

4

Engineering Classification of Soil

Different soils with similar properties may be classified into groups and sub-groups 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. Currently, two 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. The AASHTO classification system is used mostly by state and county highway departments. Geotechnical engineers generally prefer the Unified system.

4.1 AASHTO Classification System

The AASHTO system of soil classification was developed in 1929 as the Public Road Administration Classification System. It has undergone several revisions, with the present version proposed by the Committee on Classification of Materials for Subgrades and Granular Type Roads of the Highway Research Board in 1945 (ASTM designation D-3282; AASHTO method M145).

The AASHTO classification in present use is given in Table 4.1. According to this system, 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 under groups A-4, A-5, A-6, and A-7. These soils are mostly silt and clay-type materials. The classification system is based on the following criteria:

1. *Grain size*
 - a. *Gravel*: fraction passing the 75-mm (3-in.) 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

Table 4.1 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				
General classification	Silt-clay materials (more than 35% of total sample passing No. 200)						
Group classification	A-4	A-5	A-7 A-7-5 ^a A-6	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, $PI > LL - 30$

- 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, 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 4.1, 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. Figure 4.1 shows a plot of the range of the liq-

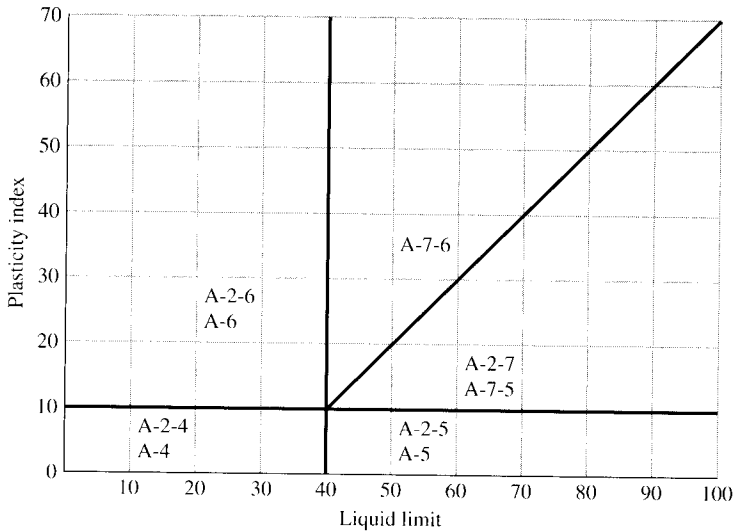


Figure 4.1 Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6, and A-7

liquid limit and the plasticity index for soils that fall into 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. This index is written in parentheses after the group or subgroup designation. The group index is given by the equation

$$GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \quad (4.1)$$

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

LL = liquid limit

PI = plasticity index

The first term of Eq. (4.1)—that is, $(F_{200} - 35)[0.2 + 0.005(LL - 40)]$ —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 Eq. (4.1) yields a negative value for GI , it is taken as 0.
2. The group index calculated from Eq. (4.1) 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 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

$$GI = 0.01(F_{200} - 15)(PI - 10) \quad (4.2)$$

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

Example 4.1

The results of the particle-size analysis of a 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 AASHTO system.

Solution

Using Table 4.1, since 58% of the soil is passing through the No. 200 sieve, it falls under silt-clay classifications — that is, it falls under group A-4, A-5, A-6, or A-7. Proceeding from left to right, it falls under group A-4.

From Eq. (4.1),

$$\begin{aligned} GI &= (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \\ &= (58 - 35)[0.2 + 0.005(30 - 40)] + (0.01)(58 - 15)(10 - 10) \\ &= 3.45 \approx 3 \end{aligned}$$

So, the soil will be classified as **A-4(3)**. ■

Example 4.2

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

According to Table 4.1, this soil falls under group A-7. (Proceed in a manner similar to Example 4.1.) Since

$$40 > 60 - 30$$

↑ ↑

PI LL

this is an A-7-6 soil. Hence,

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

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

Example 4.3

For a soil, given

Sieve No.	Percent passing
4	90
10	76
200	34

Liquid limit = 37

Plasticity index = 12

Classify the soil by the AASHTO system.

Solution

The percentage passing through the No. 200 sieve is less than 35, so the soil is a granular material. From Table 4.1, we see that it is type A-2-6. From Eq. (4.2),

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

For this soil, $F_{200} = 34$ and $PI = 12$, so

$$GI = 0.01(34 - 15)(12 - 10) = 0.38 \approx 0$$

Thus, the soil is type **A-2-6(0)**. ■

4.2 Unified Soil Classification System

The original form of the Unified Soil Classification System was proposed by Casagrande in 1942 during World War II for use in airfield construction undertaken by the Army Corps of Engineers. In cooperation with the U.S. Bureau of Reclamation, the Corps revised this system in 1952. At present, it is widely used by engineers (ASTM designation D-2487). In order to use the classification system, the following points must be kept in mind:

1. The classification is based on material passing a 75 mm (3 in.) sieve.
2. Coarse fraction = percent retained above No. 200 sieve = $100 - F_{200} = R_{200}$.

Table 4.2 Unified Classification System (Based on Materials Passing 75 mm (3 in.) Sieve (Based on ASTM-2487))

Major division	Group symbol	Criteria	
$F_{200} < 50$	Gravels $\frac{R_4}{R_{200}} > 0.5$	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 A-line</i> (Fig. 4.2)
		GC	$F_{200} > 12$; $PI > 7$ and plots <i>on or above A-line</i> (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 $\frac{R_4}{R_{200}} \leq 0.5$	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 A-line</i> (Fig. 4.2)
		SC	$F_{200} > 12$; $PI > 7$ and plots <i>on or above A-line</i> (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	
$F_{200} \geq 50$	Silts and Clays $LL < 50$	ML	$PI < 4$ or plots <i>below A-line</i> (Fig. 4.2)
		CL	$PI > 7$ and plots <i>on or above A-line</i> (Fig. 4.2)
		CL-ML	PI plots in the hatched area (Fig. 4.2)
	Silts and Clays $LL \geq 50$	OL	$\frac{LL_{(\text{oven dried})}}{LL_{(\text{not dried})}} < 0.75$; PI plots in the OL area in Fig. 4.2
		MH	PI plots <i>below A-line</i> (Fig. 4.2)
		CH	PI plots <i>on or above A-line</i> (Fig. 4.2)
		OH	$\frac{LL_{(\text{oven dried})}}{LL_{(\text{not dried})}} < 0.75$; PI plots in the OH area in Fig. 4.2
		Pt	Peat
	Highly organic matter		

Note: C_u = uniformity coefficient = $\frac{D_{60}}{D_{10}}$; C_z = coefficient of gradation = $\frac{D_{30}^2}{D_{60} \times D_{10}}$

LL = liquid limit on minus 40 sieve fraction

PI = plasticity index on minus 40 sieve fraction

3. Fine fraction = percent passing No. 200 sieve = F_{200} .
4. Gravel fraction = percent retained above No. 4 sieve = R_4 .

According to the Unified Soil Classification System, the soils are divided into two major categories:

1. *Coarse-grained soils* that are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve (that is, $F_{200} < 50$). The group symbols start with prefixes of either G or S. G stands for gravel or gravelly soil, and S for sand or sandy soil.
2. *Fine-grained soils* with 50% or more passing through the No. 200 sieve (that is, $F_{200} \geq 50$). The group symbols start with prefixes of M, which stands for inorganic silt, C for inorganic clay, and O for organic silts and clays. The symbol Pt is used for peat, muck, and other highly organic soils.

Other symbols used for the classification are:

- W — well graded
- P — poorly graded
- L — low plasticity (liquid limit less than 50)
- H — high plasticity (liquid limit more than 50)

Table 4.2 gives the details of the soil classification system to determine the *group symbols*.

More recently, ASTM designation D-2487 created an elaborate system to assign *group names* to soils. These names are summarized in Figures 4.3, 4.4, and 4.5. In using these figures, it is important to remember that, in a given soil, percentage of gravel = R_4 and percentage of sand = $R_{200} - R_4$.

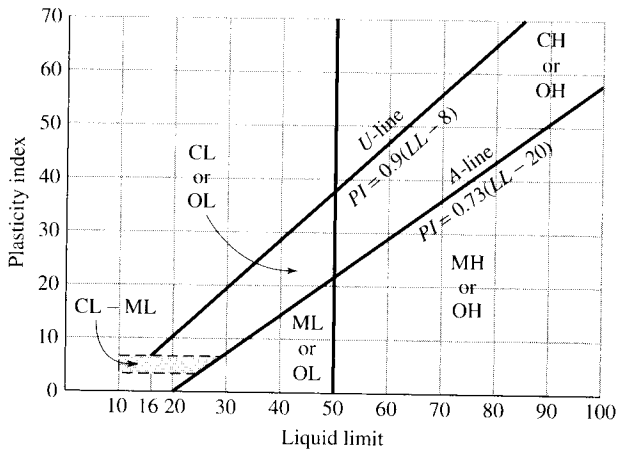


Figure 4.2 Plasticity chart

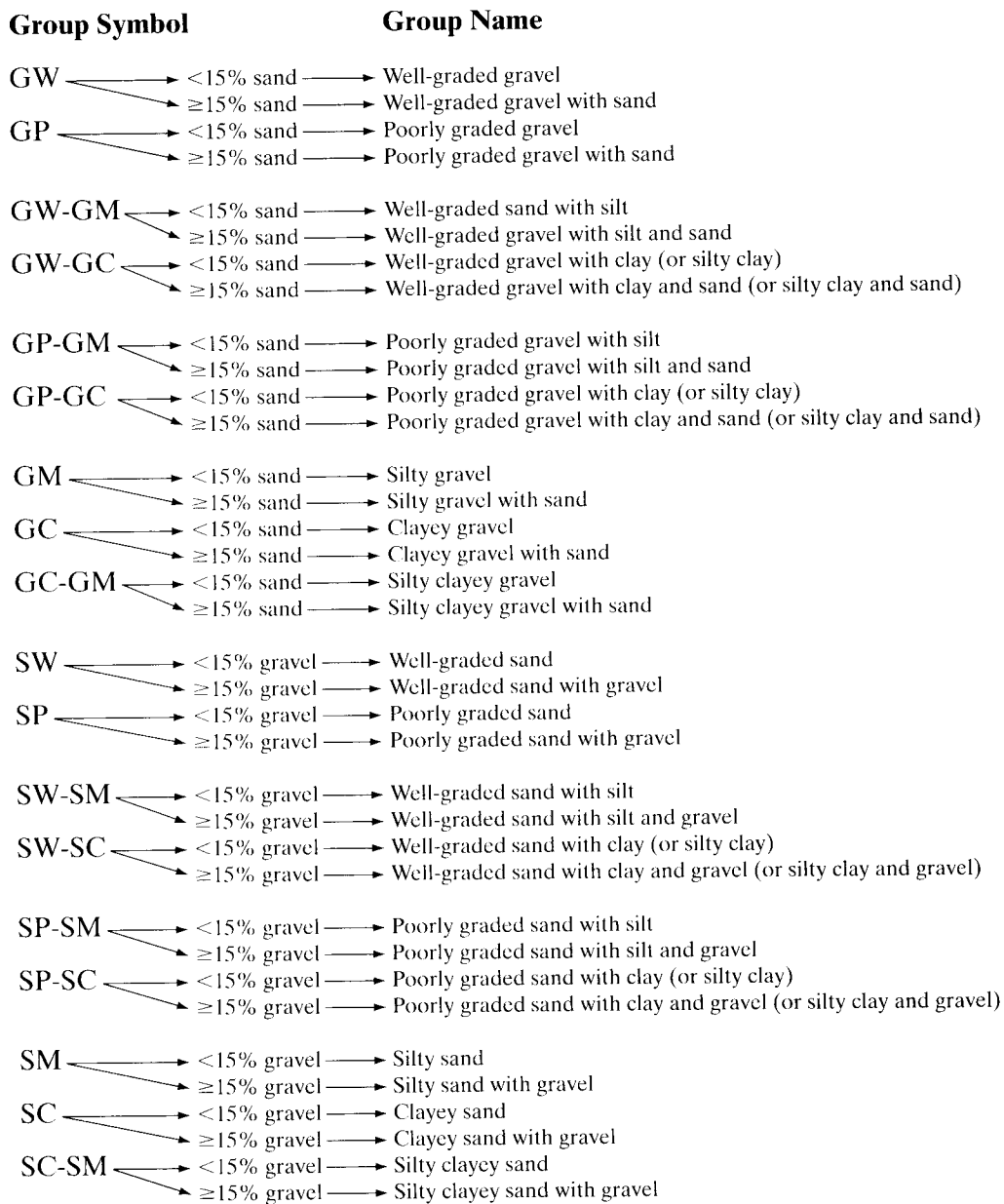


Figure 4.3 Flowchart group names for gravelly and sandy soil. *Source:* From “Annual Book of ASTM Standards, 04.08.” Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

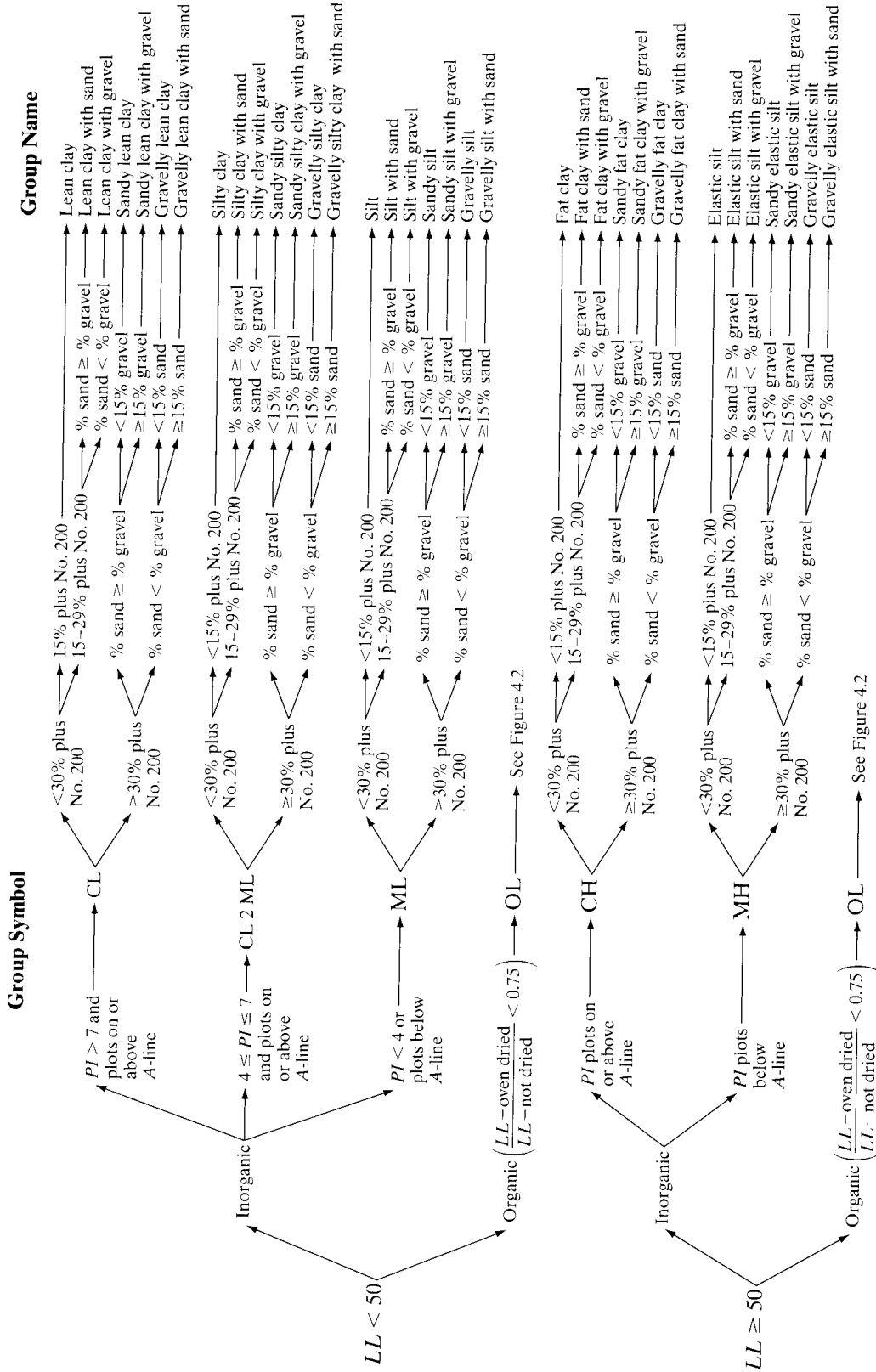


Figure 4.4 Flowchart group names for inorganic silty and clayey soils. *Source:* From "Annual Book of ASTM Standards, 04.08." Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

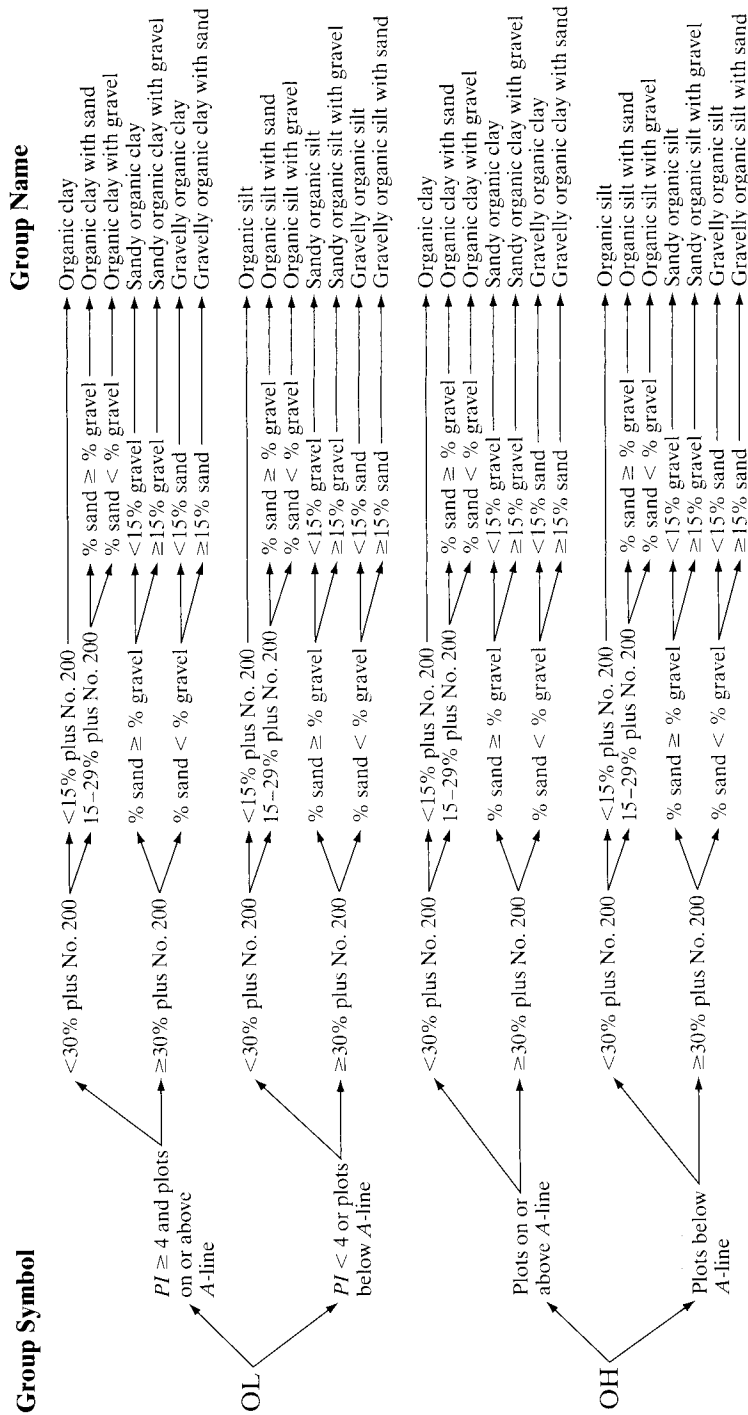


Figure 4.5 Flowchart group names for organic silty and clayey soils. *Source:* From "Annual Book of ASTM Standards, 04.08." Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

Example 4.4

Figure 4.6 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.

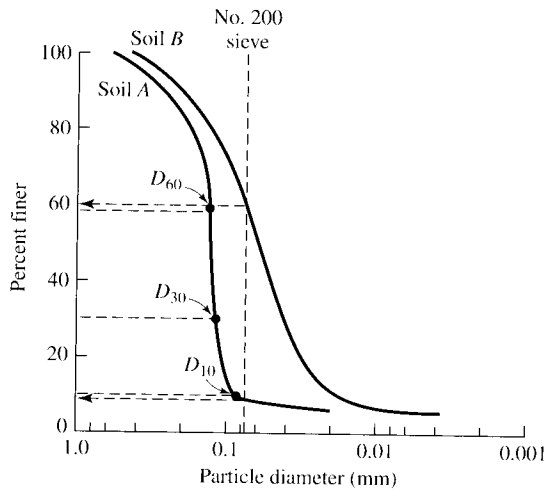


Figure 4.6 Particle-size distribution of two soils

Solution**Soil A**

The grain-size distribution curve indicates that $F_{200} = 8$. So this is a coarse-grained soil, and

$$R_{200} = 100 - F_{200} = 100 - 8 = 92$$

From Figure 4.6, $R_4 \approx 0$; therefore,

$$\frac{R_4}{R_{200}} = \frac{0}{92} < 0.5$$

Hence, it is a sandy soil (Table 4.2). From Figure 4.6, $D_{10} = 0.085$ mm, $D_{30} = 0.12$ mm, and $D_{60} = 0.135$ mm. Thus,

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

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

With $LL = 30$ and $PI = 30 - 22 = 8$ (which is greater than 7), it plots above the A-line in Figure 4.2. Hence, the group symbol is **SP-SC**.

In order to determine the group name, we refer to Figure 4.3.

$$\text{Percentage of gravel} = R_4 = 0 \text{ (which is } < 15\%)$$

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

Soil B

From the grain-size distribution curve, $F_{200} = 61$. Hence, this is a fine-grained soil. Given: $LL = 26$ and $PI = 26 - 20 = 6$. In Figure 4.2, the PI plots in the hatched area. So, from Table 4.2, the group symbol is **CL-ML**.

For group name, assuming that the soil is inorganic, we go to Figure 4.4 and obtain

$$\text{Plus No. 200 sieve} = R_{200} = 100 - F_{200} = 100 - 61 = 39 \text{ (which is greater than 30)}$$

$$\text{Percentage of gravel} = R_4 = 0; \text{ percentage of sand} = R_{200} - R_4 = 39$$

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

Example 4.5

The grain-size analysis for a soil is given next:

Sieve no.	% passing
4	94
10	63
20	21
40	10
60	7
100	5
200	3

Given that the soil is nonplastic, classify the soil by using the Unified Soil Classification System.

Solution

$$F_{200} = 3$$

$$R_{200} = 100 - 3 = 97$$

$$R_4 = 100 - F_4 = 100 - 94 = 6$$

$$\frac{R_4}{R_{200}} = \frac{6}{97} < 0.5$$

Thus, this soil is sandy. The grain-size distribution is shown in Figure 4.7. From this figure, we obtain

$$D_{60} = 1.41 \text{ mm} \quad D_{30} = 0.96 \text{ mm} \quad D_{10} = 0.41 \text{ mm}$$

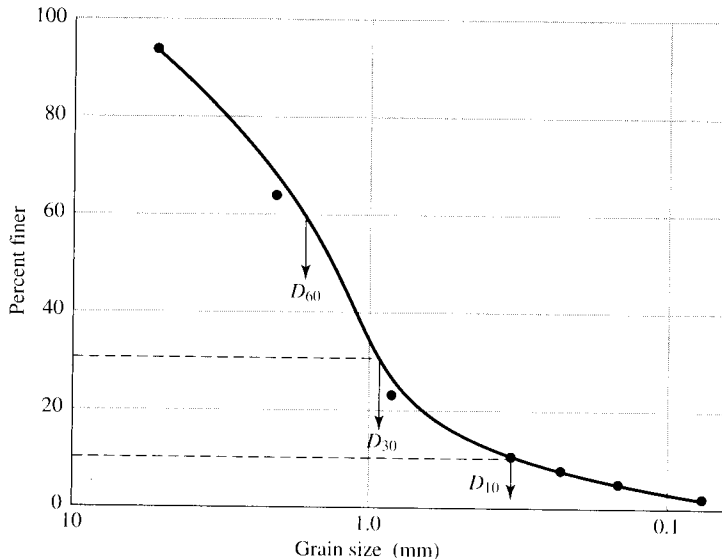


Figure 4.7 Grain-size distribution curve

Thus,

$$C_u = \frac{D_{60}}{D_{10}} = \frac{1.41}{0.41} = 3.44$$

$$C_z = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{0.96^2}{1.41 \times 0.41} = 1.59$$

From Table 4.2, we see that the group symbol is **SP**. For this soil, $R_4 = 6$. Referring to Figure 4.3, we find that the group name is **poorly graded sand**. ■

4.3

Summary and Comparison between the AASHTO and Unified Systems

Both soil classification systems, AASHTO and Unified, are based on the texture and plasticity of soil. Also, both systems divide the soils into two major categories, coarse grained and fine grained, as separated by the No. 200 sieve. According to the AASHTO system, a soil is considered fine grained when more than 35% passes through the No. 200 sieve. According to the Unified system, a soil is considered fine grained when more than 50% passes through the No. 200 sieve. A coarse-grained soil that has about 35% fine grains will behave like a fine-grained material. This is because enough fine grains exist to fill the voids between the coarse grains and hold them apart. In this respect, the AASHTO system appears to be more appropriate. In the AASHTO system, the No. 10 sieve is used to separate gravel from sand; in the Unified

system, the No. 4 sieve is used. From the viewpoint of soil-separate size limits, the No. 10 sieve is the more accepted upper limit for sand. This limit is used in concrete and highway base-course technology.

In the Unified system, the gravelly and sandy soils are clearly separated; in the AASHTO system, they are not. The A-2 group, in particular, contains a large variety of soils. Symbols like GW, SM, CH, and others that are used in the Unified system are more descriptive of the soil properties than the A symbols used in the AASHTO system.

The classification of organic soils as OL, OH, and Pt is provided in the Unified system. Under the AASHTO system, there is no place for organic soils. Peats usually have a high moisture content, low specific gravity of soil solids, and low unit weight. Figure 4.8 shows the scanning electron micrographs of four peat samples collected in Wisconsin. Some of the properties of the peats are given in Table 4.3.

Liu (1967) compared the AASHTO and Unified systems. The results of his study are presented in Tables 4.4 and 4.5.

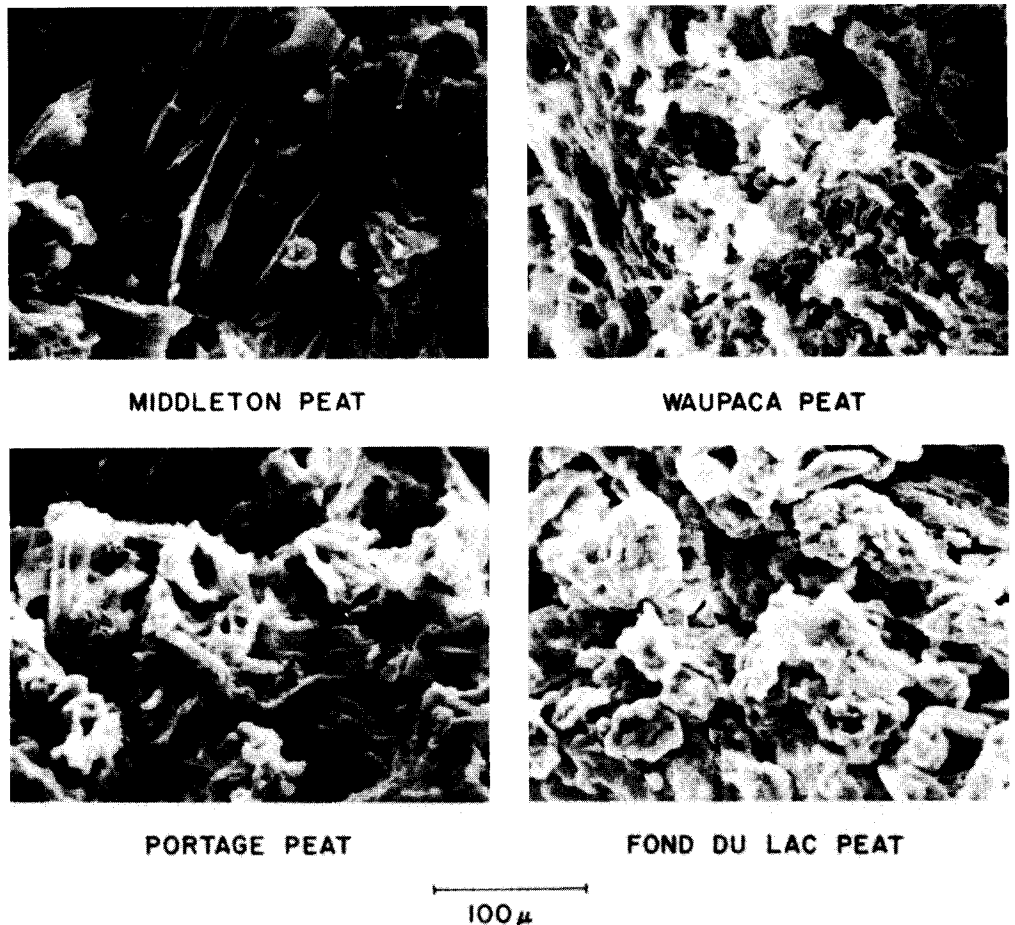


Figure 4.8 Scanning electron micrographs for four peat samples (after Dhowian and Edil, 1980)

Table 4.3 Properties of the Peats Shown in Figure 4.8

Source of peat	Moisture content (%)	Unit weight		Specific gravity, G_s	Ash content (%)
		kN/m ³	lb/ft ³		
Middleton	510	9.1	57.9	1.41	12.0
Waupaca County	460	9.6	61.1	1.68	15.0
Portage	600	9.6	61.1	1.72	19.5
Fond du Lac County	240	10.2	64.9	1.94	39.8

Table 4.4 Comparison of the AASHTO System with the Unified System*

Soil group in AASHTO system	Comparable soil groups in Unified system		
	Most probable	Possible	Possible but improbable
A-1-a	GW, GP	SW, SP	GM, SM
A-1-b	SW, SP, GM, SM	GP	—
A-3	SP	—	SW, GP
A-2-4	GM, SM	GC, SC	GW, GP, SW, SP
A-2-5	GM, SM	—	GW, GP, SW, SP
A-2-6	GC, SC	GM, SM	GW, GP, SW, SP
A-2-7	GM, GC, SM, SC	—	GW, GP, SW, SP
A-4	ML, OL	CL, SM, SC	GM, GC
A-5	OH, MH, ML, OL	—	SM, GM
A-6	CL	ML, OL, SC	GC, GM, SM
A-7-5	OH, MH	ML, OL, CH	GM, SM, GC, SC
A-7-6	CH, CL	ML, OL, SC	OH, MH, GC, GM, SM

*After Liu (1967)

Table 4.5 Comparison of the Unified System with the AASHTO System*

Soil group in Unified system	Comparable soil groups in AASHTO system		
	Most probable	Possible	Possible but improbable
GW	A-1-a	—	A-2-4, A-2-5, A-2-6, A-2-7
GP	A-1-a	A-1-b	A-3, A-2-4, A-2-5, A-2-6, A-2-7
GM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6	A-4, A-5, A-6, A-7-5, A-7-6, A-1-a
GC	A-2-6, A-2-7	A-2-4	A-4, A-6, A-7-6, A-7-5
SW	A-1-b	A-1-a	A-3, A-2-4, A-2-5, A-2-6, A-2-7
SP	A-3, A-1-b	A-1-a	A-2-4, A-2-5, A-2-6, A-2-7
SM	A-1-b, A-2-4, A-2-5, A-2-7	A-2-6, A-4	A-5, A-6, A-7-5, A-7-6, A-1-a
SC	A-2-6, A-2-7	A-2-4, A-6, A-4, A-7-6	A-7-5
ML	A-4, A-5	A-6, A-7-5, A-7-6	—
CL	A-6, A-7-6	A-4	—
OL	A-4, A-5	A-6, A-7-5, A-7-6	—
MH	A-7-5, A-5	—	A-7-6
CH	A-7-6	A-7-5	—
OH	A-7-5, A-5	—	A-7-6
Pt	—	—	—

*After Liu (1967)

Problems

- 4.1 The sieve analysis of 10 soils and the liquid and plastic limits of the fraction passing through the No. 40 sieve are given in the following table:

Soil	Sieve analysis, % finer			Liquid limit	Plastic limit
	No. 10	No. 40	No. 200		
1	95	79	53	36	21
2	100	95	78	65	26
3	100	80	62	35	20
4	90	55	45	28	20
5	90	71	60	40	26
6	95	65	32	25	16
7	100	55	8	—	NP
8	96	82	65	40	24
9	85	60	23	20	15
10	100	92	86	70	38

Classify the soils by the AASHTO classification system and give the group indices for each.

- 4.2 Classify the following soils using the AASHTO classification system, and give the group indices:

Soil	Sieve analysis, % finer			Liquid limit	Plastic limit
	No. 10	No. 40	No. 200		
A	62	30	8	—	NP
B	90	67	35	32	8
C	90	76	34	37	12
D	100	78	8	—	NP
E	85	68	45	38	9

- 4.3 Classify the following soils using the AASHTO classification system, and give the group indices also:

Sieve size	Percent passing				
	A	B	C	D	E
No. 4	94	98	100	100	100
No. 10	63	86	100	100	100
No. 20	21	50	98	100	100
No. 40	10	28	93	99	94
No. 60	7	18	88	95	82
No. 100	5	14	83	90	66
No. 200	3	10	77	86	45
0.01 mm	—	—	65	42	26
0.002 mm	—	—	60	47	21
Liquid limit	—	—	63	55	36
Plasticity index	NP	NP	25	28	22

- 4.4 Classify soils 1–6 given in Problem 4.1 using the Unified classification system. Give the group symbols and the group names.
- 4.5 Classify the soils given in Problem 4.3 using the Unified classification system. Give the group symbols and the group names.
- 4.6 Classify the following soils using the Unified classification system:

Soil	<i>Sieve analysis, % finer</i>		Liquid limit	Plasticity index
	No. 4	No. 200		
A	80	52	30	8
B	79	45	26	4
C	91	80	60	32
D	95	75	41	12
E	82	41	24	2

Give the group symbols and the group names.

- 4.7 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 according to

- the AASHTO soil classification system;
- the Unified soil classification system. Give group names and group symbols.

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