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SOIL MECHANICS

CHAPTER FOUR

2020-2021

Third

Stage Students

Undergraduate students (3th stage students)
Faculty of Engineering
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Water Resources Engineering Department

CHAPTER FOUR

SOIL CLASSIFICATION

Classification of Soil

4.1 Introduction

- Different soils with similar properties may be classified into groups and subgroups according to their engineering behavior.
- Classification systems provide a common language to concisely express the general characteristics of soils, which are infinitely varied, without detailed descriptions.
- Soil classification systems are based on simple index properties such as particle-size distribution and consistency limits (Atterberg limits)
- 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 sand, silt, and clay-size fractions present in a given soil.

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 AASHTO classification system.**
- **b. The Unified classification system**.

4.2. Soil Classification

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

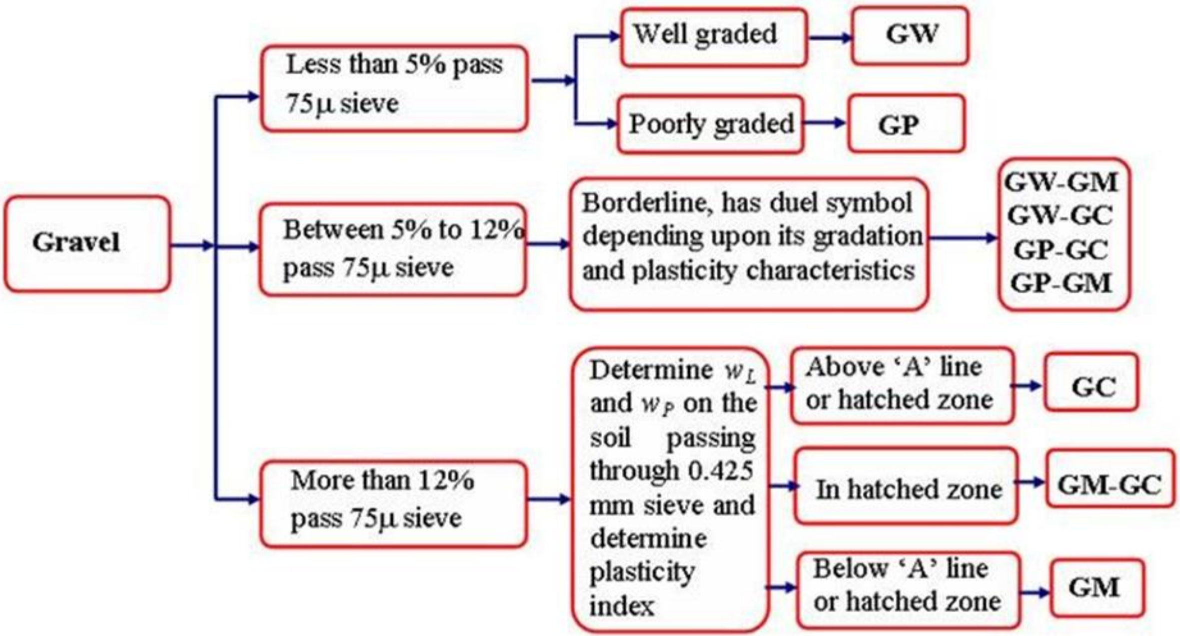
The aim of a classification system is to establish a set of conditions which will allow useful comparisons to be made between different soils. The system must be simple. The relevant criteria for classifying soils are the size distribution of particles and the plasticity of the soil. Particle Size Distribution for measuring the distribution of particle sizes in a soil sample, it is necessary to conduct different particle-size tests. Wet sieving is carried out for separating fine grains from coarse grains by washing the soil specimen on a 75 micron sieve mesh.

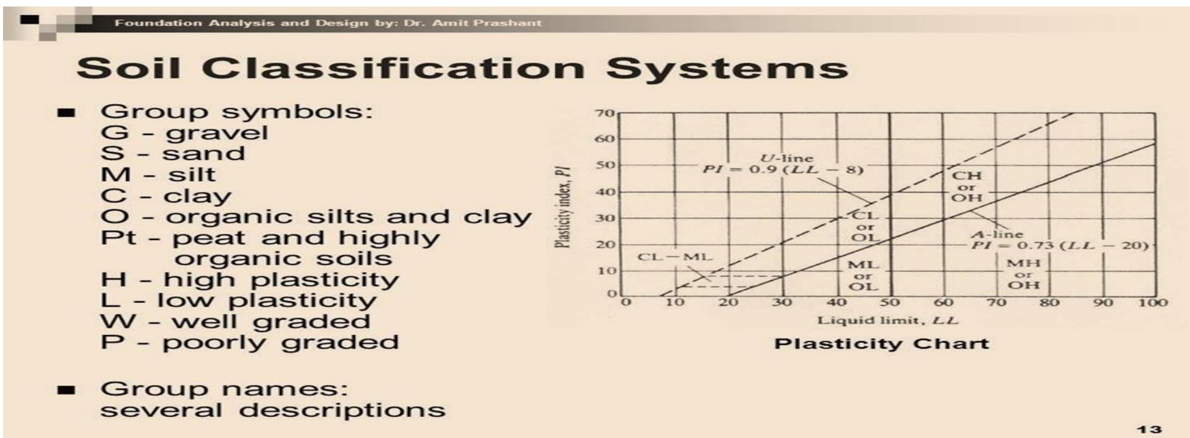
4.2.1. Dry sieve analysis is carried out on particles coarser than 75 micron. Samples (with fines removed) are dried and shaken through a set of sieves of descending size. The weight retained in each sieve is measured. The cumulative percentage quantities finer than the sieve sizes (passing each given sieve size) are then determined. The resulting data is presented as a distribution curve with grain size along x-axis (log scale) and percentage passing along y-axis (arithmetic scale).

U.S. Standard sieve sizes

Sieve no.	Opening (mm)
4	4.750
6	3.350
8	2.360
10	2.000
16	1.180
20	0.850
30	0.600
40	0.425
50	0.300
60	0.250
80	0.180
100	0.150
140	0.106
170	0.088
200	0.075
270	0.053

A set of sieves for a test in the laboratory





4.2.2. Hydrometer (Sedimentation) 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, and weight. For simplicity, it is assumed that all the soil particles are spheres, and the velocity of soil particles can be expressed by Stokes' law, according to which:

Trial pit	Liquid limit (%)	Plasticity index	Symbol	Classification
1	29.23	17.7	CL	Inorganic clays, silty clays, sandy clays.
2	38.7	12.2	CL	Inorganic clays, silty clays, sandy clays.
3	43.0	33.5	CH	Inorganic clays of high plasticity, fatty clays
4	32.7	16.7	CL	Inorganic clays, silty clays, sandy clays.
5	34.0	17.0	CL	Inorganic clays, silty clays, sandy clays.

4.3 Textural Classification (Triangular classification)

In a general sense, *texture* of soil refers to its surface appearance. Soil texture is influenced by the size of the individual particles present in it**,** this classification divided soils into gravel, sand, silt, and clay categories on the basis of particle size.

- ✓ Figure 4.1 shows the textural classification systems developed by the U.S. Department of Agriculture
- ✓ This chart is based on only the fraction of soil that passes through the **No. 10 sieve (2 mm diameter),** Hence, if the particle-size distribution of a soil is such that a certain percentage of the soil particles is larger than 2 mm in diameter, a correction will be necessary
- ✓ The use of this chart can best be demonstrated by an example.

[illegible]

Illustrative example-1: If the particle-size distribution of soil A shows 30% sand, 40% silt, and 30% clay-size particles, to classify this soil using the triangular classification, can be determined by proceeding in the manner indicated by the arrows in Figure 4.1. This soil falls into the zone of clay loam.

Illustrative example-2: If soil *B* has a particle-size distribution of 20% gravel, 10% sand, 30% silt, and 40% clay, the modified textural compositions are:

$$Sand\ size = \frac{10x100}{100-20} = 12.5\%$$

$$Silt\ size = \frac{30x100}{100-20} = 37.5\%$$

$$Clay\ size = \frac{40x100}{100-20} = 50.0\%$$

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

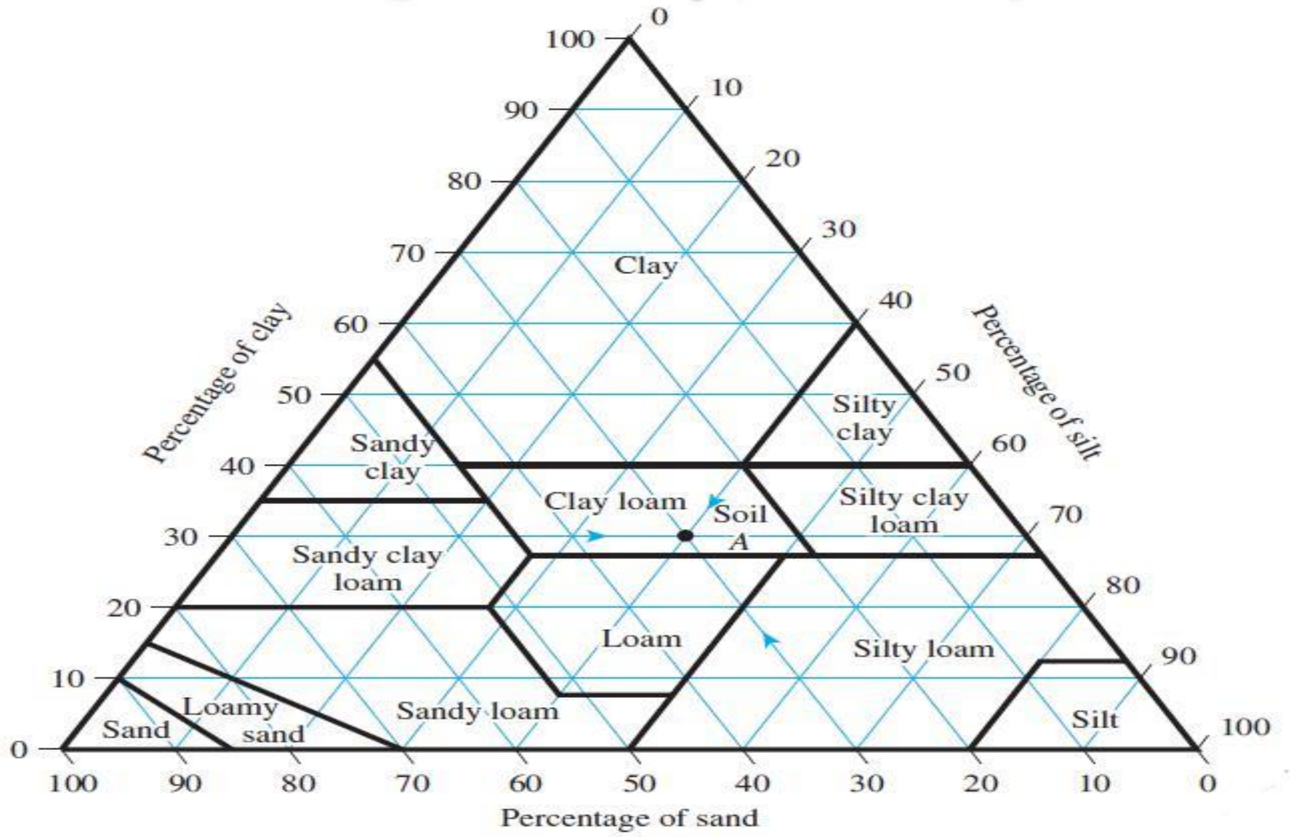


Figure 4.1 U.S. Department of Agriculture textural classification (*USDA*)

Illustrative example-3: Classify the following soils according to the USDA textural classification system.

Particle-size Soil 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

Solution

Step 1. Calculate the modified percentages of sand, gravel, and silt as follows:

$$\text{Modified \% Sand} = \frac{\text{\% Sand}}{100 - \text{\%gravel}} x100\%$$

$$\text{Modified \% Silt} = \frac{\text{\% Silt}}{100 - \text{\%gravel}} x100\%$$

$$\text{Modified \% Clay} = \frac{\text{\% Clay}}{100 - \text{\%gravel}} x100\%$$

Thus, the following table results:

Particle-size Soil 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 4.1 to determine the zone into which each soil falls. The results are as follows:

Classification of soil			
A	B	C	D
Gravelly clay loam	Gravelly loam	Clay	Gravelly clay

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

4.4 Classification by Engineering Behavior

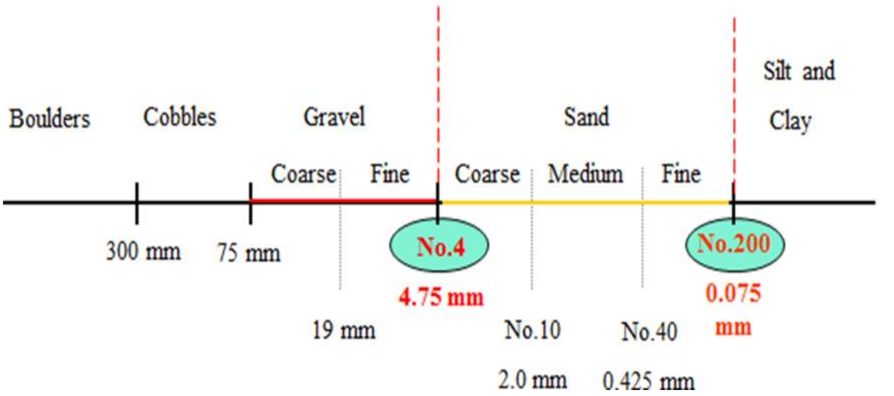
The textural classification of soil is relatively simple, it is based entirely on the particle-size distribution, the soils engineer must consider *plasticity*, so that the textural classification of soil are inadequate for most engineering purposes , Currently, two more elaborate classification systems are commonly used by soils engineers. Both systems take into consideration the particle-size distribution and Atterberg limits. They are:

- **American Association of State Highway and Transportation Officials (AASHTO) classification system, The AASHTO classification system is used mostly by state and county highway departments.**
- **Unified Soil Classification System (USCS), Geotechnical engineers generally prefer the Unified system.**

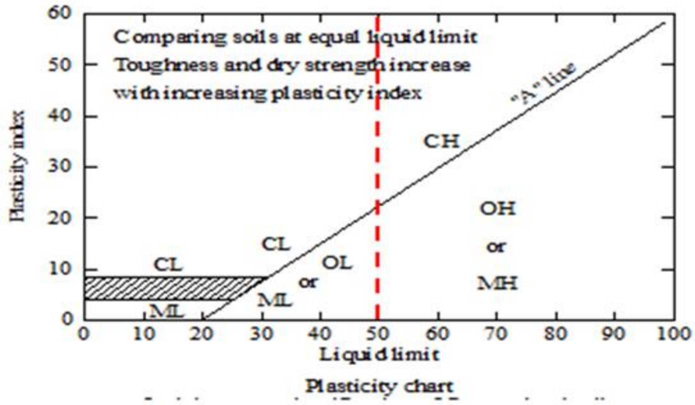
1. Unified Soil Classification System (USCS)

i. Definition of Grain Size

No specific grain size-use Atterberg limits



Used for Fine grained soils to determine whether silt (M) or clay (C)



Plasticity chart

Below A-line is silt – use symbol M

Above A-line is clay – use symbol C

LL > 50 → High plasticity

LL< 50 → low plasticity

4.5 AASHTO Classification System

The AASHTO classification system which is given in Fig 4.1 is classify the soil into General classification and Group classification which is consist of seven major groups: A-1 through A-7 then the major groups divided in to subgroups

The AASHTO method uses Atterberg limits (LL and PL), and information on grain size distribution curve (F10, F40, and F200), which are the percentage passing on No. 10 sieve, No. 40 sieve, and No. 200 sieve, respectively.

✓ **General classification:**

Can be categorized according to the percentage passing the dominated sieve (No. 200)

- Granular Materials *if* (35% or less of total sample passing No. 200)
- Silt-Clay Materials *if* (more than 35% of total sample passing No. 200)

✓ **Group classification :**

- Soils classified under groups A-1, A-2, and A-3 are granular materials
- Soils classified under groups A-4, A-5, A-6, & A-7 are Silt-Clay Materials

Table 5.1. AASHTO Classification System

General Classification	*Granular materials (35% or less passing No. 200 Sieve (0.075 mm)*							*Silt-clay Materials More than 35% passing No. 200 Sieve (0.075 mm)*			
Group Classification	*A—1*		*A—3*	*A—2*				*A—4*	*A—5*	*A—6*	*A—7*
	A—1—a	*A—1—b*		*A—2—4*	*A—2—5*	*A—2—6*	*A—2—7*				*A—7—5* *A—7—6*
(*a*) Sieve Analysis: Percent Passing											
(*i*) 2.00 mm (No. 10)	50 max										
(*ii*) 0.425 mm (No. 40)	30 max	50 max	51 min								
(*iii*) 0.075 mm (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
(*b*) Characteristics of fraction passing 0.425 mm (No. 40)											
(*i*) Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
(*ii*) Plasticity index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min*
(*c*) Usual types of significant Constituent materials	Stone Fragments Gravel and sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
(*d*) General rating as subgrade.	Excellent to Good							Fair to Poor			

* If plasticity index is equal to or less than (liquid Limit—30), the soil is A—7—5 (*i.e.* PL > 30%)
If plasticity index is greater than (Liquid Limit—30), the soil is A—7—6 (*i.e.* PL < 30%)

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

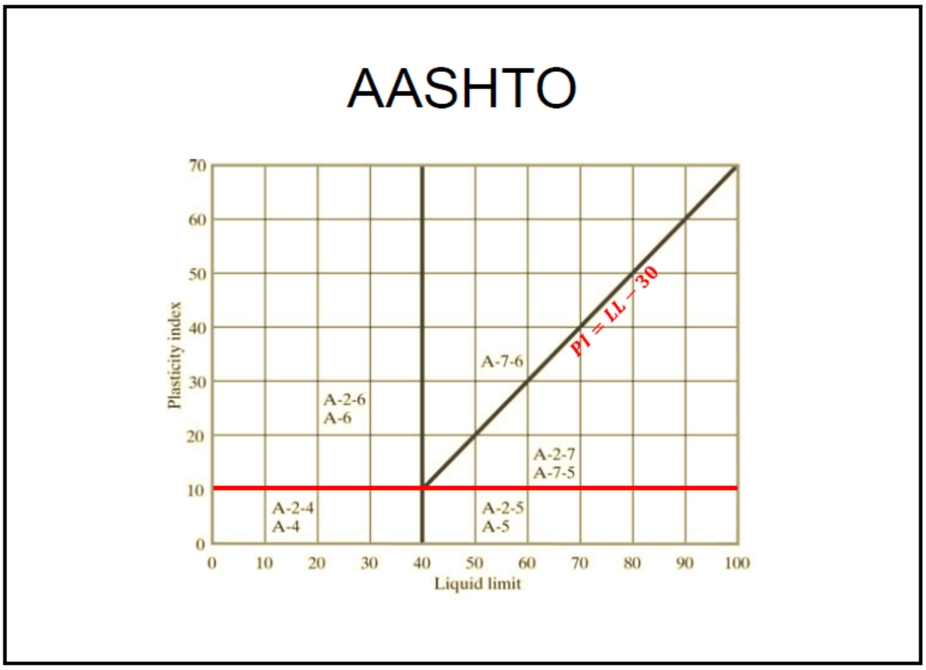
b. *Sand:* fraction passing the No. 10 (2-mm) U.S. sieve and retained on the No. 200 (0.075-mm) U.S. sieve

c. *Silt and clay:* fraction 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* (size larger than 75 mm) are encountered



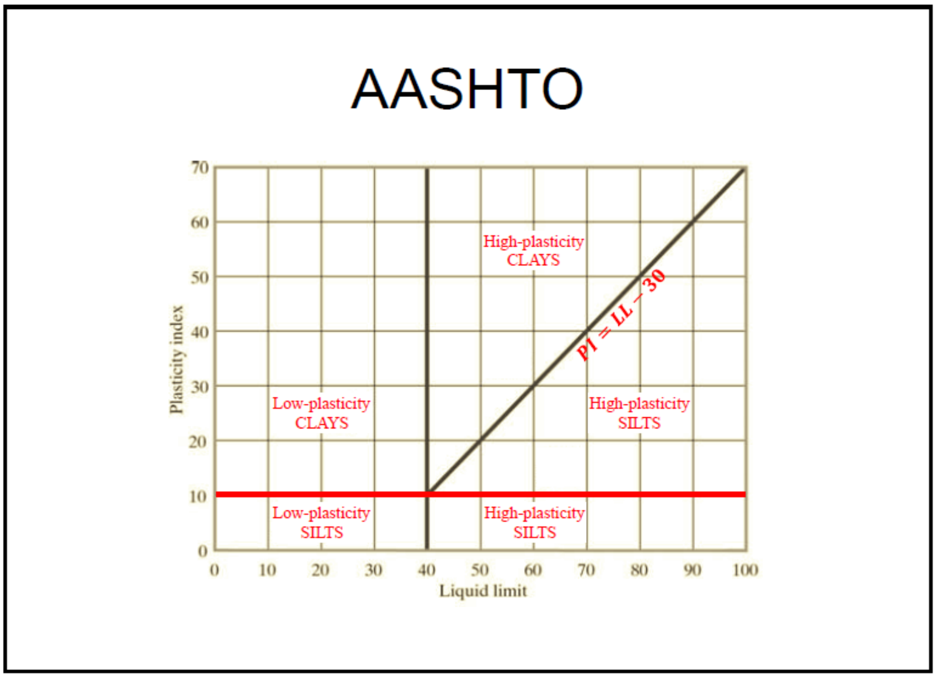


Figure 4.2 shows a plot of the range of the liquid limit and the plasticity index for soils that fall into groups A-2, A-4, A-5, A-6, and A-7.

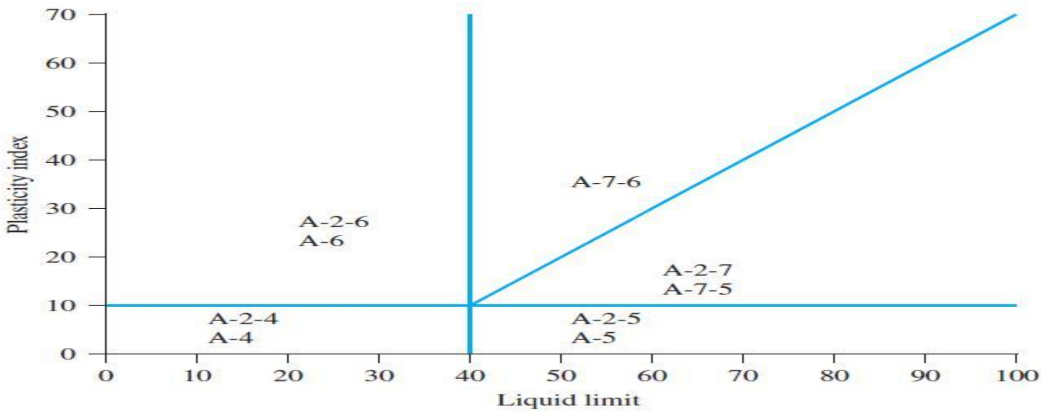


Figure 4.2 Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5,A-6, and A-7

To evaluate the ***quality of a soil*** as a highway subgrade material, one must also incorporate a number called the **group index (GI)** with the groups and subgroups of the soil.

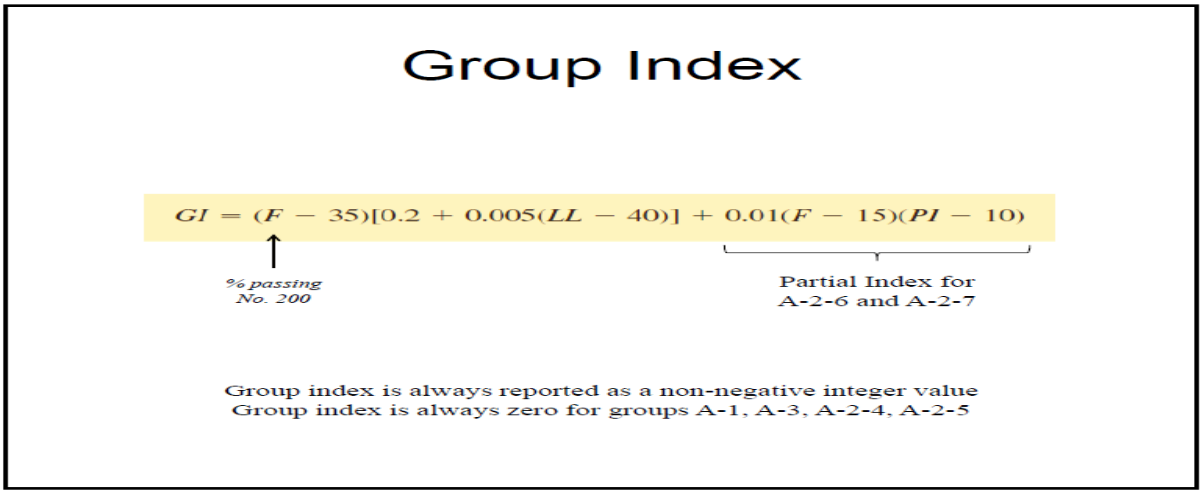
GI = (F200 − 35) [0.2 + 0.005(LL − 40)] + 0.01(F200 − 15)(PI − 10)....... (4.1)

There are some rules in Equation (4.1):

1. When GI is calculated as negative values, report GI = 0.
2. GI is reported in rounded integer numbers. For example, GI = 4.4 should be reported as 4 and GI = 4.5 should be reported as 5.
3. 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.

4. For A-2-6 and A-2-7 subgroups, use only the second term of Equation (4.1) and assign the first term always as zero, that is,

GI = 0.01(F200 − 15)(PI − 10) .... (4.2)



The standard says that under average conditions of good drainage and thorough compaction processes, the supporting value of a material as subgrade may be assumed as an inverse ratio to the group index; that is, a group index of 0 indicates a “good” subgrade material and a group index of 20 or greater indicates a “very poor” subgrade material.

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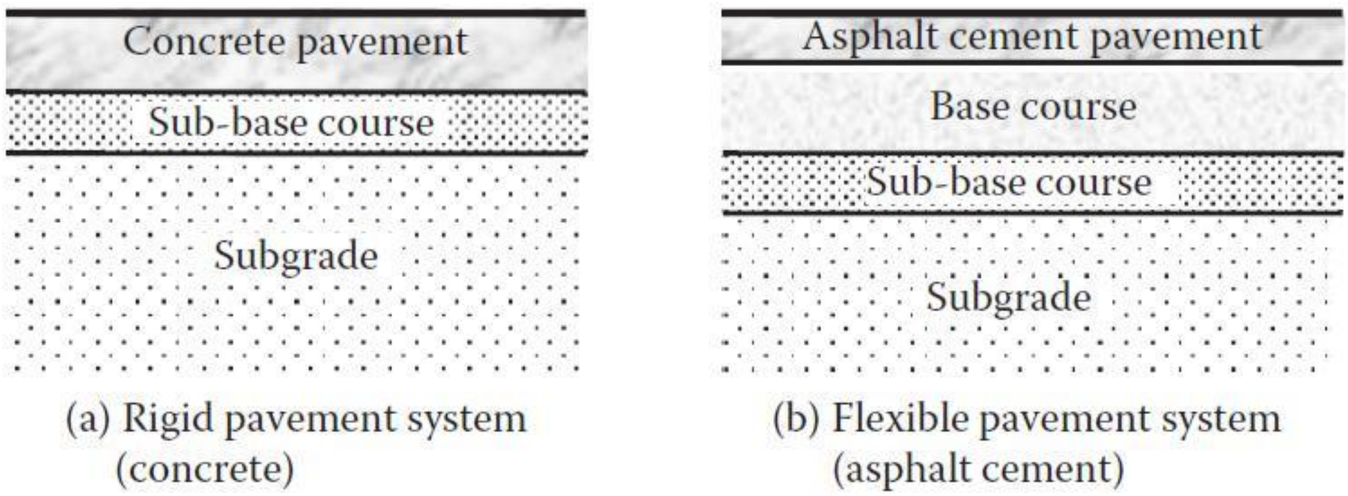


Typical road pavement systems

Example 1

The results of the particle-size analysis of a 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 plastic limit of the minus No. 40 fraction of the soil are 25 and 20, respectively. Classify the soil by the AASHTO system.

Solution

Since 20% (i.e., less than 35%) of soil is passing No. 200 sieve, it is a granular soil. Hence it can be A-1, A-2, or A-3. Refer to Table 5.1. Starting from the left of the table, the soil falls under A-1-b

PI=LL-PL=25-20=5<6

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

Example 2

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 5.1. Starting from the left of the table, it falls under A-7-6

GI = (F200 − 35) [0.2 + 0.005(LL − 40)] + 0.01(F200 − 15)(PI − 10)

GI = (95 − 35) [0.2 + 0.005(60 − 40)] + 0.01(95 − 15)(40 − 10)

GI =42

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

Thus;

- Possible group names for gravelly soils are : **GW, GP, GM,** and **GC**
- Possible group names for sandy soils are : **SW, SP, SM,** and **SC**
- Possible group names for silty soils are : **MH** and **ML**

4.6 UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

First developed by Arthur Casagrande for wartime airfield construction in 1942, This is the most widely used classification system by geotechnical engineers.

- **Quick Review**
- The system uses six simple major symbols and four modifiers as in the following:

Major symbols:
G Gravel
S Sand
M Silt
C Clay
O Organic
Pt Peat
Modifiers:
W Well graded (for gravel and sand)
P Poorly graded (for gravel and sand)
H High plasticity (for silt, clay, and organic soils)
L Low plasticity (for silt, clay, and organic soils)

- Classified group names are combinations of these characters—for example

GP for poorly graded gravel
SW for well-graded sand
CH for high-plasticity clay
SM for silty sand

- Possible group names for clayey soils are : **CH** and **CL**
- Possible group names for organic soils are : **OH** and **OL**

- Possible group names for Peat soils are :
- **Pt** stands alone

There is other possibility of grouping for several boundary soils which is called

Dual naming , such as

GW–GM for (well-graded gravel with silt)

GC–GM for (silty clayey gravel)

SW–SM for (well-graded sand with silt)

USCS

Table 4.2 Unified Soil Classification System (Based on Material Passing 75-mm Sieve)

Criteria for Assigning Group Symbols				Group Symbol
Coarse-Grained Soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c]	GW
			$C_u < 4$ and/or $1 > C_c > 3$[c]	GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 4.2)	GM
			$PI > 7$ and plots on or above "A" line (Figure 4.2)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c]	SW
			$C_u < 6$ and/or $1 > C_c > 3$[c]	SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 4.2)	SM
			$PI > 7$ and plots on or above "A" line (Figure 4.2)	SC
Fine-Grained Soils 50% or more passes No. 200 sieve	**Silts and Clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 4.2)[e]	CL
			$PI < 4$ or plots below "A" line (Figure 4.2)[e]	ML
		Organic	$\frac{\text{Liquid limit–oven dried}}{\text{Liquid limit–not dried}} < 0.75$; see Figure 4.2, OL zone	OL
	Silts and Clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 4.2)	CH
			PI plots below "A" line (Figure 4.2)	MH
		Organic	$\frac{\text{Liquid limit–oven dried}}{\text{Liquid limit–not dried}} < 0.75$; see Figure 4.2, OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

[a] Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
[b] Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.
[c] $C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$
[d] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 4.2, use dual symbol GC-GM or SC-SM.
[e] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 4.2, use dual symbol CL-ML.

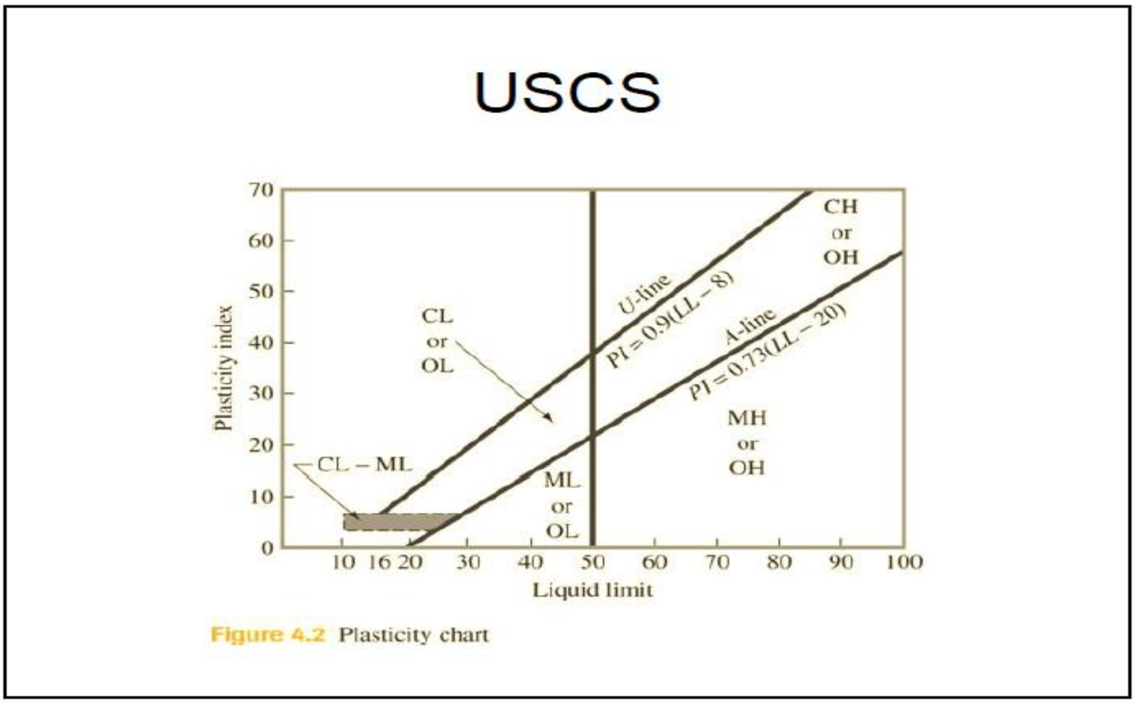


Figure 4.2 Plasticity chart

This system uses LL, PL, and PI (=− LLP), and soils' gradation information. First, from a grain size distribution curve

The percentages of each component are identified as shown in Figure **4.3**.**:**
gravel [d ≥ 4.75 mm],
sand [4.75 mm > d > 0.075 mm],
fine [d ≤ 0.075 mm]
The values of F_{200}, R_{200}, F_4, and R4 are obtained as**:**

F200: % finer than No. 200 sieve (0.075 mm) = percentage of fine content
R200: percentage retained on No. 200 sieve (0.075 mm) = percentage of sand and gravel content
F4: percentage finer than No. 4 sieve (4.75 mm) = percentage of sand and fine content
R4: percentage retained on No. 4 sieve (4.75 mm) = percentage of gravel content **Note** that in USCS, clay and silt are categorized as **fine**.

The coefficient of uniformity Cu= (D_{60}/D_{10}) and the coefficient of gradation C_g= ((D_{30})2/(D_{60} × D_{10})) are calculated.

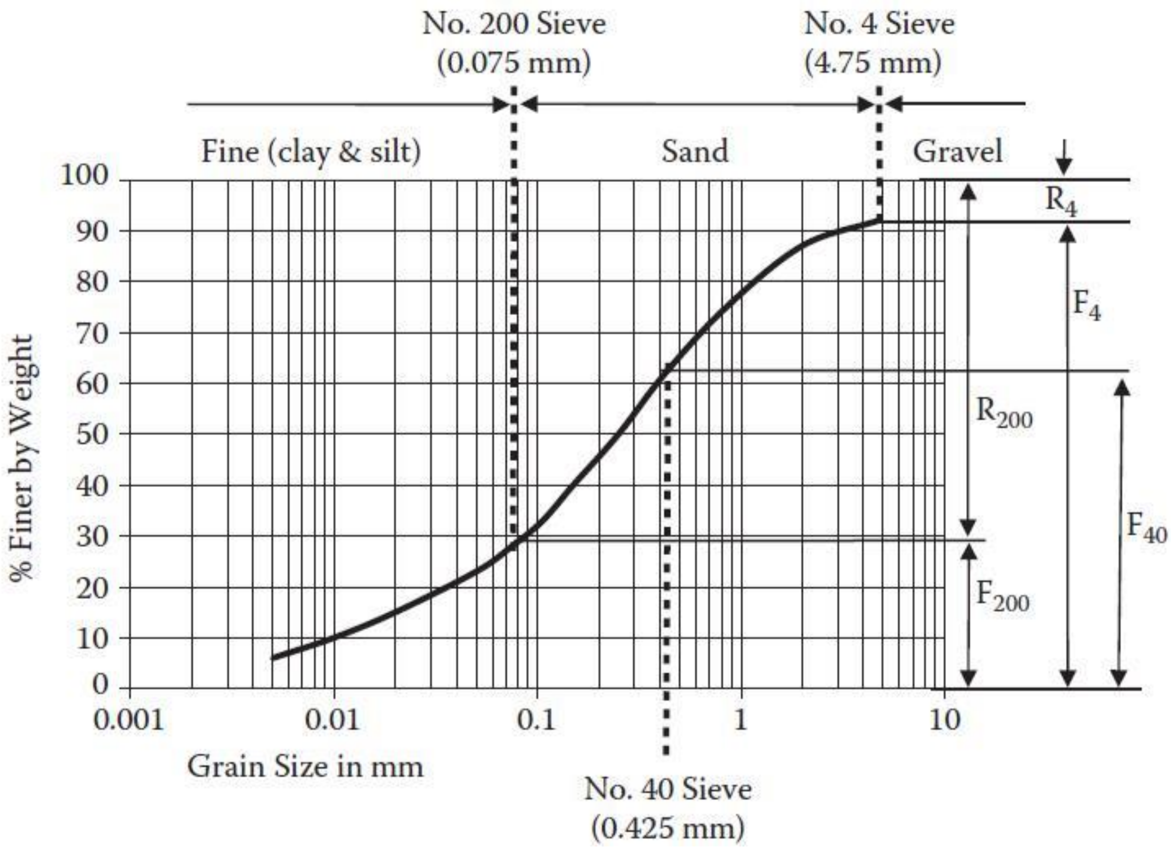


FIGURE 4.3 Definitions of F_{200}, R_{200}, F_{40}, F_4, and R_4

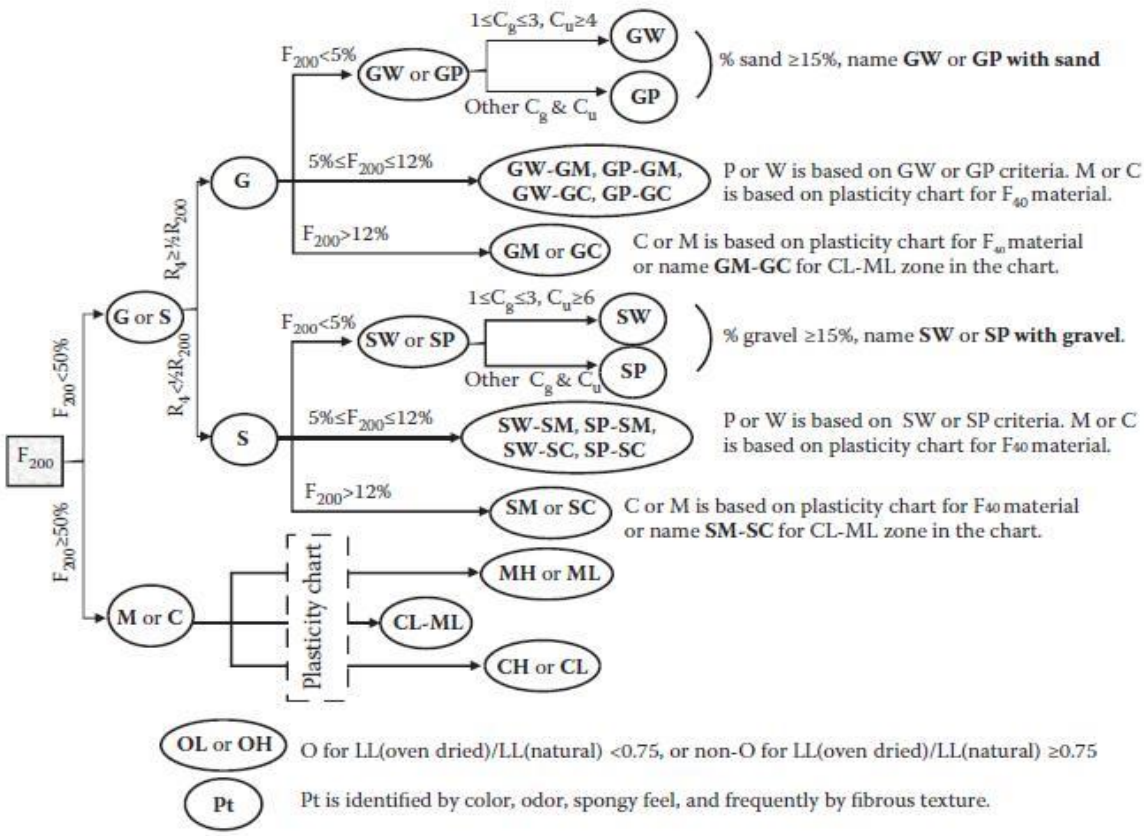


Figure 4: Flow chart for USCS.

4.4.1.For G or S

1. If $F_{200} < 50\%$ (or $R_{200} \geq 50\%$, i.e., gravel and sand content is more than 50%), then soil is **G** or **S**.

2. Then, if $R_4 \geq .F_{200}$ (gravel content ≥ sand content), it is **G,** or if $R_4 < .F_{200}$ (gravel content < sand content), it is **S**.

3. In the next step, F200 (fine content) is checked for G and S.

- If F200 < 5%,naming fine content is ignored and soils will be GW, GP, SW, or SP.

- If F200 > 12%, soils will be GM, GC, SM, or SC.

- When 5% ≤ F200 ≤ 12%,double naming comes in as GW–GM, GW–GC, GP–GM, and GP–GC for gravel or SW–SM, SW–SC, SP–SM, and SP–SC for sand.

In such double naming cases, modifier M or C is determined based on a **plasticity chart** (see Section 4.4.2) for F_{40} materials.

4. In the final step for gravel and sand, C_u and C_g values are evaluated for modifiers W or P.

- For gravel, $C_u \geq 4$ and $1 \leq C_g \leq 3$ are conditions for **W** and the other values of those are for **P**.
- For sand, the condition for **W** is $C_u \geq 6$ and $1 \leq C_g \leq 3$ and the other values are for **P**.

5. For GW and GP soils, if percentage of sand content is at or more than 15%,it is named as **GW (**or **GP) with sand**.

6. Similarly, for SW and SP soils, if percentage of gravel content is at or more than 15%, it is named as **SW (**or **SP) with gravel.**

4.4.2 F or C, M, O, or Pt

1. Going back to the F200 value in Figure 4.4, if F200≥ 50% (i.e., fine contents are at or more than 50%), then soil is either **M** or **C** (or possibly **O** or **Pt**).

2. To classify M or C, **plasticity chart** (Figure 4.5) is used.

It utilizes LL and PI (= LL − PL) values. LL and PL tests should be performed on the F40 specimen (soil passed No. 40 sieve—0.425 mm), and the LL and PI data point of the soil tested is plotted on the plasticity chart to identify soil type (**CH**, **CL**, **MH**, **ML**, or **CL-ML**) by the zone on which the data point falls.

3. On the plasticity chart, most natural soils fall below the "U" line and around the "A" line or CL–ML zone. It should be noted that LL = 50 is the boundary LL for high-plastic (LL > 50) or low-plastic (LL < 50) soils.

4. The M or C classification method by the plasticity chart is also used in subgroup names in gravel and sand category soils with their fine contents between 5% and 12%. These are GM, GC, SM, SC

And dual named soils

For gravel
GW–GM, GW–GC, GP–GM,& GP–GC
For sand
SW–SM, SW–SC,SP–SM, and SP–SC

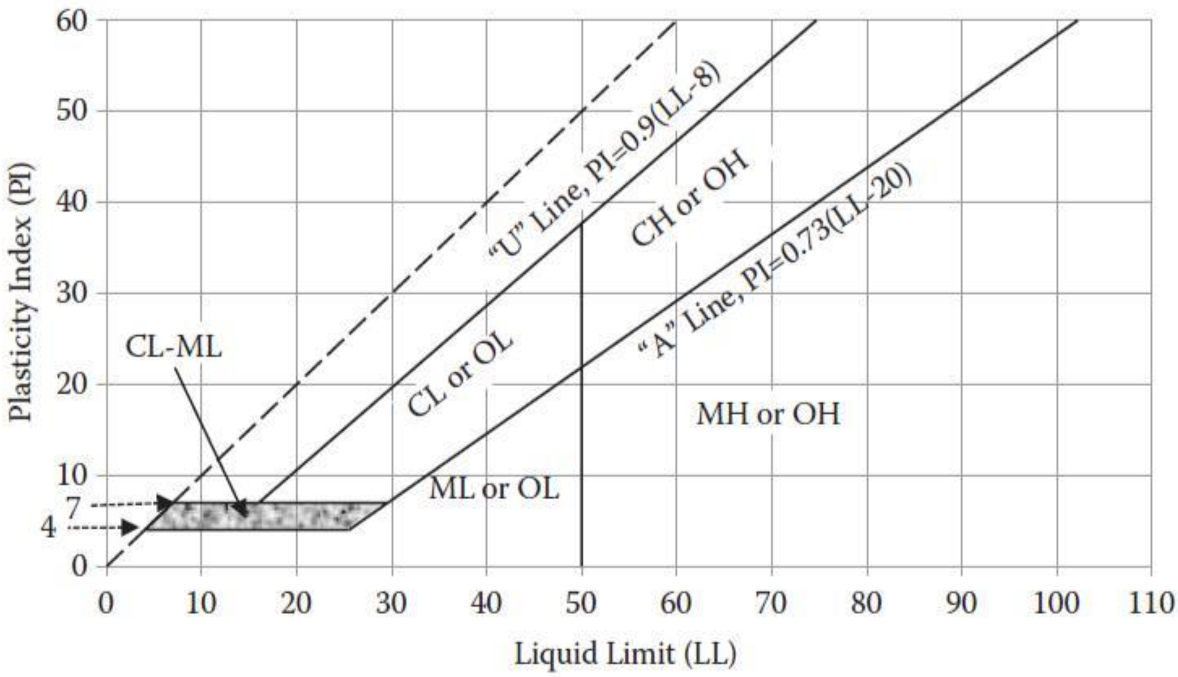


Figure 4.5 Plasticity chart for USCS.

5. **Pt** (**peat**) should be identified by its color, odor, spongy feeling, and, frequently, by its fibrous texture by testing engineers**.**

O (**organic soil**) can be identified by observing the change in LL values from natural soil to oven-dried (burns some organic) soil. If LL (oven dried)/LL (natural) is <0.75, it is classified as O. If the ratio is ≥0.75, it is non-organic.

Since USCS uses simple symbols with their meanings, it is easy to understand the nature of soils from classified group names. Also, this requires only LL and PL tests and sieve analysis. A hydrometer test is not required since the silt and clay are treated as **fine** and it uses the plasticity chart to identify the clay and silt

Ex1:
A soil gradation curve is shown in Figure 4.6 Classify the soil by USCS, classification methods. LL = 46% and PL = 35% were obtained for F_{40} material of the specimen.

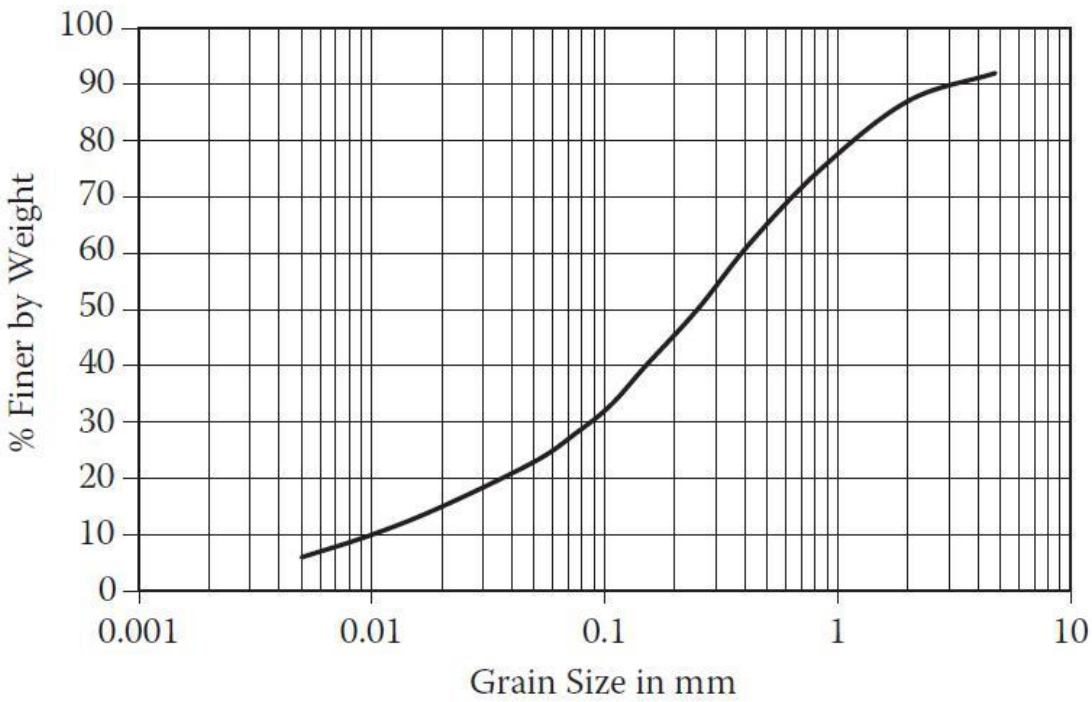


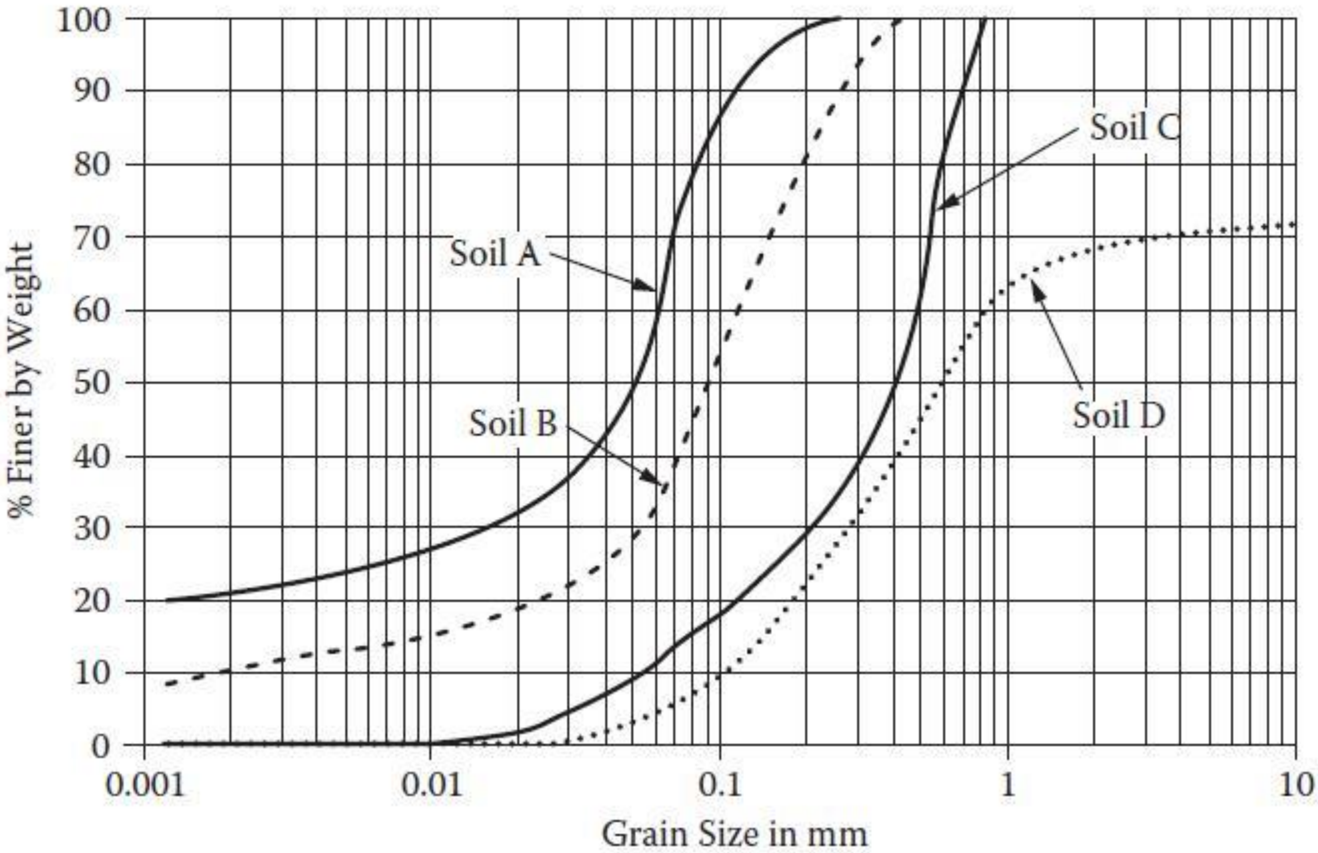
FIGURE 4.6 Gradation curve

Solution
From the gradation curve, the following values can be read.
Percentage passing No. 4 (4.75 mm) = 92%
Percentage passing No. 200 (0.075 mm) = 28%
F200 = 28%, and thus R200 = 72%
F4 = 92%, and thus R4 = 8%
D10 = 0.01 mm
D30 = 0.090 mm

D60 = 0.39 mm
Cu = D60/D10 = 0.39/0.01 = 39
Cg = (D30)2/(D60 × D10) = (0.090)2/(0.01 × 0.39) = 2.08
LL=46
PI=46−35=11

By using the flow chart in Figure 4.4, since F200 (28) < 50%,it should be G or S.
R4 (= 8%) < $^1/_2$R200 (= 72%) = 36%, and thus it should be S.
F200 (= 28%) > 12% and it should be SM or SC.
LL (= 46) and PL (= 11) fall in the region of ML or OL in the plasticity chart (Figure 4.5).
Thus, the soil is classified as **SM (silty sand)**. ←

Problem: The following figure shows grain size distribution curves for soils A,B, C, and D with their LL and PL values.



For each soil,

(a) Classify the soil according to USCS.
(b) Classify the soil according to AASHTO including GI computation.
(c) Discuss the suitability of the soil as subgrade material.

Problem	Soil	LL	PL
4.1	A	55	25
4.2	B	45	26
4.3	C	25	19
4.4	D	42	33