CE 353 **Geotechnical Engineering**

Dr M. Touahmia

5

Classification of Soil

Lecture Outline:

1. Classification Systems
2. American Association of State Highway and Transportation Officials System (AASHTO)
3. The Unified Soil Classification System (USCS)

Textbook: *Braja M. Das, "Principles of Geotechnical Engineering", 7th E.* ***(Chapter 5).***

Classification Systems

- Soils in nature rarely exist separately as gravel, sand, silt, clay or organic matter, but are usually found as mixtures with varying proportions of these components.
- 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*.
- Two commonly used systems for Classifying soils based on ***particle distribution*** and ***Atterberg limits***:

1. ***AASHTO System***: American Association of State Highway and Transportation Officials.
2. ***USCS***: Unified Soil Classification System.

AASHTO Soil Classification System

Origin:

- ***AASHTO*** system of soil classification was developed by Hogentogler and Terzaghi 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 system is based on the following three soil properties:

1. Particle-size distribution (AASHTO T-11 and AASHTO T-27 test)
2. Liquid Limit (AASHTO T-89 test).
3. Plasticity Index (AASHTO T-90 test).

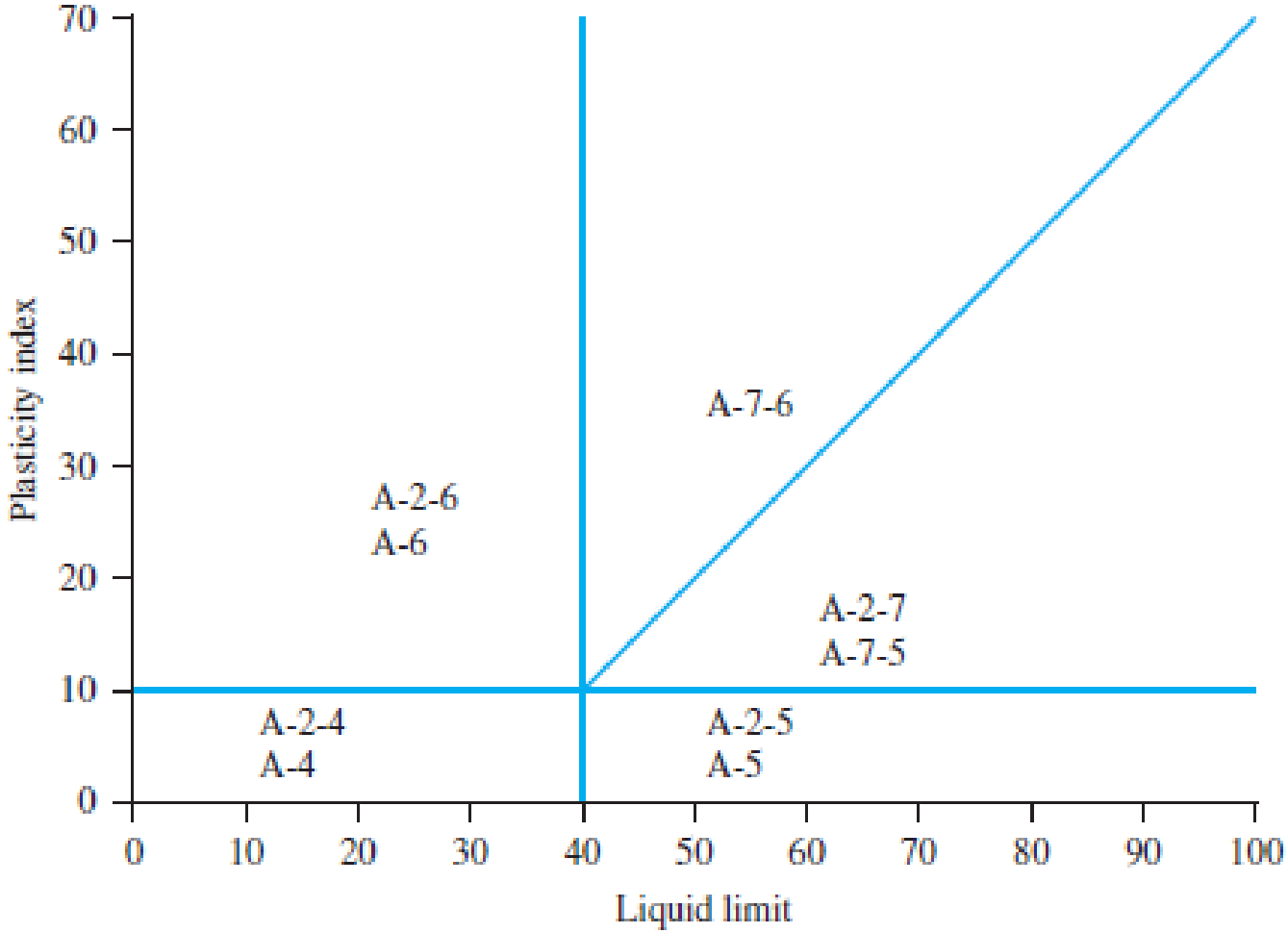
AASHTO Soil Classification System

- **Key Elements:**

1. **Grain Size:**
   - ***Gravel***: Fraction passing 75mm sieve and retained on #10 (2mm) US sieve
   - ***Sand***: Fraction passing #10 sieve and retained #200 sieve
   - ***Silt*** and ***Clay***: Fraction passing #200 sieve
2. **Plasticity:**
   - Term ***silty*** is applied when fine fractions have a $PI < 10$
   - Term ***clayey*** is applied when fine fractions have $PI > 11$
3. **Groups:** (see Tables)
   - Soils are classified into eight groups, **A-1** through **A-8**.
   - The major groups **A-1**, **A-2**, and **A-3** represent the coarse grained soils.
   - The **A-4**, **A-5**, **A-6**, and **A-7** represent fine grained soils.
   - The **A-8** are identified by visual inspection.

AASHTO Soil Classification System

- The ranges of the *LL* and *PI* for groups **A-2** , **A-4**, **A-5** , **A-6** and **A-7**:



AASHTO Soil Classification System

- **Group Index (GI):**
- To evaluate the quality of a soil as a highway subgrade material, one must 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:

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

The first term is determined by the LL

The second term is determined by the PI

where:

F_{200}: % passing #200 sieves expressed as whole number

LL: liquid limit of soil

PI: Plasticity Index of soil

AASHTO Soil Classification System

It may be noted that:

- The higher the value of GI the weaker will be the soil and vice versa. Thus, quality of performance of a soil as a subgrade material is inversely proportional to GI.
- A soil having GI of zero is considered as the best.
- If the equation gives negative value for GI, consider it zero.
- Always round off the GI to nearest whole number.
- $GI = 0$ for soils of groups A-1-a, A-1-b, A-2-4, A-2-5, and A-3.
- For groups A-2-6 and A-2-7 use partial GI for PI only:

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

AASHTO Soil Classification System

- 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						

AASHTO Soil Classification System

- 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			

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

AASHTO Soil Classification System

DESCRIPTION OF GROUPS & SUBGROUPS:

- **Group A-1:** The typical material of this group is a well-graded mixture of stone fragments or gravels, coarse sand, fine sand, and a non-plastic or slightly plastic soil binder. This group also includes stone fragments, gravels, coarse sand, volcanic cinders etc, without a well-graded binder of fine material.
- Subgroup A-1-a**:** includes those materials consisting predominantly of stone fragments or gravel, either with or without a well-graded binder of fine material.
- Subgroup A-1-b: includes those materials consisting predominantly of coarse sand with or without a well-graded soil binder.

AASHTO Soil Classification System

DESCRIPTION OF GROUPS & SUBGROUPS:

- **Group A-3:** The typical material of this group is fine beach sand or fine desert blown sand without silty or clayey fines or with a small amount of non-plastic silt. This group includes also stream-deposited mixtures of poorly graded fine sand and limited amounts of coarse sand and gravel.
- **Group A-2:** This group includes a wide variety of “granular” materials, which are at the borderline between the materials falling in groups A-1 and A-3 and the silty-clay materials of group A-4 through A-7. It include any materials not more than 35% of which passes a #200 sieve and which cannot be classified as A-1 or A-3 because of having fines content or plasticity, or both, in excess of the limitations for those groups.

AASHTO Soil Classification System

DESCRIPTION OF GROUPS & SUBGROUPS:

- **Group A-4:** The typical material of this group is a non-plastic or moderately plastic silty soil 75% or more of which usually passes the #200 sieve. The group also includes mixture of fine silty soil and up to 64% of sand and gravel retained on the #200 sieve.
- **Group A-5**:The typical material of this group is similar to that described under Group A-4, but it may be highly elastic, as indicated by high liquid limit.
- **GroupA-6:** The typical material of this group is a plastic clay soil 75% or more of which usually passes the #200 sieve. The group also includes mixtures of fine clayey soil and up to 64% of sand and gravel retained on the #200 sieve. Materials of this group usually have high volume change between wet and dry states.

AASHTO Soil Classification System

DESCRIPTION OF GROUPS & SUBGROUPS:

- **Group A-7:** The typical material of this group is similar to that described under Group A-6, but it has the high liquid limits characteristics of the A-5 group and may be elastic as well as subject to high volume change.
- Subgroup **A-7-5:** includes those materials which have moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change.
- Subgroup **A-7-6:** includes those materials which have high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change.
- **Group A-8**: The typical material of this group is peat and muck soil ordinarily found in obviously unstable, swampy areas. Characterized by:

  - low density - high compressibility - high water content and - high organic matter content.

Unified Soil Classification System, USCS

- Origin: The Unified Soil Classification system was first developed by Professor A. Casagrande in 1942 for the purpose of airfield construction during world War II. Afterwards, it was expended and revised in cooperation with the U.S. Bureau of Reclamation and the U.S. Army Corps of Engineers so that it applies not only to airfields but also to embankments, dams, foundations, and other engineering features. In 1969 the American Society for Testing and Materials (ASTM) adopted the USCS as a standard method for classification for engineering purposes (ASTM Test Designation D-2487).

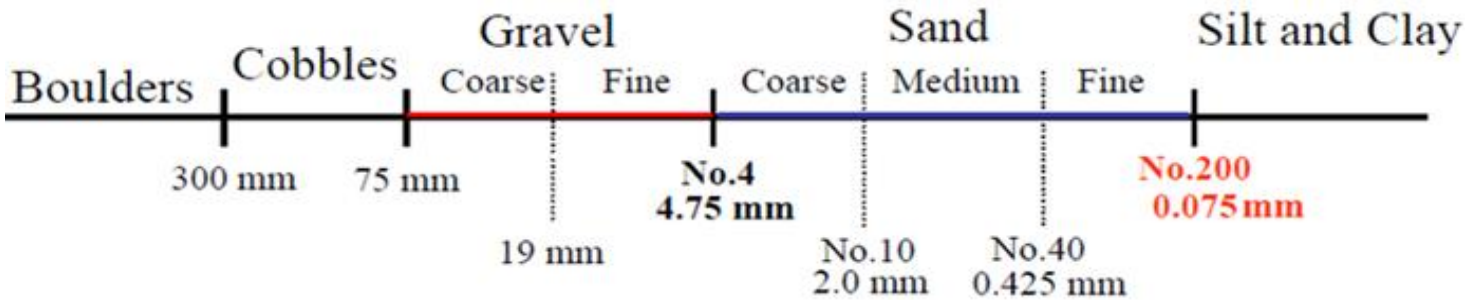
- The USCS is based on the recognition of the type and predominance of the constituents considering grain-size, gradation, plasticity and compressibility. It classifies soils into Four major categories:

  1. **Coarse-grained**
  2. **Fine-grained**
  3. **Organic soils**
  4. **Peat**

Unified Soil Classification System, USCS

Procedures for Classification:

- From sieve analysis and the grain-size distribution curve determine the percent passing as the following:



- First, Find % passing # 200.
- If 5% or more of the soil passes the # 200 sieve, then conduct Atterberg Limits (LL & PL).
- If the soil is fine-grained (≥50% passes #200) follow the guidelines for fine-grained soils.
- If the soil is coarse-grained (<50% passes #200) follow the guidelines for coarse-grained soils: Find % Gravel & Sand, calculate C_u & C_c, LL, PL &PI

Unified Soil Classification System, USCS

SYMBOLS

Soil symbols:

- G: Gravel
- S: Sand
- M: Silt
- C: Clay
- O: Organic
- Pt: Peat

Liquid limit symbols:

- H: High LL (LL>50)
- L: Low LL (LL<50)

Gradation symbols:

- W: Well-graded
- P: Poorly-graded

Well – graded soil

$1 < C_c < 3$ and $C_u \geq 4$ (for gravels)

$1 < C_c < 3$ and $C_u \geq 6$ (for sands)

GROUP SYMBOLS

- The group symbols for coarse-grained gravelly soils are: GW, GP, GM, GC, GC-GM, GW-GM, GW-GC, GP-GM, and GP-GC.
- The group symbols for fine-grained soils are: CL, ML, OL, CH, MH, OH, CL-ML, and Pt.

Example:

SW, Well-graded sand

SC, Clayey sand

SM, Silty sand,

MH, Elastic silt

Unified Soil Classification System, USCS

Classification and Symbols

COARSE-GRAINED SOILS
(more than 50% of material is larger than No. 200 sieve size.)

GRAVELS More than 50% of coarse fraction larger than No. 4 sieve size	Clean Gravels (Less than 5% fines)	
	GW	Well-graded gravels, gravel-sand mixtures, little or no fines
	GP	Poorly-graded gravels, gravel-sand mixtures, little or no fines
	Gravels with fines (More than 12% fines)	
	GM	Silty gravels, gravel-sand-silt mixtures
	GC	Clayey gravels, gravel-sand-clay mixtures
SANDS 50% or more of coarse fraction smaller than No. 4 sieve size	Clean Sands (Less than 5% fines)	
	SW	Well-graded sands, gravelly sands, little or no fines
	SP	Poorly graded sands, gravelly sands, little or no fines
	Sands with fines (More than 12% fines)	
	SM	Silty sands, sand-silt mixtures
	SC	Clayey sands, sand-clay mixtures

FINE-GRAINED SOILS
(50% or more of material is smaller than No. 200 sieve size.)

SILTS AND CLAYS Liquid limit less than 50%	ML	Inorganic silts and very fine sands, rock flour, silty of clayey fine sands or clayey silts with slight plasticity
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	OL	Organic silts and organic silty clays of low plasticity
SILTS AND CLAYS Liquid limit 50% or greater	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	CH	Inorganic clays of high plasticity, fat clays
	OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS	PT	Peat and other highly organic soils

Unified Soil Classification System, USCS

Laboratory Classification Criteria

GW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
GP	Not meeting all gradation requirements for GW	
GM	Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are borderline cases requiring use of dual symbols
GC	Atterberg limits above "A" line with P.I. greater than 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4; $C_c = \frac{D_{30}}{D_{10} \times D_{60}}$ between 1 and 3	
SP	Not meeting all gradation requirements for GW	
SM	Atterberg limits below "A" line or P.I. less than 4	Limits plotting in shaded zone with P.I. between 4 and 7 are borderline cases requiring use of dual symbols.
SC	Atterberg limits above "A" line with P.I. greater than 7	

Determine percentages of sand and gravel from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size), coarse-grained soils are classified as follows:

Less than 5 percent ..... GW, GP, SW, SP
More than 12 percent ..... GM, GC, SM, SC
5 to 12 percent ..... Borderline cases requiring dual symbols

Unified Soil Classification System, USCS

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 5.3)	GM
			$PI > 7$ and plots on or above "A" line (Figure 5.3)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands 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 5.3)	SM
			$PI > 7$ 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.

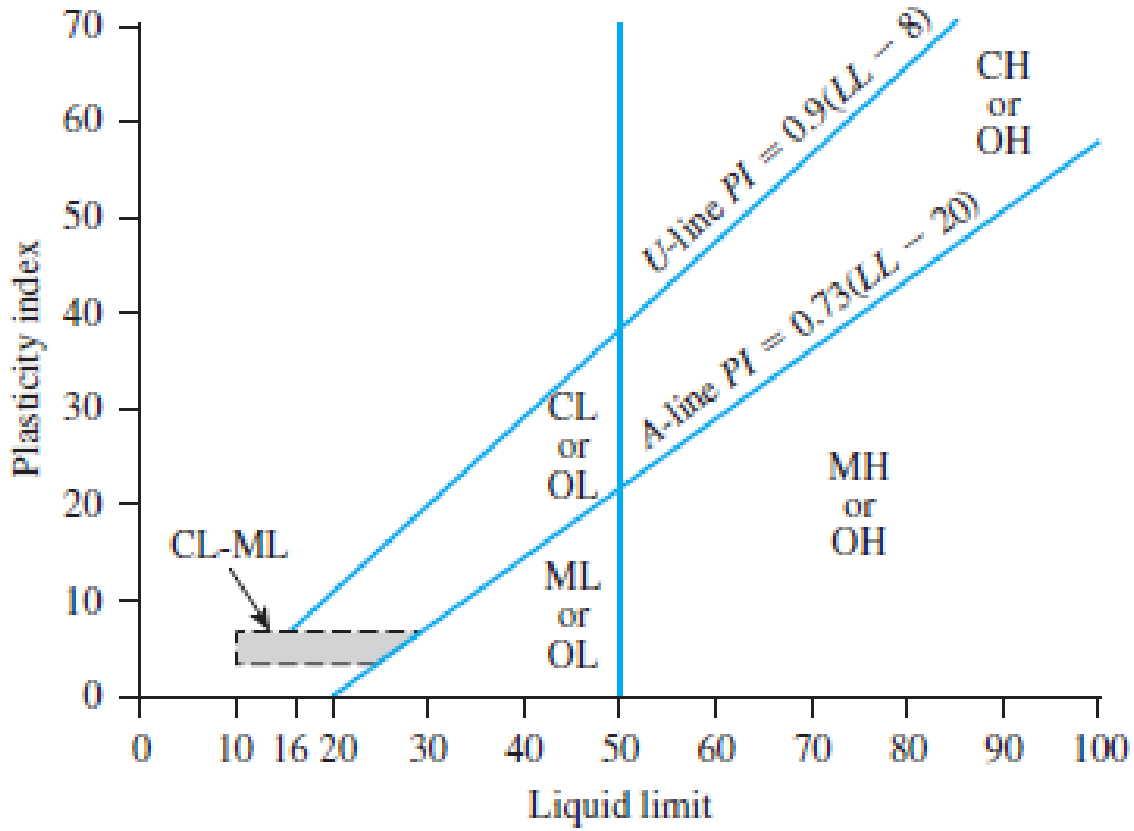
[c] $C_u = \frac{D_{60}}{D_{10}}; \quad C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

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

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

Unified Soil Classification System, USCS

Plasticity Chart :



Unified Soil Classification System, USCS

ORGANIC SOILS:

1. **Organic clay or silt(group symbol OL or OH):**

- If The soil's liquid limit (LL) after oven drying is less than 75 % of its liquid limit before oven drying 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.

2. **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.

Unified Soil Classification System, USCS

Borderline Cases (Dual Symbols): For the following three conditions, a dual symbol should be used:

1. **Coarse-grained soils with 5% - 12% fines:**

- The first symbol indicates whether the coarse fraction is well or poorly graded. The second symbol describe the contained fines. For example: SP-SM, poorly graded sand with silt.

2. **Fine-grained soils with limits within the shaded zone. (PI between 4 and 7 and LL between about 12 and 25):**

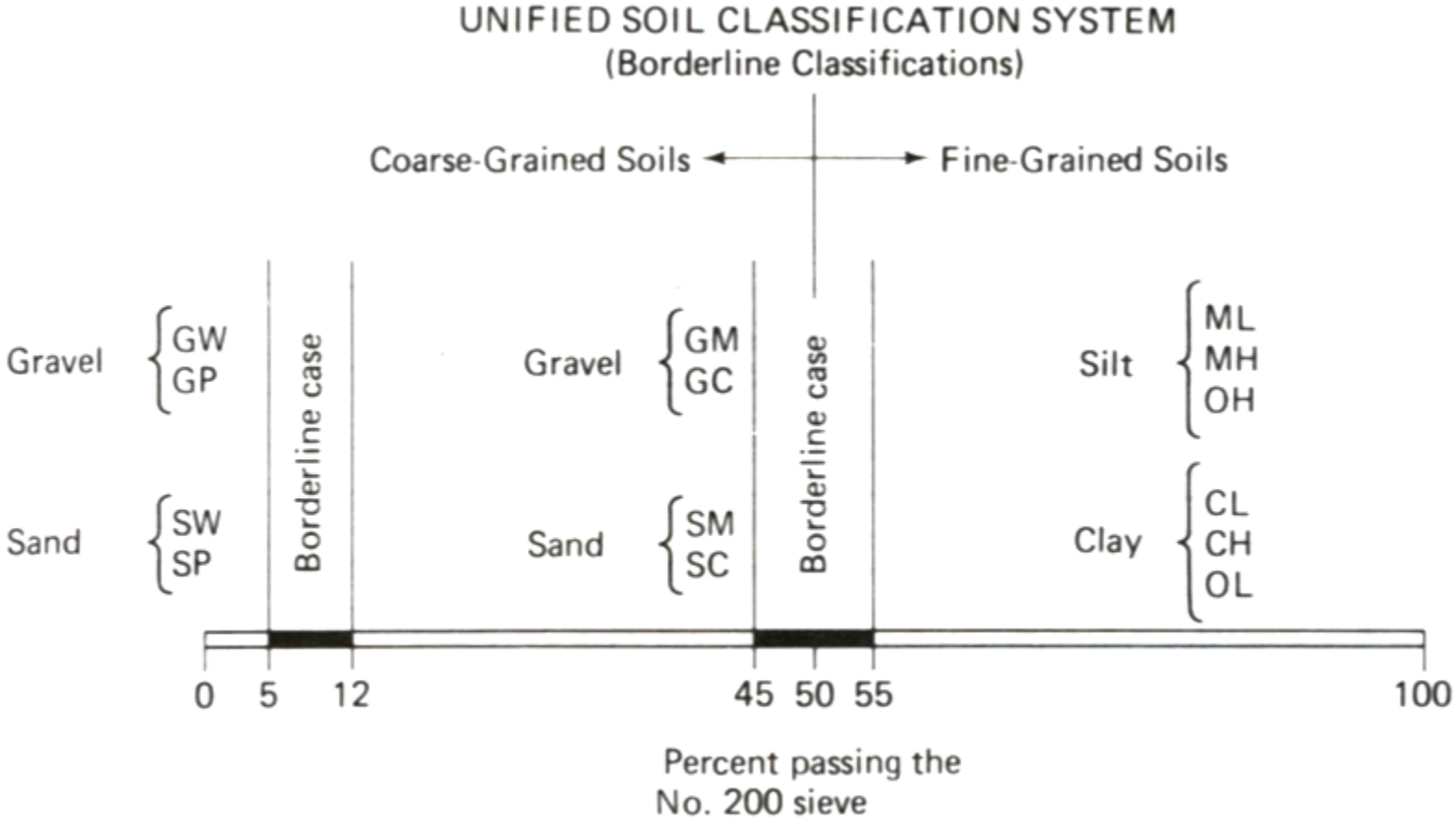
- It is hard to distinguish between the silty and more claylike materials.
- CL-ML: Silty clay, SC-SM: Silty, clayed sand.

3. **Soil contain similar fines and coarse-grained fractions:**

- possible dual symbols GM-ML.

Unified Soil Classification System, USCS

Borderline Cases:



Note: Only two group symbols may be used to describe a soil.
Borderline classifications can exist within each of the above groups.