



ECIV 3302 Engineering Geology

Chapter 5 **CLASSIFICATION OF SOIL**

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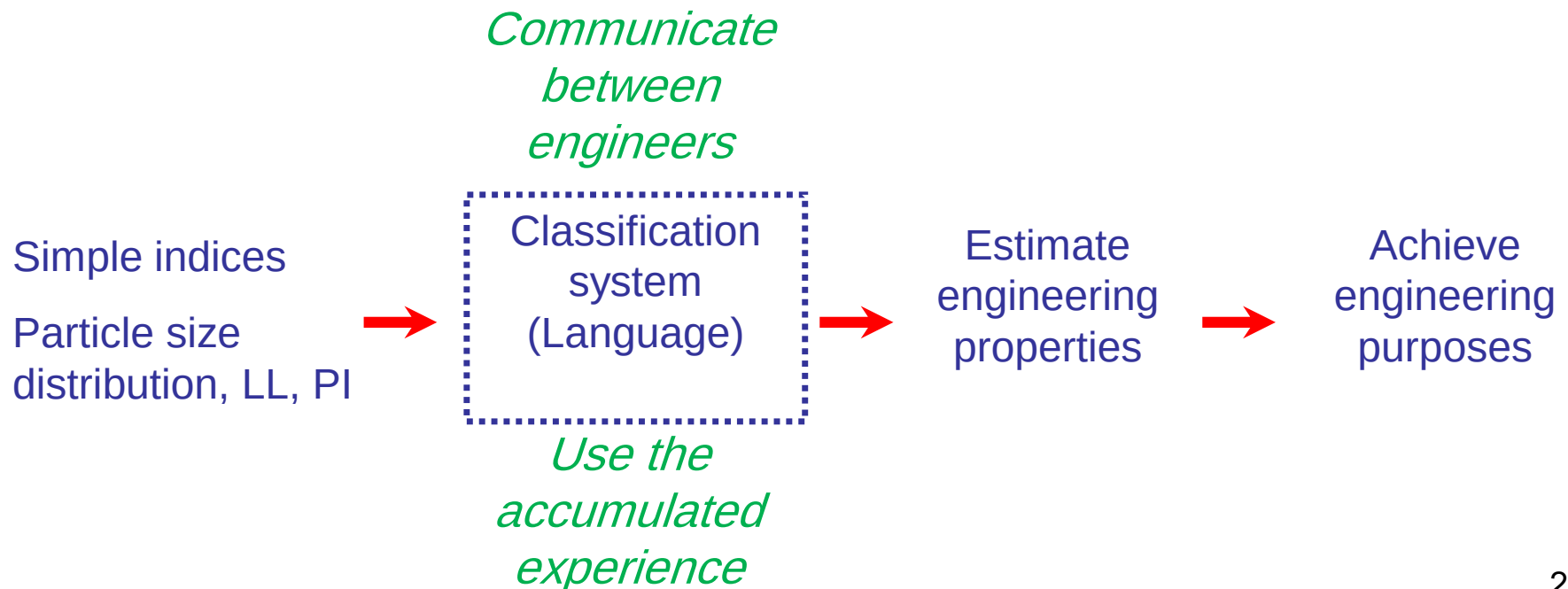
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The materials are mostly adapted from the presentation of Ahmed Abu Foul

5.1 Introduction

Classifying soils into groups with similar behavior, in terms of **simple indices**, can provide geotechnical engineers a general guidance about engineering properties of the soils through the *accumulated experience*.



5.1 Introduction

Most of the soil classification systems that have been developed for engineering purposes are based on **simple index properties** such as particle-size distribution and plasticity.

Although several classification systems are now in use, none is **totally definitive** of any soil for all possible applications because of the wide diversity of soil properties.

5.2 Textural Classification

- Texture of soil refers to its surface appearance.
- Soil texture is influenced by the size of the individual particles present in it.
- On the basis of particle size soil was divided into gravel, sand, silt, and clay categories.
- In most cases, natural soils are mixtures of particles from several size groups.
- In the textural classification system, the soils are named after their principal components, such as sandy clay, silty clay, and so forth.

5.2 Textural Classification

A number of textural classification systems were developed in the past by different organizations to serve their needs, and several of those are in use today.

Figure 5.1 shows the textural classification systems developed by the [U.S. Department of Agriculture \(USDA\)](#).

This classification method is based on the particle-size limits:

- 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

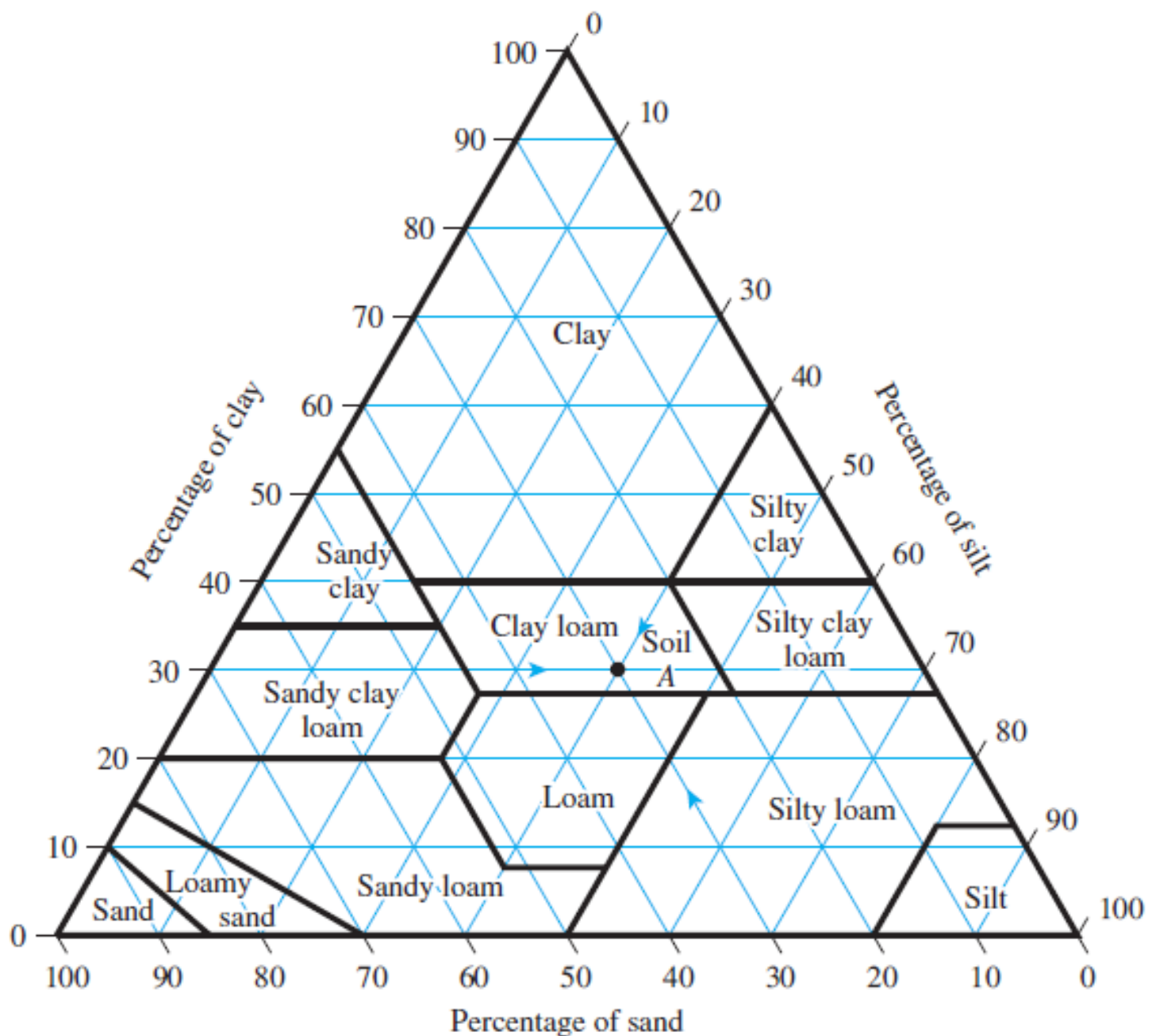


Figure 5.1 U.S. Department of Agriculture textural classification (*USDA*)

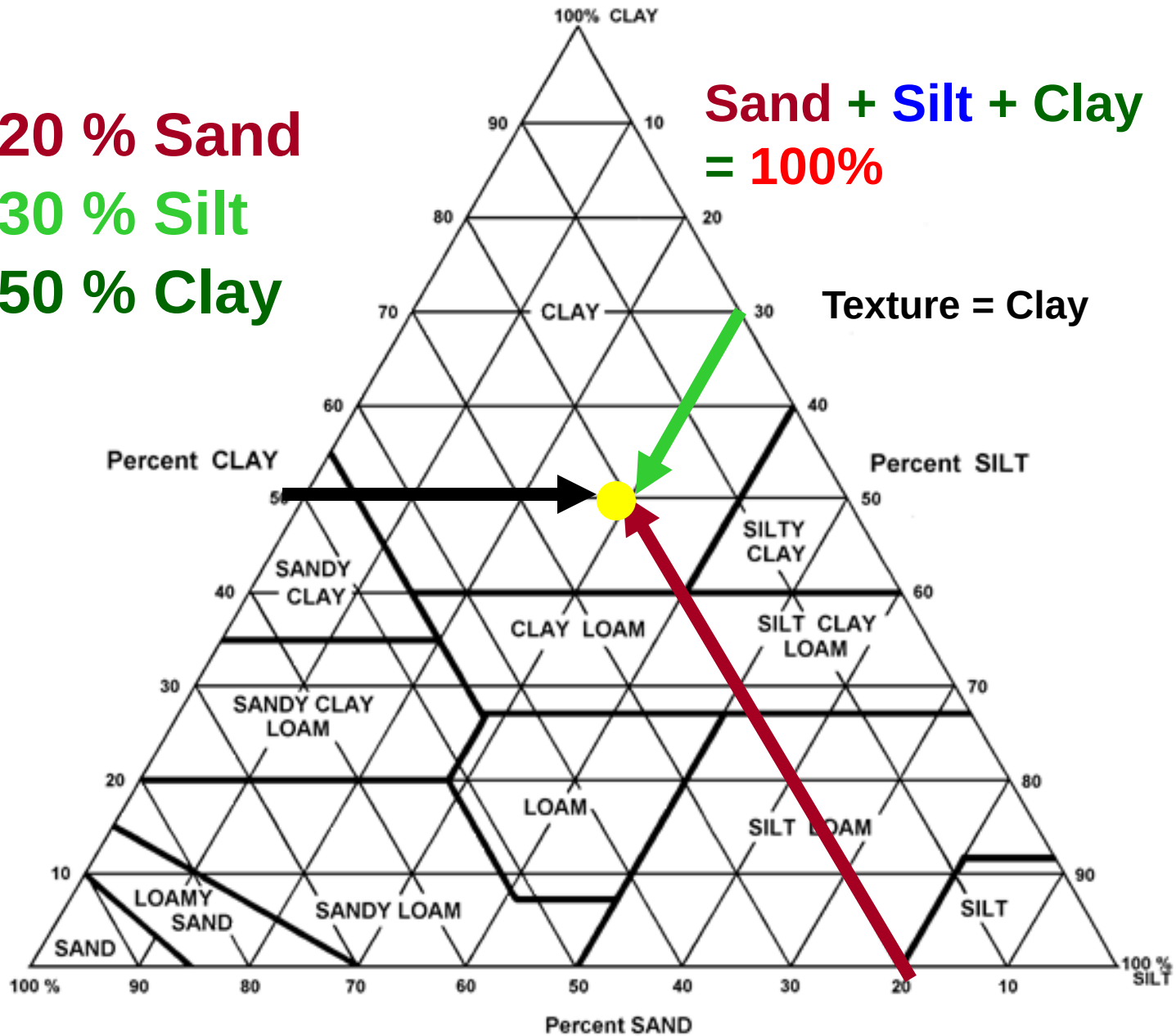
5.2 Textural Classification

The use of this chart can best be demonstrated by an example. If the particle-size distribution of soil A shows 20% sand, 30% silt, and 50% clay-size particles, its textural classification can be determined by proceeding in the manner indicated by the arrows in Figure 5.1. This soil falls into the zone of clay.

Note that this chart is based on only the fraction of soil that passes through the No. 10 sieve (2 mm).

50 % Clay

Texture = Clay



USDA Texture Triangle

Example:

- 60% silt
 - 10% sand
 - 30% clay
- = silty clay loam

What is a soil that is:

- 30% silt
- 0% sand
- 70% clay

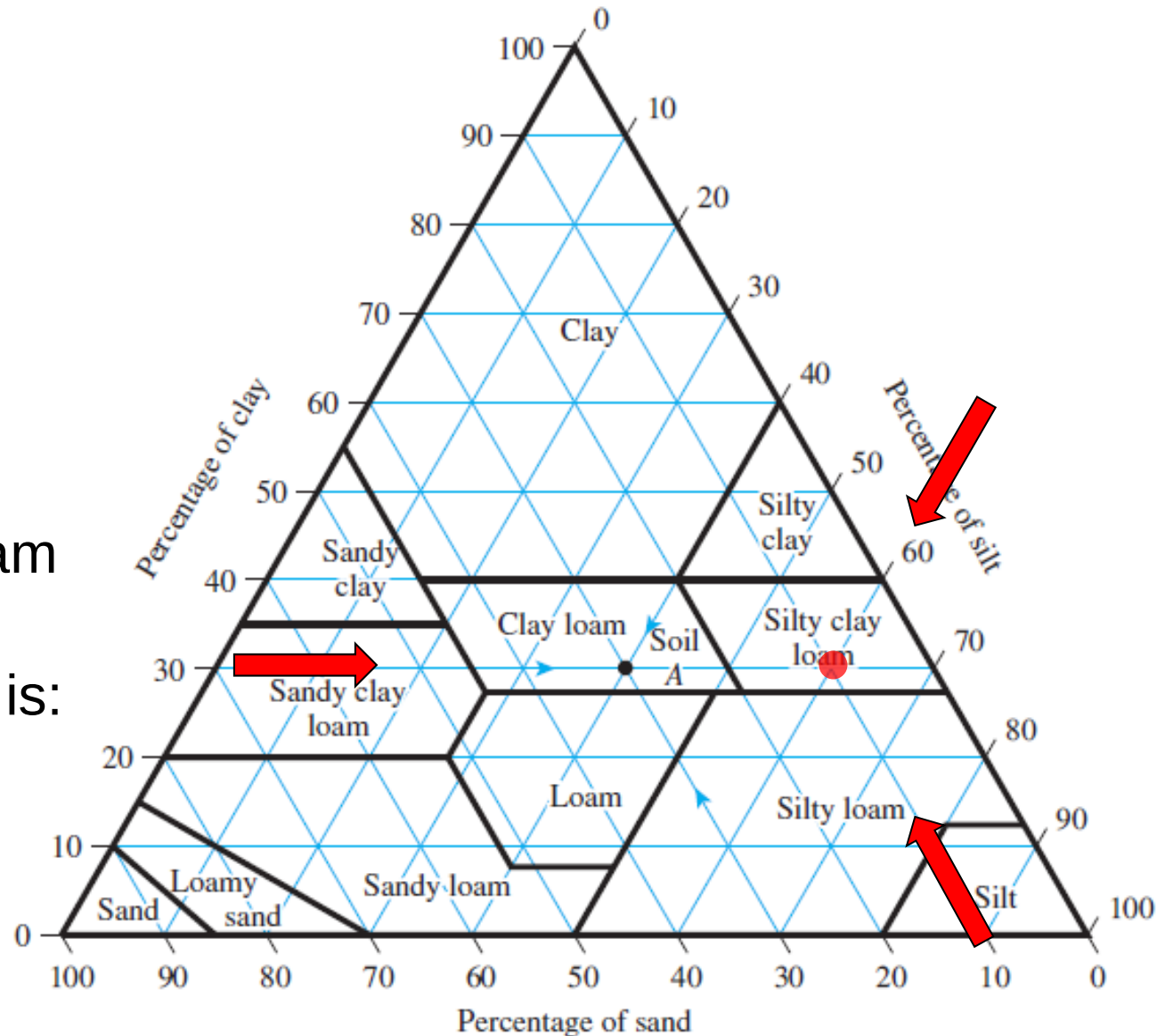


Figure 5.1 U.S. Department of Agriculture textural classification (USDA)

5.2 Textural Classification

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.

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

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

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

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

Example 5.1

Classify the following soils according to the USDA textural classification system.

Particle-size distribution (%)	Soil			
	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
Gravel	12	18	0	12
Sand	25	31	15	22
Silt	32	30	30	26
Clay	31	21	55	40

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Solution

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

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

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

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

Thus, the following table results:

Particle-size distribution (%)	Soil			
	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
Sand	28.4	37.8	15	25
Silt	36.4	36.6	30	29.5
Clay	35.2	25.6	55	45.5

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Step 2. With the modified composition calculated, refer to Figure 5.1 to determine the zone into which each soil falls. The results are as follows:

Classification of soil			
<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
Gravelly clay loam	Gravelly loam	Clay	Gravelly clay

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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.

5.3 Classification by Engineering Behavior

Although 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.

5.3 Classification by Engineering Behavior

Because textural classification systems do not take plasticity into account and are not totally indicative of many important soil properties, they 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.

5.3 Classification by Engineering Behavior

1. The American Association of State Highway and Transportation Officials (AASHTO) classification system

2. The Unified Soil Classification System.

- The AASHTO classification system is used mostly by state and county highway departments.
- Geotechnical engineers generally prefer the Unified system.

5.4 AASHTO Classification System

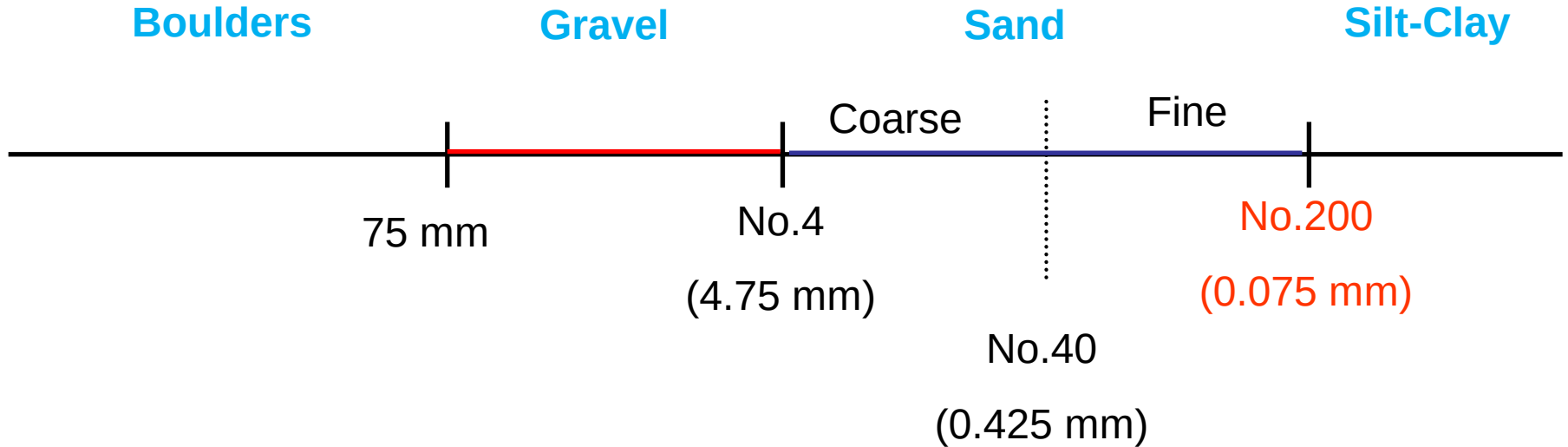
Origin of AASHTO: (for road construction)

This system was originally developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. Afterwards, there are several revisions. The present AASHTO (1978) system is primarily based on the version in 1945. (Holtz and Kovacs, 1981)

5.4 AASHTO Classification System

- Required parameters for classification:
 - Grain size analysis
 - Liquid Limit
 - Plasticity Index

Definition of Grain Size



This classification system is based on the **Grain size criteria**:

- 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

General Guidance

- 8 major groups: A1~ A7 (with several subgroups) and organic soils A8
- The required tests are sieve analysis and Atterberg limits.
- The group index, an empirical formula, is used to further evaluate soils within a group (subgroups).



- The original purpose of this classification system is used for road construction (subgrade rating).

Table 5.1 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						

Table 5.1 Classification of Highway Subgrade Materials

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			

^aFor A-7-5, $PI \leq LL - 30$

^bFor A-7-6, $PI > LL - 30$

To classify a soil according to Table 5.1, one must apply the test data from left to right. By process of elimination, the first group from the left into which the test data fit is the correct classification.

Group Index (GI)

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. This index is written in parentheses after the group or subgroup designation. The group index is given by the equation

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \quad (5.1)$$

where F_{200} = percentage passing through the No. 200 sieve

LL = liquid limit

PI = plasticity index

Group Index (GI)

Following are some rules for determining the group index:

1. If Eq. (5.1) yields a negative value for GI, then $GI = 0$.
2. GI calculated from Eq. (5.1) 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 GI.
4. GI 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 GI for soils that belong to groups A-2-6 and A-2-7, use the partial group index for PI, or

$$GI = 0.01(F_{200} - 15)(PI - 10) \quad (5.2)$$

Example 5.2

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 plasticity 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 (see the table below).

Parameter	Specifications in Table 5.1	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

$$\begin{aligned}
 GI &= (F_{200} - 35)[0.2 + 0.005(LL - 40)] \\
 &\quad + 0.01(F_{200} - 15)(PI - 10) \\
 &= 3.45 \approx 3
 \end{aligned}$$

Passing No.10 sieve	100	
Passing No.40 sieve	80	LL = 30
Passing No.200 sieve	58	PI = 10

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, $PI > LL - 30$

A-4(3)

Example

Passing No.200 86% $GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)]$
 LL=70, PI=32 $+ 0.01(F_{200} - 15)(PI - 10)$
 LL-30=40 > PI=32 $= 33.47 \cong 33$ Round off

A-7-5(33)

Silt-clay materials (more than 35% of total sample passing No. 200)				
General classification				
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			

^aFor A-7-5, $PI \leq LL - 30$

^bFor A-7-6, $PI > LL - 30$

Example

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

$$= 0.38 \approx 0$$

Passing No.4 sieve	90	
Passing No.10 sieve	76	LL = 37
Passing No.200 sieve	34	PI = 12

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 sig- nificant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand			
General subgrade rating	Excellent to good						

A-2-6(0)

Figure 5.2 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.

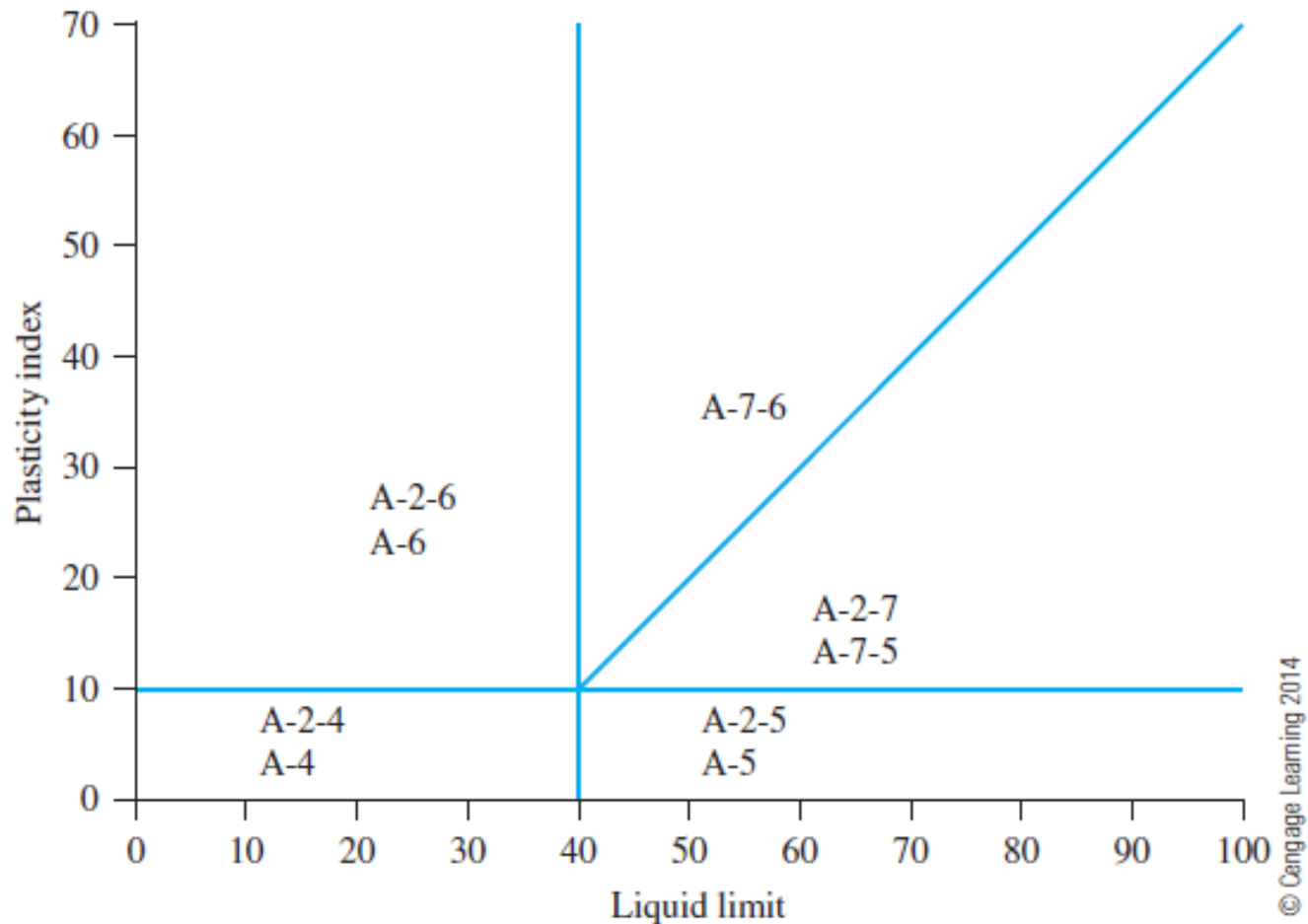


Figure 5.2 Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6, and A-7

Example 5.3

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 $\geq 36\%$) 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 (see the table below).

Parameter	Specifications in Table 5.1	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	$> LL - 30$	$PI = 40 > LL - 30 = 60 - 30 = 30$

$$\begin{aligned}GI &= (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \\&= (95 - 35)[0.2 + 0.005(60 - 40)] + (0.01)(95 - 15)(40 - 10) \\&= 42\end{aligned}$$

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

Example

- A sample of soil was tested in the laboratory, and results of the laboratory tests were as follows:
 1. Liquid limit = 42.3%
 2. Plastic Limit = 15.8%
 3. The following sieve analysis data:

U.S. Sieve Size	Percentage Passing
No. 4	100.0
No. 10	93.2
No. 40	81.0
No. 200	60.2

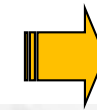
- Required: Classify the soil sample by the AASHOTO Classification System

Solution

No. 200 Sieve Passing = 60.2%

Liquid Limit = 42.3%

PI = 26.5%



A-7-6

- $PI = LL - PL = 42.3\% - 15.8\% = 26.5\%$
- $LL - 30 = 12.3\% (< PI = 26.5\%)$

TABLE:
Classification of Soils and Soil-Aggregate Mixtures by AASHTO Classification System [5]

General Classification	Granular Materials (35% or less passing 0.075 mm)							Silt-Clay Materials (more than 35% passing 0.075 mm)			
	A-1		A-3	A-2				A-4	A-5	A-6	A-7
Group Classification	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
Sieve analysis: Percent passing:											
2.00 mm (No. 10)	50 max.	—	—	—	—	—	—	—	—	—	—
0.425 mm (No. 40)	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
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.
Characteristics of fraction passing 0.425 mm (No. 40):											
Liquid limit	—	—	—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.	NP	—	10 max.	10 max.	11 min.	11 min.	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				Silty soils		Clayey soils	
General ratings as subgrade	Excellent to good							Fair to poor			

¹Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

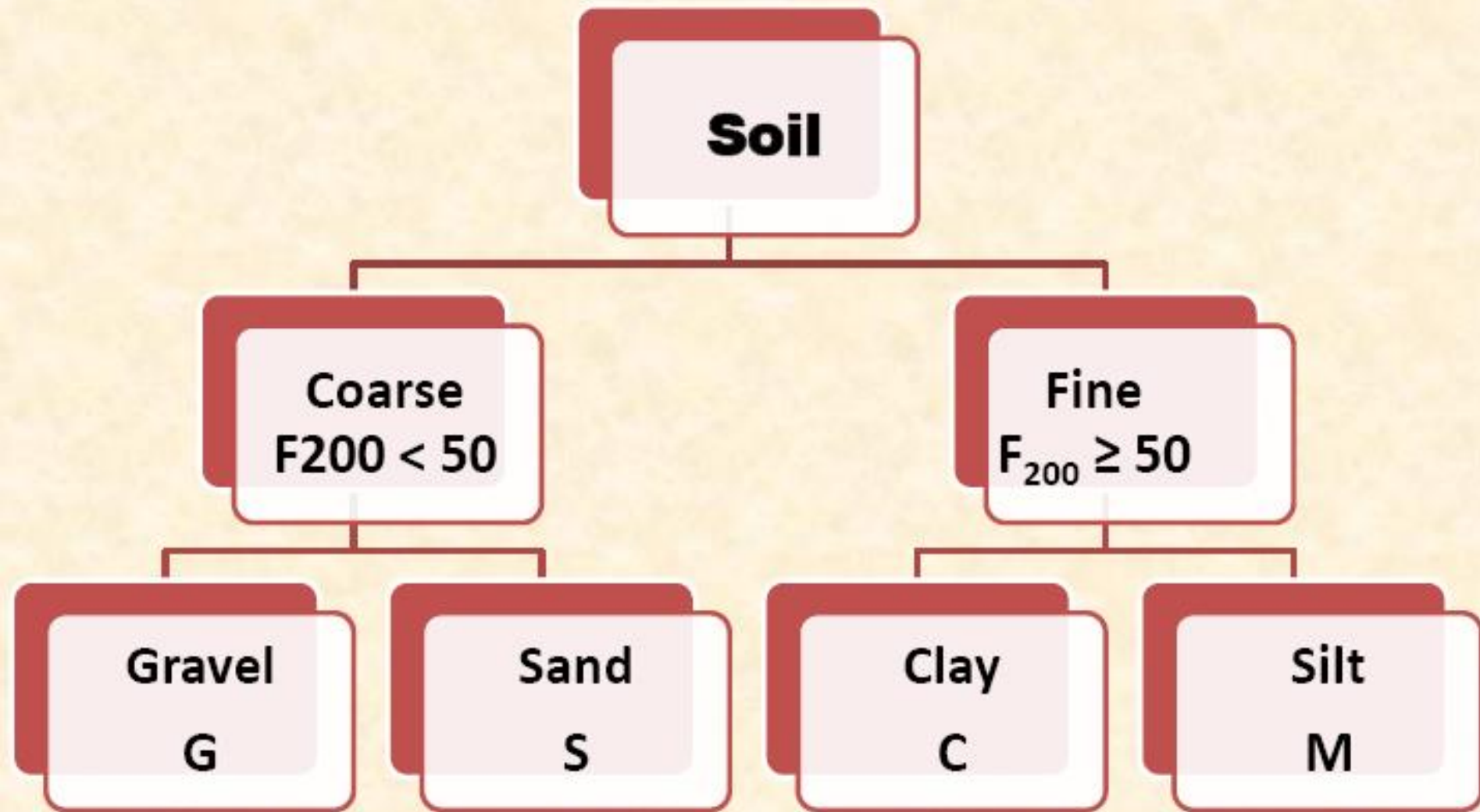
5.5 Unified Soil Classification System

- Developed by Casagrande
 - Used by Corps of Engineers
 - Soils
 - Coarse-grained
 - Fine-grained
 - Highly organic soils
- } Subdivided into 15 basic groups
- Group Symbols:
 - G: Gravel
 - C: Clay
 - W: Well graded
- | | |
|------------------|----------|
| S: Sand | M: Silt |
| O: Organic | PT: Peat |
| P: Poorly graded | |
- E.g. SW: Well graded sand

5.5 Unified Soil Classification System

- Unified Soil Classification System (USCS)
Required parameters for classification:
 - Grain-size distribution
 - Liquid Limit
 - Plasticity Index

USCS (Major Division)



USCS (Major Division) cont.

For Coarse Soil Aggregates

Gradation

```
graph TD; A[Gradation] --- B[Well Graded (W)]; A --- C[Poorly Graded (P)];
```

**Well Graded
(W)**

**Poorly
Graded
(P)**

Classification Procedure

Coarse Grained Soil

If more than **half of the material** is coarser than the 75 μm sieve (No. 200 US sieve), the soil is classified as coarse. The following steps are then followed to determine the appropriate 2 letter Symbol:

Determine the 1st letter of the symbol

- If more than **half of the coarse** fraction is **sand** then use prefix **S**
- If more than **half of the coarse** fraction is **gravel** then use prefix **G**

Determine the 2nd letter of symbol

This depends on the uniformity coefficient C_u and the coefficient of curvature C_c obtained from the grading curve, on the percentage of fines, and the type of fines.

Classification Procedure

First, determine the percentage of fines, that is the % of material passing the 75 μm sieve (No. 200 US sieve).

Then if % fines is

- < 5% use **W** or **P** as suffix
- > 12% use **M** or **C** as suffix
- between 5% and 12% use dual symbols. Use the prefix from above with first one of W or P and then with one of M or C.

If W or P are required for the suffix then C_u and C_c must be evaluated:

1. If prefix is **G** then suffix is **W** if $C_u > 4$ and C_c is between 1 & 3 otherwise use **P**
2. If prefix is **S** then suffix is **W** if $C_u > 6$ and C_c is between 1 & 3 otherwise use **P**

Classification Procedure

If M or C are required they have to be determined from the procedure used for fine grained materials discussed below.

Note that M stands for Silt and C for Clay. This is determined from whether the soil lies above or below the A-line in the plasticity chart.

For a coarse grained soil which is predominantly sand the following symbols are possible:

- **SW, SP, SM, SC**
- **SW-SM, SW-SC, SP-SM, SP-SC**

Classification Procedure

Fine Grained Soil

These are classified solely according to the results from the Atterberg Limit Tests.

Values of the Plasticity Index and Liquid Limit are used to determine a point in the plasticity chart.

The classification symbol is determined from the region of the chart in which the point lies. Examples:

- **CH** High plasticity clay
- **CL** Low plasticity clay
- **MH** High plasticity silt
- **ML** Low plasticity silt
- **OH** High plasticity organic soil (Rare)
- **Pt** Peat

Table 5.2 Unified Soil Classification System (Based on Material Passing 76.2-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	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW
		Less than 5% fines ^a	$C_u < 4$ and/or $1 > C_c > 3^c$	GP
		Gravels with Fines	$PI < 4$ or plots below “A” line (Figure 5.3)	GM
		More than 12% fines ^{a,d}	$PI > 7$ and plots on or above “A” line (Figure 5.3)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands	$C_u \geq 6$ and $1 \leq C_c \leq 3^c$	SW
		Less than 5% fines ^b	$C_u < 6$ and/or $1 > C_c > 3^c$	SP
		Sands with Fines	$PI < 4$ or plots below “A” line (Figure 5.3)	SM
		More than 12% fines ^{b,d}	$PI > 7$ and plots on or above “A” line (Figure 5.3)	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 5.3) ^e	CL
			$PI < 4$ or plots below “A” line (Figure 5.3) ^e	ML
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; OL zone	OL
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above “A” line (Figure 5.3)	CH
			PI plots below “A” line (Figure 5.3)	MH
		Organic	$\frac{\text{Liquid limit — oven dried}}{\text{Liquid limit — not dried}} < 0.75$; see Figure 5.3; 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.

$$^c C_u = \frac{D_{60}}{D_{10}}; \quad C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$$

^d If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol GC-GM or SC-SM.

^e If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.3, use dual symbol CL-ML.

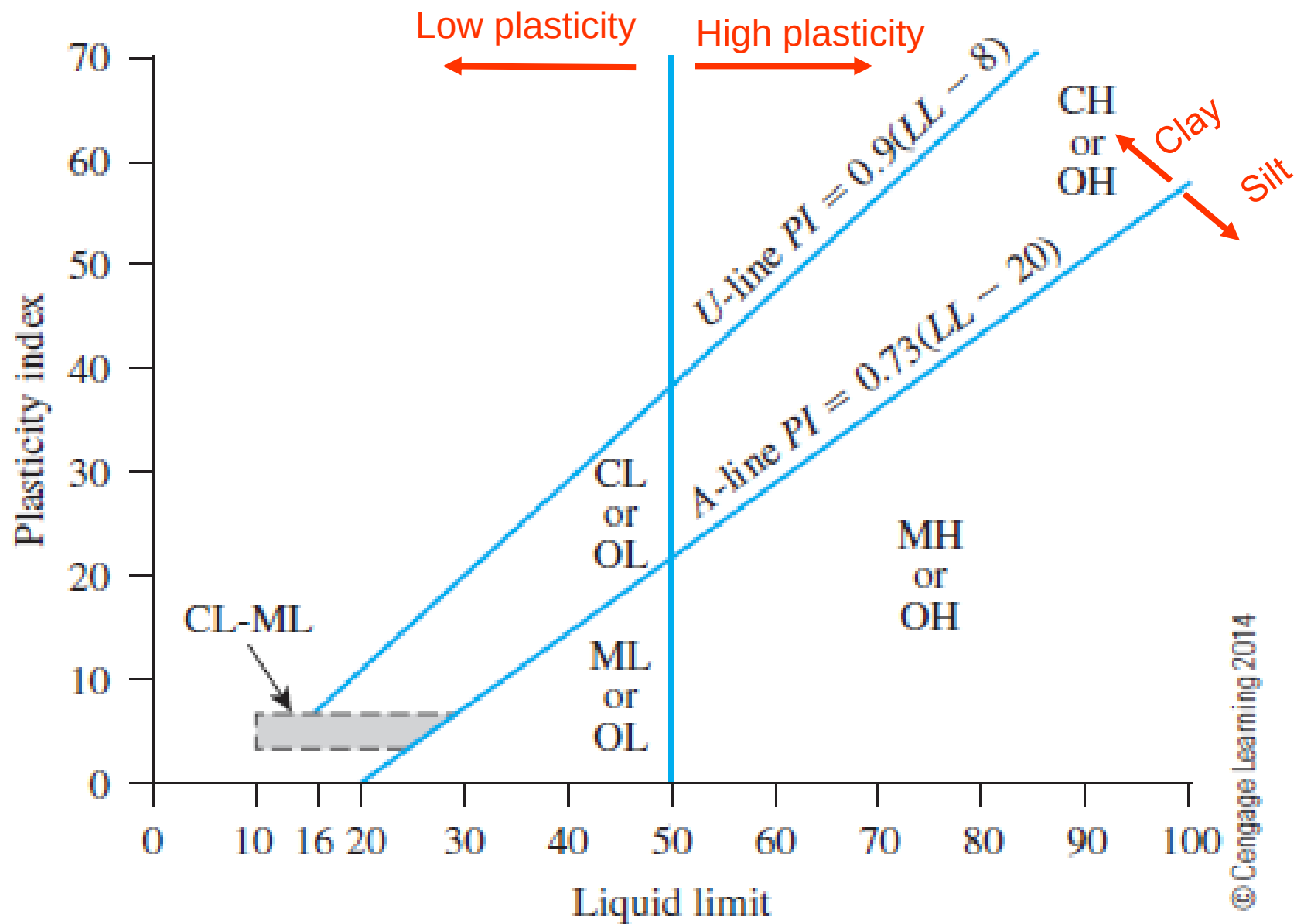
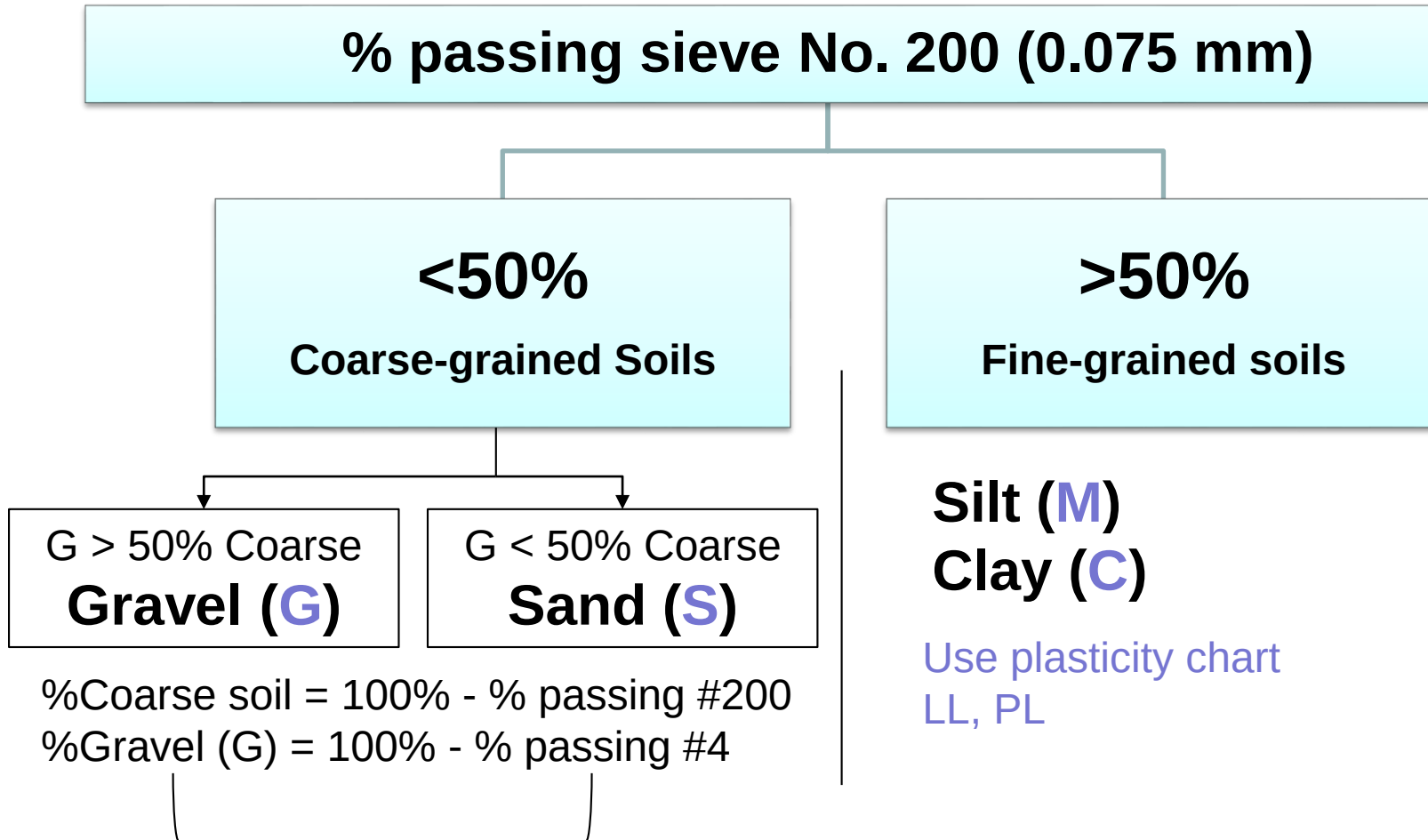


Figure 5.3 Plasticity chart

Unified Soil Classification System USCS



%Coarse soil = 100% - % passing #200
%Gravel (G) = 100% - % passing #4

% passing sieve No. 200

< 5% GW, GP, SW or SP → use Cu, Cc

5-12% dual symbols example GW-GM ...

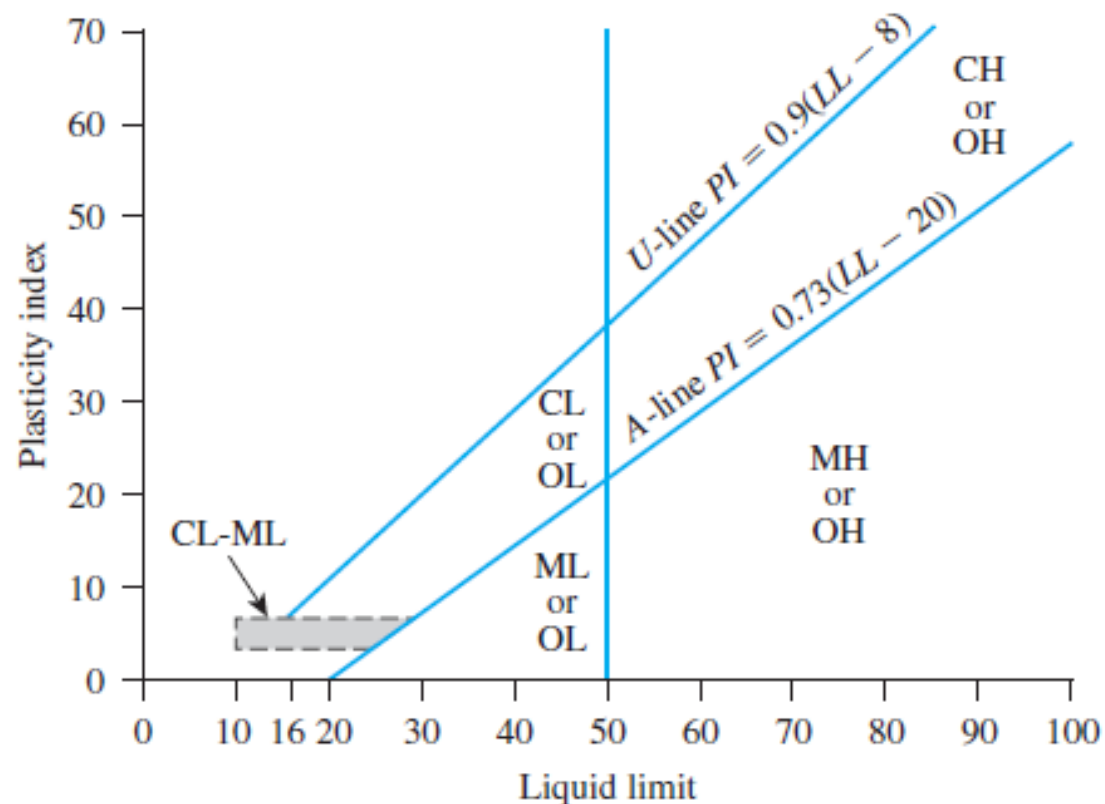
> 12% GM, GC, SM or SC → use plasticity chart

Classification Steps

Step 1: Classify Soil

Major division		Group symbol	Criteria
$F_{200} < 50$	Gravels	GW	$F_{200} < 5; C_u \geq 4; 1 \leq C_z \leq 3$
		GP	$F_{200} < 5$; Not meeting the GW criteria of C_u and C_z
		GM	$F_{200} > 12$; $PI < 4$ or plots <i>below</i> A-line (Fig. 4.2)
		GC	$F_{200} > 12$; $PI > 7$ and plots <i>on or above</i> A-line (Fig. 4.2)
		GM-GC	$F_{200} > 12$; PI plots in the hatched area (Fig. 4.2)
		GW-GM	$5 \leq F_{200} \leq 12$; satisfies C_u and C_z criteria of GW and meets the PI criteria for GM
		GW-GC	$5 \leq F_{200} \leq 12$; satisfies C_u and C_z criteria of GW and meets the PI criteria for GC
		GP-GM	$5 \leq F_{200} \leq 12$; does not satisfy C_u and C_z criteria of GW and meets the PI criteria for GM
		GP-GC	$5 \leq F_{200} \leq 12$; does not satisfy C_u and C_z criteria of GW and meets the PI criteria for GC
	Sands	SW	$F_{200} < 5; C_u \geq 6; 1 \leq C_z \leq 3$
		SP	$F_{200} < 5$; Not meeting the SW criteria of C_u and C_z
		SM	$F_{200} > 12$; $PI < 4$ or plots <i>below</i> A-line (Fig. 4.2)
		SC	$F_{200} > 12$; $PI > 7$ and plots <i>on or above</i> A-line (Fig. 4.2)
		SM-SC	$F_{200} > 12$; PI plots in the hatched area (Fig. 4.2)
		SW-SM	$5 \leq F_{200} \leq 12$; satisfies C_u and C_z criteria of SW and meets the PI criteria for SM
		SW-SC	$5 \leq F_{200} \leq 12$; satisfies C_u and C_z criteria of SW and meets the PI criteria for SC
		SP-SM	$5 \leq F_{200} \leq 12$; does not satisfy C_u and C_z criteria of SW and meets the PI criteria for SM
		SP-SC	$5 \leq F_{200} \leq 12$; does not satisfy C_u and C_z criteria of SW and meets the PI criteria for SC

$F_{200} \geq 50$	Silts and Clays	ML	$PI < 4$ or plots <i>below</i> A-line (Fig. 4.2)
		CL	$PI > 7$ and plots <i>on or above</i> A-line (Fig. 4.2)
$LL < 50$		CL-ML	PI plots in the hatched area (Fig. 4.2)
		OL	$\frac{LL_{(oven\ dried)}}{LL_{(not\ dried)}} < 0.75$; PI plots in the OL area in Fig. 4.2
	Silts and Clays	MH	PI plots <i>below</i> A-line (Fig. 4.2)
$LL \geq 50$		CH	PI plots <i>on or above</i> A-line (Fig. 4.2)
		OH	$\frac{LL_{(oven\ dried)}}{LL_{(not\ dried)}} < 0.75$; PI plots in the OH area in Fig. 4.2
	Highly organic matter	Pt	Peat



Classification Steps

Step 2: Find Soil Name

Gravel

Group symbol		Group name
GW	<15% sand	Well-graded gravel
	$\geq 15\%$ sand	Well-graded gravel with sand
GP	<15% sand	Poorly graded gravel
	$\geq 15\%$ sand	Poorly graded gravel with sand
GW-GM	<15% sand	Well-graded gravel with silt
	$\geq 15\%$ sand	Well-graded gravel with silt and sand
GW-GC	<15% sand	Well-graded gravel with clay (or silty clay)
	$\geq 15\%$ sand	Well-graded gravel with clay and sand (or silty clay and sand)
GP-GM	<15% sand	Poorly graded gravel with silt
	$\geq 15\%$ sand	Poorly graded gravel with silt and sand
GP-GC	<15% sand	Poorly graded gravel with clay (or silty clay)
	$\geq 15\%$ sand	Poorly graded gravel with clay and sand (or silty clay and sand)
GM	<15% sand	Silty gravel
	$\geq 15\%$ sand	Silty gravel with sand
GC	<15% sand	Clayey gravel
	$\geq 15\%$ sand	Clayey gravel with sand
GC-GM	<15% sand	Silty clayey gravel
	$\geq 15\%$ sand	Silty clayey gravel with sand

Sand

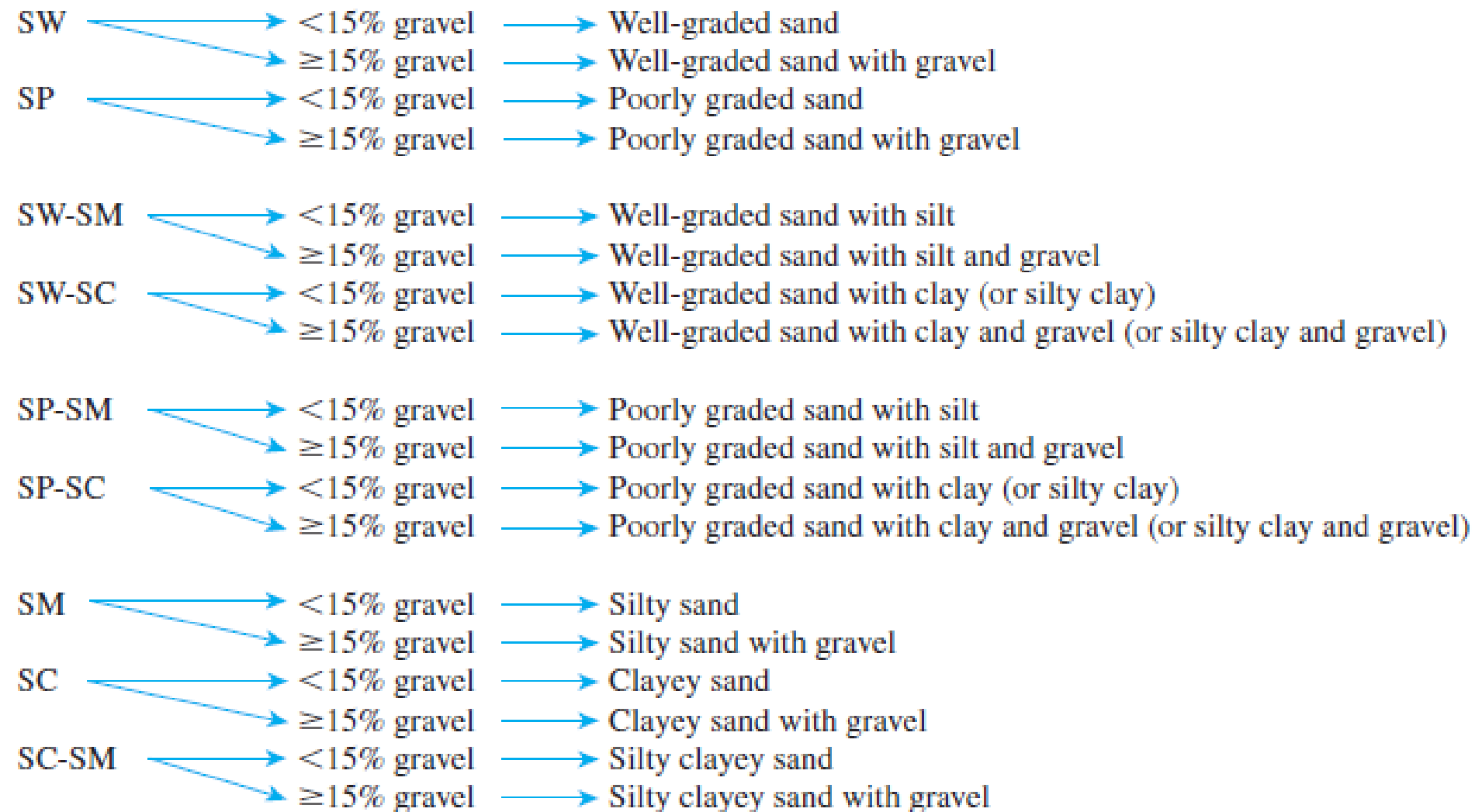


Figure 5.4 Flowchart group names for gravelly and sandy soil (*Source:* From “Annual Book of ASTM Standards, 04.08.” Copyright ASTM INTERNATIONAL. Reprinted with permission.)

Fine Aggregates

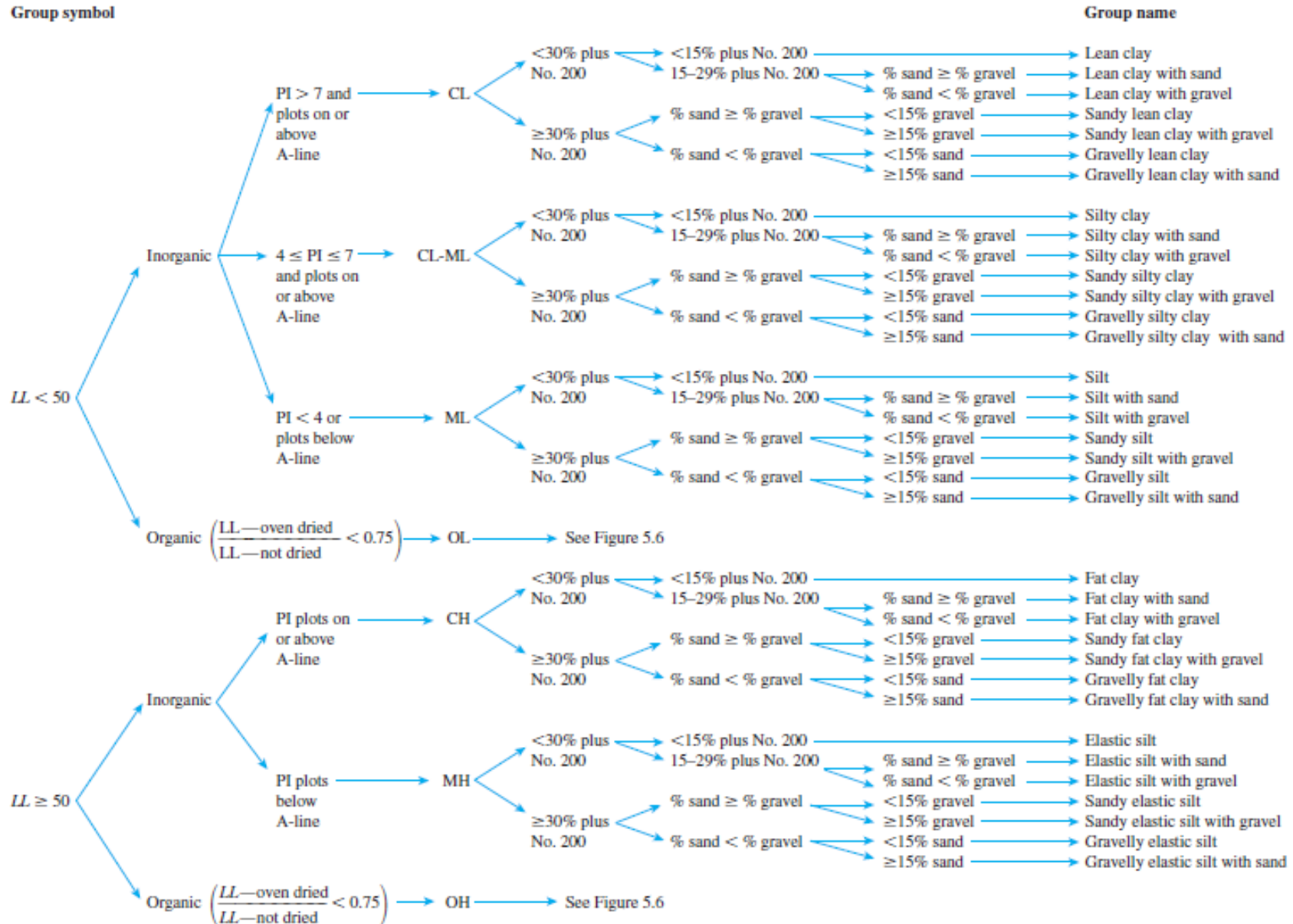


Figure 5.5 Flowchart group names for inorganic silty and clayey soils (Source: From "Annual Book of ASTM Standards, 04.08." Copyright ASTM INTERNATIONAL. Reprinted with permission.)

Fine Aggregates

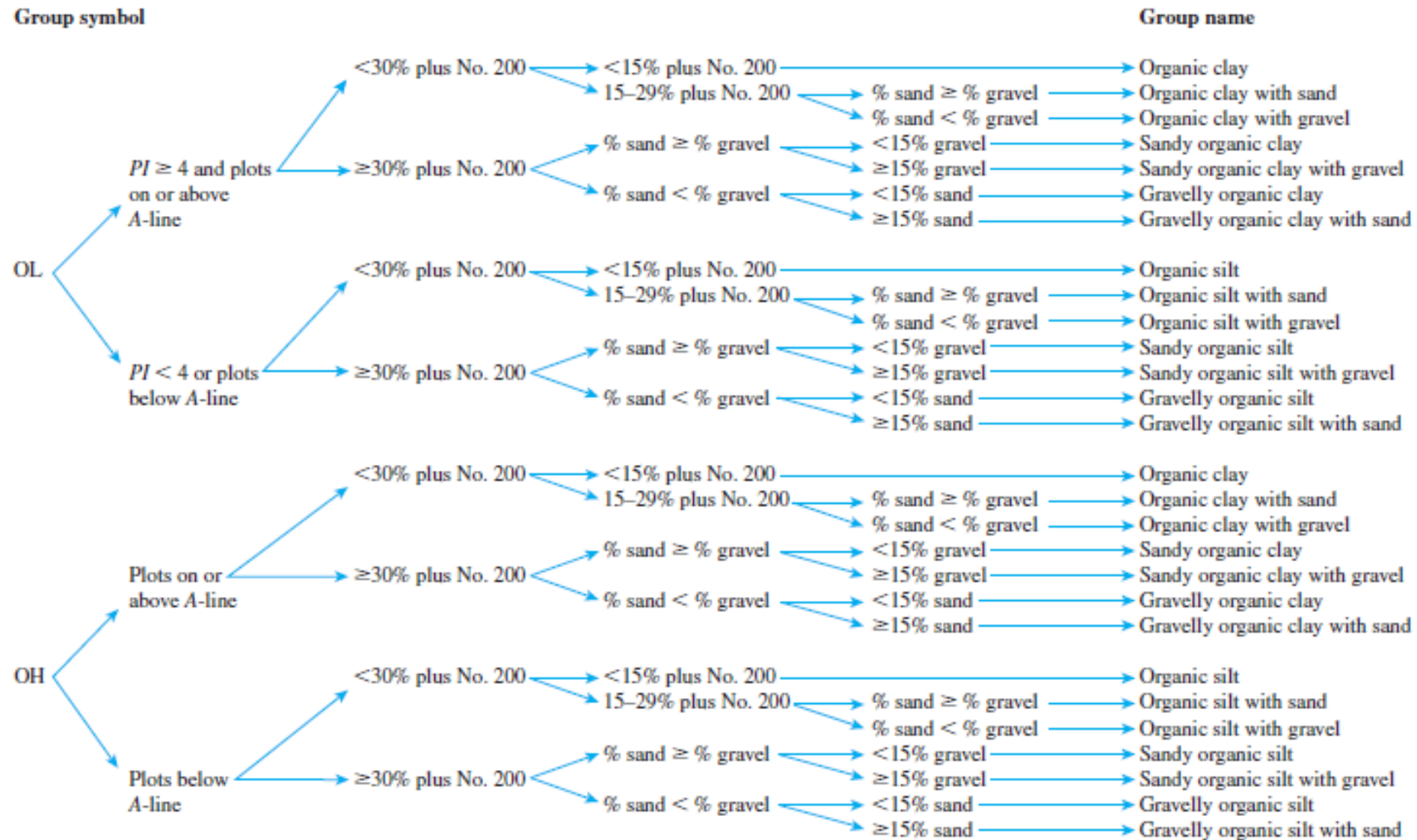


Figure 5.6 Flowchart group names for organic silty and clayey soils (Source: From "Annual Book of ASTM Standards, 04.08." Copyright ASTM INTERNATIONAL. Reprinted with permission.)

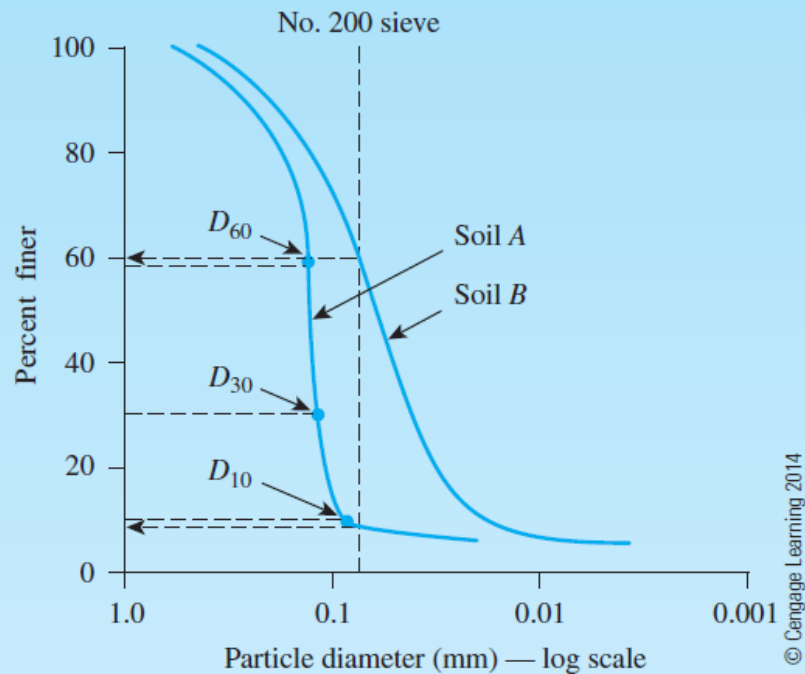
Example 5.6

Figure 5.9 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

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



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Figure 5.9 Particle-size distribution of two soils

Solution

Soil A

The grain-size distribution curve (Figure 5.9) indicates that percent passing No. 200 sieve is 8. According to Table 5.2, it is a coarse-grained soil. Also, from Figure 5.9, the percent retained on No. 4 sieve is zero. Hence, it is a sandy soil.

From Figure 5.9, $D_{10} = 0.085$ mm, $D_{30} = 0.12$ m, and $D_{60} = 0.135$ mm. Thus,

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.135}{0.085} = 1.59 < 6 \quad \text{Poorly graded}$$

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

With $LL = 30$ and $PI = 30 - 22 = 8$ (which is greater than 7), it plots above the A-line in Figure 5.3. Hence, the group symbol is **SP-SC**.

In order to determine the group name, we refer to Figure 5.4 and Figure 5.10.

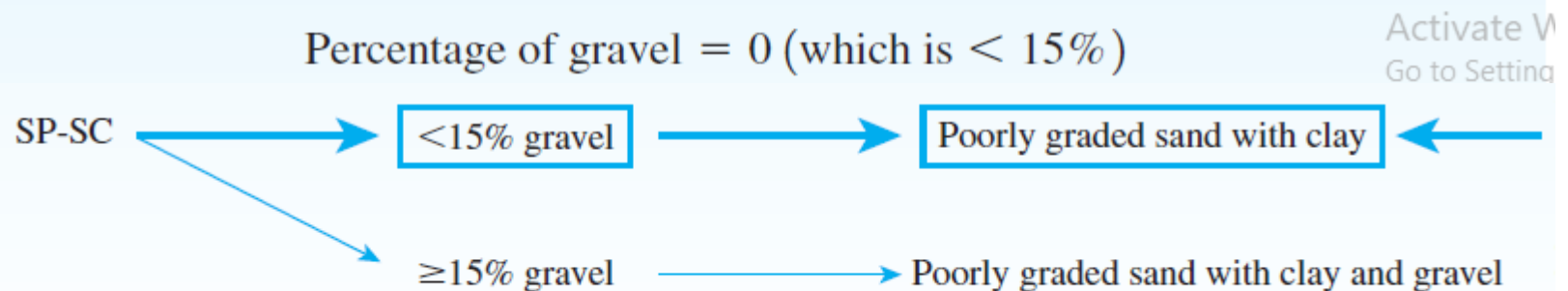


Figure 5.10 Determination of group name for soil A in Example 5.6

Soil B

The grain-size distribution curve in Figure 5.9 shows that percent passing No. 200 sieve is 61 ($>50\%$); hence, it is a fine-grained soil. Given: $LL = 26$ and $PI = 26 - 20 = 6$. In Figure 5.3, the PI plots in the hatched area. So, from Table 5.2, the group symbol is **CL-ML**.

For group name (assuming that the soil is inorganic), we go to Figure 5.5 and obtain Plus No. 200 sieve = $100 - 61 = 39$ (which is greater than 30).

$$\text{Percentage of gravel} = 0; \text{percentage of sand} = 100 - 61 = 39$$

Thus, because the percentage of sand is greater than the percentage of gravel, the soil is **sandy silty clay** as shown in Figure 5.11.

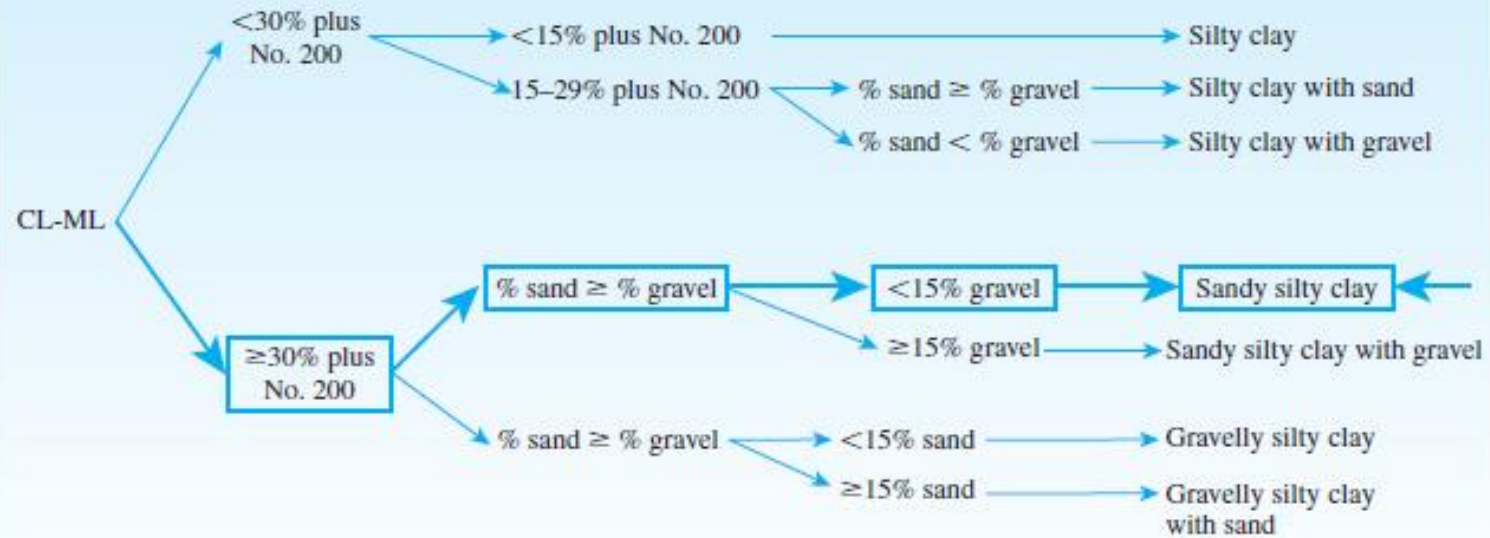


Figure 5.11 Determination of group name for soil *B* in Example 5.6

Example 5.6

For a given soil, the following are known:

- Percentage passing No. 4 sieve = 70
- Percentage passing 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

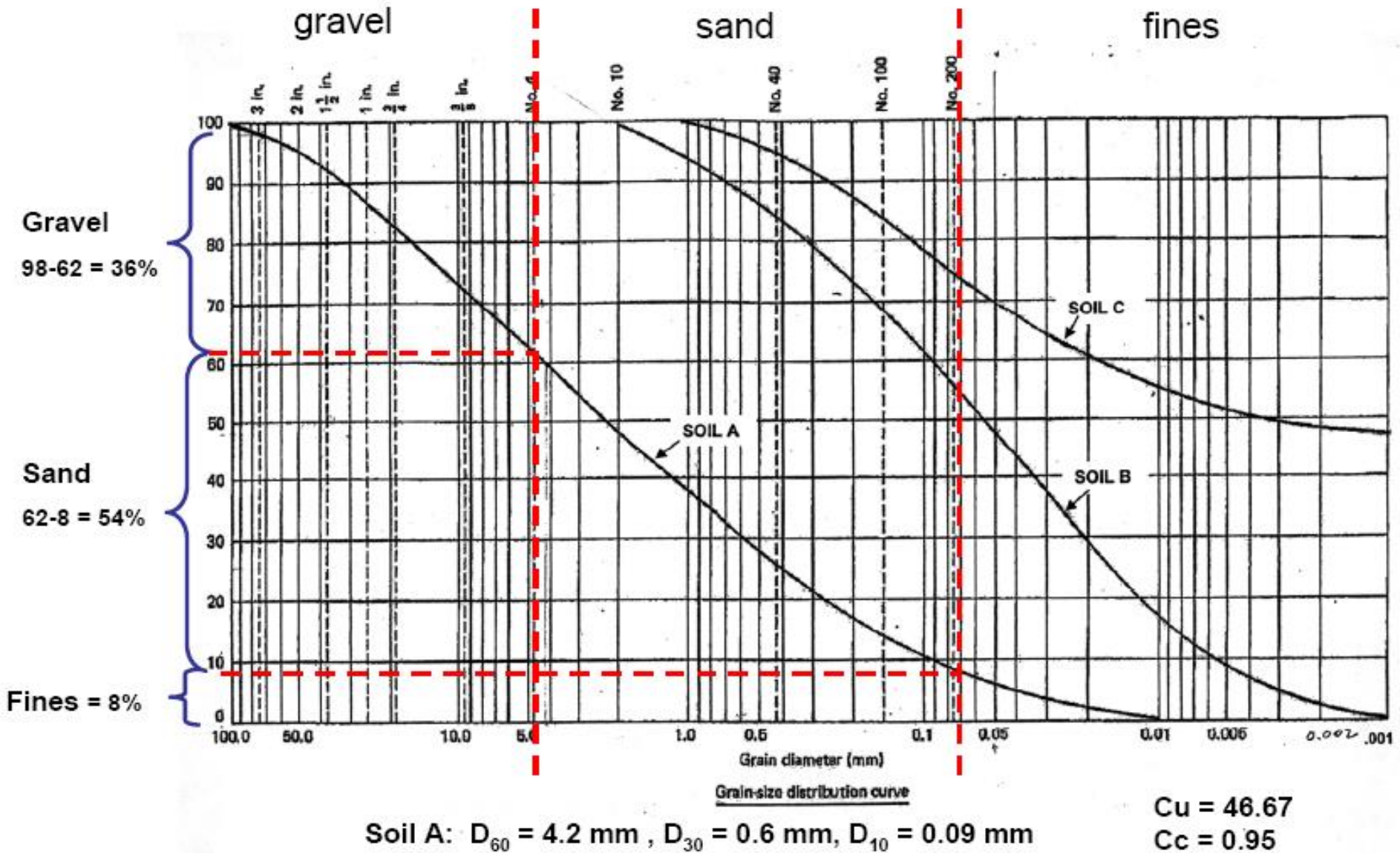
Refer to Table 5.2. The percentage passing No. 200 sieve is 30%, which is less than 50%. So it is a coarse-grained soil. Thus,

$$\text{Coarse fraction} = 100 - 30 = 70\%$$

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 in Figure 5.3. Thus, the group symbol is SC.

For the group name, refer to Figure 5.4. Since the percentage of gravel is more than 15%, it is **clayey sand with gravel**. ■

Example – Soil A



Grave = 36%
 Sand = 54%
 Fines = 8%
 $C_u = 46.7$
 $C_c = 0.95$

LL = 42
 PL = 31
 PI = 42 - 31 = 11



GO TO Plasticity Chart

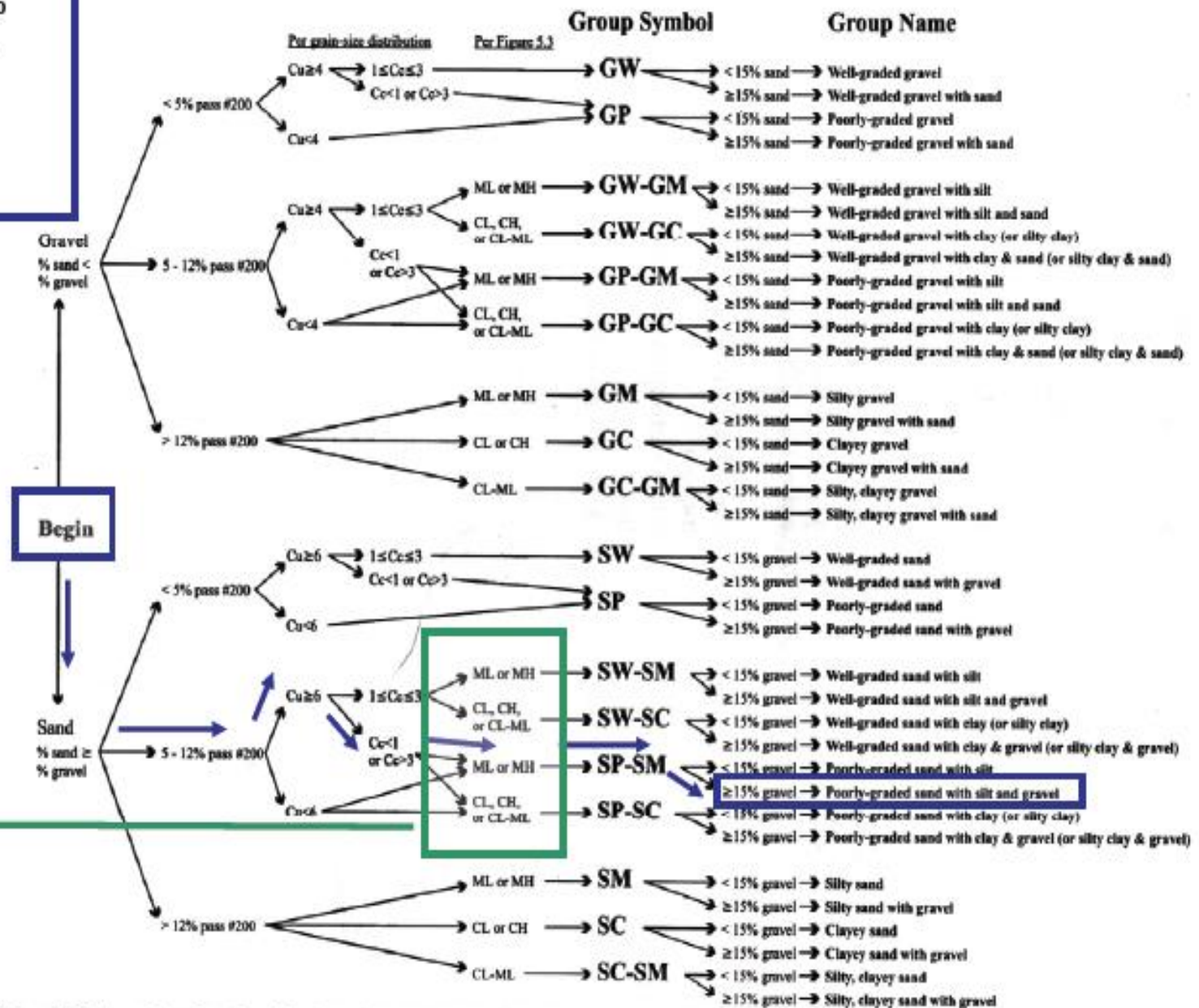
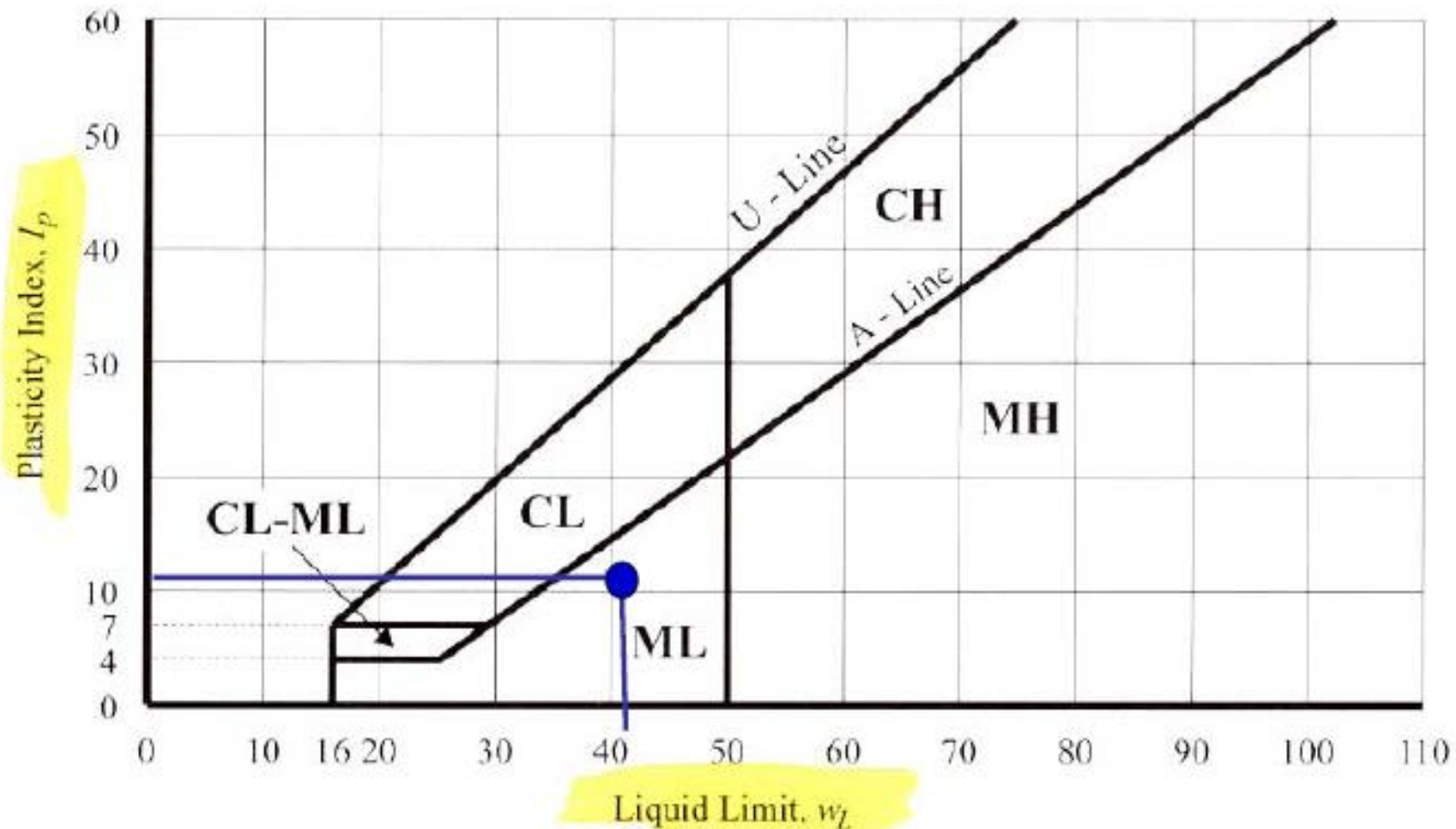


Figure 5.6 Flow chart for classification of coarse-grained soils (< 50% passing #200 sieve) (Adapted from ASTM D2487). C_u and C_c are the coefficients of uniformity and curvature as defined in Chapter 4. The alternative endings for some group names (shown in parenthesis) are for soils that plot as CL-ML on Figure 5.3.

Example – Soil A (Cont.)



LL = 42

PL = 31

PI = 42 - 31 = 11



ML

Soil A is then classified as

SP-SM – Poorly-grades sand with silt and gravel

Example 4

Passing No.200 sieve 30 %

LL= 33

Passing No.4 sieve 70 %

PI= 12

Passing No.200 sieve 30 %

Passing No.4 sieve 70 %

LL= 33

PI= 12

PI= 0.73(LL-20), A-line

PI=0.73(33-20)=9.49

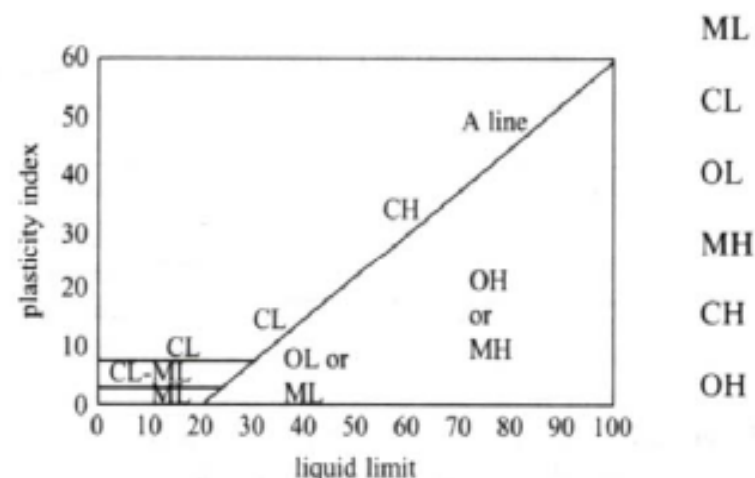
SC

(≥15% gravel)

Clayey sand with
gravel

COARSE More than 50% retained sieve #200	Gravel: more than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 4, 1 \leq C_c \leq 3$	→ GW
		More than 12% fines	Not satisfying GW	→ GP
	Sand: less than 50% coarse fraction retained on sieve #4	Less than 5% fines	Below 'A' line	→ GM
			Above 'A' line	→ GC
		More than 12% fines	Below 'A' line	→ SM
			Above 'A' line	→ SC

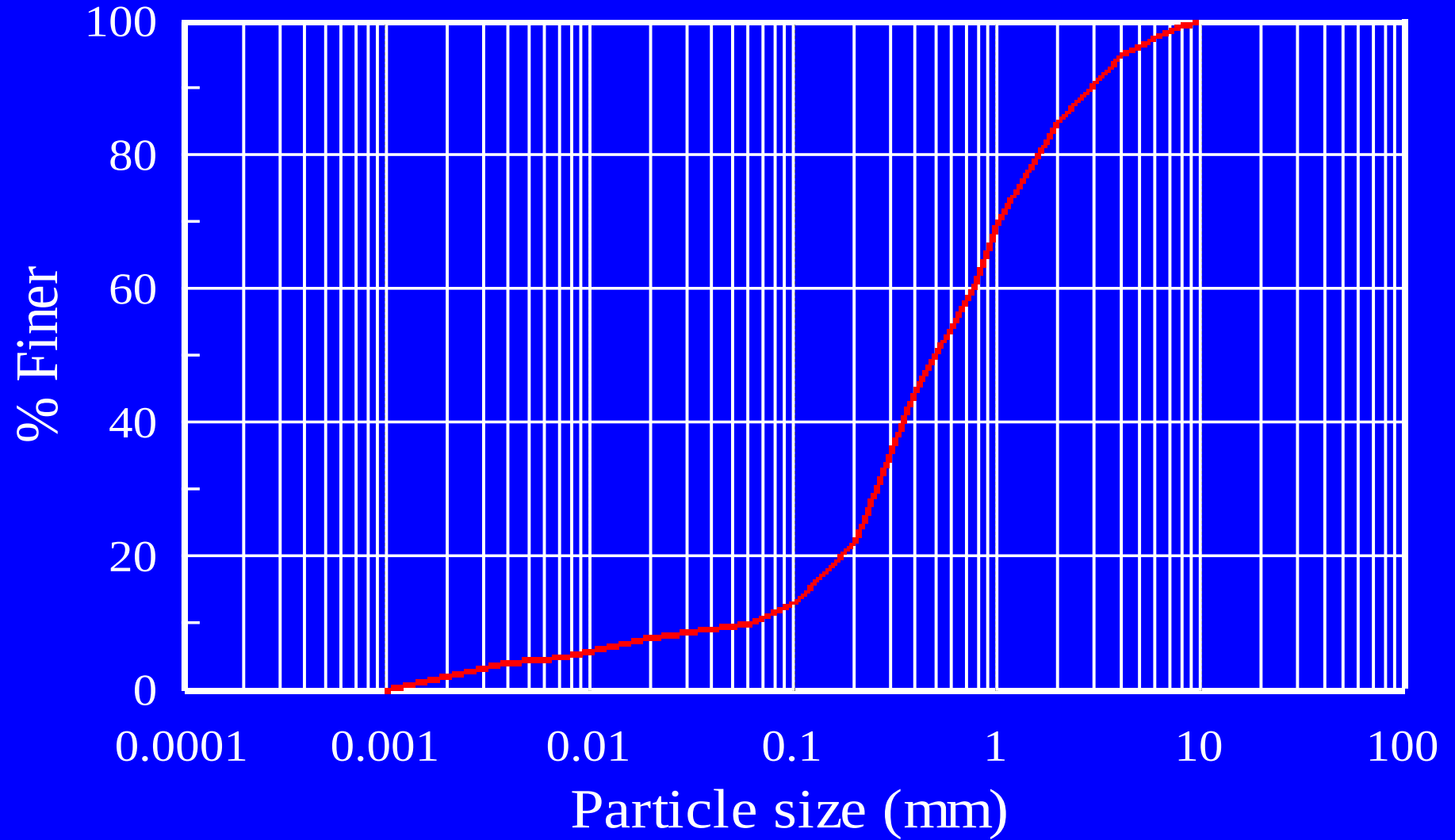
FINE
LL < 50
Less than 50% retained sieve #200
LL > 50



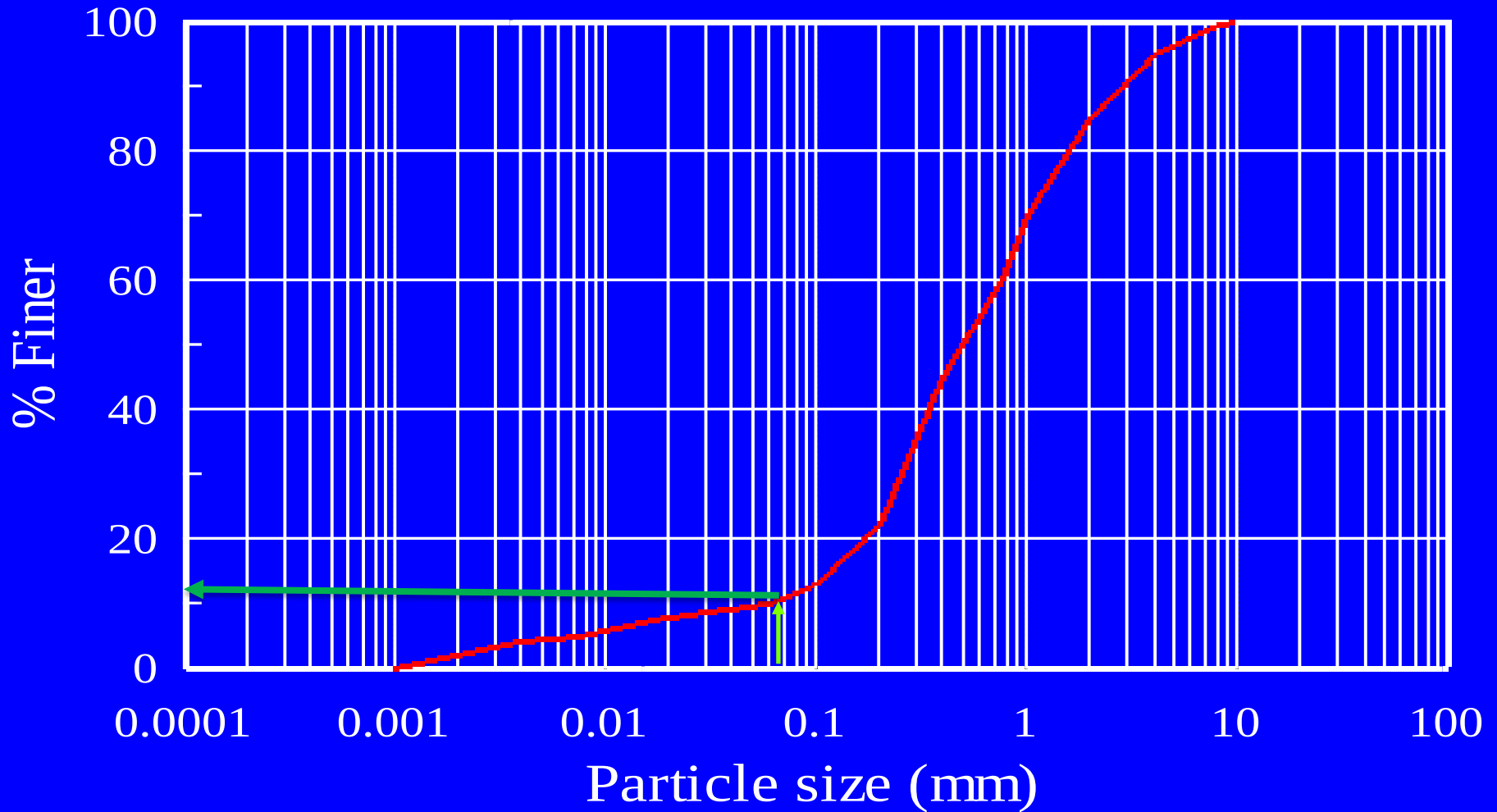
Highly
ORGANIC SOILS

→ Pt

Example 4

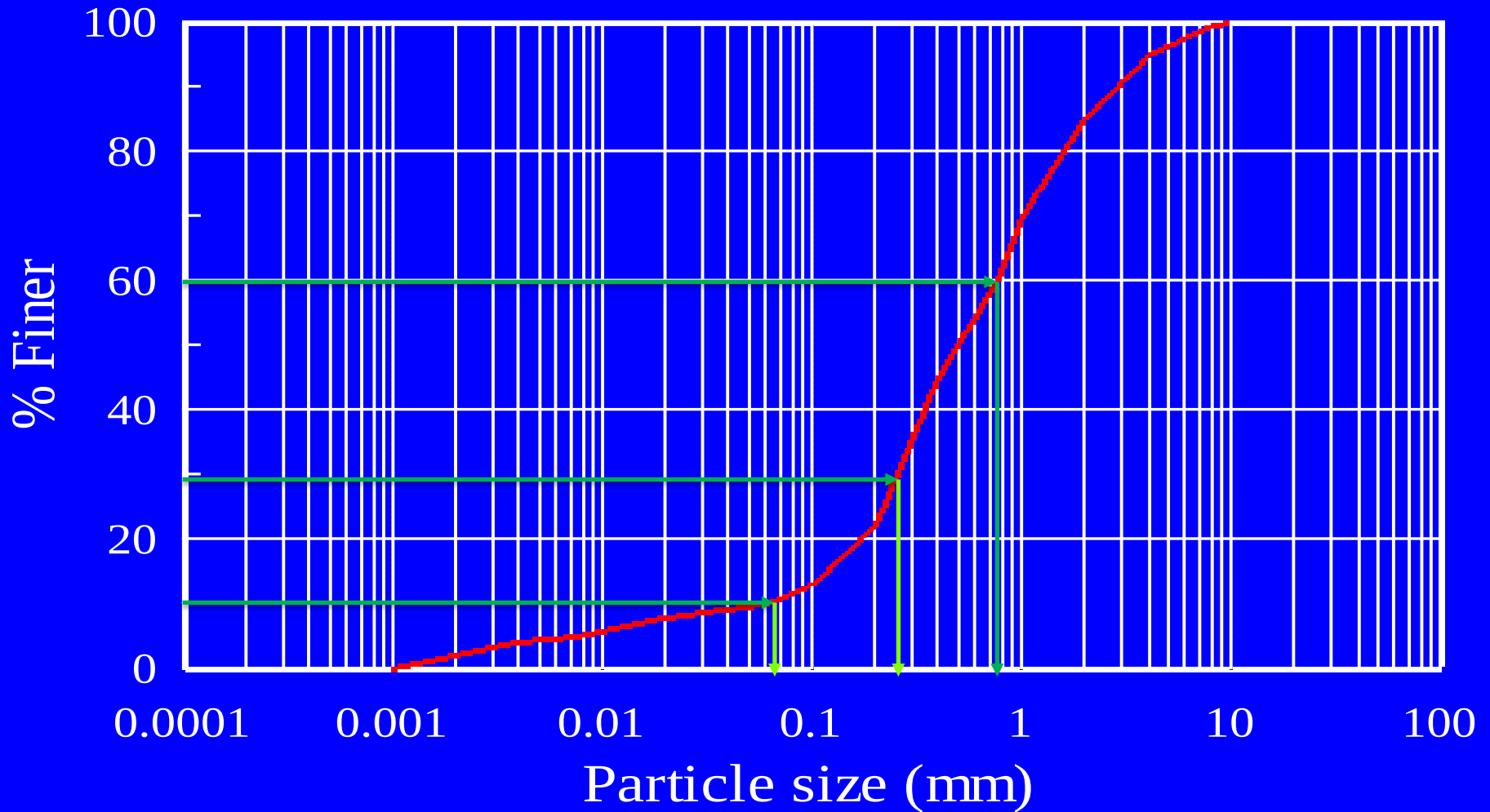


Example 4



- %fines (% finer than 75 μm) = 11% - Dual symbols required

Example 4



- %fines (% finer than 75 μm) = 11% - Dual symbols required
- $D_{10} = 0.06$ mm, $D_{30} = 0.25$ mm, $D_{60} = 0.75$ mm

The graph shows the particle size distribution of a soil sample. The x-axis represents particle size in millimeters (mm) on a logarithmic scale, ranging from 0.0001 to 100. The y-axis represents the percentage of soil finer than a given particle size, ranging from 0 to 100. The curve starts at 0% finer for particle sizes up to approximately 0.00075 mm, then rises gradually until about 0.075 mm, where it is at approximately 10% finer. Between 0.075 mm and 2.0 mm, the curve rises steeply, passing through approximately 40% finer at 0.425 mm and 85% finer at 2.0 mm. Beyond 2.0 mm, the curve levels off, reaching 100% finer at approximately 10 mm.

Particle size (mm)	% Finer
0.00075	0
0.0015	2
0.003	4
0.006	6
0.012	8
0.025	10
0.05	10
0.075	10
0.15	20
0.3	40
0.425	40
0.6	55
0.85	70
1.0	75
2.0	85
3.0	90
4.75	95
7.5	98
10.0	100

Particle size fractions:	Gravel	17%
	Sand	73%
	Silt and Clay	10%

Example 4

Of the coarse fraction about 81% is sand, hence
Prefix is S

$$C_u = 12.5, C_c = 1.38$$
$$\text{Suffix}_1 = W$$

From Atterberg Tests:

$$LL = 32, PL = 26$$
$$PI = 32 - 26 = 6$$

From Plasticity Chart point lies below A-line

$$\text{Suffix}_2 = M$$

Dual Symbols are SW-SM

To complete the classification the Symbols should
be accompanied by a description

Example 5

- A sample of soil was tested in the laboratory with the following results:
 - Liquid limit = 30%
 - Plastic limit = 12%
 - Sieve analysis data:

U.S. Sieve Size	Percentage Passing
3/8 inch	100.0
No. 4	76.5
No. 10	60.0
No. 40	39.7
No. 200	15.2

- Required: Classify the soil by the Unified Soil Classification System

Solution

- **Step 1:** Retained on the No.200 sieve
 $100 - 15.2 = 84.8\%$ ($>50\%$)
“Coarse grained soil”
- **Step 2:** Retained on the No. 4 sieve
 $100 - 76.5 = 23.5\%$
- Fraction retained on the No. 4 sieve
 $23.5 / 84.8 = 27.7\%$
- Fraction passed the No.4 sieve
 $100 - 27.7 = 72.3\%$ ($>50\%$)
“Sand”
- **Step 3:** Passing the No. 200
 15.2% ($>12\%$)
“Sands with fines: More than 12% fines.”

U.S. Sieve Size	Percentage Passing
3/8 in.	100.0
No. 4	76.5
No. 10	60.0
No. 40	39.7
No. 200	15.2

Solution

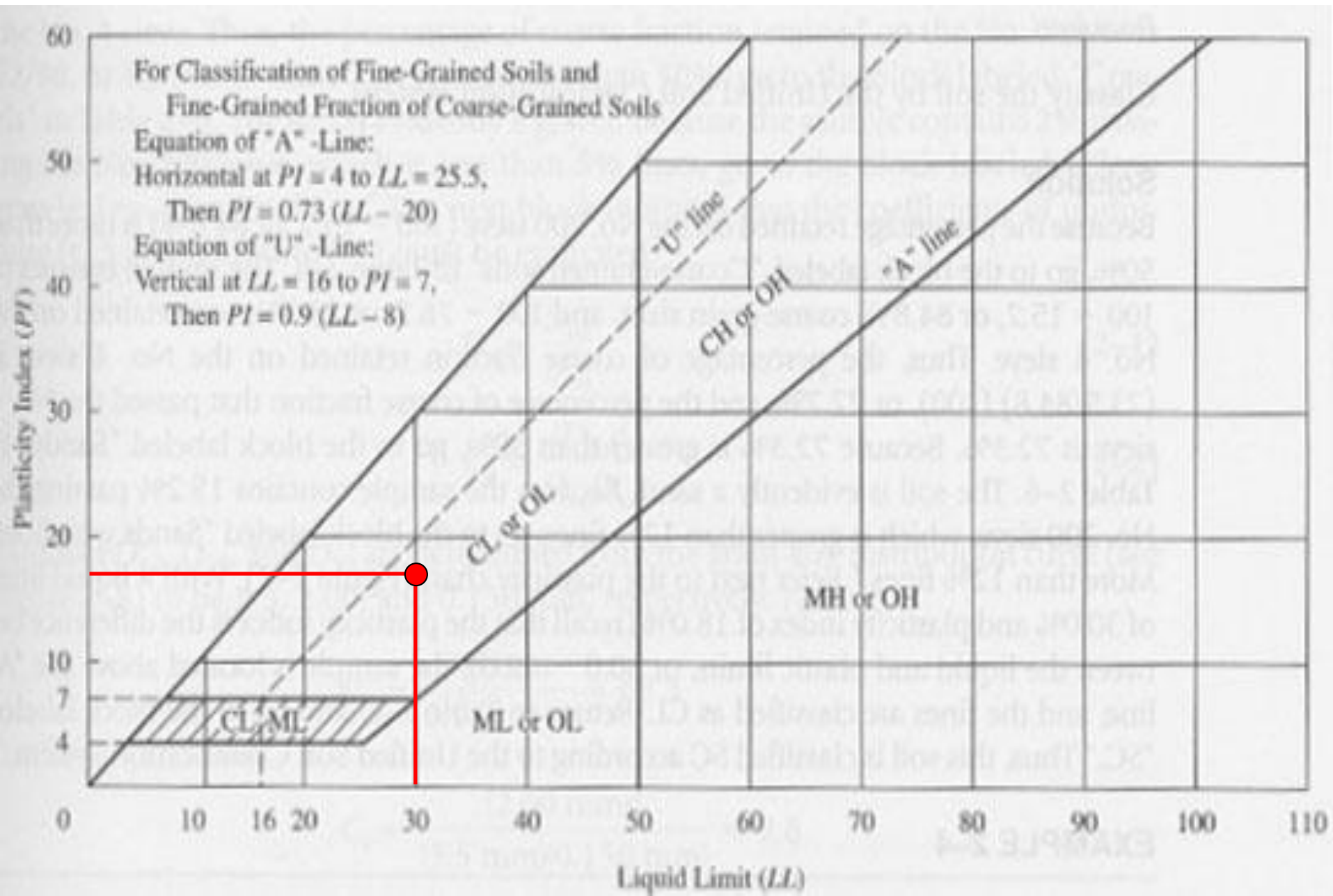
Soil Classification Chart by Unified Soil Classification System [8]

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests ^A				Soil Classification		
				Group Symbol	Group Name ^B	
Coarse-grained soils: More than 50% retained on No. 200 sieve	Gravels: More than 50% of coarse fraction retained on No. 4 sieve	Clean gravels: Less than 5% fines ^C	$C_u \geq 4$ and $1 \leq C_c \leq 3^E$	GW	Well-graded gravel ^E	
			$C_u < 4$ and/or $1 > C_c > 3^E$	GP	Poorly graded gravel ^E	
		Gravels with fines:	Fines classify as ML or MH	GM	Silty gravel ^{E,G,H}	
		More than 12% fines ^C	Fines classify as CL or CH	GC	Clayey gravel ^{E,G,H}	
	Sands: 50% or more of coarse fraction passes No. 4 sieve	Clean sands: Less than 5% fines ^D	$C_u \geq 6$ and $1 \leq C_c \leq 3^E$	SW	Well-graded sand ^I	
			$C_u < 6$ and/or $1 > C_c > 3^E$	SP	Poorly graded sand ^I	
	Sands with fines: More than 12% fines ^D	Fines classify as ML or MH	SM	Silty sand ^{G,H,I}		
		Fines classify as CL or CH	SC	Clayey sand ^{G,H,I}		
Fine-grained soils: 50% or more passes the No. 200 sieve	Silts and clays:	Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line ^J	CL	Lean clay ^{K,L,M}
				$PI < 4$ or plots below "A" line ^J	ML	Silt ^{K,L,M}
			Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$	OL	Organic clay ^{K,L,M,N}
	Liquid limit 50 or more	Inorganic	PI plots on or above "A" line	CH	Fat clay ^{K,L,M}	
			PI plots below "A" line	MH	Elastic silt ^{K,L,M}	
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$	OH	Organic clay ^{K,L,M,P}	
						Organic silt ^{K,L,M,Q}
	Highly organic soils	Primarily organic matter, dark in color, and organic color			PT	Peat

Solution

- Step 4: Check Plasticity chart
 - Liquid Limit = 30%
 - Plasticity Index = 18% ($= 30\% - 12\%$)
 - Sample is located above the “A” line
 - Fines are classified as CL.
- Step 5: Check the Soil Classification Chart
 - Soil is classified “SC”, Clayey Sand
- Step 6: Check item G, H, I of the table
 - G: If fines classify as CL-ML? No.
 - H: If fines are organic? No.
 - I: If soil contains $>15\%$ gravel? Yes.
- Answer: “SC with gravel”

Solution



Example 6

- Given

A sample of soil was tested in the laboratory with the following results:

- Liquid limit = NP (non plastic)
- Plastic limit = NP (non plastic)
- Sieve analysis data:

- Required

Classify the soil by the USCS

U.S. Sieve Size	Percentage Passing
1 in.	100
¾ in.	85
½ in.	70
3/8 in.	60
No. 4	48
No. 10	30
No. 40	16
No. 100	10
No. 200	2

Solution

- Step 1
 - Retained on the No. 200 sieve = $100 - 2 = 98\%$ ($>50\%$)
 - “Coarse-grained soils”
- Step 2
 - Retained on the No. 4 sieve = $100 - 48 = 52\%$
 - Fraction retained on the No. 4 sieve = $52 / 98 = 53.1\%$ ($>50\%$)
 - “Gravels”
- Step 3
 - Passing the No. 200 sieve = 2% ($<5\%$)
 - “Clean gravels: Less than 5% fines.”

Solution

Soil Classification Chart by Unified Soil Classification System [8]

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests ^A				Soil Classification	
				Group Symbol	Group Name ^B
Coarse-grained soils: More than 50% retained on No. 200 sieve	Gravels: More than 50% of coarse fraction retained on No. 4 sieve Sands: 50% or more of coarse fraction passes No. 4 sieve	Clean gravels: Less than 5% fines ^C	$C_u \geq 4$ and $1 \leq C_c \leq 3^E$	GW	Well-graded gravel ^F
		Gravels with fines: More than 5% fines ^C	$C_u < 4$ and/or $1 > C_c > 3^E$	GP	Poorly graded gravel ^E
		Clean sands: Less than 5% fines ^D	Fines classify as ML or MH	GM	Silty gravel ^{E,G,H}
		Sands with fines: More than 12% fines ^D	Fines classify as CL or CH	GC	Clayey gravel ^{E,G,H}
			$C_u \geq 6$ and $1 \leq C_c \leq 3^E$	SW	Well-graded sand ^I
			$C_u < 6$ and/or $1 > C_c > 3^E$	SP	Poorly graded sand ^I
			Fines classify as CL or CH	SM	Silty sand ^{G,H,I}
Fine-grained soils: 50% or more passes the No. 200 sieve	Silts and clays: Liquid limit less than 50 Liquid limit 50 or more	Inorganic	$PI > 7$ and plots on or above "A" line ^J	CL	Lean clay ^{K,L,M}
			$PI < 4$ or plots below "A" line ^J	ML	Silt ^{K,L,M}
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$	OL	Organic clay ^{K,L,M,N}
		Inorganic	PI plots on or above "A" line	CH	Fat clay ^{K,L,M}
			PI plots below "A" line	MH	Elastic silt ^{K,L,M}
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$	OH	Organic clay ^{K,L,M,P}
					Organic silt ^{K,L,M,Q}
Highly organic soils	Primarily organic matter, dark in color, and organic color			PT	Peat

Solution

- Step 4

$$D_{60} = 9.5 \text{ mm}$$

$$D_{30} = 2.0 \text{ mm}$$

$$D_{10} = 0.15 \text{ mm}$$

Coefficients of uniformity (C_u)

$$C_u = D_{60} / D_{10} = 9.5 \text{ mm} / 0.150 \text{ mm} = 63.3$$

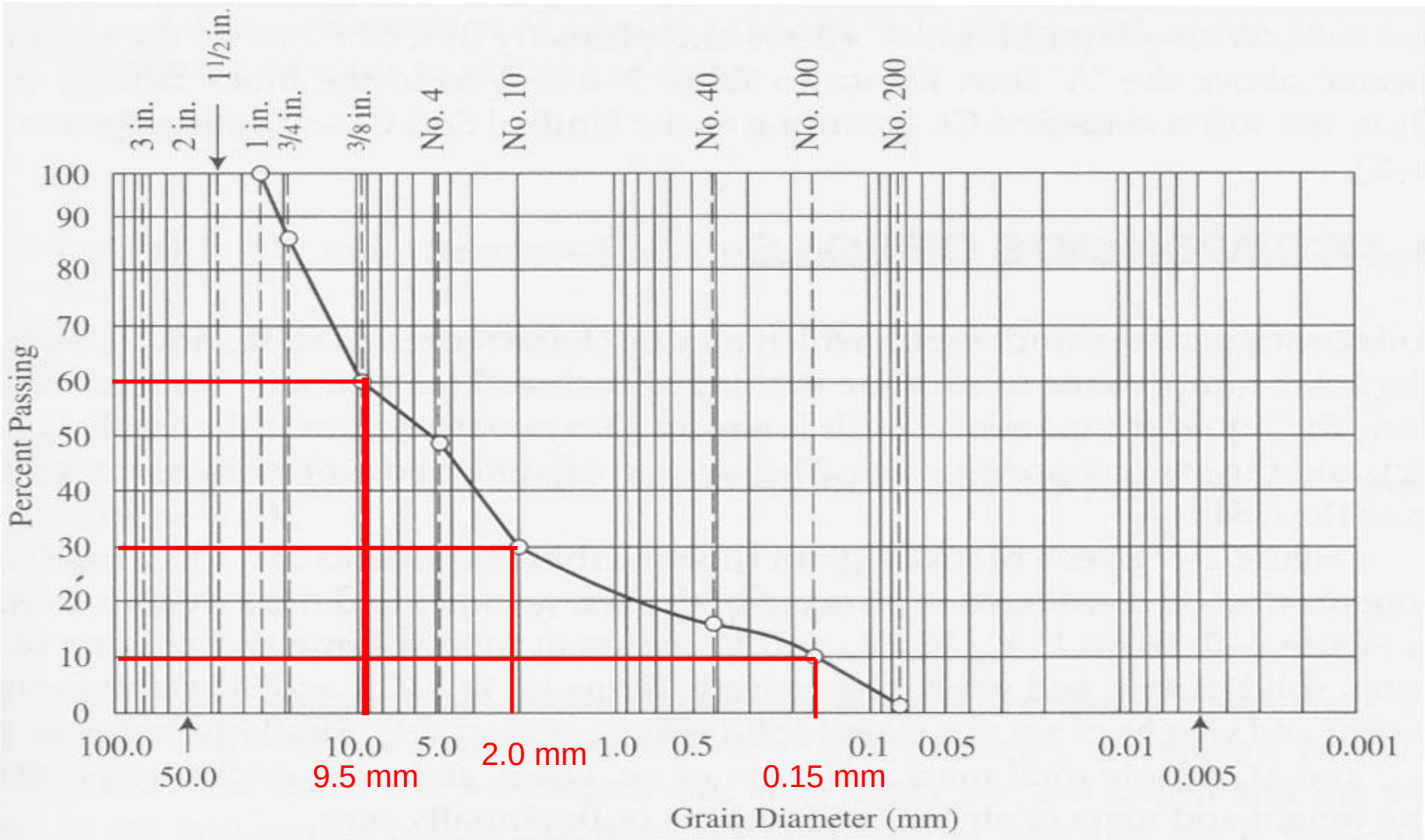
Coefficient of curvature (C_c)

$$\begin{aligned} C_c &= (D_{30})^2 / (D_{60} D_{10}) \\ &= (2.0\text{mm})^2 / [(9.5\text{mm})(0.15\text{mm})] = 2.8 \end{aligned}$$

$$C_u > 4 \text{ and } 1 < C_c < 3$$

- “GW” – Well-graded gravel

Solution



Organic Soils

Highly organic soils- Peat (Group symbol PT)

- A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT.

Organic clay or silt(group symbol OL or OH):

- “The soil’s liquid limit (LL) after oven drying is less than 75 % of its liquid limit before oven drying.” If the above statement is true, then the first symbol is O.
- The second symbol is obtained by locating the values of PI and LL (not oven dried) in the plasticity chart.

H.W

All Problems