University of Tennessee at Chattanooga ENCE 3610 Soil Mechanics

Lecture 2

Size Gradation of Soil Particles
Soil Classification

Importance of Particle Size and Gradation

- Of all of the characteristics of soils, particle size is the single most important one
- Soils respond differently to loads and many other actions (compaction, addition of water, etc.) based on their particle size
- Unfortunately virtually any soil sample is a composite of different particle sizes, and the proportion of the different particle sizes is also important in determining soil properties
- We must be able to determine the distribution of different particle sizes in a given soil sample

Figure 2-2. Example of laboratory sieves for mechanical analysis for grain size distributions. Shown (right to left) are sieve nos. 3/8-in (9.5-mm), No. 10 (2.0-mm), No. 40 (0.425 mm) and No. 200 (0.075 mm). Example soil particle sizes shown at the bottom of the photo include (right to left): medium gravel, fine gravel, medium-coarse sand, silt, and clay (kaolin) (FHWA, 2002b).

Gradation Tests

ASTM #	Description	Sample Size	Comments
D6913	Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis	50 g – 70 kg (depends upon particle size)	For maximum particle size (99% passing): 0.425 mm: 50 g required 2 mm: 50 g 50 g – 70 kg 4.75 mm: 75 g 9.5 mm: 165 g 19 mm: 1.3 kg 25.4 mm: 3 kg 38.1 mm: 10 kg 50.8 mm: 25 kg 76.2 mm: 70 kg
D7928	Particle- Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis	50 g (dry)	Passing No. 10 sieve and retained on No. 200 sieve

Sieve Analysis

- Primarily applied to granular (cohesionless) soils
- Passes soil sample through a series of sieves of varying mesh fineness
- Different portions of soil with different grain size pass through each mesh
- Distribution of grain sizes constructed and plotted

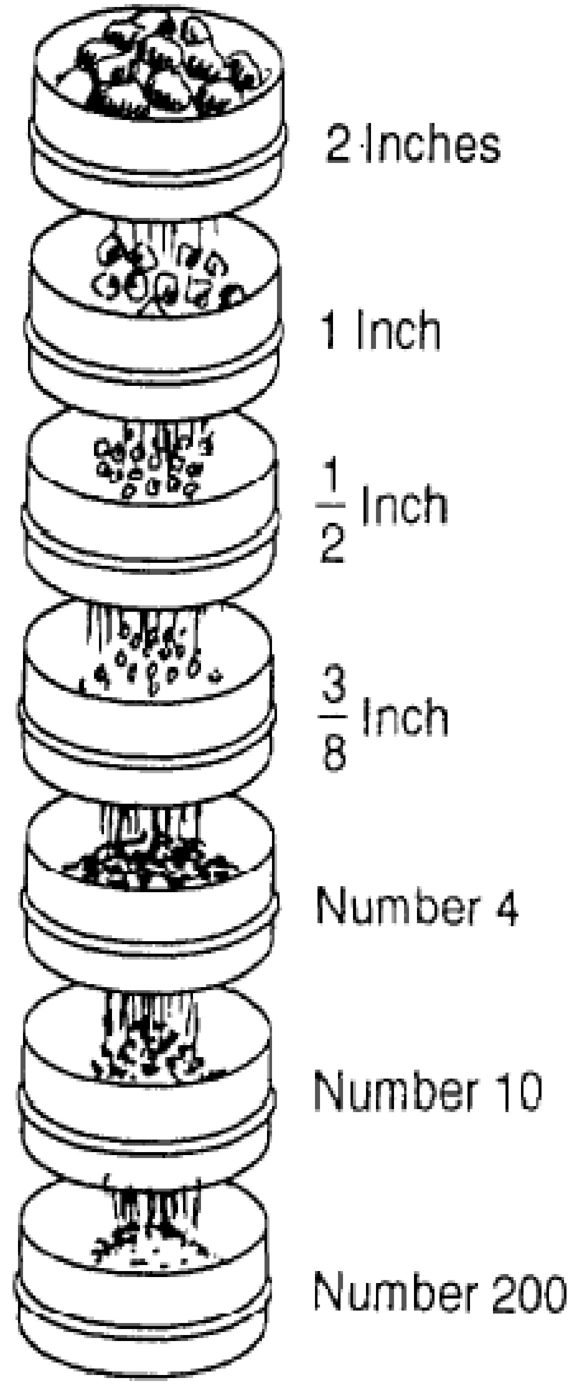


Figure 4-3. Dry sieve analysis.

U.S. Standard Sieve Sizes

Table 2-3
U.S. standard sieve sizes and corresponding opening dimension

U.S. Standard Sieve No.[1]	Sieve Opening (in)	Sieve Opening (mm)	Comment (Based on the Unified Soil Classification System (USCS) discussed in Chapter 4)
3	0.2500	6.35	
4	0.1870	4.75	• Breakpoint between fine gravels and coarse sands • Soil passing this sieve is used for compaction test
6	0.1320	3.35	
8	0.0937	2.36	
10	0.0787	2.00	• Breakpoint between coarse and medium sands
12	0.0661	1.70	
16	0.0469	1.18	
20	0.0331	0.850	
30	0.0234	0.600	
40	0.0165	0.425	• Breakpoint between medium and fine sands • Soil passing this sieve is used for Atterberg limits
50	0.0117	0.300	
60	0.0098	0.250	
70	0.0083	0.212	
100	0.0059	0.150	
140	0.0041	0.106	
200	0.0029	0.075	• Breakpoint between fine sand and silt or clay
270	0.0021	0.053	
400	0.0015	0.038	

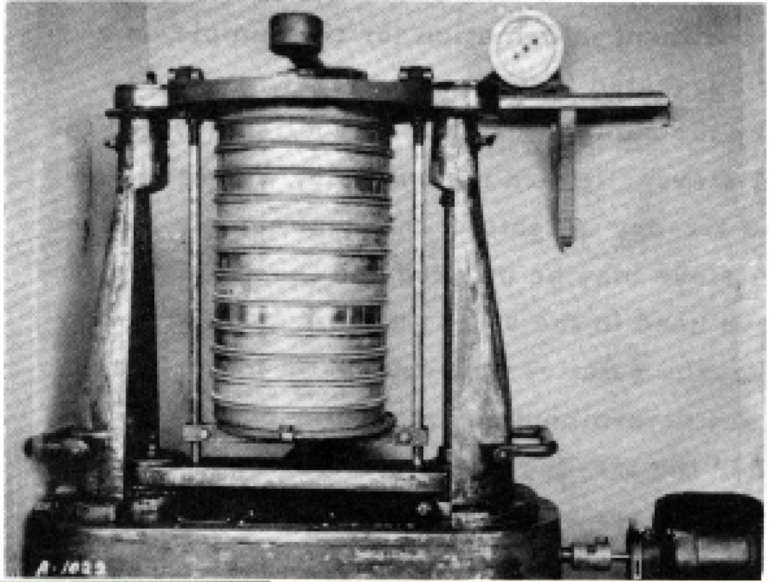
Note:

1. The sieve opening sizes for various sieve numbers listed above are based on Table 1 from ASTM E 11. Sieves with opening size greater than No. 3 are identified by their opening size. Some of these sieves are as follows:

4.0 in	(101.6 mm)	1-1/2 in	(38.1 mm)	½ in	(12.7 mm)
3.0 in	(76.1 mm)*	1-1/4 in	(32.0 mm)	3/8 in	(9.5 mm)
2-1/2 in	(64.0 mm)	1.0 in	(25.4 mm)	5/16 in	(8.0 mm)
2.0 in	(50.8 mm)	¾ in	(19.0 mm)**		
1-3/4 in	(45.3 mm)	5/8 in	(16.0 mm)		

* The 3 in (76.1 mm) sieve size differentiates between cobbles and coarse gravels.
**The ¾ in (19 mm) sieve differentiates between coarse and fine gravels.

Sieve Analysis for Cohesionless Soils



Results of Sieve Analysis

U.S. Standard sieve Nos	Total dry weight of soil sample sieved 200.0 g	Retained on sieve		Cumulative retained		Cumulative passing	
		g	%	g	%	g	%
1	2	3	4	5	6	7	8
	G						
4		0.00	0.00	0.00	0.00	200.00	100.00
10		2.84	1.42	2.84	1.42	197.16	98.58
20		5.66	2.83	8.50	4.25	191.50	95.75
40		46.04	23.02	54.54	27.27	145.46	72.72
60		44.00	22.00	98.54	49.27	101.46	50.73
100		23.64	11.82	122.18	61.09	77.82	38.91
140		11.26	5.63	133.44	66.72	66.56	33.28
200		63.16	31.58	196.60	98.30	3.40	1.70
-200 (Pan)		3.40	1.70	200.00	100.00		
		200.00g	100.00%				

Figure 5-2. Example grain size distribution based on sieve analysis (Jumikis, 1962).

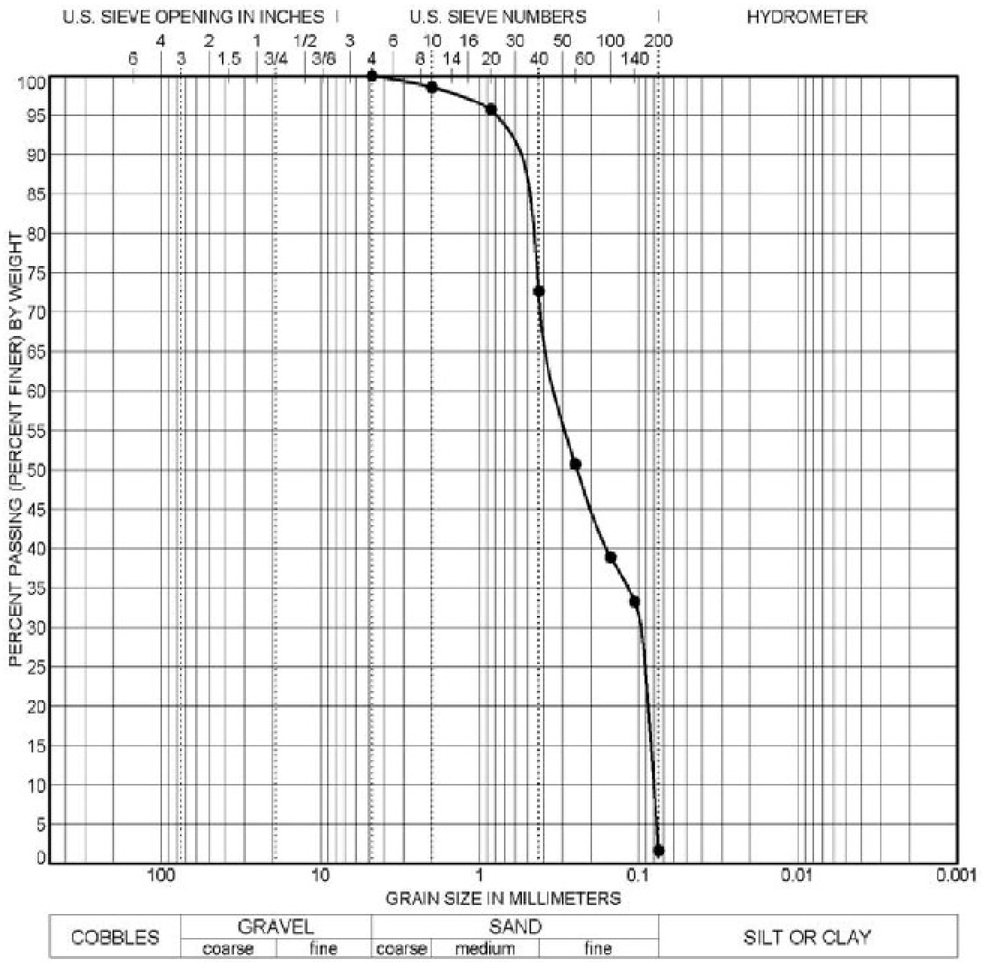
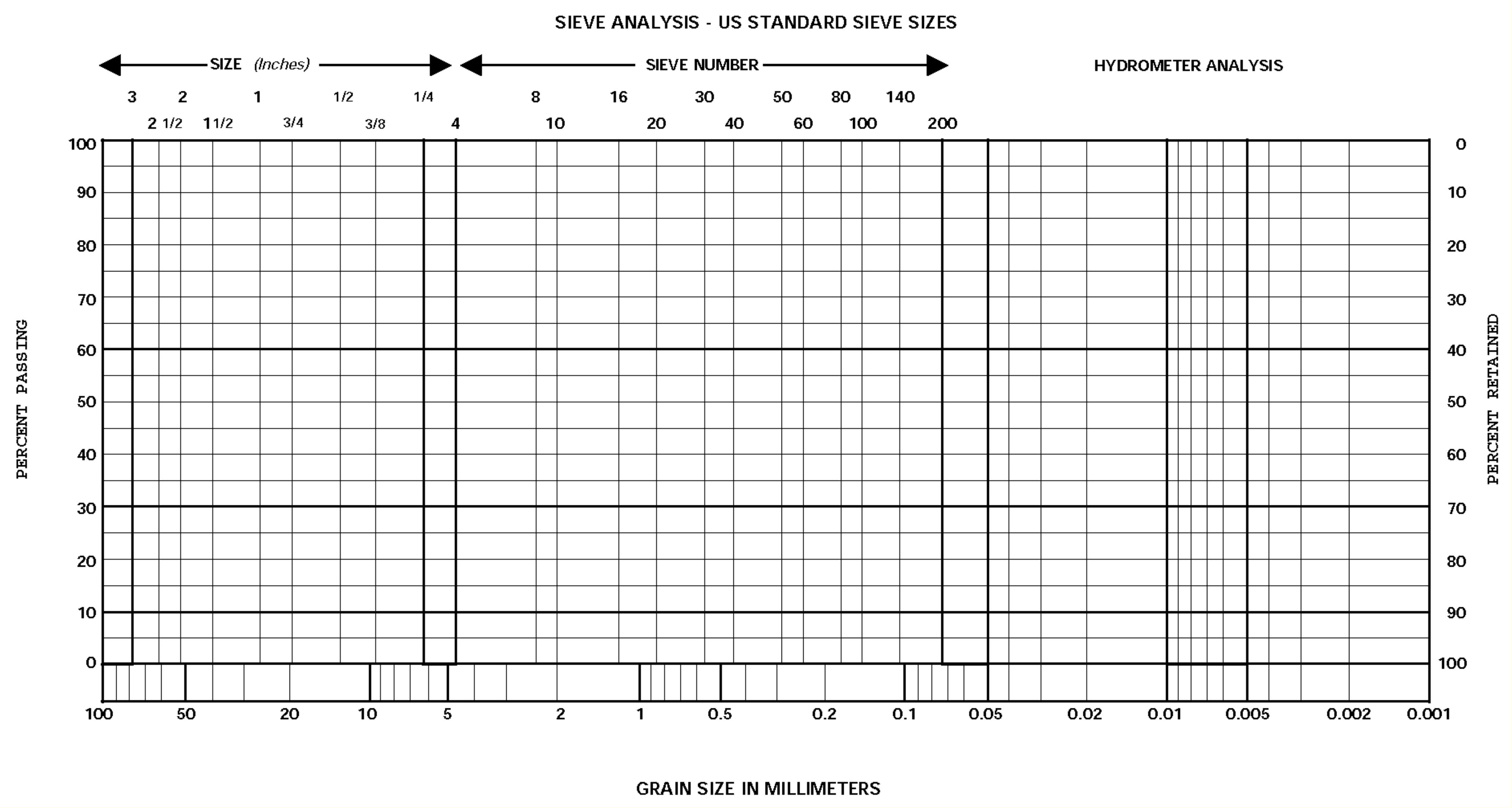


Figure 5-3. Grain size distribution curve based on data in Figure 5-2.

Blank Gradation Chart from DD-1207 (the best to use)



Sample Results of Sieve Analysis

GRAIN-SIZE ANALYSIS (SIEVE METHOD)

1. PROJECT: ENGINEER CENTER EXPANSION		2. DATE: 1 DEC 99
3. JOB NUMBER: 16-P-T	4. EXCAVATION: 5-C	5. DATE COMPLETED: 5 DEC 99
6. NOTES ABOUT SAMPLE/DESCRIPTION: RED IN COLOR, VERY FINE SANDS		7. SAMPLE NUMBER: 5-C-1 8. ORIGINAL SAMPLE WEIGHT: 4404.7
9. PREWASHED: X YES / NO	10. + #200 SAMPLE WEIGHT, WASHED: 2814.2	11. - #200 SAMPLE WEIGHT, WASHED: 1569.7

12. SIEVE SIZE	13. SIEVE WEIGHT	14. SIEVE-SAMPLE WEIGHT	15. WEIGHT RETAINED	16. CUMULATIVE WEIGHT RETAINED	17. PERCENT RETAINED	18. PERCENT PASSING
2"	584.5	584.5	0	0	0	100
1 1/2"	713.6	797.3	83.7	83.7	1.9	98.1
3/4"	577.2	738.2	161.0	244.7	3.7	94.4
1/4"	540.4	1168.4	628.0	872.7	14.3	80.1
#4	506.7	624.5	117.8	990.5	2.7	77.4
#16	464.3	826.9	417.6	1408.1	9.5	67.9
#30	595.6	820.0	224.4	1632.5	5.1	62.7
#40	402.0	634.3	232.3	1864.8	5.3	57.4
#60	533.5	966.4	432.9	2297.7	9.9	47.6
#80	351.4	655.2	303.8	2601.5	6.9	40.6
#100	265.2	328.9	63.7	2665.2	1.5	39.2
#200	347.1	460.7	113.6	2778.8	2.6	36.6

19. TOTAL WEIGHT RETAINED IN SIEVES *(Sum of column 15)*	2778.8	24. ERROR *(8-23)*	25. ERROR IN PERCENTAGE
20. WEIGHT SIEVED THROUGH #200 *(Weight in pan)*	32.9		$\left(\frac{24}{8}\right) \times 100 =$
21. WASHING LOSS *(8 - (10+11))*	26.8	4404.7 -4381.4	$\frac{23.3}{4404.7} \times 100 = 0.5\%$
22. TOTAL WEIGHT PASSING #200 SIEVE *(20+11)*	1602.6	23.3	
23. TOTAL WEIGHT OF FRACTIONS *(19+22)*	4381.4		

26. PERCENT GRAVEL *(% G)*	27. PERCENT SAND *(% S)*	28. PERCENT FINES *(% F)*	29. DECIMAL FINES *(% F ÷ 100)*
22.6%	40.8%	36.6%	0.366

30. REMARKS

USCS SC w/GRAVEL

SAMPLE

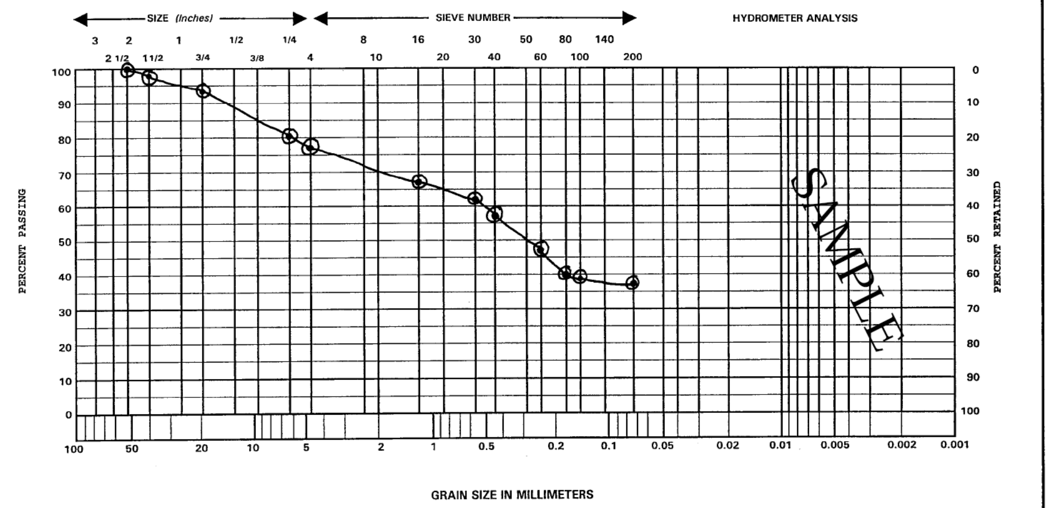
31. TECHNICIAN *(Signature)*	32. COMPUTED BY *(Signature)*	33. CHECKED BY *(Signature)*
PV2 Dishman	PV2 Dishman	SSG Dobbs WD

DD FORM 1206, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADATION CHART

1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION 16-P-T	6 DEC 99

SIEVE ANALYSIS - US STANDARD SIEVE SIZES



EXCAVATION NUMBER	SAMPLE NUMBER	LL	PL	PI	Cu (D_{60}/D_{10})	Cc $(D_{30})^2/(D_{60} \times D_{10})$	SOIL DESCRIPTION/REMARKS	CLASSIFICATION (USCS)
5-C	5-C-1	20	10	10	N/A	N/A	RED IN COLOR, VERY FINE SANDS.	SC

3. TECHNICIAN *(Signature)*	4. PLOTTED BY *(Signature)*	5. CHECKED BY *(Signature)*
PV2 Dishman	PV2 Dishman	SSG Dobbs WD

DD FORM 1207, DEC 1999 PREVIOUS EDITION IS OBSOLETE.

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

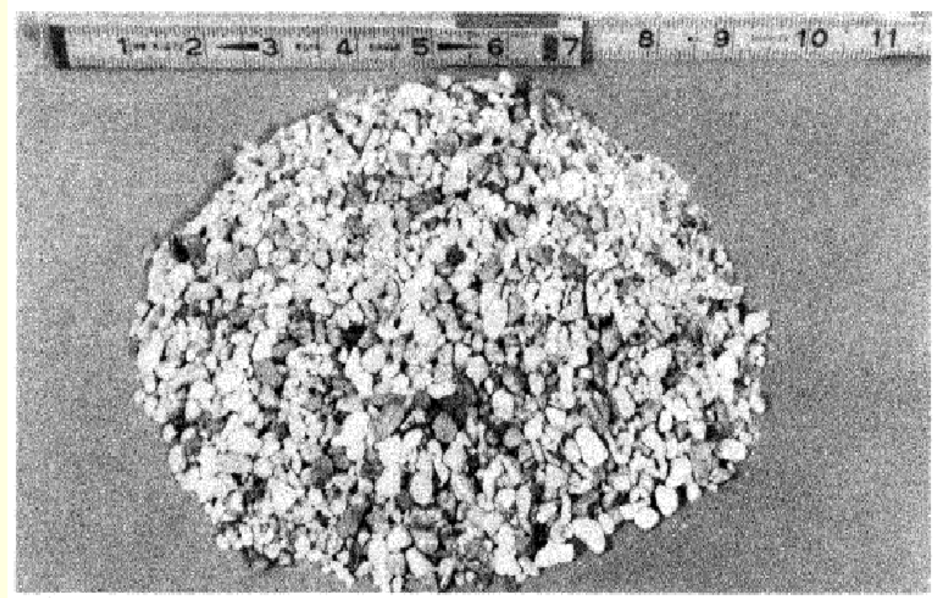
Gradation based on C_u and C_c parameters

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.

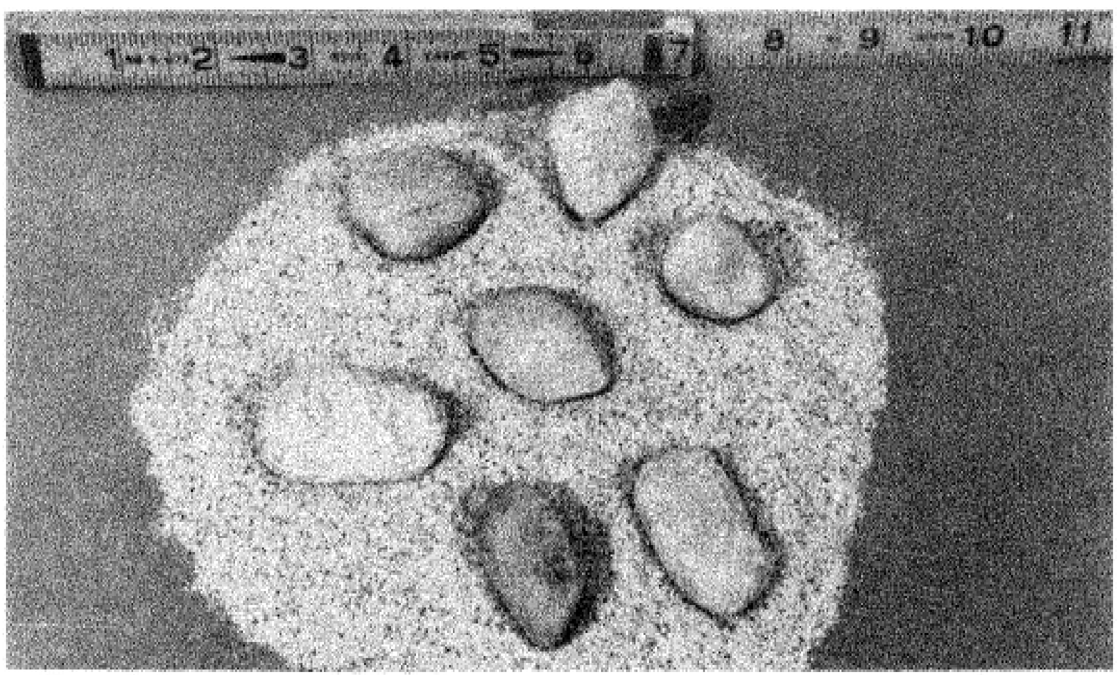
Soil Gradation

a. Well graded



b. Uniformly or poorly graded

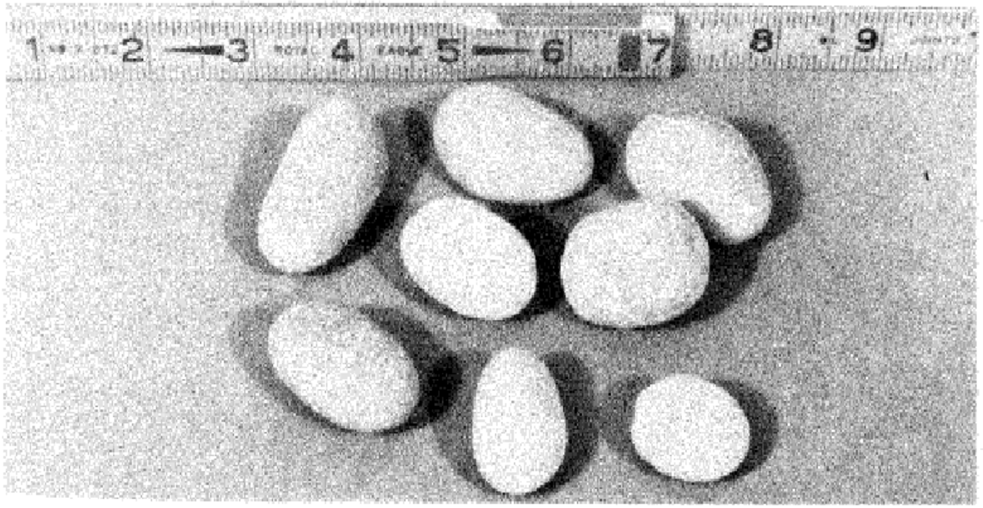
Figure E-2. Photographs of several soils to aid in selecting terms for describing the gradations of coarse-grained soils (Continued)



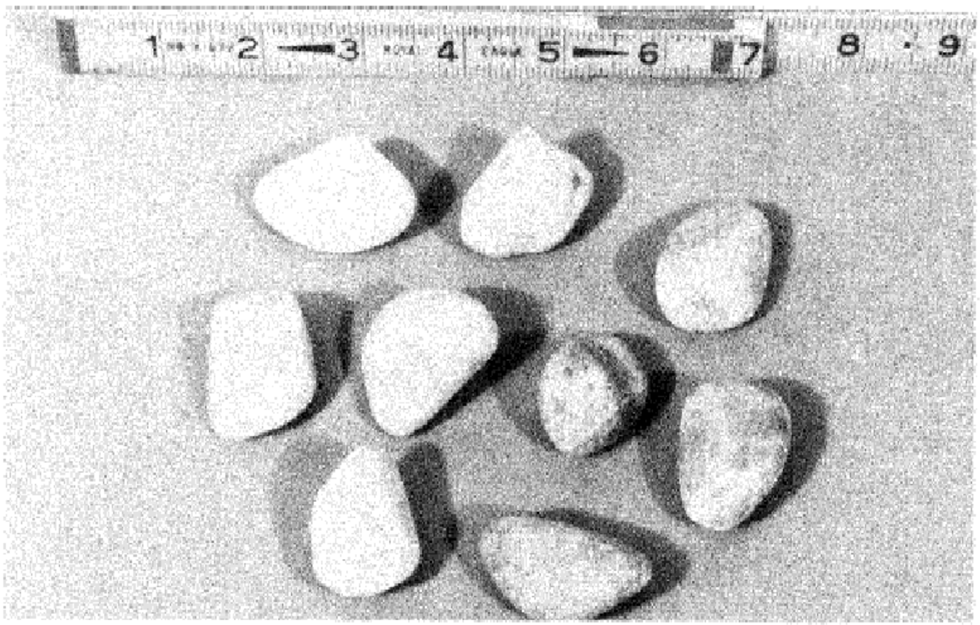
c. Gap graded

Figure E-2. (Concluded)

Angularity

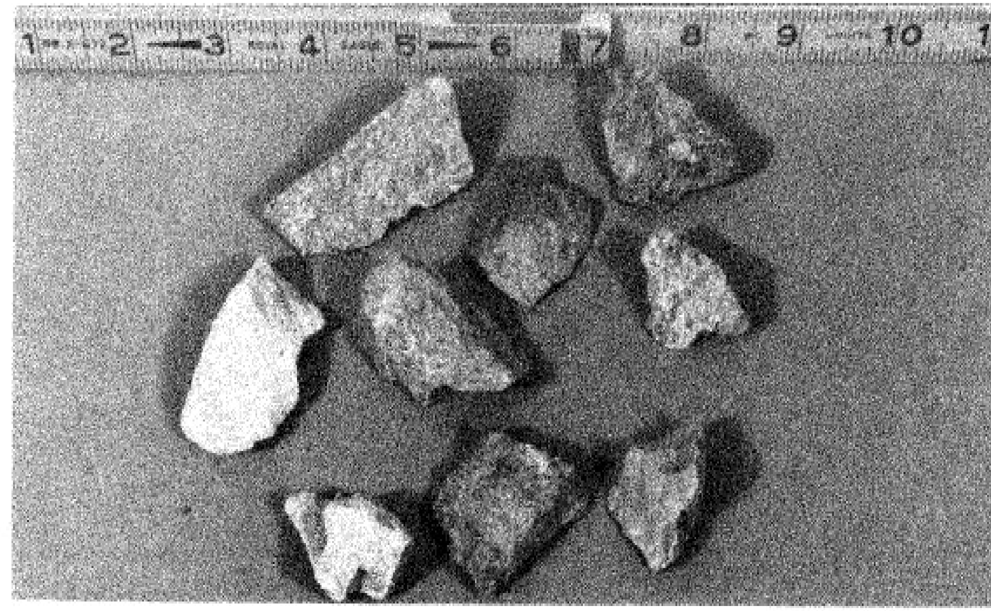


a. Rounded

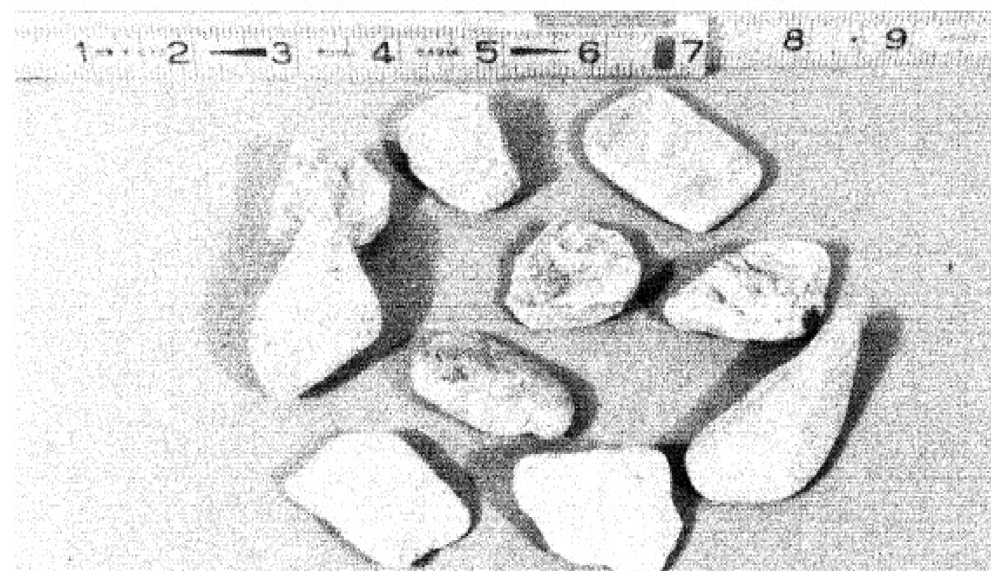


b. Subrounded

Figure E-3. Photographs of several soils to aid in selecting terms for describing the grain shape of coarse-grained soils (Continued)



c. Subangular

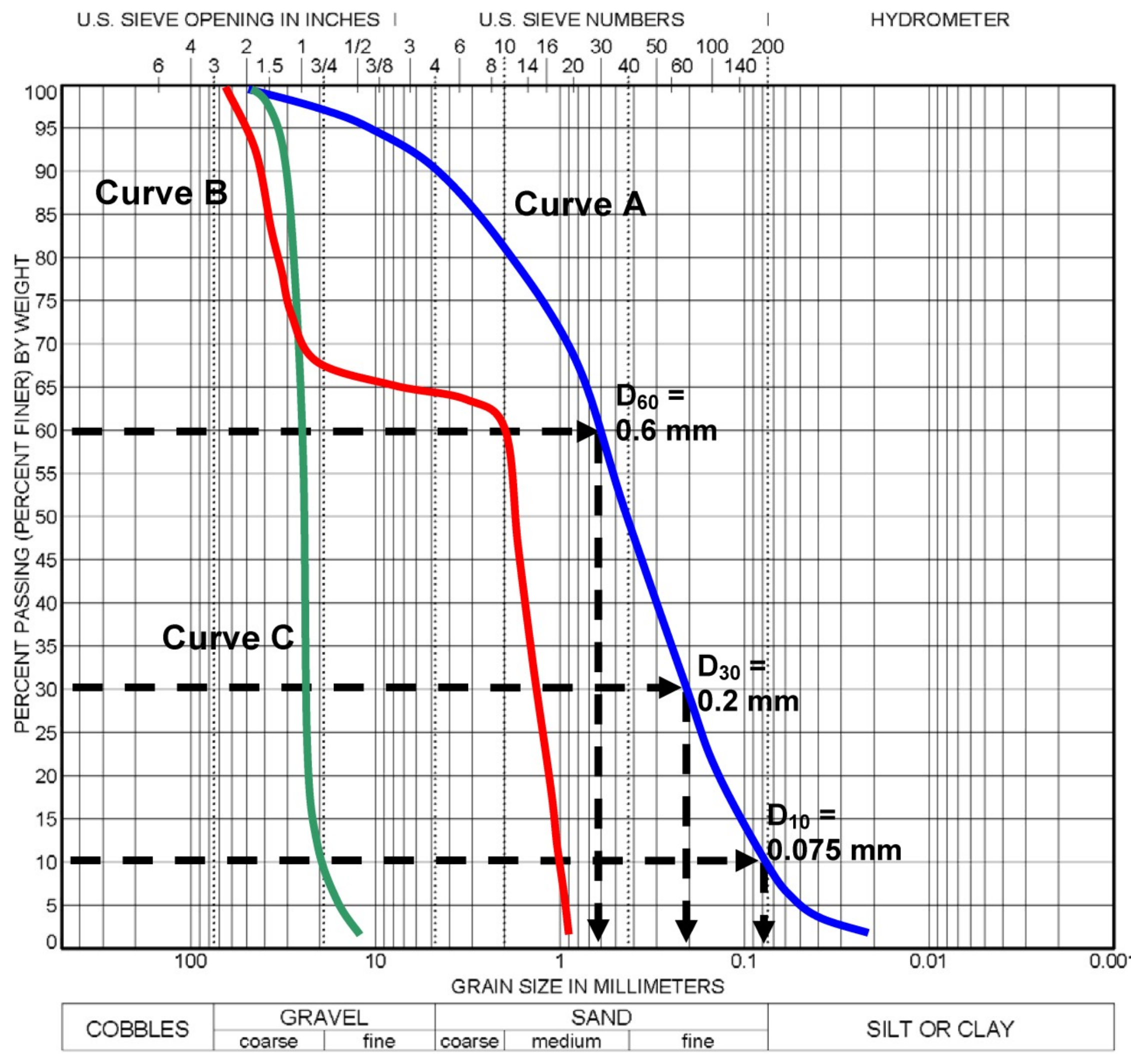


d. Angular

Figure E-3. (Concluded)

Angular particled soils generally exhibit better engineering properties; also can frequently pass larger particles through a given sieve size

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.

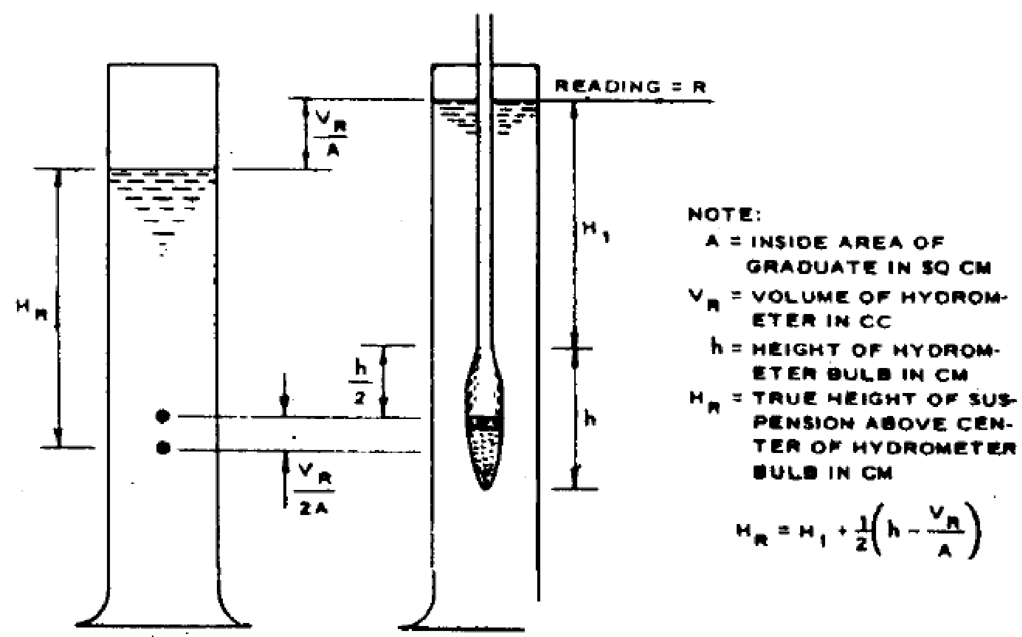
Hydrometer Test (for fraction smaller than #200 sieve)

For particles smaller than about 0.05 mm the grain size can not be determined by sieving, because the size of the holes in the mesh would become unrealistically small, and also because during shaking the small particles might fly up in the air, as dust. The amount of particles of a particular size can then be determined much better by measuring the velocity of deposition in a glass of water. This method is based upon a

formula derived by Stokes. This formula expresses that the force on a small sphere, sinking in a viscous fluid, depends upon the viscosity of the fluid, the size of the sphere and the velocity. Because the force acting upon the particle is determined by the weight of the particle under water, the velocity of sinking of a particle in a fluid can be derived. The formula is

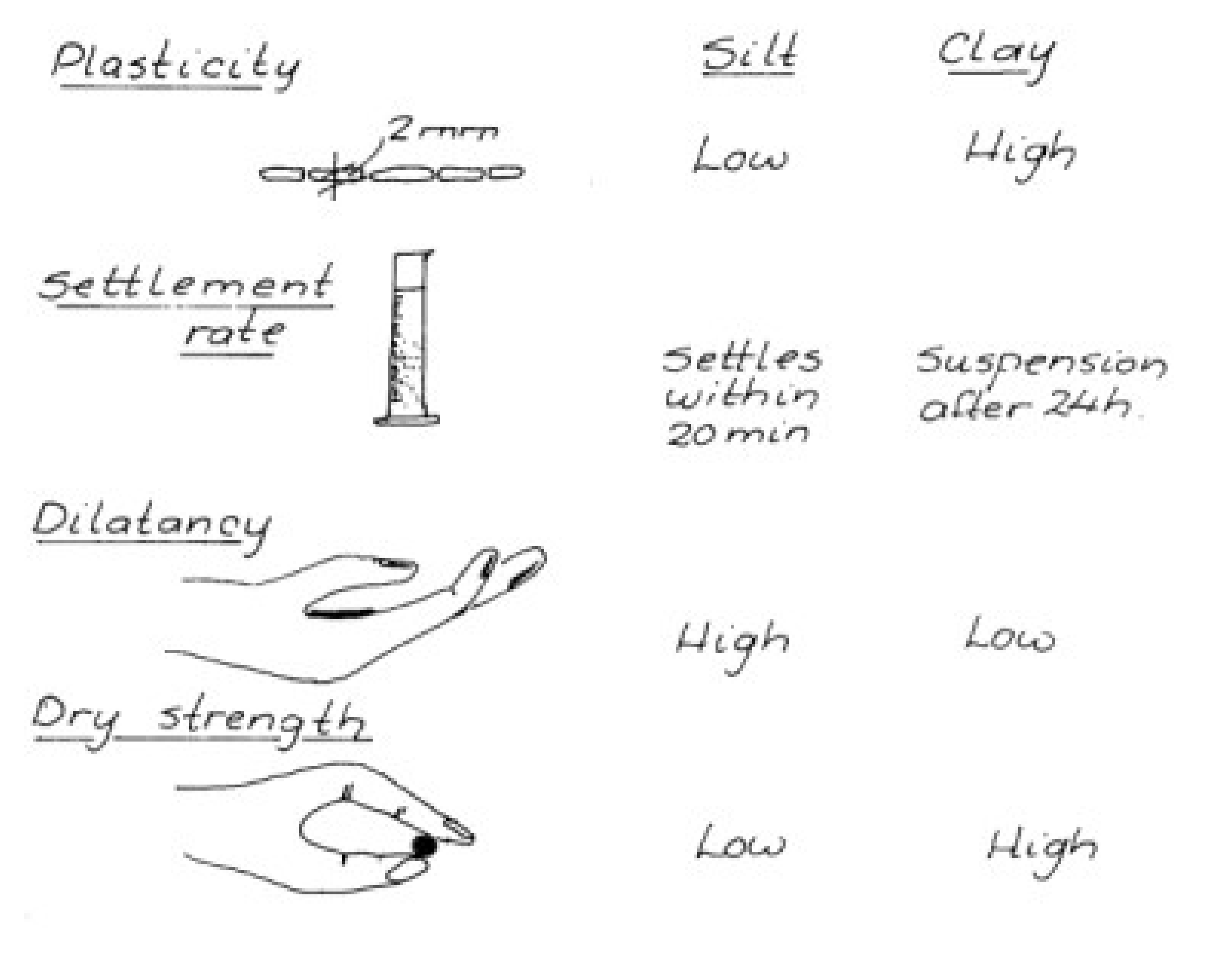
$$v = \frac{(\gamma_p - \gamma_f)D^2}{18\mu}, \tag{2.2}$$

where γ_p is the volumetric weight of the particle, γ_f is the volumetric weight of the fluid, D is the grain size, and μ is the dynamic viscosity of the fluid. Because for very small particles the velocity may be very small, the test may take rather long.



a. DETERMINATION OF TRUE HEIGHT OF SUSPENSION ABOVE CENTER OF HYDROMETER BULB

Properties of Clay Soils



States of Clay Soils

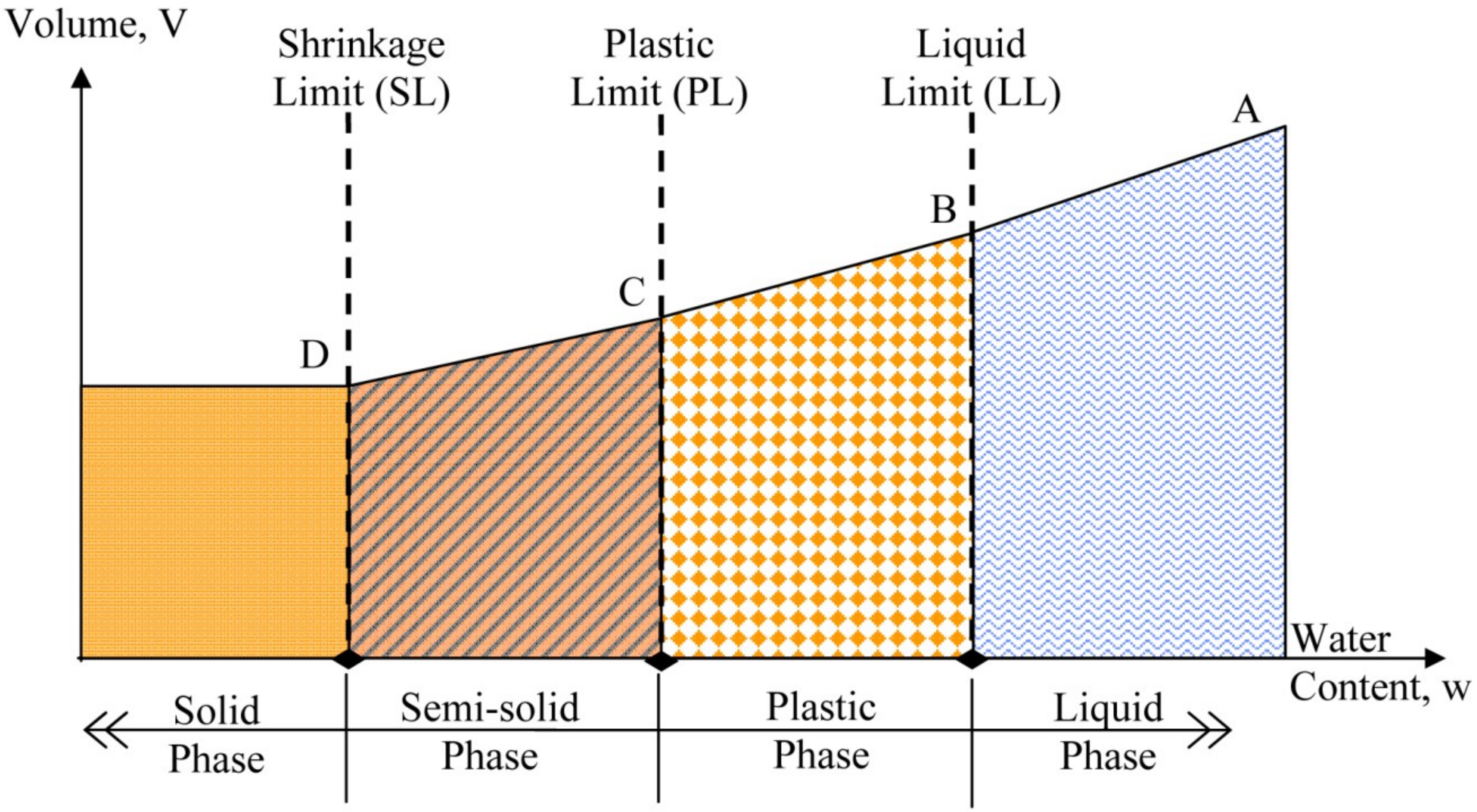


Figure 2-5. Conceptual changes in soil phases as a function of water content.

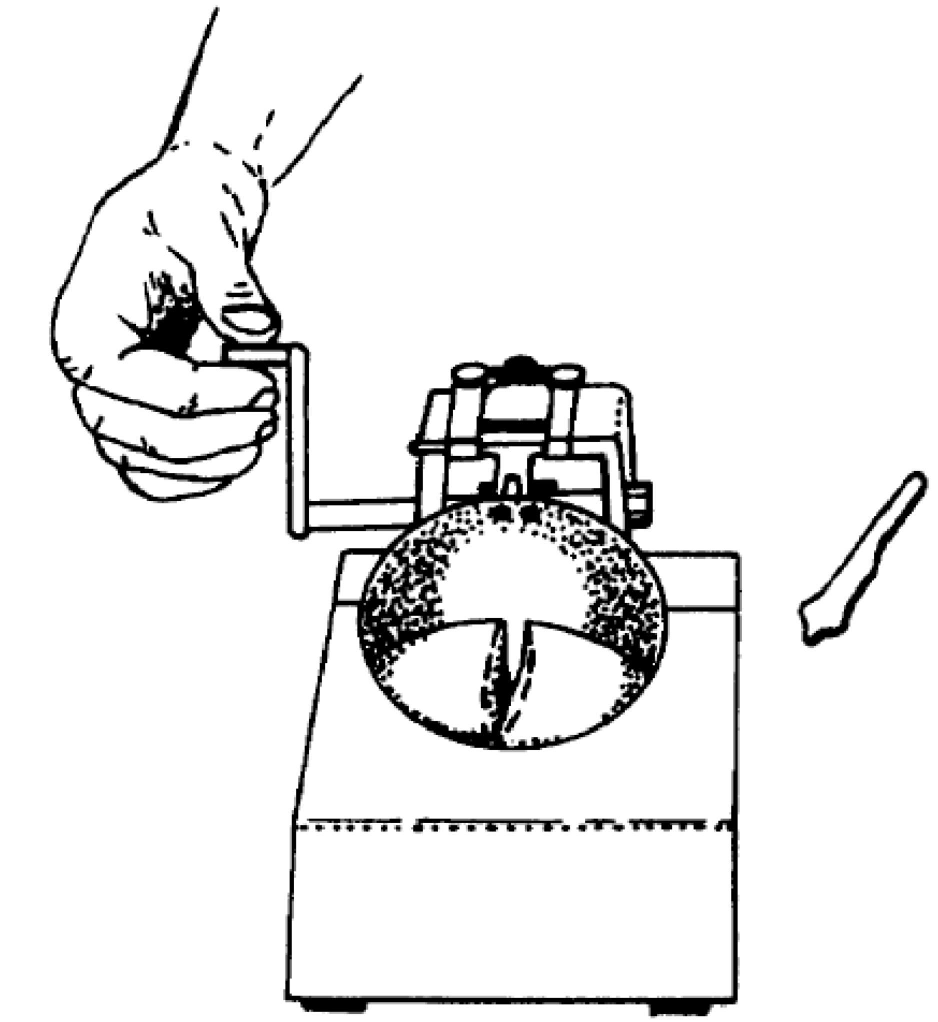
Atterberg Limits

- Shrinkage Limit (SL)
- Plastic Limit (PL)
- Liquid Limit (LL)
- Plasticity Index PI = LL – PL
- Liquidity Index LI = (w-PL)/PI
- Consistency Index CI or I_c = (LL-w)/PI
- The more plastic a soil, it will:
  - Be more compressible
  - Have higher shrink-swell potential
  - Be less permeable

- Help identify and classify the soil.
- PI (plasticity index) is an indicator of soil compressibility and potential for volume change.
- PL (plastic limit) can indicate if clay has been preconsolidated. Most soils are deposited at or near their liquid limit. If the in situ natural water content (w) is near the plastic limit (PL), then the soil is probably preconsolidated. Some stress has been applied in the past to squeeze that water out.
- PL, LL, PI, LI and CI are always expressed as percentages

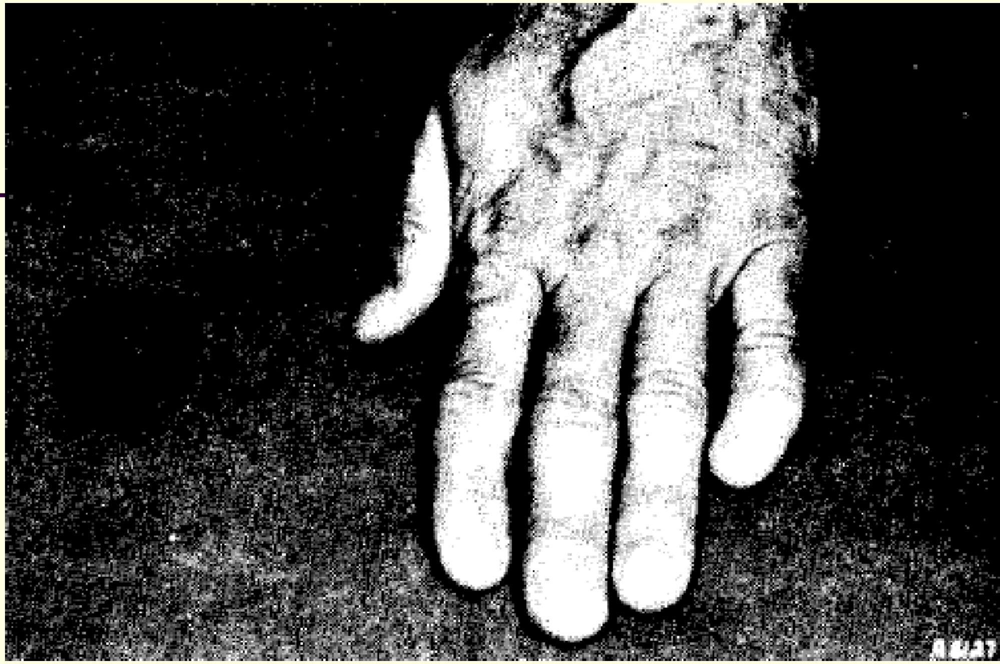
Liquid Limit Test

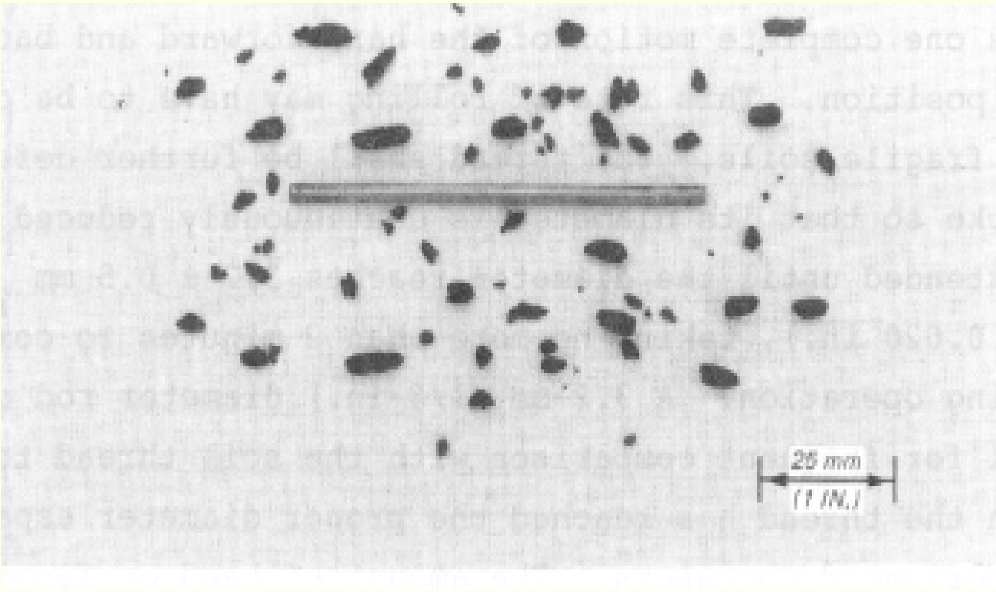
- Several samples are prepared with varying moisture contents
- Specimens placed in bottom of cup and split with grooving tool
- Crank turned and cup is impacted until groove is closed
- LL is moisture content at which groove closes with 25 blows



Plastic Limit Test

- Samples prepared at varying moisture contents
- Sample rolled out on glass plate to 4.2 mm (1/8”) diameter
- PL is defined as the moisture content at which rolled sample crumbles





Liquid and Plastic Limit Test Sample Results

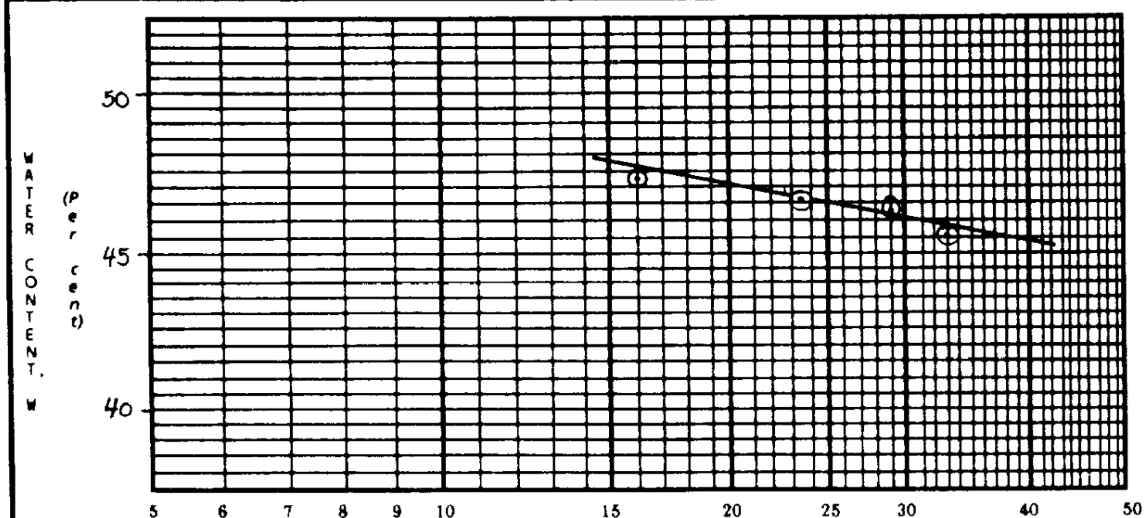
ATTERBERG LIMITS DETERMINATION

PROJECT Britt Airfield	**EXCAVATION NUMBER** 2 + 81	**SAMPLE NUMBER** B-P3-1	**DATE** 2 APR 1970

LIQUID LIMIT, W_L

RUN NUMBER	1	2	3	4		
TARE NUMBER	41	42	43	44		
A. WEIGHT OF WET SOIL + TARE	44.41	44.89	41.07	41.27		
B. WEIGHT OF DRY SOIL + TARE	41.08	41.52	38.16	38.39		
C. WEIGHT OF WATER, W_W *(A. - B.)*	3.33	3.37	2.91	2.88		
D. WEIGHT OF TARE	34.04	34.29	31.88	32.06		
E. WEIGHT OF DRY SOIL, W_s *(B. - D.)*	7.04	7.23	6.28	6.33		
WATER CONTENT, $w = (\frac{W_W}{W_s} \times 100)$	47.3	46.6	46.3	45.5		
NUMBER OF BLOWS	15-17-16	23-24	29-28-30	33-33		

W_L LL = 46	W_P PL = 18	I_P $(W_L - W_P)$ PI = 28



PLASTIC LIMIT, W_P

RUN NUMBER	1	2	3		NATURAL WATER CONTENT
TARE NUMBER	45	46	47		48
F. WEIGHT OF WET SOIL + TARE	56.21	55.15	60.60		58.72
G. WEIGHT OF DRY SOIL + TARE	55.90	54.89	60.10		57.82
H. WEIGHT OF WATER, W_W *(F. - G.)*	0.31	0.26	0.50		0.90
I. WEIGHT OF TARE	54.10	53.40	57.43		55.02
J. WEIGHT OF DRY SOIL, W_s *(G. - I.)*	1.80	1.49	2.67		2.80
WATER CONTENT, $w = (\frac{W_w}{W_s} \times 100)$	17.2	17.4	18.7		32.1
PLASTIC LIMIT, I_P *(Average w)*					

REMARKS: Casagrande grooving tool used in liquid limits (LL) test.

TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*
W. Denton	W. Denton	J. Shapher

DD Form 1209, AUG 57

Atterberg Limit Example

- Given soil with following Atterberg Limits:
  - LL = 46
  - PL = 18
- Find
  - Plasticity Index
  - Shrinkage Limit Using Holtz and Kovacs' "Quick and Dirty Method"

- Solution
  - PI = LL – PL
  - PI = 46 – 18
  - PI = 28
  - Holtz and Kovacs Method for SL in equation form:

$$SL \approx \frac{46.4LL - 43.5PI}{PI + 46.4}$$

$$SL \approx \frac{46.4 \times 46 - 43.5 \times 28}{28 + 46.4}$$

$$SL \approx 12$$

Consistency

- Refers to the texture and strength of a cohesive soil
- Can be measured in the field with pocket penetrometers, vane shear or torvane testers

TABLE 4-7 EMPIRICAL VALUES FOR UNCONFINED COMPRESSIVE STRENGTH (q_u) AND CONSISTENCY OF COHESIVE SOILS BASED ON UNCORRECTED N

(after Bowles, 1977)

Consistency	Very Soft	Soft	Medium	Stiff	Very Stiff	Hard
q_u, kPa (ksf)	0 – 24 (0 – 0.5)	24 – 48 (0.5 – 1.0)	48 – 96 (1.0 – 2.0)	96 – 192 (2.0 – 4.0)	192 – 384 (4.0 – 8.0)	384+ (8.0+)
Standard Penetration N value	0 - 2	2 - 4	4 – 8	8 - 16	16 - 32	32+
γ (saturated), kN/m^3 (lb/ft^3)	15.8 - 18.8 (100 – 120)	15.8 - 18.8 (100 – 120)	17.3 - 20.4 (110 – 130)	18.8 - 22.0 (120 – 140)	18.8 - 22.0 (120 – 140)	18.8 - 22.0 (120 – 140)

The undrained shear strength is 1/2 of the unconfined compressive strength.

Correlations are unreliable. Use for preliminary estimates only.

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

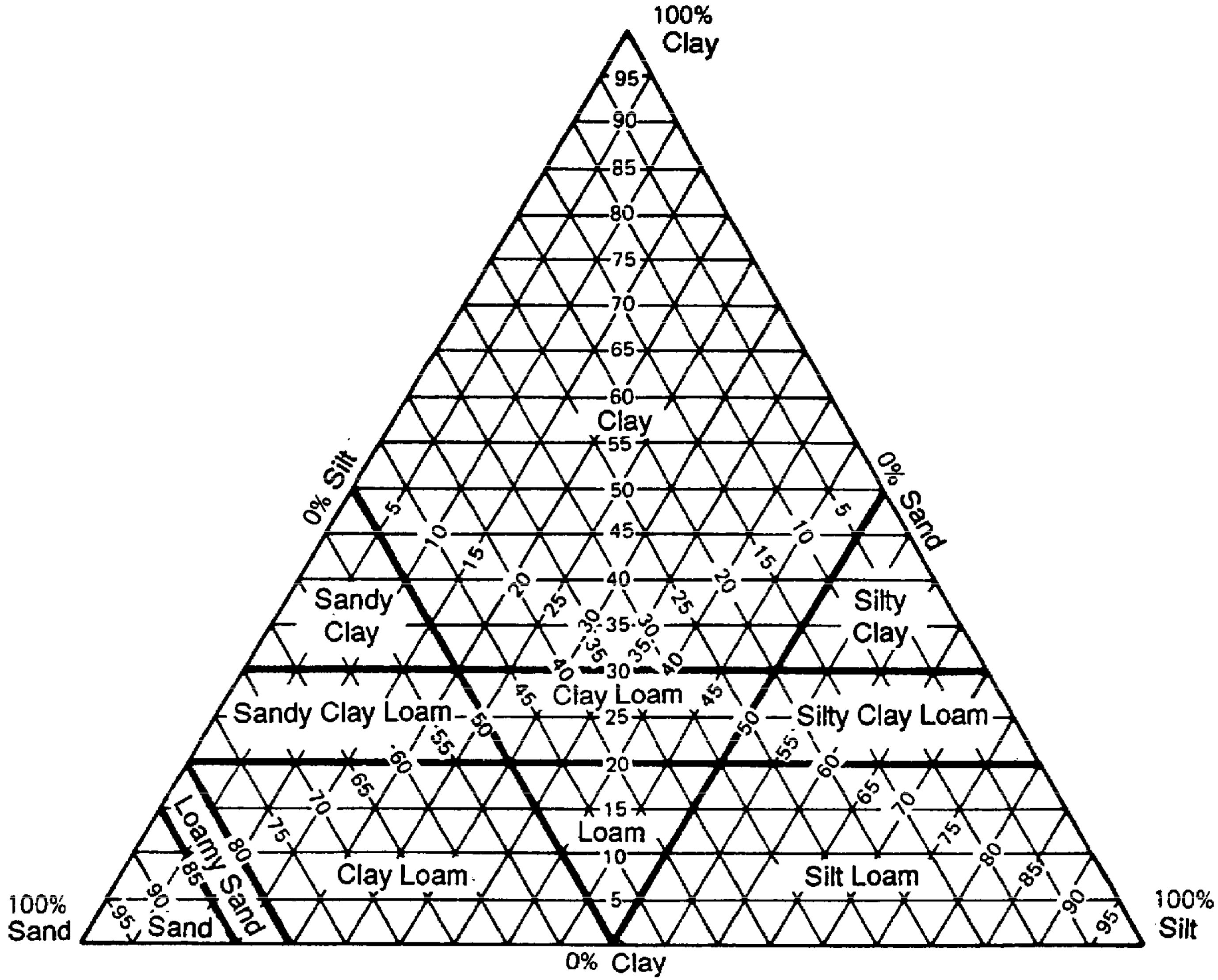


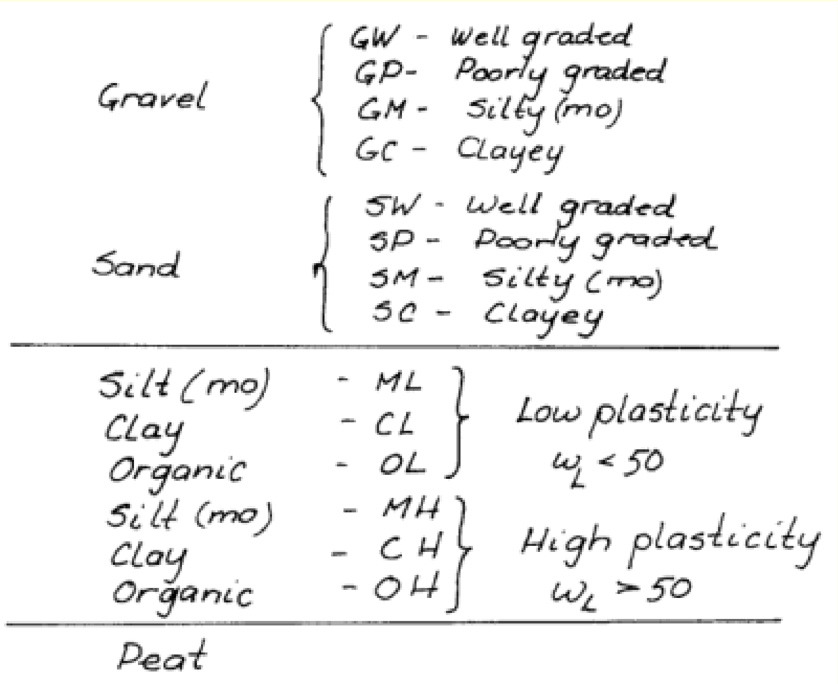
Figure 5-10. US Department of Agriculture textural classification chart.

Unified Classification System

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

SM

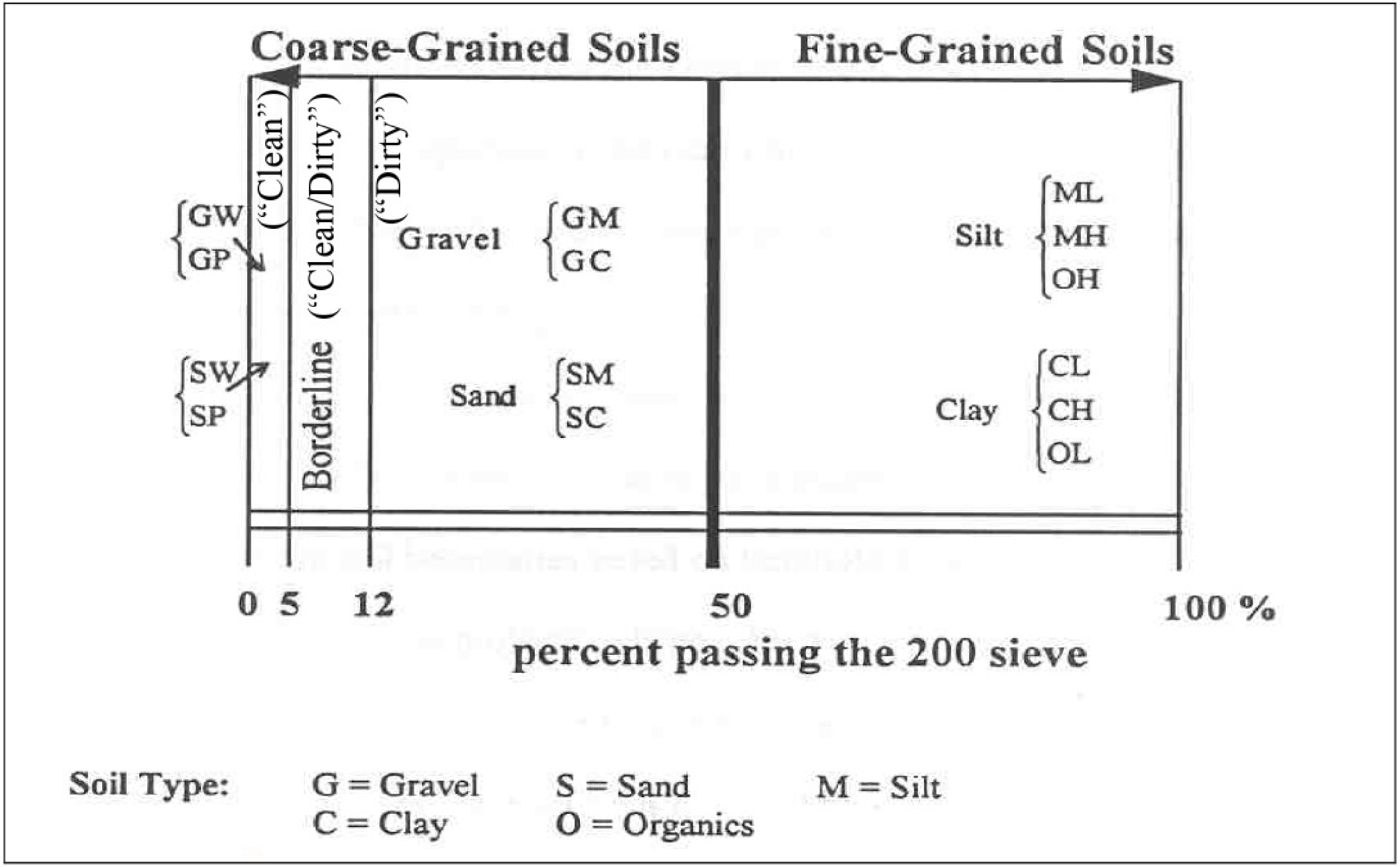
- Secondary Characteristics
  - W: well graded
  - P: poorly graded
  - M: silty (as opposed to a predominant silt in the left column)
  - C: clayey (as opposed to a predominant clay in the left column)
  - L: lean (LL < 50)
  - H: fat (LL > 50)



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)



Soil Classification Chart (Laboratory Method)

Table 4-9

Soil classification chart (laboratory method) (after ASTM D 2487)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[a] **COARSE-GRAINED SOILS (Sands and Gravels)** - more than 50% retained on No. 200 (0.075 mm) sieve **FINE-GRAINED (Silts and Clays)** - 50% or more passes the No. 200 (0.075 mm) sieve			Soil Classification	
			Group Symbol	**Group Name**[b]
GRAVELS More than 50% of coarse Fraction retained on No. 4 Sieve	CLEAN GRAVELS < 5% fines	$C_u \geq 4$ and $1 \leq C_c \leq 3$[e]	GW	Well-graded gravel[f]
		$C_u < 4$ and/or $1 > C_c > 3$[e]	GP	Poorly-graded gravel[f]
	GRAVELS WITH FINES > 12% of fines[c]	Fines classify as ML or MH	GM	Silty gravel[f,g,h]
		Fines classify as CL or CH	GC	Clayey gravel[f,g,h]
SANDS 50% or more of coarse fraction passes No. 4 Sieve	CLEAN SANDS < 5% fines[d]	$C_u > 6$ and $1 < C_c < 3$[e]	SW	Well-graded Sand[i]
		$C_u < 6$ and/or $1 > C_c > 3$[e]	SP	Poorly-graded sand[i]
	SANDS WITH FINES > 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]
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	$\frac{\text{Liquid limit - overdried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay[k,l,m,n]
				Organic silt[k,l,m,o]
SILTS AND CLAYS 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 fibrous organic soils	Primary organic matter, dark in color, and organic odor		Pt	Peat

Table 4-9 (Continued)

Soil classification chart (laboratory method) (after ASTM D 2487)

NOTES:

a Based on the material passing the 3 in (75 mm) sieve.

b If field sample contained cobbles and/or boulders, add "with cobbles and/or boulders" to group name.

c Gravels with 5 to 12% fines require dual symbols:
GW-GM, well-graded gravel with silt
GW-GC, well-graded gravel with clay
GP-GM, poorly graded gravel with silt
GP-GC, poorly graded gravel with clay

d Sands with 5 to 12% fines require dual symbols:
SW-SM, well-graded sand with silt
SW-SC, well-graded sand with clay
SP-SM, poorly graded sand with silt
SP-SC, poorly graded sand with clay

e $C_u = \frac{D_{60}}{D_{10}} \quad C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})}$
[C_u: Uniformity Coefficient; C_c: Coefficient of Curvature]

f If soil contains ≥ 15% sand, add "with sand" to group name.

g If fines classify as CL-ML, use dual symbol GC-GM, SC-SM.

h If fines are organic, add "with organic fines" to group name.

i If soil contains ≥ 15% gravel, add "with gravel" to group name.

j If the liquid limit and plasticity index plot in hatched area on plasticity chart, soil is a CL-ML, silty clay.

k If soil contains 15 to 29% plus No. 200 (0.075 mm), add "with sand" or "with gravel," whichever is predominant.

l If soil contains ≥ 30% plus No. 200 (0.075mm), predominantly sand, add "sandy" to group name.

m If soil contains ≥ 30% plus No. 200 (0.075 mm), predominantly gravel, add "gravelly" to group name.

n PI ≥ 4 and plots on or above "A" line.

o PI < 4 or plots below "A" line.

p PI plots on or above "A" line.

q PI plots below "A" line.

Plasticity Chart

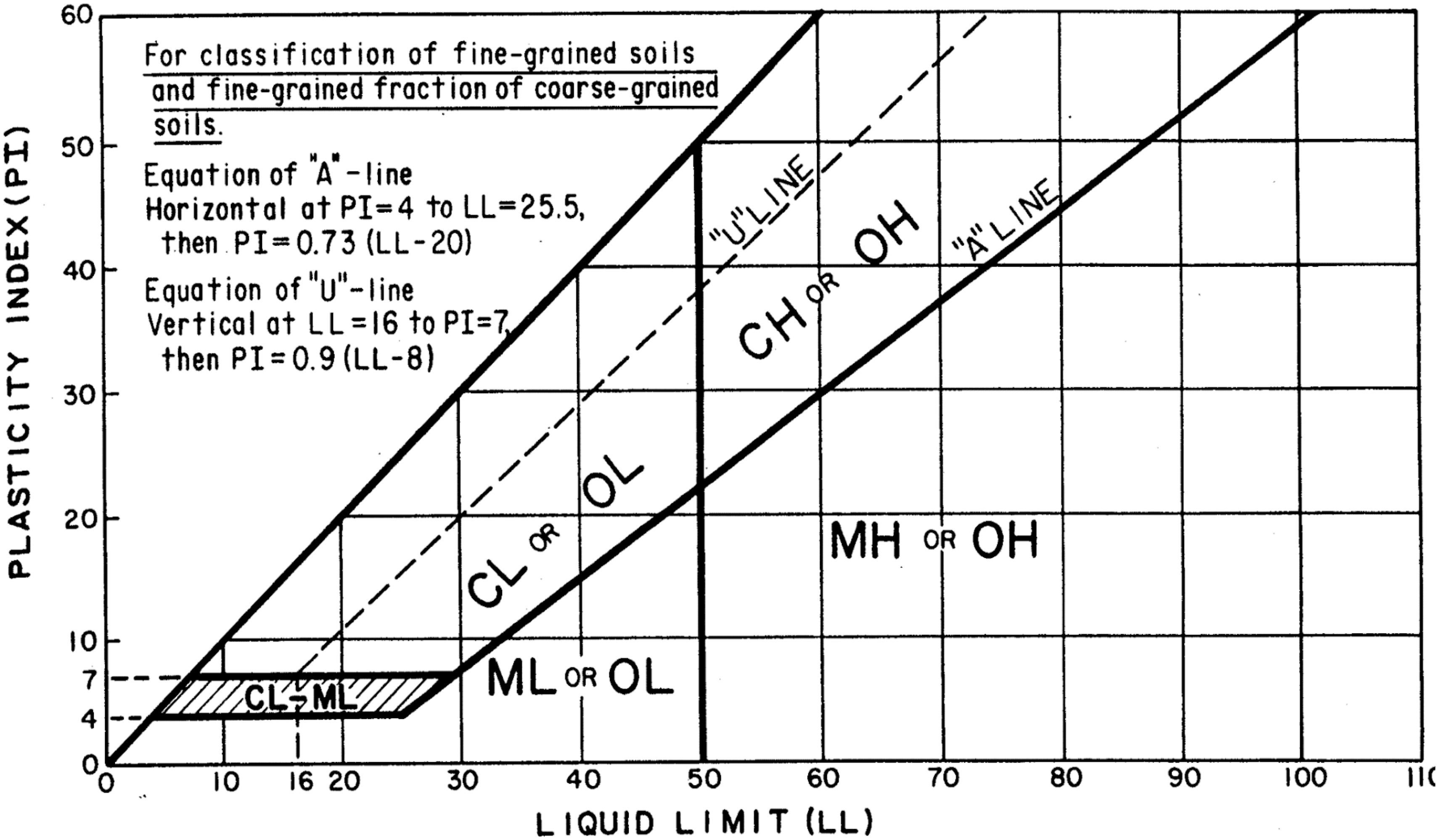
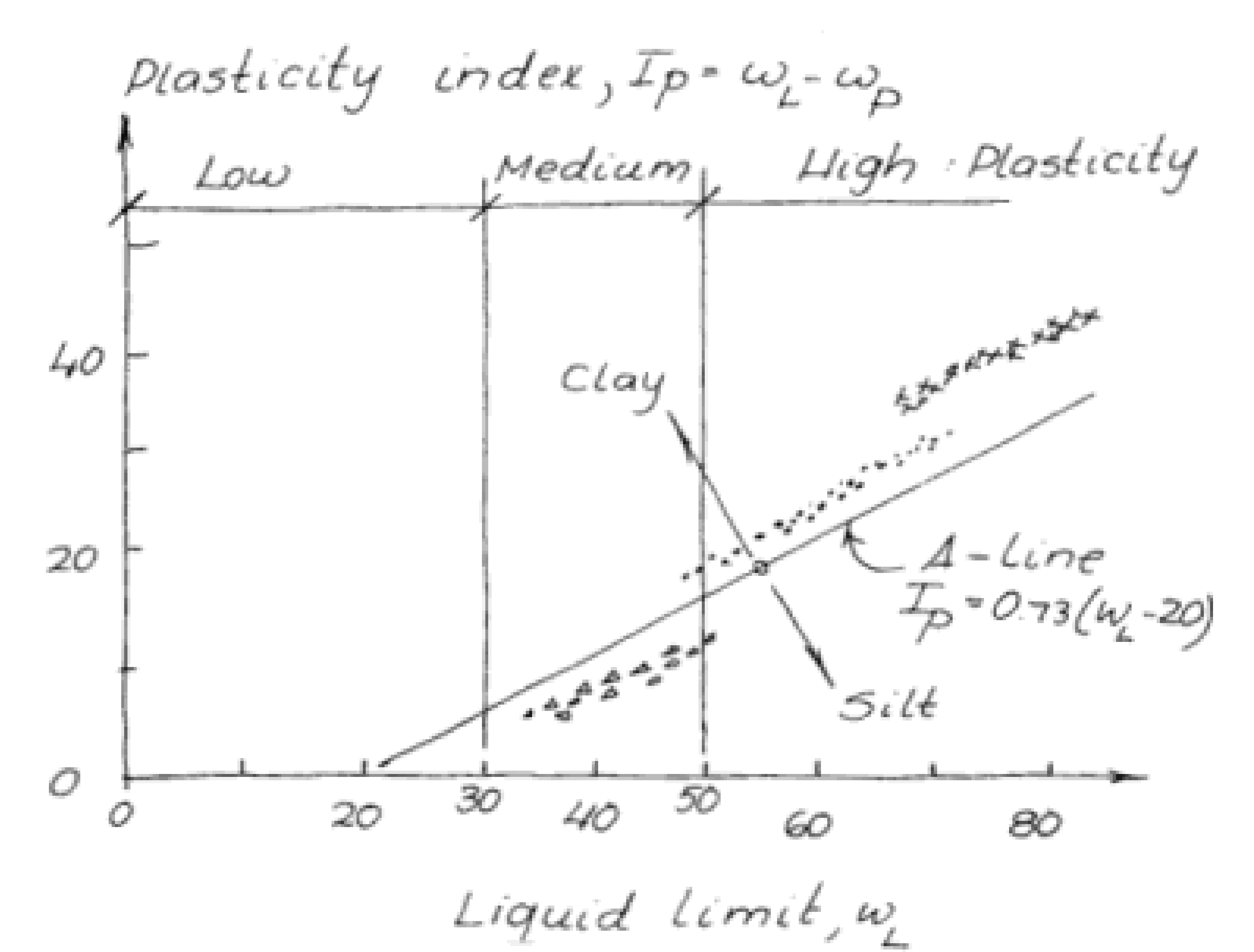
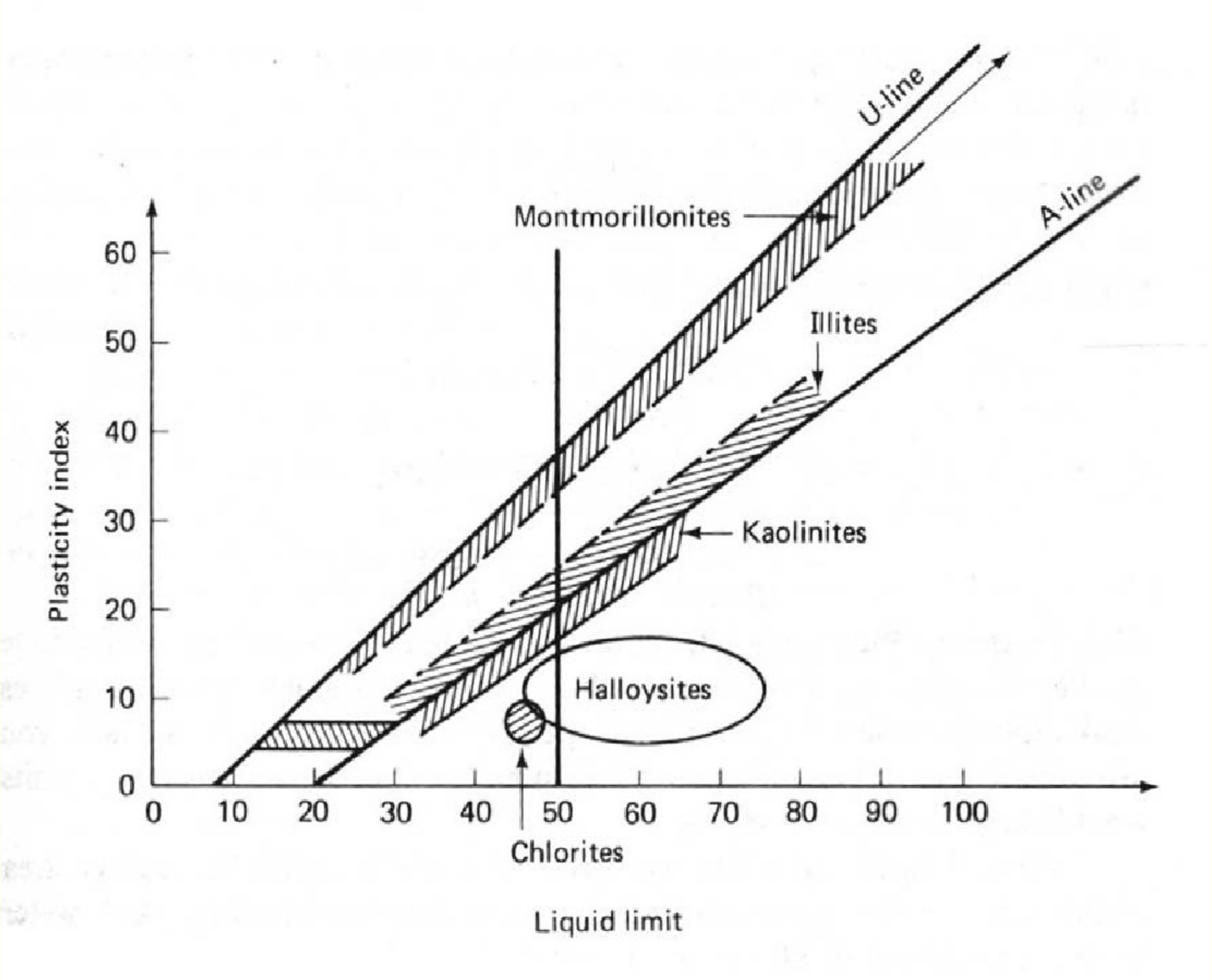


Figure 4-3. Plasticity chart for Unified Soil Classification System (ASTM D 2487).

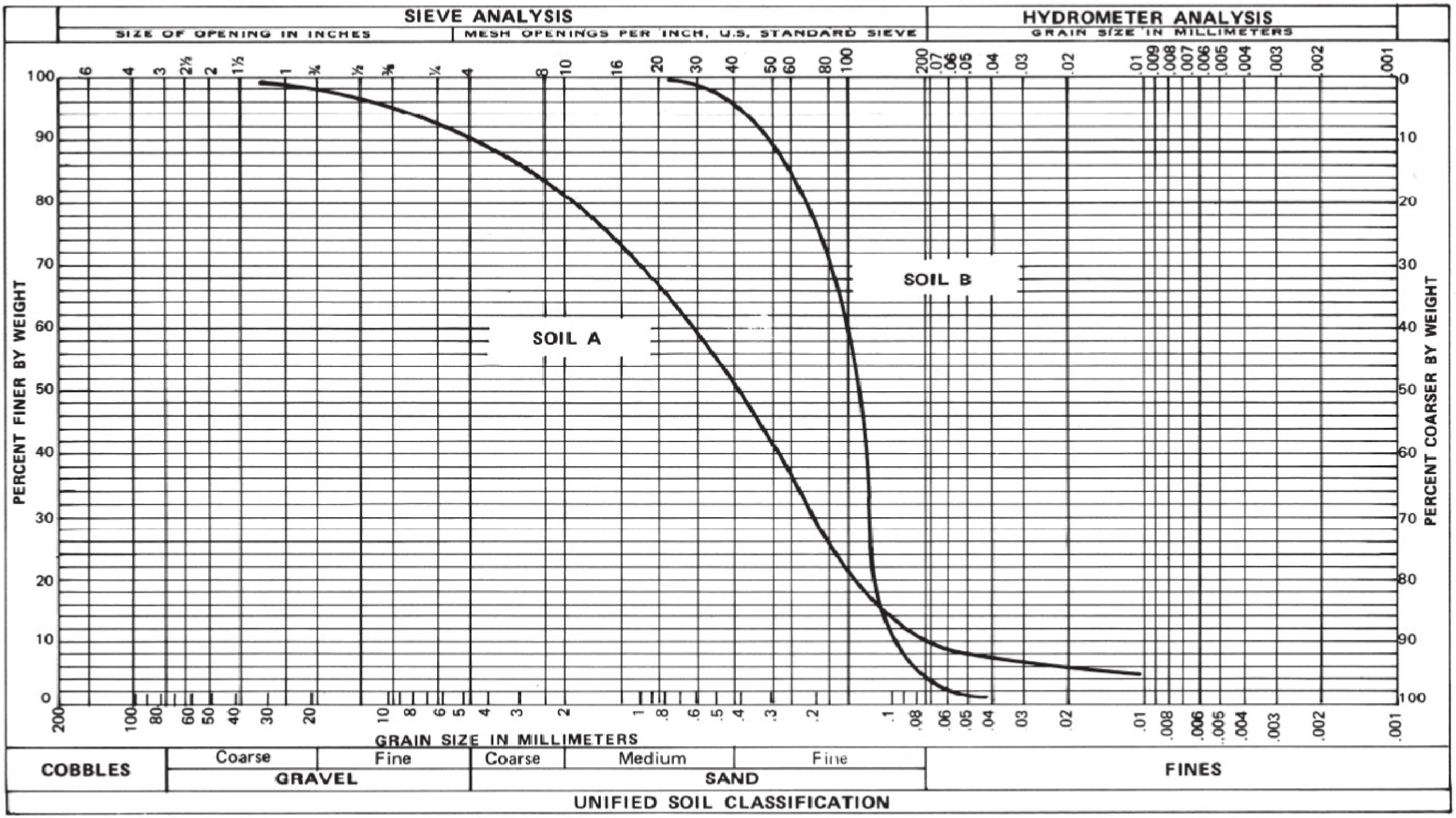
Importance of Plasticity Index and "A" Line



Location of clay minerals on the Casagrande Plasticity Chart



Unified Classification Example (Soil A)



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

- 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 eliminated
- 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

Unified Soil Classification Example, Using Original Gradation Information

- Since less than 5% of the sample passes the #200 sieve, we can say the following:
  - Soil is a sand (S) or gravel (G)
  - We can eliminate any soils but “W” (well graded) or “P” (poorly graded) soils
- Since all of the sample passes the #4 sieve, there is no gravel, thus the sample is sand, thus we are left with SW or SP
- D_{60} = 0.35, D_{30} = 0.1, D_{10} = 0.08 from chart, thus $C_u = D_{60}/D_{10}$ = 0.35/0.08 = **4.375** and $C_c = D_{30}^2/(D_{10}D_{60}) = (0.1)^2/((0.08)(0.35))$ = **0.357**
- We can see that neither C_u is nor C_c is in the range for well-graded status, thus it is a poorly graded sand (SP)

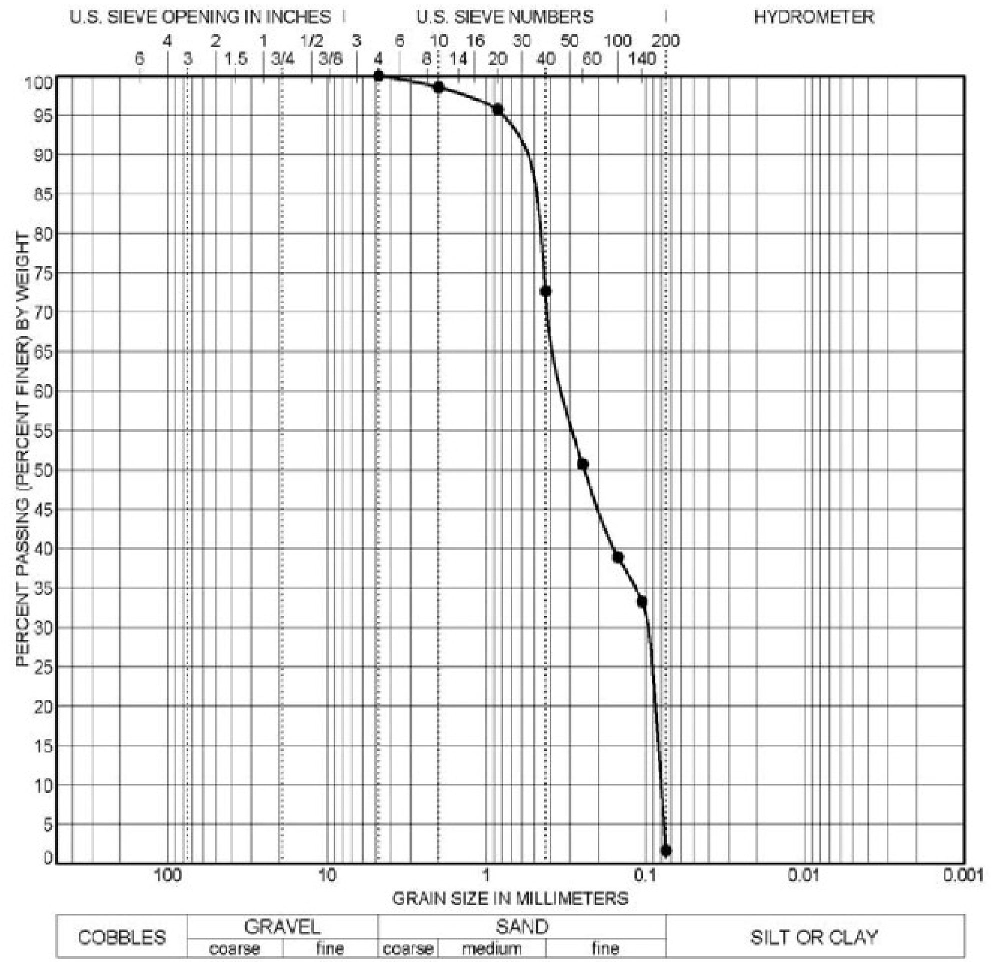


Figure 5-3. Grain size distribution curve based on data in Figure 5-2.

AASHTO System

Table 1-5 AASHTO Soil Classification System

Instructions: Work from left to right checking each column. The classification is the first one that matches all the criteria in the column.

General Classification	Coarse-grained (granular) Materials (35% or less passing No. 200 sieve)							Fine-grained (Silt-Clay) Materials (more than 35% passing No. 200 sieve)					Highly Organic
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7[b]		A-8
	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:													
#10 (2 mm)	≤ 50												
#40 (0.4 mm)	≤ 30	≤ 50	≥ 51										
#200 (0.075 mm)	≤ 15	≤ 25	≤ 10	≤ 35	≤ 35	≤ 35	≤ 35	≥ 36	≥ 36	≥ 36	≥ 36	≥ 36	
Characteristics of fraction passing #40													
Liquid Limit				≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41	≤ 40	≥ 41	≥ 41	
Plasticity Index	≤ 6	≤ 6	NP[a]	≤ 10	≤ 10	≥ 11	≥ 11	≤ 10	≤ 10	≥ 11	≥ 11	≥ 11	
Usual types of significant constituent materials	Stone fragments; gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils			Peat or muck
General rating as subgrade	Excellent to good							Fair to poor					Unsuitable

Notes:

[a]NP indicates that the soil is "non-plastic." NP soils have $LL = PL$, $LL < PL$, or PL that cannot be determined.

[b]Use the following criteria to divide A-7: A-7-5 has $PI \leq (LL - 30)$ and A-7-6 has $PI > (LL - 30)$.

Group Index, GI

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

Calculate the group index as:

where: F = %fines = P#200, LL = liquid limit, and PI = plasticity index.

If a negative value is calculated for GI, then report $GI = 0$.

Note: Use only the second term in the GI equation for A-2-6 and A-2-7 soils.

Notes on AASHTO System

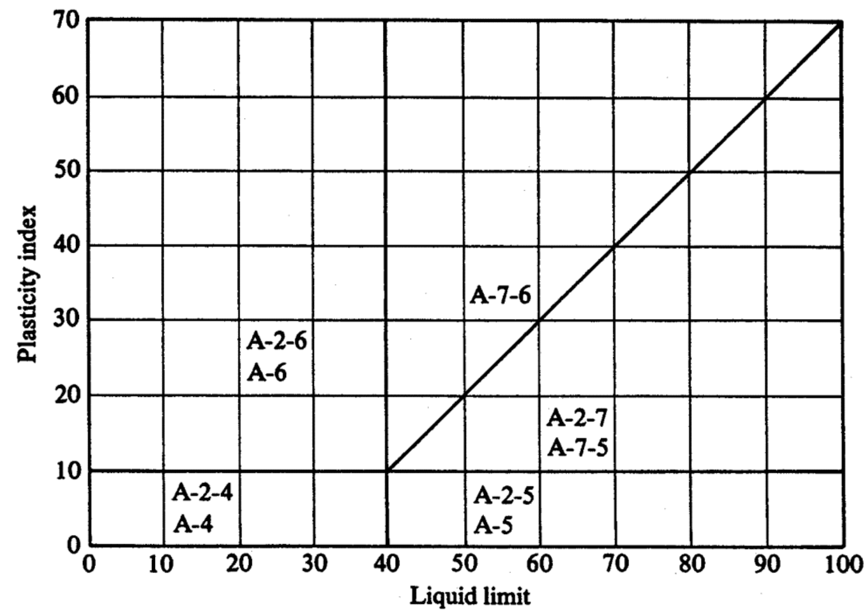


Figure 4-5. Range of liquid limit and plasticity index for soils in groups A-2, A-4, A-5, A-6 and A-7 per AASHTO M 145 (or ASTM D 3282).

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 (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_O/LL × 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 A-2-5				35 Max.	40 Max. 41 Min.	10 Max.	0	
	Gravel and/or Stone Fragments with Sand, Silt and Clay	A-2-6 A-2-7				35 Max.	40 Max. 41 Min.	11 Min.	4	
	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 unlikely since LL > PL , thus soil has plasticity
  - #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
  - $PGI = 0.01(F_{200} - 15)(PI - 10) = (0.01(10\text{-}15)(21\text{-}10) < 0$, so $PGI = 0$
- Classification is A-2-7(0)

AASHTO Soil Classification Example, Using Original Gradation Information

- Sieve Analysis Cumulative Passing Results:
  - #10, 98.58%
  - #40, 72.72%
  - #200, 1.7%
- These number exceed all of the maximum values for A-1-a and A-1-b
- For A-3, #40 = 72.72% > 51% and #200 = 1.7% < 10%. Additionally no Atterberg Limits are required, so soil can be classified as A-3.

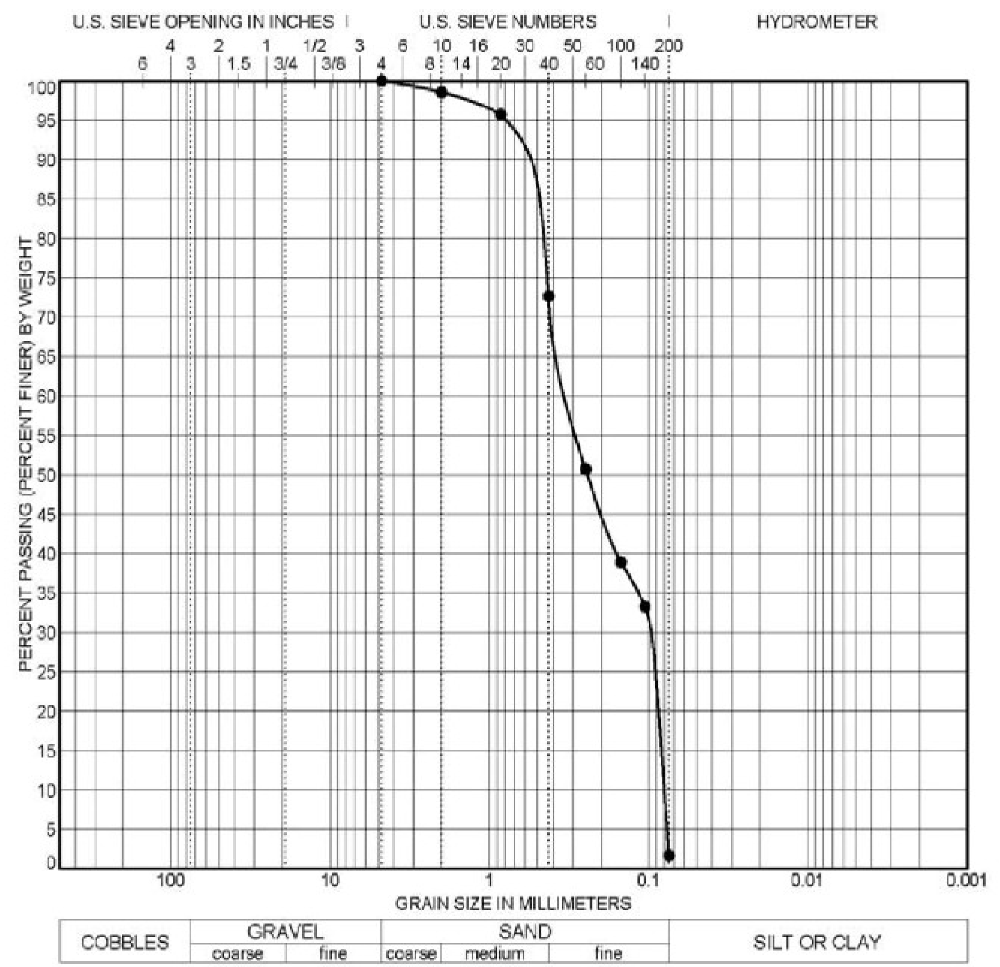


Figure 5-3. Grain size distribution curve based on data in Figure 5-2.

Differences between Unified and AASHTO Classification Systems

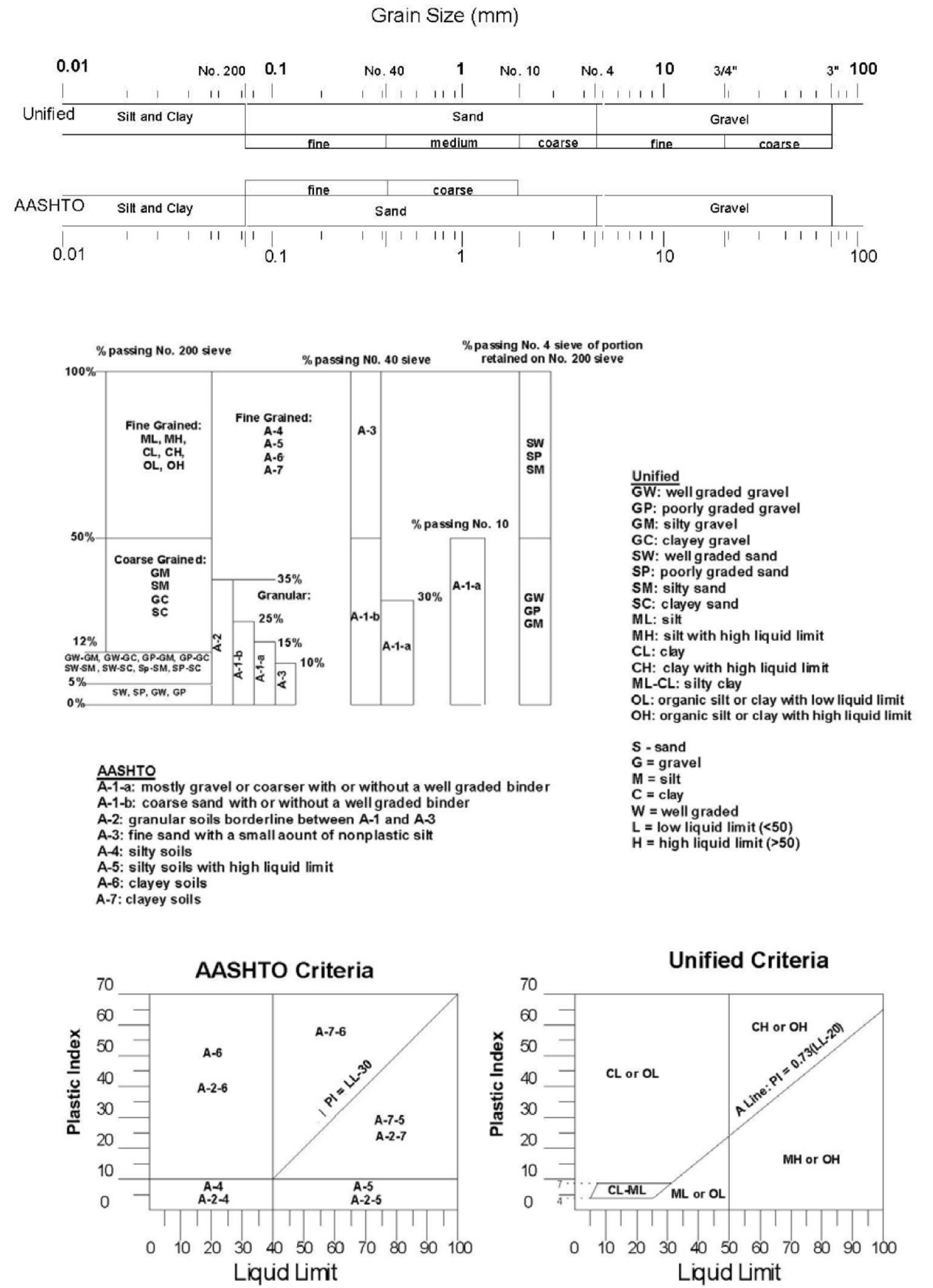


Figure 4-6. Comparison of the USCS with the AASHTO soil classification system (after Utah DOT – Pavement Design and Management Manual, 2005).

Questions?