

Soil Mechanics

Assistant Professor Dr. Khalid R. Mahmood, Instructor

Catalogue Description

- Origin of Soil and Grain Size
- Weight-Volume Relationships, Plasticity, and Structure of Soil
- Engineering Classification of Soil
- \bullet Permeability
- Seepage
- In Situ Stresses (Effective Stress Concept)
- Stresses in a Soil Mass
- Compressibility of Soil
- Shear Strength of Soil
- Soil Compaction



Textbook and Reference Books

Textbook-Fundamentals of Geotechnical Engineering, Braja M. Das, 3rd ed., 2008

- 1. Principles of geotechnical engineering, Braja M. Das, 8th edition
- 2. Soil mechanics, R.F. Craig, 8th ed.
- 3. Solving problems in soil mechanics, B.H.C. Sutton, 2nd ed.
- 4. Soil mechanics laboratory manual, Braja M. Das, 6th ed., 2002

Types of Civil Engineering

- Structural Engineering
- Transportation Engineering
- Environmental Engineering
- Coastal Engineering

Geotechnical Engineering Soil Mechanics

Foundation Engineering



Problems in Geotechnical Engineering

• Shear Failure-Loads have exceeded shear strength capacity of soil!





• Settlement





• Seepage Problems





Engineering problems related to Soil Mechanics

1- Soil as a foundation





For difficult soil condition such as **expansive soil**, **collapsible soil** (gypseous soil) special precautions must be taken in designing and construction of foundations on such soils.



2- Soil as a construction material

It can be used in works such as:

- Pavement works (Flexible and Rigid pavements works)
- Earth dams and embankments
- Earth filling.

Here we must take into consideration the following factors

- Type of soil to be selected.
- Quality control of compacting soil.
- Proper methods are used for replacement and compaction of the soil.
- The availability of the required type of soil near the site.



The Unique Nature of Soil

The soils are often highly variable, even within a distance of few millimeters. Another way of saying this is that soils are-

- Heterogeneous rather than homogenous materials.
- Anisotropic instead of being Isotropic
- The stress-strain relationships did not obey linear stress- strain laws.
- their behavior depends on pressure, time, and the environment.

Most of the theories we have for the mechanical behavior of engineering materials assume that the materials are Homogenous, Isotropic and obey linear stress- strain laws, so most of the relations used in Soil Mechanics are empirical relationships.



The solution of soil engineering problems

It includes the basic principles of-

Soil mechanics

Geology, Exploration

Experience

Economics

}

+ Engineering Judgment =

Solutions



Origin of Soil and Grain Size

Soils and Rocks

Definition of "Soil" and "Rock"

• Soil

Naturally occurring mineral particles which are readily separated into relatively small pieces, and in which the mass may contain air, water, or organic materials (derived from the decay of vegetation).

Rock

Naturally occurring material composed of mineral particles so firmly bonded together that relatively great effort is required to separate the particles (i.e., blasting or heavy crushing forces).

Types of Rocks

- Igneous rocks (Intrusive and extrusive) such as Granite, Basalt,etc.
- Sedimentary rocks such as sandstone, limestone, shales,....etc.
- Metamorphic rocks such as gneiss, marble, slate



Methods of Classifying Rocks

- Visual Classification
- Weathering Classification
- Discontinuity Classification
- Colour and Grain Size
- Hardness Classification
- Geological Classification
- Classification by Field Measurements and Strength Tests
- Strength
- Rock Quality Designation and Velocity Index Rock **Rock Quality Designation (RQD)**
- Based on a modified core recovery procedure
 - L_i = length of a given recovered piece \geq 4"
 - L_t = total length of core sample

$$RQD = \frac{\sum L_i}{L_i}$$





• Velocity index

- Square of the ratio of the field compression wave velocity to the laboratory compression wave velocity
- Typically used to determine rock quality using geophysical surveys

		, , , , , , , , , , , , , , , , , , , ,
RQD%	VELOCITY INDEX	ROCK MASS QUALITY
90 - 100	0.80 - 1.00	Excellent
75 - 90	0.60 - 0.80	Good
50 - 75	0.40 - 0.60	Fair
25 - 50	0.20 - 0.40	Poor
0 - 25	0 - 0.20	Very Poor

Rock Quality Designation (RQD)







Weathering

Physical or Mechanical weathering causes disintegration of the rocks into smaller particle sizes, the processes that cause physical weathering are-

- Freezing and thawing
- Temperature changes
- Erosion (Abrasion)
- Activity of plants and animals including man

Chemical weathering causes decomposition in rocks by -

- Oxidation union of oxygen with minerals in rocks forming another mineral
- Hydration water will enter the crystalline structure of minerals forming another group of minerals
- Hydrolysis the release Hydrogen from water will union with minerals forming another mineral
- Carbonation when Co₂ is available with the existence of water the minerals changed to Carbonates



Basic Soil Types

Parent Rocks			
Sedimentary Soils	Transported Soils		
	transported and deposited by		
• Residual	 Alluvial 	running water	
• Organic	• Aeolian	wind	
	• Glacial	glaciers, or by melt water from the glacier	
	• Marine	ocean waves and currents in shore and offshore	
	 Colluvial 	gravity	
	 Pyroclastic 	Material-propelled lava	



Special Soils (problematic soil)

- Expansive Soils
- Collapsing Soils
- Permafrost and Frost Penetration
- Man-made and Hydraulic Fills
- Limestone and Related Soils
- Karst Topography

- Calcareous Soils
- Quick Clays
- Dispersive Clays
- Submarine Soils

Soil-Particle Size or Grain Sizes

We are often interested in the particle or grain sizes present in a particular soil as well as the distribution of those sizes.

Its range Boulders or cobbles D > 75 mmBoulders or cobbles D > 75 mm $D^8 \text{ max. log scale}$ Ultra fine – grained colloidal materials D < 0.001 mm



DIE 2.1 Soil-separate-size limits	<u>Cohesionless soils</u> Cohesive so Grain size (mm)		ils	
Name of organization	Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	< 0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	< 0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	< 0.002
Unified Soil Classification System (U.S. Army Corps of Engineers; U.S. Bureau of	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays)	
Reclamation; American Society for Testing and Materials)			<0.075	

T-1-1-2401 1 1 1



Soil Cohesion

Coarse-grained, Granular or Cohesionless Soils	Fine-Grained or Cohesive Soils
 Generally are granular or coarse-grained 	Generally are fine grained
 Particles do not naturally adhere to each other 	 Particles have natural adhesion to each other
•Have higher permeability	 due to the presence of clay minerals
 Excellent foundation material for supporting 	Have low permeability
structures and roads.	 Very often, possess low shear strength.
•The best embankment material.	 Plastic and compressible.
 The best backfill material for retaining walls. 	 Loses part of shear strength upon wetting.
 Might settle under vibratory loads or blasts. 	 Loses part of shear strength upon disturbance.
 Dewatering can be difficult due to high 	 Shrinks upon drying and expands upon wetting.
permeability.	 Very poor material for backfill.
•If free draining does not frost susceptible	 Poor material for embankments.
	 Practically impervious.
	 Clay slopes are prone to landslides.



Silts

• Characteristics	Compared to Clays	
 Relatively low shear strength 	 Better load sustaining qualities 	
 High Capillarity and frost susceptibility 	 Less compressible 	
 Relatively low permeability 	 More permeable 	
 Difficult to compact 	 Exhibit less volume change 	

Aspects of Cohesionless Soils

Angularity

- Angular Sharp Edges
- Subangular Edges distinct but well rounded





Density

- Both unit weight and strength of soil can vary with particle arrangement
- Denser soils have both higher load carrying capacity and lower settlement



Relative Density

$$D_r = \frac{e_{\max} - e_o}{e_{\max} - e_{\min}} x 100$$

- e_{max} = void ratio of the soil in its loosest condition
- e_{min} = void ratio of the soil in its densest condition
- e_0 = void ratio in the natural or condition of interest of the soil
- Convenient measure for the strength of a cohesionless soil



Properties of Fine Soils





Aspects of Cohesive and Fine-Grained Soils

- Structure of Clay Minerals
- Types of Clay Minerals
- Clay Minerals and Water
- Particle Orientation of Clay Soils
- Thixotropy



Structure of Clay Minerals

Clay minerals are very tiny crystalline substances evolved primarily from chemical weathering of certain rock forming minerals, they are *complex alumino – silicates plus other metallic ions*.

All clay minerals are very small with colloidal – sized (D < 1 μ m). Because of their small size and flat shape, they have very large specific surfaces.

There is usually a negative electric charge on the crystal surfaces and electro – chemical forces on these surfaces are therefore predominant in determining their engineering properties.

In order to understand why these materials behave as they do, it will be necessary to examine their crystal structure in some detail.



- Atoms of clay minerals form sheets
 - Silica tetrahedral sheets



Alumina octahedral sheets



Octahedral unit

- Sheets can layer in different ways, forming different types of clay minerals
- Clay minerals tend to form flat, platelike, and niddle shapes



• Electro – Chemical Forces

- Primary valency bonds
- Van der Waals forces or molecular bonds
- Polar forces
- Hydrogen bonds

Isomorphic substitutions and absorbed ions

It is the replacement of the silicon and aluminum ions in the crystal by other elements, with no change in the crystalline structure



Types of Clay Minerals





Specific surface

$$S.S = \frac{As}{V} \left(\frac{1}{length}\right) ; \quad S.S = \frac{As}{m} \left(\frac{length^2}{mass}\right)$$

Cube	S.S
1x1x1 cm ³	$\frac{6(1cm^2)}{1cm^3} = 6/cm = 0.6/mm$
1x1x1 mm ³	$\frac{6(1mm^2)}{1mm^3} = 6/mm$
1x1x1 μm ³	$\frac{6(1\mu m^2)}{1\mu m^3} = 6 / \mu m = 6000 / mm$



How is water absorbed on the surface of a clay particle?





Gradation of Particle Size

Sieve Analysis Hydrometer Analysis











Dx – designates particle size for which x percent of sample has passed

• D₁₀ – effective size – particle size at which 10% of the sample has passed. It is useful to determine permeability









Sieve Analysis Example



$$Cc = \frac{D_{30}^2}{D_{10}D_{60}} = \frac{0.24^2}{0.07x0.6} = 1.37$$

Asst. Prof. Khalid R. Mahmood (PhD.)



Weight-Volume Relationships, Plasticity, and Structure of Soil

Topics

- Basic Concepts
- Phase Diagram
- Important variables-(Water or Moisture Content-Unit Weight or Mass-Void ratio-Specific Gravity......etc.
- Atterberg limits and consistency indices
- Soil Structure and Fabric



Basic Concepts

- Soil is a collection of particles that do not form a totally solid substance
- Soil is a combination of:
 - ♦ Soil material in particles
 - ♦ Air
 - ♦ Water

• The relationship between this combination defines much of what any particular soil can do to support foundations





Asst. Prof. Khalid R. Mahmood (PhD.)


Basic Formulas

 $V_{total} = V_{air} + V_{water} + V_{soil}$ $W_{total} = W_{water} + W_{soil} \quad or \quad M_{total} = M_{water} + M_{soil}$ $W_{x} = \gamma_{x} \times V_{x} \quad or \quad M_{x} = \rho_{x} \times V_{x}$

Specific Gravity and Density

• Unit Weight of Water (γ_w)	Density of Water
• 62.4 lb/ft^3	• 1.95 slugs/ft ³
♦ 9.81 kN/m³≈10 kN/m³	♦ 1 g/cm ³ = 1 Mg/m ³ = 1 Metric Ton/m ³

Typical Specific Gravities for Soil Solids

♦ Quartz Sand: 2.64 – 2.66	◆ Chalk: 2.60 – 2.75
♦ Silt: 2.67 – 2.73	◆ Loess: 2.65 – 2.73
♦ Clay: 2.70 – 2.9	♦ Peat: 1.30 – 1.9
	 Except for organic soils, range is fairly
	narrow



Weight and Volume Relationships $W_x = G_x \times \gamma_w \times V_x$ $M_x = G_x \times \gamma_w \times V_x$

In most cases, calculations in soil mechanics are done on a weight basis. Exceptions include wave propagation problems (earthquakes, pile dynamics,..... etc.) **Important Variables**

1. Void ratio, e

 $e = \frac{Vv}{Vs}$ Expressed as decimal Sands (0.4 – 1.0) Clays (0.3 – 1.5)

2. Porosity, n

$$n = \frac{Vv}{Vt} x100\%$$
 Expressed as percentage (0-100%)



Prove that
$$n = \frac{e}{1+e}$$
 or $e = \frac{n}{1-n}$

3. Degree of saturation, S

$$S = \frac{Vw}{Vv} x100\%$$
 S = 0 % Dry Soil, S = 100 % Saturated soil

4. Air Content, Ac

$$Ac = \frac{Va}{V} \times 100\%$$

So we can show that Ac =

$$Ac = n(1-S)$$

5. Water Content, ω

$$\boldsymbol{\omega} = \frac{Ww}{Ws} \mathbf{x100\%}$$

ω can be equal to zero in dry soil and may be reached500% in some marine and organic soils.



6. Unit weight, γ Total unit weight, $\gamma_t = \frac{Wt}{Vt} = \frac{Ws + Ww}{Vt}$ Solid unit weight, $\gamma_s = \frac{Ws}{Vs}$ γ_s range (25.4 kN/m³ - 28.5 kN/m³) Water unit weight, $\gamma_w = \frac{Ww}{Vw}$

There are three other useful densities in soils engineering; they are

- Dry Unit weight,
$$\gamma_d = \frac{Ws}{Vt}$$

- Saturated Unit Weight,
$$\gamma_{sat} = \frac{Ws + Ww}{Vt} = \frac{W_t}{V_t}$$
 (Va = 0, S = 100 %)

- Submerged Unit Weight,
$$\gamma' = \gamma_{sat} - \gamma_w$$



7. Specific gravity $G = \frac{\gamma}{\gamma_{w}} \qquad \text{apparent} \qquad G_{s} = \frac{\gamma_{s}}{\gamma_{w}} \qquad \text{Solid}$

From the basic definitions provided above, other useful relationships can be derived such as:

$$\gamma_t = \frac{1+\omega}{1+e} G_s \gamma_w = \frac{G_s + Se}{1+e} \gamma_w \quad \gamma_d = \frac{\gamma_t}{1+\omega} = \frac{G_s}{1+e} \gamma_w \quad \gamma_{sat} = \frac{G_s + e}{1+e} \gamma_w$$
$$\gamma' = \frac{G_s - 1}{1+e} \gamma_w$$

 $Se = G_s \omega$ H.W #1 prove these equations using basic definitions



Solutions of phase problems

Probably the single most important thing you can do in solving phase problems is to draw a phase diagram & remember the following simple rules,

- 1. Remember the basic definitions of ω , e, γs , S, etc.
- 2. Assume either Vs = 1 or Vt = 1 if not given
- 3. Often use $Se = G_s \omega$



Moist unit weight (7)		Dry unit weight (ye)		Saturated unit weight (yat)	
Given	Relationship	Given	Relationship	Given	Relationship
w, G _p e	$\frac{(1+w)G_s\gamma_w}{1+\epsilon}$	y. w	$\frac{\gamma}{1+w}$	G _p e	$\frac{(G_s + \epsilon)\gamma_w}{1 + \epsilon}$
S, G, e	$\frac{(G_s + Se)\gamma_w}{1 + e}$	Ghe	$\frac{G_{i}\gamma_{w}}{1+\epsilon}$	G2. R	$[(1-n)G_s+n]\gamma_w$
GS	$(1+w)G_{z}\gamma_{w}$	G _p a	$G_i \gamma_w (1-n)$	G ₂ , w _{at}	$\left(\frac{1}{1+w_{ad}G_{2}}\right)G_{2}\gamma_{ad}$
	$1 + \frac{wG_s}{S}$	G, w, S	$\frac{G_i \gamma_w}{1 + (\frac{wG_i}{2})}$	e, 101	$\left(\frac{\epsilon}{w_{mil}}\right)\left(\frac{1+w_{mil}}{1+\epsilon}\right)$
w, G, R	$G_{i}\gamma_{w}(1-n)(1+w)$		esv-	R. 10ml	$n\left(\frac{1+w_{m}}{w}\right)\gamma_{w}$
5, Op #	$G_i \gamma_{ij} (1 - h) + h S \gamma_{ij}$	e, w, S	(1 + e)w	10000	(•)
		Ym. C	7m - CYu	74.0	$\gamma_{e} + \left(\frac{1+e}{1+e}\right)\gamma_{e}$
7	Yat - RYu	74 R	74 + MYe		
		× 6	$(\gamma_{\rm mi}-\gamma_{\rm w})G_s$	74 S	$\left(1-\frac{1}{G_{2}}\right)\gamma_{4}+\gamma_{w}$
		THE OF	$(G_{x} - 1)$	Ye Wat	Ya(1 + 10mm)

Various Unit-Weight Relationships



Example 1

For saturated sample with void ratio e = 0.6 and Gs = 2.65.

Find:

- 1. porosity
- 2. moisture or water content
- 3. total unit weight

Solution:

Let
$$Vs = 1 m^3$$
 and $\gamma_w = 10 \text{ kN/m}^3$
 $e = \frac{V_v}{V_s} \Longrightarrow V_v = eV_s = 0.6 \text{ xl} = 0.6 m^3$
 $G_s = \frac{\gamma_s}{\gamma_w} = \frac{\frac{W_s}{V_s}}{\gamma_w} \Longrightarrow W_s = V_s \gamma_w G_s = 1 \text{ x10} \text{ x2.65} = 26.5 \text{ KN}$



Since the sample is saturated then S=100%

$$\therefore V_{w} = V_{v} = 0.6 \text{ m}^{3}$$

$$\gamma_{w} = \frac{W_{w}}{V_{w}} \Rightarrow W_{w} = \gamma_{w}V_{w} = 10 \times 0.6 = 6KN$$

$$W_{t} = W_{w} + W_{s} = 6 + 26.5 = 32.5KN$$

$$V_{t} = V_{s} + V_{v} = 1 + 0.6 = 1.6m^{3}$$

$$n = \frac{V_{v}}{V_{t}} = \frac{0.6}{1.6} \times 100\% = 37.5\%$$

$$\omega = \frac{W_{w}}{W_{s}} = \frac{6}{26.5} \times 100\% = 27.7\%$$

$$\gamma_{t} = \frac{W_{t}}{V_{t}} = \frac{32.5}{1.6} \approx 20KN/M^{3}$$



Example 2

A soil sample with dry unit weight $\gamma_d = 18.5 \text{ KN/m}^3$ & specific gravity of solids Gs = 2.68 submerges with water, the void ratio increases by 20%. Find-

1. The porosity of the soil before it was merged

2. The weight of 2 m3 of the soil under the water table. Solution:

$$\gamma_d = \frac{G_s}{1+e} \gamma_w$$

$$18.5 = \frac{2.68}{1+e} \mathbf{x} 10 \Longrightarrow \mathbf{e} = 0.449 = \mathbf{e}_{dry}$$

$$\therefore \mathbf{n} = \frac{\mathbf{e}}{1+e} = \frac{0.449}{1+0.449} \mathbf{x} 100\% \cong 31\%$$

Since void ratio increased by 20% after it had been submerged



$$\therefore e_{sat} = 1.2e_{dry} = 0.539$$
$$\gamma' = \frac{G_s - 1}{1 + e} \gamma_w = \frac{2.68 - 1}{1 + 0.539} \times 10 = 10.92 \quad kN / m^3$$

The weight of 2 m³ of submerged soil,

 $W_{sub} = \gamma'.2 = 21.84 \quad kN$



Example 3

A sample of saturated soil with $\omega = 14$ % and Gs = 2.7.

Find void ratio, total unit weight, and dry unit weight Solution

$$Se = G_s \omega \Rightarrow (1)e = (2.7)(0.14) \Rightarrow e = 0.38$$

$$\gamma_t = \frac{1+\omega}{1+e} G_s \gamma_w = \frac{1+0.14}{1+0.38} \times 2.7 \times 10 = 22.3 \quad k N / m^3$$

$$\gamma_d \frac{\gamma_t}{1+\omega} = \frac{22.3}{1+0.14} = 19.56 \quad kN / m^3$$

or

$$\gamma_{d} \frac{G_{s}}{1+e} \gamma_{w} = \frac{2.7}{1+0.38} = 19.56 \ kN/m^{3}$$



Atterberg limits and Consistency indices

They are water contents at certain limiting or critical stages in soil behavior (especially, fine- grained soils). They, along with the natural water content (ω_n) are the most important items in the description of fine- grained soils and they are correlated with the engineering properties & behavior of fine- grained soils.

They are-

- 1- Liquid Limit (L.L or ω_L).
- 2- Plastic Limit (P.L or ω_P).
- 3- Shrinkage limit (S.L or ω_s).







Liquid Limit

Definition

Atterberg defined the liquid limit as a water content at which the soil becomes a viscous liquid.





In practice, it is difficult to mix the soil so that the groove closure occurs at exactly 25 blows, so Casagrande did the following:





Plastic Limit

Atterberg defined the plastic limit as water content at which soil becomes in a plastic state.





Shrinkage Limit

It defines as a water content at which no further volume change occurs with continuous loss of moisture.





Other index properties for the soil

- Plasticity index,
$$P.I = L.L - P.L$$

- Flow index,
$$F.I = \frac{\omega_2 - \omega_1}{\log N_2 - \log N_1} = \frac{\Delta \omega}{\log \frac{N_2}{N_1} = 1 \text{ for } \dots \text{ one } \dots \text{ cycle}} = \Delta \omega$$

the slope of flow curve, it shows how close the clayey soil from the plastic state

- Toughness index,

 $T.I = \frac{P.I}{F.I}$ express the soil consistency in the plastic State.

- Consistency index,



$$C.I = \frac{L.L - \omega_n}{L.L - P.L} = \frac{L.L - \omega_n}{P.I}$$

- Liquidity index,
$$L.I = \frac{\omega_n - P.L}{P.I}$$

$$L.I < 0 --- \text{ the soil is in Brittle state}$$

$$L.I (0 -1) - \text{ the soil is in plastic state}$$

L.I >1 --- the soil is in viscous liquid state

Factors affecting the Atterberg Limits

1. Shape and size of grains.

As the grains size gets smaller the plasticity increases while grains with flaky shape had more plasticity characteristics than other shapes.



2. The content of clay minerals.

As the content of clay minerals increase the plasticity characteristics increase.

3. Type of clay minerals.

As we will describe later the characteristics of each type of clay mineral group the type will affect the plasticity characteristics and for instance

Montomorillonite Plasticity increase

4. Type of ions.

The type of absorbed ions will affect the plasticity characteristics such as Na; Mg will give high plasticity while Ca will give low plasticity.

5. The content of organic matter.

As the organic matter content increase the plasticity characteristics Increase.



Activity

Skempton (1953) observed the following relationship. He defined a quantity called "*Activity*" which the slope of the line correlating P.I & % finer than 2 μ m.

 $A = \frac{P.I}{\% of clay - size fraction, by weight}$



% of clav fraction ($< 2 \mu$)



This term used for identifying the swelling potential of clay soils and for certain classification properties.

Α	Soil classification
< 0.75	Non Active
0.75 - 1.25	Normally Active
1.25 - 2.0	Active

Α	Type of clay minerals
0.4 - 0.5	Kaolinite
0.5 - 1.0	Illite
1.0 - 7.0	Montomorillonite



<u>Example</u>

The following data were obtained from the liquid & plastic limits tests for a soil with ω_n = 15 %

Liquid limit test		Plastic limit test	
No. of blows	Moisture content;ω %		
15	42	DI = 19.704	
20	40.8	F.L = 10.7 70	
28	39.1		

<u>Required</u>

- a- Draw the flow curve & find the liquid limit.
- b-Find the plasticity index of the soil
- c- Find L.I, C.I, F.I, T.I



Solution



The soil is heavily preconsolidated since ω_n is smaller than P.L & lower than L.L.



Plasticity Chart

Casagrande (1932)









Soil Structure and Fabric

In geotechnical engineering, the structure of a soil affects or governs the engineering behavior of particular soil and is taken to mean both –

- 1. *Geometric arrangement* of the particles or mineral grains with respect to each other (soil fabric).
- 2. Interparticle forces which may act between the particles or minerals grains. They probably have two main causes : Orientation of the adsorbed water and Cementation

Factors that affect the soil structure are-

- The shape, size, and mineralogical composition of soil particles,
- The nature and composition of soil water.



Structures in Cohesionless Soil

The structures generally encountered in cohesionless soils can be divided into two major categories:-

- 1. Single grained structure
- 2. Honeycombed structure

<u> Single – grained structure</u>

A useful way to characterize the density of a natural granular soil is with relative density D_r as described before.

Honeycombed structure

In this structure, relatively fine sand and silt form small arches with chains of particles as shown in the figure below. Soils exhibiting honeycombed structure have large void ratios and they can carry the ordinary static load.



However, under heavy load or when subjected to shock loading, the structure breaks down, resulting in large settlement.





Structures in Cohesive Soils

- 1. Dispersed structure
- 2. Flocculated structure

The interparticle forces are relatively large, so that the interparticle forces and the geometric arrangement of the grains will make the structure in cohesive soils.

If two particles approach each other in a suspension, the forces acting on them are

- 1. the Van der Waals forces of attraction, and
- the repulsion between the two positively ionised adsorbed layers.





Soil Classification

Introduction

A soil classification system-

- ◆ It is the arrangement of different soils with similar properties into groups & subgroups based on their application or to their probable engineering behavior.
- ◆ It provides a common language to briefly express the general characteristics of soils, which are infinitely varied, without detailed descriptions.
- Most of the soils classification systems that have been developed for engineering
 purposes are based on simple index properties such as *particle size distribution & plasticity.*
- Although there are several classification systems now in use, none is totally definitive of any soil for all possible applications, because of the wide diversity of soil properties.

Asst. Prof. Khalid R. Mahmood (PhD.)



The role of classification system in geotechnical engineering practice is-





A- Textural classification

In general classification systems divided soils into the following categories on the basis of particle size. *Gravel; Sand; Silt; and Clay,*

but the nature of soils are mixtures of particles from several size groups, so if we know the principle components of the soils, we can name the soils such as Sandy Clay, Silty Clay; and so forth.

One of these systems is the system developed by AASHTO (American Association of State Highway and Transportation Official).the the following chart is used to classify the soil, It is based on the particle size limits

- Sand size 2.0 0.05 mm in diameter
- Silt size 0.05 0.002 mm in diameter
- Clay size smaller than 0.002 mm in diameter







The chart is based only on the fraction of the soil that passes through the no. 10 sieve. Otherwise, a correction will be necessary if a certain percentage of the soil particles are larger than 2 mm in diameter, as shown below-

The modified textural composition are-

Modified % Sand =
$$\frac{\% sand}{100 - \% gravel} x100\%$$

Modified % Silt = $\frac{\% silt}{100 - \% gravel} x100\%$
Modified % Clay = $\frac{\% clay}{100 - \% gravel} x100\%$


Then the soil is classified by proceeding in the manner indicated by the arrows & the soil named according to the zone that falls in it as shown in the following example.

<u>Example</u>

Given

30 70	Particle – size distribution (%)					
Soil	Gravel	Sand	Silt	Clay		
А	0	18	24	58		
В	18	51	22 ,	ġ		
×		62.2	26.83	10.96		

Required-

Classify the soils using textural classification of AASHTO



<u>Solution-</u>Soil B percentages need to be corrected while percentages of soil A need no correction and we can use the % directly

<u>Soil B</u>

Modified % Sand =
$$\frac{51}{100-18} x 100 = 62.2\%$$

Modified % Silt
$$=\frac{22}{100-18}=26.83\%$$

Modified % Clay $=\frac{9}{100-18}=10.96\%$

Using AASHTO chart we classified the soil A as clay and soil B As gravelly Sandy loam



Other classification systems

1-AASHTO System

2-Unified Soil Classification System (USCS). At present, we will consider (USCS) only

	<u>ت</u>	Š				SAND				
AASHTO		NITOOD	10/1V 0.2	77 4000	COARSE	MEDIUM	FINE	SILT	CLAY	TODAL
		75		4.75	2	0.425	0.075	0.005	0.001	col
	S	2	GRAVEL		SAND					
USCS	BOULDER	COBBLLES	COARSE	FINE	COARSE	MEDIUM	FINE	FINES (SILT &	E CLAY)	
	300	75	19	4.75	2	0.425	0.075			



Unified Soil Classification System (USCS)

Casagrande in 1942 during World War 2, it was revised in 1952. At present, it widely used among engineers.

This system classifies soils under two broad categories

- 1-Coarse grained soils that are gravelly and sandy in nature with less than 50% passing through the no.200 sieve. The group symbols start with prefixes of either G or S. besides cobble and boulder without the symbol.(see the table in your notes)
- 2-Fine grained soils with 50% or more passing through the no. 200 sieve. The group symbols start with prefixes M; C; O & Pt. (see the tables in your notes).

Other symbols used for the classification are -

W – well graded

 \mathbf{P} – poorly graded



- L low plasticity (L.L < 50%)
- H high plasticity (L.L > 50%)

So the group symbols may be one of the followings for-

- Coarse – grained soils

 $GW, SW \quad GW - GM, SW - SM \quad GM, SM$ $GP, SP \quad GW - GC, SW - SC \quad GC, SC$ GP - GM, SP - SMGP - GC, SP - SC

- Fine – grained soils

CL, ML, OL CH, MH, OH CL-ML&Pt

Asst. Prof. Khalid R. Mahmood (PhD.)



The plasticity chart used in USCS is shown below which is developed by Casagrande (1948) and modified to some extent here.



University of Anbar College of Engineering Civil Engineering Department Iraq-Ramadi





Asst. Prof. Khalid R. Mahmood (PhD.)



Example

Following are the results of a sieve analysis and L.L & P.L tests for two soils

Sieve size	Soil 1 % passing	Soil 2 % passing
No.4 (4.75 mm)	99	97
No. 10 (2 mm)	92	90
No. 40 (0.475 mm)	86	40
No. 100	78	8
No. 200 (0.075 mm)	60	5
L.L	20	. 6
P.L	15	-
P.I	5	NP (Not Plastic)



<u>Required</u>

Classify the soil according to USCS

Solution

- 1-Plot the GSD curve for the two soils.
- 2-For soil, 1 % passing no. 200 sieve is greater than 50% so it is fine grained soil and by using plasticity chart the soil plots in the zone (CL ML).
- 3-For soil 2 % passing no. 200 sieve is less than 50% so it is coarse grained soil.
- F_1 (% passing no. 4 & retained on No.200 sieve)

 $F_1 > \frac{100-5}{2} = 47.5\%$ so the symbol is S (Sand)

Referring to the GSD curve we find $D_{10} = 0.18 \text{ mm}$ $D_{30} = 0.34 \text{ mm}$ $D_{60} = 0.71 \text{ mm}$

University of Anbar College of Engineering Civil Engineering Department Iraq-Ramadi



$$C_{u} = \frac{D_{60}}{D_{10}} = 3.9 < 6; \ C_{c} = \frac{D_{30}^{2}}{D_{10} \cdot D_{60}} \cong 0.91 \approx 1$$

as $C_u \& C_c$ does not meet the requirements of well- graded the soil is poorly graded, the symbol will be SP, but since % passing no. 200 sieve = 5% the soil will take a dual symbol since the soil is NP so the symbol is SM

so the symbol will be SP - SM.