Spherical soil grains with the sedimentation velocity to be function of their maximum diameter

$$d_o = \sqrt{\frac{30nL}{980(Gs-1)t}}$$

a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension.

Where,

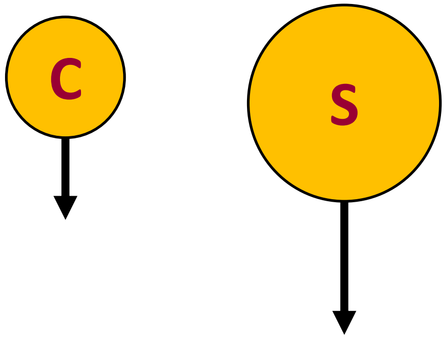
d$_o$: soil grain maximum diameter, in mm

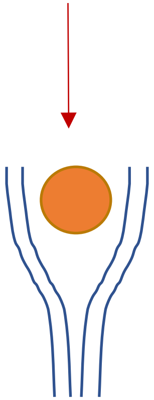
n: viscosity coefficient of the dispersing medium (water), in poises

L: distance from the surface of the suspension to the level at which the density of the suspension is being measured, in cm

t: interval of time from beginning of sedimentation to the taking of the reading, in min

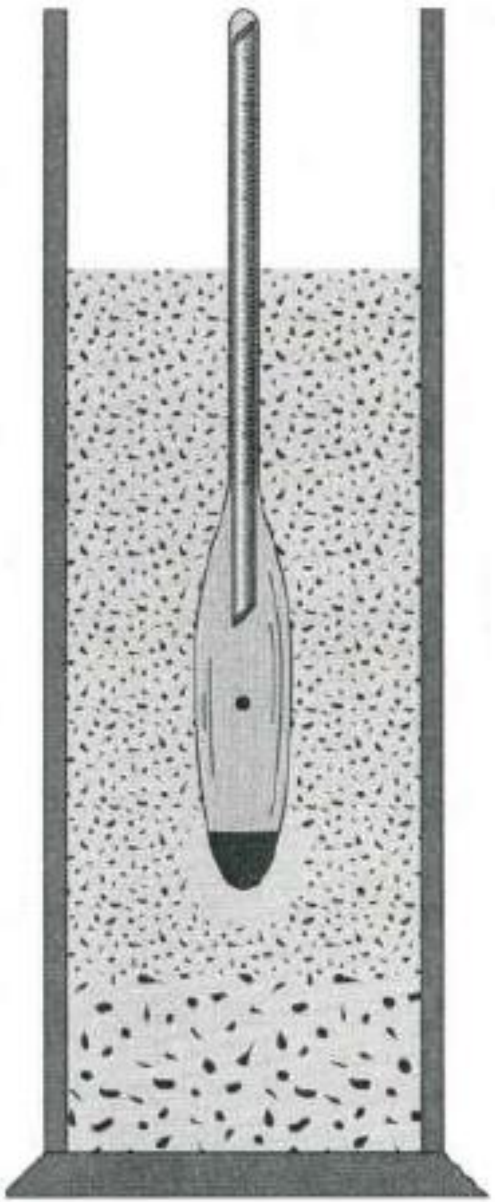
Gs: Soil grains specific gravity





**Silt is settling faster than the clay.

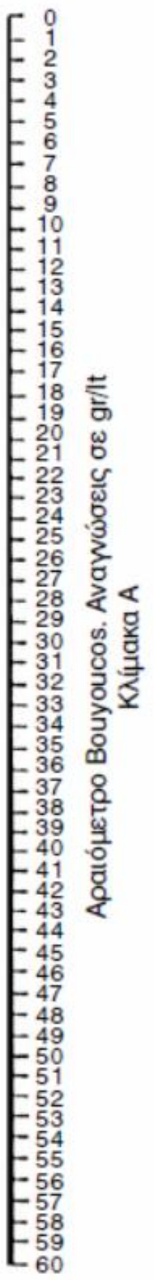
GRAIN SIZE ANALYSIS WITH HYDROMETER



- The Hydrometer records the density of the solid (grains) with are in suspension in the liquid medium (in water).
- It has a cylindrical body and a thin measuring scale
- The scale is divided from 0 έως 60 gr/lt (hydrometer 152H)
- Scale values are asceding from top to bottom of the measuring scale
- Calibration is being done in water of 20°C.

- Provides <u>indirectly</u> the quantity of soil in suspension.
- Calculates the % weight of the soil <u>finer that a defined grain size</u>

Grain size distribution of soil grains finer than 0,075mm



GRAIN SIZE ANALYSIS WITH HYDROMETER

Lab equipment

**Lab scale
acc 0.1%**

**Dispersing
agent e.g.
$Na(PO_3)_6$**

**Dispersion
cup**

**Volumetric
tube 1L**

**Hydromete
r**

**Thermometer
acc. 0,5 °C**

Timer

LABORATORY TEST

Laboratory test steps:

1. Selecting 50gr from the sample passing sieve No10.
2. Selected sample is oven-dried at 60 °C for 24hrs.
3. Any soil cloggings are braken apart in a mortar
4. The specimen is placed in a 250ml beaker, mixed with a solution of 125 ml of dispersing agent (sodium hexametaphosphate) and left for 12 hours.
5. The specimen-agent solution is moved to the dispersion cup
6. Stirring in the dispersion cup for 1min
7. The finally prepared soil suspension is placed in a 1000ml volumetric cylinder (sedimentation cylinder) filled with distilled water until the 1000ml mark.

LABORATORY TEST

8. The volumetric cylinder with the suspension is placed in a water bath of constant temperature (20 °C) until the suspension to maintain the bath’s temperature.
9. After setting of temperature the cylinder is shaked (with vertical motions) for 1 min (the cylinder is covered with a rubber cup during shaking)
10. The exact time of finishing shaking is recorded, and the volumetric cylinder is placed again in the water bath.
11. At this exact time the hydrometer is placed in the suspension and a reading is recorded in 2 min
12. Further readings are recorded in 5,15,30,60,250 and 1440 min
13. In every reading the solution temperature is also recorded.

* If the suspension temperature is different than 20 °C the reading (R) in the hydrometer is corrected (using correction factors from Tables).

LABORATORY TEST

https://youtu.be/JGkpcfgtNFw

CALCULATIONS (1)

- ☐ Sample ID
- ☐ Hydrometer type (152H)
- ☐ Dispersing agent
- ☐ Soil solids Specific Gravity Gs
- ☐ Dry soil weight (Ws) in gr

i. Correction factor "α" for Different Specific Gravities of Soil Particles

$$\alpha = \frac{2.65 - 1}{2.65} * \frac{Gs}{Gs - 1}$$

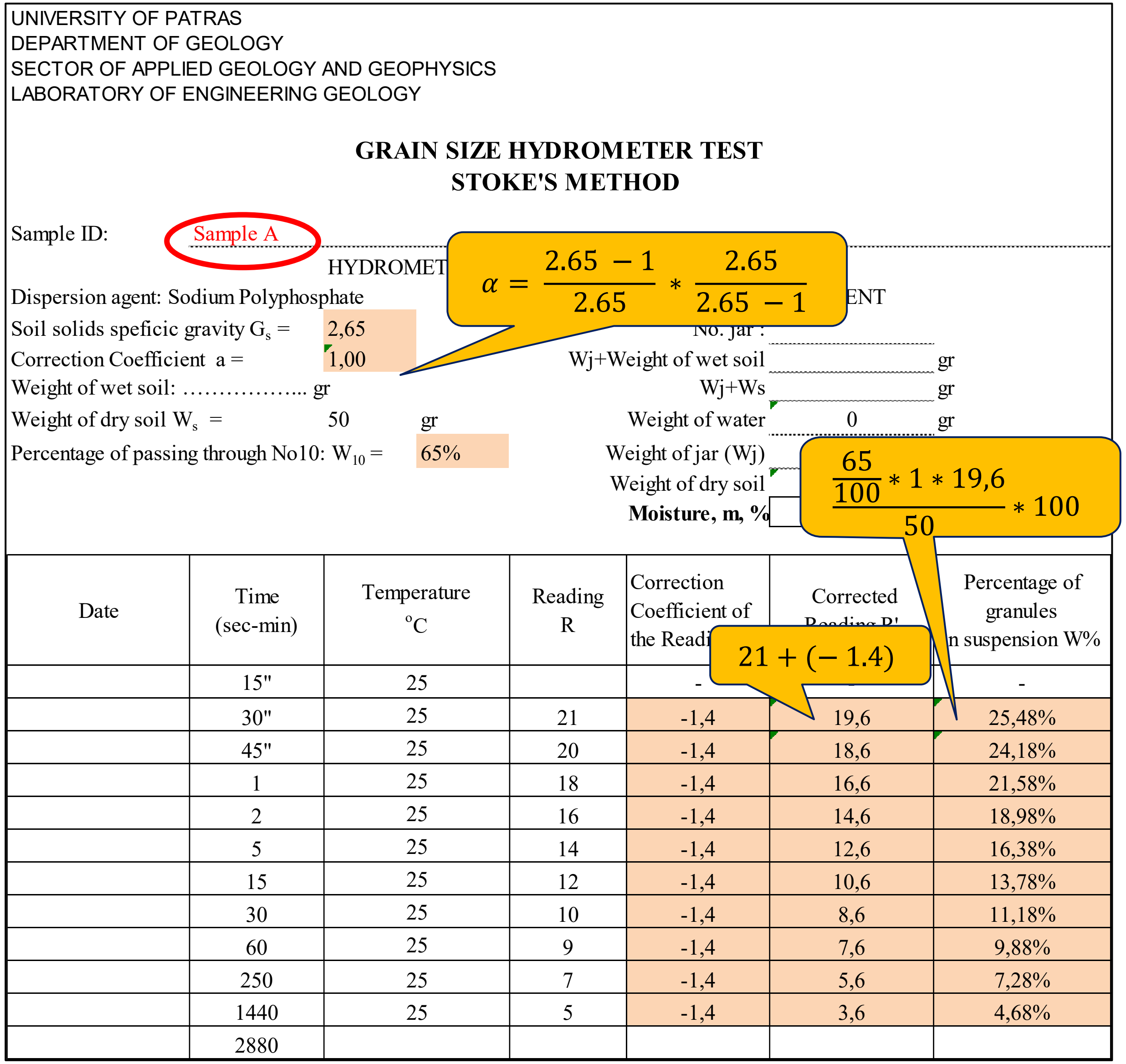
ii. Recording the No10 sieve passing % (W10)

1. **Hydrometer reading correction factor**
2. **Corrected Reading (R') by adding a correction coefficient to the initial reading (temperature correction)**

R' = R + Correction factor

3. **Calculation of the % of soil grains in suspension (W%), meaning the total passed % in respect of the total sample.**

$$W(\%) = \frac{W10(\%) * \alpha * R'}{Ws} * 100$$



UNIVERSITY OF PATRAS
DEPARTMENT OF GEOLOGY
SECTOR OF APPLIED GEOLOGY AND GEOPHYSICS
LABORATORY OF ENGINEERING GEOLOGY

GRAIN SIZE HYDROMETER TEST
STOKE'S METHOD

Sample ID: Sample A

HYDROMET

ENT

Dispersion agent: Sodium Polyphosphate

Soil solids speficic gravity G_s = 2,65

Correction Coefficient a = 1,00

Weight of wet soil: …………….. gr

Weight of dry soil W_s = 50 gr

Percentage of passing through No10: W_{10} = 65%

No. jar :

Wj+Weight of wet soil gr

Wj+Ws gr

Weight of water 0 gr

Weight of jar (Wj)

Weight of dry soil

Moisture, m, %

$$\alpha = \frac{2.65 - 1}{2.65} * \frac{2.65}{2.65 - 1}$$

$$\frac{\frac{65}{100} * 1 * 19,6}{50} * 100$$

$$21 + (-1.4)$$

Date	Time (sec-min)	Temperature °C	Reading R	Correction Coefficient of the Readi	Corrected Reading R'	Percentage of granules n suspension W%
	15"	25		-		-
	30"	25	21	-1,4	19,6	25,48%
	45"	25	20	-1,4	18,6	24,18%
	1	25	18	-1,4	16,6	21,58%
	2	25	16	-1,4	14,6	18,98%
	5	25	14	-1,4	12,6	16,38%
	15	25	12	-1,4	10,6	13,78%
	30	25	10	-1,4	8,6	11,18%
	60	25	9	-1,4	7,6	9,88%
	250	25	7	-1,4	5,6	7,28%
	1440	25	5	-1,4	3,6	4,68%
	2880					

HYDROMETER READING CORRECTION FACTOR

What do we check;

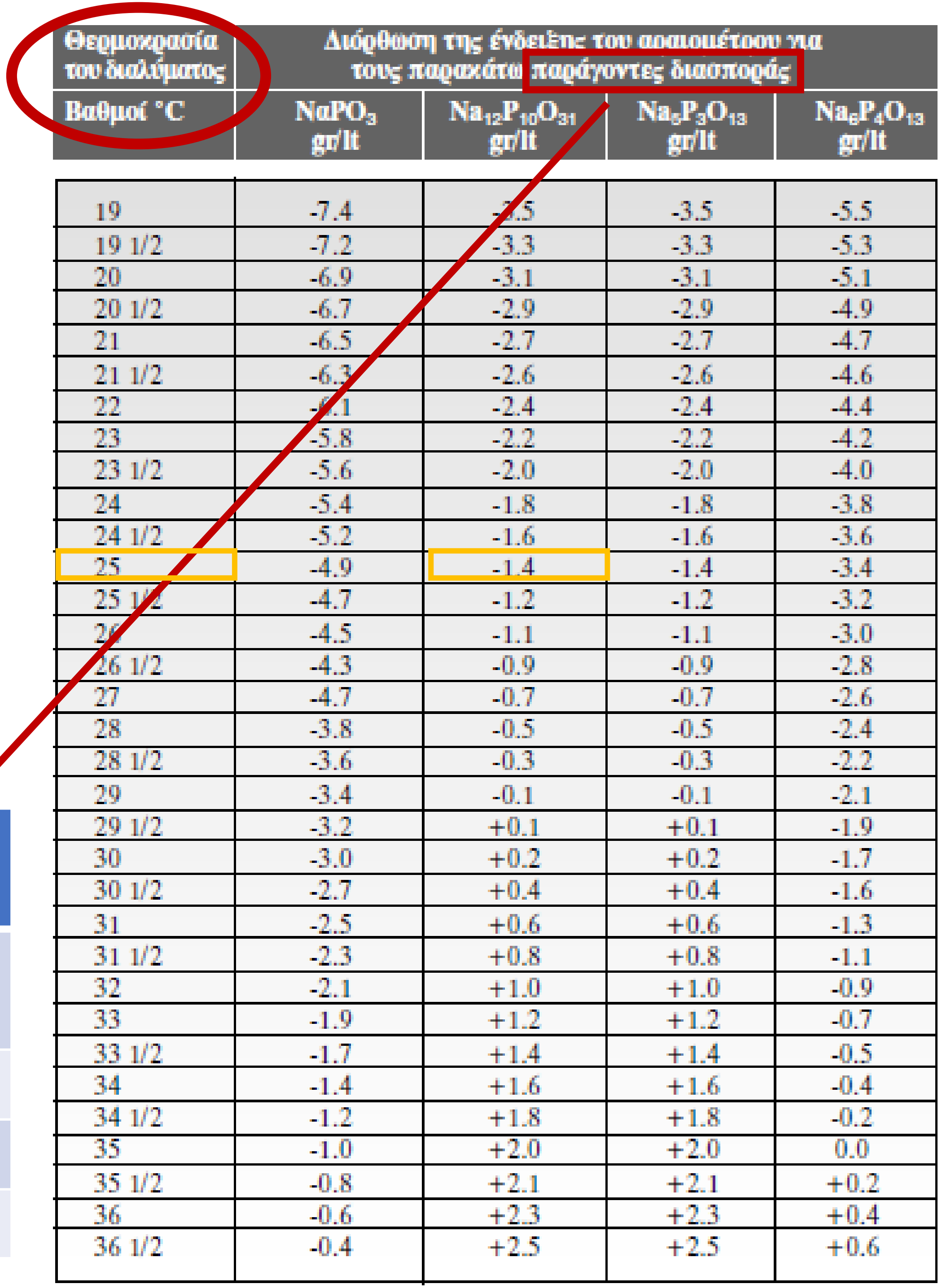
- Suspension temperature at every reading (°C)
- Type of dispersion agent

What we are looking for;

- The correction coefficient for our hydrometer type (e.g. 152H) in order to correct the initial reading.

Why we are doing this correction;

- To correct the initial reading to the reading in 20 (°C)



Θερμοκρασία του διαλύματος	Διόρθωση της ένδειξης του αραιομέτρου για τους παρακάτω παράγοντες διασποράς			
Βαθμοί °C	$NaPO_3$ gr/lt	$Na_{12}P_{10}O_{31}$ gr/lt	$Na_5P_3O_{13}$ gr/lt	$Na_6P_4O_{13}$ gr/lt
19	-7.4	-3.5	-3.5	-5.5
19 1/2	-7.2	-3.3	-3.3	-5.3
20	-6.9	-3.1	-3.1	-5.1
20 1/2	-6.7	-2.9	-2.9	-4.9
21	-6.5	-2.7	-2.7	-4.7
21 1/2	-6.3	-2.6	-2.6	-4.6
22	-6.1	-2.4	-2.4	-4.4
23	-5.8	-2.2	-2.2	-4.2
23 1/2	-5.6	-2.0	-2.0	-4.0
24	-5.4	-1.8	-1.8	-3.8
24 1/2	-5.2	-1.6	-1.6	-3.6
25	-4.9	-1.4	-1.4	-3.4
25 1/2	-4.7	-1.2	-1.2	-3.2
26	-4.5	-1.1	-1.1	-3.0
26 1/2	-4.3	-0.9	-0.9	-2.8
27	-4.7	-0.7	-0.7	-2.6
28	-3.8	-0.5	-0.5	-2.4
28 1/2	-3.6	-0.3	-0.3	-2.2
29	-3.4	-0.1	-0.1	-2.1
29 1/2	-3.2	+0.1	+0.1	-1.9
30	-3.0	+0.2	+0.2	-1.7
30 1/2	-2.7	+0.4	+0.4	-1.6
31	-2.5	+0.6	+0.6	-1.3
31 1/2	-2.3	+0.8	+0.8	-1.1
32	-2.1	+1.0	+1.0	-0.9
33	-1.9	+1.2	+1.2	-0.7
33 1/2	-1.7	+1.4	+1.4	-0.5
34	-1.4	+1.6	+1.6	-0.4
34 1/2	-1.2	+1.8	+1.8	-0.2
35	-1.0	+2.0	+2.0	0.0
35 1/2	-0.8	+2.1	+2.1	+0.2
36	-0.6	+2.3	+2.3	+0.4
36 1/2	-0.4	+2.5	+2.5	+0.6

Dispersing Agent	gr of agent per 1000ml of solution	Chemical Formula
sodium hexametaphosphate	45,7	$NaPO_3$ (or $NaPO_3)_6$
sodium polyphosphate	21,6	$Na_{12}P_{10}O_{31}$
sodium triphosphate	18,8	$Na_5P_3O_{10}$
sodium tetraphosphate	31,5	$Na_6P_4O_{13}$

CALCULATIONS (2)

The maximum soil grain diameter (do) in suspension (under specific conditions) correspond to certain sedimentation time.

Specific Conditions:

- ❑ Fixed distance of sedimentation (vertical distance L during sedimentation = 17.5cm.
- ❑ Water as sedimentation medium voscocity index “n” = 0,01005 poise (at 20 °C).
- ❑ Specific gravity of soil solds: Gs: 2.65

So, the actual sedimentation diameters **must be corrected** according to the test conditions by applying correction coefficients.

Correction factors “K” (from Tables) :

- **K_n :** viscosity coefficient (according to the liquid i.e. water**)**
- **K_L :** length coefficient (compensating the uplift of the pycnometer in the suspension)
- **K_G :** Specific gravity coefficient

❖ **Υπολογισμός της διαμέτρου των κόκκων σε αιώρηση d’**

$$d' = do * KG * KL * Kn$$

Calculation of grain size diameter

Time (sec-min)	Maximum grain diameter d_o (mm)	**K_n (according to °C)**	**K_L (according to R)**	**K_G (according to Gs)**	**Grain diameter in suspension d' (mm)**
15"	0,11	-	-	-	-
30"	0,08	0,935	0,890	1	0,0666
45"	0,065	0,935	0,897	1	0,0545
1	0,058	0,935	0,911	1	0,0494
2	0,041	0,935	0,924	1	0,0354
5	0,026	0,935	0,938	1	0,0228
15	0,015	0,935	0,950	1	0,0133
30	0,011	0,935	0,962	1	0,0099
60	0,0074	0,935	0,967	1	0,0067
250	0,0037	0,935	0,979	1	0,0034
1440	0,0015	0,935	0,990	1	0,0014
2880	0,00106	-	-	-	

$0{,}08 * 0{,}935 * 0{,}890 * 1$

CORRECTION COEFFICIENTS

What do we check?

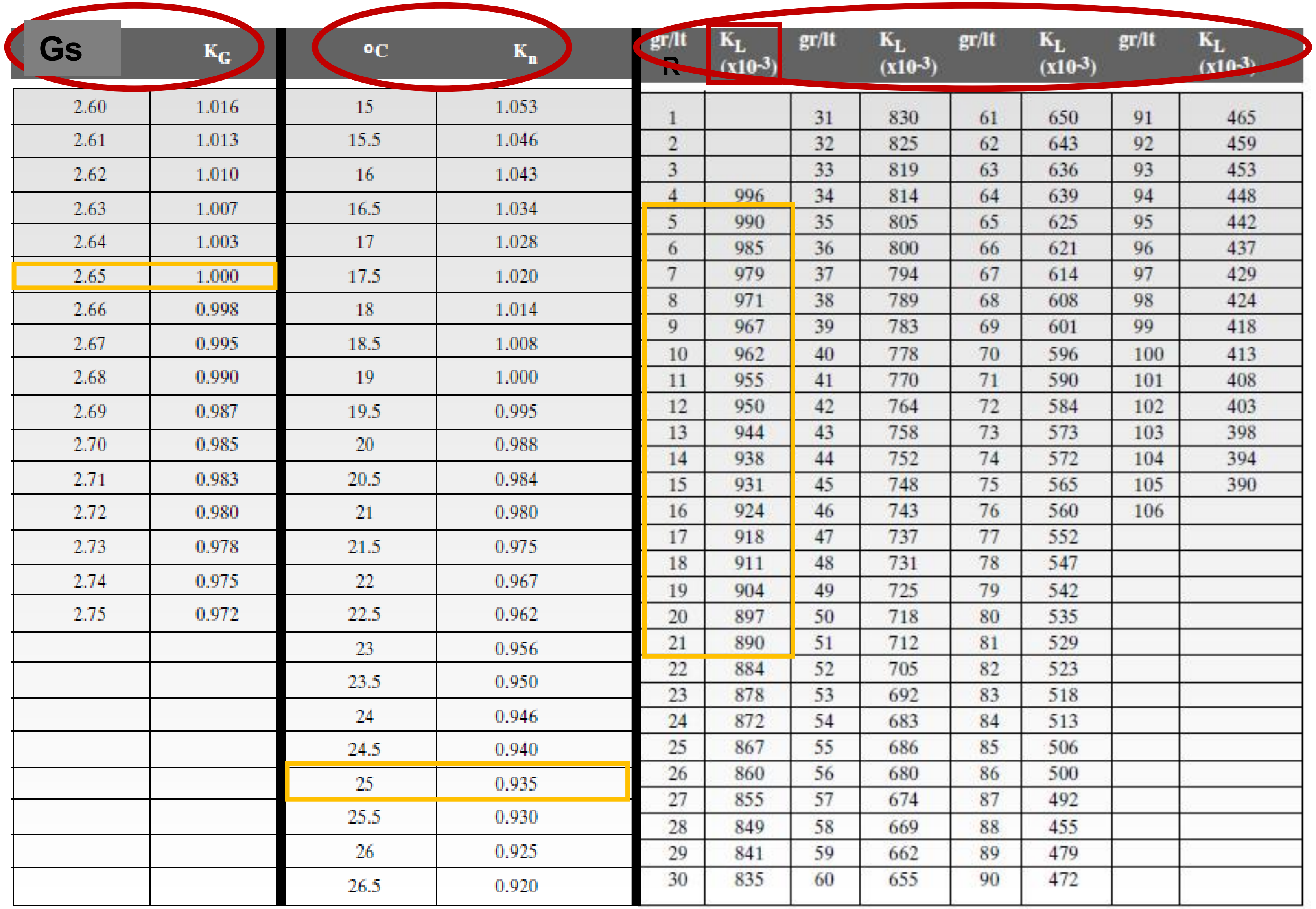
- Sample’s Spec. Gravity (Gs)
- Sunspension temperature (°C)
- Pycnometer Reading R (gr/lt)

What do we find?

- K_G
- K_n
- K_L

Why are we doing this?

- To calculate the correct soil grain diameter (d’) in suspension



Gs	K_G
2.60	1.016
2.61	1.013
2.62	1.010
2.63	1.007
2.64	1.003
2.65	1.000
2.66	0.998
2.67	0.995
2.68	0.990
2.69	0.987
2.70	0.985
2.71	0.983
2.72	0.980
2.73	0.978
2.74	0.975
2.75	0.972

°C	K_n
15	1.053
15.5	1.046
16	1.043
16.5	1.034
17	1.028
17.5	1.020
18	1.014
18.5	1.008
19	1.000
19.5	0.995
20	0.988
20.5	0.984
21	0.980
21.5	0.975
22	0.967
22.5	0.962
23	0.956
23.5	0.950
24	0.946
24.5	0.940
25	0.935
25.5	0.930
26	0.925
26.5	0.920

gr/lt R	K_L ($x10^{-3}$)	gr/lt	K_L ($x10^{-3}$)	gr/lt	K_L ($x10^{-3}$)	gr/lt	K_L ($x10^{-3}$)
1		31	830	61	650	91	465
2		32	825	62	643	92	459
3		33	819	63	636	93	453
4	996	34	814	64	639	94	448
5	990	35	805	65	625	95	442
6	985	36	800	66	621	96	437
7	979	37	794	67	614	97	429
8	971	38	789	68	608	98	424
9	967	39	783	69	601	99	418
10	962	40	778	70	596	100	413
11	955	41	770	71	590	101	408
12	950	42	764	72	584	102	403
13	944	43	758	73	573	103	398
14	938	44	752	74	572	104	394
15	931	45	748	75	565	105	390
16	924	46	743	76	560	106	
17	918	47	737	77	552		
18	911	48	731	78	547		
19	904	49	725	79	542		
20	897	50	718	80	535		
21	890	51	712	81	529		
22	884	52	705	82	523		
23	878	53	692	83	518		
24	872	54	683	84	513		
25	867	55	686	85	506		
26	860	56	680	86	500		
27	855	57	674	87	492		
28	849	58	669	88	455		
29	841	59	662	89	479		
30	835	60	655	90	472		

FORMULAS (sum up)

What do we calculate:

- Correction coefficient (α)
- Corrected pycnometer reading (R')
- Percent of soil grains in suspension (W%)
- Diameter of soil in suspension (d')

$$\alpha = \frac{2.65\ -1}{2.65} * \frac{Gs}{Gs\ -1}$$

$$\mathrm{R' = R + Correction\ coefficient}$$

$$W(\%) = \frac{W10 * \alpha\ * R'}{Ws}$$

$$d' = do\ * \ K_G\ * \ KL\ * K_n$$

What do we find from Tables:

- Correction Coefficient according to the pycnometer type (e.g. 152H)
- Correction coeffients Kn , K_L , K_G

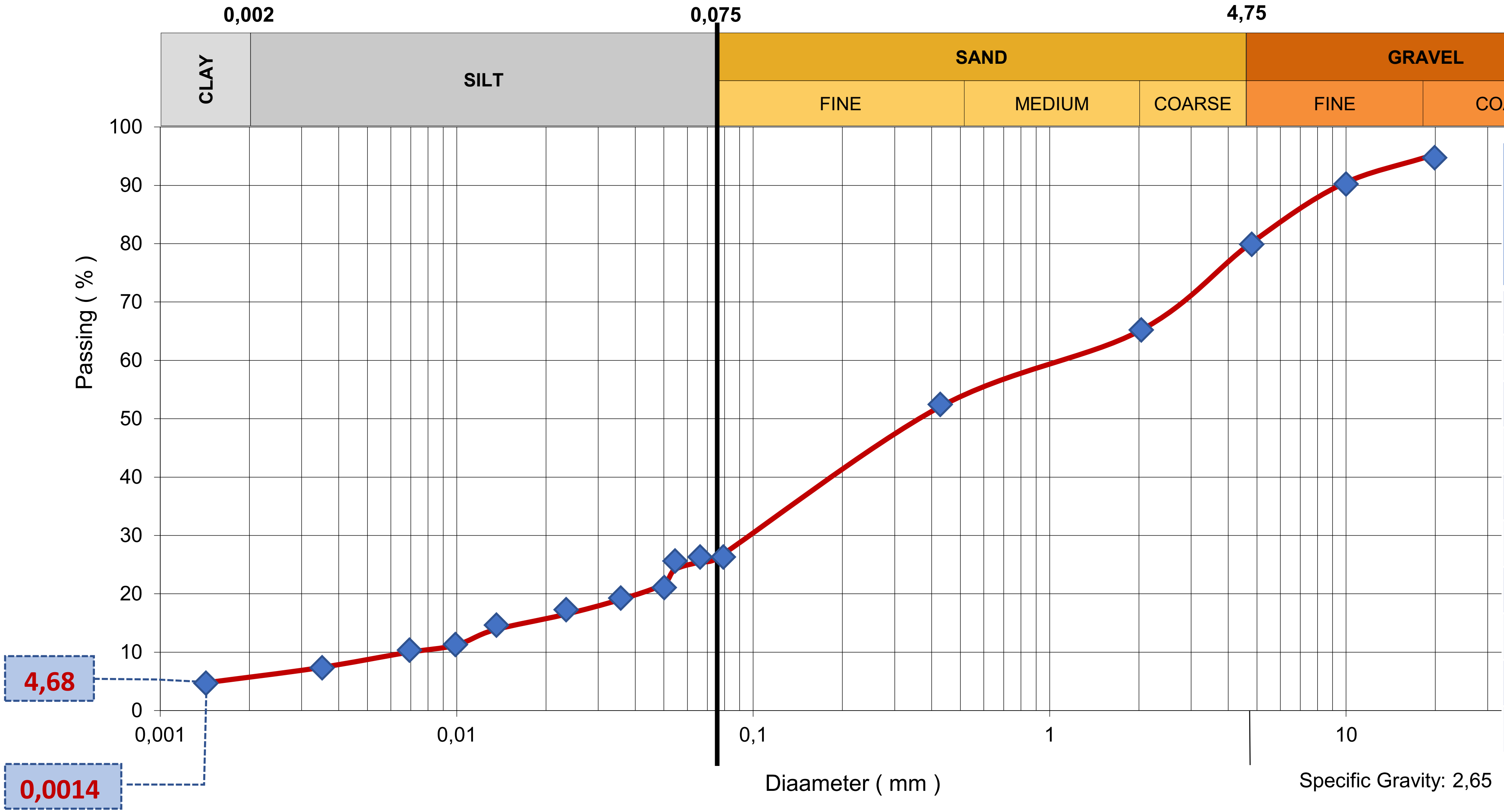
What data do we need to complete the grain-size distribution curve?

- Percent of soil grain (W%) → (as "passing") an in respect to the total sample
- Soil grain size (diameter, d')

Grain size (d' ,mm)	Percent (per weight) (%)
0,0666	25,48
0,0545	24,18
0,0494	21,58
0,0354	18,98
0,0228	16,38
0,0133	13,78
0,0099	11,18
0,0067	9,88
0,0034	7,28
0,0014	4,68

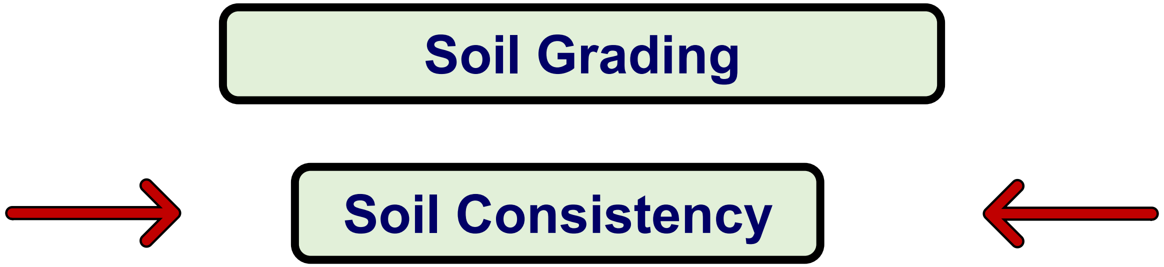
Grain size distribution curve

Sample ID: **Sample A**



Grain size (mm)	Percent (%)
0,0666	25,48
0,0545	24,18
0,0494	21,58
0,0354	18,98
0,0228	16,38
0,0133	13,78
0,0099	11,18
0,0067	9,88
0,0034	7,28
0,0014	4,68

SOIL CLASSIFICATION PROPERTIES



Soil Grading

→ Soil Consistency ←

Soil consistency

Resistance of a fine-grained soil to mechanical stress and manipulation

- Under different water moisture
- Without being ruptured

It reflects the amount of water which is absorbed around the clayey-size soil particles.

Consitency depends on

- Soil moisture (w %)
- Percent of clay minerals
- Types of clay minerals
- Organic matter (%)

Response of a fine soil in the change of its moisture content.

CONSISTENCY INDICES

Soil Consistency states:

Criterion: Percent of moisture content (w, %)

Liquid — Plastic — Semi-solid — Solid

Soil consistency Limits (or “Atterberg” limits)

Values of soil moisture (w, %) among the above soil consistency states

- Liquid Limit (**LL**)
- Plastic Limit (**PL**)
- Shrinkage Limit (**SL**)

Reducing of moisture content (w, %) →

LL — PL — SL

Soil consistency Indices

- Plasticity Index **PI**
- Liquidity Index **LI**
- Consistency Index **Ic**
- Shrinkage Index **Is**

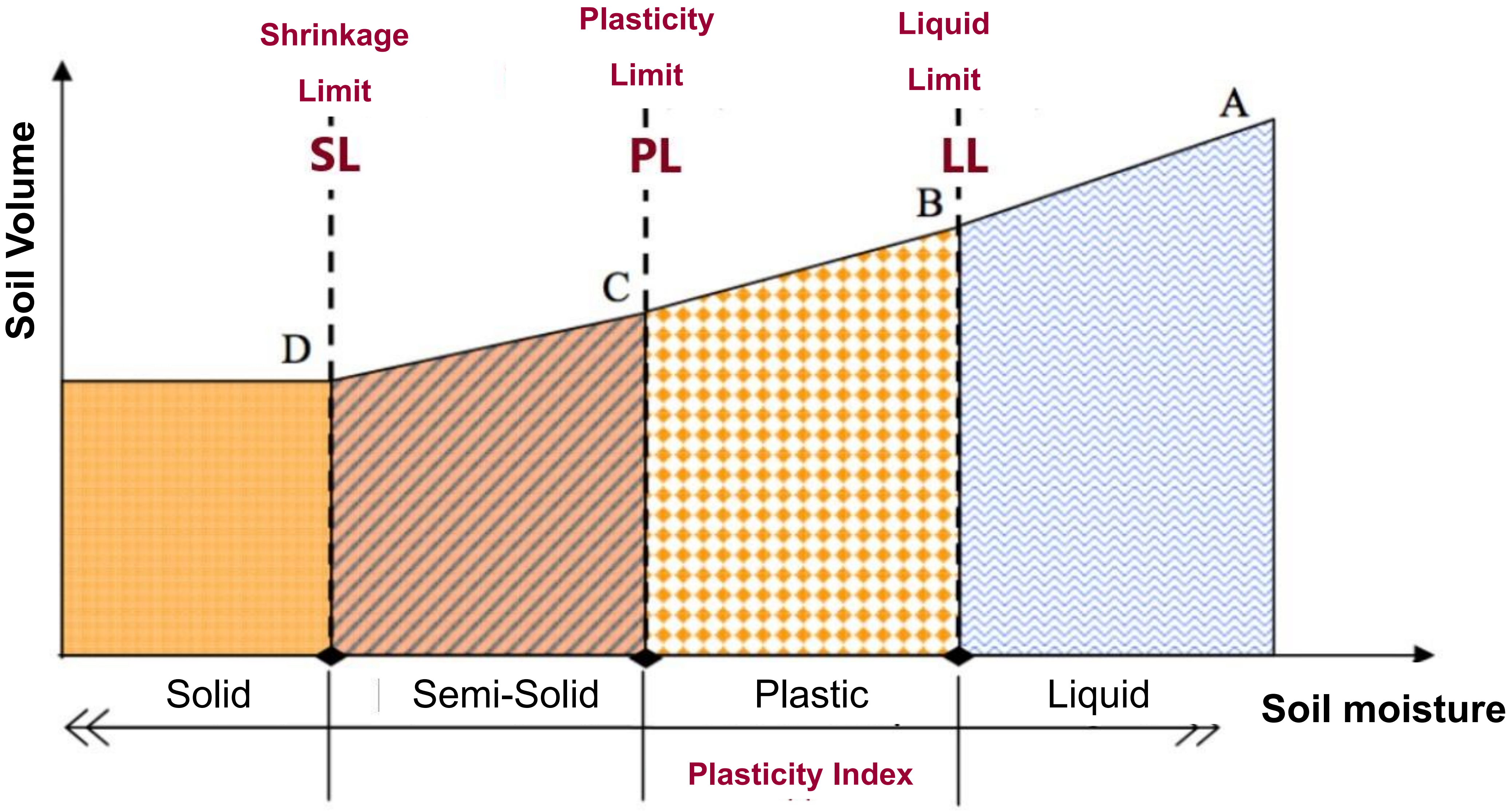
$$PI = LL - PL$$

$$LI = (w - PL)/PI$$

$$Ic = (LL - w)/PI$$

$$Is = PL - SL$$

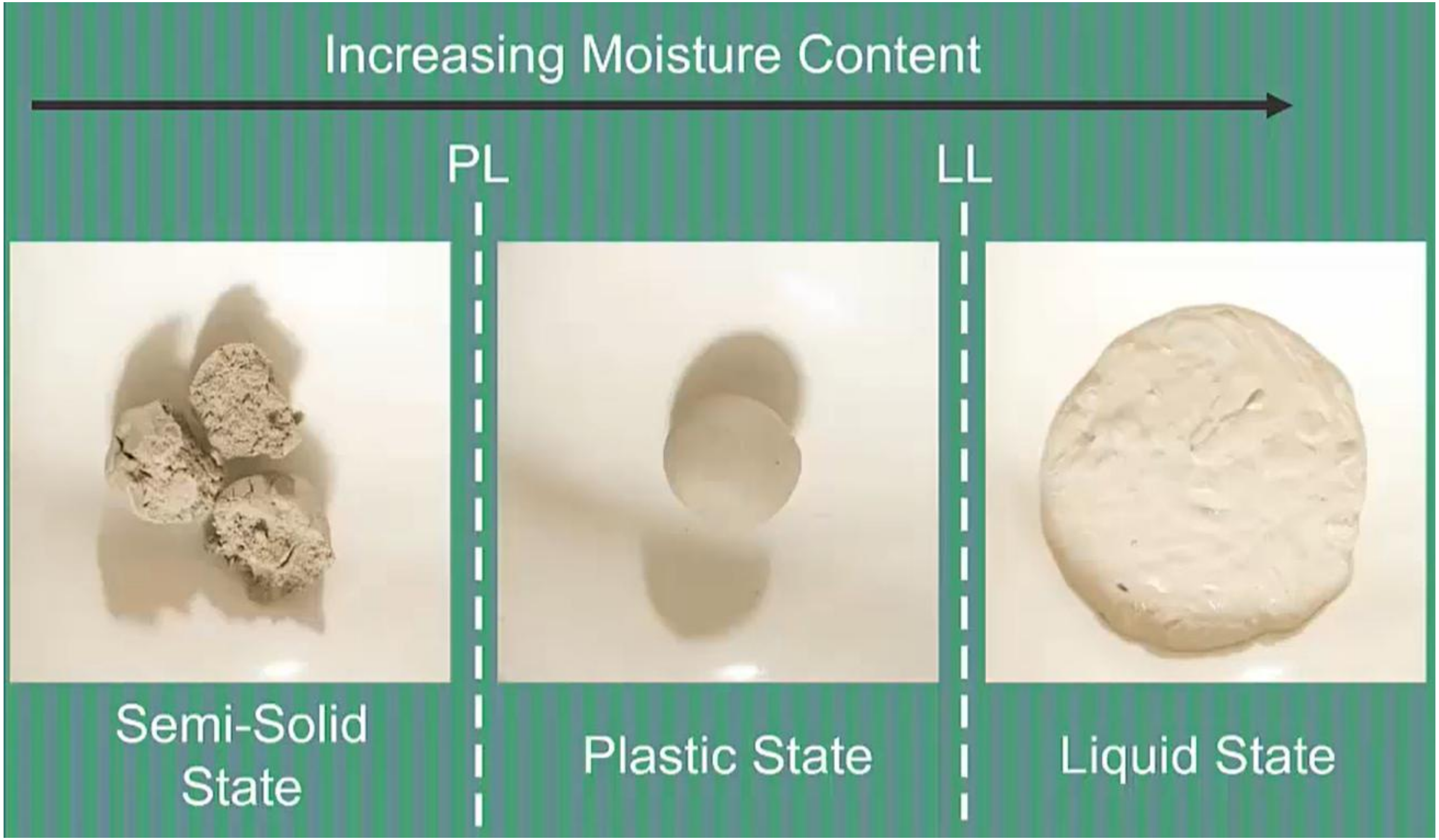
VOLUMETRIC CHANGE OF SOIL



PI = LL - PL

**In natural soils usually PL< w <LL

CONSISTENCY STATES



PLASTICITY INDEX

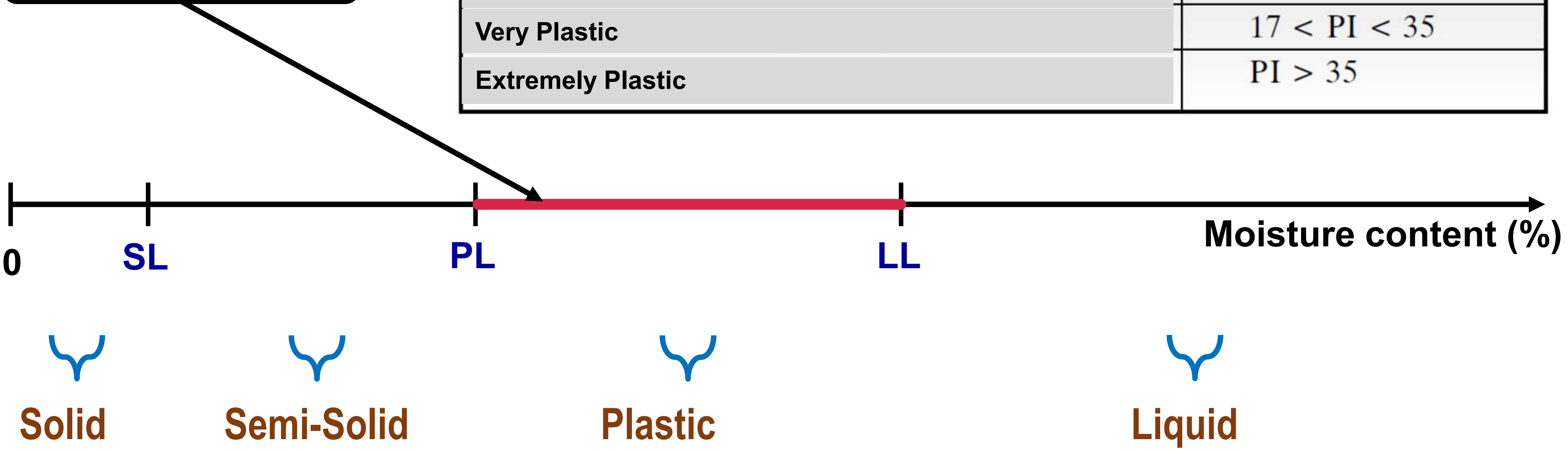
Plasticity Index (PI)

The range of moisture content where the soil has plastic properties and behave as plastic.

- Soil strength is inversely proportional to the values of PI

$$PI = LL - PL$$

No Plastic	$PI < 1$
Low Plastic	$1 < PI < 7$
Medium Plastic	$7 < PI < 17$
Very Plastic	$17 < PI < 35$
Extremely Plastic	$PI > 35$



0 **SL** **PL** **LL**

Moisture content (%)

Solid **Semi-Solid** **Plastic** **Liquid**

LABORATORY DETEMRINATION OF CONSISTENCY LIMITS

Objective

Determination of Liquid Limit (LL) with Casagrande apparatus, of Plasticity Limit (PL) and of the Plasticity Index PI

(test only in fine soils)

Lab equipment

Scale
acc 0.1%

Mortar

Casagrande apparatus

Dish for drying

Lab oven

LAB TEST PROCEDURE (LL and PL)

https://youtu.be/I2IF6Gz4aw8

LAB TEST PROCEDURE (LL)

Steps of lab test for the determination of Liquid Limit LL:

1. Selection of representative soil sample (ws= 100gr) passing from No40 sieve
2. Sample must have been dried at 60°C
3. Breaking apart any soil clogging in the mortar
4. Place the sample in porcelane container (small bowl), gradually adding distilled water and manipulate the sample.
5. Manipulating the sample in order to produce a thick and moist soil mass.
6. A portion of the sample is placed in the Casagrande’s device cup and it is flattened (with a spatula) so the maximum thickness of the soil in the cup be 1cm.
7. The prepared soil in the cup is half-splitted with a special flat grooving tool to provide a certain separation line in the middle of the sample
8. The device is mechanically moved up and down (with a Cam) making the cup to stroke from 1cm height gauge.
9. The number of strokes is recorded until the split-line of the sample is closed.

LAB TEST PROCEDURE (LL)

- The same procedure is repeated at least three (3) times (in three different specimens) with 3 different moisture contents (multipoint-method A, ASTM D-4318).
- Acceptable range of Casagrande device strokes (N) is generally between 15 and 35. ➡

Specimen 1: 25<N<35
Specimen 2: 20<N<30
Specimen 3: 15<N<25

- The moisture content in respect to the Casagrande blows is plotted in a semi-log plot.
- The interpolation straight line of the test points (blows, w%) is designed, which is called **flow curve**
- The moisture content which corresponds to <u>25 strokes is the Liquid Limit.</u>

Liquid Limit is the moisture content at which the groove line is closed at a length of approx. <u>13mm (12.7mm)</u> for 25 strokes.

ASTM D-4318

LAB TEST PROCEDURE (PL)

Lab methodology for the laboratory determination of Plasticity Limit (PL):

1. Selection of approximately 20gr from the same prepared sample
2. The sample is placed in a porcelane bowl and distilled water is gradually added.
3. The moist soil mass is manipulated forming a plastic mass into a small ball.
4. 8grs of soil is selected and is slightly squeezed to make it cylindrical.
5. The cylindrical mass is placed on a glass surface and is rolled by hand to form thin soil roll.
6. When the sample roll is 3mm without being fractured, it is breaked in 6-8 small pieces, manipulated again in hand and rolled again.
7. The process (5-6) is repeated until the soil roll starts to break when diameter is 3 mm.

LAB TEST PROCEDURE (PL)

Lab methodology for the laboratory determination of Plasticity Limit (PL):

8. All parts of the broker soil roll are placed in a lab disk (of known weight).
9. The disk with the sample is weighted.
10. Sample + disk are dried in the lab oven at 110°C
11. Dry soil is weighted.
12. The “loss of water” after drying is the moisture content
13. The average of the moisture content of at least 2 specimens of the same sample is the soil’s Plasticity Limit.

The Plasticity Limit represents the moisture content of the breaked soil rolls of 3mm diameter.

CALCULATIONS

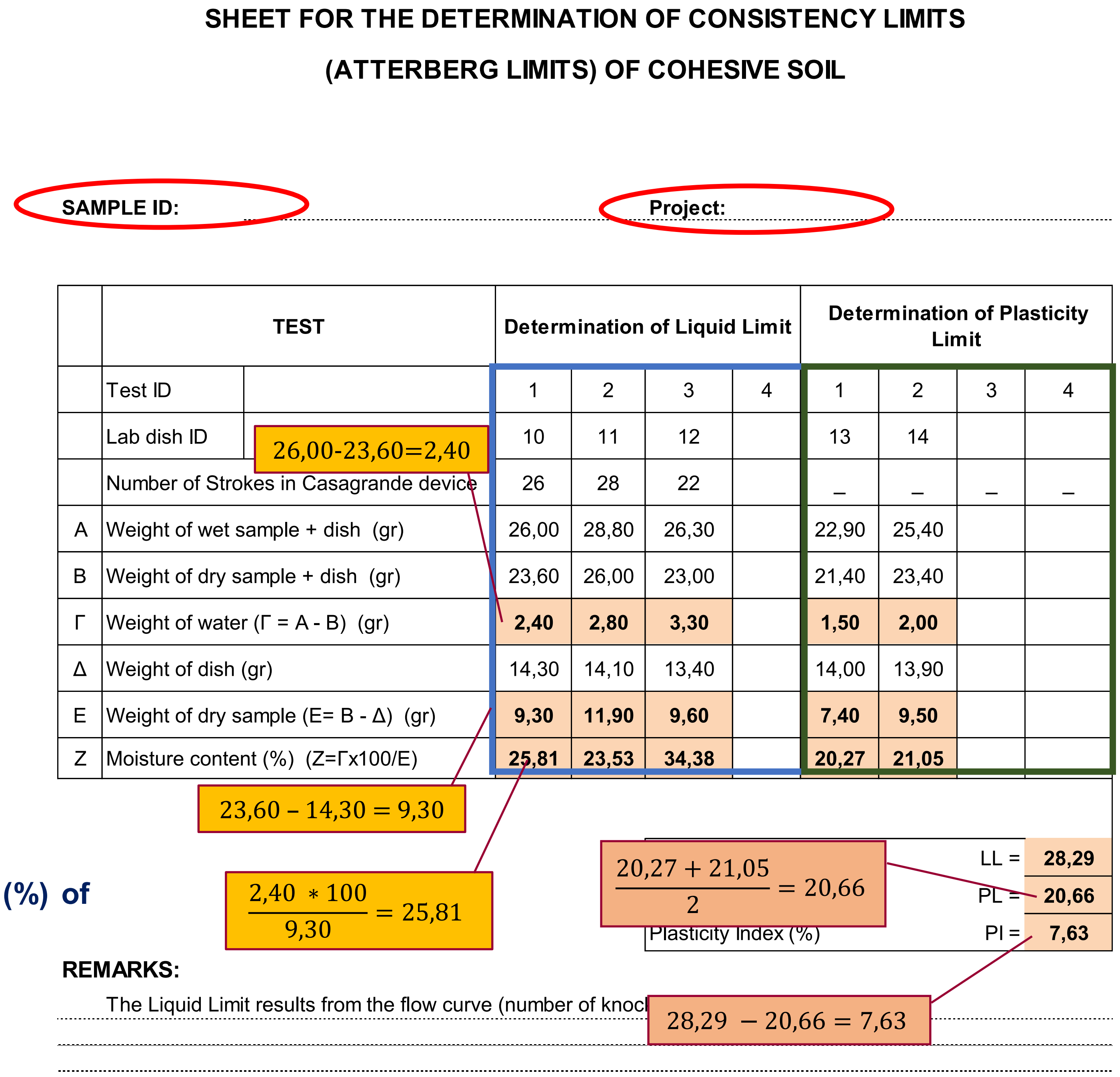
1. Test ID
2. Dish (container) ID
3. Sample Data (eg Project)
4. Number of strokes counted in Casagrande Device
5. Weight of wet sample + container (gr)
6. Weight of dry sample + container (gr)
7. Weight of container (gr)

We initially calculate (per specimen):

- Weight of water (gr)
- The weight of dry sample (gr)
- The moisture content (%)

We finally calculate:

- The Plastic Limit as the average of the moisture contents (%) of the tested specimens.
- The Liquid Limit from the flow curve (see next slide)
- The Plasticity Index as PI = LL - PL



SHEET FOR THE DETERMINATION OF CONSISTENCY LIMITS

(ATTERBERG LIMITS) OF COHESIVE SOIL

SAMPLE ID: **Project:**

	TEST	**Determination of Liquid Limit**				**Determination of Plasticity Limit**			
	Test ID	1	2	3	4	1	2	3	4
	Lab dish ID	10	11	12		13	14		
	Number of Strokes in Casagrande device	26	28	22		_	_	_	_
A	Weight of wet sample + dish (gr)	26,00	28,80	26,30		22,90	25,40		
B	Weight of dry sample + dish (gr)	23,60	26,00	23,00		21,40	23,40		
Γ	Weight of water (Γ = A - B) (gr)	**2,40**	**2,80**	**3,30**		**1,50**	**2,00**		
Δ	Weight of dish (gr)	14,30	14,10	13,40		14,00	13,90		
E	Weight of dry sample (E= B - Δ) (gr)	**9,30**	**11,90**	**9,60**		**7,40**	**9,50**		
Z	Moisture content (%) (Z=Γx100/E)	**25,81**	**23,53**	**34,38**		**20,27**	**21,05**		

26,00-23,60=2,40

$23,60 - 14,30 = 9,30$

$$\frac{2,40 * 100}{9,30} = 25,81$$

$$\frac{20,27 + 21,05}{2} = 20,66$$

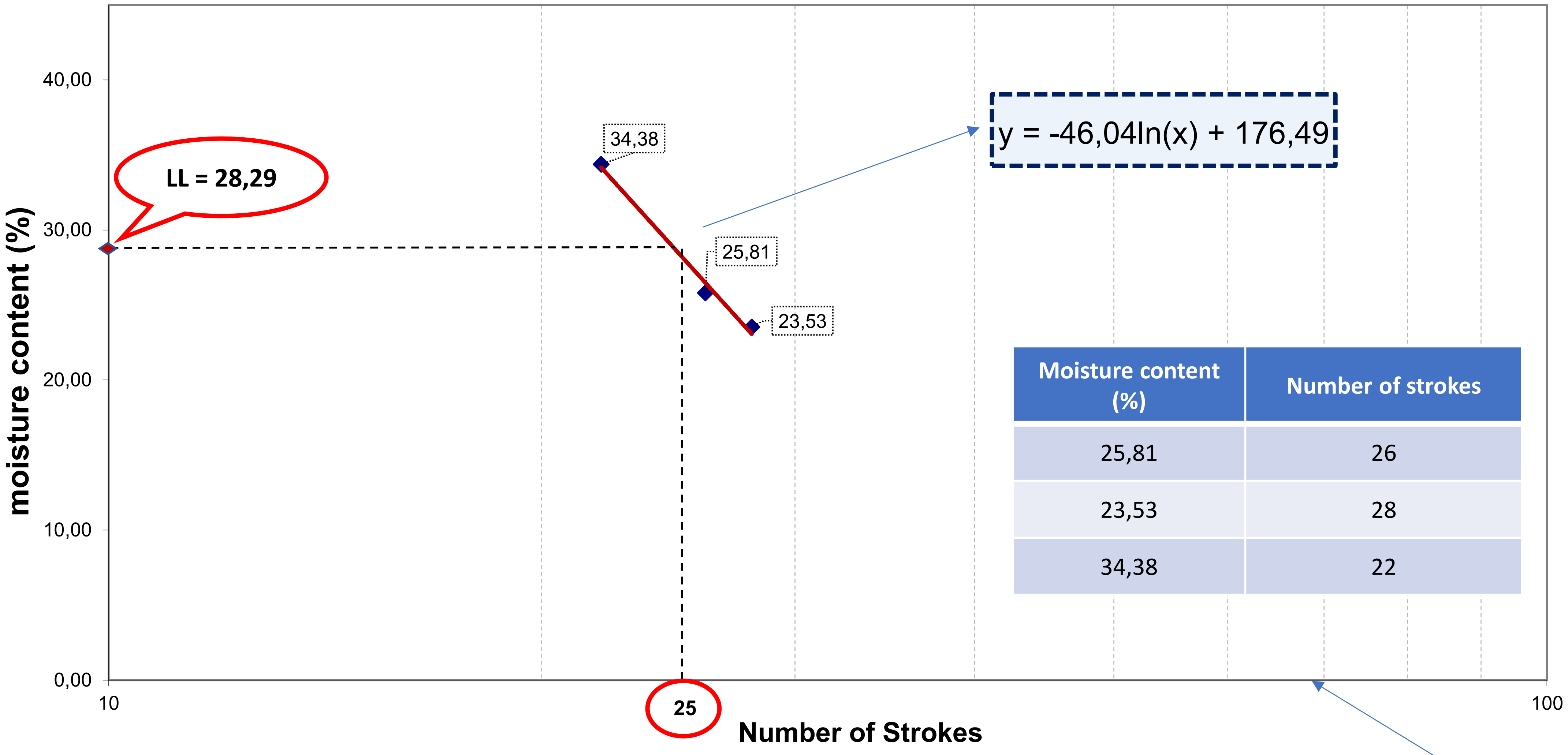
	LL =	**28,29**
	PL =	**20,66**
Plasticity Index (%)	PI =	**7,63**

$28,29 - 20,66 = 7,63$

REMARKS:

The Liquid Limit results from the flow curve (number of knoc

FLOW CURVE



Moisture content (%)	Number of strokes
25,81	26
23,53	28
34,38	22

** Log scale

FORMULAS and key-data (in brief)

Weight of water (gr)	(Weight of wet sample + container) – (Weight of dry sample + container)
Weight of dry soil (gr)	(Weight of dry sample + container)– Weight of container
Moisture content (%)	(Weight of water / Weight of dry soil) *100
Plastic Limit	Average of the moisture contents of the tested specimens
Liquid Limit	Moisture content at 25 stokes according to the flow curve (* multi point method)
Plasticity Index	PI = LL – PL

ENGINEERING CLASSIFICATION OF SOIL

Why do we classify soils?

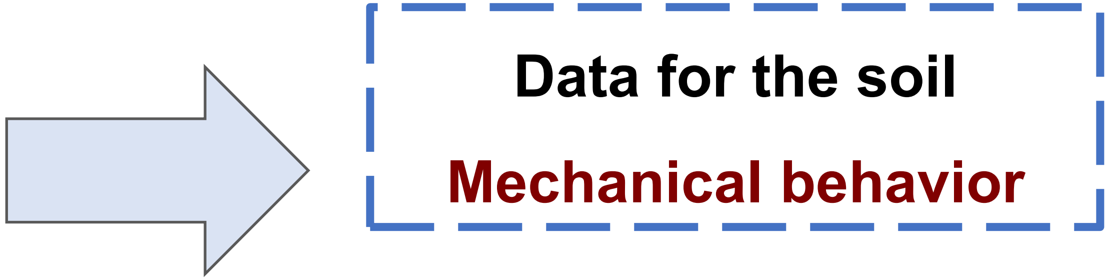
1. Grouping of soils with similar properties
2. Easiest communication-cooperation among engineers - specialists
3. Easiest to use (through simple symbols and standard nomenclature)

Soil Classification “Systems”

Grouping of soil in certain groups according to :

✓ Similar properties

✓ Similar engineering behavior (e.g. strength, compressibility, permeability etc)



Data for the soil

Mechanical behavior

SOIL CLASSIFICATION PROPERTIES

Soil grading

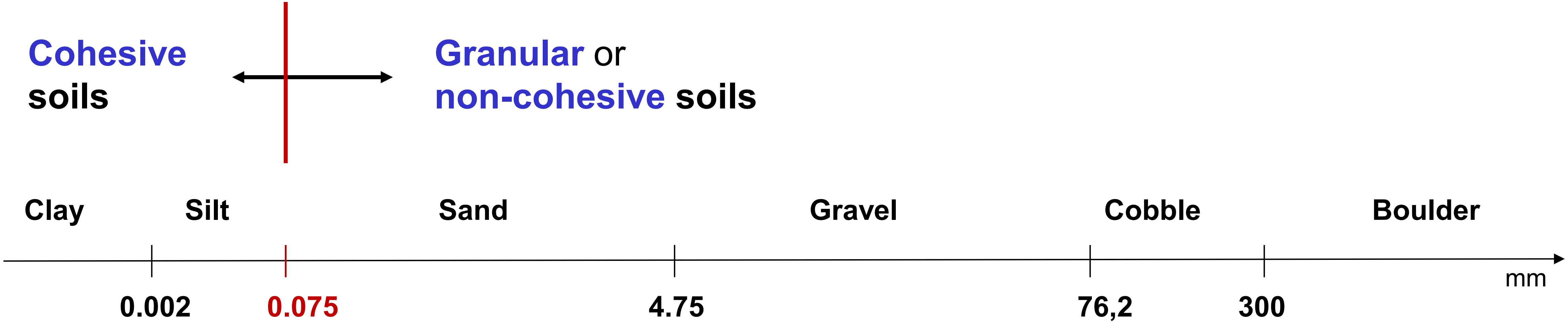
The process of separation of soil in distinct classification classes (grain size groups).
Every grain size group has a certain grain size range (in mm or inches)

- Laboratory grain size analysis with sieves and pycnometer.

Soil Consistency

Resistance of a fine-grained soil to mechanical stress and manipulation under different moisture content and without being breaked.

- Laboratory Determination of Atterberg Limits



Cohesive soils

Granular or non-cohesive soils

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

ASTM D2487-17: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

Coarse soils → >50% is retained from Sieve No.200

Fine Soils → >50% passes from Sieve No.200

(USCS)				
Sieve (No.)	**Opening diameter, D (mm)**	**Soil fraction**		**Main Symbol**
3 - in	76,2	Coarse	**Gravel**	**G**
3/4 - in	19	Fine		
4	4,75	Coarse	**Sand**	**S**
10	2	Medium		
40	0,425	Fine		
200	0,075		**Silt**	**M**
			Clay	**C**

Every soil group is defined by applying two (2) Symbols, according to the dominant soil fraction:

- **Coarse Soils:**
  1. Soil Grading
     - Well-Graded Soil (**W**)
     - Poorly graded soil (**P**) → Uniformity Coefficient Cu, Curvature Coefficient Cc

$$Cu = D_{60}/D_{10}$$

$$C_c = D_{30}^2 / D_{60} * D_{10}$$

Dxx = : % passing from the grain size distribution curve

  2. Presence of fine soil (silt and clay) as a secondary soil fraction.
     - Clay (**C**)
     - Silt (**M**)

     e.g. examples for gravels : GW, GP, GC, GM

- **Fine Soils**
  1. Liquid Limit (LL) and Plasticity Index (PI)
     - Low Plasticity (**L**)
     - High Plasticity (**H**)

     e.g. examples for clays : CL, CH

CLASSIFICATION OF COARSE SOILS

Criteria for the symbology of coarse soils				Soil Classification	
Coarse Soils More than 50% is retained from No. 200 sieve	**GRAVELS** More than 50% of the coarse fraction is retained from No.4 sieve	**Clean Gravels** Less than 5% fines	$Cu \geq 4$ and $1 \leq Cc \leq 3$	**GW**	Well graded Gravel
			$Cu<4$ and $Cc<1$ ή $Cc>3$	**GP**	Poorly graded Gravel
		Gravels with fines More than 12% fines	Fines ML or MH	**GM**	Silty Gravel
			Fine CL or CH	**GC**	Clayey Gravel
	SAND 50% or more of the coarse fraction passes from No.4 sieve	**Clean Sands** Less than 5% fines	$Cu \geq 6$ and $1 \leq Cc \leq 3$	**SW**	Well graded Sand
			$Cu<6$ & $Cc<1$ ή $Cc>3$	**SP**	Poorly graded Sand
		Sands with fines More than 12% fines	Fines ML or MH	**SM**	Silty Sand
			Fines CL or CH	**SC**	Clayey Sand

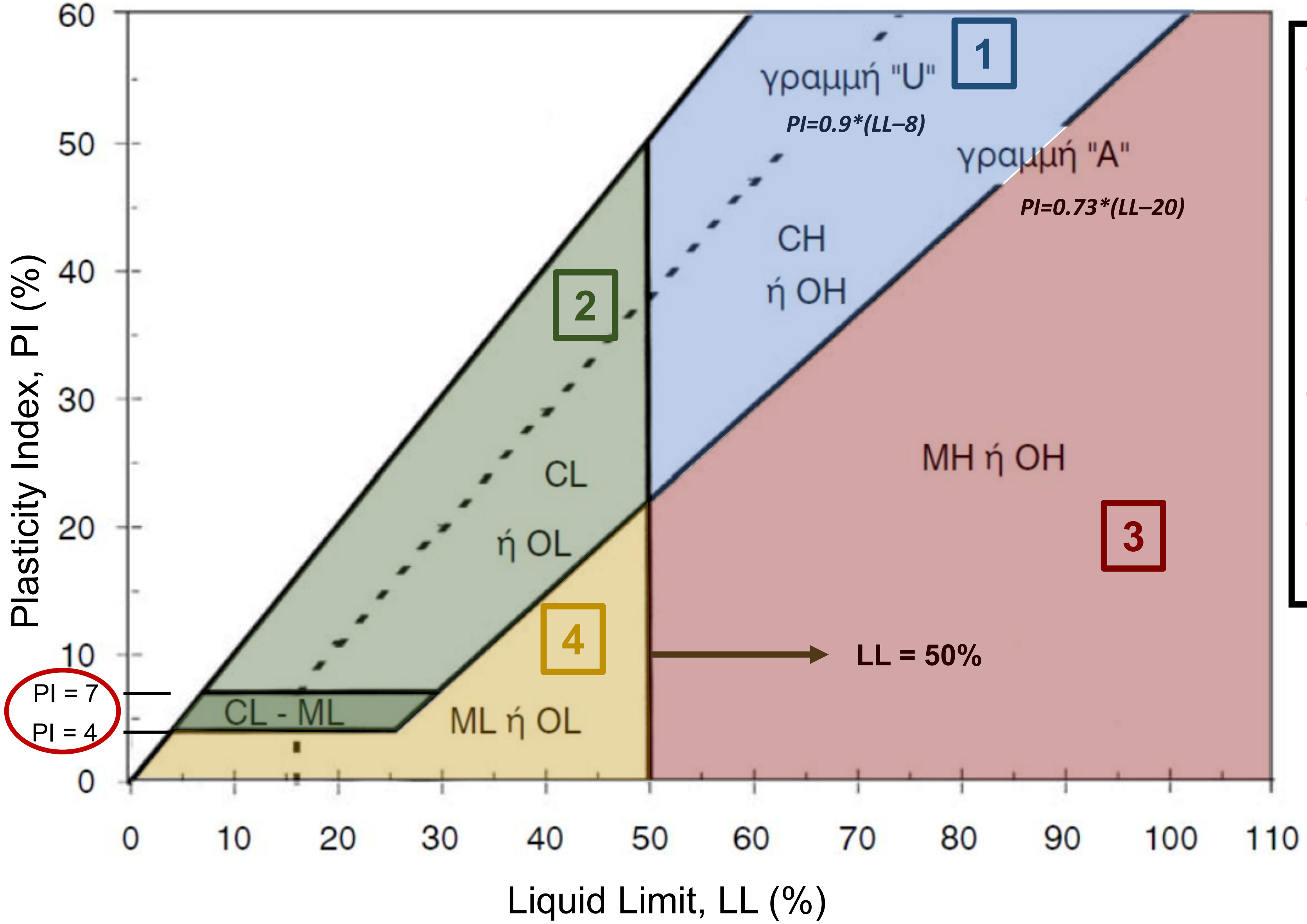
Fines: passing % from No. 200 sieve

CLASSIFICATION OF FINE SOILS

Criteria for the symbology of fine soils				Soil Classification	
Fine Soils 50 % or more **passes from** No. 200 sieve	SILTS AND CLAYS Liquid Limit lower than 50% **(LL < 50%)**	**Soils without organic matter**	PI>7 and plotted above Line “A”	**CL**	Lean Clay
			PI<4 and plotted below Line “A”	**ML**	Silt
		Soils with organic matter	LL1/LL2 < 0.75	**OL**	Organic Clay
					Organic Silt
	SILTS AND CLAYS Liquid Limit greater than 50% **(LL > 50%)**	**Soils without organic matter**	PI is plotted above Line “A”	**CH**	Fat Clay
			PI is plotted below Line “A”	**MH**	Elastic Silt
		Soils with organic matter	LL1/LL2 < 0.75	**OH**	Organic Clay
					Organic Silt
Many organic matter	Mainly organic matter or gray – black colour			**Pt**	Peat

LL1: Liquid Limit measured after oven-drying the soil & LL2: Liquid Limit measured without drying the soil

Casagrande Plasticity Chart



Area 1 : Above Line A and LL>50%

- **CH** or OH

Area 2 : Above Line - A and LL<50%

- PI>7: **CL** or OL
- 4<PI<7: **CL – ML**

Area 3 : Below Line - A and LL>50% :

- **MH** or OH

Area 4 : Below Line - A and LL<50% :

- **ML** or OL

SOIL CLASSIFICATION (USCS)

What do we check/test?

- Percent (%) of passing (grain size analysis)
- Soil Uniformity and Skewness coefficients
- Atterberg Limits and Indices

What do we use?

- USCS Soil classification charts
- Special remarks of the soil classification chart (see below)
- Casagrande Plasticity Chart

Remarks: Regarding DOUBLE soil symbology:

1. Gravelly soils with fines between 5% and 12% require DOUBLE symbology e.g. GW – GM, GW – GC, GP – GM, GP – GC
2. Sandy soils with fines between 5% and 12% require DOUBLE symbology e.g SW – SM, SW – SC, SP – SM, SP – SC
3. When 4<PI<7 , above Line - A and LL<50% the soil requires DOUBLE symbology CL – ML
4. When the fines at a granular soil is classified as CL – ML then a DOUBLE symbology is used e.g. GC – GM (in gravels) and SC – SM (in sands).

SOIL CLASSIFICATION (USCS)

Remarks: Regarding Soil naming – description:

1. In gravelly soils, when sand is ≥15% the term **«…with sand»** is added.
2. In sandy soils, when gravels are ≥15% the term **«…with gravels»** is added.
3. In fine soils, when the retained from No200 sieve is between 15 and 29% and it is mainly sand, the term **«…with sand»** is added.
4. In fine soils, when the retained from No200 sieve is between 15 and 29% and it is mainly gravels, the term **«…with gravels»** is added.
5. In fine soils, when the retained from No200 sieve is ≥30% and it is mainly sand, the term **«sandy….»** is added.
6. In fine soils, when the retained from No200 sieve is ≥30% and it is mainly gravels, the term **«gravelly….»** is added.

EXAMPLE OF SOIL CLASSIFICATION ACCORDING TO USCS

	SIEVE ANALYSIS PASSING %					ATTERBERG LIMITS			Uniformity Coefficient	Skewness Coefficient	A.U.S.C.S Soil classification
	3\8	**4**	**10**	**40**	**200**	**LL**	**PL**	**PI**	**Cu**	**Cc**	
1	100	100	100	95	92	30,0	20,0	10,0	-	-	CL
2	100	90	90	38	13	33,0	17,0	16,0	-	-	SC
3	80	78	63	30	10	17,0	16,0	1,0	-	-	SM-SW or SM-SP
4	58	47	43	25	3	NO PLASTIC			45,00	1,30	GW

My data:

- **Passing percents from sieves 3/8 in, No. 4, 10, 40 and 200.**
- **Liquid Limit LL and Plasticity Index PI (PI = LL – PL)**
- **Coefficients of Uniformity (Cu) & Skewness (Cc)**

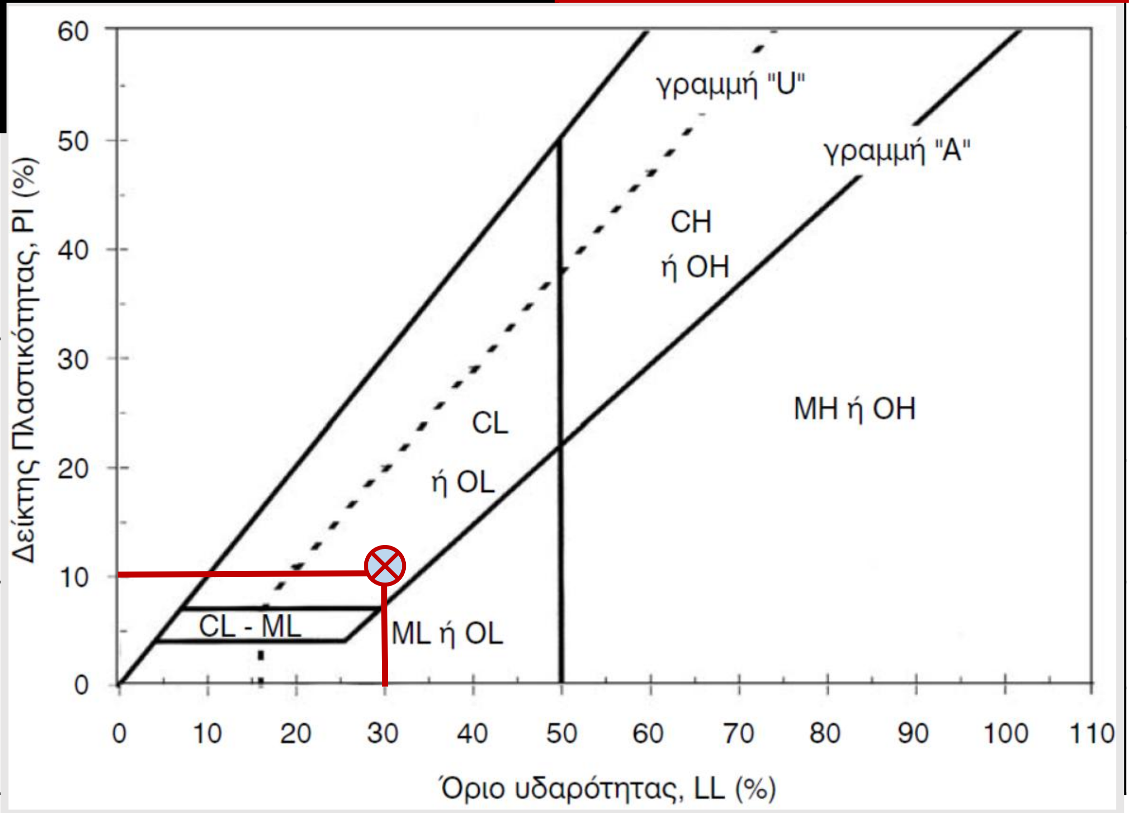
EXAMPLE 1: Clayey soil

GRAVELS:0%
SAND:8%
SILT & CLAY:92%

	SIEVE ANALYSIS PASSING %					ATTERBERG LIMITS			Uniformity Coefficient	Skewness Coefficient	A.U.S.C.S Soil classification
	3\8	4	10	40	200	LL	PL	PI	Cu	Cc	
1	100	100	100	95	92	30,0	20,0	10,0	-	-	**CL**

- ✓ Passing from No. 200 sieve = 92% (> 50%) → **Fine soil**
- ✓ Plotting of LL and PI on the Plasticity Chart → **CL**

Fine soils 50 % or more passing from No. 200 sieve	**SILTS & CLAYS** Liquid Limit less than 50% **(LL < 50%)**	**Soils without organics**	PI>7 and plotted above line «A»	**CL**	Lean Clay
		Soils with organics			
	SILTS & CLAYS Liquid Limit greater than 50% **(LL < 50%)**	**Soils without organics**			
		Soils with organics			



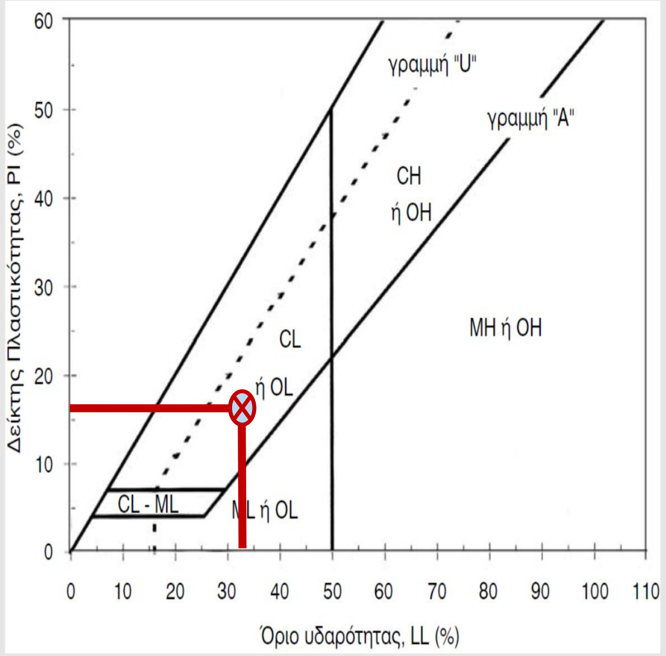
EXAMPLE 2: Sandy soil

GRAVEL:10%
SAND:77%
SILT & CLAY:13%

	SIEVE ANALYSIS PASSING %					ATTERBERG LIMITS			Uniformity Coefficient	Skewness Coefficient	A.U.S.C.S Soil
	3\8	4	10	40	200	LL	PL	PI	Cu	Cc	
2	100	90	90	38	13	33,0	17,0	16,0	-	-	**SC**

- ✓Passing from No. 200 = 13% < 50% → Coarse Soil
- ✓Passing from No. 4 = 90% > 50%→ Sandy soil
- ✓Fines (passing from No. 200 = 13%> 12%→ Sand with fines
- ✓ Plotting of LL and PI on the Plasticity Chart → CL

Coarse Soil More than 50% <u>is retained from</u> No. 200 sieve	**GRAVELS** More than 50% of the coarse soil fraction is retained from No.4	**Clean Gravels** Less than 5% of fines	Cu≥4 & 1≤Cc≤3	**GW**	
			Cu<4 & Cc<1 or Cc>3	**GP**	
		Gravels with fines More than 12% of fines	Fines ML or MH	**GM**	
			Fines CL or CH	**GC**	
	SANDS 50% or more of the coarse soil fraction passes from No.4 sieve	**Clean Sands** Less than 5% of fines	Cu≥6 & 1≤Cc≤3	**SW**	
			Cu<6 & Cc<1 or Cc>3	**SP**	
		Sands with fines More than 12% of fines	Fines ML or MH	**SM**	
			Fines CL or CH	**SC**	Clayey Sand



EXAMPLE 3: Sandy soil with double symbology

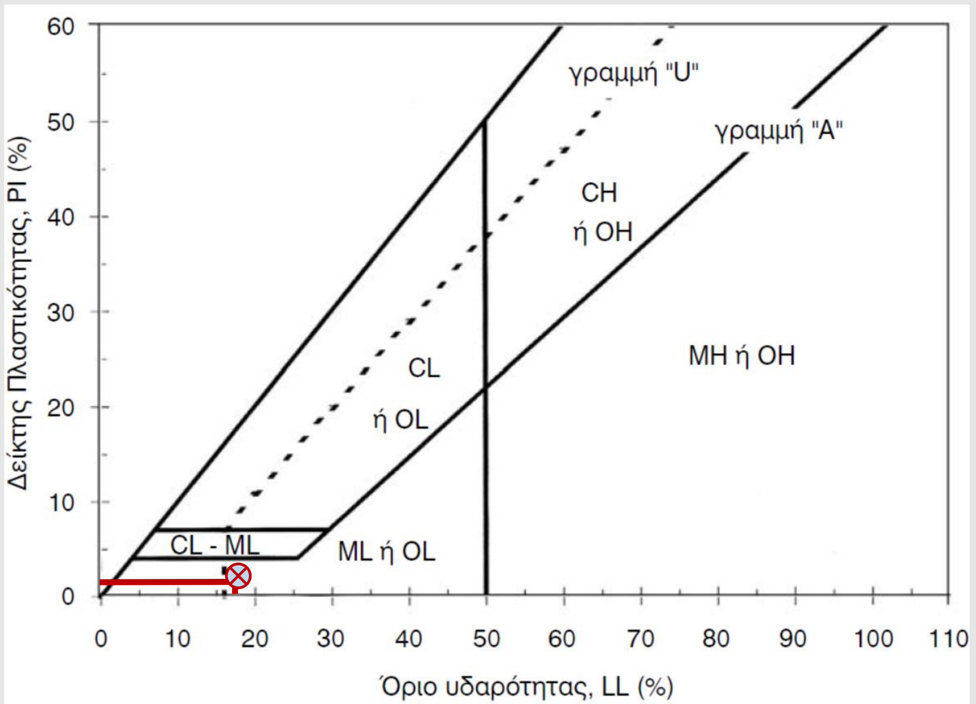
SIEVE ANALYSIS PASSING %						ATTERBERG LIMITS			Uniformity Coefficient	Skewness Coefficient	A.U.S.C.S Soil
	3\8	4	10	40	200	LL	PL	PI	Cu	Cc	
3	80	78	63	30	10	17,0	16,0	1,0	-	-	SM-SW or SM-SP

GRAVEL:22%
SAND:68%
SILT AND CLAY:10%

- ✓Passing from No. 200 = 10% < 50% → Coarse Soil
- ✓Passing from No 4 = 78% > 50%→ Sandy Soil
- ✓ Fines = 10% → (between 5% & 12% → <u>double symbology</u>
- ✓ Plotting of LL,PI o Plasticity Chart → ML
- ✓ Gravels = 22% > 15%→ adding the term <u>“…..with gravels</u>”

nce fines are between 5% and 12%, we must also calculate the uniformity and ewness coefficient and the classification of the fines (Plasticity chart)

More than 5 is retained from No. 200 sieve	from No.4	**Clean Gravels** an es	Cu≥4 & 1≤Cc≤3	**GW**	Well-graded gravel
			Cu<4 & Cc<1 or Cc>3	**GP**	Poorly graded gravel
		Gravels with fines More than 12% of fines	Fines ML or MH	**GM**	Silty gravel
			Fines CL or CH	**GC**	Clayey gravel
	SANDS 50% or more of the coarse soil fraction passes from No.4 sieve	**Clean Sands** Less than 5% of fines	Cu≥6 & 1≤Cc≤3	**SW**	Well-graded sand
			Cu<6 & Cc<1 or Cc>3	**SP**	Poorly graded sand
		Sands with fines More than 12% of fines	Fines ML or MH	**SM**	Silty sand
			Fines CL or CH	**SC**	Clayey sand



EXAMPLE 4: Gravels

ΚΟΚΚΟΜΕΤΡΗΣΗ ΔΙΕΡΧΟΜΕΝΟ %						ΟΡΙΑ ATTERBERG			Συντελεστής Ομοιομορφίας	Συντελεστής Κυρτότητας	ΚΑΤΑΤΑΞΗ A.U.S.C.S
	3\8	**4**	**10**	**40**	**200**	**LL**	**PL**	**PI**	**Cu**	**Cc**	
4	58	47	43	25	3	ΜΗ ΠΛΑΣΤΙΚΟ			45,00	1,30	**GW**

- ✓ Passing from No. 200 = 3% < 50% → Coarse Soil
- ✓ Passing from No. 4 = 47% < 50% → Gravels
- ✓ Fines = 3% < 5% → Clean Gravels
- ✓ Cu: 45 > 4 and Cc:1,30 (1≤Cc≤3) → good grading
- ✓ Sand = 44% > 15%→ term "…..with sand" is added

GRAVEL:53%
SAND:44%
SILT AND CLAY:3%

Coarse Soil More than 50% is retained from No. 200 sieve	**GRAVELS** More than 50% of the coarse soil fraction is retained from No.4	**Clean Gravels** Less than 5% of fines	Cu≥4 & 1≤Cc≤3	**GW**	Well-graded gravels
			Cu<4 & Cc< 1 or Cc>3	**GP**	Poorly graded gravels
		Gravels with fines More than 12% of fines	Fines ML or MH	**GM**	Silty gravels
			Fines CL or CH	**GC**	Clayey gravels
	SANDS 50% or more of the coarse soil fraction passes from No.4 sieve	**Clean Sands** Less than 5% of fines	Cu≥6 & 1≤Cc≤3	**SW**	Well-graded sand
			Cu<6 & Cc<1 or Cc>3	**SP**	Poorly graded sand
		Sands with fines More than 12% of fines	Fines ML or MH	**SM**	Silty sand
			Fines CL or CH	**SC**	Clayey sand