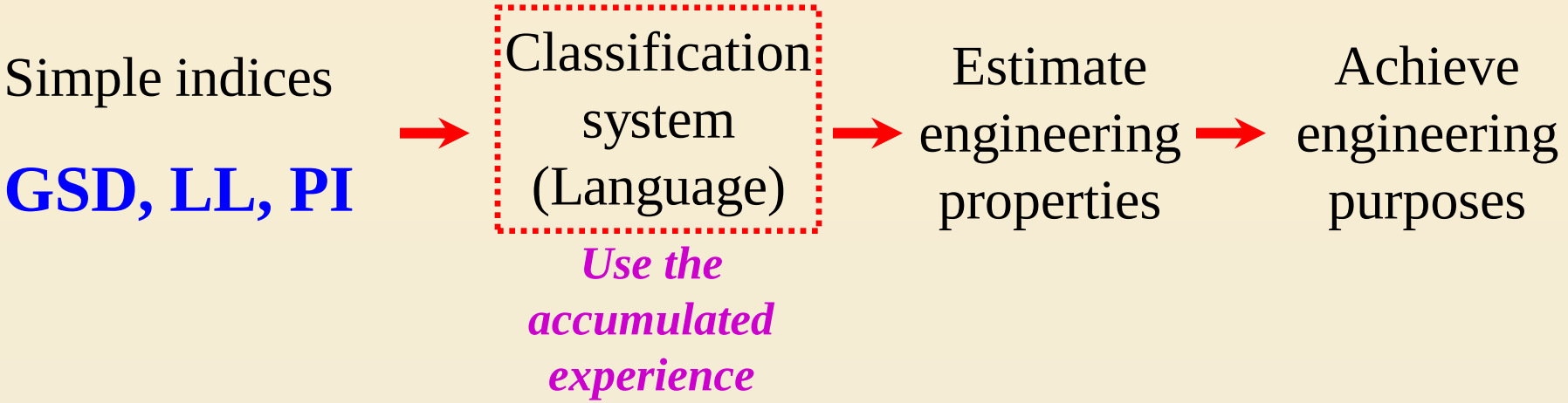
Soil Classification

Outline

1. Purpose
2. Classification Systems
3. The Unified Soil Classification System (USCS)
4. American Association of State Highway and Transportation Officials System (AASHTO)
5. Texural Classification System
6. Suggested Homework

1. Purpose

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.*



2. Classification Systems

Two commonly used systems:

- Unified Soil Classification System **(USCS).**
- American Association of State Highway and Transportation Officials **(AASHTO)** System

** **Additional::Texural Soil Classification**

Note: BS- similar way. Please try yourself

3. Unified Soil Classification System (USCS)

Origin of USCS:

This system was first developed by **Professor A. Casagrande** (1948) for the purpose of airfield construction **during World War II.** Afterwards, it was modified by **Professor Casagrande**, the U.S. Bureau of Reclamation, and the U.S. Army Corps of Engineers to enable the system to be **applicable to dams, foundations, and other construction** (Holtz and Kovacs, 1981).

Four major divisions:

(1) Coarse-grained

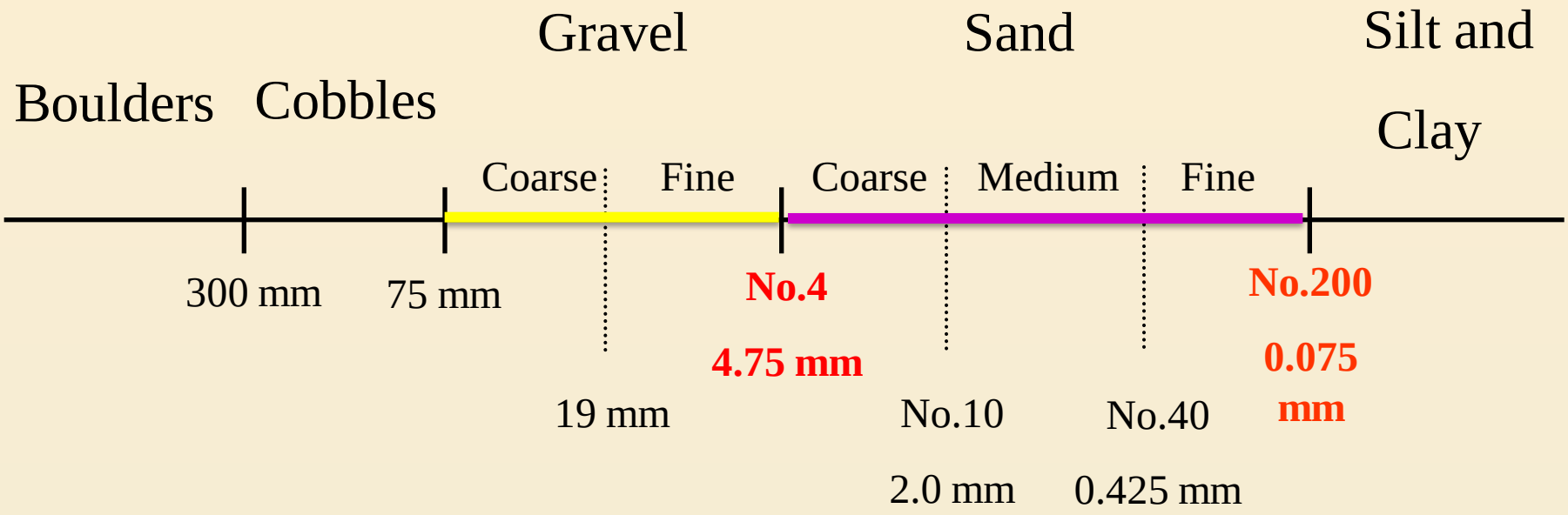
(2) Fine-grained

(3) Organic soils

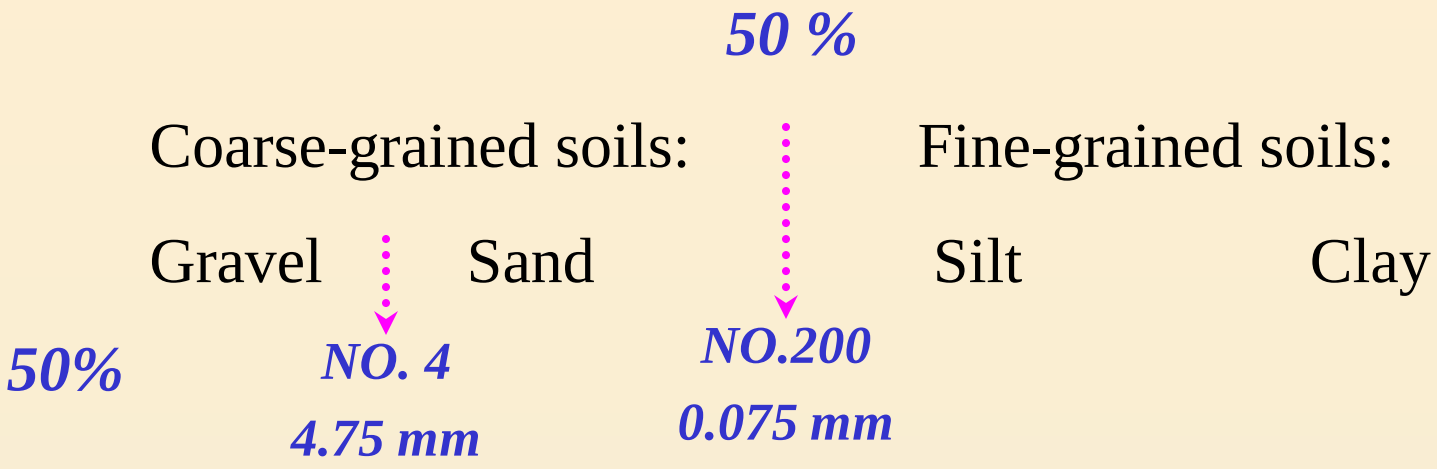
(4) Peat

3.1 Definition of Grain Size

No specific grain size-use Atterberg limits



3.2 General Guidance



- Grain size distribution
- C_u
- C_c

- PL, LL
- Plasticity chart

LL>50
LL <50

Required tests:

Sieve analysis **Atterberg limit**

3.3 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

Example: SW, Well-graded sand

SC, Clayey sand

SM, Silty sand,

MH, Elastic silt

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*)

3.4 Plasticity Chart

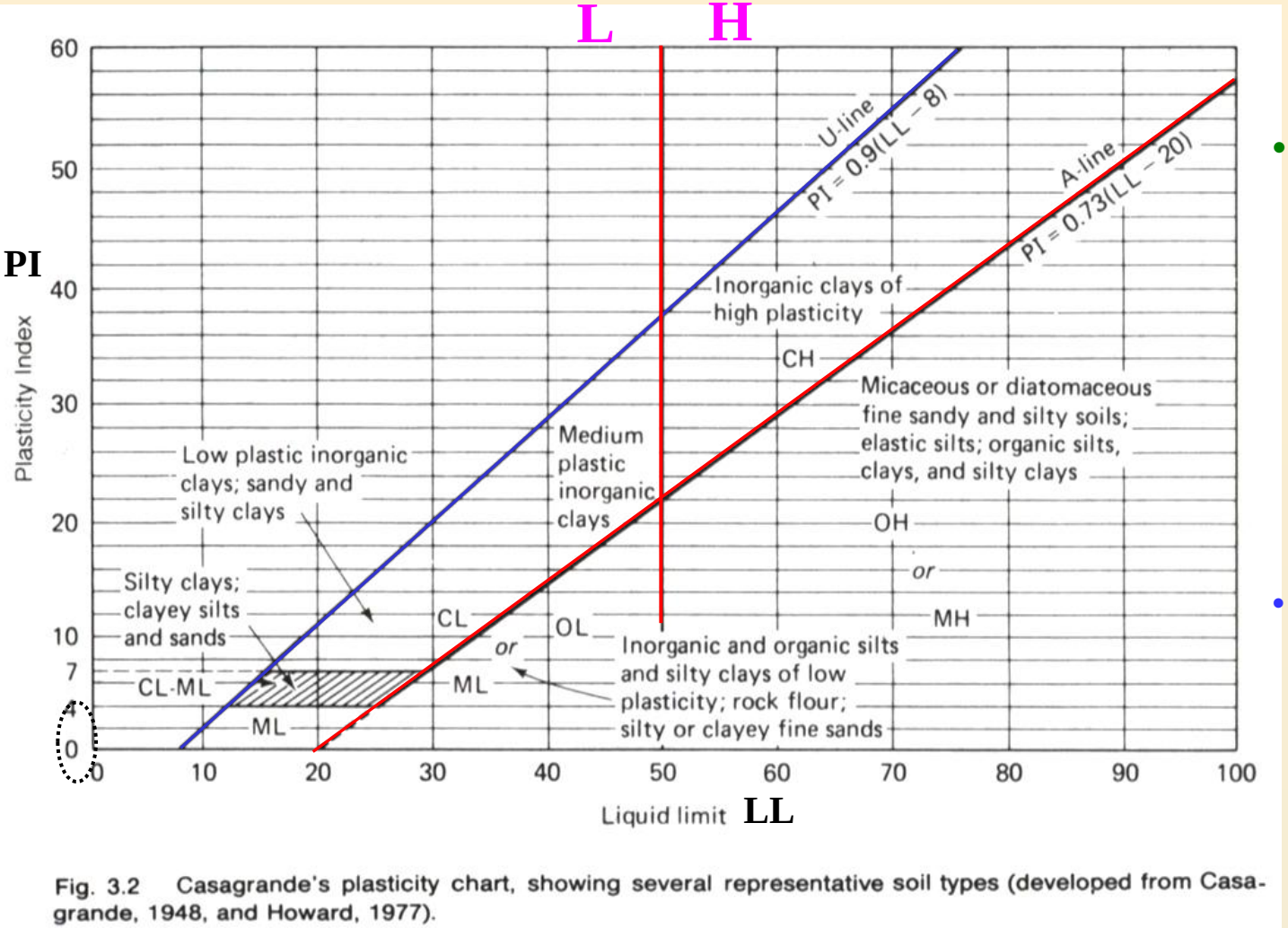


Fig. 3.2 Casagrande's plasticity chart, showing several representative soil types (developed from Casagrande, 1948, and Howard, 1977).

(Holtz and Kovacs, 1981)

- The A-line generally separates the more clay like materials from silty materials, and the organics from the inorganics.
- **The U-line indicates the upper bound for general soils.**

Note: ***If the measured limits of soils are on the left of U-line, they should be rechecked.***

3.5 Procedures for Classification

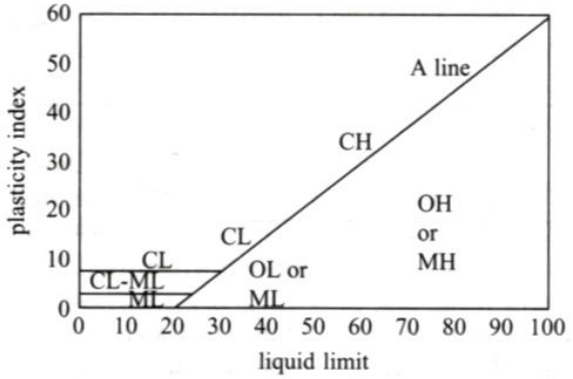
Coarse-grained material

Grain size distribution

Fine-grained material

LL, PI

COARSE More than 50% retained sieve #200	Gravel: more than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 4,\ 1 \le C_c \le 3$	→ GW
			Not satisfying GW	→ GP
		More than 12% fines	Below 'A' line	→ GM
			Above 'A' line	→ GC
	Sand: less than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 6,\ 1 \le C_c \le 3$	→ SW
			Not satisfying SW	→ SP
		More than 12% fines	Below 'A' line	→ SM
			Above 'A' line	→ SC
FINE Less than 50% retained sieve #200	$LL < 50$			→ ML → CL → OL
	$LL > 50$			→ MH → CH → OH
Highly ORGANIC SOILS				→ Pt



(Santamarina et al., 2001)

3.6 Example

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

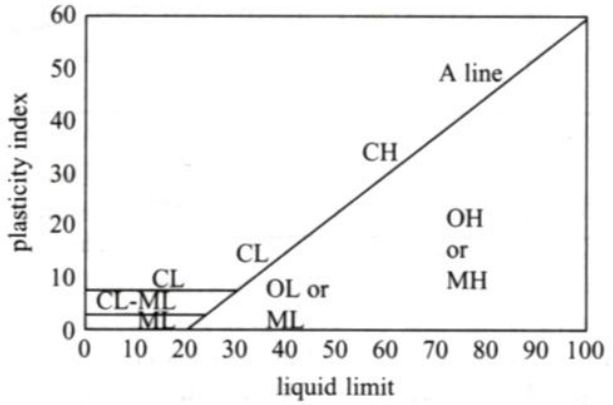
PI=0.73(33-20)=9.49

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	$C_u > 4, 1 \le C_c \le 3$	→ GW
			Not satisfying GW	→ GP
		More than 12% fines	Below 'A' line	→ GM
			Above 'A' line	→ GC
	Sand: less than 50% coarse fraction retained on sieve #4	Less than 5% fines	$C_u > 6, 1 \le C_c \le 3$	→ SW
			Not satisfying SW	→ SP
		More than 12% fines	Below 'A' line	→ SM
			Above 'A' line	→ SC
FINE Less than 50% retained sieve #200	$LL < 50$			ML CL OL
	$LL > 50$			MH CH OH
Highly ORGANIC SOILS				→ Pt



(Santamarina et al., 2001)

3.7 Organic Soils

- **Highly organic soils- Peat (Group symbol P_T)**
  - 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.

3.8 Borderline Cases (Dual Symbols)

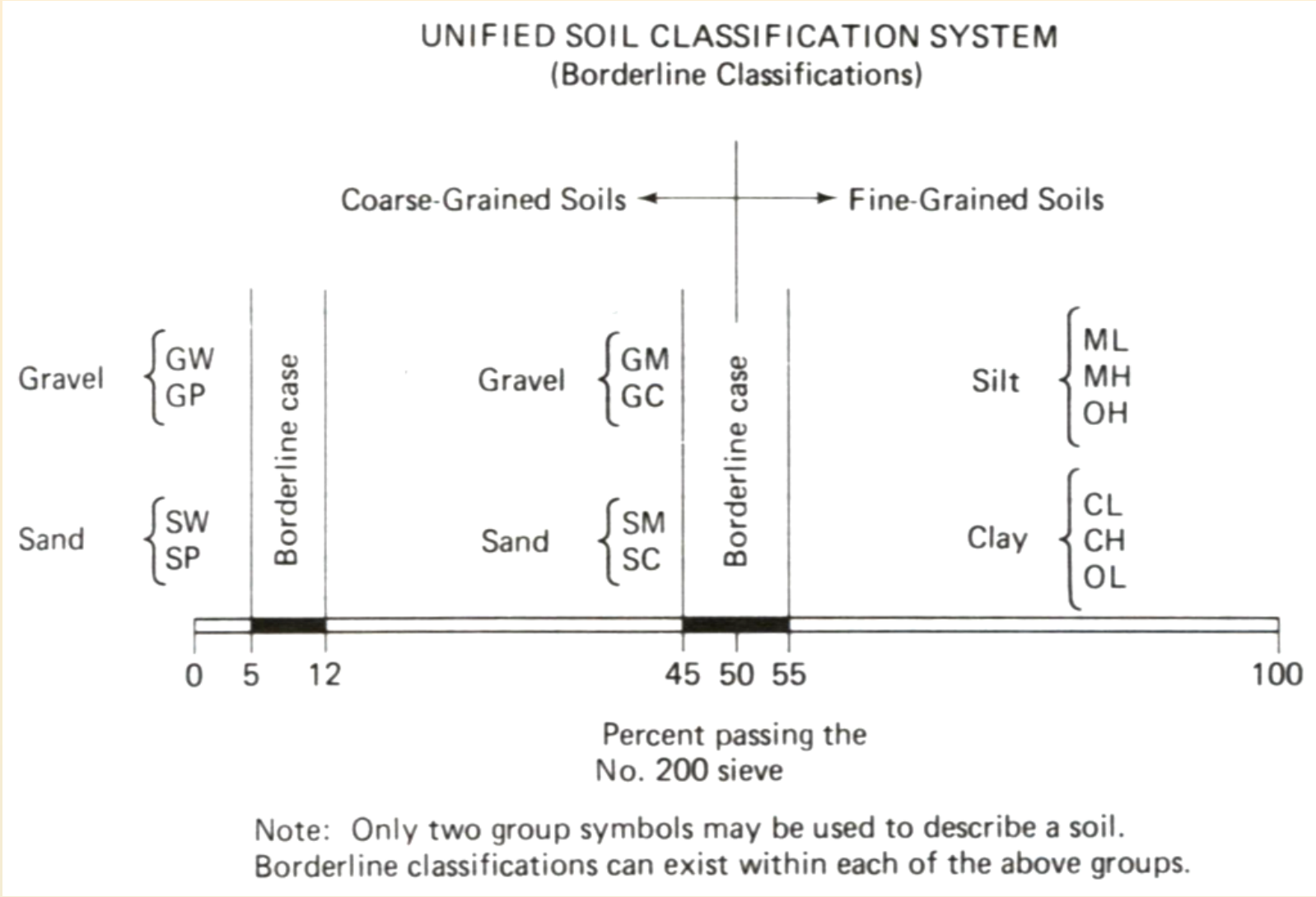
For the following three conditions, a dual symbol should be used.

- **Coarse-grained soils with 5% - 12% fines.**
  - **About 7 % fines can change the hydraulic conductivity of the coarse-grained media by orders of magnitude.**
  - **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.**

- **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, clayey sand.**

- **Soil contain similar fines and coarse-grained fractions.**
  - possible dual symbols **GM-ML**

3.8 Borderline Cases (Summary)



(Holtz and Kovacs, 1981)

USCS

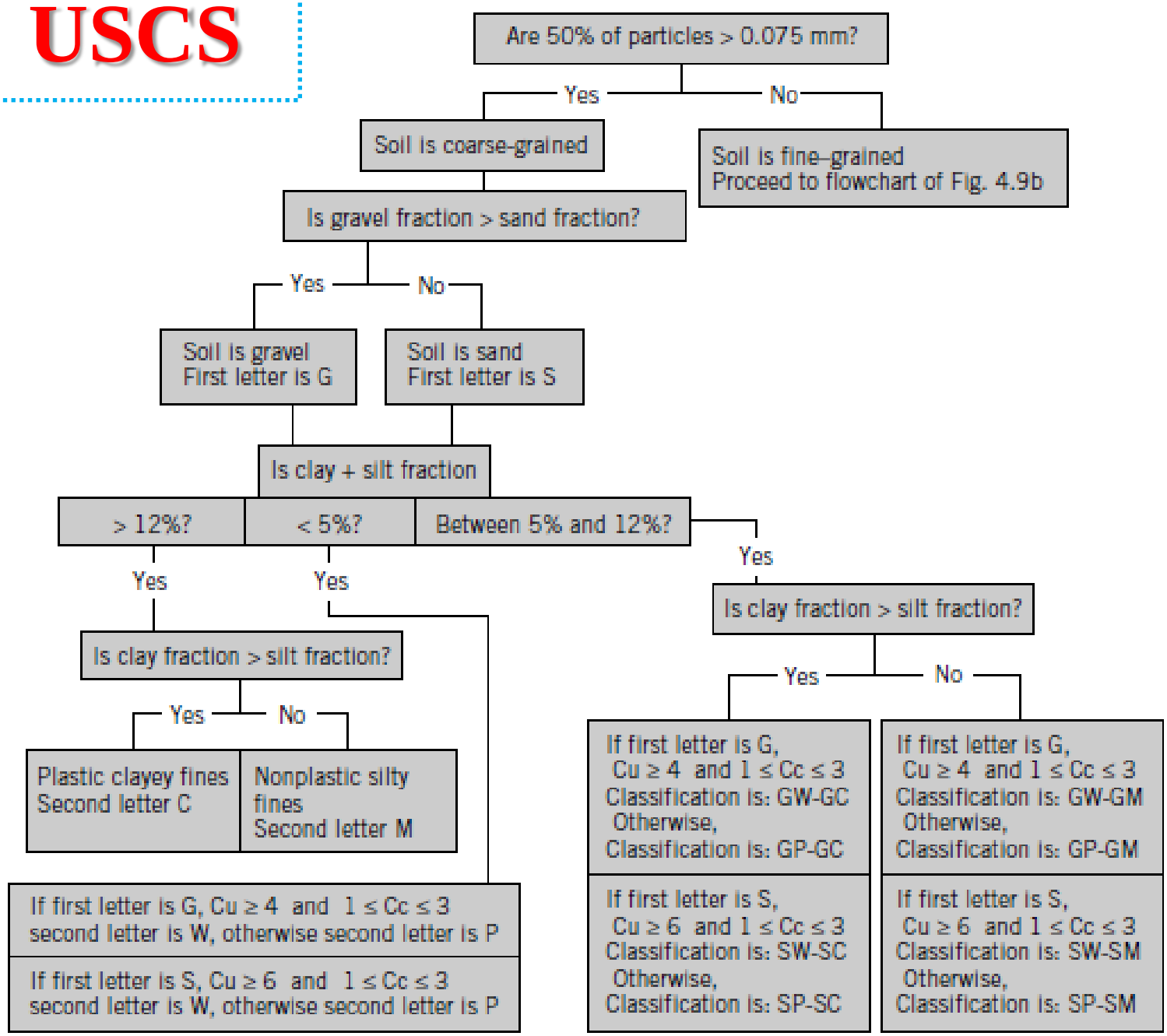


FIGURE 4.9a Unified Soil Classification System flowchart for coarse-grained soils.

USCS

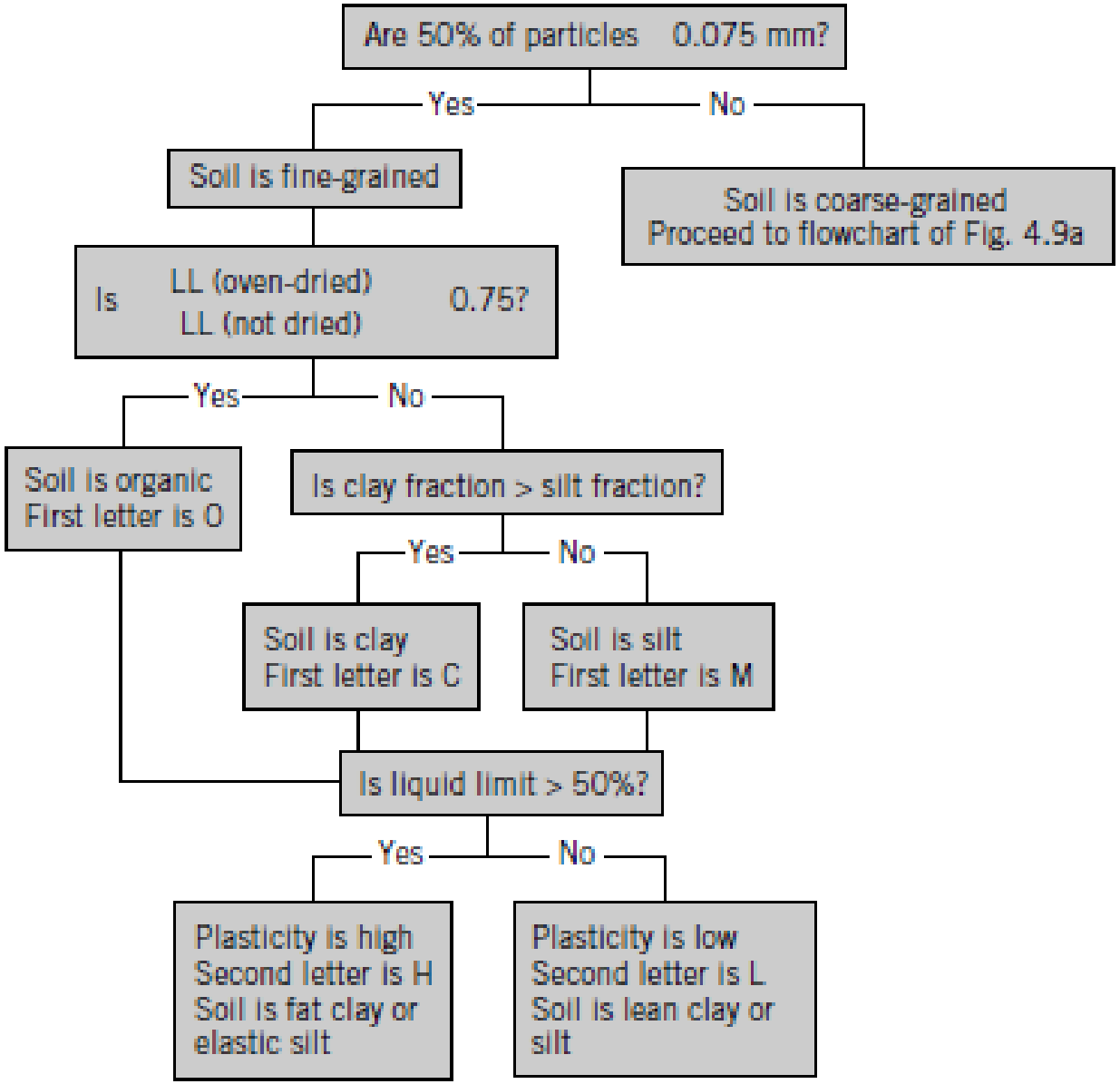


FIGURE 4.9b Unified Soil Classification System flowchart for fine-grained soils.

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

USCS

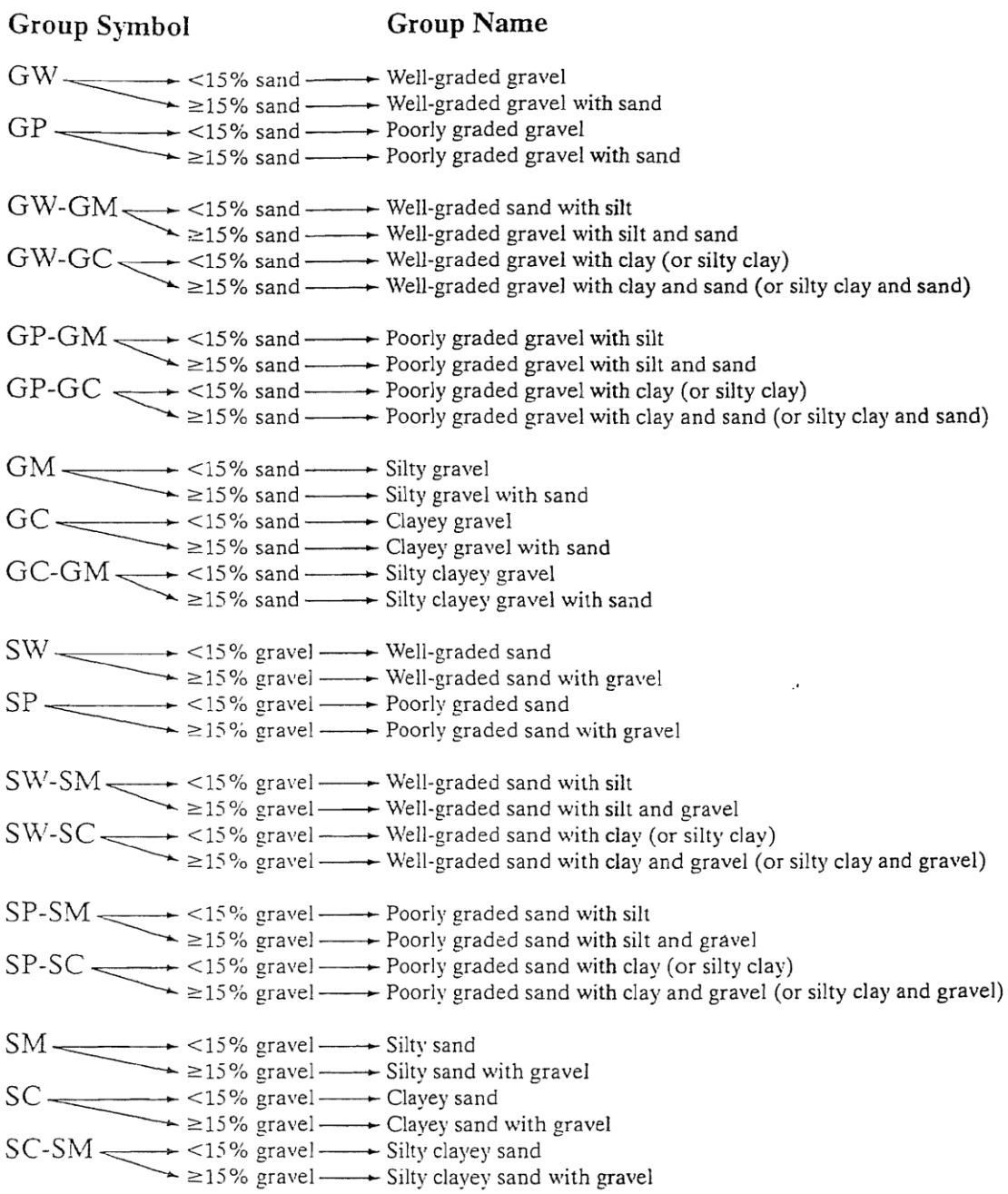


Figure 4.3 Flowchart group names for gravelly and sandy soil. *Source:* From "Annual Book of ASTM Standards, 04.08." Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

USCS

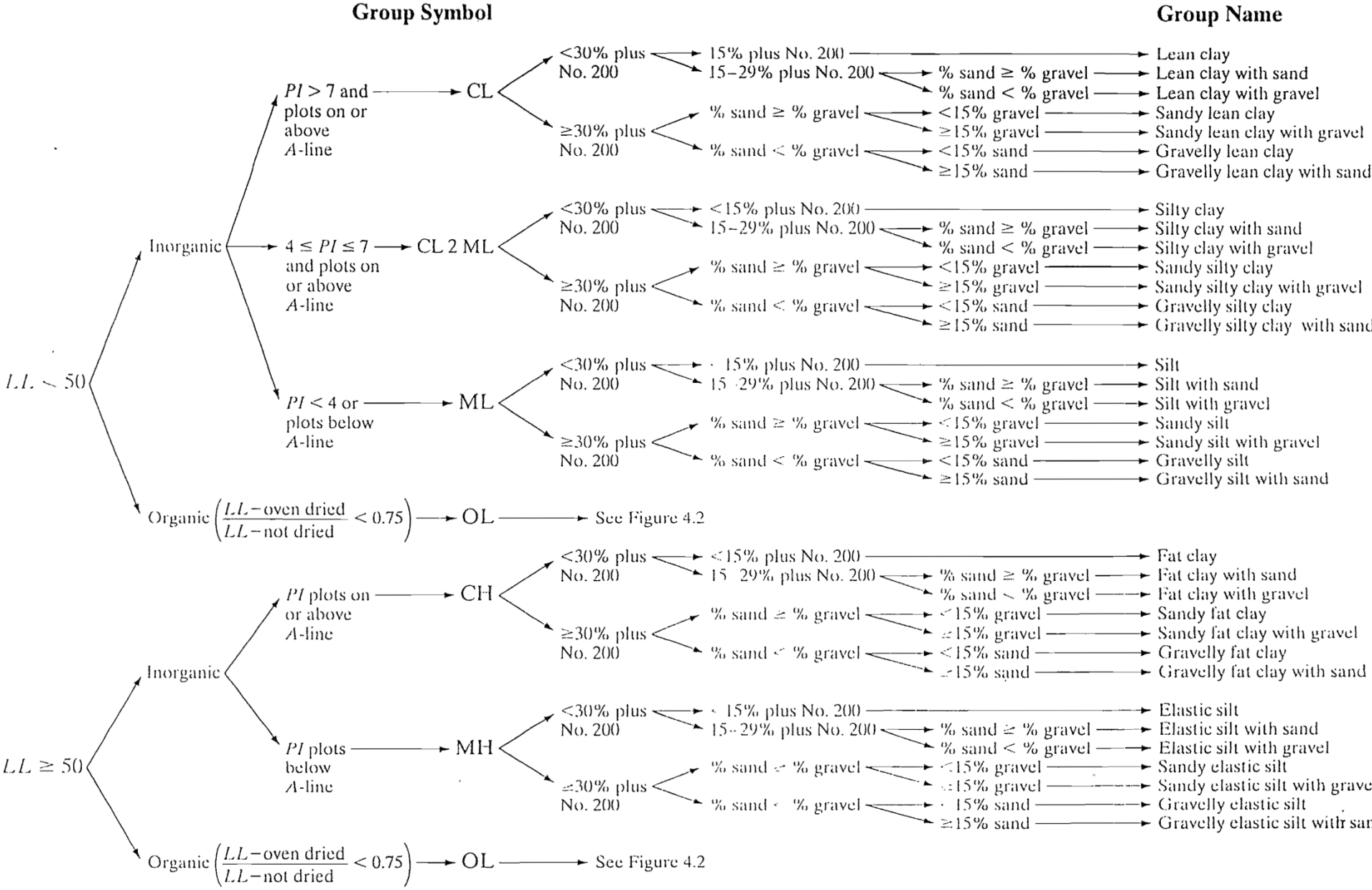


Figure 4.4 Flowchart group names for inorganic silty and clayey soils. *Source:* From "Annual Book of ASTM Standards, 04.08." Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

USCS

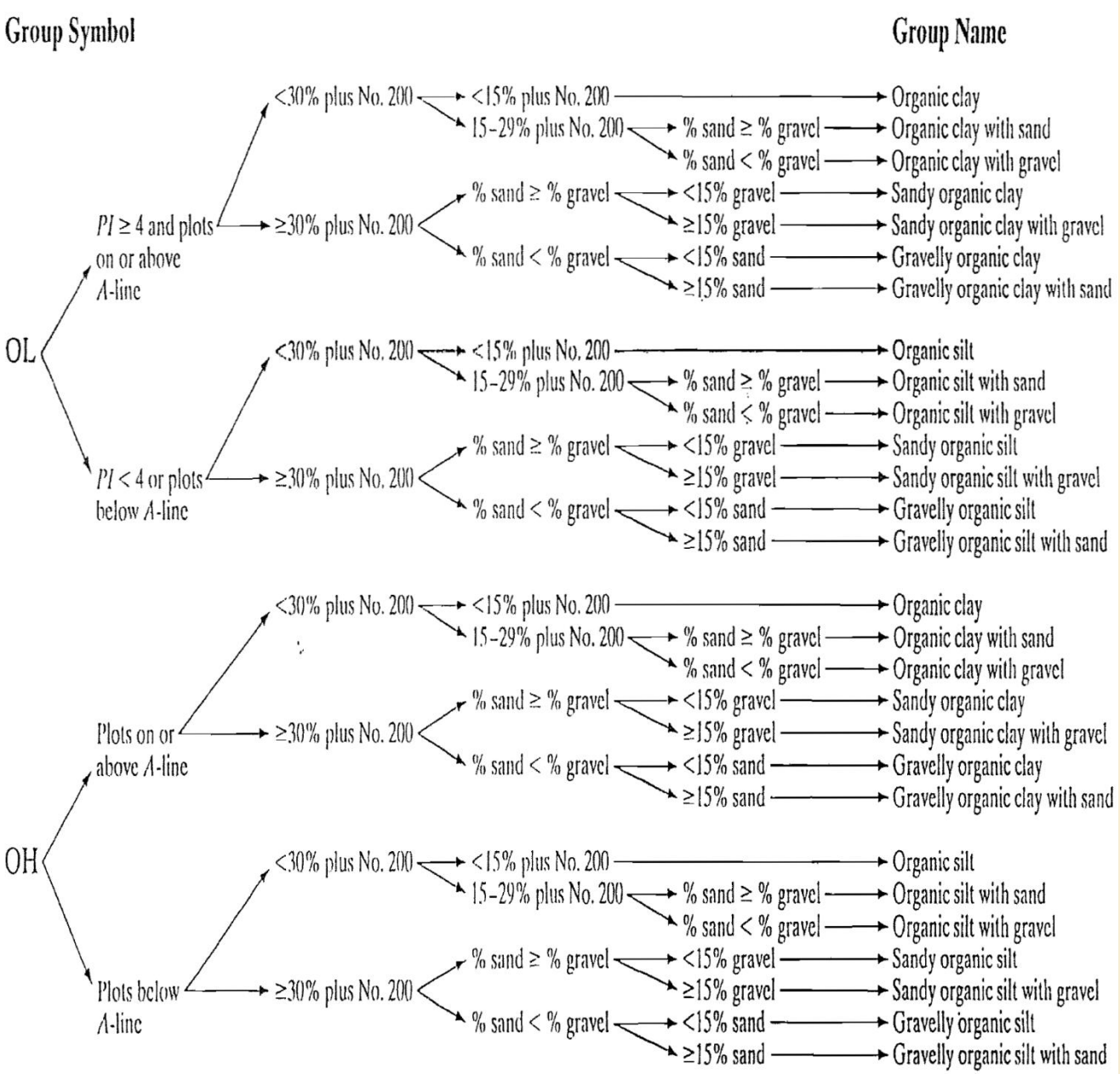


Figure 4.5 Flowchart group names for organic silty and clayey soils. *Source:* From "Annual Book of ASTM Standards, 04.08." Copyright © 1999 American Society for Testing and Materials. Reprinted with permission.

USCS

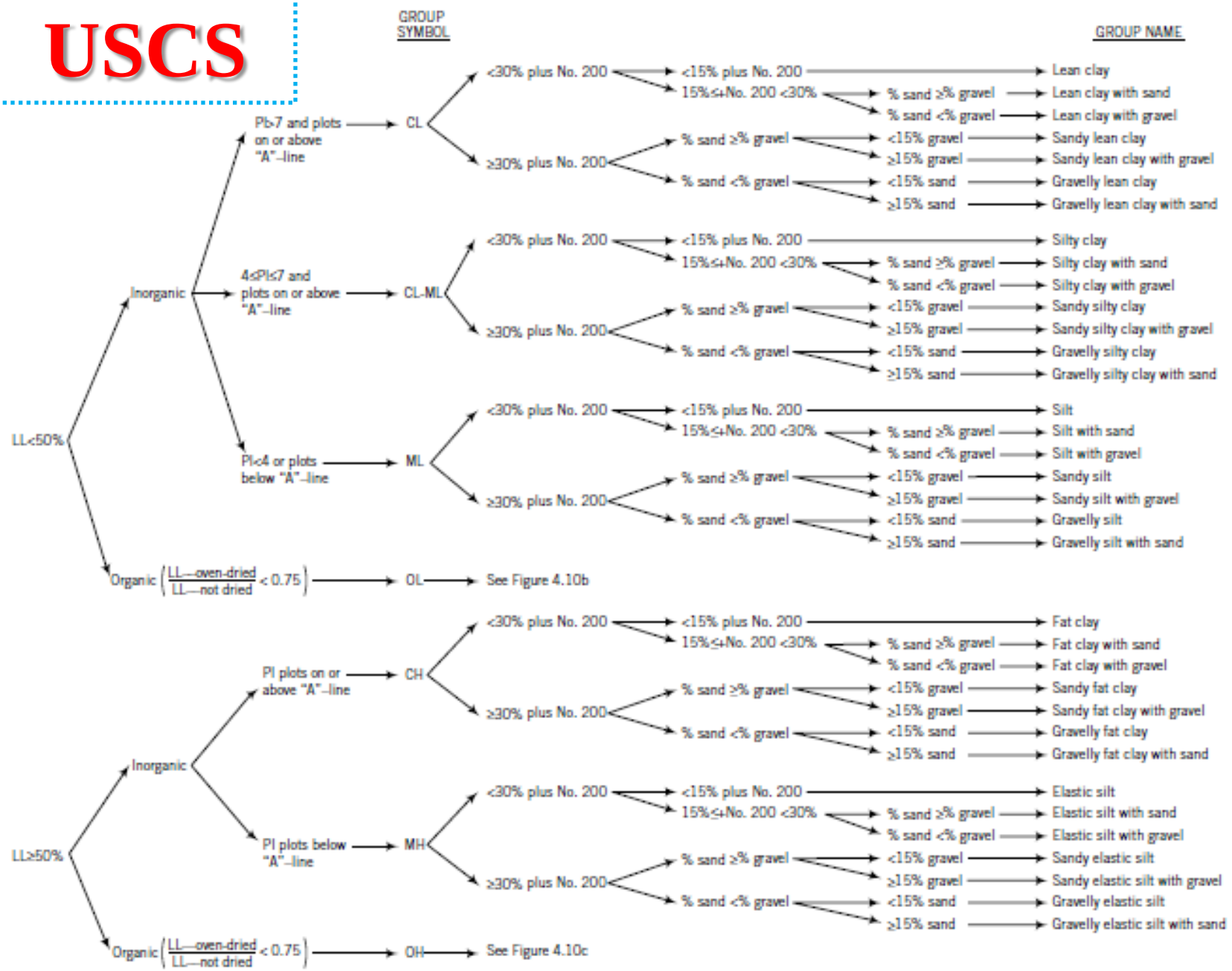


FIGURE 4.10b Flowchart for classifying inorganic fine-grained soils (50% or more fines). (Source: Reprinted with permission from ASTM D 2487-10 Standard Practice for Classification of Soils for Engineering Purposes, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.)

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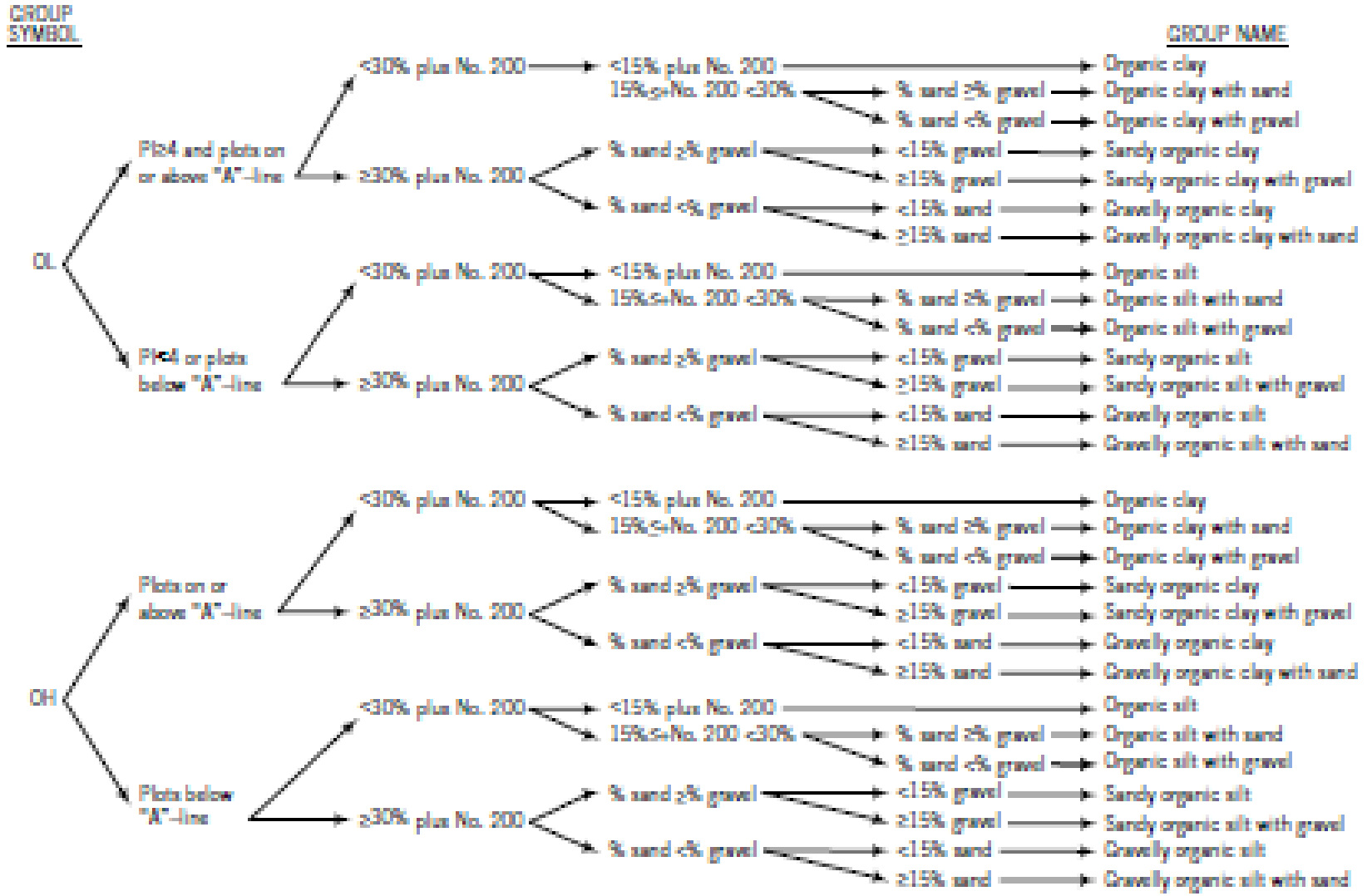

FIGURE 4.10c Flowchart for classifying organic fine-grained soils (50% or more fines). (Source: Reprinted with permission from ASTM D 2487-10 Standard Practice for Classification of Soils for Engineering Purposes, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428.)

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British Classification System

Table 2.3 British Soil Classification System for engineering purposes

Soil groups (see note 1)		*Sub-groups and laboratory identification*					
GRAVEL and SAND may be qualified sandy GRAVEL and gravelly SAND, etc.		*Group symbol (see notes 2 and 3)*	*Subgroup symbol (see note 2)*		*Fines (% less than 0.06 mm)*	*Liquid limit (%)*	*Name*
COARSE SOILS Less than 35% of the material is finer than 0.06 mm	GRAVELS More than 50% of coarse material is of gravel size (coarser than 2 mm)	Slightly silty or clayey GRAVEL	G	GW	GW		0 to 5		Well-graded GRAVEL
				GP	GPu	GPg			Poorly graded/uniform/gap graded GRAVEL
		Silty GRAVEL	G–F	G–M	GWM	GPM	5 to 15		Well graded/poorly graded silty GRAVEL
		Clayey GRAVEL		G–C	GWC	GPC			Well graded/poorly graded clayey GRAVEL
		Very silty GRAVEL	GF	GM	GML, etc.		15 to 35		Very silty GRAVEL; subdivide as for GC
		Very clayey GRAVEL		GC	GCL GCI GCH GCV GCE				Very clayey GRAVEL (clay of low, intermediate, high, very high, extremely high plasticity)
	SANDS More than 50% of coarse material is of sand size (finer than 2 mm)	Slightly silty or clayey SAND	S	SW	SW		0 to 5		Well graded SAND
				SP	SPu	SPg			Poorly graded/uniform/gap graded SAND
		Silty SAND	S–F	S–M	SWM	SPM	6 to 15		Well graded/poorly graded silty SAND
		Clayey SAND		S–C	SWC	SPC			Well graded/poorly graded clayey SAND
		Very silty SAND	SF	SM	SML, etc.		15 to 35		Very silty SAND; subdivided as for SC
		Very clayey SAND		SC	SCL SCI SCH SCV SCE				Very clayey SAND (clay of low, intermediate, high, very high, extremely high plasticity)

FINE SOILS More than 35% of the material is finer than 0.06 mm	Gravelly or sandy SILTS and CLAYS 35% to 65% fines	Gravelly SILT	FG	MG	MLG, etc.		Gravelly SILT; subdivide as for CG
		Gravelly CLAY (see note 4)		CG	CLG	< 35	Gravelly CLAY of low plasticity
					CIG	35 to 50	of intermediate plasticity
					CHG	50 to 70	of high plasticity
					CVG	70 to 90	of very high plasticity
					CEG	> 90	of extremely high plasticity
	SILTS and CLAYS 65% to 100% fines	Sandy SILT (see note 4)	FS	MS	MLS, etc.		Sandy SILT; subdivide as for CG
		Sandy CLAY		CS	CLS, etc.		Sandy CLAY; subdivide as for CG
		SILT (M-SOIL)	F	M	ML, etc.		SILT; subdivide as for C
		CLAY (see notes 5 and 6)		C	CL	< 35	CLAY of low plasticity
					CI	35 to 50	of intermediate plasticity
					CH	50 to 70	of high plasticity
					CV	70 to 90	of very high plasticity
					CE	> 90	of extremely high plasticity
ORGANIC SOILS	Descriptive letter 'O' suffixed to any group or subgroup symbol				Organic matter suspected to be a significant constituent. Example MHO. Organic SILT of high plasticity		
PEAT	Pt	Peat soils consist predominantly of plant remains which may be fibrous or amorphous					

Note 1: The name of the soil group should always be given when describing soils, supplemented, if required, by the group symbol, although for some additional applications (e.g. longitudinal sections) it may be convenient to use the group symbol alone.

Note 2: The group symbol or subgroup symbol should be placed in brackets if laboratory methods have not been used for identification, e.g. (GC).

Note 3: The designation FINE SOIL or FINES, F, may be used in place of SILT, M, or CLAY, C, when it is not possible or not required to distinguish between them.

Note 4: GRAVELLY if more than 50% of coarse material is of gravel size. SANDY if more than 50% of coarse material is of sand size.

Note 5: SILT (M-SOIL), M, is material plotting below the A-line, and has a restricted plastic range in relation to its liquid limit, and relatively low cohesion. Fine soils of this type include clean silt-sized materials and rock flour, micaceous and diatomaceous soils, pumice, and volcanic soils, and soils containing halloysite. The alternative term 'M-soil' avoids confusion with materials of predominantly silt size, which form only a part of the group.

Organic soils also usually plot below the A-line on the plasticity chart, when they are designated ORGANIC SILT, MO.

Note 6: CLAY, C, is material plotting above the A-line, and is fully plastic in relation to its liquid limit.

British Classification System

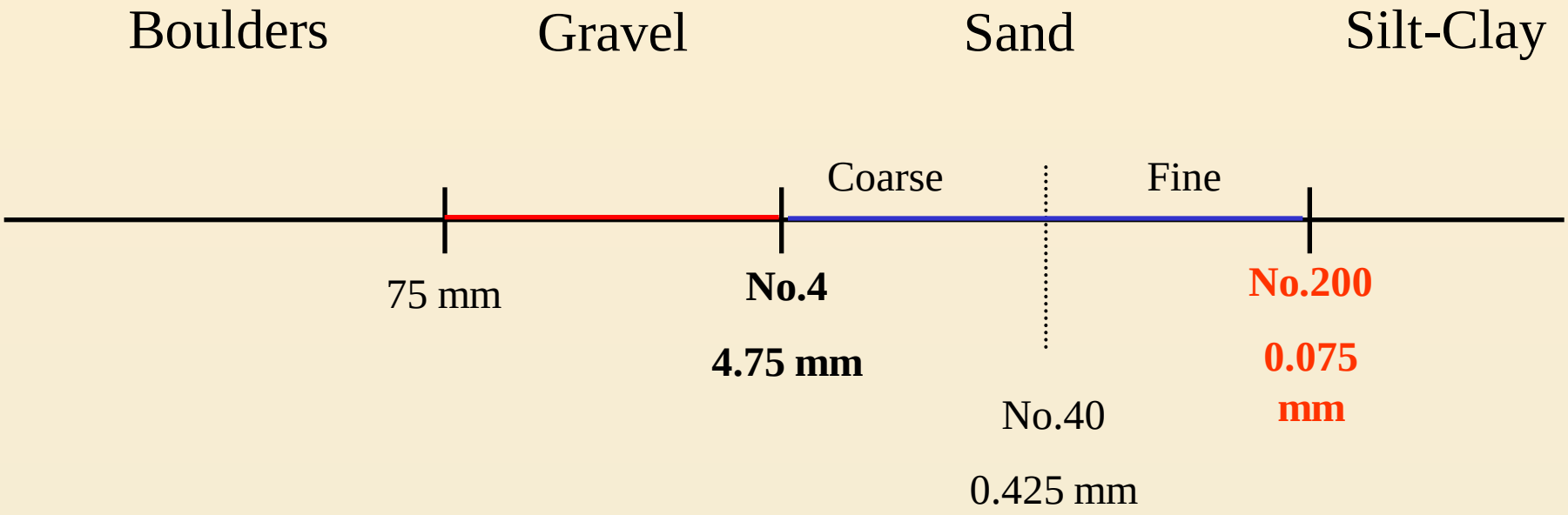
4. American Association of State Highway and Transportation Officials system (AASHTO)

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)

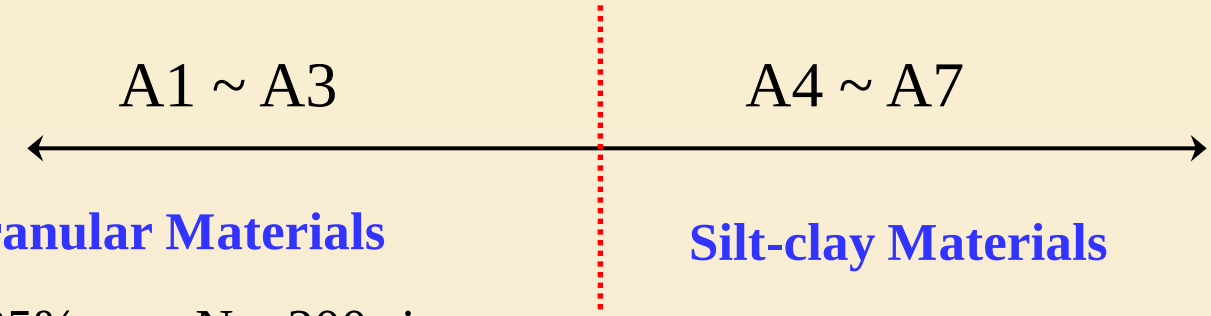
4.1 Definition of Grain Size

No specific grain size-use Atterberg limits



4.2 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).**

4.3 Group Index

The first term is determined by the LL

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

The second term is determined by the PI

For Group A-2-6 and A-2-7

$$GI = 0.01(F_{200} - 15)(PI - 10)$$ use the second term only

F200: percentage passing through the No.200 sieve

In general, the rating for a pavement subgrade is inversely proportional to the group index, GI.

4.4 Classification

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						

Das, 1998

4.4 Classification (Cont.)

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, $PI > LL - 30$

Note: The first group from the left to fit the test data is the correct AASHTO classification.

Das, 1998

4.4 Example

Passing No.200 = 86%

LL=70, PI=32

LL-30=40 > PI=32

Passing No.200= 86%

LL=70, PI=32

LL-30=40 > PI=32

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

$$= 33.47 \cong 33 \quad \textit{Round off}$$

A-7-5(33)

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, $PI > LL - 30$

TEXTURAL SOIL CLASSIFICATION

- U.S. Department of **Agriculture** System (USDA)
- By making use of the **grain size limits mentioned in the table** for **sand, silt and clay,** a triangular classification chart has been developed for classifying mixed soils.
- the percentages of sand, silt and clay-size materials in a given sample by mechanical analysis.
- With the given relative percentages of the **sand, silt and clay**, a point is located on **the triangular chart** as shown in Fig

5. TEXTURAL SOIL CLASSIFICATION

Soil fraction	Diameter in mm
Gravel	>2.00
Sand	2–0.05
Silt	0.05–0.002
Clay	<0.002

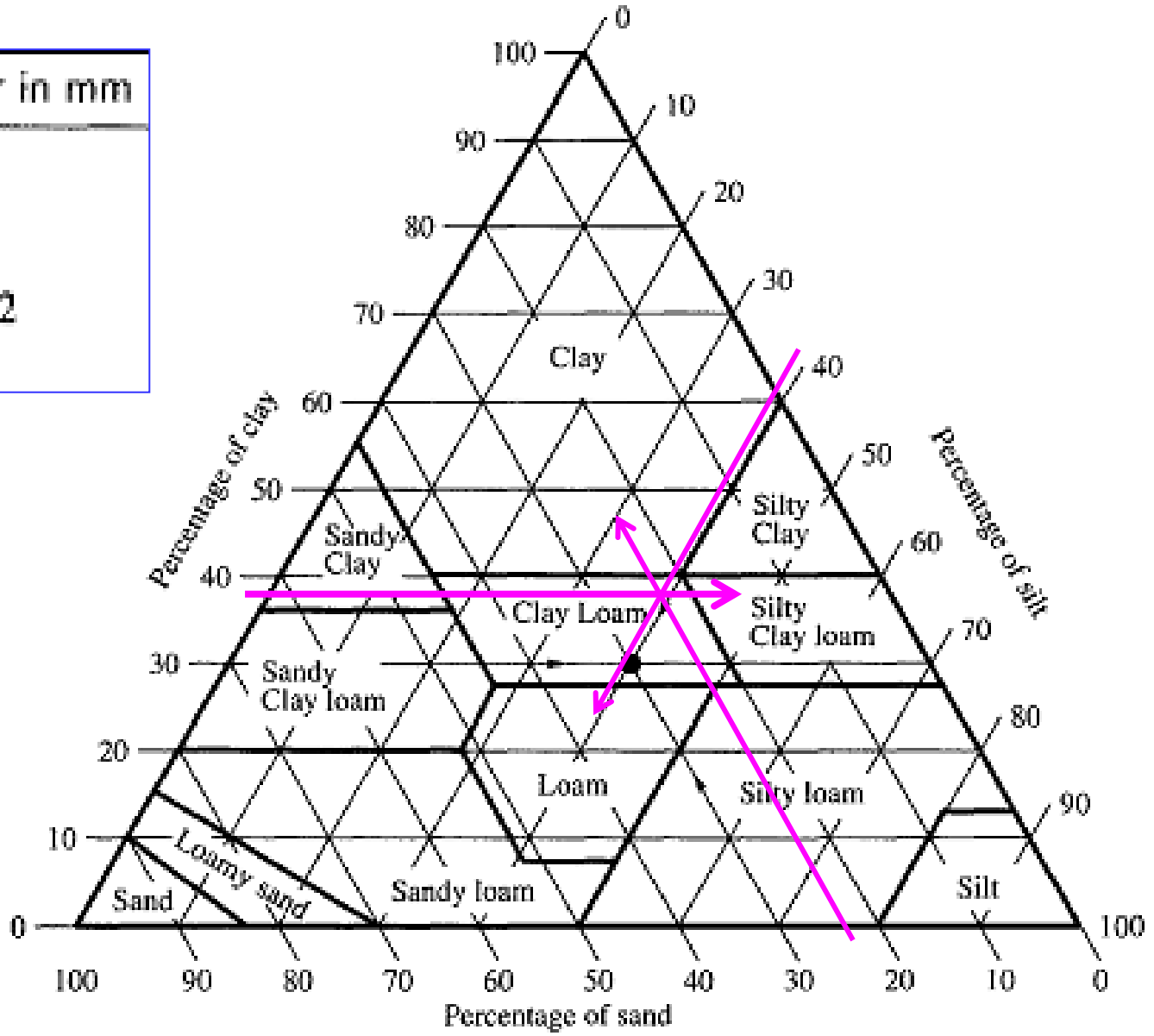


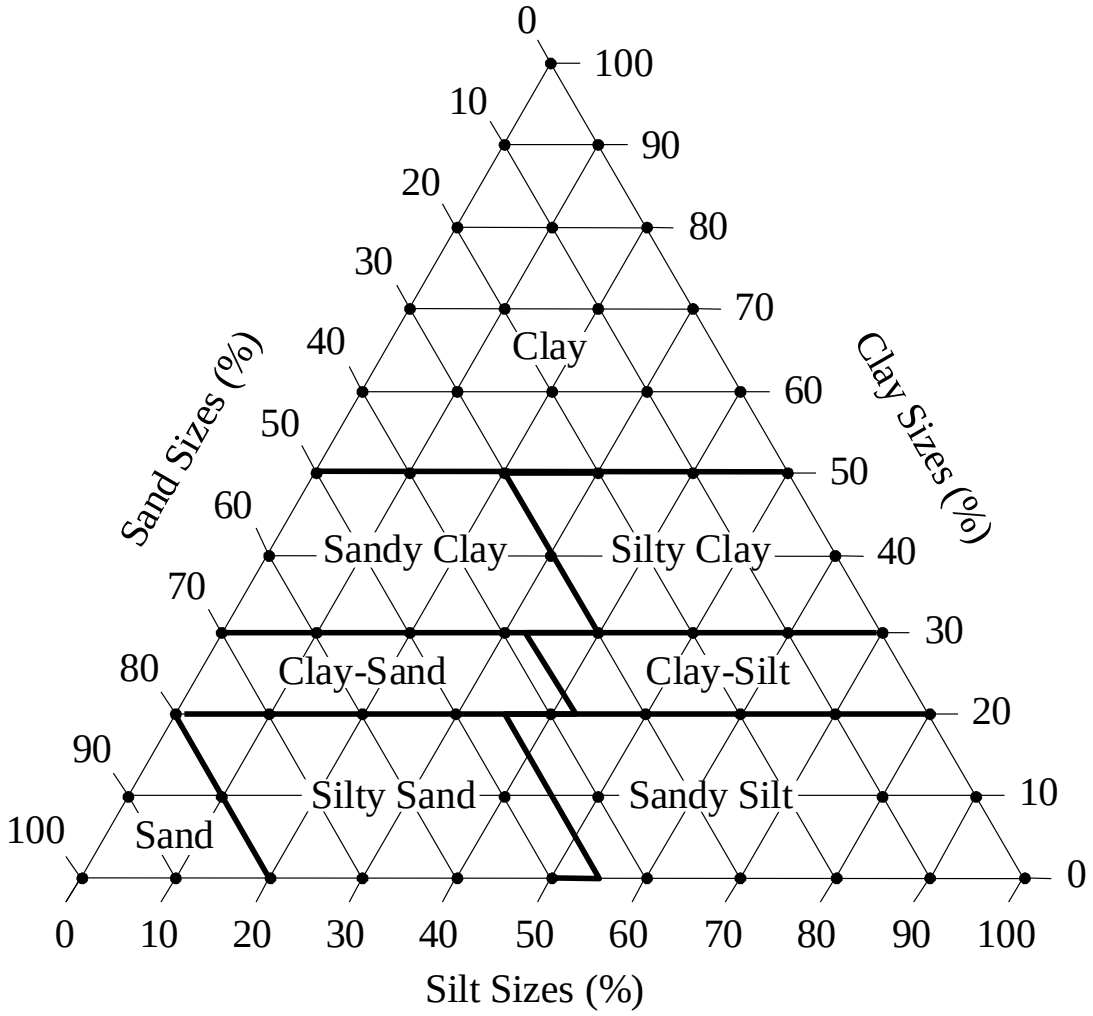
Figure 3.20 U.S. Department of Agriculture textural classification

- **This method of classification does not reveal any properties of the soil other than grain-size distribution.**
- **Because of its simplicity, it is widely used by workers in the field of agriculture.**
- **disadvantage of this method is that the textural name as derived from the chart does not always correctly express the physical characteristics of the soil.**

In this system , the term **Loam** used to describe **a mixture of sand, silt and clay particles in verious proportions**. The term **LOAM** originated in agricultural engineering where the suitability of a soil is judged for crops. This term is not used in soil engineering. In order to eliminate the term loam the **Mississipi River Commission** proposed a modified Triangular system. The term Loam is replaced by silty Clay.

Mississipi River Commission (modified triangular system)

Important observations from figure are that any soil containing more than 50% of clay sized particles would be classified as a clay, whereas sand and silt require 80% of the particles to be in that size range. Also any soil having more than 20% clay would have some clay like properties.



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The chart is based only on the fraction of soil that passes through the no. 10 sieve. Otherwise a correction will be necessary **if a certain percentage of the soil particles are larger than 2 mm in diameter,** as shown below-

The modified textural composition are-

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

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

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

Original
20% Gravel
30% Sand
40% Silt
10% Clay

Modified
37.5% Sand
50% Silt
12.5% Clay

6. Suggested Homework

1. Please read Book
2. Read ASTM D2487 and D 2488.
3. Please go over Examples

References

Main References:

Das, B.M. (1998). *Principles of Geotechnical Engineering*, 4th edition, PWS Publishing Company. (Chapter 3)

Holtz, R.D. and Kovacs, W.D. (1981). *An Introduction to Geotechnical Engineering*, Prentice Hall. (Chapter 3)