SOIL CLASSIFICATION FOR GEOTECHNICAL ENGINEERS

Soil Properties and Classification

- *Soil Formation*
- *Soil Types*
- *Particle Size Analysis and Grading Characteristics*
- *Consistency Indices*
- *Engineering classification of soils*
- *Physical Properties of Soils*
- *Engineering use of soils.*

SOIL FORMATION

- What is the main difference between soil and rock
- Geological Processes active in soil formation
  - Physical and Chemical Weathering Weathering (+ Biological)
  - Residual or Transported
    - Importance of Mode of Transportation
    - Gravity, Wind, Water, Ice.
    - Particle Size, Shape, Sorting, packing

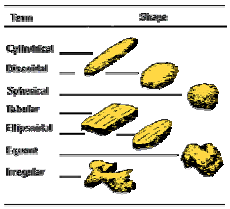
HONG KONG
VOLCANICS

RESIDUAL
VOLCANIC SOIL

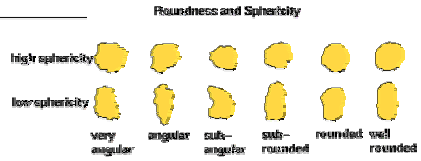
WIND

GRAVITY

GLACIAL TILL



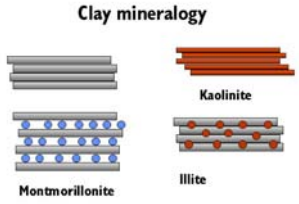
PARTICLE SHAPE



SOIL TYPES

Soil Type	Term	Field test
Sands, gravels	Loose	Can be excavated with a spade; 50mm wooden peg can be easily driven
	Dense	Requires a pick for excavation; 50mm wooden peg is hard to drive
	Slightly cemented	Visual examination; pick removes soil in lumps which can be abraded
Silts	Soft or loose	Easily moulded or crushed in the fingers.
	Firm or dense	Can be moulded or crushed by strong pressure in the fingers
Clays	Very soft	Exudes between the fingers when squeezed in the hand
	Soft	Moulded by light finger pressure
	Firm	Can be moulded by strong finger pressure
	Stiff	Cannot be indented by the thumbnail
	Very stiff	Can be indented by the thumbnail
Organic,Peat	Firm	Fibres already compressed together
	Spongy	Very compressible and open structure
	Plastic	Can be moulded in the hand and smears the fingers

IMPORTANT CLAY MINERALS

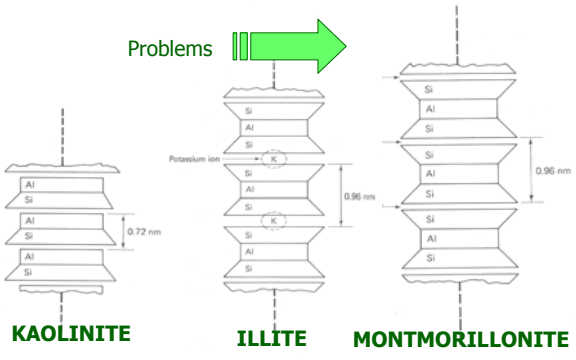


Mineral name	Structure	Between layers	Approx. size (μm)	Specific surface(m^2/g)	Approx. exchange capacity (me/100g)
Kaolinite		H-bond linkage	l = 0.2-2.0 t= 0.05-0.2	10-30	5
Halloysite		H_2O	tubular l = 0.5 t= 0.05	40-50	15
Illite		K^+ linkage	l = 0.2-2.0 t= 0.001-0.01	50-100	30
Montmor-illonite		Weak cross-linkage between Mg/Al ions	l = 0.1-0.50 t= 0.001-0.01	200-800	100
Vermiculite		Mg^{2+} linkage	l = 0.15-1.0 t= 0.01-0.1	20-400	150

CLAY MINERALS

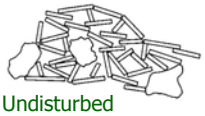
- **Structure and its engineering importance**

THE THREE MOST IMPORTANT CLAY MINERALS



Kaolinite	Illite	Montmorillonite
Single sheet of silica tetrahedra (T) combined with single sheet of alumina octahedra (O).	Sheets of alumina octahedrons between and combined with two silica tetrahedrons. (TOT:TOT)	Same basic structure as illite.
Very limited isomorphous substitution	Substitution of Al by Mg and Iron in Octahedral sheet and partial substitution of Silicon by Al in tetrahedral sheet.	Partial substitution of Al by Mg in the octahedral sheet. Water molecules and (exchangeable) cations other than potassium present in space between combined TOT sheets.
TO:TO sheets held fairly tightly together by hydrogen bonding (1 particle = 100+ stacks). Absorb little water. Low swelling and shrinkage potential,	Combined TOT:TOT sheets held together by fairly weak bonding due to potassium ions. Absorb more water than kaolinites and have higher swelling/shrinkage potential.	Very weak bond between combined TOT sheets due to these ions. Extremely high water absorption between TOT sheets, swelling and shrinkage potential.

Clay Structure



a) Undisturbed Salt water deposit

b) Undisturbed Fresh water deposit

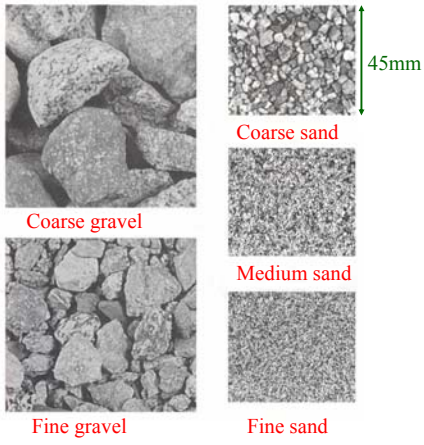
c) Remoulded

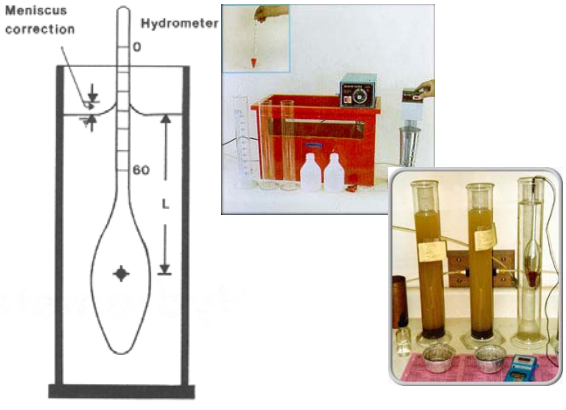
PARTICLE SIZE ANALYSIS

- Coarse Grained soils
  - Sieve Analysis
- Fine Grained soils
  - Hydrometer method
- Grading Characteristics

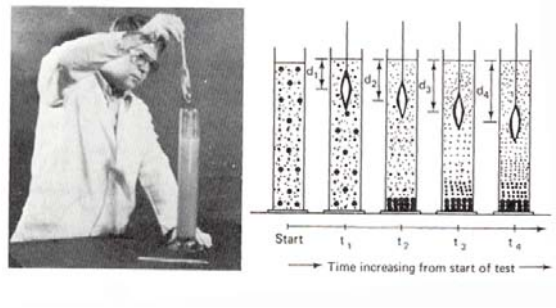
Boulders (>350mm or >12in)

Cobbles 75-350mm or 3-12in))

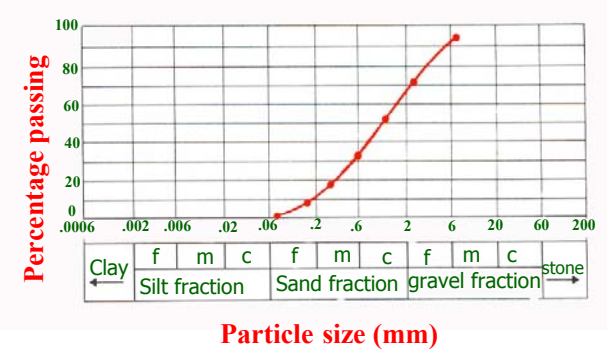




Hydrometer Size Analysis

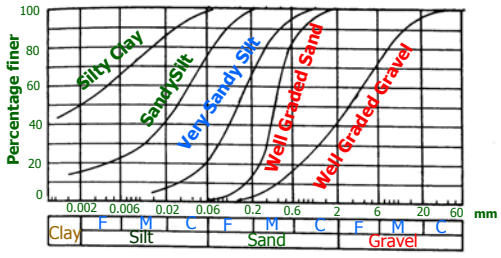


PARTICLE SIZE DISTRIBUTION



Particle size (mm)

PARTICLE SIZE DISTRIBUTION CURVE

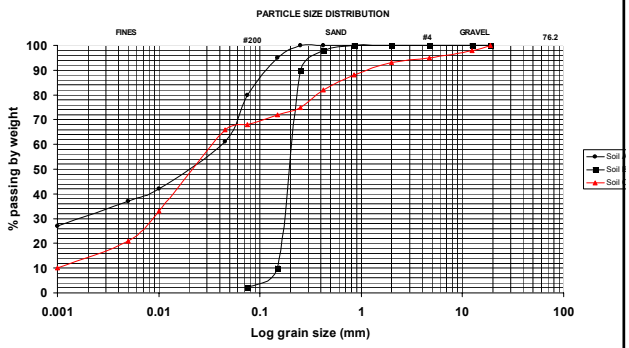


USCS PARTICLE SIZE RANGES

Sieve	*Size*	*Particle*	*Diameter*		
Passes	**Retained on**	**(in)**	**(mm)**	**Soil Classification**	
	12in	>12	>350	Boulder	Rock
12in	3in	3-12	75.0-350	Cobble	Fragments
3in	3/4in	0.75-3	19.0-75.0	Coarse gravel	Soil
3/4in	#4	0.19-0.75	4.75-19.0	Fine gravel	
#4	#10	0.079-0.19	2.00-4.75	Coarse sand	
#10	#40	0.016-0.079	0.425-2.00	Medium sand	
#40	#200	0.0029-0.016	0.075-0.425	Fine sand	
#200		<0.0029	<0.075	Fines (silt + clay)	

Sieve Identification	Opening Size (in)	Opening Size (mm)
3in	3.00	76.2 CG
2in	2.00	50.8 CG
$1^{1/2}$	1.50	38.1 CG
1	1.00	25.4 CG
¾	0.75	19.0 CG
3/8	0.375	9.52 FG
#4	0.187	4.75 FG
#8	0.929	2.36 CS
#10	0.0787	2.00 CS
#16	0.0465	1.18 MS
#20	0.0335	0.850 MS
#30	0.0236	0.600 MS
#40	0.0167	0.425 MS
#50	0.0118	0.300 FS
#60	0.00984	0.250 FS
#100	0.00591	0.150 FS
#140	0.00417	0.106 FS
#200	0.00295	0.075 S & C

STANDARD SIEVE SIZES USED IN UNIFIED SOIL CLASSIFICATION SYSTEM



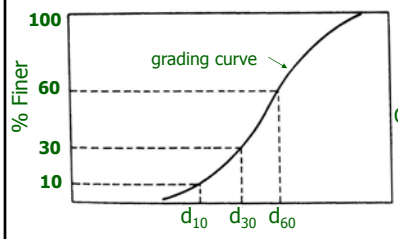
Well Graded – wide range of particle sizes. (Fine sand to Coarse gravel)

Poorly Graded – narrow range of particle sizes. (Pea gravel)

SIGNIFICANCE OF GRAIN SIZE DISTRIBUTION

- CG Soils
  - Well Graded Mixtures (poorly sorted)
    - More stable
    - Less Compressible
    - Less Permeable
- > 10% Clay - dominates permeability
- > 30% Clay - dominates strength

PARTICLL SIZE CURVE: GRADING COEFFICIENTS



Coefficient of Uniformity

$$C_U = \frac{D_{60}}{D_{10}}$$

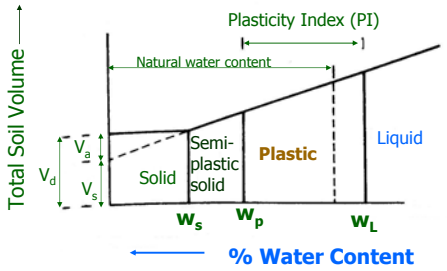
Coefficient of Curvature

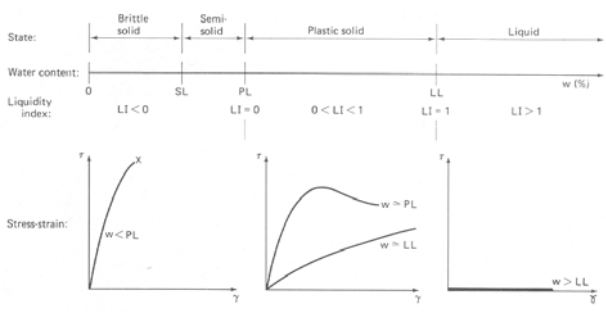
$$C_Z = \frac{D^2_{30}}{D_{60} D_{10}}$$

Consistency Indices

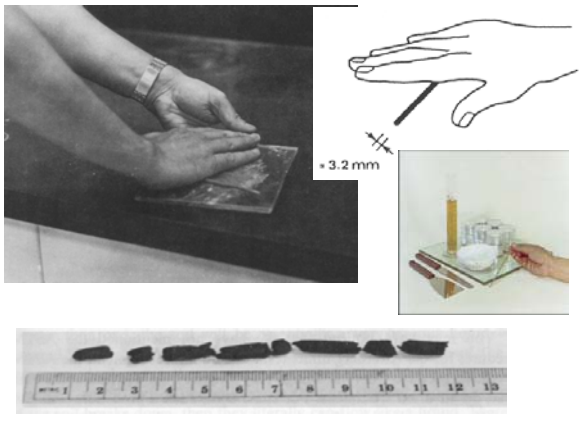
- Clays and silts are characterized by the variation in behavior with change in water content
- Particularly important is their plastic behavior.

Consistency indices (Atterberg Limits)





$$LI = \frac{w - PL}{PI}$$ = Liquidity Index



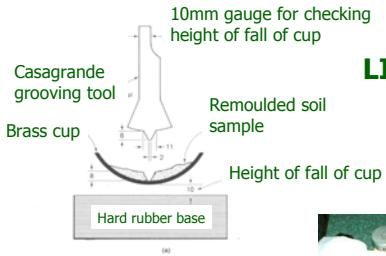
SOIL PROPERTIES IMPORTANT IN SUMO WRESTLING?

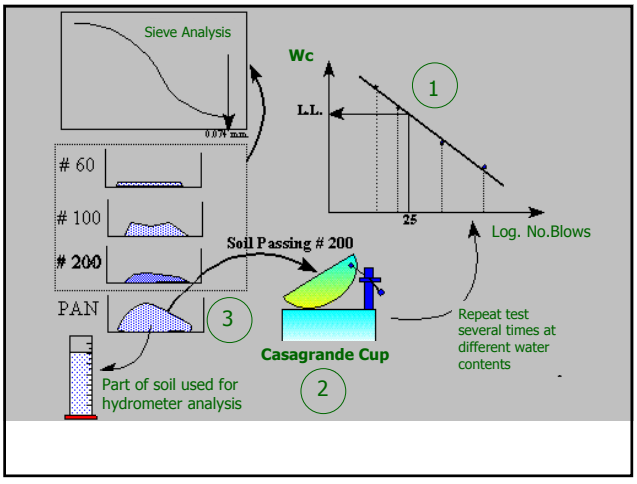
THE PLASTIC LIMIT TEST

PI%	Volume change potential(Swelling/ Shrinkage)
>35	Very High
22-48	High
12-32	Medium
<18	Low

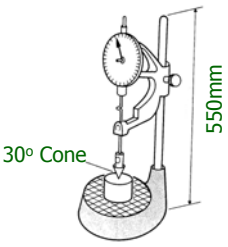
THE LIQUID LIMT TEST

LIQUID LIMIT TEST (1)

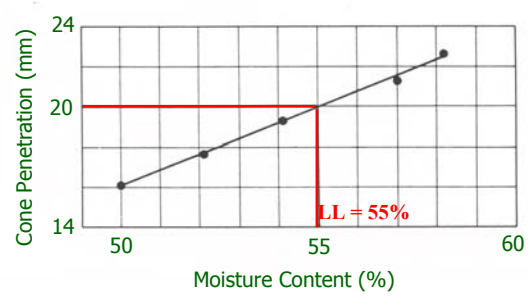




LIQUID LIMIT (2): CONE PENETRATION

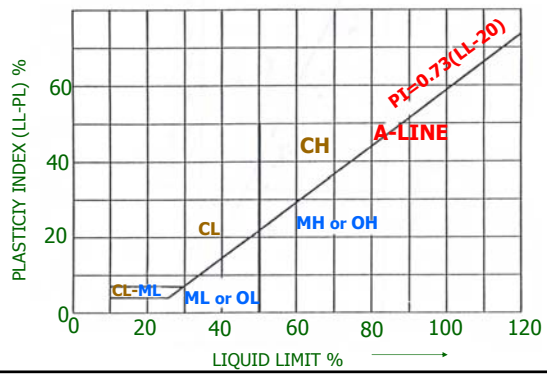


LIQUID LIMIT DETERMINATION USING THE CONE PENETRATION TEST

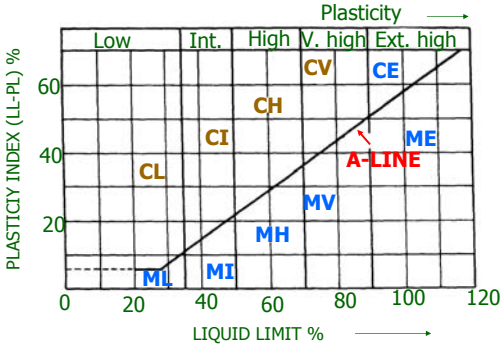


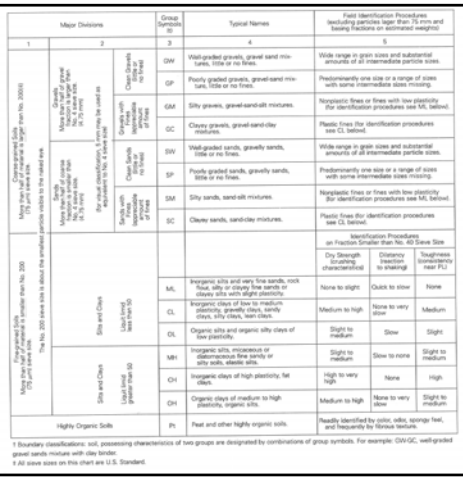
Linear Shrinkage and Shrinkage Limit

SOIL CLASSIFICATION AND CONSISTENCY INDICES (ASTM)



SOIL CLASSIFICATION AND CONSISTENCY INDICES





Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (excluding particles larger than 75 mm and basing fractions on estimated weights)		
1	2		3	4	5		
Coarse-grained Soils (More than half of material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size but smaller than 3")	Clean Gravels (little or no fines)	GW	Well-graded gravels, gravel sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Gravels with Fines (appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size. For visual classifications, 1/4" may be used as equivalent to No. 4 sieve size.)	Clean Sands (little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			SP	Poorly graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with Fines (appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near PL)
Fine-grained Soils (More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye)	Silts and Clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel, and frequently by fibrous texture.		

† Boundary classifications: soil possessing characteristics of two groups are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sand mixture with clay binder.
‡ All sieve sizes on this chart are U.S. Standard.

PLASTICITY OF SOILS

Class	PI%	Description
1	<1	Non Plastic
2	1-7	Slightly Plastic
3	7-17	Mod Plastic
4	17-35	Highly Plastic
5	>35	Extremely Plastic

TYPICAL ATTERBERG LIMITS FOR SOILS

Soil Type	W_{LL} %	W_{PL} %	I_p %
Sand	N o n	P la s	t i c
Silt	30 - 40	20 - 25	10 – 15
Clay	40 - 150	25 - 50	15 – 100

Plasticity according to Liquid Limit

Description	**Plasticity**	**Range of LL**
Lean or Silty	Low	<35
Intermediate	Intermediate	35-50
Fat	High	50-70
Very Fat	Very High	70-90
Extra Fat	Extra High	>90

Silts and Clays

TEST	METHOD	SILT	CLAY
Grittiness	Rub particles between fingers or taste	Gritty texture	Smooth texture
Toughness	Take pat of soil, moist enough to be plastic but not sticky and roll it to a thread 3mm in size in your palm. Fold and reroll thread repeatedly until it crumbles. Lump pieces together and knead to measure toughness	Soil crumbles – high silt content	Soil is tough or stiff – high clay content
Shine	Stroke soil with a blade	Dull	Shiny
Dry strength	Allow soil to dry then squeeze	Powders	Hard to break
Shaking (Dilatancy)	Squeeze a moistened sample, open hand, then shake or tap your hand	Moisture film comes to surface, glistens	No moisture film

IN THE FIELD

Fine Sand	Silt	Clay
Individual partciles visible	Some particles visible	No particles visible
Exhibits dilatancy	Exhibits dilatancy	No dilatancy
Easy to crumble and falls off hands when dry	Easy to crumble and can be dusted off hands when dry	Hard to crumble and sticks to hands when dry
Feels gritty	Feels rough	Feels smooth
No plasticity	Some Plasticity	Plasticity

SOIL CLASSIFICATION

- **AASHTO SYSTEM**
  - Used in highways
  - 7 major groups
  - 8 subgroups
  - Soil designated using Group/subgroup and a group index (GI)
- **UNIFIED SOIL CLASSIFICATION SYSTEM**
  - Most common in North America
  - Soils divided into coarse/fine based on grain size
    - Coarse soils divided into gravels and sands
    - Full designation based on grading(Well/Poor using C_u and C_c) and percentage of fines
    - Fine soils divided into inorganic silts and clays based on use of Casagrande chart (PI and LL)
  - Peat treated as separate soil type.

Table 1.
AASHTO Classification for Coarse-Grained Soils

Soil Group (1)		Grain size: Passing #10 sieve (2)	Grain size: Passing #40 sieve (3)	Grain size: Passing #200 sieve (4)	Liquid Limit* (5)	Plasticity Index* (6)	Material type (7)	Subgrade rating (8)
A-1	*A-1-a*	50max.	30max.	15max.		6max.	Stone fragments, gravel and sand	Excellent to good
	A-1-b		50max.	25max.		6max.		
A-3			51min.	10max.		Nonplastic	Fine sand	
A-2	*A-2-4*			35max.	40max.	10max.	Silty and clayey gravel and sand	
	A-2-5			35max.	41min.	10max.		
	A-2-6			35max.	40max.	11min.		
	A-2-7			35max.	41min.	11min.		

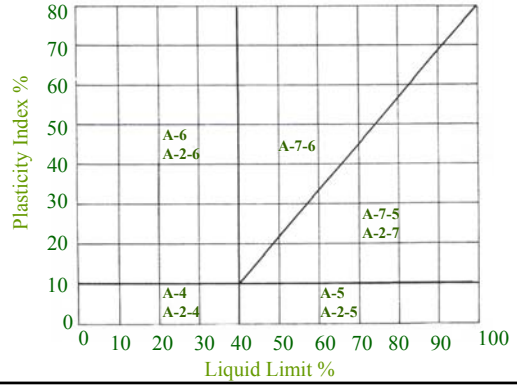
* Based on fraction passing #40 sieve

Table 2.
AASHTO Classification for Fine-Grained Soils

Soil Group (1)		Passing #200 sieve (2)	LL* (3)	PI* (4)	Material type (5)	Subgrade rating (6)
A-4		36min	40max.	10max.	Silty soil	Fair to poor
A-5		36min	41min	10max.	Silty soil	Fair to poor
A-6		36min	40max.	11min	Clayey soil	Fair to poor
A-7	*A-7-5*	36min	41min	11min and PL<=LL-30	Clayey soil	Fair to poor
	A-7-6	36min	41min	11min and PI>LL-30	Clayey soil	Fair to poor

* Based on fraction passing #40 sieve

Liquid Limit and Plasticity Index for 9 AASHTO Soil Groups



AASHTO PROCEDURE

From Table 1

%Passing	#4	#10	#40	#200	LL	PL	PI	Group/ Subgroup	GI	Name
Soil A	98	90	76	34	38	26	12	A-2-6	0	A-2-6(0)
Soil B	100	98	86	58	49	28	21	A-7-6	10	A-7-6(10)

<35%

Coarse grained

>35%

Fine grained

GI=0.01(F200-15)(PI-10) = 0.01(34-15)(12-10)=0.38 ~0

From Table 2

GI = (F200-35)[0.2 + 0.005(LL-40)] + (0.01(F200-15)(PI-10) = (58-35)[0.2 + 0.005(49-40)] + 0.01(58-15)(21-10) = 10.37 ~10

UNIFIED SOIL CLASSIFICATION

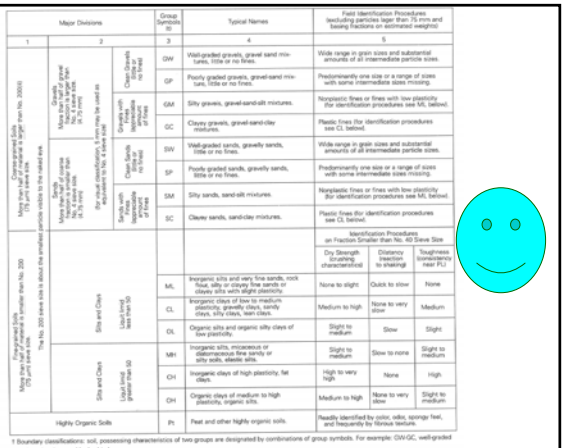
- Subdivides soil based on the % passing No. 200 sieve into
- Coarse grained
- Fine grained

- Coarse grained soils subdivided into Gravels and Sands based on % passing No. 4 sieve. (% of fines (passing No 200 sieve) is use to further describe coarse grained soils.)

- Fine grained soils are subdivided into Inorganic and Organic

- Inorganic and Organic clays are subdivided in to silts and clays of high and low plasticity using the a plasticity chart (% of coarse-grained sand or gravel used to further describe silts and clays)

Following Tables show detailed breakdown of the USC which will be used in lab exercise



Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (excluding particles larger than 75 mm and basing fractions on estimated weights)		
1	2		3	4	5		
Coarse-grained Soils (More than half of material is larger than No. 200(0.075 mm) sieve size.)	Gravels (More than half of coarse fraction is larger than No. 4 sieve size.)	Clean Gravels (Less than 5% fines)	GW	Well-graded gravels, gravel sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
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			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
	Sands (More than half of coarse fraction is smaller than No. 4 sieve size. For visual classifications, 1/2 cm may be used as equivalent to No. 4 sieve size.)	Clean Sands (Less than 5% fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			SP	Poorly graded sands, gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (consistency near PL)
Fine-grained Soils (More than half of material is smaller than No. 200 (0.075 mm) sieve size.) The No. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays (Liquid limit less than 50)		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays (Liquid limit greater than 50)		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel, and frequently by fibrous texture.		

1 Boundary classifications: soil, possessing characteristics of two groups are designated by combinations of group symbols. For example: GW-GC, well-graded gravel-sands mixture with clay binder.
2 All sieve sizes on this chart are U.S. Standard.

UNIFIED SOIL CLASSIFICATION: FINE GRAINED SOILS: LL≥50

Criteria for Group Symbol	Group Symbol	Criteria for Group Name				Group Name
		R_{200}	SF/GF	GF	SF	
LL ≥50 and PI≥ 0.73(LL-20)	CH	<15	—	—	—	Fat clay
		15 to 29	≥1	—	—	Fat clay with sand
			<1	—	—	Fat clay with gravel
		≥30	≥1	<15	—	Sandy fat clay
			≥1	≥15	—	Sandy fat clay with gravel
			<1		<15	Gravelly fat clay
			<1		≥15	Gravelly fat clay with sand
LL ≥50 and PI< 0.73(LL-20)	MH	<15	—	—	—	Elastic silt
		15 to 29	≥1	—	—	Elastic silt with sand
			<1	—	—	Elastic silt with gravel
		≥30	≥1	<15	—	Sandy elastic silt
			≥1	≥15	—	Sandy elastic silt with gravel
			<1		<15	Gravelly elastic silt
			<1		≥15	Gravelly elastic silt with sand

UNIFIED SOIL CLASSIFICATION: GRAVELLY SOILS: $R_4 > 0.5R_{200}$

Criteria for Group Symbol				Group Symbol	Criteria for Group Name	Group Name
F_{200}	C_u	C_c	Relation between LL and PI		SF	
<5	≥4	$1 \le C_c \le 3$		GW	<15	Well graded gravel
					≥15	Well graded gravel with sand
	C_u <4 and/or $1 > C_c > 3$			GP	<15	Poorly graded gravel
					≥15	Poorly graded gravel with sand
>12			PI<4 or PI<0.73(LL-20)	GM	<15	Silty gravel
					≥15	Silty gravel with sand
			PI>7 and PI ≥ 0.73(LL-20)	GC	<15	Clayey gravel
					≥15	Clayey gravel with sand
			4 ≤ PI ≤ 7 and PI≥0.73(LL-20)	GC-GM	<15	Silty, clayey gravel
					≥15	Silty, clayey gravel with sand
$5 \le F_{200} \le 12$	≥ 4	$1 \le C_c \le 3$	PI<4 or PI<0.73(LL-20)	GW-GM	<15	Well graded gravel with silt
					≥15	Well graded gravel with silt and sand
			PI>7 and PI ≥ 0.73(LL-20)	GW-GC	<15	Well graded gravel with clay
					≥15	Well graded gravel with clay and sand
	C_u <4 and/or $1 > C_c > 3$		PI<4 or PI<0.73(LL-20)	GP-GM	<15	Poorly graded gravel with silt
					≥15	Poorly graded gravel with silt and sand
			PI>7 and PI ≥0.73(LL-20)	GP-GC	<15	Poorly graded gravel with clay
					≥15	Poorly graded gravel with clay and sand

UNIFIED SOIL CLASSIFICATION: SANDY SOILS: $R_4 \le 0.5R_{200}$

Criteria for Group Symbol				Group Symbol	Criteria for Group Name	Group Name
F_{200}	C_u	C_c	Relation between LL and PI		GF	
<5	≥6	$1 \le C_c \le 3$		SW	<15	Well graded sand
					≥15	Well graded sand with gravel
	C_u <6 and/or $1 > C_c > 3$			SP	<15	Poorly graded sand
					≥15	Poorly graded sand with gravel
>12			PI<4 or PI<0.73(LL-20)	SM	<15	Silty sand
					≥15	Silty sand with gravel
			PI>7 and PI ≥ 0.73(LL-20)	SC	<15	Clayey sand
					≥15	Clayey sand with gravel
			4 ≤ PI ≤ 7 and PI≥0.73(LL-20)	SC-SM	<15	Silty, clayey sand
					≥15	Silty, clayey sand with gravel
$5 \le F_{200} \le 12$	≥ 6	$1 \le C_c \le 3$	PI<4 or PI<0.73(LL-20)	SW-SM	<15	Well graded sand with silt
					≥15	Well graded sand with silt & gravel
			PI>7 and PI ≥ 0.73(LL-20)	SW-SC	<15	Well graded sand with clay
					≥15	Well graded sand with clay & gravel
	C_u <6 and/or $1 > C_c > 3$		PI<4 or PI<0.73(LL-20)	SP-SM	<15	Poorly graded sand with silt
					≥15	Poorly graded sand with silt and gravel
			PI>7 and PI ≥0.73(LL-20)	SP-SC	<15	Poorly graded sand with clay
					≥15	Poorly graded sand with clay and gravel

PHYSICAL PROPERTIES OF SOIL

SENSITIVITY OF SOILS