SRIMAAN COACHING CENTRE-TRICHY-TNPSC-CTSE- CIVIL ENGINEERING – (DEGREE & P.G DEGREE STANDARD) STUDY MATERIAL -TO CONTACT: +91 8072230063.

2024-25 SRIMAAN

SRIMAAN

TNPSC CTSE

Combined Technical Services Examination (Non-Interview Posts)

CIVIL ENGINEERING (DEGREE / P.G DEGREE STANDARD)

UNIT-5- GEOTECHNICAL ENGINEERING

SRIMAAN COACHING CENTRE-TRICHY.

TO CONTACT:+91 8072230063.

TNPSC-CTSE

CIVIL ENGINEERING

(DEGREE STANDARD)

UNIT-5: GEOTECHNICAL ENGINEERING

Formation of soils - types of soils - classification of soils for engineering practice - Field identification of soils - Physical properties and testing of soils - Three phase diagram - permeability characteristics of soils - stress distribution in soils - Theory of consolidation, shear strength parameters of soils – stabilization of soil - Compaction of soils- Stability analysis of slope - Soil exploration - Soil sampling techniques – SPT - Borelog profile - shallow foundations - Terzhagi's bearing capacity theory - Pile foundation –pile load test- Group action of piles - settlement of foundations- Ground Improvement techniques

Introduction to Soil Mechanics:

The term "**soil**" can have different meanings, depending upon the field in which it is considered.

To a **geologist**, it is the material in the relative thin zone of the Earth's surface within which roots occur, and which are formed as the products of past surface processes. The rest of the crust is grouped under the term "rock". To a **pedologist**, it is the substance existing on the surface, which supports plant life.

To an **engineer**, it is a material that can be:

- **Built on:** foundations of buildings, bridges.
- **Built in:** basements, culverts, tunnels.
- **Built with:** embankments, roads, dams.
- **Supported:** retaining walls. Soil Mechanics is a discipline of Civil Engineering involving the study

of soil, its behaviour and application as an engineering material. Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether or not they contain an admixture of organic constituents.

Soil consists of a multiphase aggregation of solid particles, water, and air. This fundamental composition gives rise to unique engineering properties, and the description of its mechanical behavior requires some of the most classic principles of engineering mechanics.

Engineers are concerned with soil's mechanical properties: permeability, stiffness, and strength. These depend primarily on the nature of the soil grains, the current stress, the water content and unit weight.

Formation of Soils

In the Earth's surface, rocks extend upto as much as 20 km depth. The major rock types are categorized as igneous, sedimentary, and metamorphic.

- **Igneous rocks:** formed from crystalline bodies of cooled magma.
- **Sedimentary rocks:** formed from layers of cemented sediments.
- **Metamorphic rocks:** formed by the alteration of existing rocks due to heat from igneous intrusions or pressure due to crustal movement.

Soils are formed from materials that have resulted from the disintegration of rocks by various processes of physical and chemical weathering. The nature and structure of a given soil depends on the processes and conditions that formed it:

- **Breakdown** of parent rock: weathering, decomposition, erosion.
- **Transportation** to site of final deposition: gravity, flowing water, ice, wind.
- **Environment** of final deposition: flood plain, river terrace, glacial moraine, lacustrine or marine.
- **Subsequent conditions** of loading and drainage: little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching, contamination.

All soils originate, directly or indirectly, from different rock types.

Soil Types

Soils as they are found in different regions can be classified into two broad categories:

(1) Residualsoils
(2) Transported soils

Residual Soils

Residual soils are found at the same location where they have been formed. Generally, the depth of residual soils varies from 5 to 20 m.

Transported Soils

Weathered rock materials can be moved from their original site to new locations by one or more of the transportation agencies to form transported soils. Transported soils are classified based on the mode of transportation and the final deposition environment.

(a) Soils that are carried and deposited by rivers are called **alluvial deposits.**
(b) Soils that are deposited by flowing water or surface runoff while entering a lake are called **lacustrine deposits.** Alternate layers are formed in different seasons depending on flow rate.

(c) If the deposits are made by rivers in sea water, they are called **marine deposits.** Marine deposits contain both particulate material brought from the shore as well as organic remnants of marine life forms.

(d) Melting of a glacier causes the deposition of all the materials scoured by it leading to formation of **glacial deposits.**

(e) Soil particles carried by wind and subsequently deposited are known as **aeolian deposits.**

SOIL FORMATION AND SOIL TYPES

Soils are the fundamental resource supporting agriculture and forestry, as well as contributing to the aesthetics of a green planet. They are also a base from which minerals are extracted and to which solid wastes are disposed. In addition, soils act as a medium and filter for collection and movement of water. By supporting plant growth, soil becomes a major determinant of atmospheric composition and therefore earth's climate.

ORIGIN OF SOILS

Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition. When a rock surface gets exposed to atmosphere for an appreciable time, it disintegrates or decomposes into small particles and thus the soils are formed.

FORMATION OF SOILS

Soils are formed either by (A) Physical Disintegration or (B) Chemical decomposition of rocks.

A. PHYSICAL DISINTEGRATION

Physical disintegration or mechanical weathering of rocks occurs due to the following physical processes:

Soils are formed from materials that have resulted from the disintegration of rocks byvarious processes of physical and chemical weathering. The nature and structure of a givensoil depends on the processes and conditions that formed it:

- **Breakdown** of parent rock: weathering, decomposition, erosion.
- **Transportation** to site of final deposition: gravity, flowing water, ice, wind.
- **Environment** of final deposition: flood plain, river terrace, glacial moraine, lacustrineor marine.
- **Subsequent conditions** of loading and drainage: little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching,contamination.

All soils originate, directly or indirectly, from different rock types.

Soil types:

Soils as they are found in different regions can be classified into two broad categories:

(1) Residual soils

(2) Transported soils

(3) Residual Soils

Residual soils are found at the same location where they have been formed. Generally, thedepth of residual soils varies from 5 to 20 m.

Chemical weathering rate is greater in warm, humid regions than in cold, dry regions causing a faster breakdown of rocks. Accumulation of residual soils takes place as the rate of rock decomposition exceeds the rate of erosion or transportation of the weathered material. In humid regions, the presence of surface vegetation reduces the possibility of soil transportation.

As leaching action due to percolating surface water decreases with depth, there is a corresponding decrease in the degree of chemical weathering from the ground surface downwards. This results in a gradual reduction of residual soil formation with depth, until unaltered rock is found.

Residual soils comprise of a wide range of particle sizes, shapes and composition.

PHYSICAL PROPERTIES OF SOIL:

Features of the soil profile and the soil horizons are often described in the field in terms of the soil's physical properties. Horizons are defined based on difference in the physical properties. Soil physical properties affect the appearance and feel of a soil.

The major soil physical properties are:

- Soil Texture
- Soil Structure
- Soil Consistence/Soil Strength
- Soil Color
- Soil Permeability
- Soil Temperature

1. **Soil texture:**

Each soil separate represents a distinct physical size group. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes of the soil separates recognized in the United States are as follows

Sand	2.0 - 0.05 mm
Silt	0.05 - 0.002 mm
Clay	<0.002 mm

Very Coarse Sand	2.0 - 1.0 mm
Coarse Sand	1.0 - 0.5 mm
Medium Sand	0.5 - 0.25 mm
Fine Sand	0.25 - 0.10 mm
Very Fine Sand	0.10 - 0.05 mm
Silt	0.05 - 0.002 mm
Clay	0.002 mm

General classification is as follows:

2. **Soil structure:**

Structure is the arrangement of primary sand, silt and clay particles into secondary aggregates called peds or structural units which have distinct shapes and are easy to recognize. These differently shaped aggregates are called the structural type.

The five basic types of structural units are as follows:

a. **Platy:**

Plate-like aggregates that form parallel to the horizons like pages in a book. This type of structure may reduce air, water and root movement.

common structure in an E horizon and usually not seen in other horizons.

b. **Blocky:**

Two types--angular blocky and subangular blocky These types of structures are commonly seen in the B horizon.

Angular is cube-like with sharp corners while subangular blocky has rounded corners.

c. **Prismatic:**

Vertical axis is longer than the horizontal axis. If the top is flat, it is referred to as prismatic. If the top is rounded, it is called columnar.

d. **Granular:**

Peds are round and pourous, spheroidal. This is usually the structure of A horizons.

e. **Structureless**

No observable aggregation or structural units. ➢ Single grain-sand

➢ Massive-solid mass without aggregates

3. **Soil Consistence**

Expresses cohesive and adhesive forces holding soil particles together; varies with moisture content. Describes the resistance of a soil at various moisture contents to mechanical stress or manipulation. It is described at three moisture levels:

a. Wet

Stickiness (non-sticky, slightly sticky, sticky,very sticky)

Plasticity (non-plastic, slightly plastic, plastic, very plastic)

b. Moist

Very friable, friable, firm ,very firm

c. Dry

Loose.soft. slightly hard, hard, very hard ,extremely hard

It **indicates** amount and type of clay material, condition for tillage and potential for compaction. Consistence is the resistance of the soil to deform or rupture. Soil consistence is the forces of cohesion and adhesion that are holding the peds together. It refers to the degree of plasticity and stickiness of the soil. Soil consistence is affected by the type and amount of clay that is in the soil.

Soil consistence indicates: ➢ where are zones that may restrict root growth and seedling emergence.

- ➢ whether a soil is likely to develop compacted zones; ruts, crusts, hardpans etc.

Determining soil consistence

- ➢ Fingers - squeeze aggregates or push fingers into the soil.
- ➢ Penetrometer - measures how hard it is to push into the soil. this would be the same effect as a plant root.
- ➢ Examine roots : J roots or a root mat indicate problems.

Sand has a very weak consistence, there is little force between the particles.This means that a car tire can easily push the sand apart and it is easy to getstuck.

Factors Affecting Soil Consistence

- ➢ Water Content
- ➢ Soil Texture
- ➢ Soil Density

3.Soil colour:

It is the most obvious and easily determined soil property It has little direct effect on the soil, but is an indicator of soil properties. However, there are many things we can tell about the soil by observing the color.

- ➢ Organic matter content; the more organic content the darker the soil color
- ➢ Soil color and soil temperature : dark colored soils absorb more heat so they warm up quicker and have higher soil temperatures.
- ➢ Soil color and parent material : generally dark parent material will develop into dark soils.
- ➢ Soil color and drainage:
  - soil drainage refers to the length of time a soil is waterlogged. Not how fast the soil is drained.

4.Soil permeability:

Permeability is the speed of air and water movement in a soil -- this is affected bytexture and structure

1. if permeability is high : water moves quickly
2. if permeability is low : water moves slowly

1. Temperature changes

Different minerals of rocks have different coefficients of thermal expansion. Unequal expansion and contraction of these minerals occur due to temperature changes. When the stresses induced due to such changes are repeated many times, the particles get detached from the rocks and the soils are formed.

2. Wedging action of ice

Water in the pores and minute cracks of rocks gets frozen in very cold climates. As the volume of ice formed is more than that of water, expansion occurs. Rocks get broken into pieces when large stresses develop in the cracks due to wedging action of the ice formed.

3. Spreading of roots of plants

As the roots of trees and shrubs grow in the cracks and fissures of the rocks, forces act on the rocks. The segments of the rock are forced apart and disintegration of rocks occurs.

4. Abrasion

As water, wind and glaciers move over the surface of rock, abrasion and scouring takes place. It results in the formation of soils.

Note: In all the processes of physical disintegration, there is no change in the chemical composition. The soil formed has the properties of the parent rock. Coarse grained soils, such as gravel and sand, are formed by the process of physical disintegration.

<u>B. CHEMICAL DECOMPOSITION</u>

When chemical decomposition or chemical weathering of rocks takes place, original rock minerals are transformed into new minerals by chemical reactions. The soils formed do not have the properties of the parent rock. The following chemical processes generally occur in nature:

1. Hydration

In hydration, water combines with rock minerals and results in the formation of a new chemical compound. The chemical reaction causes a change in volume and decomposition of rock into small particles.

An example of hydration reaction that is taking place in soils is the hydrolysis of SiO_2

$$SiO_2 + 2H_2O \longrightarrow Si(OH)_4$$

2. Carbonation

It is a type of chemical decomposition in which carbon dioxide in the atmosphere combines with water to form carbonic acid. The carbonic acid reacts chemically with rocks and causes their decomposition.

The example for this type of is, that is taking place in sedimentary rocks which contain calcium carbonate.

3. Oxidation

Oxidation occurs when oxygen ions combine with minerals in rock. Oxidation results in decomposition of rocks. Oxidation of rocks is somewhat similar to rusting of steel.

4. Solution

Some of the rock minerals form a solution with water when they get dissolved in water. Chemical reaction takes place in the solution and the soils are formed.

5. Hydrolysis

It is a chemical process in which water gets dissociated into H^+ and OH^- ions. The hydrogen cations replace the metallic ions such as calcium, sodium and potassium in rock minerals and soils are formed with a new chemical composition.

Note: Chemical decomposition of rocks result in the formation of clay minerals. The clay minerals impart plastic properties of soils. Clayey soils are formed by chemical decomposition.

TRANSPORTATION OF SOILS

The soils formed at a place may be transported to other places by agents of transportation, such as water, ice, wind and gravity.

1. Water transported soils

Flowing water is one of the most important agents of transportation of soils. the size of the soil particles carried by water depends upon the velocity. The swift water can carry the particles of large size such as boulders and gravels. With a decrease in velocity, the coarser particles get deposited. The finer particles are carried further downstream and deposited when the velocity reduces. A delta is formed when the velocity slows down to almost zero at the confluence with a receiving body of still water such as lake, a sea or an ocean.

All types of soils carried and deposited by water are known as alluvial deposits. Deposits made in lakes are called lacustrine deposits. Marine deposits are formed when the following water carries soils to ocean or sea.

2. Wind transported soils : Soil particles are transported by winds. the particle size of the soil depends on the velocity of wind. The finer particles are carried far away from the place of the formation. Soil deposits by wind are known as Aeolian deposits.

Large sand dunes are formed by winds. Sand dunes occur in arid regions and on the lee ward side of the sea with sandy beaches.

Loess is a silt deposit made by wind. These deposits have low density and high compressibility. The bearing capacity of such soils is very low. The permeability in vertical direction is large.

3. Glacier- deposited soils

Glaciers are large masses of ice formed by the compaction of snow. As the glaciers grow and move, they carry with them soils varying in size from fine grained to huge boulders. Soils get mixed with ice and are transported far away from their original position.

BASIC BEFINITIONS

A soil mass consists of solid particles which form a porous structure. The voids in the soil mass may be filled with air, water or partly with water and partly with water. Soil is a three phase system in general.

classification of soils for engineering practice

SOIL CLASSIFICATION SYSTEM

Classification systems are used to group soils according to their order of performance under given set of physical conditions. Soils that are grouped in order of performance for one set of physical conditions will not necessarily have the same order of performance under some other physical conditions.

Classification systems are used to group soils according to their order of performance under given set of physical conditions. Soils that are grouped in order of performance for one set of physical conditions will not necessarily have the same order of performance under some other physical conditions.

Different Classification of Soils for Engineering Purpose

1. Classification based on grain size
2. Textural classification
3. AASHTO classification system
4. Unified soil classification system

Grain Size Classification System for Soils

Grain size classification systems were based on grain size. In this system the terms clay, silt, sand and gravel are used to indicate only particle size and not to signify nature of soil type. There

are several classification systems fin use, but commonly used systems are shown here.

	2.00	0.6	0.2	0.06	0.02	0.006	0.002
MIT Gravel	C	M	F	C	M	F	Clay
		Sand			Silt		

Textural Classification of Soil

The classification of soil exclusively based on particle size and their percentage distribution is known as textural classification system. This system specifically names the soil depending on the

percentage of sand, silt and clay. The triangular charts are used to classify soil by this system.

AASHTO classification system of Soil

	80	20	4.75			0.075	0.002
ISI	C	F	C	M	F	Silt	Clay
	Gravel		Sand				

AASHTO classification is otherwise known as PRA classification system. It was originally developed in 1920 by the U.S. Bureau of Public Roads for the classification of soil for highway sub-grade use.

This system is developed based on particle size and plasticity characteristics of soil mass. After some revision, this system was adopted by the AASHTO in 1945.

In this system the soils are divided into seven major groups. Some of the major groups further divided into subgroups. A soil is classified by proceeding from left to right on the classification chart to find first the group into which the soil test data will fill.

Soil having fine fractions are further classified based on their group index. The group index is defined by the following equation.

Group index = (F – 35)[0.2 + 0.005 (LL – 40)] + 0.01(F – 15)(PI – 10)

F – Percentage passing 0.075mm size

LL – Liquid limit

PI – Plasticity index

When the group index value is higher, the quantity of the material is poorer.

General classification	Granular Materials(35% 0r less passing 0.075mm sieve)							Silt-clay materials More than 35% passing 0.075mm			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7-5
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-6
(a)Sieve analysis % passing i)2.00 mm ii)0.425 mm iii)0.075mm	 50max 30max 15 max	 50max 25max	 51min 10max	35max	35max	35max	35max	36min	36min	36min	36min
(b)Characteristics passing through 0.425 mm i)Liquid limit ii)Plastic limit	 6 max		 NP	40max 10max	41min 10max	40max 11min	41min 11min	40max 10max	41min 10max	40max 11min	41min 11min*
(c)Usual type of significant constituent materials	Stone Fragments Gravel and Sands		Fine sands	Silty or Clayey Gravel Sands				Silty Soils		Clayey Soils	
(d)General rating as Subgrade	Excellent to Good							Fair to Poor			

Note: *If Plasticity index is equal to or less than (Liquid limit-30), the soil is A-7-5(PL>30%)

If Plasticity index greater than (Liquid limit-30), the soil is A-7-6(PL<30%)

Unified Soil Classification System

Unified soil classification system was originally developed by Casagrande (1948) and was known as airfield classification system. It was adopted with some modification by the U.S. Bureau of Reclamation and the U.S. Corps of Engineers.

This system is based on both grain size and plasticity characteristics of soil. The same system with minor modification was adopted by ISI for general engineering purpose (IS 1498 – 1970). IS system divides soil into three major groups, coarse grained, fine grained and organic soils and other miscellaneous soil materials.

Coarse grained soils are those with more than 50% of the material larger than 0.075mm size. Coarse grained soils are further classified into gravels (G) and sands (S). The gravels and sands are further divided into four categories according to gradation, silt or clay content.

Fine grained soils are those for which more than 50% of soil finer than 0.075 mm sieve size. They are divided into three sub-divisions as silt (M), clay (c), and organic salts and clays (O), based on their plasticity nature they are added with L, M and H symbol to indicate low plastic,

medium plastic and high plastic respectively.

Examples:

GW – well graded gravel. GP – poorly graded gravel, GM – Silty gravel

SW – Well graded sand, SP – Poorly graded sand, SM – Silty sand, SC – Clayey sand

CL – Clay of low plastic, CI – Clay of medium plastic, CH – Clay of higher plastic

ML – Silt of medium plastic, MI – Silt of medium plastic, MH – Silt of higher plastic

OL – Organic silt and clays of low plastic, OI – Organic silt and clays of medium plastic

OH – Organic silt and clays of high plastic.

Fine grained soils have been sub-divided into three subdivisions of low, medium and high compressibility instead of two sub-divisions of the original **Unified Soil Classification System**.

Table-2: Significance of letters for group symbol in table-3.

Soil	Soil Component	Symbol
Coarse Grained	Boulder	None
	Cobble	None
	Gravel	G
	Sand	S
Fine Grained	Silt	M
	Clay	C
	Organic Matter	O
Peat	Peat	Pt
Applicable to Coarse grained Soils	Well graded	W
	Poorly Graded	P
Applicable to Fine grained soils	Low compressibility W_L<35	L
	Medium compressibility (W_L 35 to 50)	I

The standard recommends that when a soil possesses characteristics of two groups either in particle size distribution or in plasticity, it is designed by combination of group symbols.

Table 3: Unified Soil Classification System (based on particle passing through 75 mm sieve)

Criteria for Assigning Group Symbols				Group Symbol
Coarse-Grained Soils More than 50% of retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3^c$	GW
			$C_u < 4$ and/or $1 > C_c > 3^c$	GP
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 3.20)	GM
			$PI > 7$ and plots on or above "A" line (Figure 3.20)	GC
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3^c$	SW
			$C_u < 6$ and/or $1 > C_c > 3^c$	SP
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 3.20)	SM
			$PI > 7$ and plots on or above "A" line (Figure 3.20)	SC
Fine-Grained Soils 50% or more passes No. 200 sieve	**Silts and Clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 3.20)[e]	CL
			$PI < 4$ or plots below "A" line (Figure 3.20)[e]	ML
		Organic	$\frac{\text{Liquid limit–oven dried}}{\text{Liquid limit–not dried}} < 0.75$; see Figure 3.20; OL zone	OL
	Silts and Clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 3.20)	CH
			PI plots below "A" line (Figure 3.20)	MH
		Organic	$\frac{\text{Liquid limit–oven dried}}{\text{Liquid limit–not dried}} < 0.75$; see Figure 3.20; OH zone	OH
Highly Organic Soils	Primarily organic matter, dark in color, and organic odor			Pt

[a] Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
[b] Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.
[c] $C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$
[d] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol GC-GM or SC-SM.
[e] If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 3.16, use dual symbol CL-ML.

INDIAN STANDARD CLASSIFICATION SYSTEM FOR SOIL

Indian Standard Classification System (ISC) was adopted by Bureau of Indian Standards is in many respect similar to the Unified Soil Classification (USC) system.

Soils are divided into three broad divisions:

2. For fine grained soils, when more than 50% of the total material passes through 75 micron IS sieve.
1. Coarse grained soils, when 50% or more of the total material by weight is retained on 75 micron IS sieve.
3. If the soil is highly organic and contains a large percentage of organic matter and particles of decomposed vegetation, it is kept in a separate category marked as peat (Pt).

In all there are 18 groups of soils: 8 groups of coarse grained, 9 groups of fine grained and one of peat.

Table 4: Basic Soil Components in ISC System

Soil	Soil components	Symbol	Particle size range and description
Coarse grained	Boulder	None	Rounded to angular, hard, rock, particle average diameter more than 300 mm
	Cobble	None	Rounded to angular, hard, rock, particle average diameter smaller than 300 mm but retained on 80 mm IS sieve.
	Gravel	G	Rounded to angular, hard, rock, particle average diameter smaller than 80 mm but retained on 4.75 mm IS sieve. Coarse : 80 to20 mm IS sieve Fine: 20 mm to 425 micron IS sieve
	Sand	S	Rounded to angular, hard, rock, particle passing through 4.75 mm but retained on 75 micron IS sieve. Coarse: 4.75 mm to 2 mm IS sieve Medium: 2.00 mm to 425 micron Fine: 425 micron to 65 micron IS sieve

Fine grained	Silt	M	Particle smaller than 75 micron , Identify behavior that slightly plastic or non-plastic regardless of moisture and exhibits little or no strength when air dried.
	Clay	C	Particle smaller than 75 micron , Identify behavior that can exhibit Plastic properties within certain considerable
	Organic matter	O	Organic matter in various sizes and stage of decomposition.

Table: 5 Classification of Coarse-grained Soils (ISC) System

Division	**Sub-division**		**Group Symbol**	**Typical Names**	**Laboratory Criteria**		**Remark**
Coarse grained soil (More than half of material is larger than the 75 – micron IS sieve	Gravel More than half of material is larger than the 4.75 mm IS sieve	Clean gravel (Fine less than 5%)	GW	Well graded gravel	$C_u > 4$ C_c between 1 &3		When fines are between 5% to 12% boarder line cases requiring use of dual symbol GWGPSWSC etc
			GP	Poor graded gravel	Not meeting all requirement for GW		
		Gravel with fines (Fines more than 12%)	GM	Silty gravel	Atterberg limit below A line or $I_p < 4$	Atterberg limits plotting above A line with I_p between 4 & 7 are boarder line cases requiring use of dual symbol GM-GC	
			GC	Clayey gravel	Atterberg limit above A line or $I_p > 7$		
	Sands More than half of material is smaller than the 4.75 mm IS sieve	Clean sand (Fine less than 5%)	SW	Well graded sands	$C_u > 6$ C_c between 1 &3		
			SP	Poor graded sands	Not meeting all requirement for SW		
		Sands with fines (Fines more than 12%)	SM	Silty Sands	Atterberg limit below A line or $I_p < 4$	Atterberg limits plotting above A line with I_p between 4 & 7 are boarder line cases requiring use of dual symbol SM-SC	
			SC	Clayey Sands	Atterberg limit above A line or $I_p > 7$		

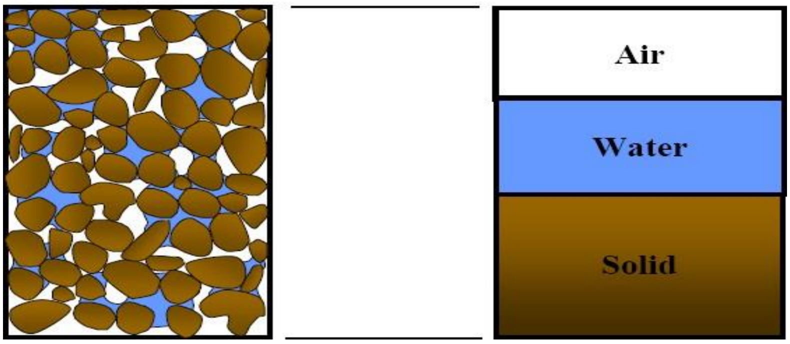
Table: 6 Classification of Fined-grained Soils (ISC) System

Division	Sub-division	Group Symbol	Typical Names	Laboratory Criteria		Remark
Fine grained soil (More than half of material is smaller than the 75 µ IS sieve)	Low compressibility (L)Liquid limit less than 35%	ML	Organic silts with none to low plasticity	Atterberg limit below A line or $I_p < 7$	Atterberg limits plotting above A line with I_p between 4 & 7 (hatched zone) ML-CL	Black cotton soils in India lies partly above and partly below the A-Line
		CL	Inorganic clays with low plasticity	Atterberg limit above A line or $I_p > 7$		
		OL	Organic silts with low plasticity	Atterberg limit below A line		Organic and inorganic soils plotted in same zone of plasticity chart are distinguished by colour, odor or liquid limit test after oven drying. Reduction in value after and before drying by three fourth indicates clear organic soils
	Intermediate compressibility (I) Liquid limit more than 35% but less than 50%	MI	Inorganic silts with medium plasticity	Atterberg limit below A line		
		CI	Inorganic clays with medium plasticity	Atterberg limit above A line		
		OI	Organic silts with medium plasticity	Atterberg limit below A line		
	High compressibility (H) Liquid limit more than 50%	MH	Inorganic silts with High plasticity	Atterberg limit below A line		
		CH	Inorganic clays with High plasticity	Atterberg limit above A line		
		OH	Organic silts with medium to High plasticity	Atterberg limit below A line		

Field Identification of Soils

In field identification of soil, the engineer concerned first determines whether the soil is coarse grained or fine grained. To make this determination, soil sample is spread on a flat surface. If more than half of the particles are visible to the naked eye, then it is classified as coarse grained or otherwise it is classified as fine grained. If the soil is coarse gained, follow the procedures outlined under the heading coarse grained soil; if the soil is fine grained, follow the procedure mentioned under the heading of fine grained soil.

Three Phase Diagram



VOLUMETRIC RELATIONSHIPS

Void Ratio

Void ratio is the volume of voids to the volume of solids. It is denoted by **'e'**

$e=V_v/V_s$ It is expressed as a decimal.

Porosity

It is defined as the ratio of volume of voids to the total volume. It is denoted by **'n'**

$n=V_v/V$ It is generally expressed as a percentage

$1/n=V/V_v= (V_v+v_s)/V_v$ $1/n= 1+ (1/e) = (1+e)/e$ $n=e/ (1+e)$ (a)

$1/e= (1/n)-1= (1-n)/n$

$e=n/ (1-n)$ (b)

In equations (a) and (b), the porosity should be expressed as a ratio and not percentage.

Degree of saturation

The degree of saturation is the ratio of the volume of water to the volume of voids. It is denoted by 'S'.

$S=V_w/V_v$ The degree of saturation generally expressed as a percentage. It is equal to zero when the soil is absolutely dry and 100% when the soil is fully saturated.

Percentage air voids

It is the ratio of volume of air to the total volume. $n_a= V_a/V$

It is also expressed as a percentage.

Air content

Air content is defined as the ratio of the volume of air to the volume of voids $a_c= V_a/V_v$

Also,

$n_a=n\, a_c$

Water content

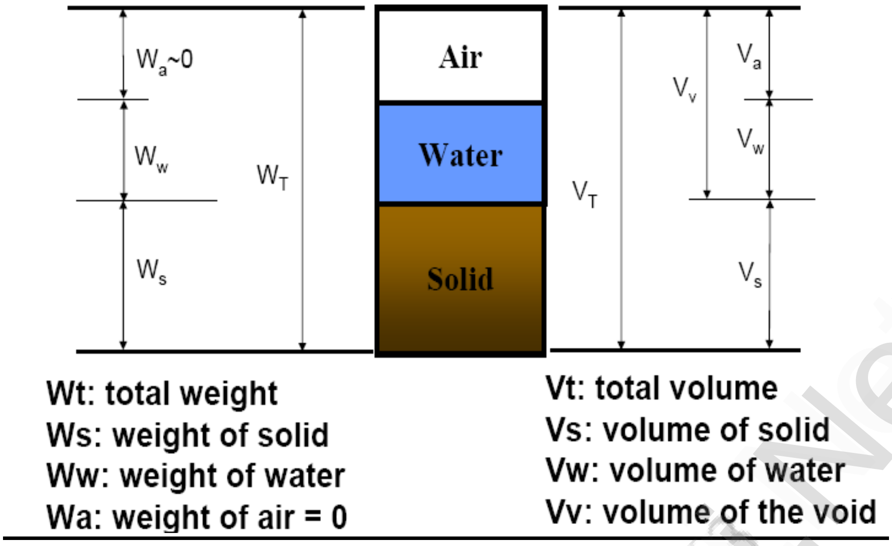
The water content (w) is defined as the ratio of the mass of water to the mass of soilids $w= M_w/M_s$

It is also known as the moisture content (m). It is expressed as a percentage but used as a decimal in computation.

VOLUME-MASS RELATIONSHIPS

1. BULK MASS DENSITY

The bulk mass density (ρ) is defined as the total mass (M) per unit volume (V) $\rho = M/V$



2. DRY MASS DENSITY

The dry mass density (ρ_d) is defined as the mass of solids per unit total volume $\rho_d = Ms/V$

3. SATURATED MASS DENSITY

The saturated mass density (ρ_{sat}) is the bulk density of the soil when it is fully saturated

$$\rho_{sat} = Msat/V$$

4. SUBMERGED MASS DENSITY

When the soil exists below water, it is in a submerged condition. The submerged mass density (ρ') of the soil is defined as the submerged mass per unit total volume. $\rho' = Msub/V$

5. MASS DENSITY OF SOLIDS

The mass density of solids (ρ_s) is equal to the ratio of the mass of solids to the volume of solids

$$\rho_s = Ms/Vs$$

VOLUME-WEIGHT RELATIONSHIPS

1. Bulk Unit Weight (γ)= W/V
2. Dry Unit Weight ($\gamma_{d)}$ = Ws/V
3. Saturated Unit Weight (γ_{sat}) = Wsat/V
4. Submerged Unit Weight (γ_{sub} or γ') = Wsub/V
5. Unit Weight Of Soil Solids (γ_s) = Ws/Vs

SPECIFIC GRAVITY OF SOLIDS

The specific gravity of soil particles (G) is defined as the ratio of the mass of a given volume of solids to the mass of an equal volume of water at 4° C.

$$G = \rho_s/\rho_w$$

The mass density of water $\rho_{w\ at}$ 4°C is 1gm/ml, 1000 kg/m^3 or 1 Mg/m^3

BASIC RELATIONSHIPS

Sl No	Relationship in mass density	Relationship in unit weight
1	$n = e/(1+e)$	$n = e/(1+e)$
2	$e = n/(1-n)$	$e = n/(1-n)$
3	$n_a = n\, a_c$	$n_a = n\, a_c$
4	$\rho = (G+Se)\rho_w/(1+e)$	$\gamma = (G+Se)\,\gamma_w/(1+e)$
5	$\rho_d = G\rho_w/(1+e)$	$\gamma_d = G\,\gamma_w/(1+e)$
6	$\rho_{sat} = (G+e)\rho_w/(1+e)$	$\gamma_{sat} = (G+e)\,\gamma_w/(1+e)$
7	$\rho' = (G-1)\rho_w/(1+e)$	$\gamma' = (G-1)\,\gamma_w/(1+e)$
8	$e = wG/s$	$e = wG/s$
9	$\rho_d = \rho/(1+w)$	$\gamma_d = \gamma/(1+w)$
10	$\rho_d = (1-na)G\,\rho_w/(1+wG)$	$\gamma_d = (1-na)G\,\gamma_w/(1+wG)$

WATER CONTENT DETERMINATION

The water content of the soil is an important parameter that controls its behaviour. It is a quantitative measure of the wetness of the soil mass. The water content of the soil can be determined by any one of the following methods

1. Oven drying method
2. Torsion balance method
3. Pycnometer method
4. Sand bath method
5. Alcohol method
6. Calcium carbide method
7. Radiation method

To find the surface area of a cylinder:

1. Find the area of each of the top and bottom circles.
2. Find the area of the rectangular side:
3. Add the areas together.

1. **To find the area of the top and bottom:** Use the formula $A = \pi r^2$. A cylinder has two circles (the top and the bottom), so we need to find the two areas, $2\pi r^2$.

Note: $\pi = 3.14$

2. **To find the area of the side of the cylinder (a rectangle):** Multiply the length times the width.

TO BE CONTINUED……

This final modified circuit so obtained is called **low power factor meter**. A modern low power factor meter is designed such that it gives high accuracy while measuring power factors even lower than 0.1.

TWO-ELEMENT WATTMETER FOR THREE-PHASE SYSTEM

two single-phase wattmeters were used to measure the power in a three-phase, three-wire sys- tem. The two single-phase wattmeters can be combined into a single instrument

The scale of this instrument indicates the sum or difference of the power values indicated by the separate meters. To make the single wattmeter, two sets of potential coils are mounted on a single shaft. Also, two sets of field coils are mounted on the instrument frame so that they have the proper relationship to the armature coils. In this way, each of two power measuring mechanisms develops a torque that is proportional to the power in the circuit to which it is connected. These torque values are added to obtain the total power in the three-phase, three wire circuit. If the power factor of the system is less than 0.5, the torque of one mechanism opposes that of the second mechanism. The difference between the torque values is the powerindication.

A wattmeter containing two dynamometer mechanisms is called a *two-element wattmeter*.