Soil Classification

Outline

- Purpose
- Classification Systems
- The Unified Soil Classification System (USCS)
- American Association of State Highway and Transportation Officials System (AASHTO)
- Suggested Homework

Introduction

- The common soil types include clay, silt, sand and gravel.
- The classification is primarily based on the size of particles.
- Accordingly a soil may be classified as coarse-grained (Greater than 4.75mm) or fine, grained and cohesion-less or cohesive soil.
- Natural soil deposits seldom comprise of a single soil type, rather they are mixture of different soil types.
- The percentage of different soil types in a soil mass varies considerably, and a soil may be classified as silty-Clay or Clayey-Sand etc.
- Such classifications, however, are not based on the character of soil which influence engineering behaviors and hence do not clearly identify whether the soil is suitable for use as a construction material or foundation support.
- The purpose of soil classification is to arrange soil into groups and label them according to certain characteristics and engineering behavior.
- The name of a group gives useful information about the behavior of soil as a construction material and foundation support.

Introduction

- In order to subdivide soil into groups of specific engineering properties and behavior, different engineering organizations have devised classification systems.
- Some of these are very useful and are extensively employed in engineering practice.
- Different classification systems, classify soil on the basis of physical properties e.g., particle size, gradation, consistency and plasticity.
- In order to predict the true behavior of soil for engineering use, additional information based on geotechnical properties may therefore be required.
- It means that classification of soil based on any classification system does not eliminate the need for detailed soil studies.
- Many of the important information which influence soil behavior, e.g., unit weight, compaction characteristics, degree of saturation, susceptibility to frost action, shear strength, permeability etc., are not directly included in any of the -classification systems.

Soil Classification Systems (SCS)

- Classification systems developed by different organizations

1. Unified soil classification system.
2. AASHTO (American Association of state Highway and Transportation Officials) soil classification system.
3. FAA (Federal Aviation Administration) soil classification system.
4. Textural soil classification system.
5. USDA (U.S. Department of Agriculture) soil classification system.

Soil Classification Systems (SCS)

- Two commonly used systems:

- Unified Soil Classification System (USCS).
- Most widely used to classify soil for use in foundation & dam engineering.

- American Association of State Highway and Transportation Officials (AASHTO) System
- Most widely and exclusively used for highways and airfields

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 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

- **Tests required for classification of soil are;**
- Liquid and plastic limit tests.
- Particle size analysis test.

Unified Soil Classification System (USCS)

- Broad Classification includes the following two types;
- Coarse-grained soil
- Fine-grained soil
- The soil is classified in to 15 groups.
- Each group is designated a symbol consisting of two capital letters
- The first letter is based on main soil type
- The second letter is based on gradation and plasticity
- **Symbols for main soil types**

Symbol	Soil Type	Main Type
G	Gravel	Coarse Grained
S	Sand	
M	Inorganic Silt	Fine Grained
C	Inorganic Clay	
O	Organic Silt & Clay	
P_t	Peat, Humus, Swamp	

Unified Soil Classification System (USCS)

- Coarse-grained soil is subdivided into two subgroups based on gradation,
- W-- for Well-Graded Soil
- P -- for Poorly-Graded Soil
- Fine-grained soil is subdivided in two subgroups based on their plasticity characteristics
- L-- for low plasticity soil (liquid limit < 50)
- H-- for high plasticity soil (liquid limit > 50)

Unified Soil Classification System (USCS)

Main Soil Type	Symbols	Subgroup	Symbols	Classification Group symbols
Gravel	G	Well-graded Poorly-graded Silty Clayey	W P M C	GW GP GM GC
Sand	S	Well-graded Poorly-graded Silty Clayey	W P M C	SW SP SM SC
Silt	M	LL < 50% LL > 50%	L H	ML MH
Clay	C	LL < 50% LL > 50%	L H	CL CH
Organic	O	LL < 50% LL > 50%	L H	OL OH
Peat	Pt			Pt

Unified Soil Classification System (USCS)

- Soils possessing characteristics of two groups are known as borderline soils and designated by dual symbols e.g.,

- GC-GM, GW-GM, GW-GC, GP-GM, GP-CG, SC-SM, SW-SM, SW-SC, SP-SM, SP-SC, CL-ML.

- Total number of groups in USC system, therefore are twenty six (26),

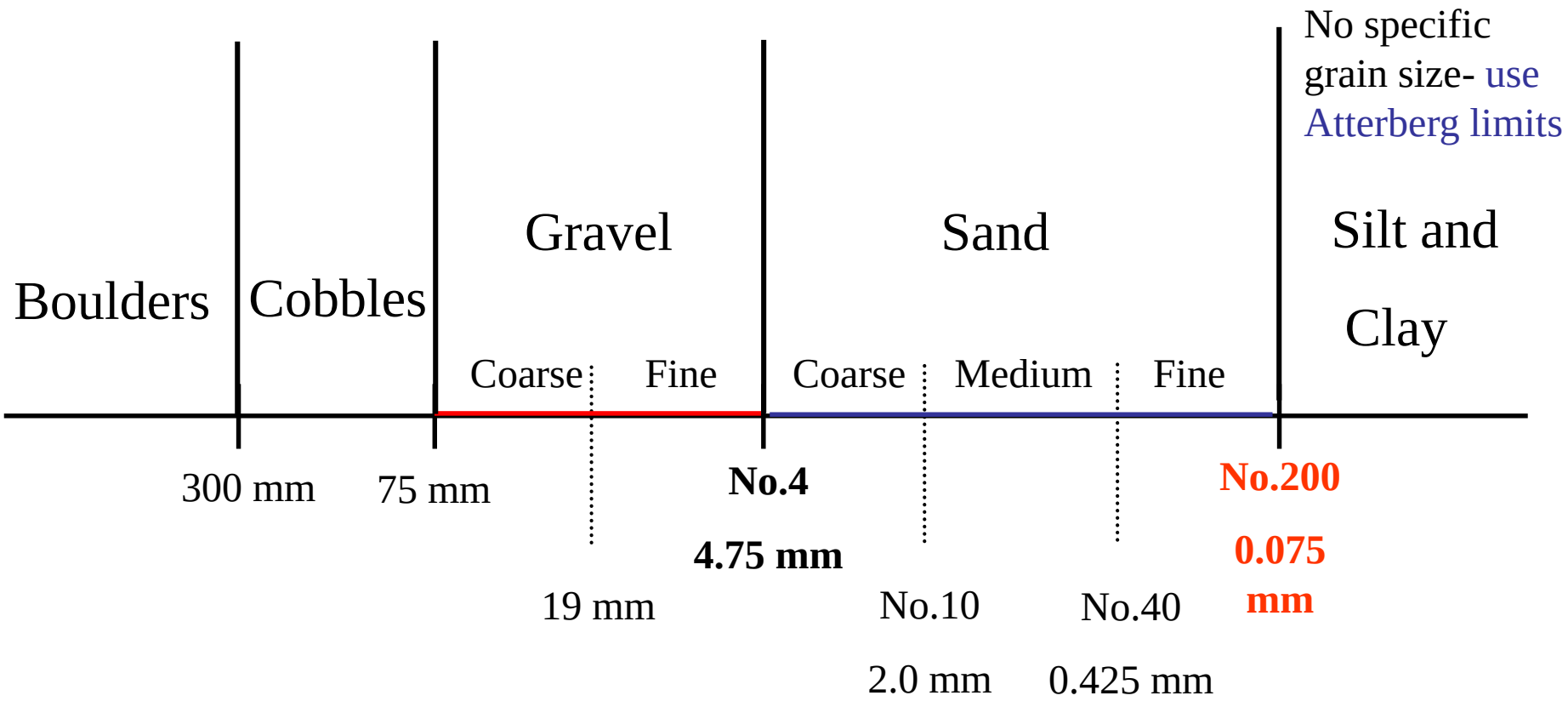
- **The Unified Soil Classification System is based on the following:**
  - Textural characteristics of coarse-grained soils with such small amount of fines, that fines do not affect the behavior.

  - Plasticity characteristics of fine-grained soils where the fines affect the engineering behavior.

Unified Soil Classification System (USCS)

- To classify a soil, following information based on particle size analysis and Atterberg limits should be available.
- %age of gravel, that is, the fraction passing 3-in. (76.2mm) sieve and retained on the No.4 (4.75mm) sieve.
- %age of sand, that is, the fraction passing No.4 sieve (4.75mm) and retained on the No.200 (0.074mm) sieve.
- %age of silt and clay, that is, the fraction finer than the No.200 (0.075mm) sieve.
- Uniformity coefficient (Cu) and the coefficient of gradation (Cc), which actually depend on the shape of particle-size-distribution curve.
- Liquid limit and plasticity index of the fraction of soil passing No.40 sieve, plotted on the plasticity chart

3.1 Definition of Grain Size



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, Highly Plastic 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)

Plasticity Chart

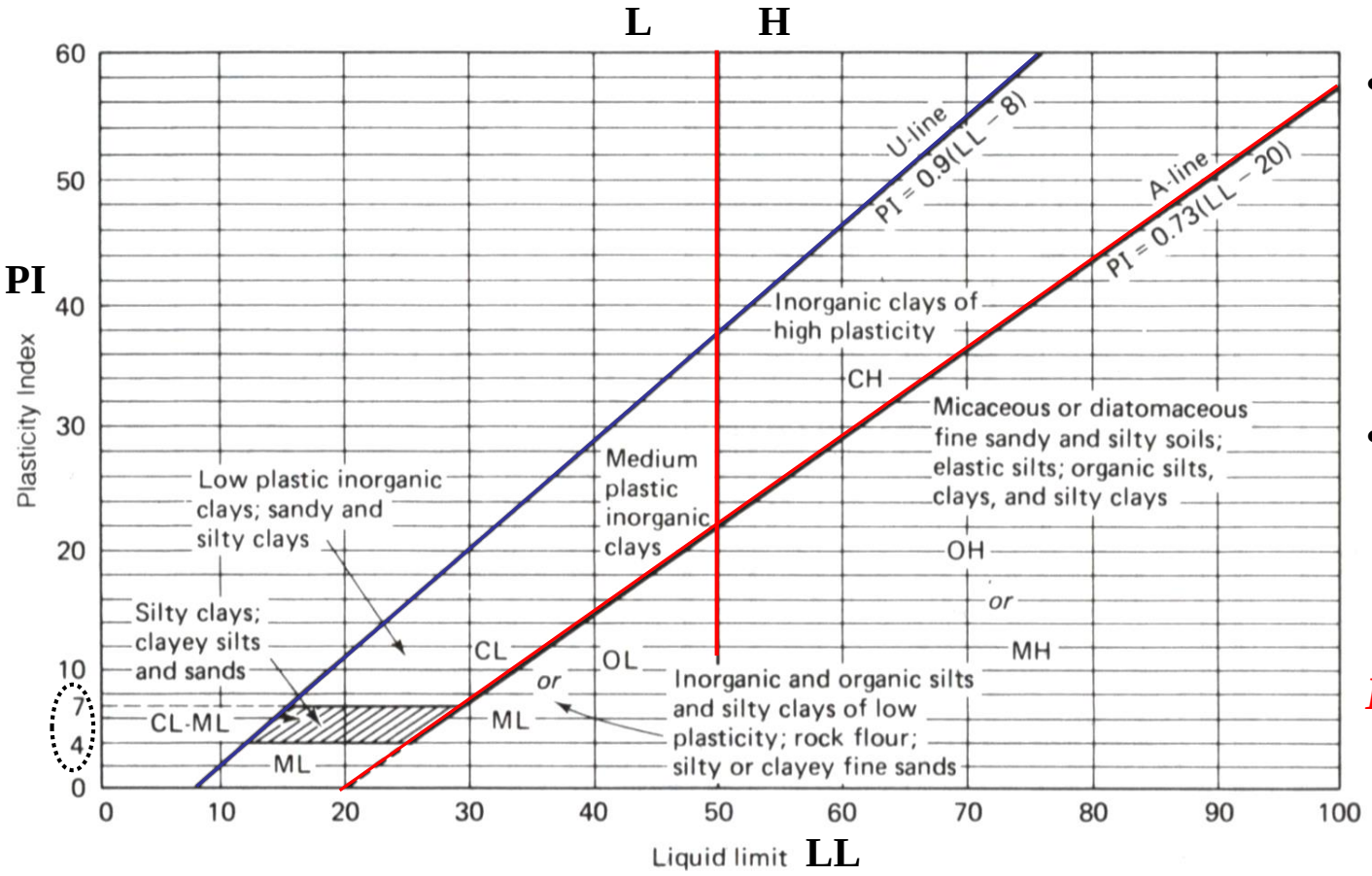


Fig. 3.2 Casagrande's plasticity chart, showing several representative soil types (developed from Casagrande, 1948, and Howard, 1977).

- The A-line generally separates the more claylike 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.

(Holtz and Kovacs, 1981)

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

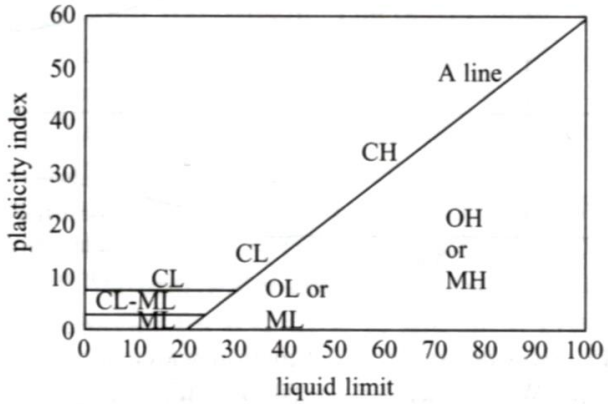
PI=0.73(33-20)=9.49

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)

Unified Soil Classification System (USCS)

- **Highly organic soils- Peat (Group symbol PT)**
- A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat, PT.

- **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.

Group Symbols for Gravelly Soil

Major Division		Laboratory Classification Criteria	Group Symbol	Typical Names
1	2	3	4	5
Coarse soil--More than half of soil is retained on No.200 sieve.	Gravel--More than half of coarse soil is retained on No.4 sieve	- No.200 < 5%; $C_u \geq 4$ and $1 \leq C_c \leq 3$	GW	Well-graded gravels, gravel-sand mixtures with little or no fines.
		- No.200 > 5%; and not meeting both criteria for GW.	GP	Poorly-graded gravels, gravel-sand mixtures with little or no fines.
		- No.200 > 12%; Atterberg's limits plot below "A" line and plasticity index less than 4.	GM	Silty gravels, gravel-sand-silt mixtures.
		- No.200 > 12%; Atterberg's limits plot above "A" line and plasticity index greater than 7.	GC	Clayey gravels, gravel-sand-clay mixtures.
		- No.200 > 12%; Atterberg's limits fall in hatched area marked CL-ML.	GC-GM	Clayey-silty gravels, Gravel-silt-clay mixtures.
		- No.200 is 5-12%; and meets the criteria for GW and GM.	GW-GM	Well-graded gravels with silt, Gravel-sand-silt mixtures.
		- No.200 is 5-12%; and meets the criteria for GW and GC.	GW-GC	Well-graded gravels with clay binder, Gravel-sand silt clay mixtures.
		- No.200 is 5-12%; and meets the criteria for GP and GM.	GP-GM	Poorly-graded gravels with silt, Gravel-silt mixtures
		- No.200 is 5-12%; and meets the criteria for GP and GC.	GP-GC	Poorly-graded gravels with clay, Gravel-clay mixtures.

- No.200, means passing No.200 sieve

Group Symbols for Sandy Soil

Major Division		Criteria for Classification	Group Symbol	Typical Names
1	2	3	4	5
Coarse soil--More than half of soil is retained on No.200 sieve.	Sand--More than half of coarse soil passes No.4 sieve.	- No.200 < 5%; $C_u \geq 6$,and $1 \leq C_c \leq 3$	SW	Well-graded sands, gravelly sands with little or no fines.
		- No.200 < 5%; and not meeting both criteria for SW.	SP	Poorly-graded sands, gravelly sands with little or no fines.
		- No.200 > 12%; Atterberg's limits plot below "A" line in the plasticity chart or plasticity index less than 4.	SM	Silty sands, sand-silt mixtures.
		- No.200 > 12%; Atterberg's limits plot above "A" line in the plasticity chart or plasticity index greater than 7.	SC	Clayey sands, sand-clay mixtures.
		- No.200 > 12%; Atterberg's limits fall in hatched area marked CL-ML on the plasticity chart.	SC-SM	Clayey-silty sand, sand-silt-clay mixtures.
		- No.200 is 5-12%; and meets the criteria for SW and SM.	SW-SM	Well-graded sand with silt, sand-silt mixtures.
		- No.200 is 5-12%; and meets the criteria for SW and SC.	SW-SC	Well-graded sand with clay, sand-silt-clay mixtures.
		- No.200 is 5-12%; and meets the criteria for SP and SM.	SP-SM	Poorly-graded sand with silt, sand-silt mixtures.
		- No.200 is 5-12%; and meets the criteria for SP and SC.	SP-SC	Poorly-graded sand with clay, sand-clay mixtures.

- No.200, means passing No.200 sieve.

Group Symbols for Silty and Clayey Soil

Major Division		Criteria for Classification	Group Symbol	Typical Names
1	2	3	4	5
Fine grained soil-- More than half of the soil passes No.200 sieve.	Silt & Clay, LL <50	Inorganic; LL < 50; PI> 7; and plots on or above "A" line (see CL zone in plasticity chart)	CL	Inorganic clays of low to medium plasticity, gravelly clay, sandy clay, silty clay, lean clays.
		Inorganic; LL < 50; PI < 4, or plots below "A" line (see ML zone in plasticity chart)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
		Inorganic; (LL for oven dried sample)/(LL for non dried sample) < 0.75; and LL < 50 (see OL zone in plasticity chart)	OL	Organic silts and organic silty clays of low plasticity.
		Inorganic; plot in the hatched zone in the plasticity chart.	CL-ML	Silty clay of low plasticity
	Silt & Clay, LL >50	Inorganic; LL ≥ 50; and PI plots above "A" line (see CH zone in plasticity chart)	CH	Inorganic clays of high plasticity, fat clays.
		Inorganic; LL ≥ 50; and PI plots below "A" line (see MH zone in plasticity chart)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
		Organic;(LL-oven-dried)/(LL-not dried) < .75 And LL ≥ 50 (see OH zone in plasticity chart)	OH	Organic clays of medium to high plasticity, organic silts.
Highly Organic Soils		Peat, muck, and other highly organic soils	Pt	Peat and other highly organic soils.

Range of material % for coarse grained soil (ASTM-1986)

Group Symbols	% Limits	Group Names
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 with 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 with 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

Range of material %-age for coarse grained soil (ASTM-1986)

Group Symbols	% Limits	Group Names
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 with 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 with 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

Range of plasticity & material % for low plastic inorganic silty & clayey soil (ASTM-1986)

Range of LL	Nature of soil	Range of plasticity	Group symbol	Range of material %age			Group Names
Liquid Limit < 50	INORGANIC	P1>7 and lies on or above A-line	CL	+ No. 200<30%	+ No. 200<15%		Lean clay
					+ No. 200 15-29%	%sand ≥%gravel	Lean clay with sand
						%sand <%gravel	Lean clay with gravel
				+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy lean clay
						Gravel ≥15%	Sandy lean clay with gravel
					%sand<% gravel	Sand <15%	Gravelly lean clay
						Sand ≥15%	Gravelly lean clay with sand
		4≤PI≤7 and lies on or above A-line	CL-ML	+ No. 200<30%	+ No. 200<15%		Silty clay
					+ No. 200 15-29%	%sand ≥%gravel	Silty clay with sand
						%sand <%gravel	Silty clay with gravel
				+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy Silty clay
						Gravel ≥15%	Sandy Silty clay with gravel
					%sand<% gravel	Sand <15%	Gravelly Silty clay
						Sand ≥15%	Gravelly Silty clay with sand
		PI<4 or lies below A-Line	ML	+ No. 200<30%	+ No. 200<15%		Silt
					+ No. 200 15-29%	%sand ≥%gravel	Silt with sand
						%sand <%gravel	Silt with gravel
				+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy silt
						Gravel ≥15%	Sandy Silt with gravel
					%sand<% gravel	Sand <15%	Gravelly Silt
						Sand ≥15%	Gravelly Silt with sand
	Organic	$\frac{LL(\text{oven dried})}{LL(\text{notdried})} < .75$	OL	Refer plasticity chart			

Range of plasticity & material %-age for highly plastic silty & clayey soil (ASTM-1986)

Range of LL	Nature of soil	Range of plasticity	Group symbol	Range of material %age			Group Names
iquid Limit ≥ 50	INORGANIC	P1lies on or above A-line	CH	+ No. 200<30%	+ No. 200<15%		Fat clay
					+ No. 200 15-29%	%sand ≥%gravel	Fat clay with sand
						%sand <%gravel	Fat clay with gravel
				+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy fat clay
						Gravel ≥15%	Sandy fat clay with gravel
					%sand<% gravel	Sand <15%	Gravelly fat clay
						Sand ≥15%	Gravelly fat clay with sand
		PI lies below A-line	MH	+ No. 200<30%	+ No. 200<15%		Plastic silt
					+ No. 200 15-29%	%sand ≥%gravel	Plastic silt with sand
						%sand <%gravel	Plastic silt with gravel
				+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy plastic silt
						Gravel ≥15%	Sandy plastic silt with gravel
					%sand<% gravel	Sand <15%	Gravelly plastic silt
						Sand ≥15%	Gravelly plastic silt with sand
	Organic	$\frac{LL(oven\ dried)}{LL(notdried)} < .75$	OH	Refer plasticity chart			

Range of plasticity & material %-age for organic soil (ASTM-1986)

Nature of soil	Range of plasticity	Group symbol	Range of material %age			Group names
ORGANIC SOIL	P1<4 or lies above A-line .	+ No. 200≥30%	+ No. 200<30%	+ No. 200<15%		Organic clay
				+ No. 200 15-29%	%sand ≥%gravel	Organic clay with sand
					%sand <%gravel	Organic clay with gravel
			+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy organic clay
					Gravel ≥15%	Sandy organic clay with gravel
				%sand<% gravel	Sand <15%	Gravelly organic clay
					Sand ≥15%	Gravelly organic clay with sand
	P1<4 or lies below A-line		%sand <%gravel	+ No. 200<15%		Organic Silt
				%sand ≥%gravel	Organic silt with sand	
				Organic silty with gravel		
			%sand≥% gravel	Gravel <15%	Sandy Organic Silt	
				Gravel ≥15%	Sandy Organic Silt with gravel	
			%sand<% gravel	Sand <15%	Gravelly Organic Silt	
				Sand ≥15%	Gravelly Organic Silt with sand	
	Lies on or above A-Line	+ No. 200≥30%	+ No. 200<30%	+ No. 200<15%		Organic clay
				+ No. 200 15-29%	%sand ≥%gravel	Organic clay with sand
					%sand <%gravel	Organic clay with gravel
			+ No. 200≥30%	%sand≥% gravel	Gravel <15%	Sandy Organic clay
					Gravel ≥15%	Sandy Organic clay with gravel
				%sand<% gravel	Sand <15%	Gravelly Organic clay
					Sand ≥15%	Gravelly Organic clay with sand
	Lies below A-Line		%sand <%gravel	+ No. 200<15%		Organic Silt
				%sand ≥%gravel	Organic Silt with sand	
				Organic Silt with gravel		
			%sand≥% gravel	Gravel <15%	Sandy Organic silt	
				Gravel ≥15%	Sandy Organic Silt with gravel	
			%sand<% gravel	Sand <15%	Gravelly Organic Silt	
				Sand ≥15%	Gravelly Organic Silt with sand	

Group symbols & their characteristics related to Roads & Airfields

Symbol	Value as Subgrade When Not Subject to Frost Action		Value as Subbase When Not Subject to Frost Action	Value as Base When Not Subject to Frost Action	Potential Frost Action	Compressibility and Expansion	Drainage Characteristics
GW	Excellent		Excellent	Good	None to very slight	Almost none	Excellent
GP	Good to excellent		Good	Fair to good	None to very slight	Almost none	Excellent
GM	D	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor
	U	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious
GC	Good		Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious
SW	Good		Fair to good	Poor	None to very slight	Almost none	Excellent
SP	Fair to good		Fair	Poor to not suitable	None to very slight	Almost none	Excellent

Group symbols & their characteristics related to Roads & Airfields

Symbol	Value as Subgrade When Not Subject to Frost Action		Value as Subbase When Not Subject to Frost Action	Value as Base When Not Subject to Frost Action	Potential Frost Action	Compressibility and Expansion	Drainage Characteristics
SM	D	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor
	U	Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious
SC	Poor to fair		Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious
ML	Poor to fair		Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor
CL	Poor to fair		Not suitable	Not suitable	Medium to high	Medium	Practically impervious
OL	Poor		Not suitable	Not suitable	Medium to high	Medium to high	Poor
MH	Poor		Not suitable	Not suitable	Medium to very high	High	Fair to poor
CH	Poor to fair		Not suitable	Not suitable	Medium	High	Practically impervious
OH	Poor to very poor		Not suitable	Not suitable	Medium	High	Practically impervious
Pt	Not suitable		Not suitable	Not suitable	Slight	Very high	Fair to poor

Description of USC-Groups

Coarse grained soil

1 GW and SW groups:

- Well-graded gravelly and sandy soils with little or no fines ($\leq$ 5%).
- Fines must not change the strength & free-draining characteristics
- In areas prone to frost action, they should not contain > 3% of grains smaller than 0.02 mm.

2. GP and SP groups:

- Poorly graded gravels and sands with little or no fines.
- Poorly or Gap-graded materials are non-uniform mixtures of very coarse material and very fine sands with intermediate sizes lacking.

3. GM and SM groups:

- Silty gravel & silty sand with fines (>12%) of low or no plasticity.
- These lie below the "A" line on the plasticity chart.
- Both well and poorly-graded materials are included in these groups.

•Usually these soil has little or no dry strength. But presence of fine may increase it

GMd and SMu groups:

Suffices "d" and "u" mean desirable and undesirable base materials

- This subdivision applies to roads and airfields only
- Subdivision is based on the liquid limit and plasticity index
- Suffix "d" is used when LL is 25 or less and the PI is 5 or less;
- Suffix "u" is used otherwise.

Unified Soil Classification System (USCS)

- **GC and SC groups:**
- Gravelly or sandy soils with fines (> 12 %) that are more clay-like.
- The fines range in plasticity from low to high.
- The LL and PI of these groups plot above “A” line on plasticity chart.
- Both, well and poorly-graded soils are included in these groups.
- **FINE-GRAINED SOIL**
- **ML and MH groups:**
- Sandy silts, clayey silts, or inorganic silts with relatively low plasticity.
- Loess-type soils, rock flours, micaceous and diatomaceous soils are also included.
- Some types of kaolinite and clays also fall under these groups.
- Suffices L & M means low and high
- Micaceous and diatomaceous soils generally fall within the MH group but may extend into the ML group when their LL is less than 50.

Unified Soil Classification System (USCS)

- **CL an CH Group**
- The CL and CH groups include clays with low and high liquid limits
- They are primarily inorganic clays.
- The medium and high plasticity clays are classified as CH and include fat clays, gumbo clays, bentonite, and some volcanic clays.
- The low plasticity clays are classified as CL and usually include lean clays, sandy clays, or silty clays.
- **OL and OH Group**
- These groups are characterized by the presence of organic matter.
- Organic silts and clays are included in these two groups, and they have a plasticity range corresponding to the ML, and MH groups.
- **Highly Organic Soil**
- These soils are designated by group symbol (Pt).
- They are usually very compressible and have undesirable engineering characteristics.
- These includes peat, humus, and swamp soils with a high organic texture.
- Common components of these soils are particles of leaves, grass, branches, or other fibrous vegetable matter.

Table: Engineering use chart

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	IMPORTANT PROPERTIES			
		PERME-ABILITY WHEN COMPACTED	SHEARING STRENGTH WHEN COMPACTED AND SATURATED	COMPRESS-IBILITY WHEN COMPACTED AND SATURATED	WORKABILITY AS A CONSTRUCTION MATERIAL
WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT
POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GP	VERY PERVIOUS	GOOD	NEGLIGIBLE	GOOD
SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES	GM	SEMIPERVIOUS TO IMPERVIOUS	GOOD	NEGLIGIBLE	GOOD
CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND- CLAY MIXTURES	GC	IMPERVIOUS	GOOD TO FAIR	VERY LOW	GOOD
WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT
POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES.	SP	PERVIOUS	GOOD	VERY LOW	FAIR
SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES	SM	SEMIPERVIOUS TO IMPERVIOUS	GOOD	LOW	FAIR

Table: Engineering use chart

CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES	SC	IMPERVIOUS	GOOD TO FAIR	LOW	GOOD
INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY	ML	SEMIPERVIOUS TO IMPERVIOUS	FAIR	MEDIUM	FAIR
INORGANIC CLAYS OF LOW TO MEDIUM CLAYS, SANDY CLAYS SILTY CLAYS, LEAN CLAYS	CL	IMPERVIOUS	FAIR	MEDIUM	GOOD TO FAIR
ORGANIC SILTS AND ORGANIC SILT-CLAY OF LOW PLASTICITY	OL	SEMIPERVIOUS TO IMPERVIOUS	POOR	MEDIUM	FAIR
INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	MH	SEMPERVIOUS TO IMPERVIOUS	FAIR TO POOR	HIGH	POOR
INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	CH	IMPERVIOUS	POOR	HIGH	POOR
ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY	OH	IMPERVIOUS	POOR	HIGH	POOR
PEAT AND OTHER HIGHLY ORGANIC SOILS	PT	--	--	--	--

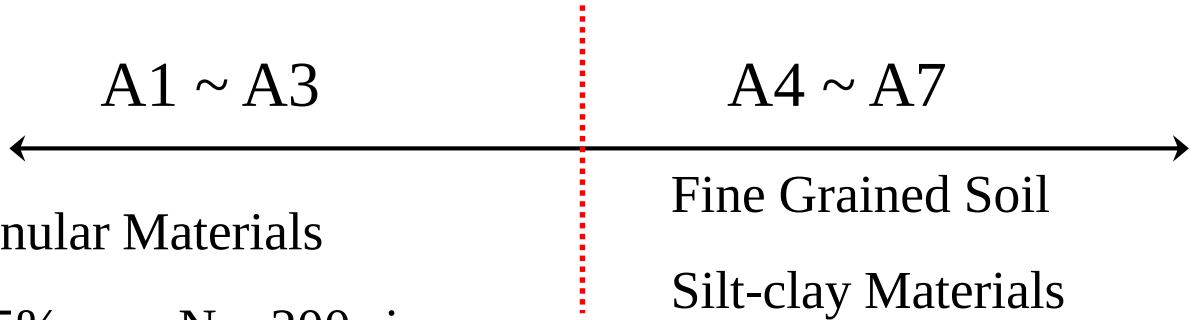
American Association of State Highway and Transportation Officials system (AASHTO)

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)

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).



Granular Materials

≤ 35% pass No. 200 sieve

Using LL and PI separates silty materials from clayey materials (only for A_2 group)

Fine Grained Soil

Silt-clay Materials

≥ 36% pass No. 200 sieve

Using LL and PI separates silty materials from clayey materials

- The original purpose of this classification system is used for road construction (subgrade rating).

Group Index

- For quantitative analysis if of a given soil as a highway subgrade materials a number is referred Group index has also been developed
- The higher the value of Group Index for a given soil, the weaker will be the soil for pavement subgrade
- A group Index of 20 or more indicates very poor subgrade materials.
- A soil having a zero Group Index indicates a very best soil for pavement
- Formula is given as:

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

- F200 = Percent passing NO. 200 sieve, expressed as whole number
- LL = Liquid Limit
- PI = Plasticity index

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.

Following are some rules for determination of group index:

a. If the equation for group index gives a negative value for GI, it is taken as zero.

b. The group index calculated from the equation is rounded off to the nearest whole number (for example, GI = 4.4 is rounded off to 4; and GI = 4.5 is rounded off to 5).

c. There is no upper limit for the group index.

d. 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.

e. When calculating the group index for soils belonging to groups A-2-6, and A-2-7, the partial group index equation related to plasticity index (as given below) should be used.

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

Classification

Table: Classification of Soil-Aggregate Mixtures (with Suggested Subgroups)

General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing No. 200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	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: % Passing: No. 10 No. 40 No.200	50 Max. 30 Max. 15 Max.	50 Max. 25 Max.	51 Min. 10 Max.	35 Max.	35 Max.	35 Max.	35 Max.	36 Min.	36 Min.	36 Min.	36 Min.
Fraction passing No.40: Liquid Limit Plasticity Index	6 Max		N.P.	40 Max. 10 Max.	41 Min. 10 Max.	40 Max. 11 Min.	41 Min. 11 Min.	40 Max. 10 Max.	41 Min. 10 Max.	40 Max. 10 Min.	41 Min. 11 Min.
Group Index	0		0	0		4 Max.		8 Max.	12 Max.	16 Max.	20 Max.
Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to Poor			

PI of A-7-5 subgroup is equal or less than (LL-30), PI of A-7-6 subgroup is greater than (LL-30)

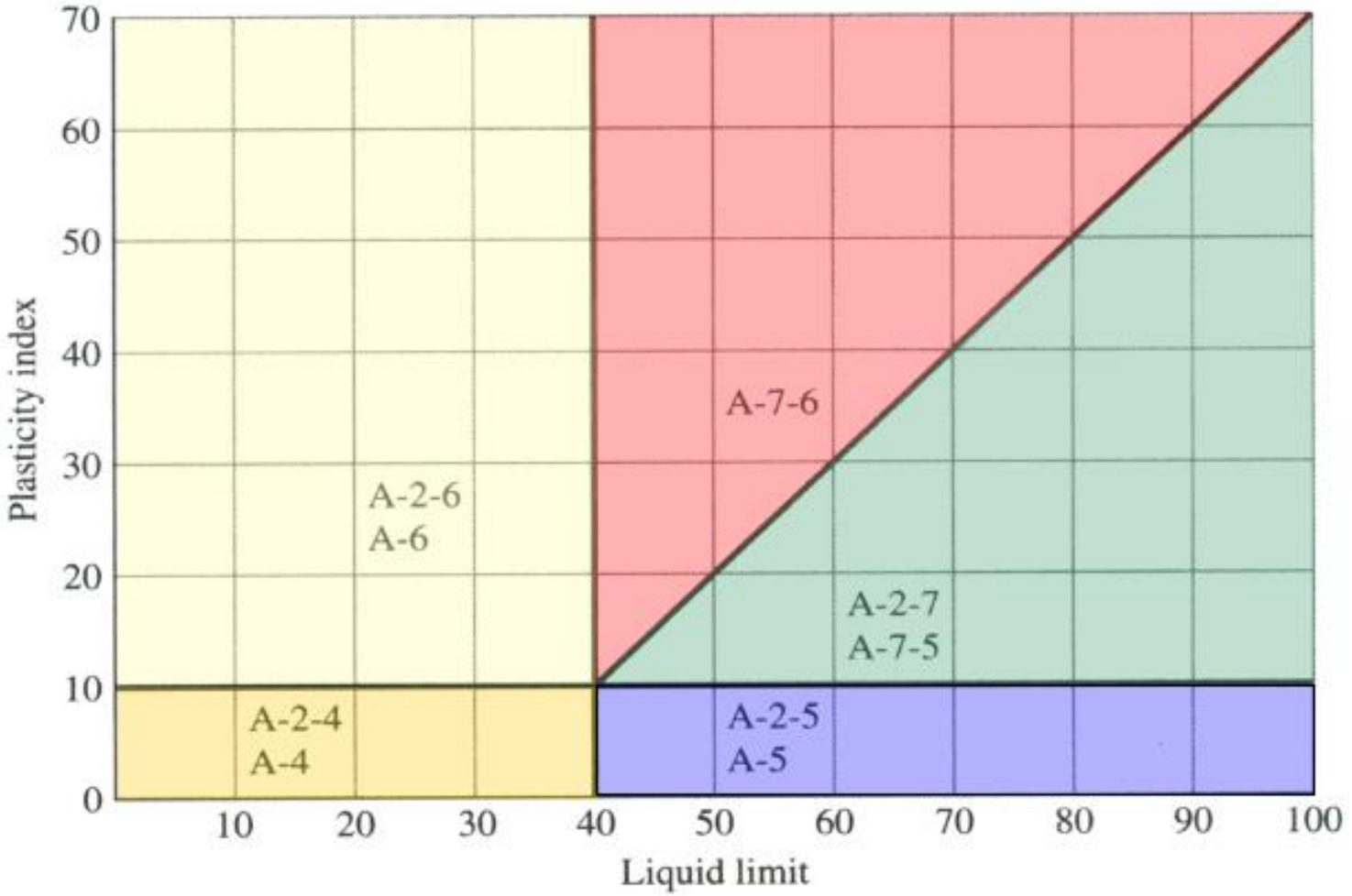


Fig: Liquid limit and plasticity index ranges for silt-clay material

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

$$GI = (F_{200} - 35)\left[0.2 + 0.005(LL - 40)\right] + 0.01(F_{200} - 15)(PI - 10) = 33.47 \cong 33$$ *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, $PI > LL - 30$

Comparison of the AASHTO and unified soil classification systems

AASHTO system	Unified system
1.It is based on texture and plasticity of soil.	1-It is also based on texture and plasticity of soil.
2. The soil is divided into two major categories i.e., coarse grained and fine grained, as separated by the No. 200 sieve.	2-The soil is divided into two major categories i.e., coarse grained and fine grained, as separated by the No. 200 sieve.
3- A soil is considered fine grained when more than 35% passes the No. 200 sieve. (A coarse-grained soil having about 35% fines behaves like a fine-grained material, since there are enough fines to fill the voids between the coarse grains and hold them apart. In this respect AASHTO system appears to be more appropriate.)	3- A soil is considered fine grained when more than 50% passes the No. 200 sieve.
AASHTO system	Unified system
4- No. 10 sieve is used to separate gravels from sand. The No.10 sieve is more accepted as upper limit for sand. (Therefore AASHTO system is more appropriate.)	4- No. 4 sieve is used to separate gravels from sand
5- Gravelly and sandy soils are not clearly separated. The A-2 group in particular, contains a large variety of soils 6- The symbols A-1, A-2, etc., of this group are not well descriptive of the soil properties. 7- Organic soils are not well discussed in this system.	5- Gravelly and sandy soils are clearly separated. 6- The symbols such as GW, SM, CH, and others are more descriptive of the soil properties 7- The classification of organic soils such as OL, OH, & Pt has been provided in this system.

Description of Classification Groups

- **Group A-1**
- The typical material of this group is well graded mixture of stone fragments or gravels, coarse sand, fine sand and non plastic or slightly plastic soil binder.
- This group is subdivided in to two subgroups
- **Subgroup A-1-a**
- Stone fragments or gravel, either with or without well graded soil binder
- **Subgroup A-1-b**
- Coarse sand, either with or without well graded soil binder
- **Group A-3**
- This group comprise of material consisting of sands deficient in coarse material and soil binder.
- Fine beach sand or fine desert sand without silt or clay fines or with very small amount of non plastic silt
- This group is also include poorly graded fine sand and limited amount of coarse sand and gravel.
- These soil suitable sub grades for all types of pavements

Description of Classification Groups

- **Group A-2**
- This group include a wide variety of granular materials which are borderline between the materials falling in group A-1 and A-3 and silty clay material of groups A-4, A-5, A-6 and A-7
- It includes all materials containing 35 % or less passing the No. 200 sieve which can not be classified as A-1 or A-3
- This group is subdivided in to two subgroups
- **Subgroup A-2-4 and A-2-5**
- These groups include various granular materials containing 35 % or less passing the No. 200 Sieve and with the proportion of materials passing No. 40 sieve having characteristics of A-4 and A-5 groups.
- **Subgroup A-2-6 and A-2-7**
- These group include material similar to A-2-4 and A-2-5 except that the fine portion contains plastic clay having characteristics of the A-6 and A-7 group
- The approximate combined effect of plasticity index of more than 10 and percentages passing the No. 200 sieve of more than 15, is reflected by group index values of 0 to 4

Description of Classification Groups

- **Group A-4**
- The typical material of this group is non plastic or moderately plastic silt, usually having 75 percent or more passing the No. 200 sieve
- The group includes also mixtures of fine silty soil and up to 64 % of sand and gravel retained on the No. 200 sieve.
- The group index values ranges from 1 to 8, with increasing % of coarse material being reflected by decreasing group index values.
- **Group A-5**
- The typical materials of this group is similar that described in group A-4 except that is usually of **diatomaceous or micaceous** and may be highly plastic as indicated by the high liquid limit.
- The group index values range from 1 to 12, with increasing values indicating the combined effect of increasing liquid limit and decreasing percentages of coarse material

Group A-6: The typical material of this group is a plastic clay soil usually having 75 percent or more passing the No.200 sieve. The group includes also mixtures of fine clayey soil and up to 64 percent of sand and gravel retained on the No. 200 sieve. Materials of this group usually have high volume change between wet and dry states. The group index values range from 1 to 16, with increasing values indicating the combined effect of increasing plasticity indices and decreasing percentages of coarse material. These soils are quite common in occurrence and are widely used in fills. When moisture content is properly controller, they compact quite readily with either a sheep-foot or pneumatic-tired roller. They have high dry strength but loose much of the strength upon absorbing water. The A-6 soils will compress when wet and shrink and swell with changes in moisture content. When placed in the shoulders adjacent to the pavement, they tend to shrink away from the pavement edge upon drying and thereby provide an access of surface water to the underside of the pavement. The A-6 soils do not drain readily and may absorb water by capillarity with resulting loss in strength. Therefore, the pavement structural design should be based on the strength of these soils when saturated.

Group A-7: The typical materials and problems of this group are similar to those described under Group A-6, except that they have the high liquid limits characteristic of the A-5 group and may be plastic as well as subject to high volume changes. The range of group index values is 1 to 20, with increasing values indicating the combined effect of increasing liquid limits and plasticity indices and decreasing percentages of coarse material.

Subgroup A-7-5: This group includes those materials with moderate plasticity indices in relation to liquid limit and which may be highly plastic as well as subject to considerable volume change.

Subgroup A-7-6: This group includes those materials with high plasticity indices in relation to liquid limit and which are subject to extremely high volume change.

Highly organic soils such as peat and muck may be classified as an A-8 group. Classification of these materials is based on visual inspection and is not dependent on the percentage passing the No. 200 sieve, liquid limit or plasticity index. The material is primarily composed of partially decayed organic material, and generally has a fibrous texture, dark brown or black color and odor of decay. Because of their many undesirable properties, their use should be avoided, if possible, in all types of construction. They are highly compressible and have low strength.

- **Classify the following soils Using Unified Classification System.**

Soil	No. 4 Sieve	No. 200 Sieve	LL	PI
(cumulative % passing)				
A	92	48	30	10
B	99	76	60	32
C	80	35	24	2

- **Classify the following soils Using Unified Classification System.**

Soil A

Coarse = 100-48 = 52% (retained on N o. 2 0 0), so COARSE-GRAINED SOIL
8% retained on No. 4, vs. 52% coarse,
8/52 = 15% (<50%), so SAND
Using the LL and PL values in the USAC
Atterberg limits above line A, so Clay
Classification SC, clayey sand

Soil B

Coarse = 100 - 76 = 24%, so FINE-GRAINED SOIL
LL = 60, and P I = 32 Using Casagrandi Chart
Classification CH, inorganic clay with high plasticity

Soil C

Coarse = 100 - 35 = 65%, so COARSE-GRAINED SOIL
20% retained on No. 4, vs. 65%
coarse, 20/65 = 31% (<50%), so SAND
Using Casagrandi Chart
Classification SM, Silty sand

- **Classify the following soils Using Unified Classification System.**

Soil	Sieve analysis, % finer		Liquid limit	Plasticity index
	No. 4	No. 200		
A	80	52	30	8
B	79	45	26	4
C	91	80	60	32
D	95	75	41	12
E	82	41	24	2

Soil A

Gravel = 100 – 80 = 20%

Sand = 80 – 52 = 28%

Fines = 52% > 50% => Fine-grained soil

3.13 EXAMPLES

Example-3.1 Classify the soil sample by the AASHTO classification system. The results of the sieve analysis and the Atterberg limit tests are given as under.

U.S. Sieve Size	Percentage Passing
No. 4	100
No. 10	93.2
No. 40	81.0
No. 200	60.2

Liquid limit = 41.2% Plastic limit = 15.5%

Required: Determine the AASHTO classification group

Solution:

Plasticity index (PI) = Liquid limit - Plastic limit

PI = 41.2 - 15.5 = 25.7%

Entering the Table 3.13 and moving from left to right the sample is classified as A-7. According to the AASHTO classification system, the plasticity index of the A-7-5 subgroup is equal to or less than the liquid limit minus 30, and the plasticity index of the A-7-6 subgroup is greater than the liquid limit minus 30

LL - 30% = 41.2 - 30 = 11.2

[PI = 25.7%]> [LL- 30% = 11.2%]

Hence, this is A-7-6 material.

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

Putting the values

$$GI = (60.2 - 35)\left[0.2 + 0.005(41.2 - 40)\right] + 0.01(60.2 - 15)(25.7 - 10)$$

GI (group index) = 12.28

Hence, the soil is A-7-6 (12), according to the AASHTO classification system.

3.2 The laboratory tests gave the following results on a soil sample.
Liquid limit = 31.6% Plastic limit = 12.8%.

Sieve analysis data as under

U.S. Sieve Size	Percentage Passing
3/8 in.	100
No. 4	76.5
No. 10	60.0
No. 40	39.7
No. 200	15.2

Classify the soil according to the Unified Soil Classification System.

The percentage retained on the No. 200 sieve is 84.8% i.e., (100 -15.2 = 84.8), which is more than 50%. The soil is broadly classified as "Coarse-grained" according to column-1 of Table 3.3.

The percentage of the sample retained on the No. 4 sieve is 23.5% i.e., (100 - 76.5 = 23.5). Thus, the percentage of the coarse fraction retained on the No. 4 sieve is 27.7%, i.e., (23.5/84.8)(100), and the percentage of coarse fraction that passed the No. 4 sieve is 72.3%. Since 72.3% is greater than 50%, then according to column -2 of the Table 3.4, the main classification group is "Sand".

Since the sample contains 15.2% passing the No. 200 sieve, which is greater than 12% fines, the soil is termed as "Sands with fines: More than 12% fines."

Now refer to the plasticity chart of Fig 3.1. With the liquid limit of 31.6% and plasticity index of 18.6% (31.6- 12.8 = 18.6), the sample is located above the "A" line, and the fines are classified as CL or low plasticity clay.

Thus, according to columns-3&4 of the Table 3.4, the soil is classified SC according to the Unified Soil Classification System.

3.3 A soil sample was tested in the laboratory and the following results were obtained

Liquid limit = NP (non-plastic).

Plastic limit = NP (non-plastic).

Sieve analysis results as follows

U.S. Sieve Size	Percentage Passing
1 in.	100
¾ in.	86
½ in.	69
3/8 in.	61
No. 4	48
No. 10	30
No. 40	17
No. 100	10
No. 200	2

Classify the soil according to the Unified Soil Classification System.

The percentage retained on the No. 200 sieve is 98% i.e., (100 - 2 = 98), which is more than 50%. According to column-1 of Table 3.3 the soil is broadly classified as "Coarse-grained".

The percentage of the sample retained on the No. 4 sieve is 52% i.e., (100 - 48 = 52). Thus, the percentage of the coarse fraction retained on the No. 4 sieve is 53.1%, i.e., [(52/98)(100) = 53.1]. Since 53.1% is greater than 50%, then according to column-2 of the Table 3.3, the main soil group is "Gravel".

The sample contains 2% passing the No. 200 sieve, which is less than 5% fines, the soil lies in the first row of column-3 of table 3.3.

Now calculate the coefficients of uniformity (Cu) and curvature (Cc) by the equations given below.

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

$$C_c = \frac{(D_{30})^2}{D_{60} D_{10}}$$

After drawing the gradation curve, the values of D_{60}, D_{30} and D_{10} determined from the curve (Fig 3.3) are 9.6mm, 2.00mm, and 0.16 mm, respectively. Hence,

$$C_u = \frac{9.6}{0.16} = 60$$

$$C_c = \frac{2^2}{9.6 \times 0.16} = 2.6$$

The value of C_u is greater than 4 and the value of C_c is between 1 and 3, the sample therefore meets both criteria for well-graded gravel. Hence from table 3.3 the soil is classified as "GW".

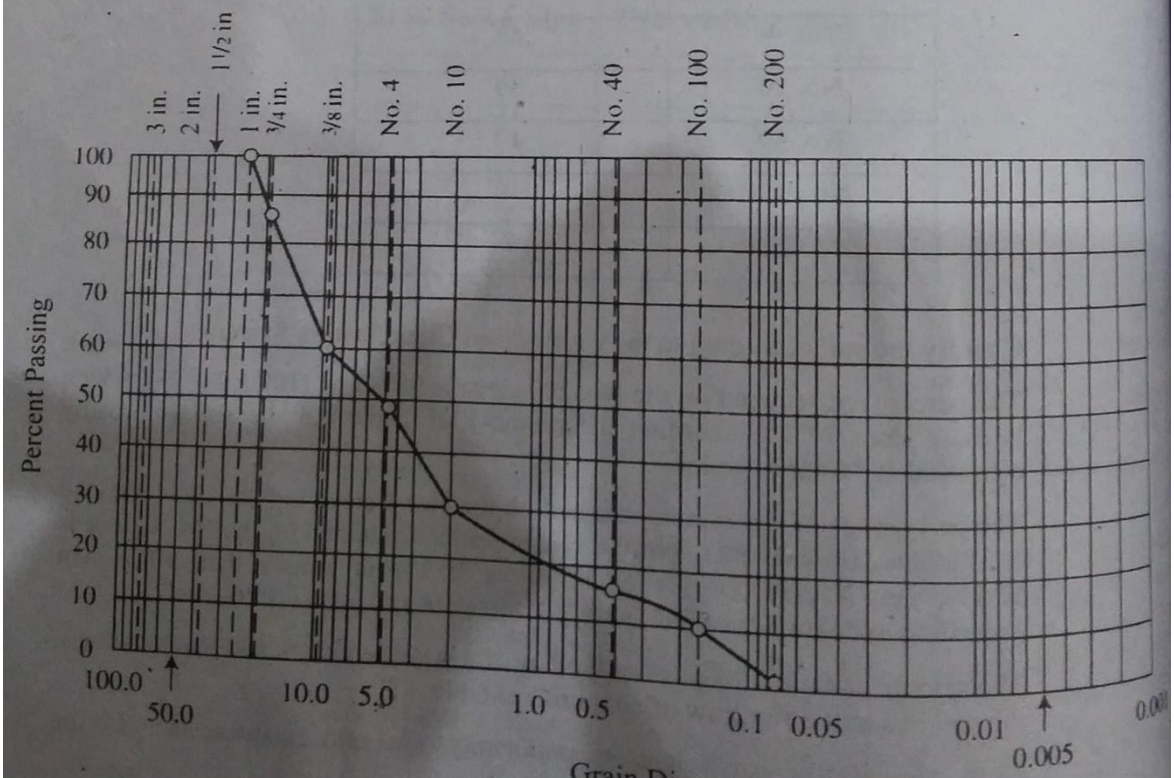


Figure 3.3 Grain-size distribution curve

An inorganic soil sample was tested in the laboratory for classification and the following results were obtained.

Liquid limit = 44%.
Plastic limit = 18%.
The results of the sieve analysis are as follows

U.S. Sieve Size	Percentage Passing
No. 4	100
No. 10	93.2
No. 40	81.0
No. 200	60.2

Classify the soil by the Unified Soil Classification System.

The percentage of the sample passing the No. 200 sieve is 60.2%, which is greater than 50%. According to the column-1 of table 3.5, the soil is termed as "Fine-grained".

The liquid limit is 44%, which is less than 50%, so go to the upper portion of column-2 of the table 3.5 "Silt and clays, LL < 50."

Now, since the soil sample is inorganic soil and the plasticity index is 44 - 18 = 26%, which is greater than 7, refer to the plasticity chart of Fig·3.1. With a liquid limit of 44% and plasticity index of 26%, the sample is located above the "A" line. Thus, according to column-4 of the table 3.5, the soil is classified as CL according to the Unified Soil Classification System.

ample- 3.5 The tests for the classification of a soil gave the following results;

Percentage passing No. 4 sieve = 85%
Percentage passing No. 10 sieve = 70%
Percentage passing No. 40 sieve = 66%
Percentage passing No. 200 sieve = 41%
Liquid limit = 33%
Plasticity index = 13%

Classify the following soil by the AASHTO classification system.

From the Table 3.13, since more than 35% passes through the No. 200 sieve, it is a silt-clay material; and it may be A-4, A-5, A-6, or A-7. Now as the LL = 33% (i.e., less than 40) and PI = 13% (i.e., greater than 11), it falls in group A-6. Determine the group index by the equation given below.

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

$$GI = (41 - 35)[0.2 + 0.005(33 - 40)] + 0.01(41 - 15)(13 - 10)$$
$$= 1.77 \approx 2$$

Hence the soil is A-6(2)

Example- 3.6 The tests for the classification of a soil gave the following results;

Percentage passing No. 4 sieve = 85%
Percentage passing No. 10 sieve = 70%
Percentage passing No. 40 sieve = 66%
Percentage passing No. 200 sieve = 41%
Liquid limit = 33%
Plasticity index = 13%

Required: Classify the following soil by the Unified classification system.

Solution: The percentage of the sample passing the No. 200 sieve is 41%, and retained on the No. 200 sieve is 59% which is greater than 50%. According to the column-1 of table 3.4, the soil is termed as "Coarse-grained".

The percentage of the sample retained on the No. 4 sieve is 15% i.e., (100 - 85 = 15). Thus, the percentage of the coarse fraction retained on the No. 4 sieve is 25.4%, i.e., (15/59) (100), and the percentage of coarse fraction that passed the No. 4 sieve is 74.6%. Since 74.6% is greater than 50%, then according to column -2 of the Table 3.4, the main classification group is "Sand".

Since the sample contains 41% passing the No. 200 sieve, which is greater than 12% fines, according to column-3 of the table 3.4, the soil is termed as "Sand with fines" and it is either SM or SC.

Now refer to the plasticity chart of Fig 3.1. With the liquid limit of 33% and plasticity index of 13%, the sample is located above the "A" line, and the fines are classified as CL or low plasticity clay.

Thus, according to columns-3 & 4 of the Table 3.4, the soil is classified SC according to the Unified Soil Classification System. For the group name, refer to table 3.6. The gravel fraction (i.e., the percentage retained on the No. 4 sieve) is 100-85 = 15%, therefore the group name is **clayey sand with gravel.**

THANK YOU!