Soil Classification

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1. Purpose

- Main soil types are; Clay, Silt, Sand, Gravels, Boulders etc.
- Above types seldom exist separately in nature
- Natural soil deposits comprise mixture of above types in varying proportions
- Soil classification means to arrange soil in groups and label them based on their properties and behaviour.
- Soil Classification Systems have been developed by different organizations

Basis for Classification

- Classification is based on the following physical properties

- ◆Grain Size Distribution (GSD)
- ◆Liquid limit (LL)
- ◆Plasticity Index (PI)

- Classification gives some idea about the general behaviour of soil

- However to predict true behaviour additional information based on geotechnical properties are yet required

- Classifying soils into groups with similar behavior, in terms of *simple* indices, can provide geotechnical engineers a general guidance about engineering properties of the soils through the *accumulated experience*.

Communicate between engineers

Simple indices GSD, LL, PI → Classification system (Language) → Estimate engineering properties → Achieve engineering purposes

Use the accumulated experience

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.

2. Classification Systems

- **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

3. Unified Soil Classification System (USCS)

Origin of USCS:

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

Four major divisions:

(1) Coarse-grained
(2) Fine-grained
(3) Organic soils
(4) Peat

- Tests required for classification of soil are;

1. Liquid and plastic limit tests.
2. Particle size analysis test.

Broad Classification includes the following two types;

1. Coarse-grained soil
2. 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

G - Gravel S - Sand	Coarse grained soil
M - Inorganic Silt C - Inorganic Clay O - Organic Silt and Clay	Fine grained soil
P_t - Peat, Humus, Swamp	

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)

Classification Group Symbols

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

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:

1. Textural characteristics of coarse-grained soils with such small amount of fines, that fines do not affect the behaviour.
2. Plasticity characteristics of fine-grained soils where the fines affect the engineering behaviour.

Textural characteristics are evaluated by particle-size analysis.

Plasticity characteristics are evaluated by the plasticity chart.

To classify a soil, following information based on particle size analysis and Atterberg limits should be available.

1. **%age of gravel, that is, the fraction passing 3-in. (76.2mm) sieve and retained on the No.4 (4.75mm) sieve.**

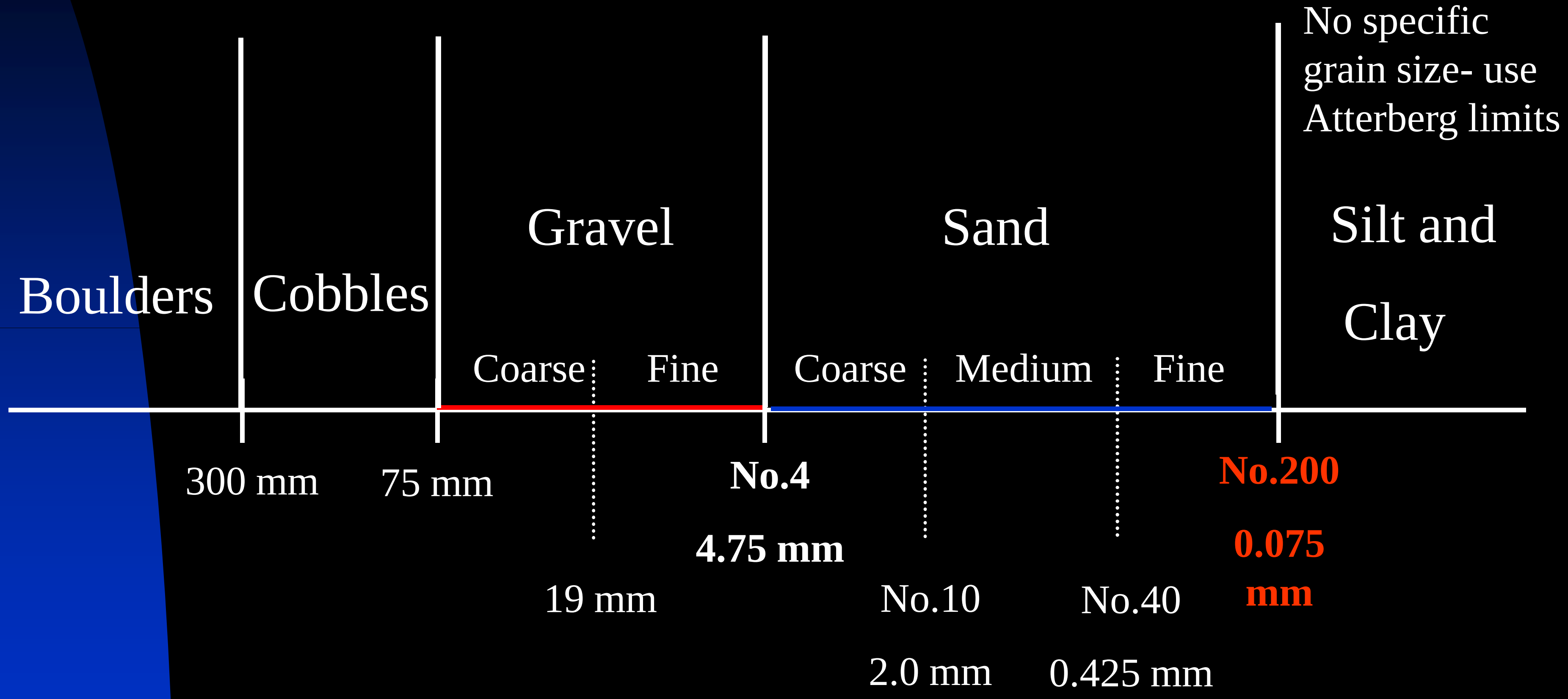
2. **%age of sand, that is, the fraction passing No.4 sieve (4.75mm) and retained on the No.200 (0.074mm) sieve.**

3. **%age of silt and clay, that is, the fraction finer than the No.200 (0.075mm) sieve.**

4. **Uniformity coefficient (C_u) and the coefficient of gradation (C_c), which actually depend on the shape of particle-size-distribution curve.**

5. **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



3.2 General Guidance

50% *50 %*

Coarse-grained soils: Fine-grained soils:

Gravel Sand Silt Clay

NO. 4

4.75 mm

NO.200

0.075 mm

- Grain size distribution
- C_u
- C_c

- PL, LL
- Plasticity chart

LL>50
LL <50

Required tests: Sieve analysis
Atterberg limit

3.3 Symbols

- **Soil symbols:**
- G: Gravel
- S: Sand
- M: Silt
- C: Clay
- O: Organic
- Pt: Peat

- **Liquid limit symbols:**
- H: High LL (LL>50)
- L: Low LL (LL<50)
- **Gradation symbols:**
- W: Well-graded
- P: Poorly-graded

Example: SW, Well-graded Sand

SC, Clayey Sand

SM, Silty Sand,

MH, Highly Plastic Silt

3.4 Plasticity Chart

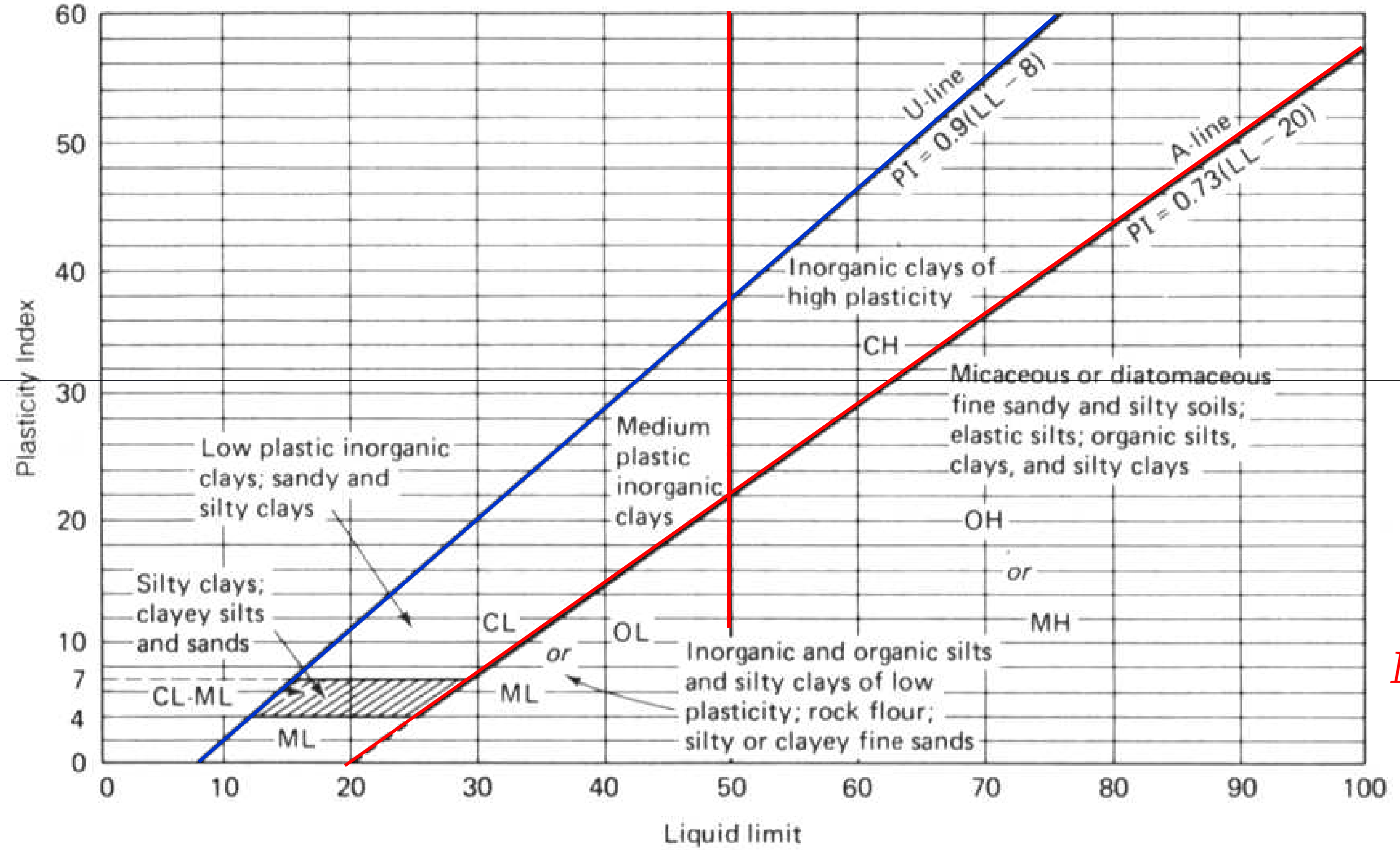


Fig. 3.2 Casagrande's plasticity chart, showing several representative soil types (developed from Casagrande, 1948, and Howard, 1977).

(Holtz and Kovacs, 1981)

The A-line generally separates the more claylike materials from silty materials, and the organics from the inorganics.

The U-line indicates the upper bound for general soils.

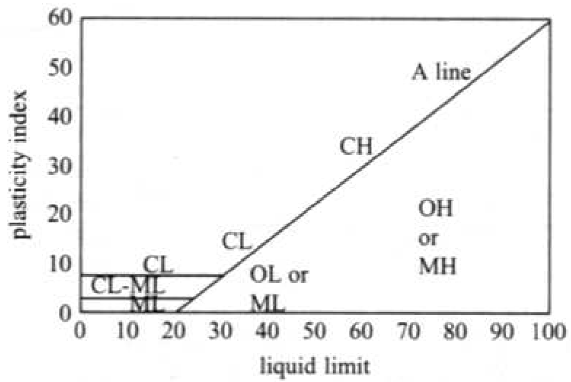
Note: If the measured limits of soils are on the left of U-line, they should be rechecked.

3.5 Procedures for Classification

Coarse-grained material

Grain size distribution

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



Fine-grained material

LL, PI

3.7 Organic Soils

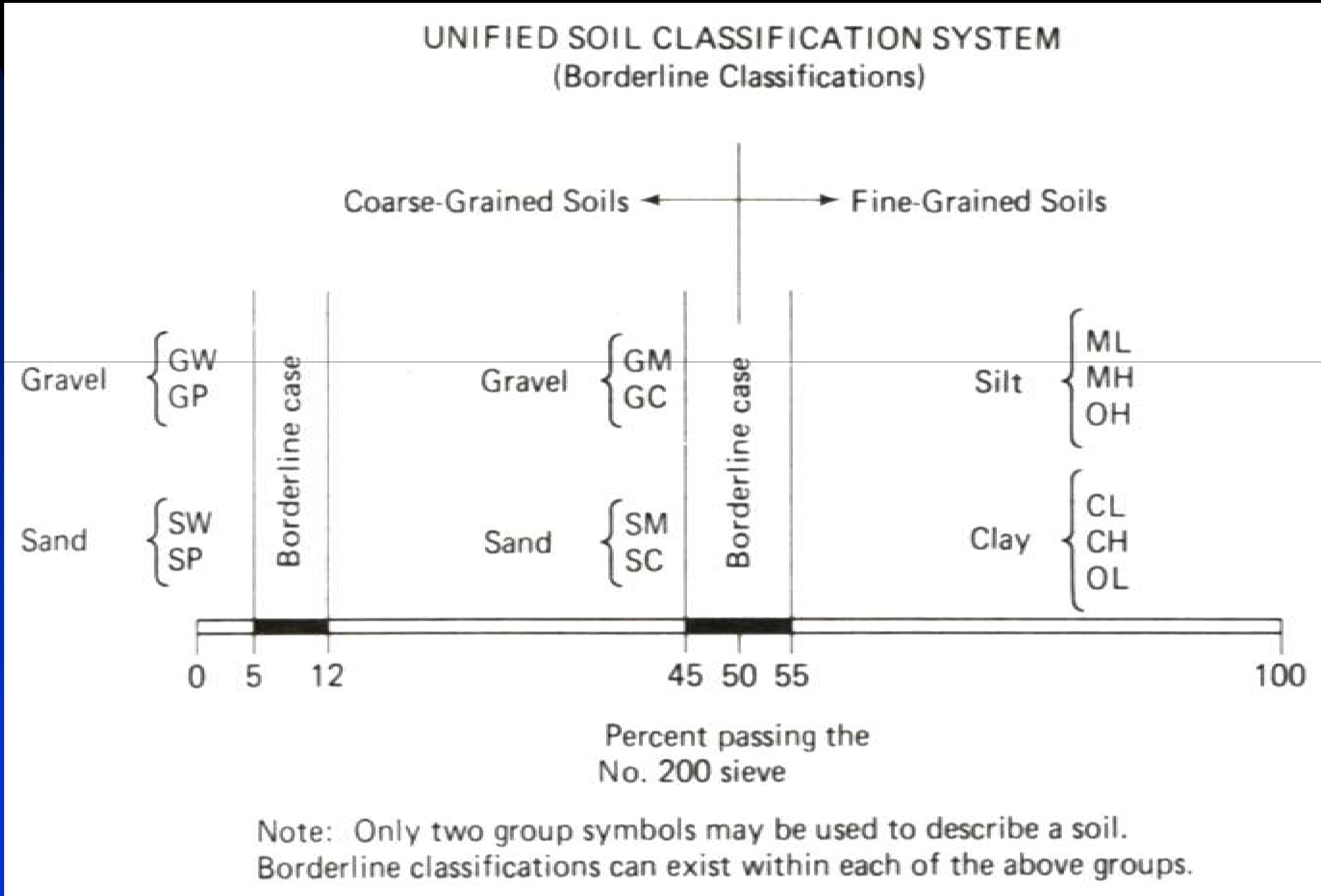
- **Highly organic soils- Peat (Group symbol PT)**
  - A sample composed primarily of vegetable tissue in various stages of decomposition and has a fibrous to amorphous texture, a dark-brown to black color, and an organic odor should be designated as a highly organic soil and shall be classified as peat,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

3.8 Borderline Cases (Dual Symbols)

- For the following three conditions, a dual symbol should be used.
  - Coarse-grained soils with 5% - 12% fines.
    - **About 7 % fines can change the hydraulic conductivity of the coarse-grained media by orders of magnitude**.
    - The first symbol indicates whether the coarse fraction is well or poorly graded. The second symbol describe the contained fines. For example: SP-SM, poorly graded sand with silt.
  - Fine-grained soils with limits within the shaded zone. (PI between 4 and 7 and LL between about 12 and 25).
    - It is hard to distinguish between the silty and more claylike materials.
    - CL-ML: Silty clay,   SC-SM: Silty, clayey sand.
  - Soil contain similar fines and coarse-grained fractions.
    - possible dual symbols GM-ML

3.8 Borderline Cases (Summary)



1981)

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

Table: 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.

Table: Group Symbols for Silty and Clayey Soil

Major Division 1	Major Division 2	Criteria for Classification 3	Group Symbol 4	Typical Names 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	$\frac{LL(oven\ dried)}{LL(not dried)}$	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	LL(oven dr / LL(notdrie	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 (≤ 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.

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.

4. 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

1. 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 illite 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.

2. CL and CH groups:

- 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.

3. OL and OH groups:

- 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 Soils

- 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	--	--	--	--

Table: Engineering use chart

GROUP SYMBOLS	RELATIVE DESIRABILITY FOR VARIOUS USES									
	ROLLED EARTH DAMS			CANAL SECTIONS		FOUNDATIONS		ROADWAYS		
	HOMOGENEOUS EMBANKMENT	CORE	SHELL	EROSION RESISTANCE	COMPACTED EARTH LINING	SEEPAGE IMPORTANT	SEEPAGE NOT IMPORTANT	FROST HEAVE NOT POSSIBLE	FROST HEAVE POSSIBLE	SURFACING
GW	--	--	1	1	--	--	1	1	1	3
GP	--	--	2	2	--	--	3	3	3	--
GM	2	4	--	4	4	1	4	4	9	5
GC	1	1	--	3	1	2	6	5	5	1
SW	--	--	3 IF GRAVELLY	6	--	--	2	2	2	4
SP	--	--	4 IF GRAVELLY	7 IF GRAVELLY	--	--	5	6	4	--

Table: Engineering use chart

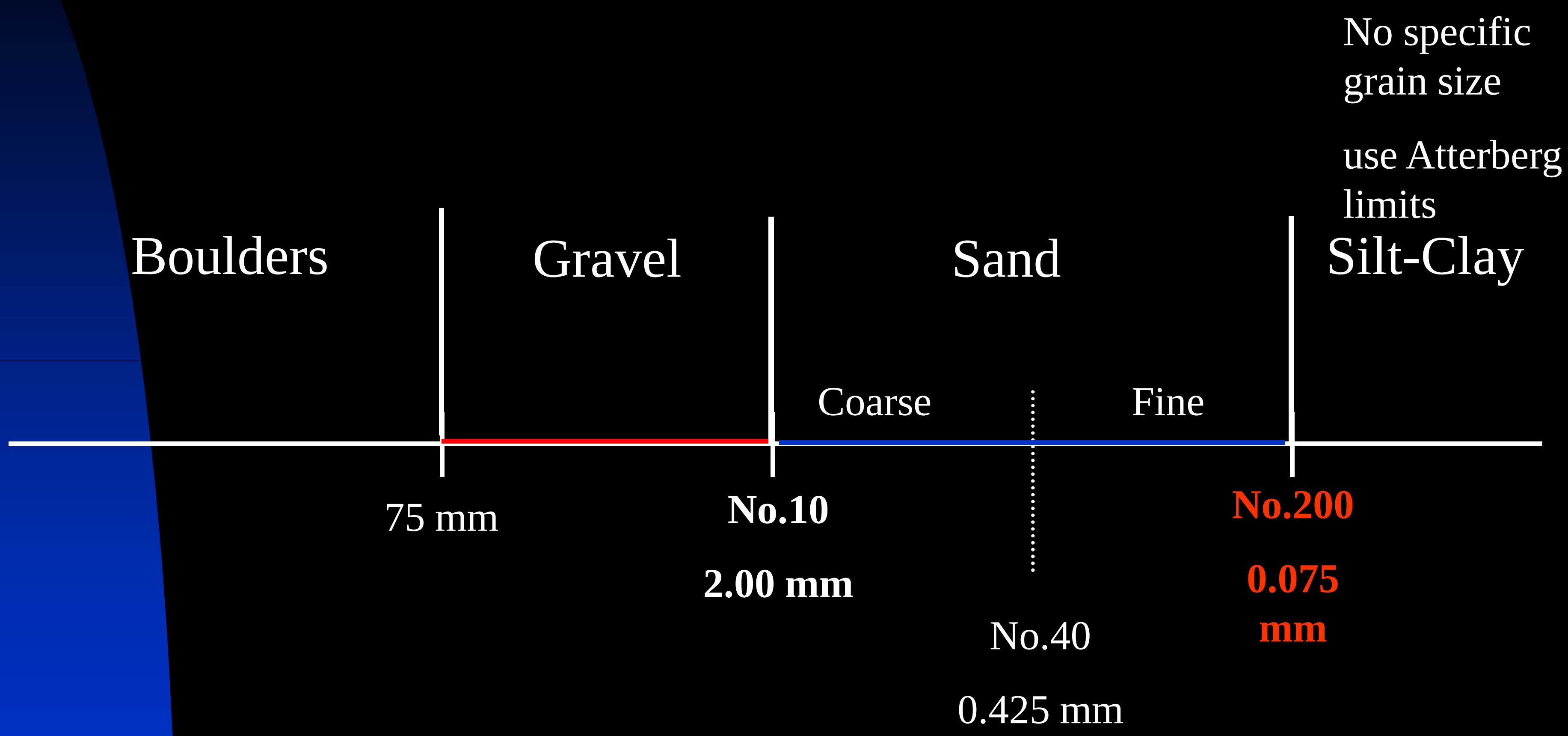
SM	4	5	--	8 IF GRAVELLY	5 EROSION CRITICAL	3	7	8	10	6
SC	3	2	--	5	2	4	8	7	6	2
ML	6	6	--	--	6 EROSION CRITICAL	6	9	10	11	--
CL	5	3	--	9	3	5	10	9	7	7
OL	8	8	--	--	7 EROSION CRITICAL	7	11	11	12	--
MH	9	9	--	--	--	8	12	12	13	--
CH	7	7	--	10	8 VOLUME CHANGE CRITICAL	9	13	13	8	--
OH	10	10	--	--	--	10	14	14	14	--
PT	--	--	--	--	--	--	--	--	--	--

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

Origin of AASHTO: (For road construction)

This system was originally developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. Afterwards, there are several revisions. The present AASHTO (1978) system is primarily based on the version in 1945. (Holtz and Kovacs, 1981)

4.1 Definition of Grain Size



4.2 General Guidance

- 8 major groups: A1~ A7 (with several subgroups) and organic soils A8
- The required tests are sieve analysis and Atterberg limits.
- The group index, an empirical formula, is used to further evaluate soils within a group (subgroups).

A1 ~ A3	A4 ~ A7
Granular Materials	Silt-clay Materials
≤ 35% pass No. 200 sieve	≥ 36% pass No. 200 sieve
Using LL and PI separates silty materials from clayey materials (only for A2 group)	Using LL and PI separates silty materials from clayey materials

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

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.

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

4.4 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	50 Max.										
No. 40	30 Max.	50 Max.	51 Min.								
No.200	15 Max.	25 Max.	10 Max.	35 Max.	35 Max.	35 Max.	35 Max.	36 Min.	36 Min.	36 Min.	36 Min.
Fraction passing No.40: Liquid Limit				40 Max.	41 Min.	40 Max.	41 Min.	40 Max.	41 Min.	40 Max.	41 Min.
Plasticity Index	6 Max		N.P.	10 Max.	10 Max.	11 Min.	11 Min.	10 Max.	10 Max.	10 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			

4.4 Classification

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			A-2			
Group classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*
Sieve analysis (percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone fragments, gravel, and sand		Fine sand	Silty or clayey gravel and sand			
General subgrade rating	Excellent to good						

4.4 Classification (Cont.)

General classification	Silt-clay materials (more than 35% of total sample passing No. 200)			
Group classification	*A-4*	*A-5*	*A-6*	*A-7* *A-7-5*[a] *A-7-6*[b]
Sieve analysis (percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Silty soils		Clayey soils	
General subgrade rating	Fair to poor			

[a] For A-7-5, $PI \leq LL - 30$
[b] For A-7-6, $PI > LL - 30$

Das, 1998

Note:

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

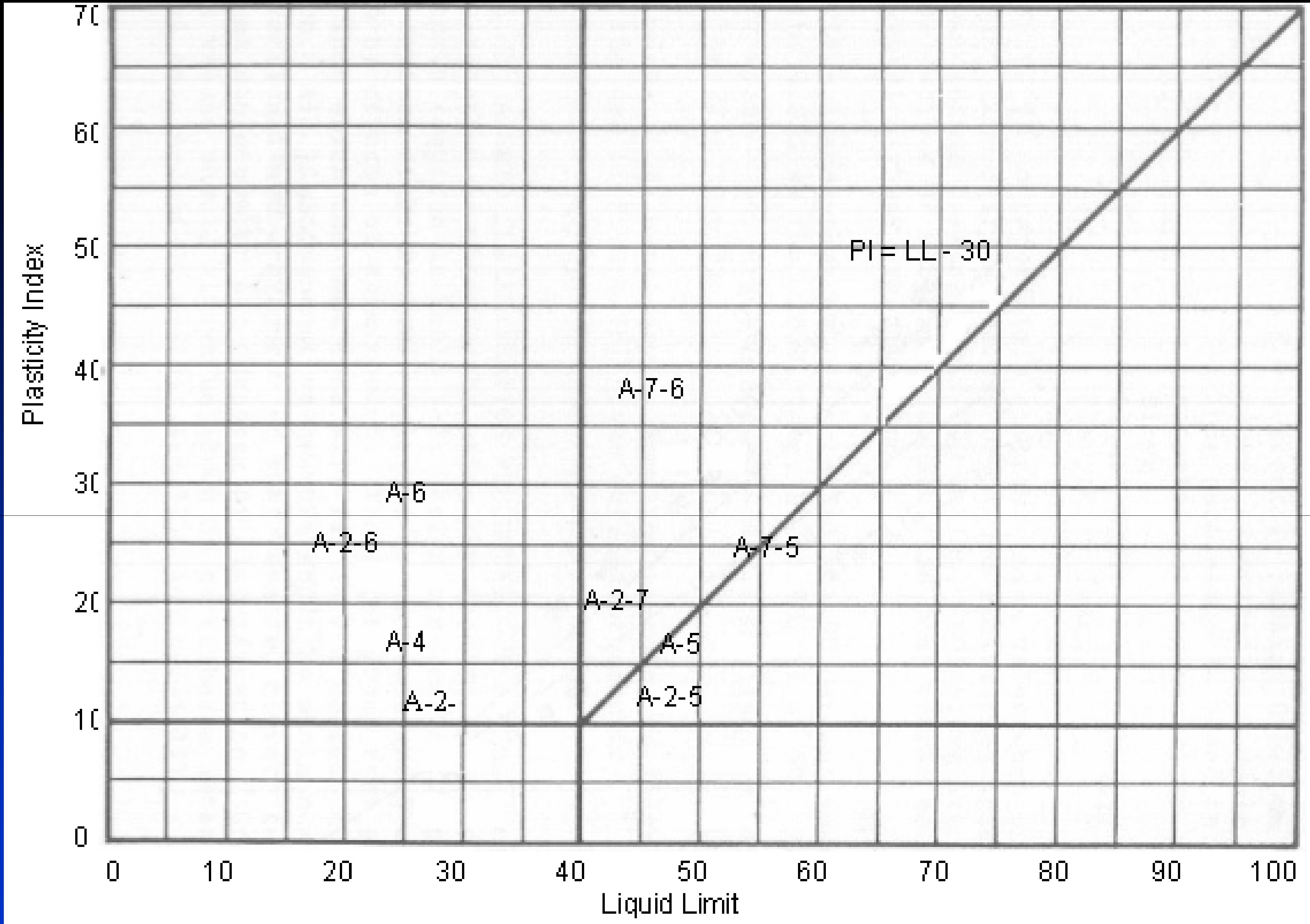


Fig: Liquid limit and plasticity index ranges for silt-clay material

4.4 Example

Passing No.200 86%

LL=70, PI=32

LL-30=40 > PI=32

Passing No.200 86%

LL=70, PI=32

LL-30=40 > PI=32

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, $PI \le LL - 30$

[b] For A-7-6, $PI > LL - 30$

Table: 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.

COMPARISON OF THE AASHTO AND UNIFIED SOIL CLASSIFICATION GROUPS

Table Comparison of the systems

Soil group in AASHTO system	Most Probable Group in USCS
A-1-a	GW, GP
A-1-b	SW, SP, GM,SM
A-3	SP
A-2-4	GM, SM
A-2-5	GM, SM
A-2-6	GC, SC
A-2-7	GM, GC, SM, SC
A-4	ML, OL
A-5	OH, MH, ML, OL
A-6	CL
A-7-5	OH, MH
A-7-6	CH, CL

Table Comparison of the systems

Soil group in Unified system	Most Probable groups in AASHTO system
GW	A-1-a
GP	A-1-a
GM	A-1-b, A-2-4, A-2-5, A-2-7
GC	A-2-6, A-2-7
SW	A-1-b
SP	A-3, A-1-b
SM	A-1-b, A-2-4, A-2-5, A-2-7 A-2-6, A-2-7
SC	A-2-6, A-2-7
ML	A-4, A-5
CL	A-6, A-7-6
OL	A-4, A-5
MH	A-7-5, A-5
CH	A-7-6
OH	A-7-5, A-5
Pt	--

Example 1:

- The porosity of a soil sample is 35% and the specific gravity of its particles is 2.7. Calculate its voids ratio, dry density, saturated density and submerged density.
- Solution:

$$e = \frac{n}{1-n} = \frac{0.35}{1-0.35} = 0.538$$

$$\rho_d = \frac{G\rho_w}{1+e} = \frac{2.7}{1.538} = 1.755 \text{ g/cm}^3, \ \rho_w = 1 \text{ g/cm}^3$$

$$\rho_{sat} = \frac{(G+e)\rho_w}{1+e} = \frac{2.7+0.538}{1.538} = 2.105 \text{ g/cm}^3$$

$$\rho' = \rho_{sat} - \rho_w = 2.105 - 1 = 1.105 \text{ g/cm}^3$$

- **Example 2:**
- The mass specific gravity of a soil sample is 1.7. If the specific gravity of soil solids is 2.72, determine the voids ratio with assumption that the sample is perfectly dry. What would be the voids ratio if the sample is assumed to have a water content of 10%.
- Solution:

$$G_m = \frac{\rho_d}{\rho_w} = 1.7 \text{ (when the sample is dry)}$$

$$e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.72}{1.7} - 1 = 0.6$$

$$w = 10\%, \frac{\rho}{\rho_w} = 1.7, \rho_w = 1.0 \text{ g/cm}^3$$

$$\rho_d = \frac{\rho}{1 + w} = \frac{1.7}{1.1} = 1.545 \text{ g/cm}^3$$

$$e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.72}{1.545} - 1 = 0.76$$

- **Example 3:**
- The in-situ percentage voids of a sand deposit are 40%. If the maximum and minimum dry densities of sand as determined from laboratory tests are 2.2 and 1.45 g/cubic cm respectively, determine the density index. Assume specific gravity of sand particles as 2.65.
- Solution:

$$n = 0.4$$

$$e = \frac{n}{1-n} = \frac{0.4}{0.6} = 0.667$$

For maximum dry density

$$e_{min} = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.65}{2.2} - 1 = 0.205$$

For minimum density

$$e_{max} = \frac{2.65}{1.45} - 1 = 0.83$$

- **Example 4:**
- A compacted sample of soil with a bulk density of 2 g/cubic cm has a water content of 15%. What are its dry density and degree of saturation? Assume G=2.65. If the sample is allowed to get fully saturated without an increase in its volume, what would be its bulk density?

$$\rho = 2.0 \text{ g/cm}^3, w = 0.15,$$

$$G = 2.65$$

$$\rho_d = \frac{\rho}{1+w} = \frac{2}{1.15} = 1.74 \text{ g/cm}^3$$

$$e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.65}{1.74} - 1 = 0.523$$

$$S_r = \frac{wG}{e} = \frac{0.15 \times 2.65}{0.523} = 0.76 = 76\%$$

When fully saturated

$$\rho_{sat} = \frac{(G+e)\,\rho_w}{1+e} = \frac{2.65 + 0.523}{1.523} = 2.08 \text{ g/cm}^3$$

Alternatively;

$$w_{sat} = \frac{e}{G} = \frac{0.523}{2.65} = 0.197$$

$$\rho_{sat} = \rho_d (1 + w_{sat}) = 1.74 (1 + 0.197)$$

$$= 2.08 \text{ g/cm}^3$$

$$\gamma_{sat} = 2.08 \times 9.8 = 20.384 \text{ kN/m}^3$$

NOTE: Whenever degree of saturation is required, calculate in the following order: w, ρd , e and Sr

- **Example 5:**
- The volume of a clay sample having a natural water content of 40% is 25.6 cubic cm and its wet mass is 43.50g. Calculate the degree of saturation of the sample, if G=2.75?

$$\rho = \frac{W}{V} = \frac{43.5}{25.6} = 1.7 \text{ g/cm}^3$$

$$\left(\gamma = \frac{Wg}{V} = 16.66 \text{ kN/m}^3\right)$$

$$\rho_d = \frac{\rho}{1+w} = \frac{1.7}{1.4} = 1.214 \text{ g/cm}^3$$

$$(\gamma_d = 11.89 \text{ kN/m}^3)$$

$$e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.75}{1.214} - 1 = 1.26$$

$$S_r = \frac{wG}{e} = \frac{0.4 \times 2.75}{1.26} = 0.874 = 87.4\%$$

- **Example 6:**
- The in-situ mass of an unsaturated soil sample of 60 cubic cm is found to be 100g. On oven-dry, the mass got reduced to 85.5g. If the particle specific gravity is 2.7, what were the water content and degree of saturation of the undistributed sample?
- Solution:

$$w = \frac{W_w}{W_d} = \frac{100 - 85.5}{85.5} = 0.17$$

$$\rho = \frac{W}{V} = \frac{100}{60} = \frac{5}{3} \text{ g/cm}^3$$

$$(\gamma = 16.33 \text{ kN/m}^3)$$

$$\rho_d = \frac{\rho}{1 + w} = \frac{5}{3 \times 1.17} = 1.425 \text{ g/cm}^3$$

$$(\gamma_d = 13.96 \text{ kN/m}^3)$$

Alternatively;

$$\rho_d = \frac{W_d}{V} = \frac{85.5}{60} = 1.425 \text{ g/cm}^3$$

$$e = \frac{G\rho_w}{\rho_d} - 1 = \frac{2.7}{1.425} - 1 = 0.895$$

$$S_r = \frac{wG}{e} = \frac{0.17 \times 2.7}{0.895}$$

$$= 0.513 = 51.3\%$$

Group No.1 Reg-01 to 20

Q#	*Statements*	*Answer*
01.	A saturated soil sample having a volume of 300cm^3 presents a mass of 423g. After being fully dried in an oven at 105 ^{0}C, its mass decreased to 320g.considering G_s=2.65, obtain the water content w, the initial void ratio and the total dry and submerged unit weight?	W=32%,e=0.85 y_d=14.3kN/m^3 y_{sat}=18.9kN/m^3 y_{sub}=8.9 kN/m^3
02.	Repeat previous exercise considering that soil sample is obtained from an iron ore mining region and has a high percentage of hematite, in which G_s=5. ?	W=32%,e=1.6 y_d=19.2kN/m^3 y_{sat}=25.4kN/m^3 y_{sub}=15.4kN/m^3
03.	A rock fill is being constructed with granite rock blocks (G_s=2.7), presenting a void ratio of 0.5 after placement. Evaluate the apparent total, dry and submerged unit weight?	y_d=18kN/m^3 y_{sub}=11.3kN/m^3
04.	Considering that the Rio de Janeiro clay presents 55% of particles with diameter under 2*10^{-6}m, obtain a plot of activity of this clay against depth. Classify the results according to skempton.?	
05.	A sand embankment is to be constructed and design specifications require a minimum relative density of 70%. If e_{min}=0.565 and e_{max}=0.878 for the sand, what should the void ratio be after placement?	y_d=14.6kN/m^3 e=0.84
06.	A sample of saturated clay weighed 1526g in its natural state, and 1053g after drying. Determine the natural eater content. If the specific gravity of the solid constituents was 2.70.what was the void ratio? The porosity? The total unit weight?	W=44.9% e=1.21 N=0.55 Y=17.36kN/m^3

Group-21 Reg. 40

07.	A sample of hardpan had a weight of 129.1g and a volume of 56.4cm^3 in its natural state. Its dry weight was 121.5g. The specific gravity of the solid constituents was 2.70.compute the water content, the void ratio, and degree of saturation.	W=6.3% e=0.25 S_r=67%
08.	The density of sand backfill was determined by field measurement to be 1.75Mg/m_3.the water content at the time of test was 8.6%, and the specific gravity of solid constituents was 2.60. In the laboratory void ratios in the loosest and densest states were found to be 0.642 and 0.462 respectively. What were the void ratio and relative density if the fill?	e=0.616 D_r=14%
09.	A dry quartz and sample weighs 1.54Mg/m^3.what is its density when saturated?	P=1.96 Mg/m^3
10.	A sample of silty clay had a volume of 14.88 cm^3. its weight at natural water content was 28.81g and after oven drying was 24.83g. The specific gravity of solid constituents was 2.70. Calculate the void ratio and degree of saturation of the sample. ?	e=0.617 S_r=70%
11.	The natural water content of soft saturated clay is 45%. If the specific gravity of soil solids is 2.72, find e,n and $p_{sat.}$?	e=1.224, n=55%, $p_{sat.}$=1.774g/cm^3
12.	The in-situ voids ratio of a bed of sand is 0.6.if the density of sand particles is 2.65G/cm3, calculate p_d and p_{sat}. Of sand. If sand gets completely submerged, what would be effective density?	p_d=1.655g/cm^3 p_{sat}.=2.03 g/cm^3 Peff.=1.03 g/cm^3

Group-3 Reg. 41 and onwards

13.	A saturated sample of soil has a water content of 33%. If G=2.68, find p_d, $p_{sat.}$ And $p^/$. ?	p_d=1.421g/cm^3 p_{sat}.=1.892 g/cm^3 $p^/$ =0.892 g/cm^3
14.	A soil sample weighing 1.6g/cm^3 has a water content of 32%.the specific gravity of soil particles is 2.65. Determine e, n and S.?	e=1.182, n=54.1%, S=71.7%
15.	The natural water content and in situ density of a sample of sand above water table are 14% and 1.9g/cm^3 respectively. The e_{max} and e_{min} corresponding to the loosest and densest states as determined by laboratory tests on dried samples are respectively 0.80 and 0.48.if the particles specific gravity is 2.65, calculate S_r and I_D. ?	S_r=62.8% I_D.=0.656
16.	An earth embankment is compacted at w=18% to a bulk density of 1.92g/cm^3. if G=2.7, find e and S_r of compacted embankment.?	E=0.66 S_r=73.6%
17.	The wet mass of a soil sample having a volume of 44.8cm^3 is 85.4g. after oven-drying, the mass reduces to 76.4g. find S_r, if G=2.66. what will be the water content as full saturation.?	S_r =56%, 21%
18.	A saturated sample of soil has a water content of 35%. Adopting G=2.70, calculate Y_d , $Y_{sat.}$ and $Y^/$?	Y_d=1.39g/cm^3, Y_{sat}=1.88g/cm^3 Y/ =0.88 g/cm^3