ENCE 3610
Soil Mechanics

Soil Classification

Methods of Classifying Soils

- USDA Method
  - Developed primarily for agricultural and surface soil purposes
  - Not used often in soil mechanics
- Unified Classification System
  - Developed by Arthur Casagrande during World War II for the U.S. Army Corps of Engineers
  - Most widely used classification system
- AASHTO System
  - Originally developed in the 1920's as the Bureau of Public Roads system
  - Primarily aimed at classification for pavement purposes
- All methods similar, but differences are significant enough that they should be understood

USDA System

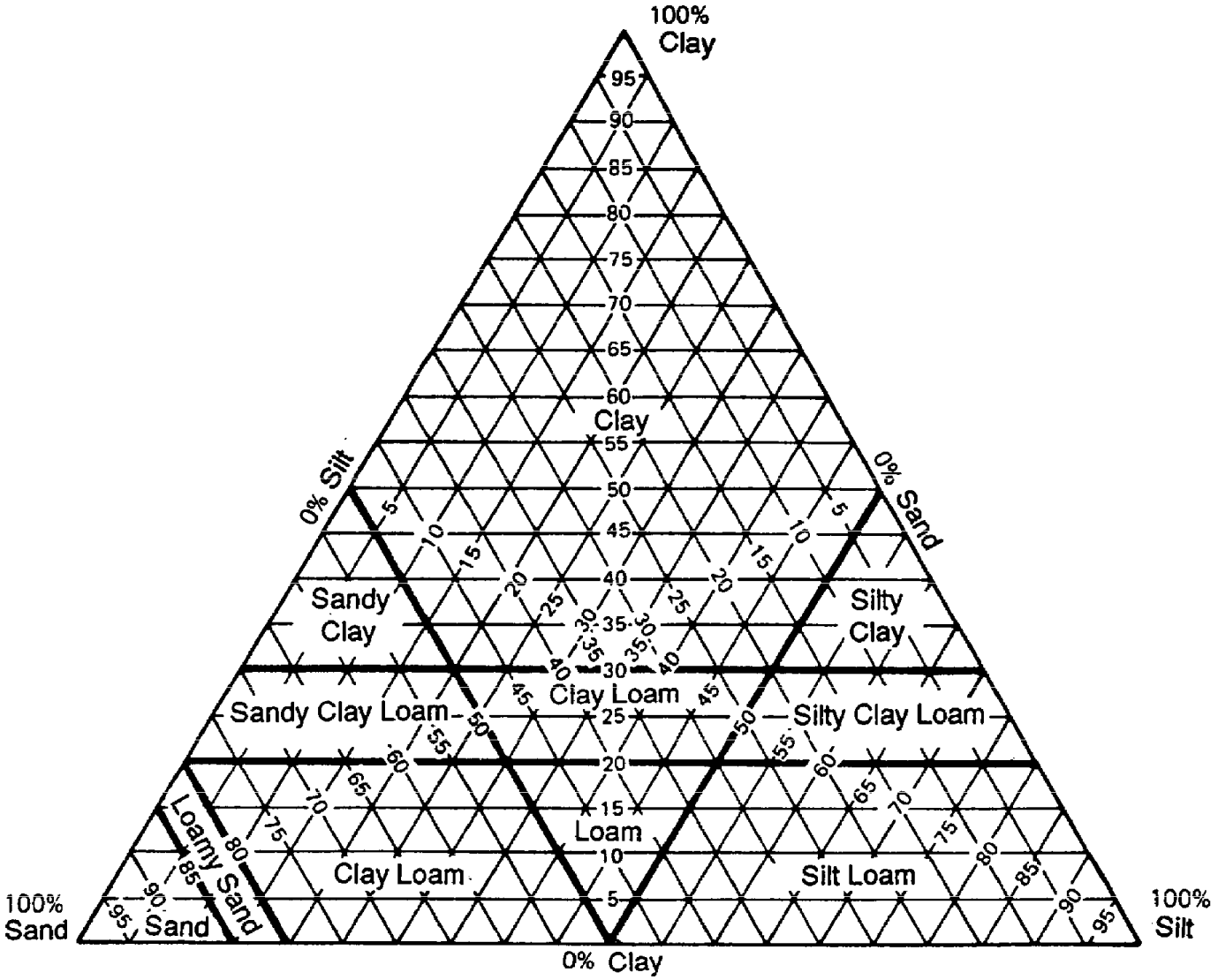


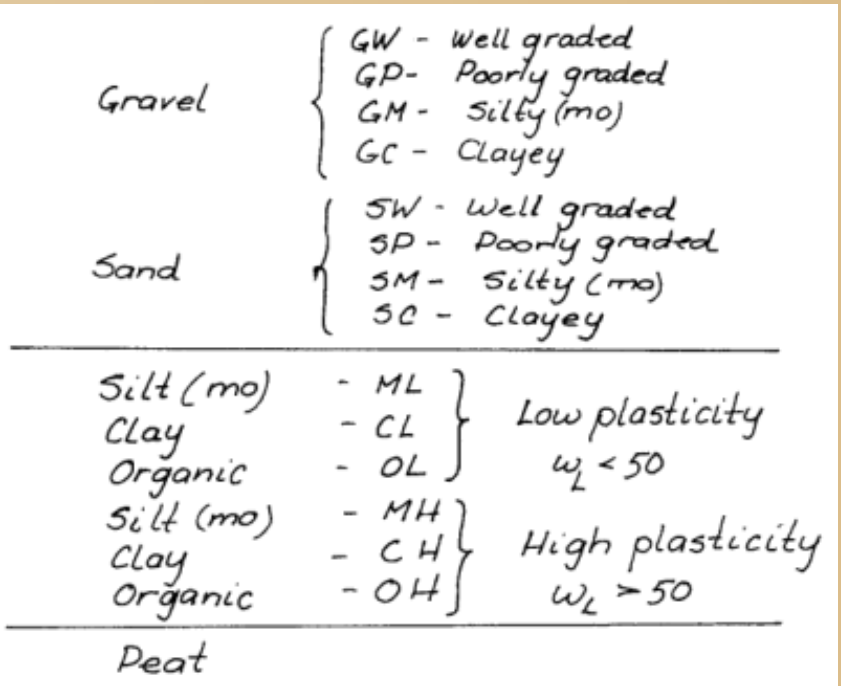
Figure 5-10. US Department of Agriculture textural classification chart.

Unified Classification System

- Primary Characteristics
  - G: gravels
  - S: sands
  - C: clays
  - M: silts
  - O: organic soils
  - Pt: peat

SM

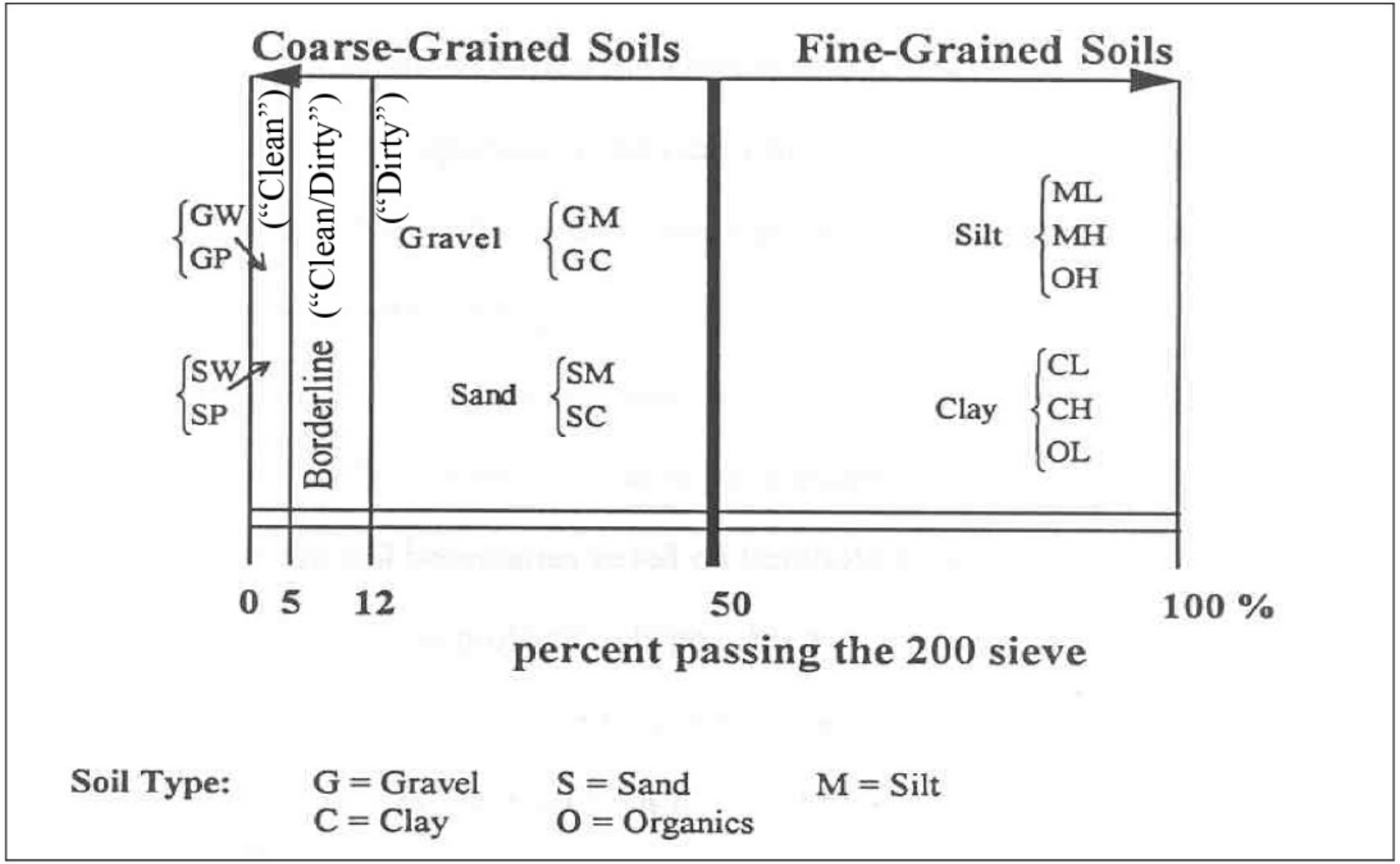
- Secondary Characteristics
  - W: well graded
  - P: poorly graded
  - M: silty (as opposed to a predominant silt in the left column)
  - C: clayey (as opposed to a predominant clay in the left column)
  - L: lean (LL < 50)
  - H: fat (LL > 50)



First Decision for Unified System: Coarse or Fine Grained?

Table 4-8

Basic USCS soil designations based on percent passing No. 200 sieve (0.075 mm) (after ASTM D 2487; Holtz and Kovacs, 1981)



Unified Method of Soil Classification

TABLE 3
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification			Group Symbol	Typical Names	Laboratory Classification Criteria	Supplementary Criteria For Visual Identification
Coarse-grained soils. (More than half of material finer than 3-inch sieve is larger than No. 200 sieve size.)	Gravel. (More than half of the coarse fraction is larger than No. 4 sieve size about 1/4 inch.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve size.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.*	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4. $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3.	Wide range in grain size and substantial amounts of all intermediate particle size.
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.*	Not meeting both criteria for GW.	Predominantly one size (uniformly graded) or a range of sizes with some intermediate sizes missing (gap graded).

* Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SC, etc.

Unified Method of Soil Classification

TABLE 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification			Group Symbol	Typical Names	Laboratory Classification Criteria		Supplementary Criteria For Visual Identification
.....do....	.....do....	Gravels with fines. (More than 12% of material smaller than No. 200 sieve size.)*	GM	Silty gravels, and gravel-sand-silt mixtures.	Atterberg limits below "A" line, or PI less than 4.	Atterberg limits above "A" line with PI between 4 & 7 is borderline case GM-GC	Nonplastic fines or fines of low plasticity.
			GC	Clayey gravels, and gravel-sand-clay mixtures.	Atterberg limits above "A" line, and PI greater than 7.		Plastic fines.
....do.....	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.*	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6. $C_z = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3.		Wide range in grain sizes and substantial amounts of all intermediate particle sizes.
			SP	Poorly graded sands and gravelly sands, little or no fines.*	Not meeting both criteria for SW.		Predominately one size (uniformly graded) or a range of sizes with some intermediate sizes missing (gap graded).

* Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SC, etc.

Unified Method of Soil Classification

TABLE 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification			Group Symbol	Typical Names	Laboratory Classification Criteria		Supplementary Criteria For Visual Identification
.....do....	.....do....	Sands with fines. (More than 12% of material smaller than No. 200 sieve size.)*	SM	Silty sands, sand-silt mixtures.	Atterberg limits below "A" line, or PI less than 4.	Atterberg limits above "A" line with PI between 4 and 7 is borderline case SM-SC.	Nonplastic fines or fines of low plasticity.
			SC	Clayey sands, sand-clay mixtures.	Atterberg limits above "A" line with PI greater than 7.		Plastic fines.

* Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SC, etc.

Unified Method of Soil Classification

TABLE 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification		Group Symbol	Typical Names	Laboratory Classification Criteria		Supplementary Criteria For Visual Identification		
						Dry Strength	Reaction to Shaking	Toughness Near Plastic Limit
Fine-grained soils. (More than half of material is smaller than No. 200 sieve size.) (Visual: more than half of particles are so fine that they cannot be seen by naked eye.)	Silts and clays. (Liquid limit less than 50.)	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands.	Atterberg limits below "A" line, or PI less than 4.	Atterberg limits above "A" line with PI between 4 and 7 is borderline case ML-CL.	None to slight	Quick to slow	None
	.....do.....	CL	Inorganic clays of low to medium plasticity; gravelly clays, silty clays, sandy clays, lean clays.	Atterberg limits above "A" line, with PI greater than 7.		Medium to high	None to very slow	Medium
	.....do.....	OL	Organic silts and organic silt-clays of low plasticity.	Atterberg limits below "A" line.		Slight to medium	Slow	Slight

Unified Method of Soil Classification

TABLE 3 (continued)
Unified Soil Classification System

Primary Divisions for Field and Laboratory Identification		Group Symbol	Typical Names	Laboratory Classification Criteria	Supplementary Criteria For Visual Identification		
					Dry Strength	Reaction to Shaking	Toughness Near Plastic Limit
.....do....	Silts and clays. (Liquid limit greater than 50.)	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts.	Atterberg limits below "A" line.	Slight to medium	Slow to none	Slight to medium
	.....do.....	CH	Inorganic clays of high plasticity, fat clays.	Atterberg limits above "A" line.	High to very high	None	High
	.....do.....	OH	Organic clays of medium to high plasticity.	Atterberg limit below "A" line	Medium to high	None to very slow	Slight to medium
.....do....	Highly organic soils.....	Pt	Peat, muck and other highly organic soils.	High ignition loss, LL and PI decrease after drying.	Organic color and odor, spongy feel, frequently fibrous texture.		

Plasticity Chart

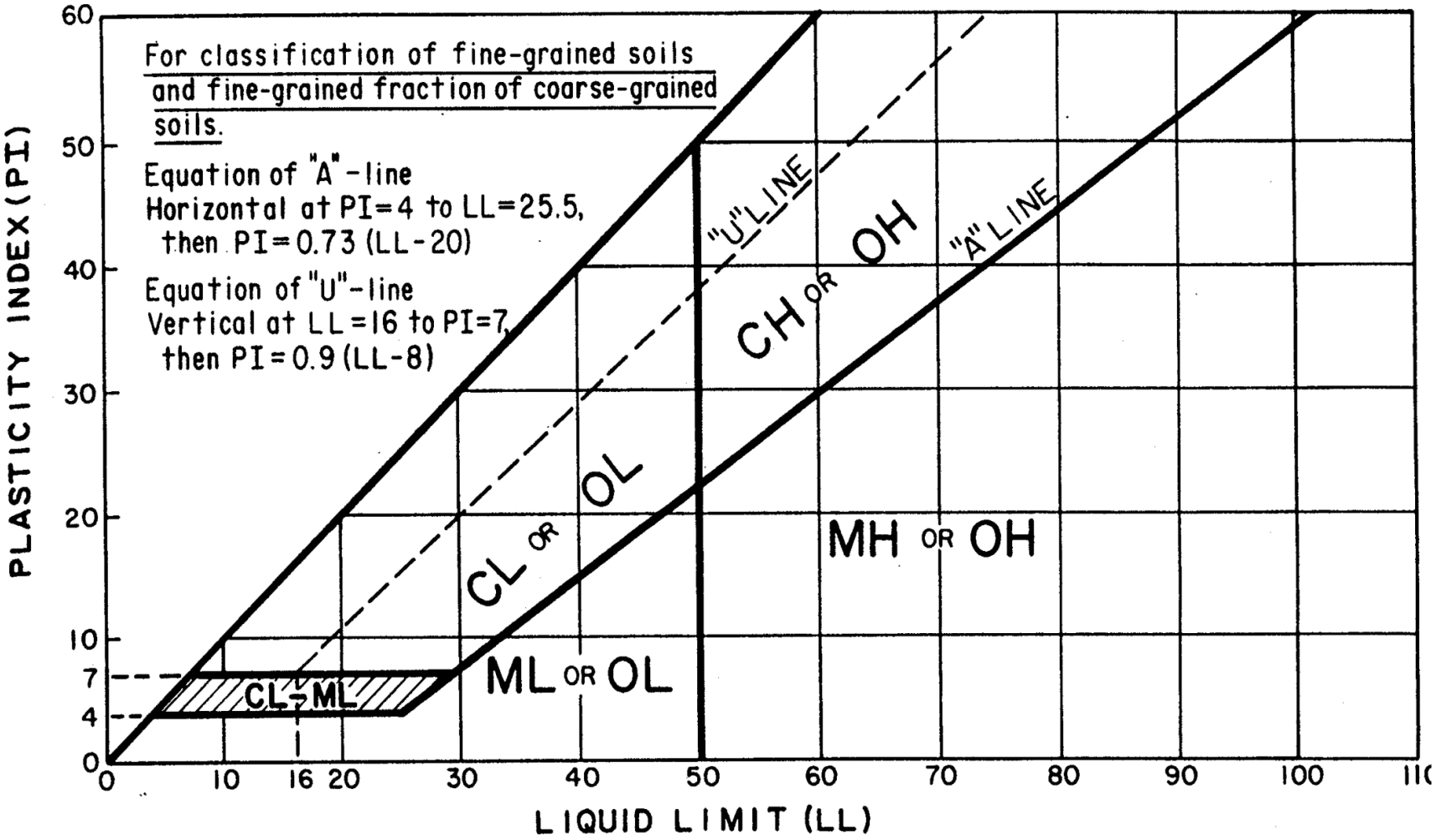
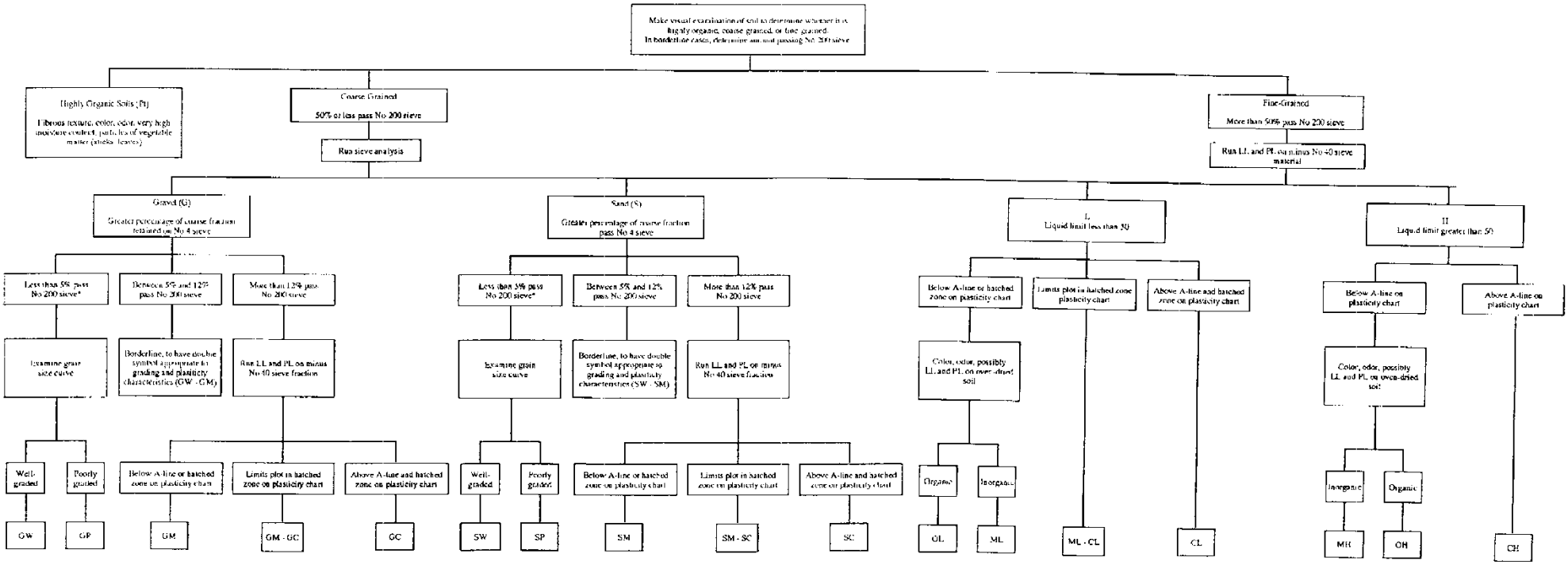


Figure 4-3. Plasticity chart for Unified Soil Classification System (ASTM D 2487).

Table 5-2. Auxiliary laboratory identification procedure.



Note: Sieve sizes are US Standard.
* If fines interfere with free draining properties, use a double symbol such as (GW - GM).

Gradation

4.2.1.1 Classification of Coarse-Grained Soils

Coarse-grained soils are defined as those in which 50 percent or more by weight are retained on the No. 200 sieve (0.075 mm). The flow chart to determine the group symbol and group name for coarse-grained soils is given in Figure 4-1. This figure is identical to Figure 3 in ASTM D 2487 except for the recommendation to capitalize the primary soil type; e.g., GRAVEL.

- **The shape of the grain-size distribution (GSD) curve or "gradation curve" as it is frequently called, is one of the more important aspects in a soil classification system for coarse-grained soils.** The shape of the gradation curve can be characterized by a pair of "shape" parameters called the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, to which numerical values may be assigned. By assigning numerical values to such shape parameters it becomes possible to compare grain-size distribution curves for different soils without having to plot them on the same diagram. In order to define shape parameters certain characteristic particle sizes must be identified that are common to all soils. Since the openings of a sieve are square, particles of many different shapes are able to pass through a sieve of given size even though the abscissa on the gradation curve is expressed in terms of particle "diameter," which implies a spherical-shaped particle. Therefore, the "diameter" shown on the gradation curve is an effective diameter so that the characteristic particle sizes that must be identified to define the shape parameters are in reality effective grain sizes (EGS).

  A useful EGS for the characterizing the shape of the gradation curve is the grain size for which 10 percent of the soil by weight is finer. This EGS is labeled D_{10}. This size is convenient because Hazen (1911) found that the ease with which water flows through a soil is a function of the D_{10}. In other words, Hazen found that the sizes smaller than the D_{10} affected the permeability more than the remaining 90 percent of the sizes. Therefore, the D_{10} is a logical choice as a characteristic particle size. Other convenient sizes were found to be the D_{30} and the D_{60}, which pertain to the grain size for which thirty and sixty percent, respectively, of the soil by weight is finer. These EGSs are used as follows in the Unified Soil Classification System (USCS) for the classification of coarse grained soils.

- **Slope of the gradation curve**: The shape of the curve could be defined relative to an arbitrary slope of a portion of the gradation curve. Since one EGS has already been identified as the D_{10}, the slope of the gradation curve could be described by identifying another convenient point (EGS) that is "higher" on the curve. Hazen selected this other convenient size as the D_{60} that indicates the particle size for which 60 percent of the soil by weight is finer. The slope between the D_{60} and the D_{10} can then be related to the degree of uniformity of the sample through a parameter called the "Coefficient of Uniformity" or the "Uniformity Coefficient," C_u, which is expressed as follows:

$$C_u = \frac{D_{60}}{D_{10}} \qquad 4\text{-}1$$

- **Curvature of the gradation curve**: The second "shape" parameter is used to evaluate the curvature of the gradation curve between the two arbitrary points, D_{60} and D_{10}. A third EGS, D_{30}, that indicates the particle size for which 30 percent of the soil by weight is finer, is chosen for this purpose. The curvature of the slope between the D_{60} and the D_{10} can then be related to the three EGS' through a parameter called the "Coefficient of Curvature" or the "Coefficient of Concavity" or the "Coefficient of Gradation," C_c, which is expressed as follows:

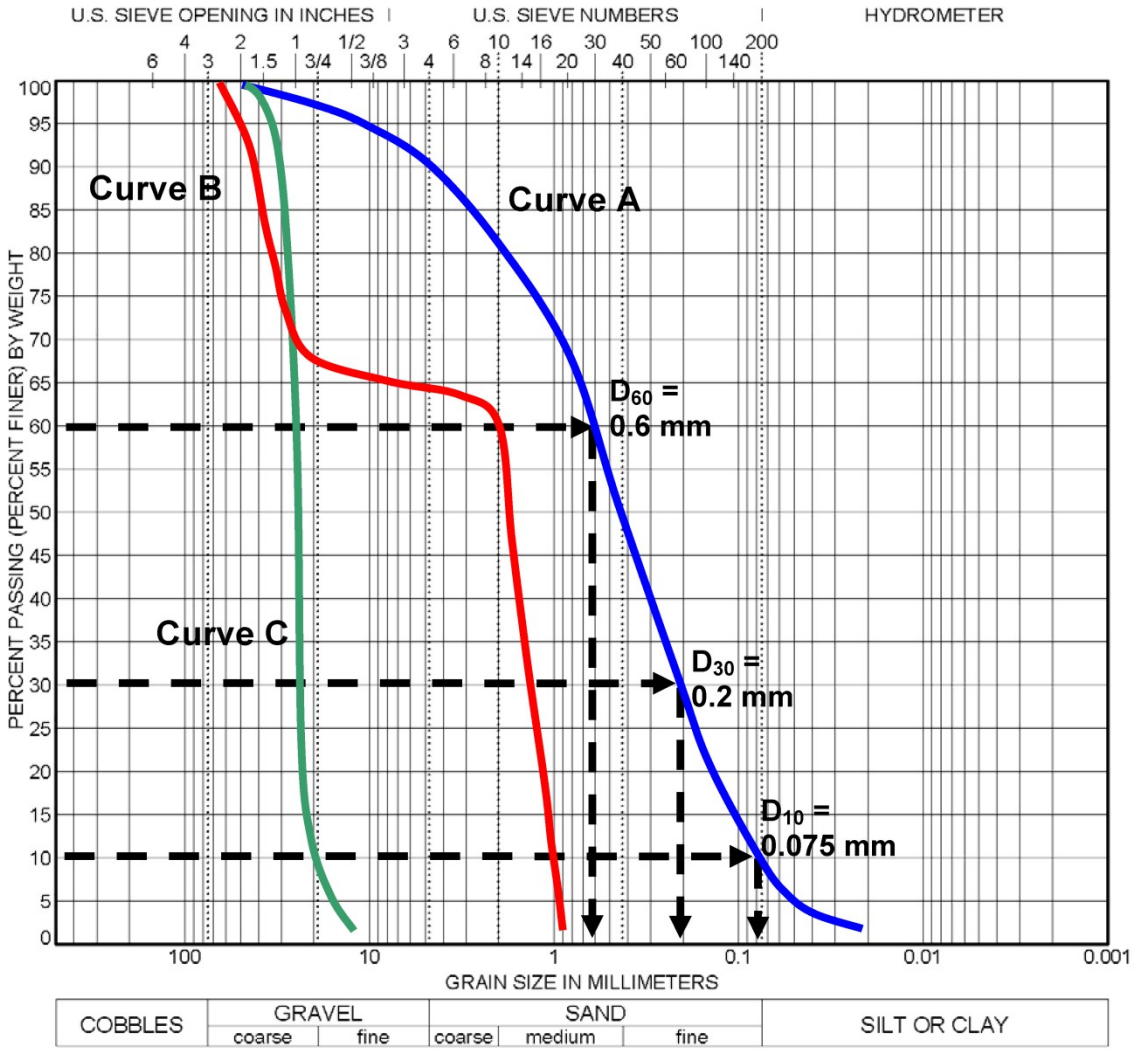
$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \qquad 4\text{-}2$$

By use of the two "shape" parameters, C_u and C_c, the uniformity of the coarse-grained soil (gravel and sand) can now be classified as well-graded (non-uniform), poorly graded (uniform), or gap graded (uniform or non-uniform). Table 4-10 presents criteria for such classifications.

Table 4-10
Gradation based on C_u and C_c parameters

Gradation	Gravels	Sands
Well-graded	$C_u \geq 4$ and $1 < C_c < 3$	$C_u \geq 6$ and $1 < C_c < 3$
Poorly graded	$C_u < 4$ and $1 < C_c < 3$	$C_u < 6$ and $1 < C_c < 3$
Gap graded*	C_c not between 1 and 3	C_c not between 1 and 3
*Gap-graded soils may be well-graded or poorly graded. In addition to the C_c value it is recommended that the shape of the GSD be the basis for definition of gap-graded.		

Example of Gradation



Curve	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	C_u	C_c	Gradation
A	0.075	0.2	0.6	8.0	0.9	Well graded (1)
B	1	1.5	2	2.0	1.12	Poorly graded - Gap graded (2)
C	19	25	27	1.4	1.2	Poorly graded

(1) Soil does not meet C_u and C_c criteria for well-graded soil but GSD curve clearly indicates a well-graded soil

(2) The C_u and C_c parameters indicate a uniform (or poorly) graded material, but the GSD curve clearly indicates a gap-graded soil.

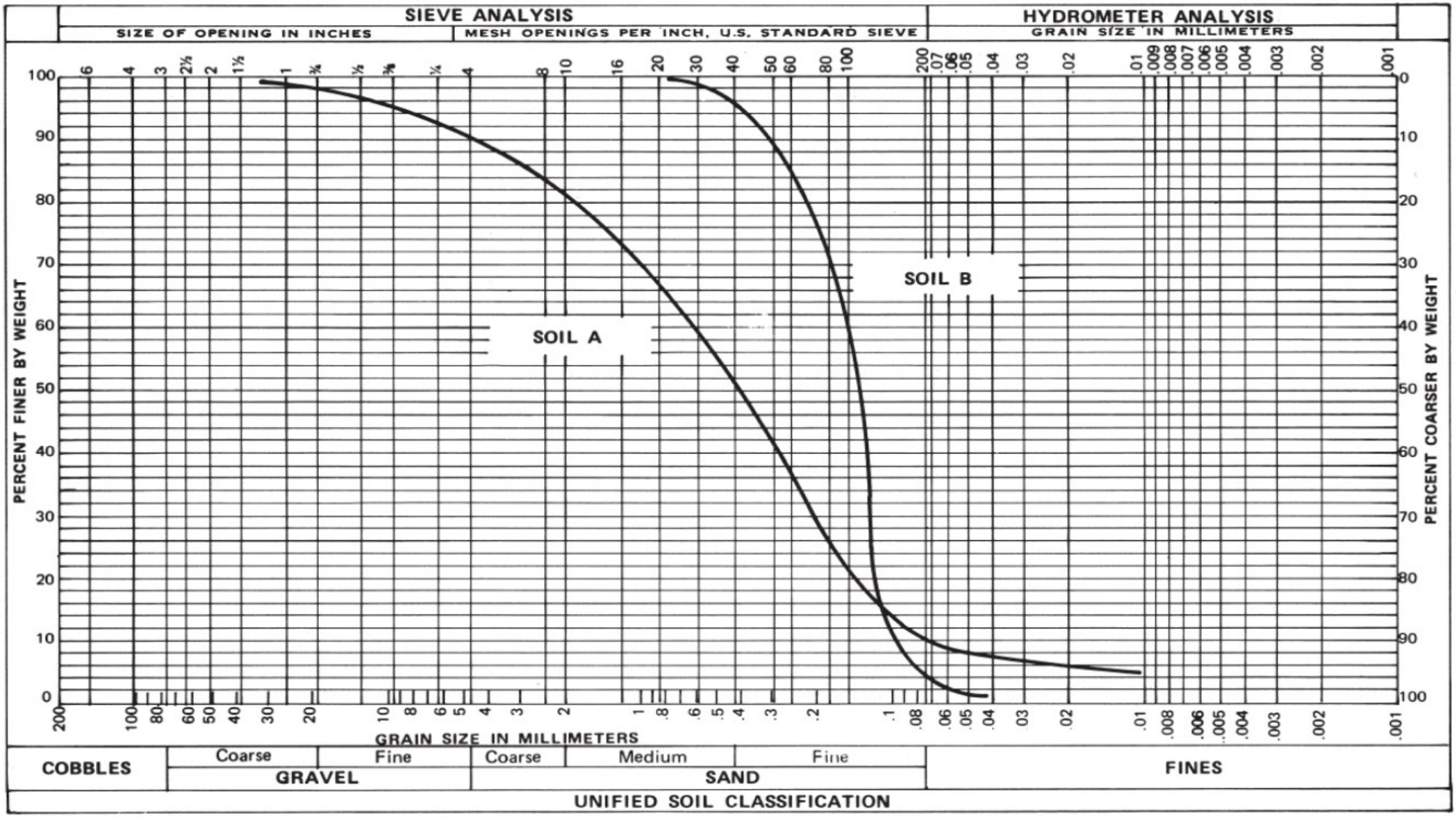
Note: For clarity only the D_{10}, D_{30}, and D_{60} sizes for Curve A are shown on the figure.

Figure 4-2. Evaluation of type of gradation for coarse-grained soils.

Unified Classification Example

- Given
  - Results of Sieve Test
    - Uniformity Coefficient $C_u = 8.1$
    - Curvature Coefficient $C_c = 0.9$
    - Percentage Passing #200 Sieve = 10%
    - Percentage Passing #4 sieve = 89%
  - Result of Atterberg Limit Tests (for portion passing #40 sieve)
    - Liquid Limit LL = 63
    - Plastic Limit PL = 42
    - Plasticity Index = LL-PL=21
- Find
  - Unified Soil Classification

Unified Classification Example (Soil A)



Unified Classification Example

- Question 1:
  - What is the percentage of the material passing the #200 (0.074 mm opening) sieve?
- Answer:
  - 10%. Since this is < 50%, the soil is a cohesionless (coarse grained) soil
- Remaining: “G” or “S” classification soils

- Question 2:
  - What is the percentage of the coarse fraction which is gravel?
- Answer:
  - 11% of this sample is retained on the #4 sieve
  - This represents 11/(100-10) = 12.2% of coarse fraction
  - Since this is < 50%, this eliminates all of the “G” classification soils
- Remaining: “S” classification soils

Unified Classification Example

- Question 3:
  - How “clean” are the sands?
- Answer:
  - “Clean” sands or gravels have less than 5% of the material passing the #200 sieve
  - Sands (or gravels) “with fines” have more than 12% of material passing the #200 sieve
  - Since 5% < 10% < 12%, no classifications are elimiated
- Remaining: “S” classification soils

- Question 4:
  - How is the soil graded?
- Answer:
  - Uniformity Coefficient C_u = 8.1, Curvature Coefficient C_c = 0.9.
  - For SW, $C_u > 6$ *and* $1 < C_c < 3$, so this is eliminated
- Remaining: SP, SM and SC

Unified Classification Example

- Question 5:
  - What are the Atterberg Limits?
- Answer:
  - Liquid Limit LL = 63, Plastic Limit PL = 42, Plasticity Index = LL-PL=21
  - A-Line Analysis: PI = 0.73(LL -20) = 31.39 > 21, so below the “A” Line
  - “A” Line analysis eliminates SC classification
- Remaining: SP and SM

- Final Classification
  - Atterberg Limit is below the “A” line, so SM is possible
  - C_u and C_c do not meet the classification for SW, so SP is possible
  - Soil in question is subject to a dual classification, or SM-SP

AASHTO System

Table 4-13

AASHTO soil classification system based on AASHTO M 145 (or ASTM D 3282)

GENERAL CLASSIFICATION	GRANULAR MATERIALS (35 percent or less of total sample passing No. 200 sieve (0.075 mm)							SILT-CLAY MATERIALS (More than 35 percent of total sample 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
Sieve analysis, percent passing:											
No. 10 (2 mm)	50 max.										
No. 40 (0.425 mm)	30 max.	50 max.	51 min.								
No. 200 (0.075 mm)	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 No 40 (0.425 mm)											
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 significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
Group Index**	0		0	0		4 max.		8 max.	12 max.	16 max.	20 max.

Classification procedure:

With required test data available, proceed from left to right on chart; correct group will be found by process of elimination. The first group from left into which the test data will fit is the correct classification.

*Plasticity 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 (see Fig 4-5).

**See group index formula (Eq. 4-3). Group index should be shown in parentheses after group symbol as: A-2-6(3), A-4(5), A-7-5(17), etc.

Notes on AASHTO System

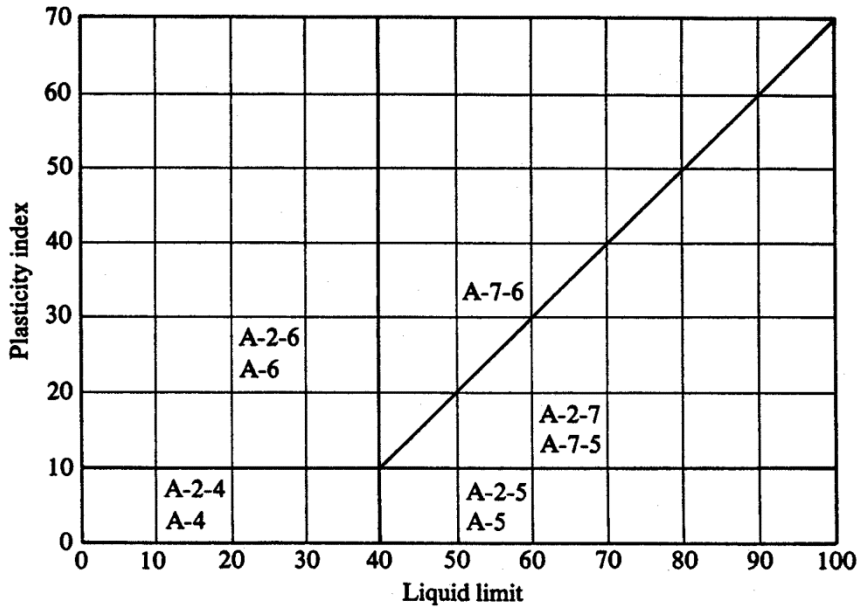


Figure 4-5. Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6 and A-7 per AASHTO M 145 (or ASTM D 3282).

The first term of Equation 4-3 is the partial group index determined from the liquid limit. The second term is the partial group index determined from the plasticity index. Following are some rules for determining group index:

- If Equation 4-3 yields a negative value for GI, it is taken as zero.
- The group index calculated from Equation 4-3 is rounded off to the nearest whole number, e.g., GI=3.4 is rounded off to 3; GI=3.5 is rounded off to 4.
- There is no upper limit for the group index.
- The group index of soils belonging to groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3 will always be zero.
- When the group index for soils belonging to groups A-2-6 and A-2-7 is calculated, the partial group index for PI should be used, or

$$GI=0.01(F-15)\,(PI-10) \qquad 4\text{-}4$$

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

AASHTO System

♦ **AASHTO SOIL CLASSIFICATION**

GENERAL CLASSIFICATION	GRANULAR MATERIALS (35% OR LESS PASSING 0.075 SIEVE)							SILT-CLAY MATERIALS (MORE THAN 35% PASSING 0.075 SIEVE)			
GROUP CLASSIFICATION	A–1		A–3	A–2				A–4	A–5	A–6	A–7–5 A–7–6
	A–1–a	A–1–b		A-2-4	A-2-5	A-2-6	A-2-7				
SIEVE ANALYSIS, PERCENT PASSING:											
2.00 mm (No. 10)	≤ 50	–	–	–	–	–	–	–	–	–	–
0.425 mm (No. 40)	≤ 30	≤ 50	≥ 51	–	–	–	–	–	–	–	–
0.075 mm (No. 200)	≤ 15	≤ 25	≤ 10	≤ 35	≤ 35	≤ 35	≤ 35	≥ 36	≥ 36	≥ 36	≥ 36
CHARACTERISTICS OF FRACTION PASSING 0.425 SIEVE (No. 40):											
LIQUID LIMIT	–		–	≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41
PLASTICITY INDEX *	6 max		NP	≤ 10	≤ 10	≥ 11	≥ 11	≤ 10	≤ 10	≥ 11	≥ 11
USUAL TYPES OF CONSTITUENT MATERIALS	STONE FRAGM'TS, GRAVEL, SAND		FINE SAND	SILTY OR CLAYEY GRAVEL AND SAND				SILTY SOILS		CLAYEY SOILS	
GENERAL RATING AS A SUBGRADE	EXCELLENT TO GOOD							FAIR TO POOR			

*Plasticity index of A-7-5 subgroup is equal to or less than LL-30. Plasticity index of A-7-6 subgroup is greater than LL-30.
NP = Non-plastic (use "0"). Symbol "–" means that the particular sieve analysis is not considered for that classification.

If the soil classification is A4-A7, then calculate the group index (GI) as shown below and report with classification. The higher the GI, the less suitable the soil. Example: A-6 with GI = 15 is less suitable than A-6 with GI = 10.

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10)$$

where: F = Percent passing No. 200 sieve, expressed as a whole number. This percentage is based only on the material passing the No. 200 sieve.
LL = Liquid limit
PI = Plasticity index

If the computed value of GI < 0, then use GI = 0.

AASHTO System (ODOT)

CLASSIFICATION OF SOILS

Ohio Department of Transportation

(The classification of a soil is found by proceeding from top to bottom of the chart. The first classification that the test data fits is the correct classification.)

SYMBOL	DESCRIPTION	Classifcation AASHTO	Classifcation OHIO	$LL_0/LL \times 100$*	% Pass #40	% Pass #200	Liquid Limit (LL)	Plastic Index (PI)	Group Index Max.	REMARKS
	Gravel and/or Stone Fragments	A-1-a			30 Max.	15 Max.		6 Max.	0	Min. of 50% combined gravel, cobble and boulder sizes
	Gravel and/or Stone Fragments with Sand	A-1-b			50 Max.	25 Max.		6 Max.	0	
	Fine Sand	A-3			51 Min.	10 Max.	NON-PLASTIC		0	
	Coarse and Fine Sand	--	A-3a			35 Max.		6 Max.	0	Min. of 50% combined coarse and fine sand sizes
	Gravel and/or Stone Fragments with Sand and Silt	A-2-4				35 Max.	40 Max.	10 Max.	0	
		A-2-5					41 Min.			
	Gravel and/or Stone Fragments with Sand, Silt and Clay	A-2-6				35 Max.	40 Max.	11 Min.	4	
		A-2-7					41 Min.			
	Sandy Silt	A-4	A-4a	76 Min.		36 Min.	40 Max.	10 Max.	8	Less than 50% silt sizes
	Silt	A-4	A-4b	76 Min.		50 Min.	40 Max.	10 Max.	8	50% or more silt sizes
	Elastic Silt and Clay	A-5		76 Min.		36 Min.	41 Min.	10 Max.	12	
	Silt and Clay	A-6	A-6a	76 Min.		36 Min.	40 Max.	11 - 15	10	
	Silty Clay	A-6	A-6b	76 Min.		36 Min.	40 Max.	16 Min.	16	
	Elastic Clay	A-7-5		76 Min.		36 Min.	41 Min.	≤LL-30	20	
	Clay	A-7-6		76 Min.		36 Min.	41 Min.	>LL-30	20	
	Organic Silt	A-8	A-8a	75 Max.		36 Min.				W/o organics would classify as A-4a or A-4b
	Organic Clay	A-8	A-8b	75 Max.		36 Min.				W/o organics would classify as A-5, A-6a, A-6b, A-7-5 or A-7-6

MATERIAL CLASSIFIED BY VISUAL INSPECTION

Sod and Topsoil

Pavement or Base

Uncontrolled Fill (Describe)

Bouldery Zone

Peat, S-Sedimentary W-Woody F-Fibrous L-Loamy & etc

* Only perform the oven-dried liquid limit test and this calculation if organic material is present in the sample.

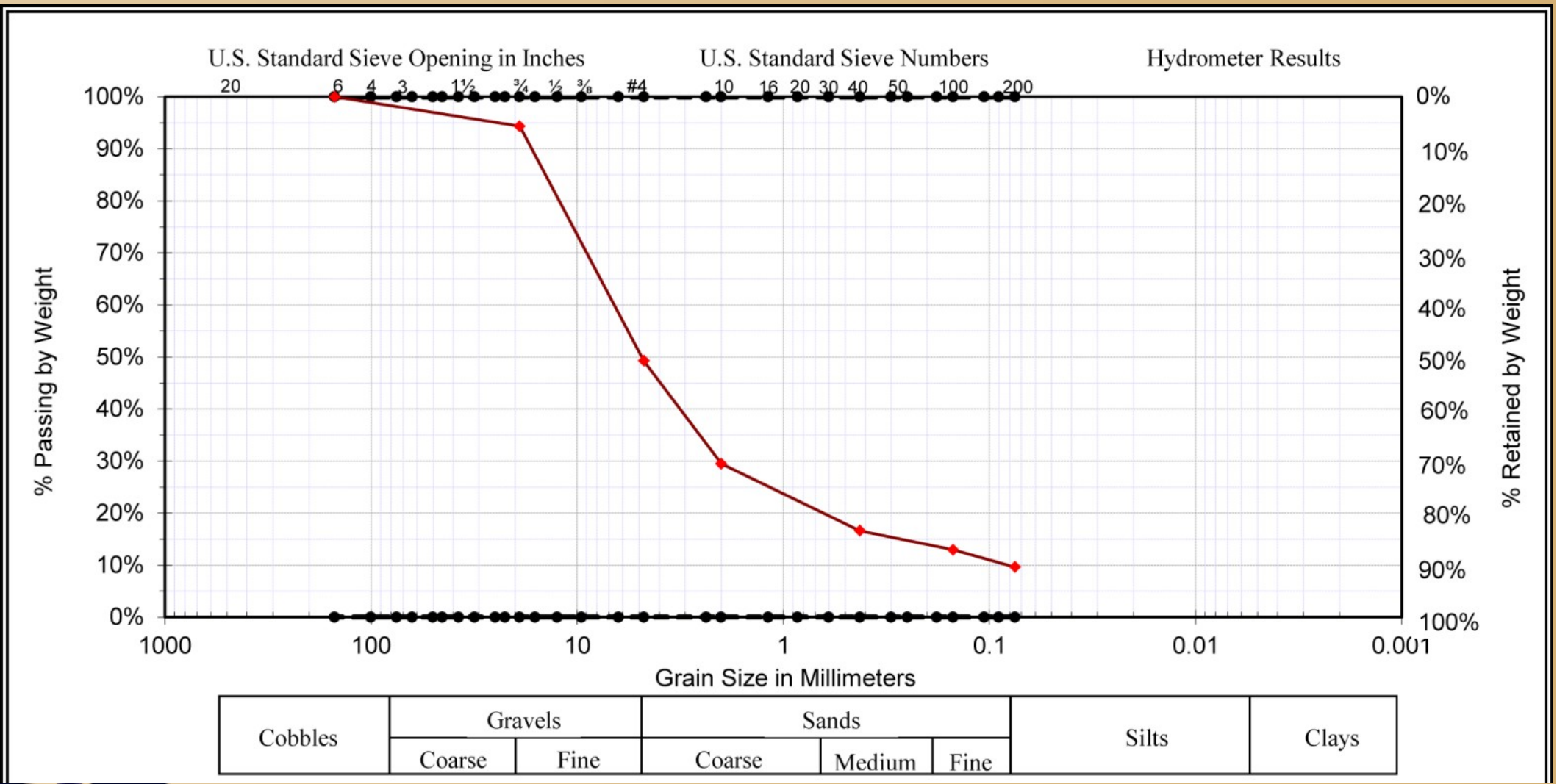
AASHTO Classification Example

- Given (same soil as before)
  - Results of Sieve Test
    - Uniformity Coefficient C_u = 8.1
    - Curvature Coefficient C_c = 0.9
    - Percentage Passing #10 Sieve: 82%
    - Percentage Passing #40 Sieve: 51%
    - Percentage Passing #200 Sieve = 10%
  - Result of Atterberg Limit Tests (for portion passing #40 sieve)
    - Liquid Limit LL = 63
    - Plastic Limit PL = 42
    - Plasticity Index = LL-PL=21
- Find
  - AASHTO Soil Classification

AASHTO Classification Example

- Examine Sieve Passing Points
  - #10: is greater than 50%, so move past A-1-a
  - #40: is greater than 50%, so eliminate A-1, but A-2 possible
  - #200: is equal to 10%, so A-3 is possible (but take a look at the curve more carefully, result may be more precise than accurate)
  - #200: is less than 35%, so A-2 is possible
- Examine Liquid Limit and Plasticity Index
  - LL > 40, so eliminate A-2-4 and A-2-6
  - PI > 10, so eliminate A-2-5
  - This leaves A-2-7, which meets all three criteria (#200 sieve, LL and PI)
- Because this is an A-2-7, we must use partial group index
  - PGI = PGI = $0.01(F_{200} - 15)$ (PI – 10) = (0.01(10-15)(21-10) < 0, so PGI = 0
- Classification is A-2-7(0)

Unified and AASHTO Example



Differences between Unified and AASHTO Classification Systems

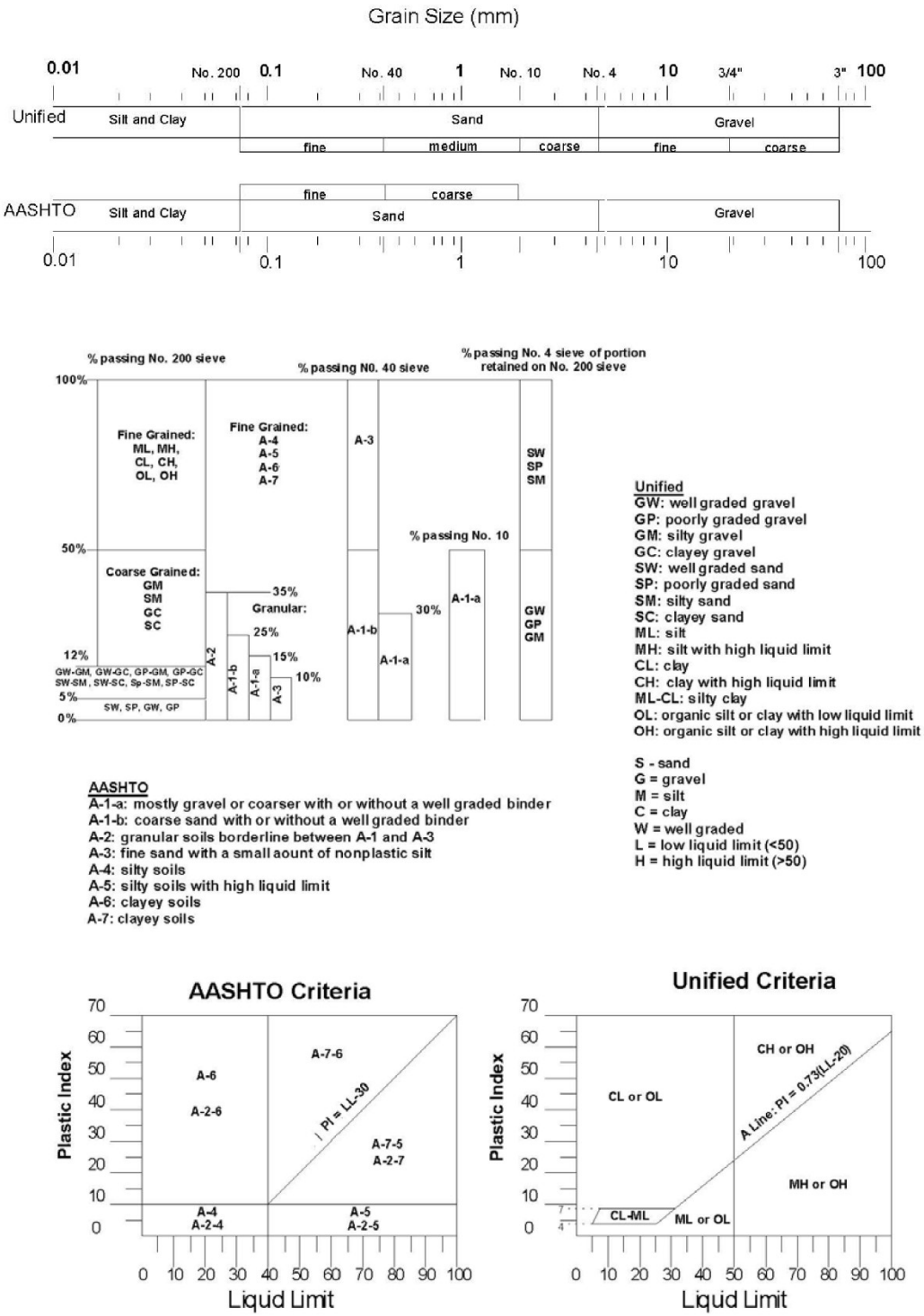


Figure 4-6. Comparison of the USCS with the AASHTO soil classification system (after Utah DOT – Pavement Design and Management Manual, 2005).

Questions?