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## UNIT-1

### SYLLABUS

**Basic Definitions & Index Properties: Definition and scope of soil mechanics, Historical development. Formation of soils. Soil composition. Minerals, Influence of clay minerals on engineering behavior. Soil structure. Three phase system. Index properties and their determination. Consistency limits. Classification systems based on particle size and consistency limits.**

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#### Definition and scope of soil mechanics

Soil mechanics is a branch of soil physics and applied mechanics that describes the behavior of soils. It differs from fluid mechanics and solid mechanics in the sense that soils consist of a heterogeneous mixture of fluids (usually air and water) and particles (usually clay, silt, sand, and gravel) but soil may also contain organic solids and other matter. Along with rock mechanics, soil mechanics provides the theoretical basis for analysis in geotechnical engineering, a sub discipline of civil engineering, and engineering geology, a sub discipline of geology. Soil mechanics is used to analyze the deformations of and flow of fluids within natural and man-made structures that are supported on or made of soil, or structures that are buried in soils.[6] Example applications are building and bridge foundations, retaining walls, dams, and buried pipeline systems. Principles of soil mechanics are also used in related disciplines such as engineering geology, geophysical engineering, coastal engineering, agricultural engineering, and hydrology and soil physics.

#### Historical development

Soil Mechanics is one of the subject of Civil Engineering involving the study of soil, its behavior and application as an engineering material. According to Terzaghi : "Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical deformation and transformation of rocks regardless of whether or not they contain an admixture of an organic constituent."

#### Formation of soils

Soil formation, or pedogenesis, is the combined effect of physical, chemical, biological and anthropogenic processes working on soil parent material. Soil is said to be formed when organic matter has accumulated and colloids are washed downward, leaving deposits of clay, humus, iron oxide, carbonate, and gypsum, producing a distinct layer called the B horizon. This is a somewhat arbitrary definition as mixtures of sand, silt, clay and humus will support biological and agricultural activity before that time. These constituents are moved from one level to another by water and animal activity. As a result, layers (horizons) form in the soil profile. The alteration and movement of materials within a soil causes the formation of distinctive soil horizons. However, more recent definitions of soil embrace soils without any organic matter, such as those regoliths that formed on Mars and analogous conditions in planet Earth deserts

An example of the development of a soil would begin with the weathering of lava flow bedrock, which would produce the purely mineral-based parent material from which the soil texture forms. Soil development would proceed most rapidly from bare rock of recent flows in a warm climate, under heavy and frequent rainfall. Under such conditions, plants (in first stage nitrogen-fixing lichens and cyanobacteria then epilithic higher plants) become established very quickly on basaltic lava, even though there is very little organic material. The plants are supported by the porous rock as it is filled with nutrient-bearing water that carries minerals dissolved from the rocks. Crevasses and pockets, local topography of the rocks, would hold fine materials and harbour plant roots. The developing plant roots are associated with mineral-weathering mycorrhizal fungi that assist in breaking up the porous lava, and by these means organic matter and a finer mineral soil accumulate with time. Such initial stages of soil development have been described on volcanoes, inselbergs, and glacial moraines.

The weathering of parent material takes the form of physical weathering (disintegration), chemical weathering (decomposition) and chemical transformation. Generally, minerals that are formed under high temperatures and pressures at great depths within the Earth's mantle are less resistant to weathering, while minerals formed at low temperature and pressure environment of the surface are more resistant to weathering.[citation needed] Weathering is usually confined to the top few meters of geologic material, because physical, chemical, and biological stresses and fluctuations generally decrease with depth.[81] Physical disintegration begins as rocks that have solidified deep in the Earth are exposed to lower pressure near the surface and swell and become mechanically unstable. Chemical decomposition is a function of mineral solubility, the rate of which doubles with each 10 °C rise in temperature, but is strongly dependent on water to effect chemical changes. Rocks that will decompose in a few years in tropical climates will remain unaltered for millennia in deserts. Structural changes are the result of hydration, oxidation, and reduction. Chemical weathering mainly results from the excretion of organic acids and chelating compounds by bacteria and fungi, thought to increase under present-day greenhouse effect.

Physical disintegration is the first stage in the transformation of parent material into soil. Temperature fluctuations cause expansion and contraction of the rock, splitting it along lines of weakness. Water may then enter the cracks and freeze and cause the physical splitting of material along a path toward the center of the rock, while temperature gradients within the rock can cause exfoliation of "shells". Cycles of wetting and drying cause soil particles to be abraded to a finer size, as does the physical rubbing of material as it is moved by wind, water, and gravity. Water can deposit within rocks minerals that expand upon drying, thereby stressing the rock. Finally, organisms reduce parent material in size and create crevices and pores through the mechanical action of plant roots and the digging activity of animals. Grinding of parent material by rock-eating animals also contributes to incipient soil formation.

Chemical decomposition and structural changes result when minerals are made soluble by water or are changed in structure. The first three of the following list are solubility changes and the last three are structural changes.

The solution of salts in water results from the action of bipolar water molecules on ionic salt compounds producing a solution of ions and water, removing those minerals and reducing the rock's integrity, at a rate depending on water flow and pore channels.[88]

Hydrolysis is the transformation of minerals into polar molecules by the splitting of intervening water. This results in soluble acid-base pairs. For example, the hydrolysis of orthoclase-feldspar transforms it to acid silicate clay and basic potassium hydroxide, both of which are more soluble. In carbonation, the solution of carbon dioxide in water forms carbonic acid. Carbonic acid will transform calcite into more soluble calcium bicarbonate.

Hydration is the inclusion of water in a mineral structure, causing it to swell and leaving it stressed and easily decomposed.

Oxidation of a mineral compound is the inclusion of oxygen in a mineral, causing it to increase its oxidation number and swell due to the relatively large size of oxygen, leaving it stressed and more easily attacked by water (hydrolysis) or carbonic acid (carbonation).

Reduction, the opposite of oxidation, means the removal of oxygen, hence the oxidation number of some part of the mineral is reduced, which occurs when oxygen is scarce. The reduction of minerals leaves them electrically unstable, more soluble and internally stressed and easily decomposed. It mainly occurs in waterlogged conditions.

### Soil composition

Silts, sands and gravels are classified by their size, and hence they may consist of a variety of minerals. Owing to the stability of quartz compared to other rock minerals, quartz is the most common constituent of sand and silt. Mica, and feldspar are other common minerals present in sands and silts. The mineral constituents of gravel may be more similar to that of the parent rock.

The common clay minerals are montmorillonite or smectite, illite, and kaolinite or kaolin. These minerals tend to form in sheet or plate like structures, with length typically ranging between  $10^{-7}$  m and  $4 \times 10^{-6}$  m and thickness typically ranging between  $10^{-9}$  m and  $2 \times 10^{-6}$  m, and they have a relatively large specific surface area. The specific surface area (SSA) is defined as the ratio of the surface area of particles to the mass of the particles. Clay minerals typically have specific surface areas in the range of 10 to 1,000 square meters per gram of solid. Due to the large surface area available for chemical, electrostatic, and van der Waals interaction, the mechanical behavior of clay minerals is very sensitive to the amount of pore fluid available and the type and amount of dissolved ions in the pore fluid. To anticipate the effect of clay on the

way a soil will behave, it is necessary to know the kinds of clays as well as the amount present. As home builders and highway engineers know all too well, soils containing certain high-activity clays make very unstable material on which to build because they swell when wet and shrink when dry. This shrink-and-swell action can easily crack foundations and cause retaining walls to collapse. These clays also become extremely sticky and difficult to work with when they are wet. In contrast, low-activity clays, formed under different conditions, can be very stable and easy to work with.

The minerals of soils are predominantly formed by atoms of oxygen, silicon, hydrogen, and aluminum, organized in various crystalline forms. These elements along with calcium, sodium, potassium, magnesium, and carbon constitute over 99 per cent of the solid mass of soils.

#### Grain size distribution

Soils consist of a mixture of particles of different size, shape and mineralogy. Because the size of the particles obviously has a significant effect on the soil behavior, the grain size and grain size distribution are used to classify soils. The grain size distribution describes the relative proportions of particles of various sizes. The grain size is often visualized in a cumulative distribution graph which, for example, plots the percentage of particles finer than a given size as a function of size. The median grain size,  $D_{50}$ , is the size for which 50% of the particle mass consists of finer particles. Soil behavior, especially the hydraulic conductivity, tends to be dominated by the smaller particles, hence, the term "effective size", denoted by  $D_{10}$ , is defined as the size for which 10% of the particle mass consists of finer particles.

Sands and gravels that possess a wide range of particle sizes with a smooth distribution of particle sizes are called well graded soils. If the soil particles in a sample are predominantly in a relatively narrow range of sizes, the sample is uniformly graded. If a soil sample has distinct gaps in the gradation curve, e.g., a mixture of gravel and fine sand, with no coarse sand, the sample may be gap graded. Uniformly graded and gap graded soils are both considered to be poorly graded. There are many methods for measuring particle-size distribution. The two traditional methods are sieve analysis and hydrometer analysis.

#### Minerals, Influence of clay minerals on engineering behavior

Montmorillonite clay is made of four planes of oxygen with two silicon and one central aluminium plane intervening. The alumino-silicate montmorillonite clay is said to have a 2:1 ratio of silicon to aluminum. The seven planes together form a single crystal of montmorillonite. The crystals are weakly held together and water may intervene, causing the clay to swell up to ten times its dry volume. It occurs in soils which have had little leaching, hence it is found in arid regions. As the crystals are not bonded face to face, the entire surface is exposed and available for surface reactions, hence it has a high cation exchange capacity (CEC).

Illite is a 2:1 clay similar in structure to montmorillonite but has potassium bridges between the faces of the clay crystals and the degree of swelling depends on the degree of weathering of the potassium. The active

surface area is reduced due to the potassium bonds. Illite originates from the modification of mica, a primary mineral. It is often found together with montmorillonite and its primary minerals. It has moderate CEC

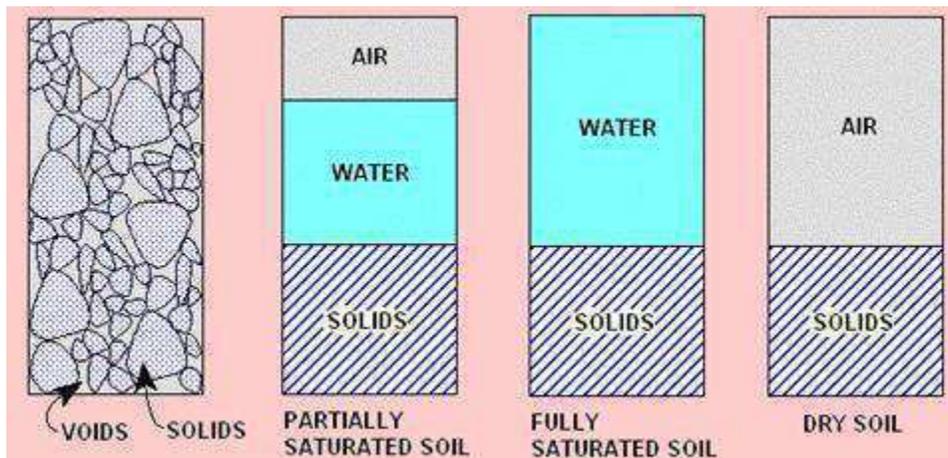
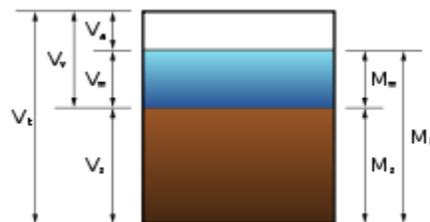
Vermiculite is a mica-based clay similar to illite, but the crystals of clay are held together more loosely by hydrated magnesium and it will swell, but not as much as does montmorillonite. It has very high CEC.

Chlorite is similar to vermiculite, but the loose bonding by occasional hydrated magnesium, as in vermiculite, is replaced by a hydrated magnesium sheet that firmly bonds the planes above and below it. It has two planes of silicon, one of aluminum and one of magnesium; hence it is a 2:2 clay. Chlorite does not swell and it has low CEC

Kaolinite is very common, highly weathered clay, and more common than montmorillonite in acid soils. It has one silica and one alumina plane per crystal; hence it is a 1:1 type clay. One plane of silica of montmorillonite is dissolved and is replaced with hydroxyls, which produces strong hydrogen bonds to the oxygen in the next crystal of clay. As a result, kaolinite does not swell in water and has a low specific surface area, and as almost no isomorphs substitution has occurred it has a low CEC. Where rainfall is high, acid soils selectively leach more silica than alumina from the original clays, leaving kaolinite. Even heavier weathering results in sesquioxide clays



### Soil structure & Three phase system



For the purpose of engineering analysis and design, it is necessary to express relations between the weights and the volumes of the three phases.

The various relations can be grouped into:

1. Volume relations
2. Weight relations
3. Inter-relations

As the amounts of both water and air are variable, the volume of solids is taken as the reference quantity.

Thus, several relational volumetric quantities may be defined. The following are the basic volume relations:

$$e = \frac{V_v}{V_s}$$

1. Void ratio ( $e$ ) is the ratio of the volume of voids ( $V_v$ ) to the volume of soil solids ( $V_s$ ), and
2. Porosity ( $n$ ) is the ratio of the volume of voids to the total volume of soil ( $V$ ), and is expressed as a percentage.

$$n = \frac{V_v}{V} \times 100$$

Void ratio and porosity are inter-related to each other as follows:

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

3. The volume of water ( $V_w$ ) in a soil can vary between zero (i.e. a dry soil) and the volume of voids. This can be expressed as the degree of saturation ( $S$ ) in percentage.

$$S = \frac{V_w}{V_v} \times 100$$

4. Air content ( $\alpha_c$ ) is the ratio of the volume of air ( $V_a$ ) to the volume of voids.

$$\alpha_c = \frac{V_a}{V_v}$$

**Index properties and their determination.**

Index properties are the properties of soil that help in identification and classification of soil. These properties are generally determined in the laboratory. In situ density and relative density require undisturbed sample extraction while other quantities can be determined from disturbed soil sampling.

Following are the major properties of soils.

**Water Content**

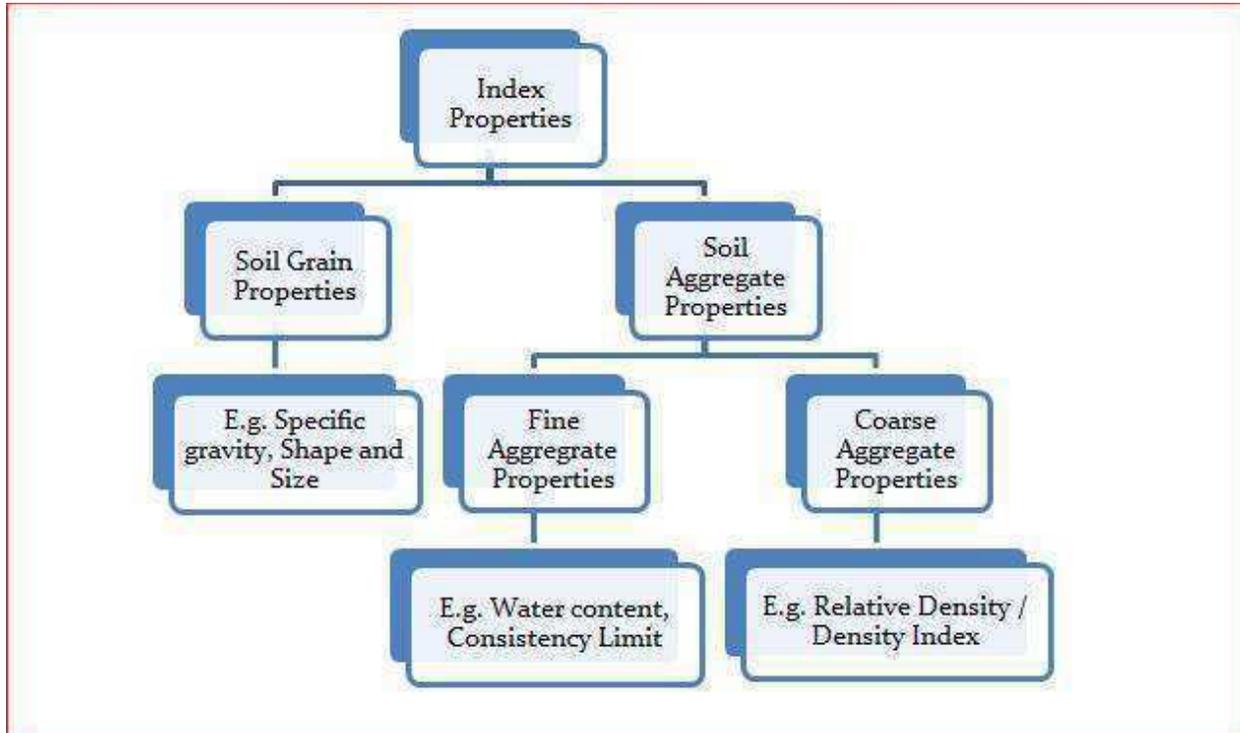
**Unit weight of Soil/ In-situ density**

**Specific Gravity**

## Consistency Limits

## Particle Size Distribution

## Sensitivity and activity of Clays



Soil index properties are properties which facilitate identification and classification of soils for engineering purposes. The nature of some properties differs for coarse- and fine-grained soils.

Coarse-grained (non-cohesive) soil index properties are:

particle-size distribution

particle shape

relative density

consistency

clay and clay minerals content

Fine-grained (cohesive) soil index properties are:

Consistency

Clay and clay minerals content

Water content

One of soil index properties which describe non-cohesive soils is particle size distribution. Soil that contains wide range of particle sizes is named well-graded. The opposite type of soil, which contains narrow range of particle sizes, is categorized as poorly graded. Well-graded soils can be more densely packed. Particle shape also influences how closely particles can be packed together. The density of soil (especially of coarse-grained) is the indication of strength and stiffness. The relative density is the ratio of the actual bulk density and the maximum possible density of the soil. Relative density is a good indicator of potential increases in density, and thus deformations that may occur under the different loads.

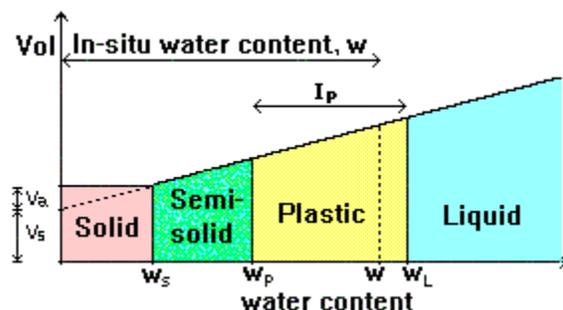
Consistency is the resistance of soils to deformation and rupture. The unconfined compression strength is often used as an indication of consistency. In practice, the terms soft, medium, stiff, very stiff, and hard are applied to rate consistency of soil. This soil index property describes both cohesive and non-cohesive soils. Consistency at non-cohesive soil depends primarily on particle shape and size distribution, while at cohesive soils this property primarily depends on water content.

Clay and clay minerals content is important soil index characteristic for both coarse- and fine-grained soils. Clay minerals are fine-sized platy silicates which are highly plastic. Therefore, depending on percentage and type of clay minerals, clayey soils are less or more plastic.

Water content is very important soil index property of fine-grained soils since their behaviour largely changes with water concentration variations. According to Atterberg there are four states: liquid, plastic, semi-solid and solid. Marginal water contents that separate these states are known as Atterberg limits and these are: shrinkage (SL), plastic (PL) and liquid limit (LL). These limits have different values for different types of fine-grained soils.

The Unified Soil Classification gives each soil type a two-letter designation. For coarse grained soils, the first letter, either G for gravel or S for sand, refers to the dominant particle size in the soil. The second letter is either W, for well graded or P, for poorly graded. The second letter can also be M for silt or C for clay if coarse-grained soils contain more than 12% of silt or clay. The first letter of the designation for fine-grained soils is M or C (silt or clay). The second letter, either H (high) or L (low), refers to the plasticity of the soil.

### Consistency limits



The consistency of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.

A gradual increase in water content causes the soil to change from solid to semi-solid to plastic to liquid states. The water contents at which the consistency changes from one state to the other are called consistency limits (or Atterberg limits).

The three limits are known as the shrinkage limit (WS), plastic limit (WP), and liquid limit (WL) as shown.

The values of these limits can be obtained from laboratory tests.

Classification systems based on particle size and consistency limits

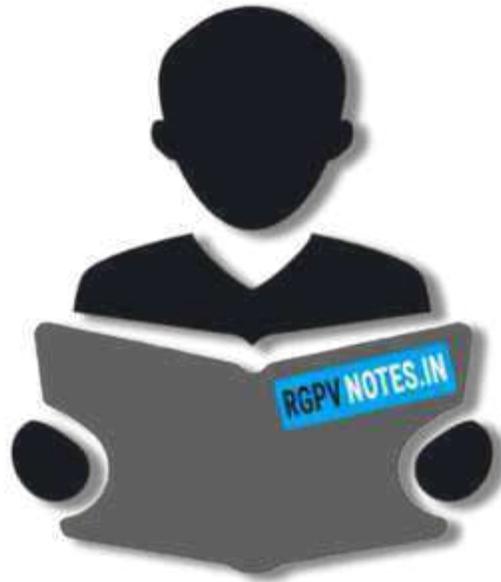
Classification Based on Grain Size

The range of particle sizes encountered in soils is very large: from boulders with dimension of over 300 mm down to clay particles that are less than 0.002 mm. Some clays contain particles less than 0.001 mm in size which behave as colloids, i.e. do not settle in water.

In the Indian Standard Soil Classification System (ISSCS), soils are classified into groups according to size, and the groups are further divided into coarse, medium and fine sub-groups.

The grain-size range is used as the basis for grouping soil particles into boulder, cobble, gravel, sand, silt or clay.

Very coarse soils	Boulder size		> 300 mm
	Cobble size		80 - 300 mm
Coarse soils	Gravel size (G)	<i>Coarse</i>	20 - 80 mm
		<i>Fine</i>	4.75 - 20 mm
	Sand size (S)	<i>Coarse</i>	2 - 4.75 mm
		<i>Medium</i>	0.425 - 2 mm
		<i>Fine</i>	0.075 - 0.425 mm
	Fine soils	Silt size (M)	
Clay size (C)			< 0.002 mm



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