Dr. Ahmed Soil Mechanics Note Chapter Three (Soil Classification)

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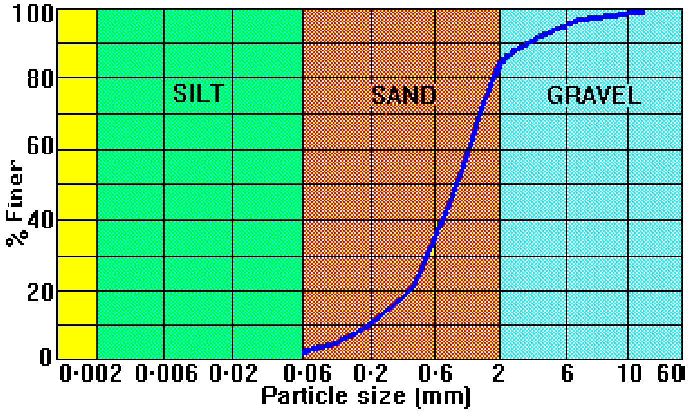


CHAPTER THREE

SOIL CLASSIFICATION

Lecture Notes

Soil Mechanics

3rd Class

Assistant Prof.

Dr. Ahmed Al-Obaidi

CHAPTER THREE

SOIL CLASSIFICATION

3.1 Introduction

Soil classification is a separation of soil into classes or groups each having similar characteristics and potentially similar behavior. A classification for engineering purposes should be based mainly on mechanical properties, e.g. permeability, stiffness, strength. The classification to which a soil belongs can be used in its description.

In general, there are two major categories into which the classification systems can be grouped.

1. The textural classification is based on the particle-size distribution of the percent of gravel, sand, silt, and clay size fractions present in a given soil. Such as ***Massachusetts Institute of Technology classification system*** (M.I.T classification) and the ***U.S. Department of Agriculture***.
2. The other major category is based on the engineering behavior of soil and takes into consideration the particle-size distribution and the plasticity (i.e., liquid limit and plasticity index). Under this category, there are two major classification systems in extensive use now:

   a. The American Association of State Highway and Transportation classification system (AASHTO), and

   b. The Unified classification system (USCS).

3.2 Mechanical Analysis of Soil

The mechanical analysis is the determination of the size range of particles present in the soil, expressed as a percentage of the total dry weight. Two methods are used to find the particle-size distribution of soil:

(1) Sieve analysis—for particle sizes larger than 0.075 mm in diameter, and (2) hydrometer analysis—for particle sizes smaller than 0.075 mm in diameter.

3.2.1 Sieve Analysis

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings. U.S. standard sieve numbers and the sizes of openings are given in Table below. The smallest-sized sieve that should be used for this type of test is the U.S. No. 200 sieve

For gravel soil, the current size designation for U.S sieve is:

100.0 mm	37.5 mm	12.5 mm
75.0 mm	31.5 mm	9.5 mm
63.0 mm	25.0 mm	8.0 mm
50.0 mm	19.0 mm	6.3 mm
45.0 mm	16.0 mm	

For sandy soils, the designation used number, i.e. No. 4 as shown in Table

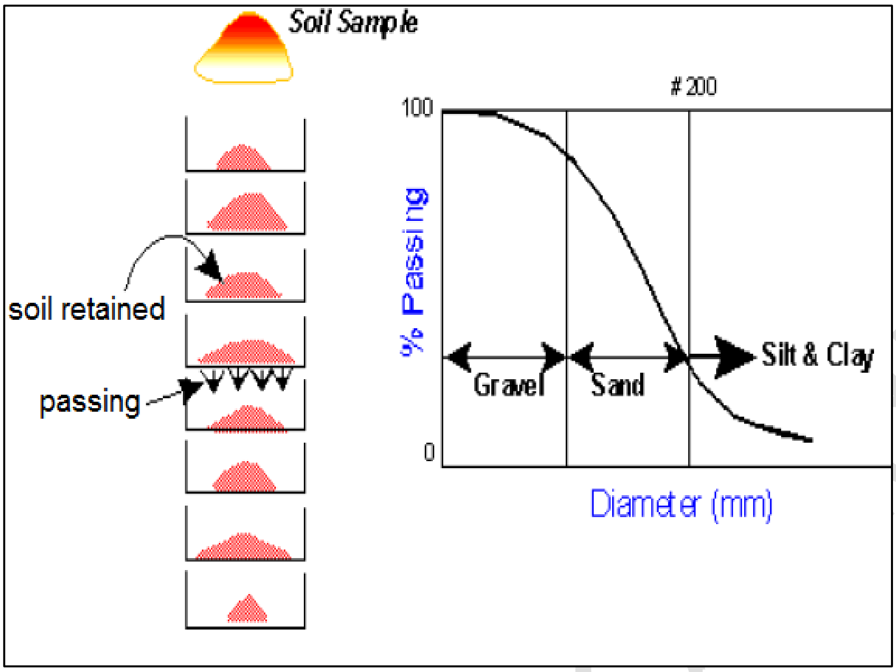
U.S. Standard Sieve Sizes

Sieve no.	Opening (mm)	Sieve no.	Opening (mm)
4	4.75	35	0.500
5	4.00	40	0.425
6	3.35	50	0.355
7	2.80	60	0.250
8	2.36	70	0.212
10	2.00	80	0.180
12	1.70	100	0.150
14	1.40	120	0.125
16	1.18	140	0.106
18	1.00	170	0.090
20	0.850	200	0.075
25	0.710	270	0.053
30	0.600		

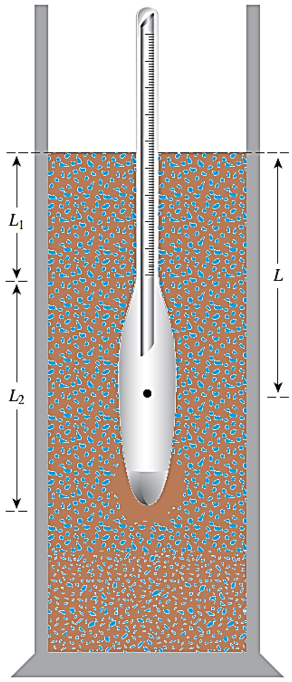
Other contraries may use a different size. In addition, some use sieve No. 270 (0.053 mm), No. 325 (0.045 mm), and No. 400 (0.038 mm).

Once the percent finer for each sieve is calculated, then are plotted on semilogarithmic graph paper with percent finer as ordinary scale, and sieve opening size as the abscissa (logarithmic scale).

This plot is referred to as the particle-size distribution curve.



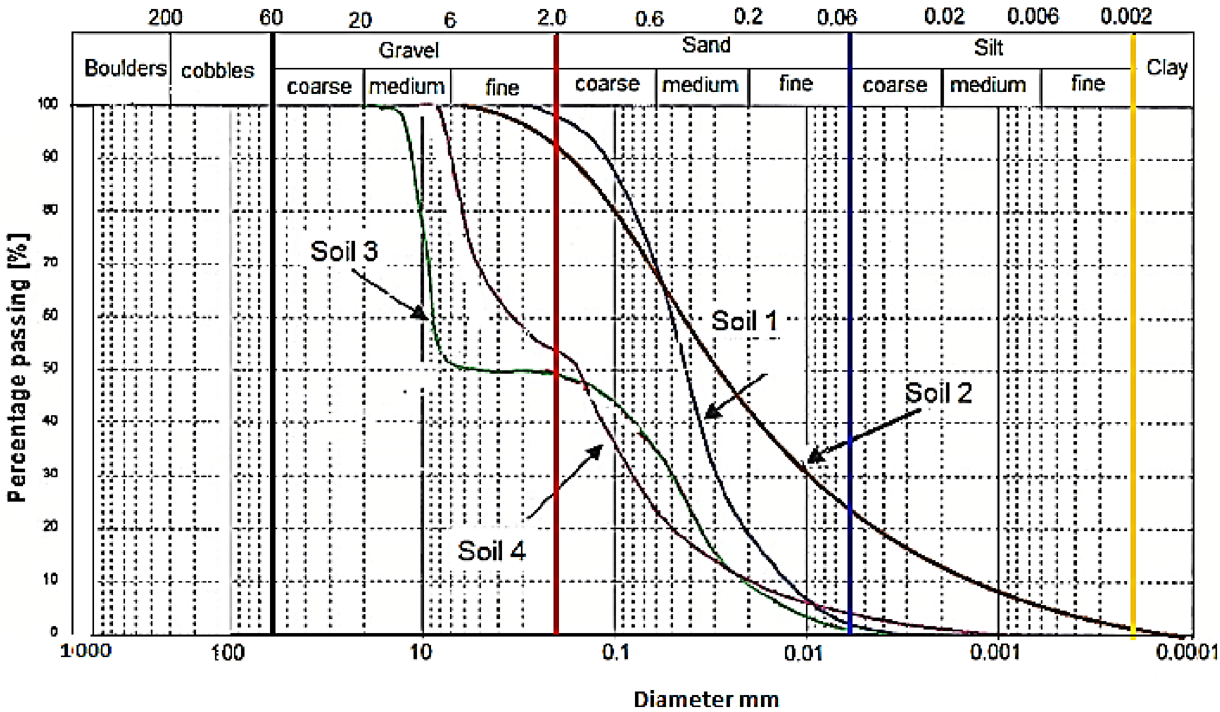
3.2.2 Hydrometer analysis



Is based on the principle of sedimentation of soil grains in water. When a soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size, weight, and the viscosity of the water. For simplicity, it is assumed that all the soil particles are spheres and that Stokes' law can express the velocity of soil particles. Used for soil particles less than 0.075mm, (U.S. No. 200 sieve)

3.3 M.I.T Soil Classification

MIT Soil classification is the classification system devised by Massachusetts Institute of Technology, the USA for dividing soil into different classes. In this classification, the particles larger than 200 mm will be considered as boulders and larger 200 is cobble. The gravel range from (60 mm to 2 mm) and sand between (2.0 mm to 0.06) and silt range from (0.06 mm to 0.002 mm). smaller than this is clay. Also, each type of soil subdivided to coarse, medium and fine).



Example (3.1)

Classify the soils shown in figure above according to M.I.T classification

Solution

Soil 1 | Soil 2

Soil		percentage	Soil		percentage
Boulders		0	Boulders		0
Cobbles		0	Cobbles		0
Gravel 2	Coarse	0	Gravel 8	Coarse	0
	Medium	0		Medium	0
	Fine	2		Fine	8
Sand 96	Coarse	28	Sand 69	Coarse	24
	Medium	51		Medium	25
	Fine	17		Fine	20
Silt 2	Coarse	2	Silt 22	Coarse	10
	Medium	0		Medium	8
	Fine	0		Fine	4
clay		0	clay		1

Soil (1) classified as sandy soil,

Soil (2) classified as Sandy silty gravel

Soil 3 Soil 4

Soil		percentage	Soil		percentage
Boulders		0	Boulders		0
Cobbles		0	Cobbles		0
Gravel 50	Coarse	0	Gravel 45	Coarse	0
	Medium	50		Medium	10
	Fine	0		Fine	35
Sand 50	Coarse	15	Sand 51	Coarse	32
	Medium	25		Medium	12
	Fine	10		Fine	7
Silt 0	Coarse	0	Silt 4	Coarse	3
	Medium	0		Medium	1
	Fine	0		Fine	0
clay		0	clay		0

Soil (3) classified as gravely sand

Soil (4) classified as sandy gravel

3.4 Textural Classification

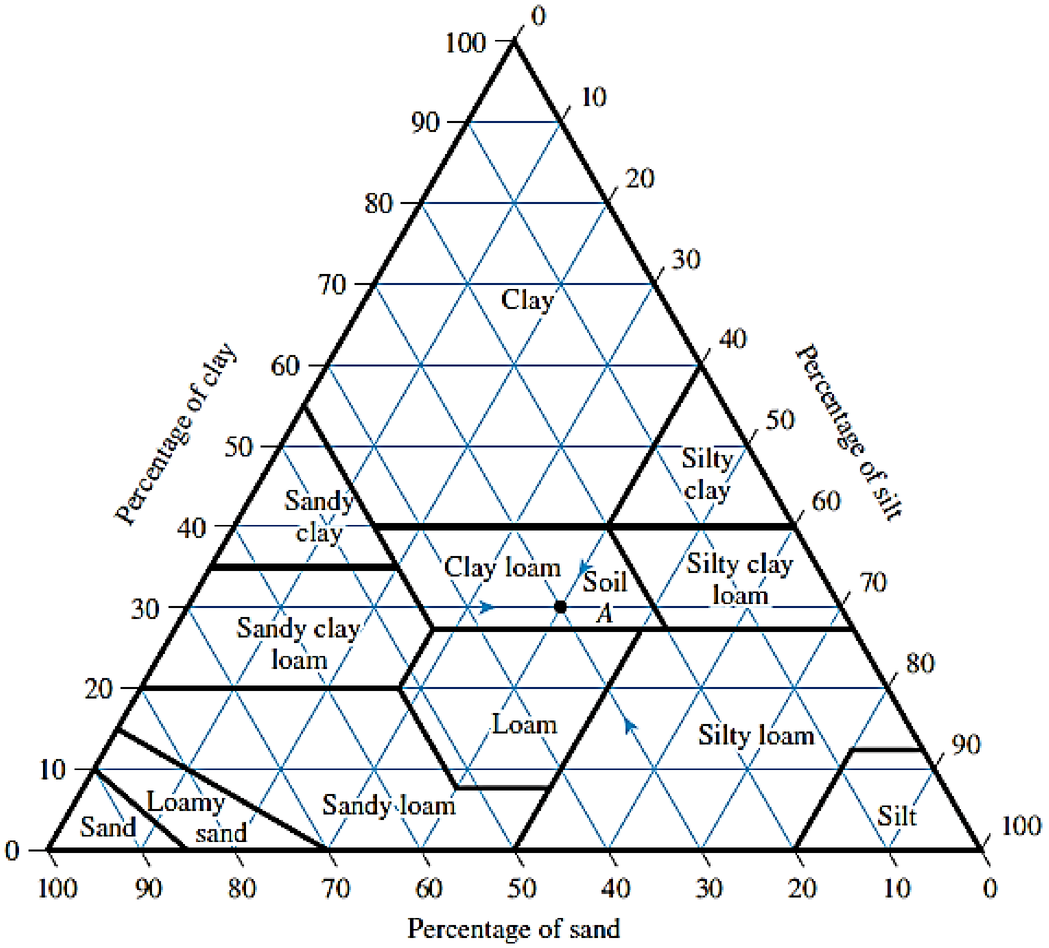
The textural classification systems developed by the U.S. Department of Agriculture (USDA). This classification method is based on the particle-size limits as described under the USDA system; that is

• Sand size: 2.0 to 0.05 mm in diameter

• Silt-size: 0.05 to 0.002 mm in diameter

• Clay size: smaller than 0.002 mm in diameter

The use of this chart can best be demonstrated by an example. If the particle-size distribution of soil (A) shows 30% sand, 40% silt, and 30% clay-size particles, its textural classification can be determined by proceeding in the manner indicated by the arrows in Figure. This soil falls into the zone of ***clay loam***.



U.S. Department of Agriculture textural classification (*USDA*)

Example (3.2)

Classify the following soil using the U.S. Department of Agriculture textural classification chart.

Particle size distribution%			
Soil	Sand	Silt	Clay
A	20	20	60
B	55	5	40
C	45	35	20
D	50	15	35
E	70	15	15

Solution

From the figure, find the zone of each soil

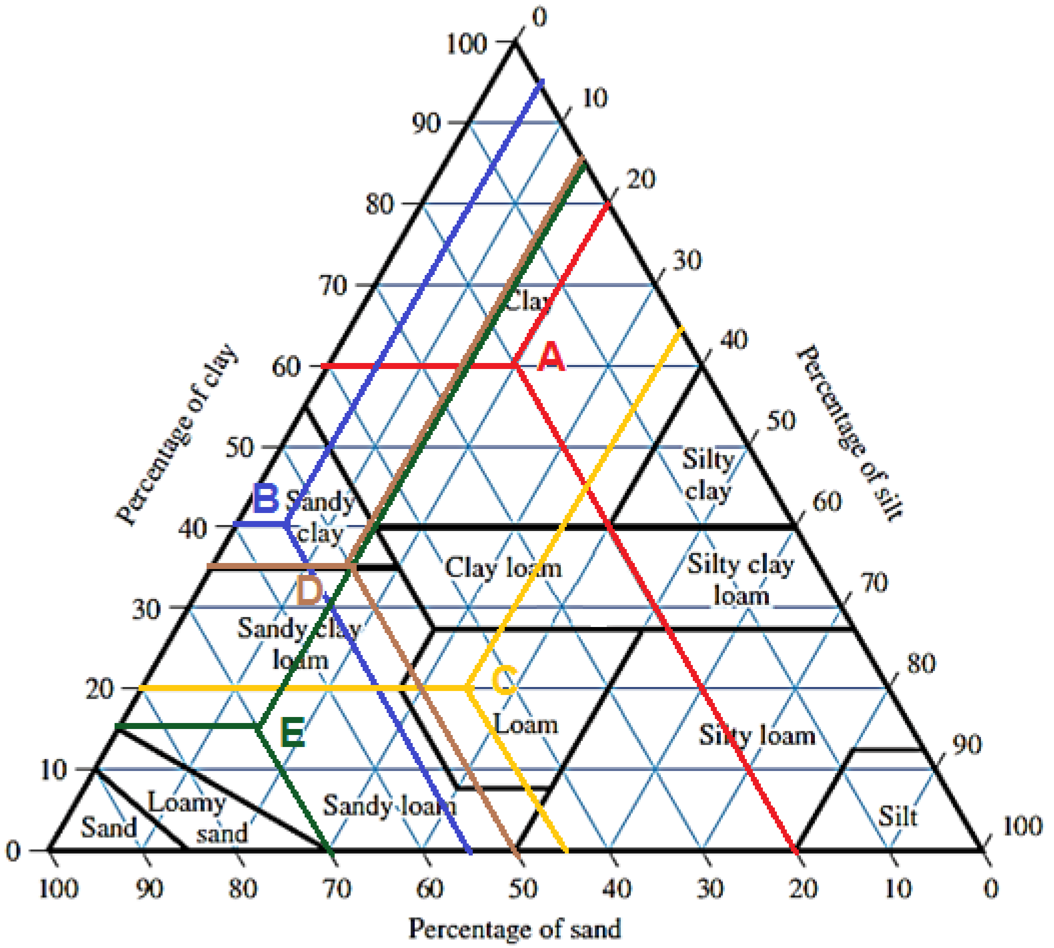
Soil A is Clay

Soil B is Sandy clay

Soil C is Loam

Soil D is Sandy clay to Sandy clay loam

Soil E is Sandy clay loam



U.S. Department of Agriculture textural classification (*USDA*)

Note that this chart is based on only the fraction of the soil that passes through the No. 10 sieve. Hence, if the particle-size distribution of soil is larger than 2 mm in diameter, a correction will be necessary. The calculate modified percentages of sand, gravel, and silt as follows

$$\text{Modified \% sand} = \frac{\%\text{sand}}{100 - \%\text{gravel}} \times 100$$

$$\text{Modified \% silt} = \frac{\%\text{silt}}{100 - \%\text{gravel}} \times 100$$

$$\text{Modified \% clay} = \frac{\%\text{clay}}{100 - \%\text{gravel}} \times 100$$

Example (3.3)

A soil has a particle-size distribution of 20% gravel, 10% sand, 30% silt, and 40% clay, the modified textural compositions are

$$Sand\,size: \frac{10 \times 100}{100 - 20} = 12.5\%$$

$$Silt\,size: \frac{30 \times 100}{100 - 20} = 37.5\%$$

$$Clay\,size: \frac{40 \times 100}{100 - 20} = 50.0\%$$

By the preceding modified percentages, the USDA textural classification is **clay**. However, because of the large percentage of gravel, it may be called **gravelly clay**.

Several other textural classification systems are also used, but they are no longer useful for civil engineering purposes.

Example (3.4)

Classify the soils in Table shown according to USDA

Solution

Step 1: use the modification equation to find the new percentage

Particle size distribution %				
Soil	A	B	C	D
Gravel	12	18	0	12
Sand	25	31	15	22
Silt	32	30	30	26
Clay	31	21	55	40

$$\text{Modified \% sand} = \frac{\%\text{sand}}{100 - \%\text{gravel}} \times 100$$

$$\text{Modified \% silt} = \frac{\%\text{silt}}{100 - \%\text{gravel}} \times 100$$

$$\text{Modified \% clay} = \frac{\%\text{clay}}{100 - \%\text{gravel}} \times 100$$

Thus, the following table results:

Particle size distribution %				
Soil	A	B	C	D
Sand	28.4	37.8	15	25
Silt	36.4	36.6	30	29.5
Clay	35.2	25.6	55	45.5

Step 2: With the modified composition calculated, refer to Figure to determine the zone into which each soil falls. The results are as follows:

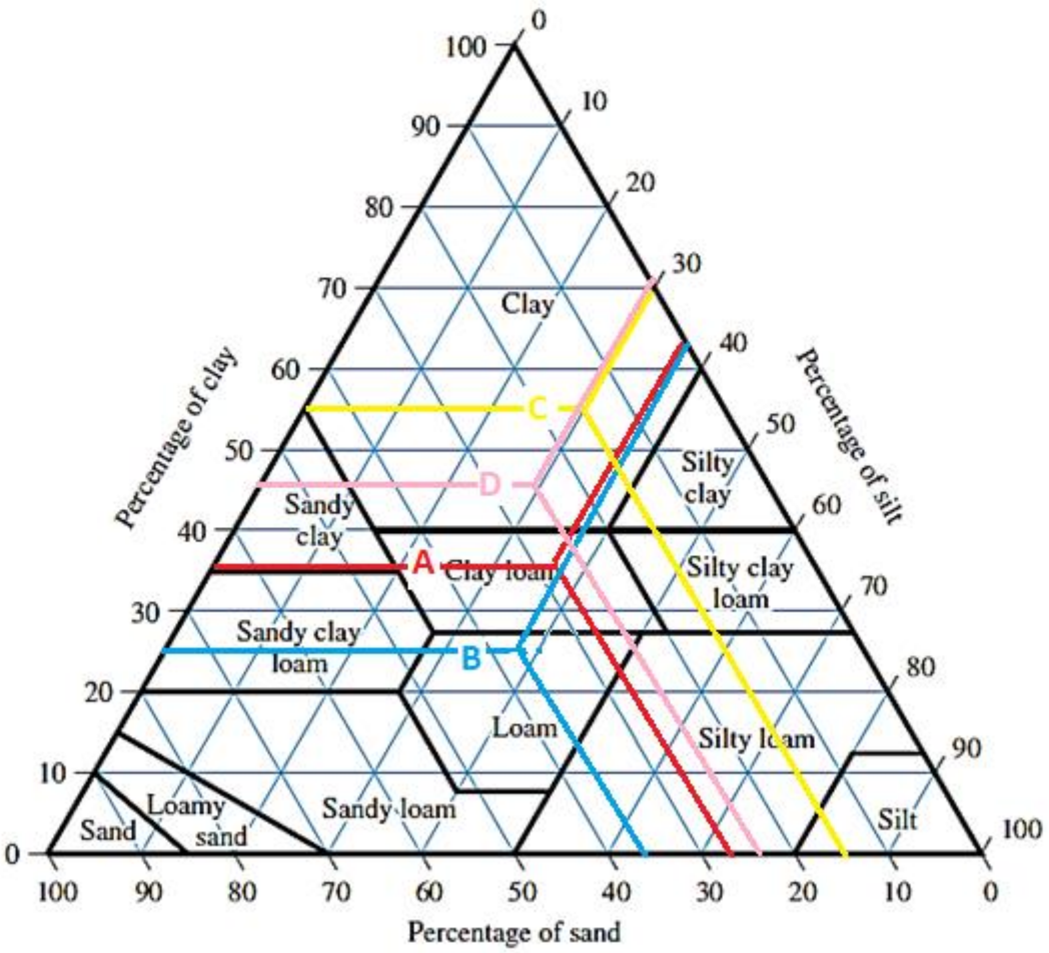
Soil (A) Gravelly clay loam

Soil (B) Gravelly loam

Soil (C) Clay

Soil (D) Gravelly clay

Note: The word gravelly was added to the classification of soils A, B, and D because of the percentage of gravel present in each.



U.S. Department of Agriculture textural classification (*USDA*)

3.5 Classification by Engineering Behavior

The textural classification of soil is relatively simple; it is based entirely on the particle-size distribution. The amount and type of clay minerals present in fine-grained soils dictate to a great extent their physical properties. Hence, the soils engineer must consider plasticity, which results from the presence of clay minerals, to interpret soil characteristics properly.

There are two more elaborate classification systems are commonly used by soils engineers. Both systems take into consideration the particle-size distribution and Atterberg limits. They are the ***American Association of State Highway and Transportation Officials (AASHTO)*** classification system and the ***Unified Soil Classification System (USCS)***. The AASHTO classification system is used mostly by state and county highway departments. Geotechnical engineers prefer the Unified Soil Classification System.

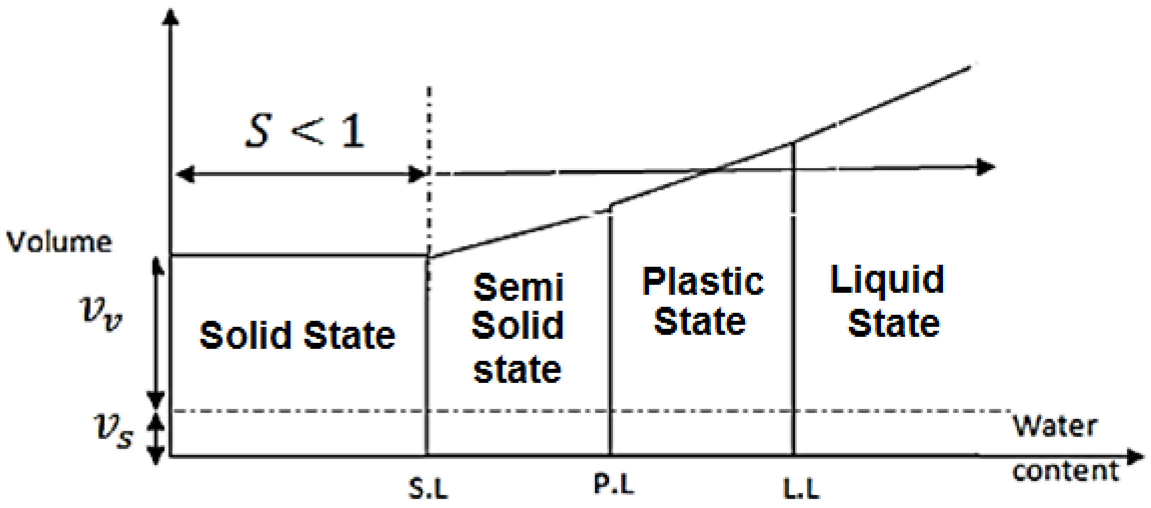
3.6 Plasticity of Fine-Grained Soils

Plasticity is the ability of soil to undergo unrecoverable deformation at constant volume without cracking or crumbling. It is due to the presence of clay minerals or organic material.

Consistency limits (Atterberg limits):

Atterberg, a Swedish scientist, developed a method for describing the limit consistency of fine-grained soils by moisture content. These limits are a ***liquid limit, plastic limit,*** and ***shrinkage limit***.

These limits are based on the concept that a fine-grained soil can exist in any four states depending on its water content



1- Shrinkage Limit (S.L.): The moisture contents in % at which the soil changes from semi-solid to solid state. It also can be considered as the minimum water content at which no decrease in soil volume

2- Plastic Limit (P.L.): The moisture contents in % at which the soil changes from plastic to a semi-solid state.

3- Liquid limit (L.L): is defined as the moisture content in percent at which the soil changes from liquid to plastic state.

4- Plasticity Index (P.I.): is the range in moisture content when the soil exhibited its plastic behavior:

$$P.I = L.L - P.L$$

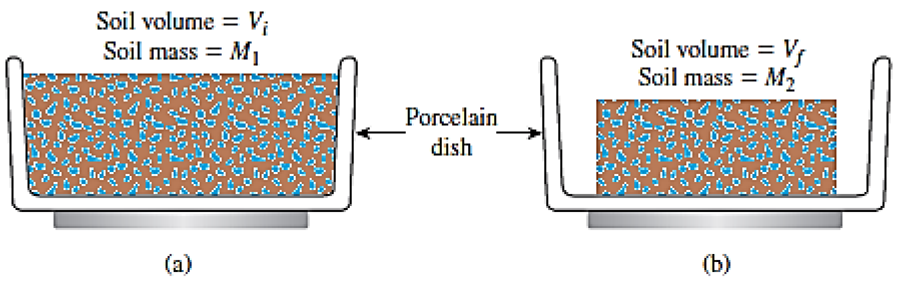
Notes on Atterberg limits

1- Plasticity property is important because it describes the response of soil to change in moisture content
2- Water Content Significantly affects properties of Silty and Clayey soils (unlike sand and gravel)
   - Strength decreases as water content increases
   - Soils swell up when water content increases
   - Fine-grained soils at very high water content possess properties similar to liquids

- As the water content is reduced, the volume of the soil decreases and the soils become plastic
- If the water content is further reduced, the soil becomes semi-solid when the volume does not change

3- Atterberg limits are important to describe the consistency of fine-grained soils
4- The knowledge of the soil consistency is important in defining or classifying a soil type or predicting soil performance when used a construction material
5- A fine-grained soil usually exists with its particles surrounded by water.
6- The amount of water in the soil determines its state or consistency
7- Four states are used to describe the soil consistency; solid, semi-solid, plastic and liquid

The shrinkage limit tests are performed in the laboratory with a porcelain dish about 44 mm in diameter and about 12.7 mm high. The inside of the dish is coated with petroleum jelly and is then filled completely with wet soil. Excess soil standing above the edge of the dish is struck off with a straightedge. The mass of the wet soil inside the dish is recorded. The soil pat in the dish is then oven-dried. The volume of the oven-dried soil pat is determined by the displacement of mercury.

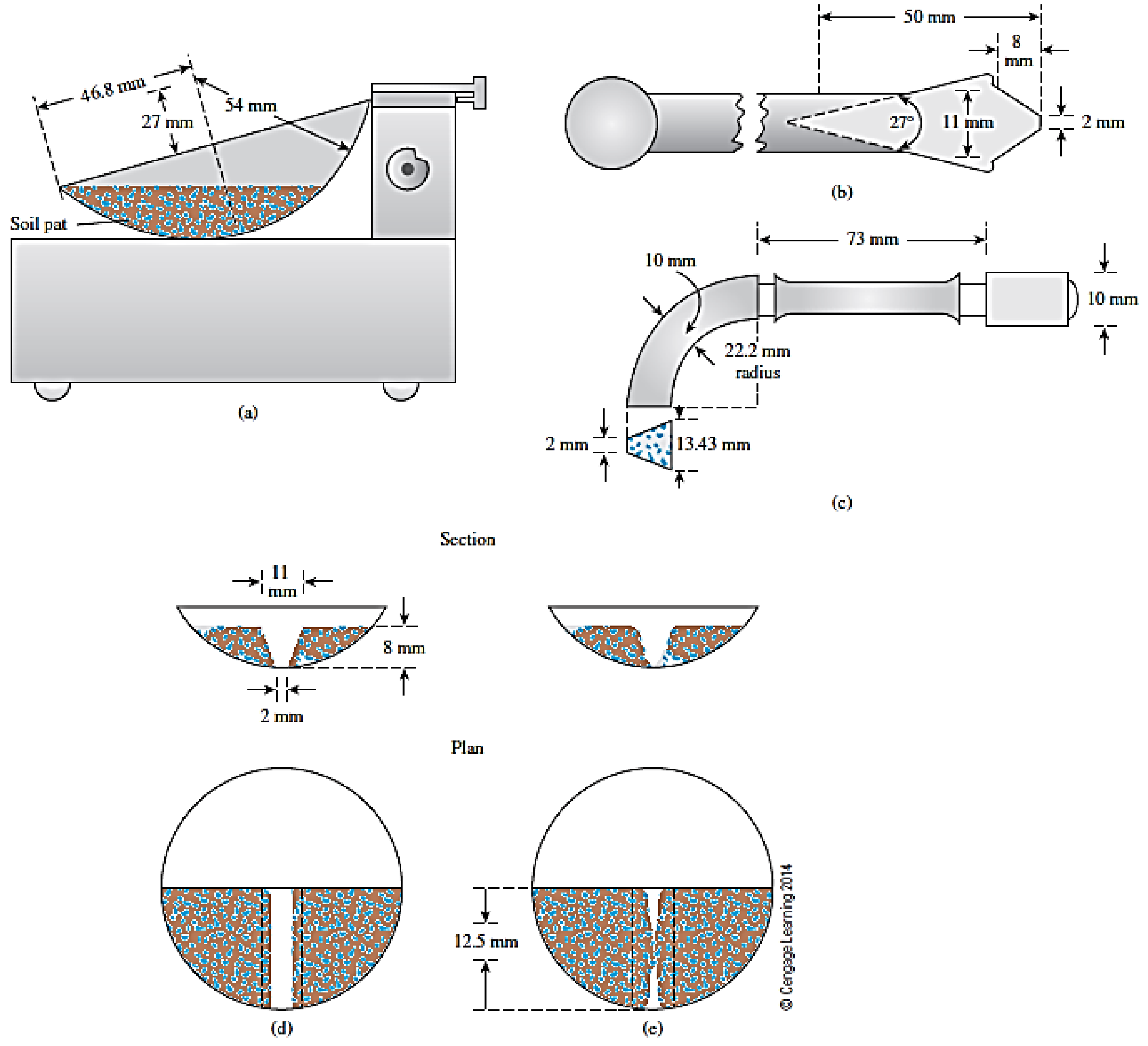


Shrinkage limit test: (a) soil pat before drying; (b) soil pat after drying

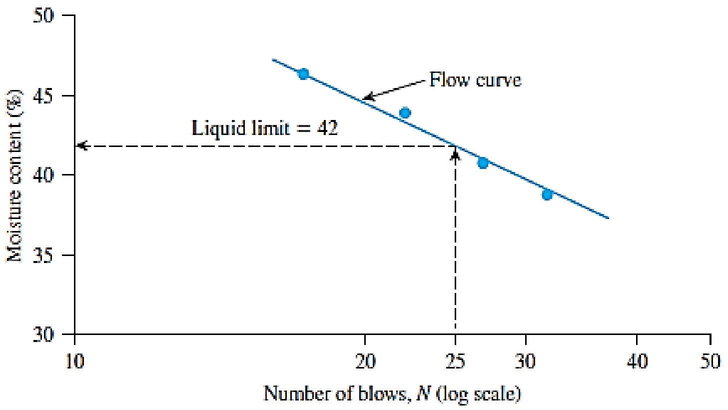
The plastic limit test is simple and is performed by repeated rolling off an ellipsoidal-sized soil mass by hand on a ground glass plate (Figure 4.8). ASTM gives the procedure for the plastic limit test in Test Designation D-4318. Casagrande defined the plastic limit as water at which a thread of soil just crumbles when it is carefully rolled out to a diameter of 3 mm. It should break up into segments about 3 – 10 mm long. If the thread crumbles to a diameter smaller than 3 mm, the soil is too wet. If the thread crumbles at diameter greater than 3 mm, the soil past the P.L

The liquid limit can be found using the device shown. This device consists of a brass cup and a hard rubber base. The brass cup can be dropped onto the base by a cam operated by a crank. To perform the liquid limit test, one must place a soil paste in the cup. A groove is then cut at the center of the soil pat with the standard grooving tool (Figures b and c). Note that there are two types of grooving tools in use. They are flat grooving tools (Figure b) and wedge grooving tools (Figure c).

By the use of the crank-operated cam, the cup is lifted and dropped from a height of 10 mm. The moisture content, in percent, required to close a distance of 12.5 mm along the bottom of the groove (see Figures d and e) after 25 blows are defined as the liquid limit.



Liquid limit test: (a) liquid limit device; (b) flat grooving tool; (c) wedge grooving tool; (d) soil pat before test; (e) soil pat after test



Flow curve for liquid limit determination of a clayey silt

Another method of determining liquid limit that is popular in Europe and Asia is the fall cone method (British Standard—BS1377). In this test, the liquid limit is defined as the moisture content at which a standard cone of apex angle 30° and weight of 0.78 N will penetrate a distance d = 20 mm in 5 seconds when allowed to drop from a position of point contact with the soil surface. The figure shows the photograph of a fall cone apparatus.

classified the plasticity index in a qualitative manner

PI	Description
0	Nonplastic
1–5	Slightly plastic
5–10	Low plasticity
10–20	Medium plasticity
20–40	High plasticity
>40	Very high plasticity

5- Toughness Index is the ratio of plasticity index to the flow index, which expresses the soil consistency in the plastic State.

$$T.I = \frac{P.I}{F.I}$$

The flow index is the slope of flow curve; it shows how close the clayey soil from the plastic state

6- Liquidity Index (L.I) is a relation between the natural moisture contents (ω_n) and (L.L.) and (P.L.) in form

$$LI = \frac{w_n - PL}{LL - PL}$$

where (ω_n) is in situ moisture content of the soil

L.I < 0; ω_n < P.L → Soil in semi or solid State

L.I = 0, ω_n = P.L →Soil at P.L

0 < L.I < 1: ω_n < L.L →Soil at plastic State

L.I =1: ω_n = L.L → Soil at L.L

L.I > 1: ω_n >L.L →Soil at Liquid State.

7- Consistency Index (CI)

$$CI = \frac{LL - w_n}{LL - PI}$$

where ω_n in situ moisture content.

If ω_n is equal to the liquid limit, the consistency index is zero.

If ω_n = PI, then CI = 1.

8- Activity (A)

$$A = \frac{PI}{(\text{\%of clay-size fraction, by weight})}$$

Factors affecting the Atterberg Limits

1. Shape and size of grains: As the grains size get smaller the plasticity increases while grains with flaky shape had more plasticity characteristics than other shapes.
2. The content of clay minerals: As the content of clay minerals increase the plasticity characteristics increase.
3. Type of clay minerals: Montmorillonite is more plasticity than illite; the Kaolinite is less clay mineral plasticity
4. Type of ions: The type of absorbed ions will affect the plasticity characteristics such as Na; Mg will give high plasticity while Ca will give low plasticity.
5. The content of organic matter: As the organic matter content increases the plasticity characteristics Increase.

Example (3.5)

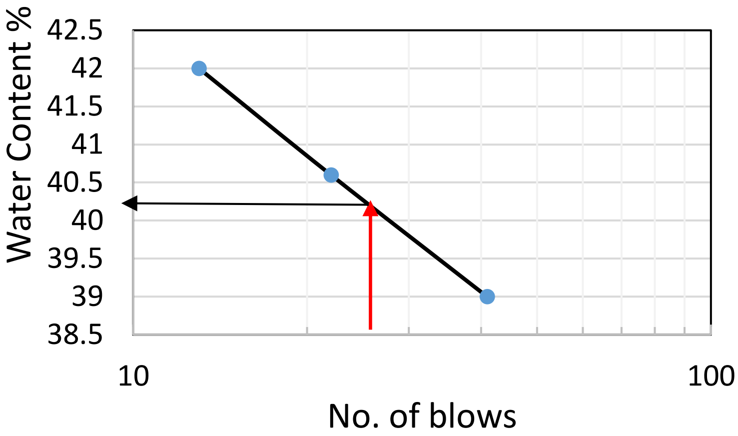
The following data were obtained from the liquid test, and plastic limits is equal = 22 for a soil with ω_n = 15 %

No. of blows	Water content
13	42
22	40.6
41	39

Solution

Draw the flow curve & find the liquid limit.

The liquid limit = 40.1



P.I = L.L – P.L = 40.1 – 22 = 18.1

$$L.I = \frac{\omega_n - P.L}{P.I} = \frac{20 - 22}{18.1}$$

$$= -0.11 < 1.0$$

$$C.I = \frac{L.L - \omega_n}{P.I} = \frac{40.1 - 22}{18.1} = 1$$

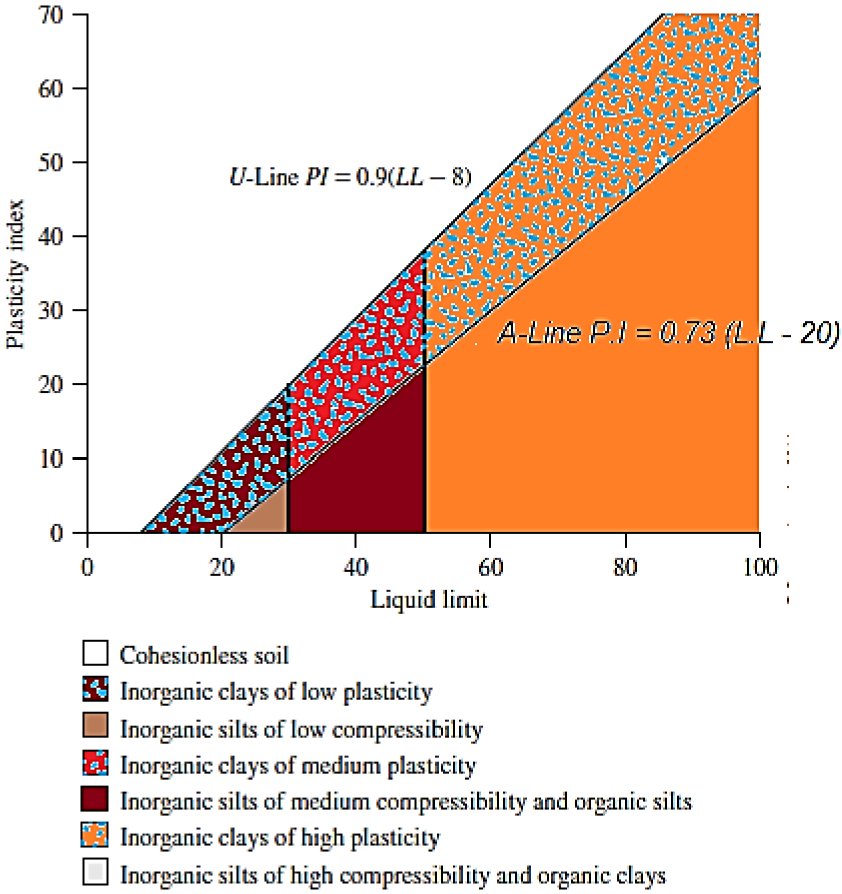
$$F.I = \frac{42 - 40.6}{\log 13 - \log 22} = -6.127$$

$$T.I = \frac{P.I}{F.I} = \frac{18.1}{-6.127} = -2.954$$

Plasticity Chart is the relationship of the plasticity index to the liquid limit of a wide variety of natural soils. By the test results, a proposed plasticity chart is shown in Figure. The important feature of this chart is the empirical *A*-line that is given by the equation *PI* = 0.73(*LL* - 20). An *A*-line separates the inorganic clays from the inorganic silts. Inorganic clay values lie above the *A*-line, and values for inorganic silts lie below the *A*-line. Organic silts plot in the same region (below the *A*-line and with *LL* ranging from 30 to 50) as the inorganic silts of medium compressibility. Organic clays plot in the same region as inorganic silts of high compressibility (below the *A*-line and *LL* greater than 50). The information provided in the plasticity chart is of great value and is the basis for the classification of fine-grained soils in the Unified Soil Classification System.

Note that a line called the *U*-line lies above the *A*-line. The *U*-line is approximately the upper limit of the relationship of the plasticity index to the liquid limit for any currently known soil. The equation for the *U*-line can be given as:

P.I = 0.9(L.L – 8)



Example (3.6)

A dry sample of soil having the following properties, L.L. = 55%, P.L. = 32%, G_s = 2.7, e = 0.50. Find Shrinkage limit, dry density, dry unit weight, and air content at dry state.

Solution

Dry sample $\Longrightarrow$ $e_{dry} = e_{shrinkage} = 0.5$

$S.e_{S.L} = G_s.\omega_{c\ S.L}$ $\Longrightarrow$ 1* 0.5 = 2.7 * S.L $\Longrightarrow$ S.L = 18.52%

$$\rho_d = \frac{G_s}{1+e}\rho_w = \frac{2.7}{1+0.5} * 1 = 1.8\ g/m^3$$

γ_{dry} = 1.8 *9.81 = 17.66 kN/m^3

At dry state S% = 0 $\Longrightarrow$ A = n = e/ (1+e) = 0.5/ (1+0.5) = 0.33 = 33.3%

Example (3.7)

A saturated soil sample has a volume of 25 cm^3 at its L.L. if L.L= 45%, P.L. = 30%, S.L. = 15%, G_s = 2.75. Find the min. volume the soil can attain.

Solution

The minimum volume occurs at S.L. or dry state.

$v_t = v_v + v_s$, v_s: is constant along all state.

At L.L.

$S.e_{L.L} = G_s.\omega_{c\,L.L} \Longrightarrow 1 * e_{L.L} = 2.75 * 0.45 \therefore e_{L.L} = 1.24$

$$e = \frac{v_v}{v_s} = \frac{v_t - v_s}{v_s} = \frac{25 - v_s}{v_s} = 1.24$$

v_s = 11.161 cm^3

At S.L

$S.e_{S.L} = G_s.\omega_{c\,S.L} \Longrightarrow 1 * e_{S.L} = 2.75 * 0.15 \therefore e_{S.L} = 0.4125$

$$e = \frac{v_v}{v_s} = \frac{v_v}{11.161} = 0.4125$$

Min v_v = 4.79

Min. soil volume = 4.79 + 11.161 = 15.95 cm^3

Example (3.8)

A sample of saturated clay had a volume of 100 cm^3 and a mass of (0.2 kg). When completely dried at the volume of the sample was (85 cm^3) and it is mass (0.160 kg). Find (a) Initial water content. (b) Shrinkage limit (c) Specific gravity

Solution

$$\rho_t = \frac{M}{V} = \frac{200}{100} = 2\ gm/cm^3$$

$$2 = \frac{G_s + e}{1 + e}\rho_w = \frac{G_s + e}{1 + e} * 1 \ldots\ldots..(1)$$

$$\omega_c = \frac{M_w}{M_s} = \frac{200 - 160}{160} = 0.25 = 25\%$$

S.e = $G_s.\omega_c$ ⟹ 1 * e = G_s * 0.25 ……. (2)

Solve (1) and (2) ⟹ G_s = 2.67 and e = 0.67

At dry state

$$\rho_{dry} = \frac{M_s}{V} = \frac{160}{85} = 1.88\ gm/cm^3$$

$$\rho_{dry} = 1.88 = \frac{G_s}{1+e}\rho_w = \frac{2.67}{1+e} * 1 \rightarrow e_{S.L} = 0.42$$

S.$e_{S.L}$ = $G_s.\omega_{c\ S.L}$ ⟹ 1 * 0.42 = 2.67 * $\omega_{c\ S.L}$

$\omega_{c\ S.L}$ = 0.1573 = 15.73%

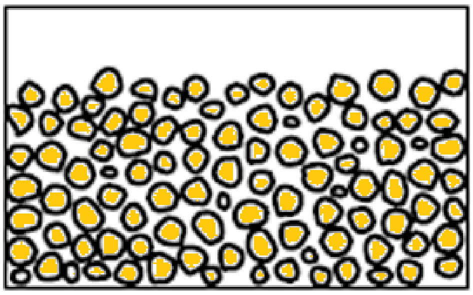
3.7 Relative Density of Cohessionless Soil

It is the ratio of the actual density to the maximum possible density of the soil it is expressed in terms of void ratio.

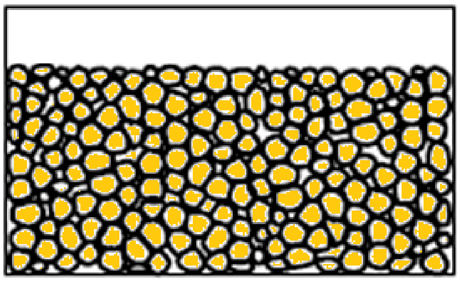
$$R_D\ or\ D_r\% = \frac{e_{max} - e_n}{e_{max} - e_{min}} * 100\%$$

or

$$D_r\% = \frac{\gamma_{dmax}}{\gamma_{dn}} * \frac{\gamma_{dn} - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}} * 100\%$$



Loose soil



Dense Soil

e_{max}: maximum void ratio at the loosest condition

e_{min}: minimum void ratio at the densest condition

e_n: void ratio at the field or natural condition

γ_{dmax}: maximum dry unit weight (at e_{min})

γ_{dmin}: minimum dry unit weight (at e_{max})

γ_{dn}: dry unit weight at field (at e_n)

Relative density	Description of soil
0 -15	Very loose
15 – 35	Loose
35 – 65	Medium
65 - 85	Dense
85 - 100	Very dense

Example (3.9)

A granular soil with γ_{dn} = 16.9 kN/m^3, if the relative density is 80%, ω_c = 10% and G_s = 2.65. Find the dry unit weight in the loosest state and e_{max} if e_{min} is 0.45

Solution:

$$\gamma_{dn} = 16.9 = \frac{G_s}{1+e_n}\gamma_w = \frac{2.65}{1+e_n} * 9.81 \rightarrow e_n = 0.538$$

$$D_r\% = \frac{e_{max}-e_n}{e_{max}-e_{min}} * 100\%, 0.80 = \frac{e_{max}-0.538}{e_{max}-0.45} \rightarrow e_{max} = 0.89$$

Dry unit weight in the loosest state = γ_{dmin}

$$\gamma_{dmin} = \frac{G_s}{1+e_{max}}\gamma_w = \frac{2.65}{1+0.89} * 9.81 = 13.75\ kN/m^3$$

Example (3.10)

A granular soil is compacted to the moist unit weight of 20.45 kN/m^3 at a moisture content of 18%. What is relative density of the compacted soil, if e_{max} = 0.85, e_{min} = 0.42 and G_s = 2.65

Solution

$$\gamma_t = \frac{G_s(1+\omega_c)}{1+e_n}\gamma_w = 20.45 = \frac{2.65*(1+0.18)}{1+e_n} * 9.81 \rightarrow e_n = 0.5$$

$$D_r\% = \frac{e_{max}-e_n}{e_{max}-e_{min}} * 100\% = \frac{0.85-0.50}{0.85-0.42} * 100\% = 81.4\%$$

3.8 AASHTO Classification System

The AASHTO system of soil classification was developed in 1929 as the Public Road Administration classification system. (ASTM Designation D-3282; AASHTO method M145).

The AASHTO classification is given in Table. The soil is classified into seven major groups: A-1 through A-7. Soils classified under groups A-1, A-2, and A-3, are granular materials of which 35% or less of the particles pass through the No. 200 sieve. Soils of which more than 35% pass through the No. 200 sieve are classified into groups A-4, A-5, A-6, and A-7. These soils are mostly silt and clay-type materials. This classification system is based on the following criteria:

1. Grain size
   a. **Gravel**: fraction passing the 75-mm sieve and retained on the No. 10 (2-mm) U.S. Sieve
   b) **Sand**: the fraction is passing the No. 10 (2-mm) U.S. sieve and retained on the No. 200 (0.075-mm) U.S. Sieve
   c) **Silt and clay**: the fraction is passing the No. 200 U.S. Sieve
2. Plasticity: The term silty is applied when the fine fractions of the soil have a plasticity index of 10 or less. The term clayey is applied when the fine fractions have a plasticity index of 11 or more.
3. If cobbles and boulders (a size larger than 75 mm) are encountered, they are excluded from the portion of the soil sample from which classification is made. However, the percentage of such material is recorded.

To classify a soil according to Table below, one must apply the test data from left to the right. By process of elimination, the first group from the left into which the experimental data fit is the correct classification. The figure shows a plot of the range of the liquid limit and the plasticity index for soils that fall into groups A-2, A-4, A-5, A-6, and A-7.

The equation gives the group index (GI) which useful in highway engineering for subgrade material

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10)$$

Where

F_{200} is percentage passing through the No. 200 sieve

L.L: liquid limit

P.I: plasticity index

The first term of Equation that is, $(F_{200} - 35) [0.2 + 0.005(LL - 40)]$ which is the partial group index determined from the liquid limit. The second term that is: $0.01(F_{200} - 15) (PI - 10)$ is the partial group index determined from the plasticity index. Following are some rules for determining the group index:

1. If Equation result yields a negative value for GI, it is taken as zero.
2. The group index calculated from Equation is rounded off to the nearest whole number (for example, GI = 3.4 is rounded off to 3; GI = 3.5 is rounded off to 4).
3. There is no upper limit for the group index.
4. The group index of soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 is always 0.
5. When calculating the group index for soils that belong to groups A-2-6 and A-2-7, use the partial group index for PI, or

$$GI = 0.01(F_{200} - 15)(PI - 10)$$

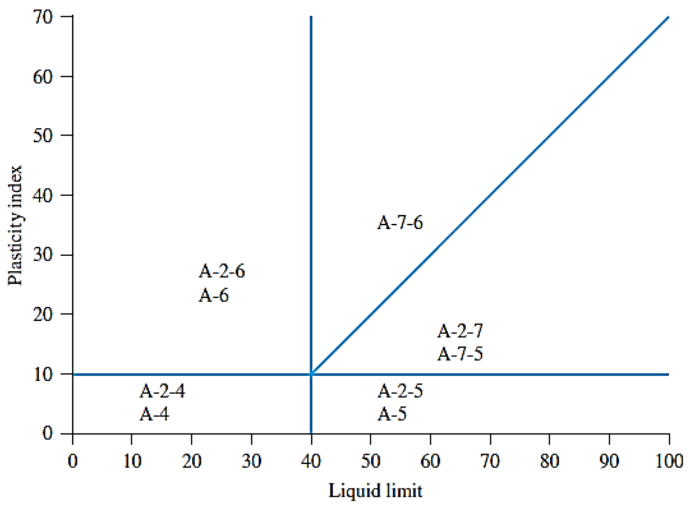
In general, the quality of performance of soil as a subgrade material is inversely proportional to the group index.

Classification of Highway Subgrade Materials

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			A-2			
Group classification	**A-1-a**	**A-1-b**	**A-3**	**A-2-4**	**A-2-5**	**A-2-6**	**A-2-7**
Sieve analysis (percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand			
General subgrade rating	Excellent to good						

General classification	Silt-clay materials (more than 35% of total sample passing No. 200)			
Group classification	**A-4**	**A-5**	**A-6**	**A-7 A-7-5**[a] **A-7-6**[b]
Sieve analysis (percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Silty soils		Clayey soils	
General subgrade rating	Fair to poor			

[a]For A-7-5, $PI \leq LL - 30$
[b]For A-7-6, $PI > LL - 30$



Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6, and A-7

Example (3.11)

The results of the particle-size analysis of soil are as follows:

• Percent passing the No. 10 sieve = 42

• Percent passing the No. 40 sieve = 35

• Percent passing the No. 200 sieve = 20

The liquid limit and plasticity index of the minus No. 40 fraction of the soil are 25 and 20, respectively. Classify the soil by the AASHTO system.

Solution

Since 20% (less than 35%) of soil is passing No. 200 sieve, it is granular soil. Hence it can be A-1, A-2, or A-3. Refer to Table. Starting from the left of the table, the soil falls under A-1-b (see the table below).

Parameter	Specifications in Table	Parameters of the given soil
Percent passing sieve		
No. 10	—	
No. 40	50 max	35
No. 200	25 max	20
Plasticity index (*PI*)	6 max	$PI = LL - PL = 25 - 20 = 5$

The group index of the soil is 0. So, the soil is **A-1-b (0)**

Example (3.12)

Ninety-five percent of a soil passes through the No. 200 sieve and has a liquid limit of 60 and plasticity index of 40. Classify the soil by the AASHTO system.

Solution

Ninety-five percent of the soil (which is ≥ 36%) is passing through No. 200 sieve. So it is a silty-clay material. Now refer to Table. Starting from the left of the table, it falls under A-7-6 (see the table below).

Parameter	Specifications in Table	Parameters of the given soil
Percent passing No. 200 sieve	36 min.	95
Liquid limit (*LL*)	41 min.	60
Plasticity index (*PI*)	11 min.	40
PI	$> LL - 30$	$PI = 40 > LL - 30 = 60 - 30 = 30$

$$GI = (F_{200} - 35)\,[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)\,(PI - 10)$$

$$= (95 - 35)\,[0.2 + 0.005(60 - 40)] + (0.01)\,(95 - 15)\,(40 - 10)$$

$$= 42$$

So, the classification is A-7-6(42).

3.9 Unified Soil Classification System (USCS)

The original form of this system was proposed by Casagrande in 1942, then this system was revised in 1952. At present, it is used widely by engineers (ASTM Test Designation D-2487). The Unified classification system is presented in Table below.

This system classifies soils into two broad categories:

1. Coarse-grained soils that are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve. The group symbols start with a prefix of **G** for **gravel** or **S** for **sandy** soil
2. Fine-grained soils are with 50% or more passing through the No. 200 sieve. The group symbols start with prefixes of **M**, for inorganic **silt** and **C** for inorganic **clay** or **O** for **organic** silts and clays. The symbol **Pt** is used for **peat, muck, and other highly organic soils**.
3. Other symbols used for the classification are:

a. W: well graded
b. P: poorly graded
c. L: low plasticity (liquid limit less than 50)
d. H: high plasticity (liquid limit more than 50)

For proper classification according to this system, some or all of the following information must be known:

1. Percent of gravel: that is, the fraction passing the 76.2 mm sieve and retained on the No. 4 sieve (4.75-mm opening)
2. Percent of sand: that is, the fraction passing the No. 4 sieve (4.75-mm opening) and retained on the No. 200 sieve (0.075-mm opening)

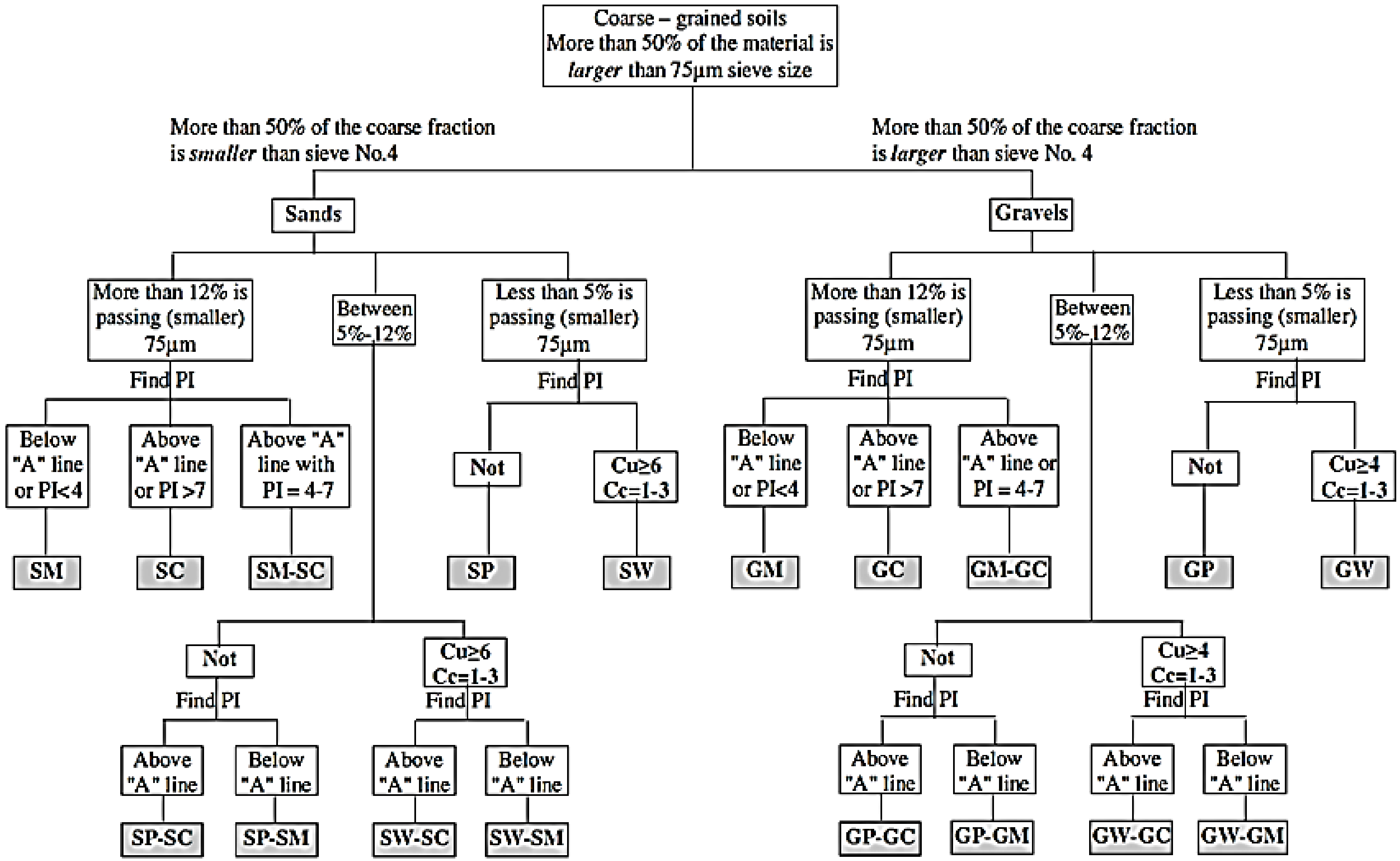
3. Percent of silt and clay: that is, the fraction finer than the No. 200 sieve (0.075-mm opening)
4. Uniformity coefficient (C_u) and the coefficient of gradation (C_c)
5. Liquid limit and plasticity index of the portions of soil is passing the No. 40 sieve

The group symbols for coarse-grained gravelly soils are GW, GP, GM, GC, GC-GM, GW-GM, GW-GC, GP-GM, and GP-GC.

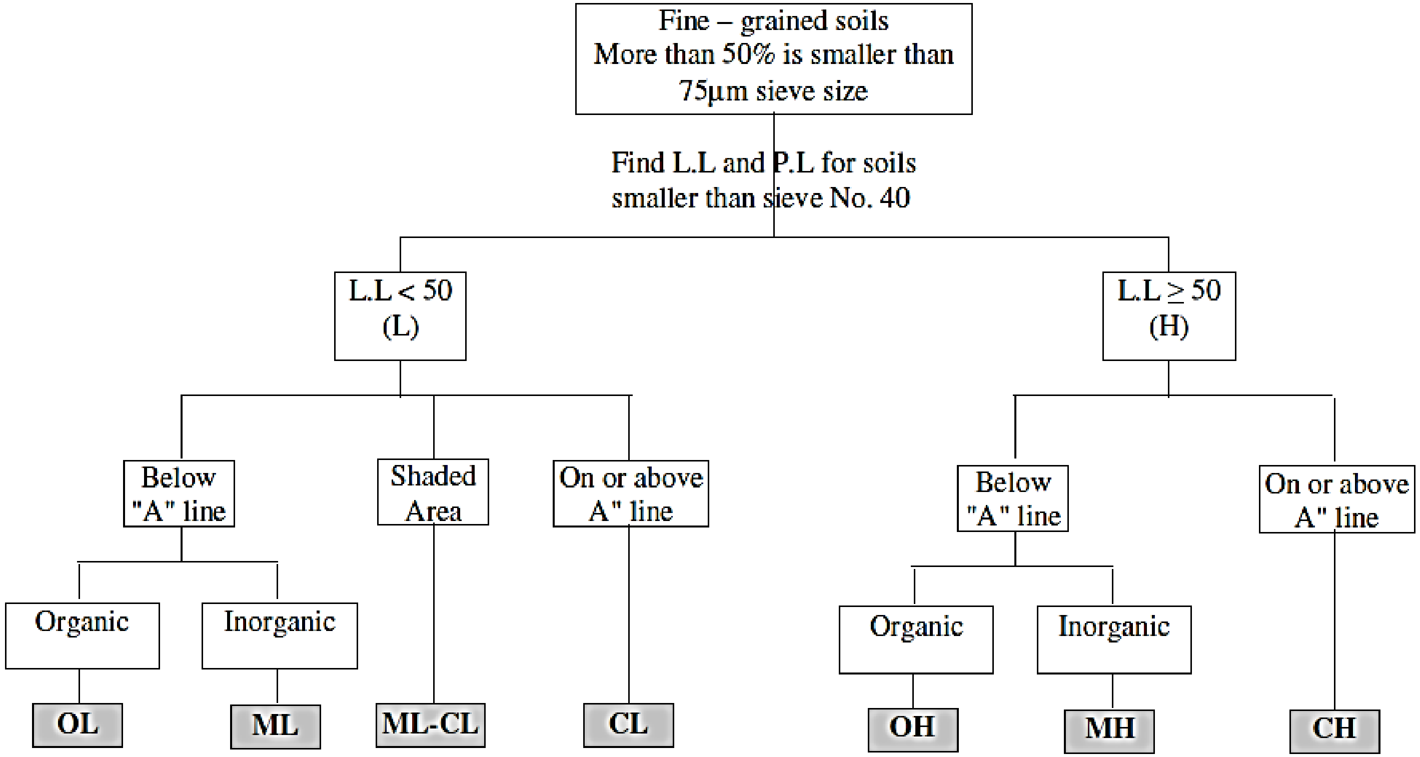
Similarly, the group symbols for fine-grained soils are CL, ML, OL, CH, MH, OH, CL-ML, and Pt.

More recently, ASTM designation D-2487 created an elaborate system to assign group names to soils. These names are summarized in Figures. In using these figures, one needs to remember that, in a given soil,

- Fine fraction _ percent passing No. 200 sieve
- Coarse fraction _ percent retained on No. 200 sieve
- Gravel fraction _ percent retained on No. 4 sieve
- Sand fraction _ (percent retained on No. 200 sieve) (percent retained on No. 4 sieve)



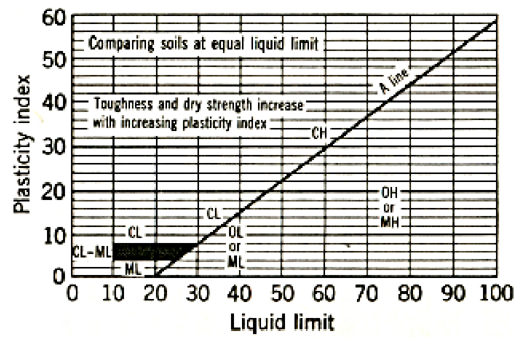
GW: Well graded gravels, gravel-sands mixtures, little or no fines **GP:** Poorly graded gravels gravel-sands mixtures, little or no fines **GM:** Silty gravels poorly graded gravel-sands-silt mixtures **GC:** Clayey gravels poorly graded gravel-sands clay mixtures **SW:** Well graded sands, gravel-sands, little or no fines **SP:** Poorly graded sands, gravel-sands, little or no fines **SM:** Silty sands, poorly graded sands-silt mixtures **SC:** Clayey sands, poorly graded sands clay mixtures



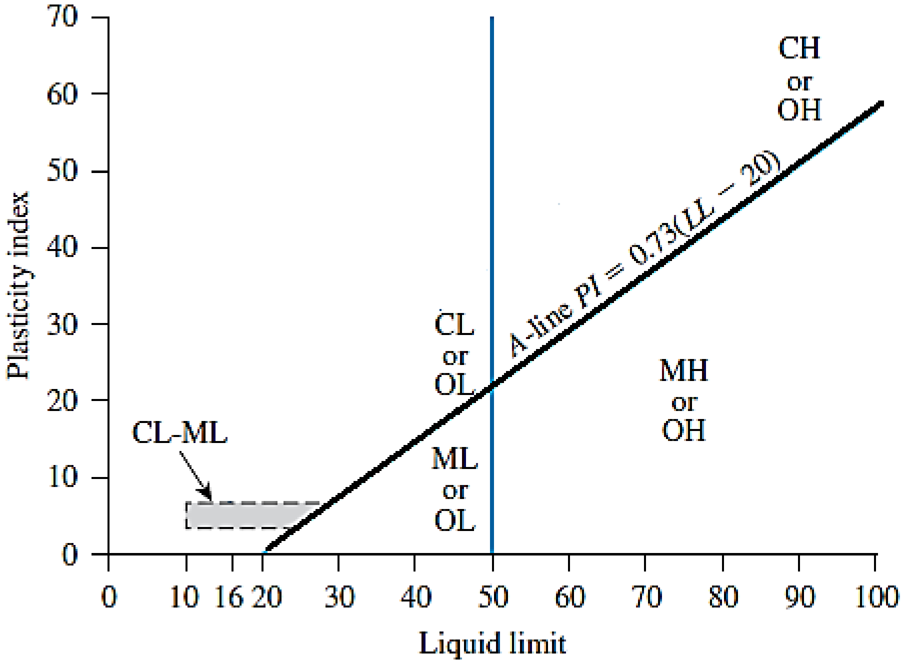
OL: Organic silts and organic silt-clay of low plasticity.
ML: Inorganic silts and very fine rock flour, silty or clayey fine sands with slight plasticity.
CL: Inorganic clays of low or medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
OH: Organic clays of medium to high plasticity.
MH: Inorganic silts micaceous or diatomaceous fine sandy or silty soils, elastic silts.
CH: Organic clays of high plasticity, fat clays.
Pt: Peat and other highly organic soils

P.L: Plastic limit **L.L:** liquid limit
PI: Plasticity index = L.L – P.L

$$C_U = \frac{D_{60}}{D_{10}} \qquad C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$



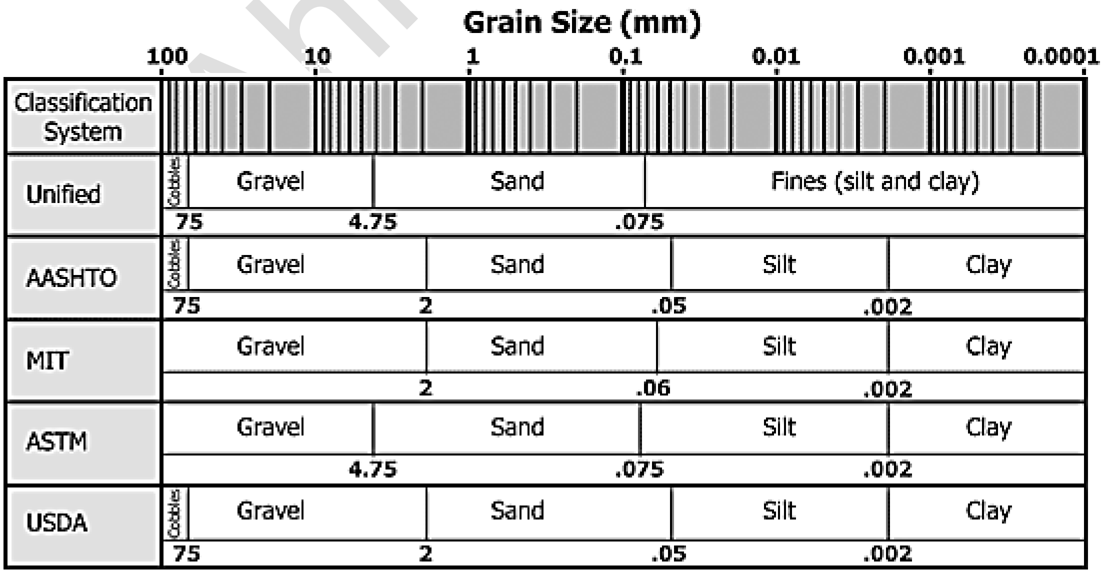
Plasticity chart
for laboratory classification of fine grained soils



Plasticity chart

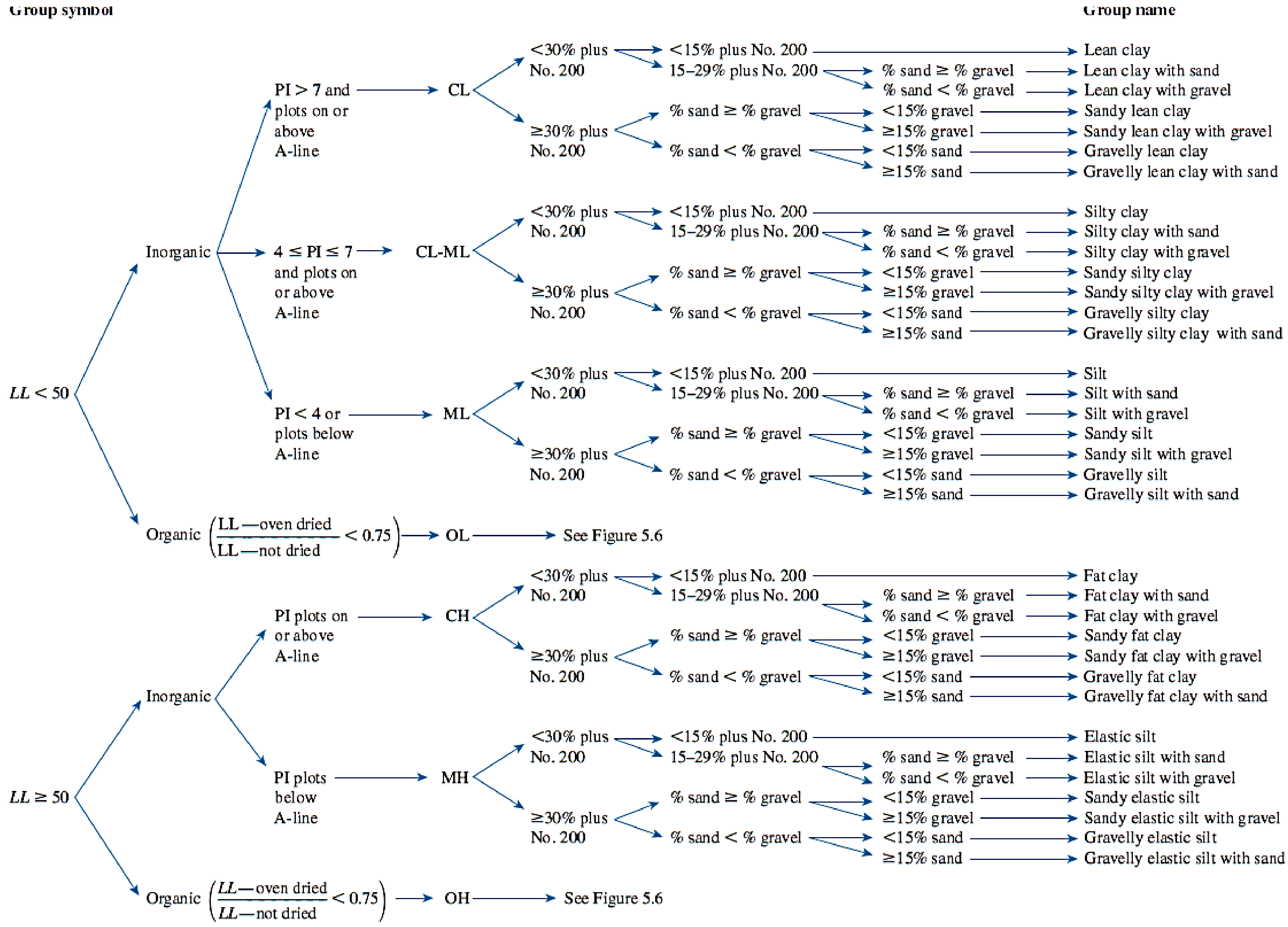
Summary

It can be found that there are different methods of soil classification; each one has its limitation and measurements. The table below summarizes these methods.

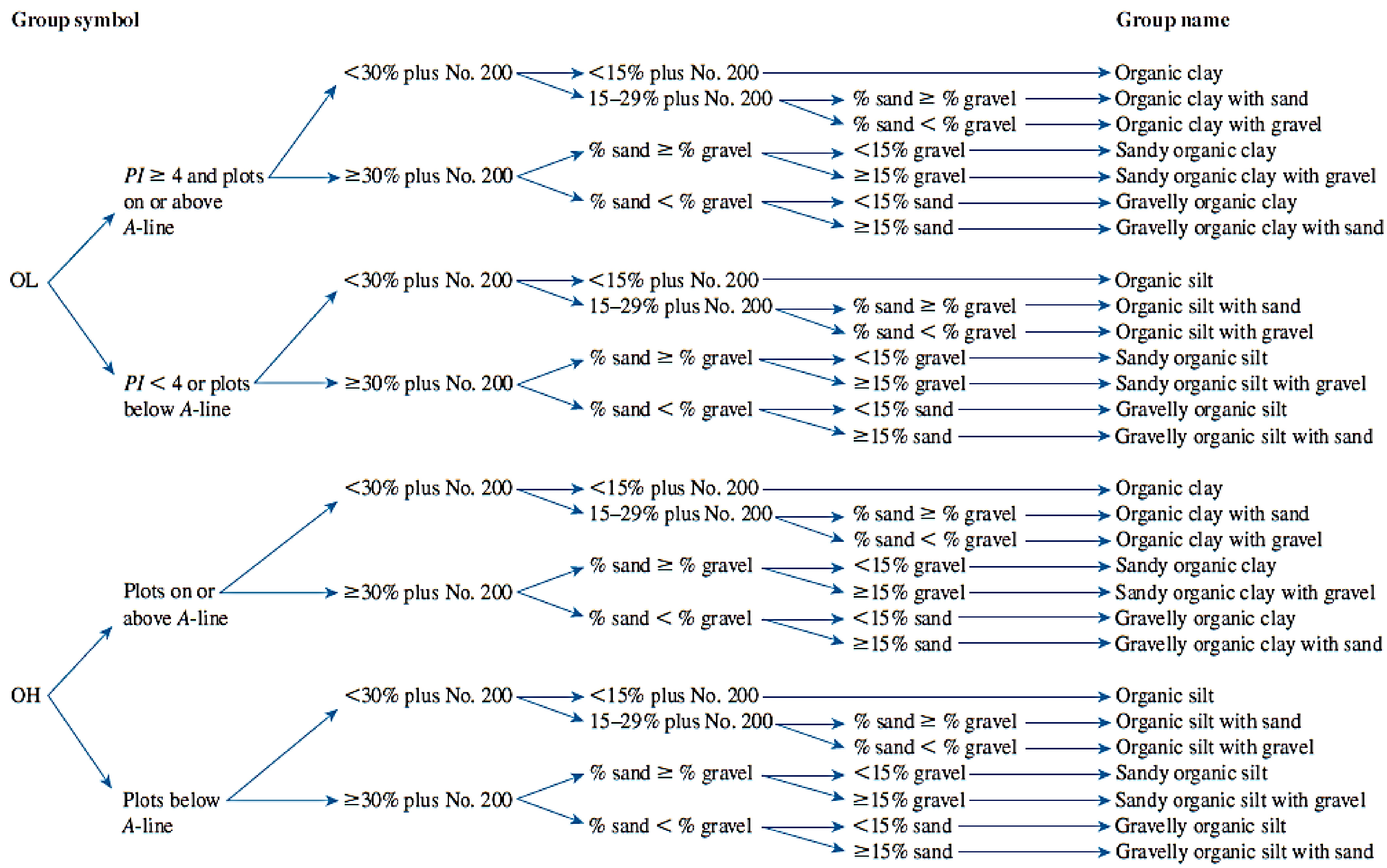


Group symbol		Group name
GW	<15% sand	Well-graded gravel
	≥15% sand	Well-graded gravel with sand
GP	<15% sand	Poorly graded gravel
	≥15% sand	Poorly graded gravel with sand
GW-GM	<15% sand	Well-graded gravel with silt
	≥15% sand	Well-graded gravel with silt and sand
GW-GC	<15% sand	Well-graded gravel with clay (or silty clay)
	≥15% sand	Well-graded gravel with clay and sand (or silty clay and sand)
GP-GM	<15% sand	Poorly graded gravel with silt
	≥15% sand	Poorly graded gravel with silt and sand
GP-GC	<15% sand	Poorly graded gravel with clay (or silty clay)
	≥15% sand	Poorly graded gravel with clay and sand (or silty clay and sand)
GM	<15% sand	Silty gravel
	≥15% sand	Silty gravel with sand
GC	<15% sand	Clayey gravel
	≥15% sand	Clayey gravel with sand
GC-GM	<15% sand	Silty clayey gravel
	≥15% sand	Silty clayey gravel with sand
SW	<15% gravel	Well-graded sand
	≥15% gravel	Well-graded sand with gravel
SP	<15% gravel	Poorly graded sand
	≥15% gravel	Poorly graded sand with gravel
SW-SM	<15% gravel	Well-graded sand with silt
	≥15% gravel	Well-graded sand with silt and gravel
SW-SC	<15% gravel	Well-graded sand with clay (or silty clay)
	≥15% gravel	Well-graded sand with clay and gravel (or silty clay and gravel)
SP-SM	<15% gravel	Poorly graded sand with silt
	≥15% gravel	Poorly graded sand with silt and gravel
SP-SC	<15% gravel	Poorly graded sand with clay (or silty clay)
	≥15% gravel	Poorly graded sand with clay and gravel (or silty clay and gravel)
SM	<15% gravel	Silty sand
	≥15% gravel	Silty sand with gravel
SC	<15% gravel	Clayey sand
	≥15% gravel	Clayey sand with gravel
SC-SM	<15% gravel	Silty clayey sand
	≥15% gravel	Silty clayey sand with gravel

Flowchart group names for gravelly and sandy soil (*Source:* From "Annual Book of ASTM Standards, 04.08." Copyright ASTM INTERNATIONAL. Reprinted with permission.)



Flowchart group names for inorganic silty and clayey soils (*Source:* From "Annual Book of ASTM Standards, 04.08." Copyright ASTM INTERNATIONAL. Reprinted with permission.)



Flowchart group names for organic silty and clayey soils (*Source:* From “Annual Book of ASTM Standards, 04.08.” Copyright ASTM INTERNATIONAL. Reprinted with permission.)

Example (3.13)

The results of the particle-size analysis of soil are as follows:

Percent passing through the No. 10 sieve =100

Percent passing through the No. 40 sieve = 80

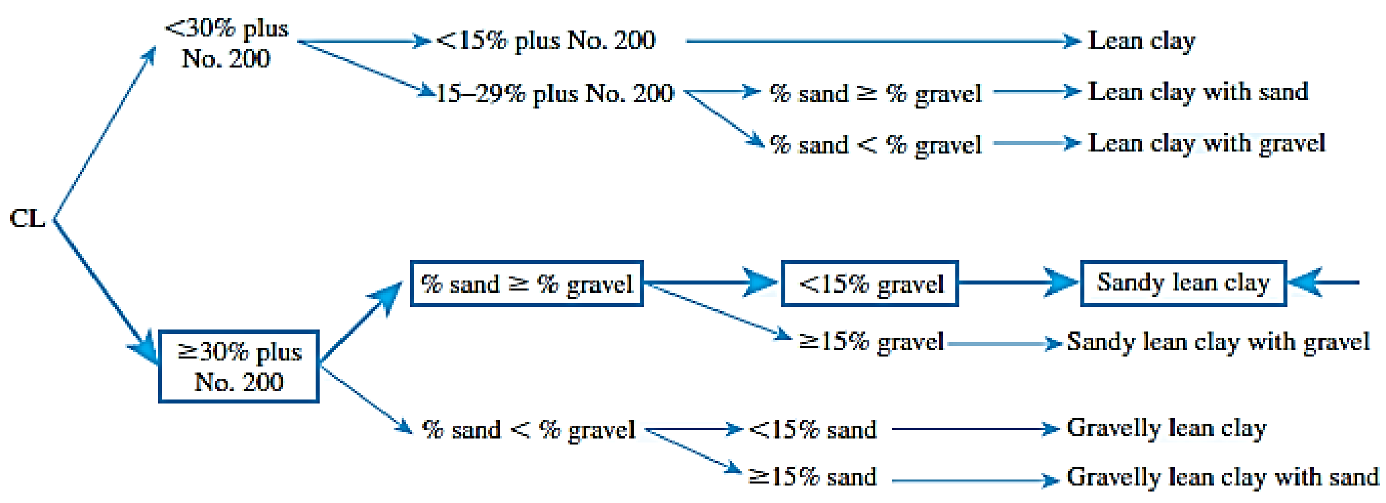
Percent passing through the No. 200 sieve = 58

The liquid limit and plasticity index of the minus No. 40 fraction of the soil are 30 and 10, respectively. Classify the soil by the Unified classification system.

Solution

Since 58% of the soil passes through the No. 200 sieve, it is a fine-grained soil. Referring to the plasticity chart, for LL = 30 and PI = 10, it can be classified (group symbol) as CL.

To determine the group name. The percent passing No. 200 sieve is more than 30%. Percent of gravel = 0; percent of sand = (100 - 58) - (0) = 42. Hence, percent sand > percent gravel. Also, percent gravel is less than 15%. Hence the group name is **sandy lean clay**.



Example (3.14)

For a given soil, the following are known:

- Percentage passing through No. 4 sieve = 70
- Percentage passing through No. 200 sieve = 30
- Liquid limit = 33
- Plastic limit = 12

Classify the soil using the Unified Soil Classification System. Give the group symbol and the group name.

Solution

The percentage passing No. 200 sieve is 30%, which is less than 50%. So it is a coarse-grained soil. Thus

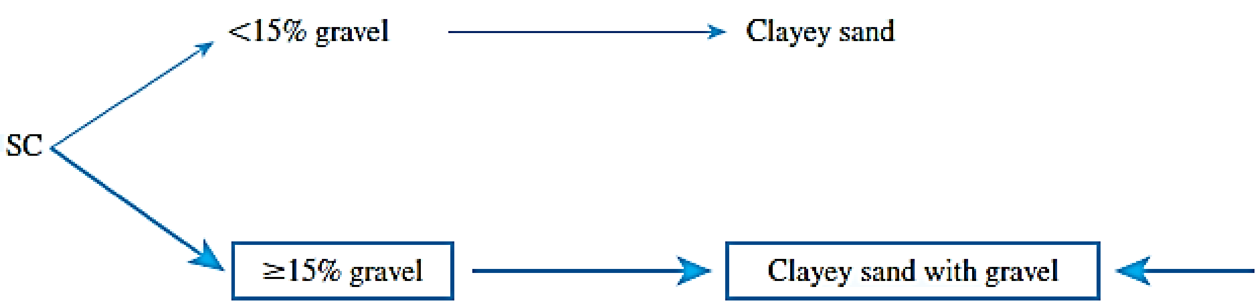
Coarse fraction = 100 - 30 = 70%

Gravel fraction = percent retained on No. 4 sieve = 100 - 70 = 30%

Hence, more than 50% of the coarse fraction is passing No. 4 sieve. Thus, it is a sandy soil. Since more than 12% is passing No. 200 sieve, it is SM or SC. For this soil,

PI = 33 -12 = 21 (which is greater than 7). With LL = 33 and PI = 21, it plots above the A-line. Thus the group symbol is SC.

Since the percentage of gravel is more than 15%, it is **clayey sand with gravel**.

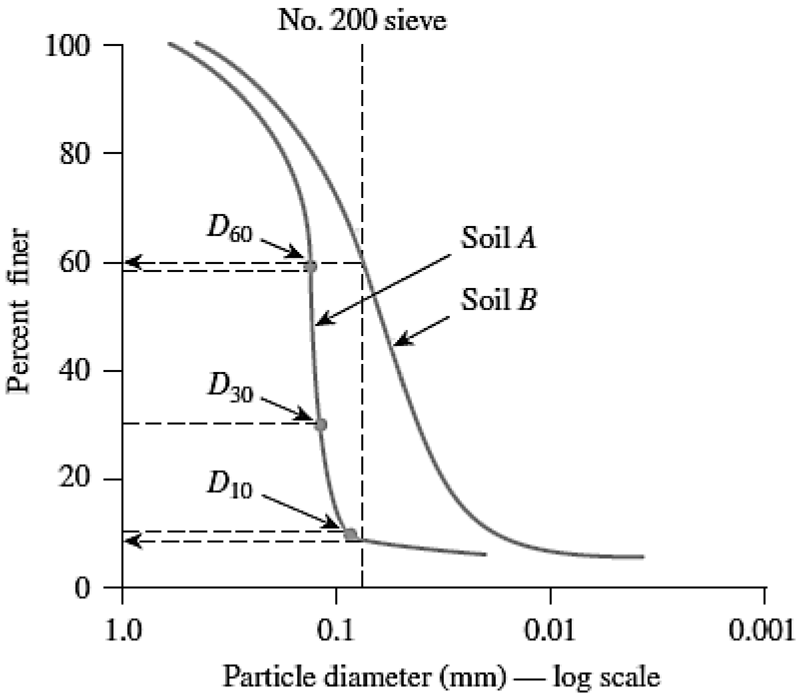


Example (3.15)

The figure gives the grain-size distribution of two soils. The liquid and plastic limits of minus No. 40 sieve fraction of the soil are as follows:

	Soil A	Soil B
Liquid limit	30	26
Plastic limit	22	20

Determine the group symbols and group names according to the Unified Soil Classification System.



Particle-size distribution of two soils

Solution

Soil A

The grain-size distribution curve indicates that percent passing No. 200 sieve is 8. Thus, it is a coarse-grained soil. Also, the percent retained on No. 4 sieve is zero. Hence, it is a sandy soil.

D_{10} = 0.085 mm, D_{30} = 0.12 m, and D_{60} = 0.135 mm. Thus,

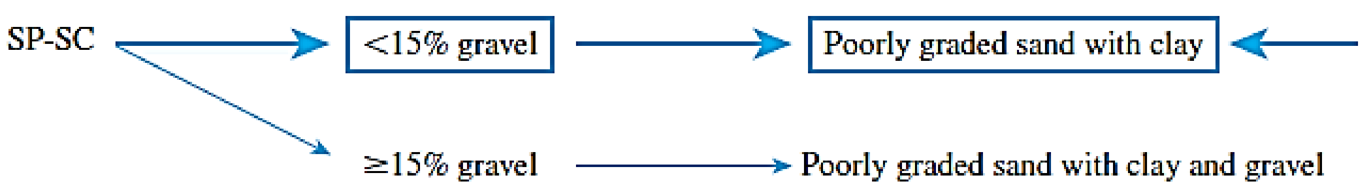
$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.135}{0.085} = 1.59 < 6$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.12)^2}{(0.135)(0.085)} = 1.25 > 1$$

With LL = 30 and PI = 30 - 22 = 8 (which is greater than 7), it plots above the A-line. Hence, the group symbol is **SP-SC**.

To determine the group name,

Percentage of gravel = 0 (which is < 15%)



So, the group name is **poorly graded sand with clay**.

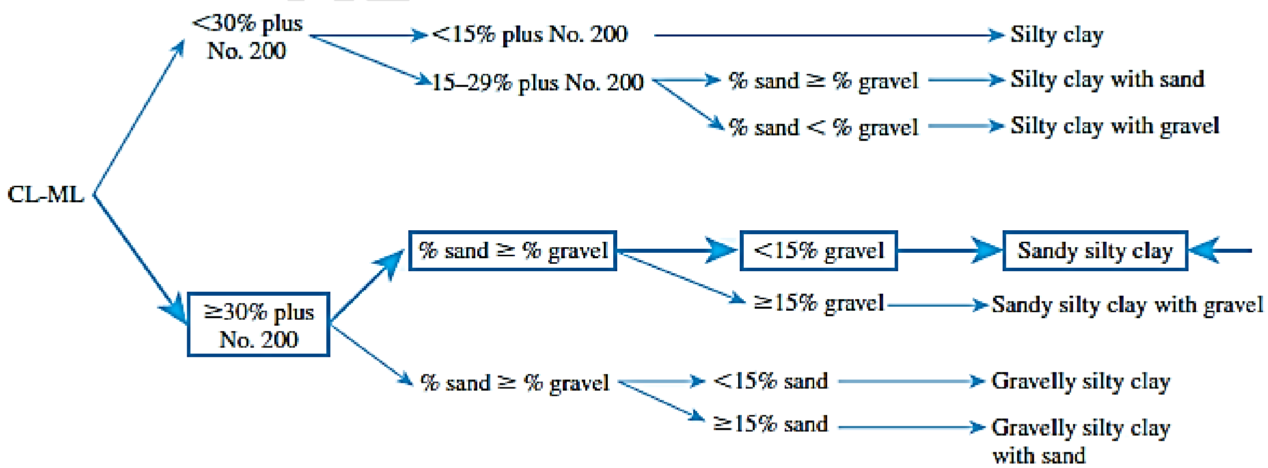
Soil B

The grain-size distribution curve shows that percent passing No. 200 sieve is 61 (>50%); hence, it is a fine-grained soil.

Given: LL = 26 and PI = 26 - 20 = 6. The *PI* plots in the hatched area. So, the group symbol is **CL-ML**.

For group name (assuming that the soil is inorganic),

percentage of gravel = 0, percentage of sand = 100 - 61 = 39 (which is greater than 30).



Thus, because the percentage of sand is greater than the percentage of gravel, the soil is **sandy, silty clay**

Homework Chapter 3

3.1 Results from liquid and plastic limit tests conducted on soil are given below.

No. of blows, N	Moisture content (%)
14	38.4
16	36.5
20	33.1
28	27.0

If the plastic limit is PL = 13.4%

a. Draw the flow curve and obtain the liquid limit.

b. What is the plasticity index of the soil?

3.2 Determine the liquidity index of the soil in Problem (1) if $w_{in\ situ}$ = 32%

3.3 Results from liquid and plastic limit tests conducted on soil are given below.

No. of blows, N	Moisture content (%)
13	33
18	27
29	22

If the plastic limit is PL = 19.1%

a. Draw the flow curve and obtain the liquid limit.

b. What is the plasticity index of the soil?

3.4 Determine the liquidity index of the soil in Problem (3) if $w_{in\ situ}$ = 21%

3.5 A saturated soil used to determine the shrinkage limit has initial volume V_i = 20.2 cm^3, final volume V_f = 14.3 cm^3, the mass of wet soil M_1 = 34 g, and mass of dry soil M_2 = 24 g. Determine the shrinkage limit and the shrinkage ratio.

3.6 For a given sandy soil, e_{max} = 0.75 and e_{min} = 0.52. If G_s = 2.67 and D_r = 65%, determine: Void ratio and Dry unit weight

3.7 For a given sandy soil, the maximum and minimum void ratios are 0.72 and 0.46, respectively. If G_s = 2.68 and ω = 11%, what is the moist unit weight of compaction (kN/m^3) in the field if D_r = 82%?

3.8 In a construction project, the field moist unit weight was 18.08 kN/m^3 at a moisture content of 8%. If maximum and minimum dry unit weight determined in the laboratory were 16.93 kN/m^3 and 14.46 kN/m^3, respectively, what was the field relative density?

3.9 Classify the following soils by the AASHTO classification system. Give the group index for each soil.

Soil	Sieve analysis—Percent finer No. 10	Sieve analysis—Percent finer No. 40	Sieve analysis—Percent finer No. 200	Liquid limit	Plasticity index
A	90	74	32	28	9
B	86	56	8	NP	
C	42	28	12	18	13
D	92	68	30	42	18
E	90	48	22	31	5

3.10 Classify the following soils by the AASHTO classification system. Give the group index for each soil.

Soil	Sieve analysis—Percent finer No. 10	Sieve analysis—Percent finer No. 40	Sieve analysis—Percent finer No. 200	Liquid limit	Plasticity index
A	98	80	72	52	21
B	90	74	58	38	12
C	84	71	64	41	14
D	100	78	82	32	12
E	80	68	48	30	11

3.11 Classify the following soils by using the Unified soil classification system. Give the group symbols and the group names.

Soil	Sieve analysis—Percent finer		Liquid limit	Plasticity index	C_u	C_c
	No. 4	No. 200				
1	70	30	33	21		
2	48	20	41	22		
3	95	70	52	28		
4	100	82	30	19		
5	100	74	35	21		
6	87	26	38	18		
7	88	78	69	38		
8	99	57	54	26		
9	71	11	32	16	4.8	2.9
10	100	2		NP	7.2	2.2
11	89	65	44	21		
12	90	8	39	31	3.9	2.1

3.12 For an inorganic soil, the following grain-size analysis is given.

U.S. Sieve No.	Percent passing
4	100
10	90
20	64
40	38
80	18
200	13

For this soil, LL = 23 and PL = 19. Classify the soil by using (a) AASHTO soil classification system (b) Unified Soil Classification System. Give group names and group symbols.