

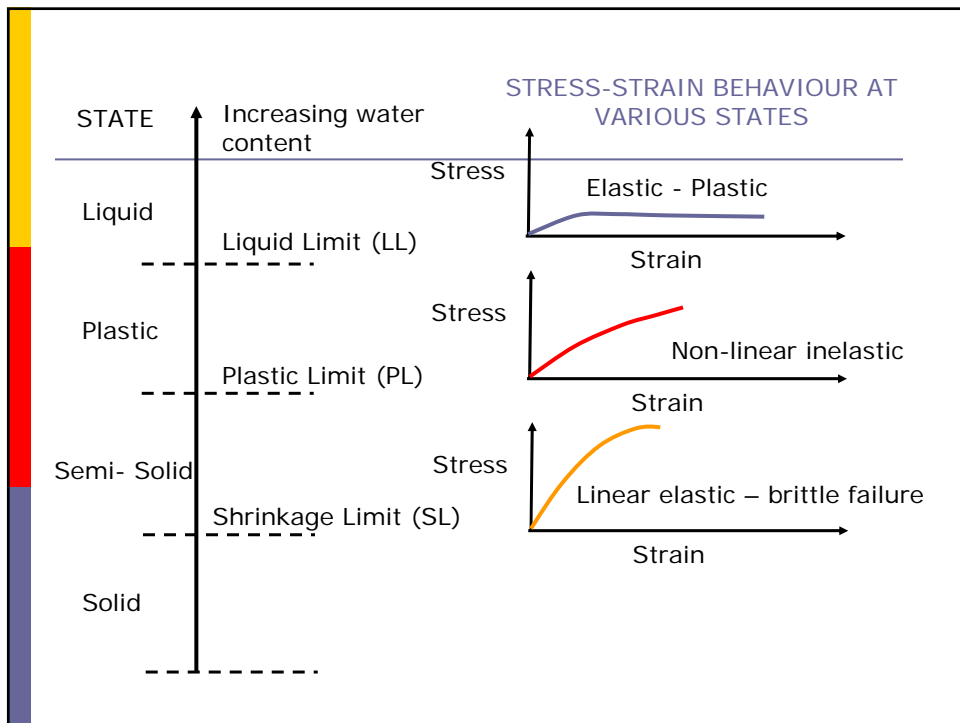
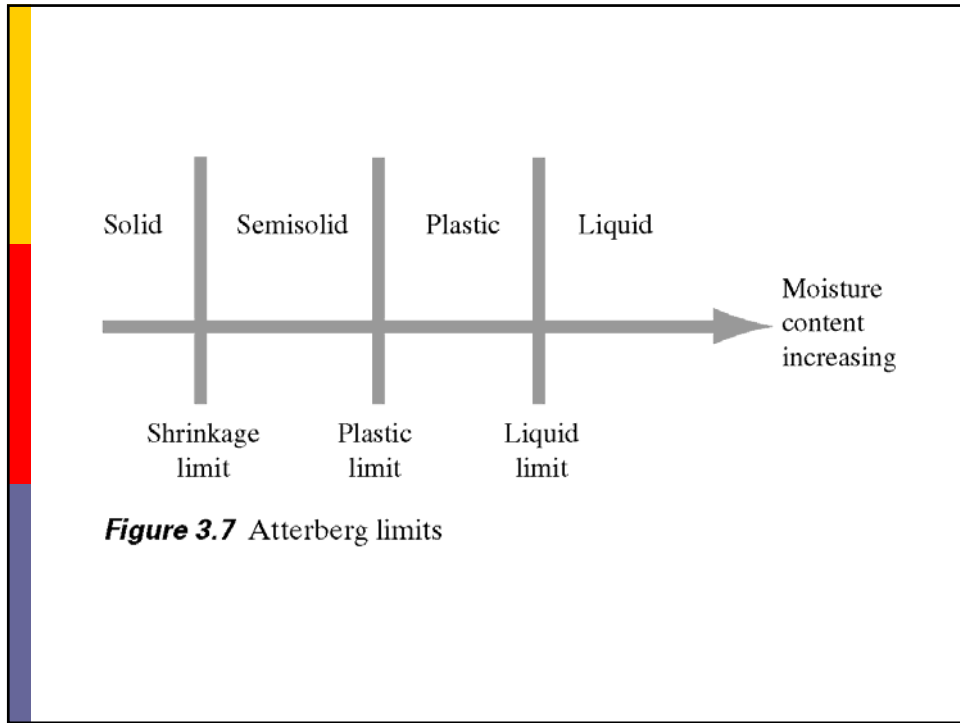
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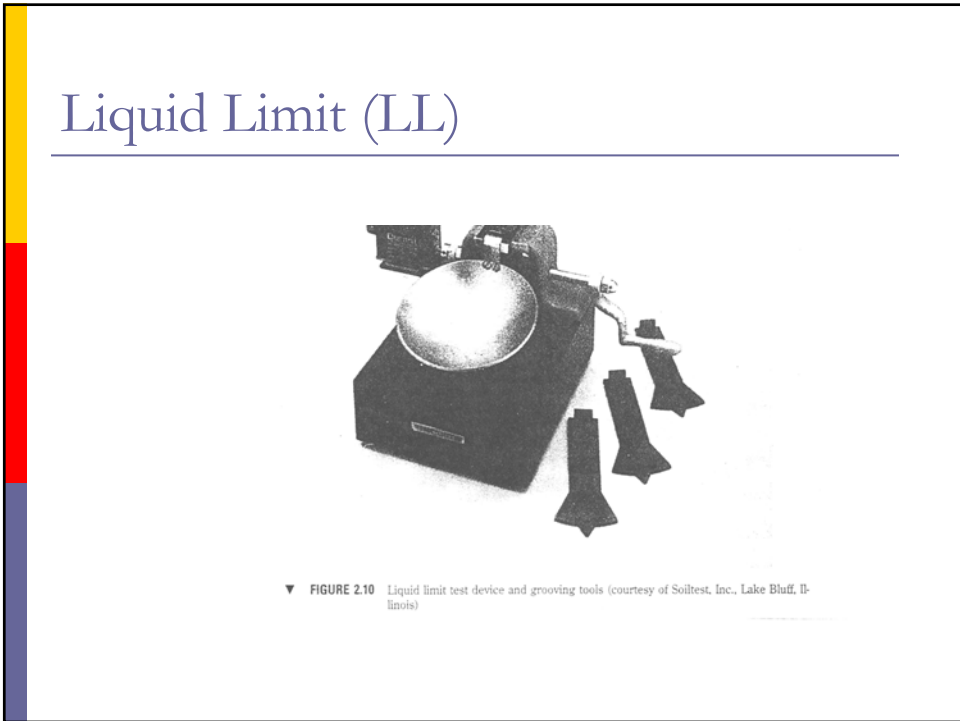
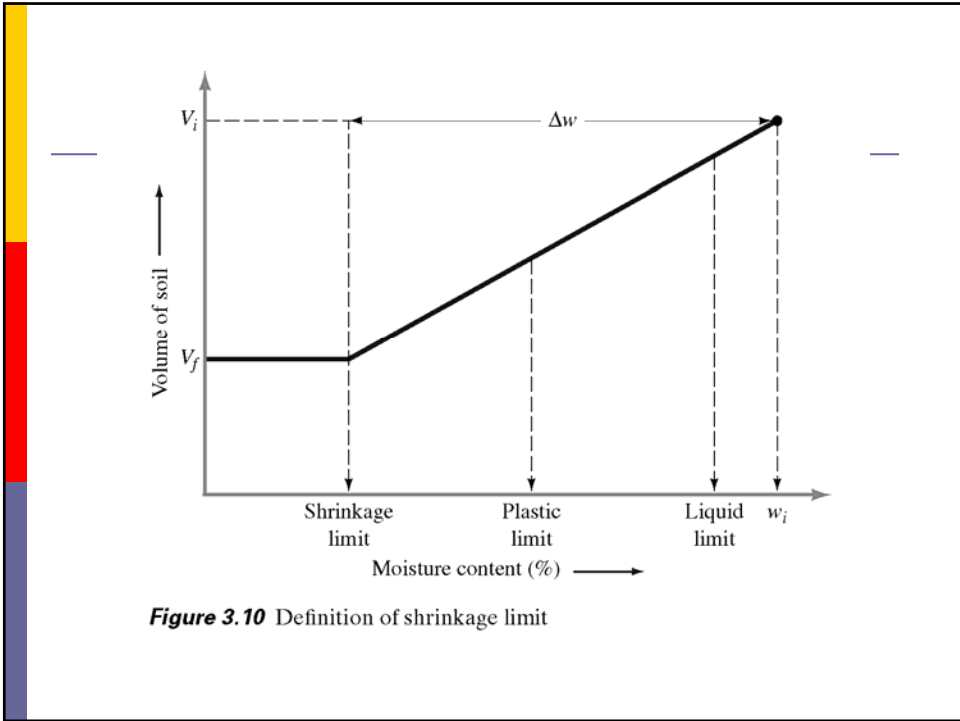


Soil Classification

Clay Soils







Atterberg Device

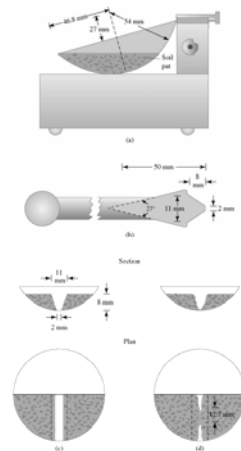


Figure 3.8 Liquid limit test: (a) liquid limit device; (b) grooving tool; (c) soil put before test; (d) soil put after test

Liquid Limit (LL)

Moisture content that closes gaps @ 25 blows

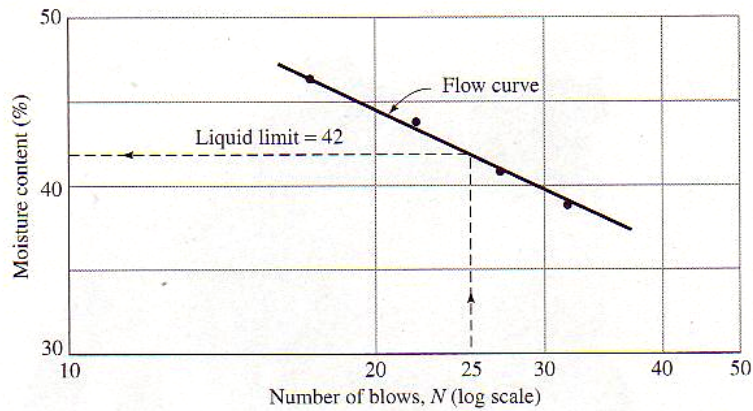


Figure 3.11 Flow curve for liquid limit determination of a clayey silt

Liquid Limit (LL)

Moisture content @ penetration = 20mm

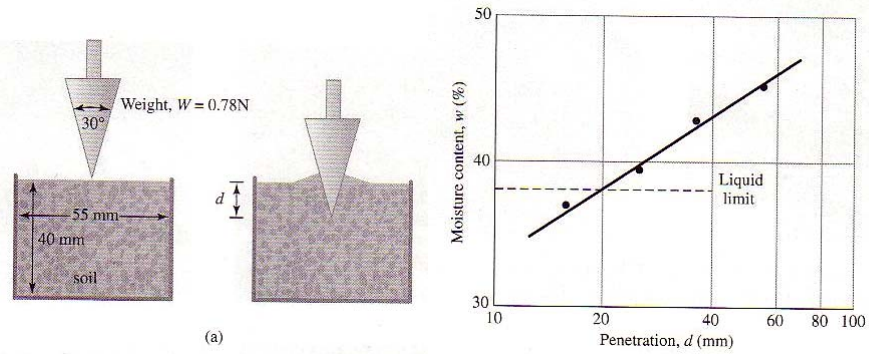
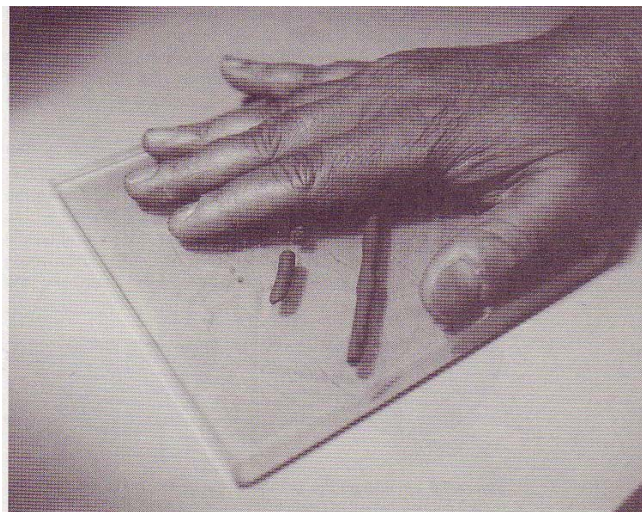


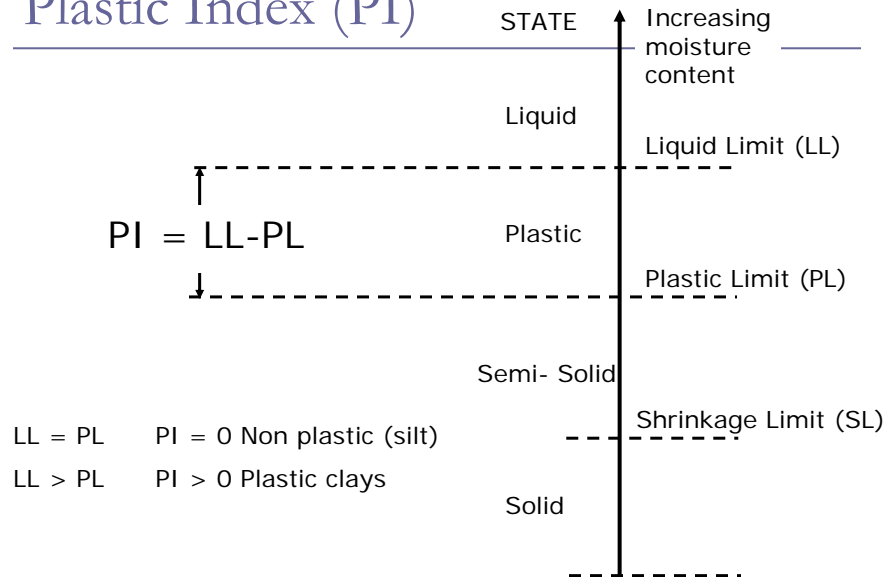
Figure 3.12 (a) Fall cone test (b) plot of moisture content vs. cone penetration for determination of liquid limit

Plastic Limit (PL)



Roll clay until
it breaks at
1/8 inch thick
(3.2mm)

Plastic Index (PI)



Burmister (1949) Classification

PI	Description
0	Nonplastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plasticity

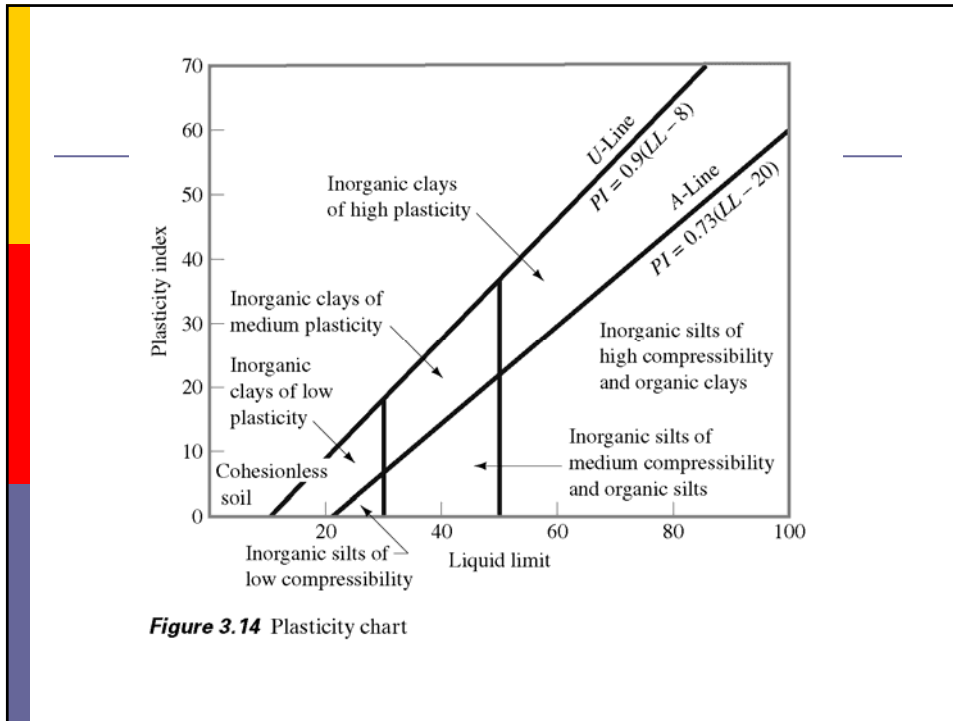


Figure 3.14 Plasticity chart

Activity (A)

$$A = \frac{PI}{(\text{percent clay} - \text{size fraction by weight})}$$

Table 3.4 Activity of clay minerals

Mineral	Activity, A
Smectites	1-7
Illite	0.5-1
Kaolinite	0.5
Halloysite (2H ₂ O)	0.5
Holloysite (4H ₂ O)	0.1
Attapulgite	0.5-1.2
Allophane	0.5-1.2

Plasticity Index and Clay Content

$$\text{Activity of a clay} = \frac{\text{plasticity index}}{\% \text{ by weight finer than } 2 \mu}$$

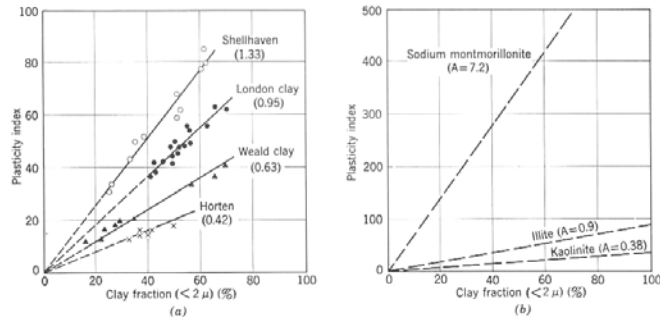


Fig. 3.5 Relation between plasticity index and clay fraction. Figures in parentheses are the "activities" of the clays. (From Skempton, 1953.)

Atterberg Limits and Clay Minerals

Table 3.4 Atterberg Limits of Clay Minerals

Mineral	Exchange-able Ion	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)
Montmorillonite	Na	710	54	656	9.9
	K	660	98	562	9.3
	Ca	510	81	429	10.5
	Mg	410	60	350	14.7
	Fe	290	75	215	10.3
	Fe ^a	140	73	67	—
Illite	Na	120	53	67	15.4
	K	120	60	60	17.5
	Ca	100	45	55	16.8
	Mg	95	46	49	14.7
	Fe	110	49	61	15.3
	Fe ^a	79	46	33	—
Kaolinite	Na	53	32	21	26.8
	K	49	29	20	—
	Ca	38	27	11	24.5
	Mg	54	31	23	28.7
	Fe	59	37	22	29.2
	Fe ^a	56	35	21	—
Attapulgite	H	270	150	120	7.6

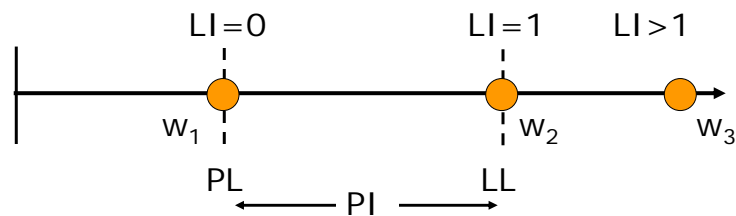
Data from Cornell, 1951.

^a After five cycles of wetting and drying.

Liquidity Index (LI)

$$LI = \frac{w - PL}{LL - PL} = \frac{w - PL}{PI}$$

- Compares field water content with LL and PL.



Bulky Soils



Sieve Analysis



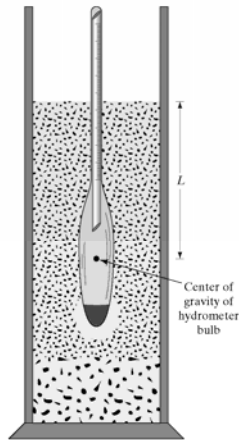
Table 2.4 Sieve analysis (mass of dry soil sample = 450 g)

Sieve no. (1)	Diameter (mm) (2)	Mass of soil retained on each sieve (g) (3)	Percent of soil retained on each sieve* (4)	Percent passing† (5)
10	2.000	0	0	100.00
16	1.180	9.90	2.20	97.80
30	0.600	24.66	5.48	92.32
40	0.425	17.60	3.91	88.41
60	0.250	23.90	5.31	83.10
100	0.150	35.10	7.80	75.30
200	0.075	59.85	13.30	62.00
Pan	—	278.99	62.00	0

* Column 4 = (column 3)/(total mass of soil) × 100

†This is also referred to as *percent finer*.

Fine sand, silt and clay



Soil fraction passing
No. 40 sieve (0.425mm)

$$D(mm) = K \sqrt{\frac{L(cm)}{t(min)}}$$

Figure 2.5 Definition of L in hydrometer test

$K = f(\text{temp and } G_s)$

Table 2.5 Variation of K with G_s

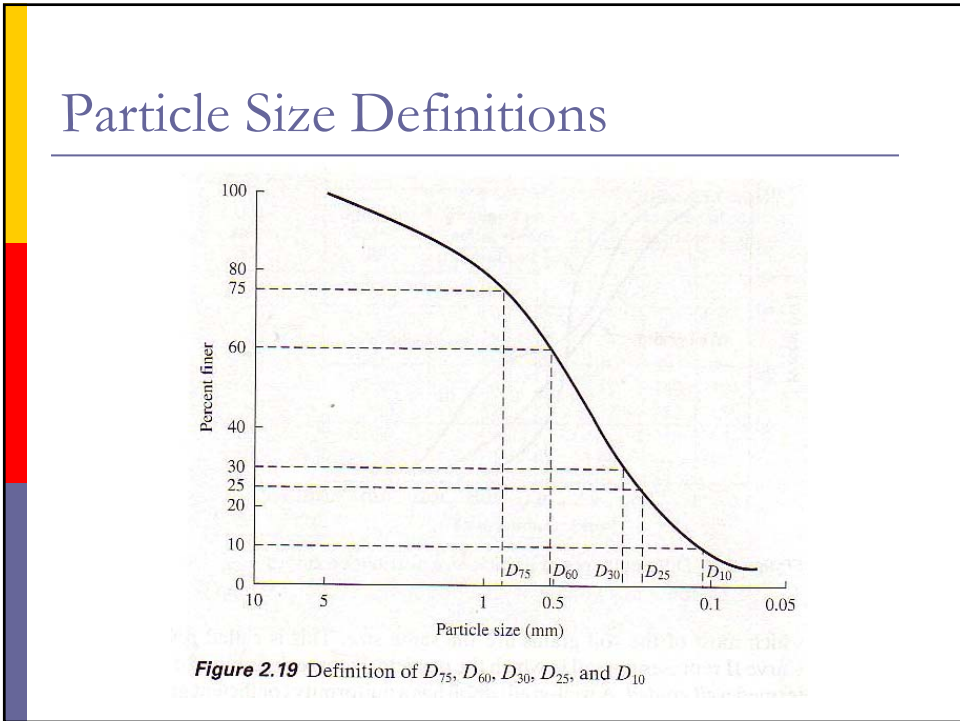
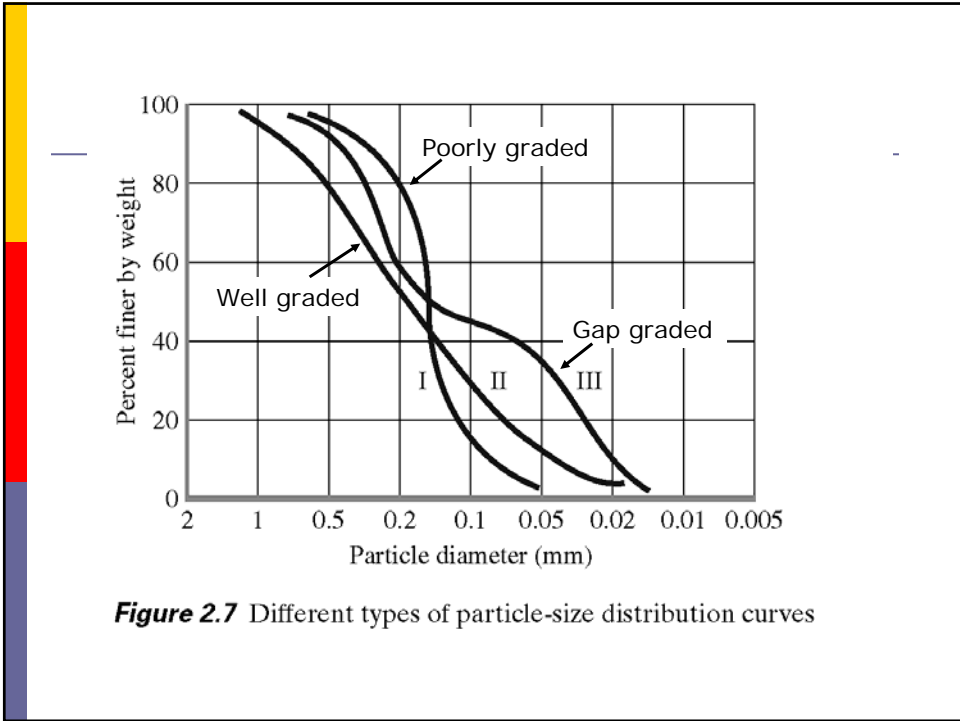
Temperature (°C)	G_s						
	2.50	2.55	2.60	2.65	2.70	2.75	2.80
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136
18	0.0147	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117

Table 2.2 Specific gravity of important minerals

Mineral	Specific gravity, G_s
Quartz	2.65
Kaolinite	2.6
Illite	2.8
Montmorillonite	2.65–2.80
Halloysite	2.0–2.55
Potassium feldspar	2.57
Sodium and calcium feldspar	2.62–2.76
Chlorite	2.6–2.9
Biotite	2.8–3.2
Muscovite	2.76–3.1
Hornblende	3.0–3.47
Limonite	3.6–4.0
Olivine	3.27–3.37

Table 2.6 Variation of L with hydrometer reading —
ASTM 152-H hydrometer

Hydrometer reading	L (cm)	Hydrometer reading	L (cm)
0	16.3	26	12.0
1	16.1	27	11.9
2	16.0	28	11.7
3	15.8	29	11.5
4	15.6	30	11.4
5	15.5	31	11.2
6	15.3	32	11.1
7	15.2	33	10.9
8	15.0	34	10.7
9	14.8	35	10.6
10	14.7	36	10.4
11	14.5	37	10.2
12	14.3	38	10.1
13	14.2	39	9.9
14	14.0	40	9.7
15	13.8	41	9.6
16	13.7	42	9.4
17	13.5	43	9.2
18	13.3	44	9.1
19	13.2	45	8.9
20	13.0	46	8.8
21	12.9	47	8.6
22	12.7	48	8.4
23	12.5	49	8.3
24	12.4	50	8.1
25	12.2	51	7.9



Particle Size Distribution Curves

$$C_u = \frac{D_{60}}{D_{10}} = \text{Coefficient of Uniformity}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \text{Coefficient of Gradation}$$

Grain Size Distribution

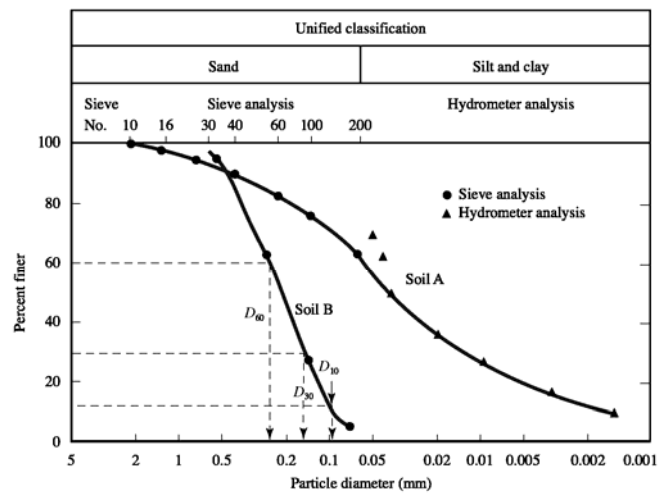


Figure 2.6 Particle-size distribution curves

Unified Soil Classification System

(USCS)

UNIFIED Soil Classification System (USCS)

	Particle diameter (mm)	
Boulder	> 300	
Cobble	76.2 - 300	
Gravel	4.75 - 76.2	
Sand	0.075 - 4.75	
Silt	.005 - 0.075	
Clay	0.002 - .005	
Colloid	< 0.002	Plate/Needle Particles

Soil Classification Systems

Table 2.1 Soil-separate-size limits

Name of organization	Grain size (mm)			
	Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unified Soil Classification System (U.S. Army Corps of Engineers; U.S. Bureau of Reclamation; American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

Table 3.6 Unified Soil Classification System (Based on Material Passing 75-mm Sieve)

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	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW	
		Less than 5% fines ^a	$C_u < 4$ and/or $1 > C_c > 3^c$	GP	
	Sands 50% or more of coarse fraction passes No. 4 sieve	Gravels with Fines	$PI < 4$ or plots below "A" line (Figure 3.16)	GM	
		More than 12% fines ^{b,d}	$PI > 7$ and plots on or above "A" line (Figure 3.16)	GC	
	Fine-Grained Soils 50% or more passes No. 200 sieve	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands	$C_u \geq 6$ and $1 \leq C_c \leq 3^c$	SW
			Less than 5% fines ^b	$C_u < 6$ and/or $1 > C_c > 3^c$	SP
Silts and Clays Liquid limit less than 50		Sands with Fines	$PI < 4$ or plots below "A" line (Figure 3.16)	SM	
		More than 12% fines ^{b,d}	$PI > 7$ and plots on or above "A" line (Figure 3.16)	SC	
Silts and Clays Liquid limit 50 or more		Inorganic	$PI > 7$ and plots on or above "A" line (Figure 3.16) ^e $PI < 4$ or plots below "A" line (Figure 3.16) ^e	CL ML	
		Organic	Liquid limit—oven dried	< 0.75; see Figure 3.16; OL zone	OL
	Liquid limit—not dried				
	Inorganic	PI plots on or above "A" line (Figure 3.16)	CH		
PI plots below "A" line (Figure 3.16)		MH			
Organic	Liquid limit—oven dried	< 0.75; see Figure 3.16; OH zone	OH		
	Liquid limit—not dried				
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 $C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$

^d If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol GC-GM or SC-SM.

^e If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol CL-ML.

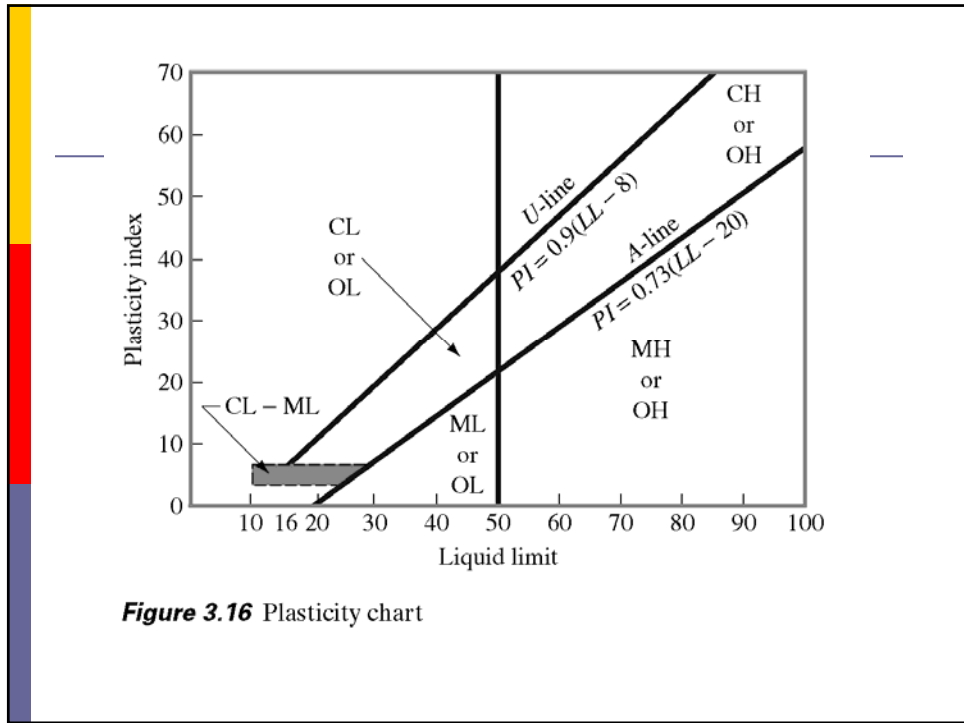


Figure 3.16 Plasticity chart

Group Symbol	Group Name
GW	<15% sand → Well-graded gravel
	≥15% sand → Well-graded gravel with sand
GP	<15% sand → Poorly graded gravel
	≥15% sand → Poorly graded gravel with sand
GW-GM	<15% sand → Well-graded gravel with silt
	≥15% sand → Well-graded gravel with silt and sand
GW-GC	<15% sand → Well-graded gravel with clay (or silty clay)
	≥15% sand → Well-graded gravel with clay and sand (or silty clay and sand)
GP-GM	<15% sand → Poorly graded gravel with silt
	≥15% sand → Poorly graded gravel with silt and sand
GP-GC	<15% sand → Poorly graded gravel with clay (or silty clay)
	≥15% sand → Poorly graded gravel with clay and sand (or silty clay and sand)
GM	<15% sand → Silty gravel
	≥15% sand → Silty gravel with sand
GC	<15% sand → Clayey gravel
	≥15% sand → Clayey gravel with sand
GC-GM	<15% sand → Silty clayey gravel
	≥15% sand → Silty clayey gravel with sand
SW	<15% gravel → Well-graded sand
	≥15% gravel → Well-graded sand with gravel
SP	<15% gravel → Poorly graded sand
	≥15% gravel → Poorly graded sand with gravel
SW-SM	<15% gravel → Well-graded sand with silt
	≥15% gravel → Well-graded sand with silt and gravel
SW-SC	<15% gravel → Well-graded sand with clay (or silty clay)
	≥15% gravel → Well-graded sand with clay and gravel (or silty clay and gravel)
SP-SM	<15% gravel → Poorly graded sand with silt
	≥15% gravel → Poorly graded sand with silt and gravel
SP-SC	<15% gravel → Poorly graded sand with clay (or silty clay)
	≥15% gravel → Poorly graded sand with clay and gravel (or silty clay and gravel)
SM	<15% gravel → Silty sand
	≥15% gravel → Silty sand with gravel
SC	<15% gravel → Clayey sand
	≥15% gravel → Clayey sand with gravel
SC-SM	<15% gravel → Silty clayey sand
	≥15% gravel → Silty clayey sand with gravel

Figure 3.17 Flowchart group names for gravelly and sandy soil (After ASTM, 2004)

