# ENVIRONMENTAL GEOSCIENCES

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## Lecture-48

## Physical Properties of Soil

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module nine. The module nine comprises of process of soil formation, impact of soil erosion, physical and chemical properties of soil. Today we will discuss the lecture four that is physical properties of soil. In this lecture, the important concepts will be covered like introduction to physical properties of soil, physical parameters of soil, soil texture, characteristics of different size fraction,

Textural classes, the specific surface of soils, soil structure, dynamic properties of soils, soil consistency and plasticity, soil compression and compaction, soil crusting and soil infiltration, permeability and soil temperature. First of all, we will see what are the physical properties of soil. The physical properties of soil play an important role in determining its suitability for crop production. The characteristics like supporting power and bearing capacity, tillage practices, moisture storage capacity, and its availability to plants, drainage, ease of penetration by roots, aeration, retention of plant nutrients, and its ability to plants are all intimately connected with the physical property of a soil. Soil as a medium of plant growth should also be physically fertile.

The soil which supports plant is a mixture of solids, mineral and organic matter, liquid that is water and gases that is air and is called a three-phase system. In a representative silt loam soil, about fifty percent of the total volume is occupied by solids. At optimum moisture for plant growth, twenty five percent of the volume is occupied by water and twenty five percent by air. The inorganic solid phase is composed of discrete mineral particles of various shapes and sizes as well as of amorphous compounds such as hydrated iron and aluminium oxides. The proportion of amorphous material is generally small.

The large soil particles are generally visible to the naked eye whereas the smaller ones are colloidal and can be seen only with the aid of an electron microscope. The liquid phase consisting of soil water also contains dissolved salts and thus it is called soil solution. The gaseous phase consists of soil air of varying composition of oxygen and carbon dioxide different from that of the atmospheric air. Now, the physical parameters of soil. There are different physical properties of soil.

First is the particle density. Second is the dry bulk density. Third is the wet bulk density. Fourth is the specific volume. Fifth is the porosity.

Sixth is the void ratio. Seventh is the degree of saturation, volumetric water content or volume wetness. Now, particle density. The particle density also called the density of the soil solids is the ratio of total mass of soil solids to total volume of soil solids and is expressed in gram centimeter cube or mg per meter cube where one mg is one mega gram that is ten to the power six gram. The particle density depends on the chemical and mineralogical composition of the soil.

In most mineral soils, the particle density varies between two point six zero and two point seven zero mg per cubic meter. The mean value of two point six five mg per cubic meter cube is usually used for all practical purposes. The presence of organic matter lowers the value of particle density. You can see here the more dense soil is there and here we are getting less dense soil. between we are getting some space. A soil sample has a total mass of soil solids of 1500 gram and occupies a total volume of 600 centimeter cube.

Then calculate the particle density of soil and if another soil sample has a mass of eighteen hundred gram then the same volume and the same volume compare its particle density with the first sample. So as per the problem we will first take the data for first soil sample.

Mass of soil solids, $M_{s1} = 1500$ g, Volume of soil solids, $V_{s1} = 600$ cm$^3$

Now given data for second soil sample is

Mass of soil solids, $M_{s2} = 1800$ g, Volume of soil solids, $V_{s2} = 600$ cm$^3$

So particle density is mass of soil solids by volume of soil solids, so for first sample you can see.

$$\text{Particle Density} = \frac{\text{Mass of Soil Solids}(M_s)}{\text{Volume of Soil Solids}(V_s)}$$

$$\text{Particle Density}_1 = \frac{1500}{600} = 2.5\ \text{g/cm}^3$$

$$\text{Particle Density}_2 = \frac{1800}{600} = 3.0\ \text{g/cm}^3$$

Or simply the bulk density is the ratio of mass of oven dried soil solid particles to the total volume of the soil. This volume includes the volume of soil solids, soil water and soil air. The bulk density is expressed as gram per centimeter cube or mg per cubic meter. Bulk density of soil is influenced by soil texture, structure, organic matter content and land management practices. The bulk density of the coarse texture soils varies from one point four zero to one point seven five mg per meter cube and of fine texture soil normally ranges from one point one zero to one point four zero mg per meter cube. Increase in organic matter content lowers the bulk density of soil.

Now, based on this dry bulk density, another example is a soil sample has a dry mass of fifteen hundred gram and occupies a total volume of seven fifty centimeter cube. Now, calculate the dry bulk density in gram per centimeter cube and mg per meter cube. So, dry bulk density, we know that it is dry mass of soil divided by total volume of soil. So, just we will put the value fifteen hundred divided by seven fifty, it is coming to two gram per centimeter cube, which is equal to the two mega gram per meter cube. Now third is the wet bulk density.

$$\text{Dry Bulk Density} = \frac{\text{Dry Mass of Soil}(M_d)}{\text{Total Volume of Soil}(V_t)}$$

$$= \frac{1500}{750} = 2.0\ \text{g/cm}^3 = 2.0\ \text{Mg/m}^3$$

It is the ratio of the total mass of moist soil to the total volume of the soil. The wet bulk density depends more on the wetness or moisture content of the soil. Based on this, the problem is that a soil sample has a total mass of eighteen hundred gram and occupies a total volume of eight hundred centimeter cube. Calculate the weight bulk density in gram per centimeter cube or in mega gram per meter cube. So weight bulk density, we know that it is equal to total mass of soil divided by total volume of soil. So just we will put the data, we can get two point two five gram per centimeter cube or two point two five mega gram per meter cube. Now fourth is the specific volume.

$$\text{Wet Bulk Density} = \frac{\text{Total Mass of Soil}(M_t)}{\text{Total Volume of Soil}(V_t)}$$

$$= \frac{1800}{800} = 2.25\ \text{g/cm}^3 = 2.25\ \text{Mg/m}^3$$

It is the ratio of total volume of soil to the total mass of dry soil. That is it is the volume of unit mass of dry soil and is expressed as gram centimeter cube or mega gram per meter cube. It is an index of the degree of compaction or looseness of a soil. A higher value of specific volume indicates lower levels of compaction.

The values for agricultural soil vary from zero point five five to zero point zero seven mega gram per meter cube for coarse textured soil and from zero point seven to zero point nine mega gram per meter cube for fine textured soils. Based on this, the example is that if the dry bulk density of a soil is one point six gram per centimeter cube, calculate its specific volume.

$$\text{Specific Volume} = \frac{1}{\text{Dry Bulk Density}}$$
$$= \frac{1}{1.6} = 0.625 \text{ cm}^3/\text{g}$$

It is the ratio of total volume of pore spaces to the total volume of soil and is expressed as a fraction or a percentage. Porosity refers to the volume fraction of pores and is an index of the relative pore volume in a soil. It usually varies from zero point three to zero point six, that is thirty percent to sixty percent. Although the size of the individual pores may be bigger in coarse-textured soil than in the fine-textured soil, the former is less porous than the latter. Two types of pore spaces we get macro and micro that occur in soils without any clear cut demarcation.

Usually pores larger than zero point zero six mm in diameter are considered as macro pores and those smaller than this is considered as micro pores. Based on this, the example is a soil has a dry bulk density of one point five gram per centimeter cube and a particle density of two point six five gram per centimeter cube. Calculate the porosity.

$$\text{Porosity} = \left(1 - \frac{\text{Dry Bulk Density}}{\text{Particle Density}}\right) \times 100\%$$
$$= \left(1 - \frac{1.5}{2.65}\right) \times 100 = (1 - 0.566) \times 100$$
$$= 43.4\%$$

So porosity is equal to one minus dry bulk density divided by particle density into hundred percent. So just we will put the data of the bulk density that is one point five and particle density that is two point six five. It is coming to forty three point four percent.

Next is the void ratio. As a result of swelling, shrinkage, or compaction, a soil undergoes a change in volume. In such case, it is advantageous to use the void ratio instead of porosity. The void ratio is the ratio of total volume of pores to the total volume of soil solids and is expressed as a fraction.

Void ratio is also an index of the relative volume of soil pores. While porosity largely used in agriculture, void ratio is preferred in engineering. The values of void ratio usually varies between zero point three and two. Next is the degree of saturation. It is the ratio of the volume of water present in the soil at a particular time to the volume of pores. Based on this,

An example is there, a soil has a porosity of forty percent. Calculate the void ratio. So void ratio we are knowing, porosity divided by one minus porosity. Just we will put the value, it is coming to zero point six seven percent. Next example is soil has a volumetric water content of twenty five percent and porosity of forty percent.

$$\text{Void Ratio}(e) = \frac{\text{Porosity}}{1 - \text{Porosity}} = \frac{0.40}{1 - 0.40} = \frac{0.40}{0.60} = 0.67$$

Calculate the degree of saturation. So degree of saturation is equal to volumetric water content by porosity into hundred. So after putting the value, we are getting the sixty two point five percent.

$$\text{Degree of Saturation}(S) = \frac{\text{Volumetric Water Content}}{\text{Porosity}} \times 100\% = \frac{25}{40} \times 100 = 62.5\%$$

Now, next is the volumetric water content or volume wetness. It is the ratio of total volume of water occupied in the pore spaces at a specified time to the total volume of soil and is expressed as a fraction or percentage. Volumetric water content can be computed from gravimetric water content by multiplying the value with bulk density.

The volumetric water content of soil has a wider application in computation of quantity of water added to soil through irrigation or rain or the amount of water used by crop or lost through drainage etc. The volumetric water content expressed as a fraction when multiplied by the depth of the soil gives the amount of water in terms of depth. In swelling soil where volume is not constant, water content is also expressed as the ratio of the volume of water to the volume of the soil solids. This is called water volume ratio or liquid ratio. Now next topic is the soil texture.

The soil solid phase as a whole can be characterized in terms of the relative proportion of its particle size groups. The relative size range of the soil particles is expressed by the term texture, which refers to the fineness or coarseness of the soil. Soil texture is defined as the relative proportions of the different particle size fractions, both qualitative and quantitative connotations. Qualitatively, it refers to the feel of the soil material, whether coarse or gritty or fine and smooth. An experienced soil classifier can tell the soil texture by feel, that is by kneading or rubbing soil with his fingers.

Quantitatively, soil texture refers to the relative proportion of various sizes of particles in a given soil. The soil texture, typically permanent, is an intrinsic attribute to the soil and the one most often used to characterize its physical makeup, having a bearing on the soil behavior. Textural fractions, the traditional method of characterizing size of the particles in soil is to divide the array of possible particle diameters into three conveniently separable size ranges known as textural fractions or separates, namely sand, silt and clay. The actual procedure of separating out these fractions and of measuring their proportions is called particle size analysis or mechanical analysis. The result of this analysis is the mechanical composition of soil, a term often used interchangeably with soil texture.

Here you can see the particle size classification. The different sized particle size fractions are named and classified arbitrarily. Many particle size classification schemes exist, each of which having different class limits for each size fraction. The classification of the International Society of Soil Sciences, renamed as International Union of Soil Sciences, and the United States Department of Agriculture are widely followed. The largest group of particles recognized as soil material is sand, which is defined as particles ranging in diameter from two mm to zero point zero two mm as per IUSS classification or to zero point zero five mm as per USDA classification.

The sand fraction in IUSS classification is further subdivided into coarse that is two to zero point two mm and the fine sand that is zero point two to zero point zero two mm or as coarse, medium and fine sand. In the table also you can see the different size ranges of clay, silt, fine sand, coarse sand, gravel. Characteristic of different size fraction. Sand particles are primarily minerals, generally rounded or angular. Sand feels gritty when passed between the fingers and the particles are generally visible to the naked eye.

The particles of sand have relatively lower surface area per unit mass or volume. Sand particles can hold little water. Soils dominated by sand are prone to be drought. The next fraction is silt that is zero point zero two to zero point zero zero two mm as per IUSS classification which is intermediate in size between sand and clay. Meteorologically and physically silt particles generally resemble sand particles but have a greater surface area per unit mass.

The clay fraction with particles ranging from zero point zero zero two mm or less than it is the colloidal fraction. Clay particles are plate-like or needle-like and are secondary minerals generally belonging to a group of minerals known as alumino silicates. Clay is the fraction that has negative charge and greater surface area per unit mass and influences the soil behavior. Clay particles absorb water and hydrate, thereby causing the soil to swell upon wetting and shrink upon drying. The relatively inert sand and silt fractions can be called the soil skeleton, while the clay as the flesh of the soil.

Together these constitute the matrix of the soil. Textural Classes. The textural classes in soil science are based on the relative proportions of sand, silt and clay in soil sample. These classes are used to describe soil texture, which affects water retention, drainage and fertility. The USDA soil texture triangle characterizes soil into these textural classes.

Sand contains at least eighty five sand and very little silt or clay, drains quickly but has poor water holding capacity. Loamy sand, slightly more silt and clay than sand, better at holding moisture than pure sand but still drains quickly. Sandy loam, more silt and clay than loamy sand but still mostly sandy, has good drainage while retaining some moisture. Loam, a balanced mixture of sand, silt and clay, considered ideal for plant growth because it retains water while allowing drainage. Silt loam contains more than fifty percent silt with some sand and clay, feels soft and floury when dry and smooth when wet.

Silt made up of at least eighty percent silt and little sand or clay holds water well but compacted easily. Sandy clay loam has more sand than a regular clay loam but still contains a fair amount of clay, drains better than clay but retains some water. Clay loam, a balanced mixture of clay, silt and sand, with clay being the dominant component, has moderate drainage and good nutrient retention. Silty clay loam contains more silt than sand, but still has a significant amount of clay, holds water well, but can become compacted. Sandy clay, mostly clay and sand, with very little silt, has poor drainage but better aeration than pure clay,

Silty clay, mostly silted clay with very little sand retains water well but can become heavy and compacted. And clay contains at least forty percent clay with little sand or silt holds water well but drains poorly and can become very hard when dry. Now the specific surface of soils. It is an important property of soil grains that results from their sizes. It is defined as the amount of surface area per unit weight or volume of the soil and is expressed in centimeter square per gram or centimeter cube. This is important for chemical and physical reactions.

Besides size, the shape and type of clay minerals also affect a specific surface of a soil. The specific surface of soil greatly influences the physical and chemical properties such as retention of water at high suction, swelling, plasticity, soil strength, cation exchange capacity and availability of nutrients. Soil structure physically, a soil is a mixture of inorganic particles, decaying organic materials, water and air. The inorganic primary particles of various sizes, sand, silt or clay fraction generally cluster together to form complex and irregular patterns of secondary particles which are called aggregates. The term soil texture refers to the arrangement of these primary and secondary particles into a certain structural pattern.

Soil structure greatly influences many soil physical processes such as water retention and movement, porosity and aeration, transport of heat etc. The various soil management practices such as tillage, cultivation, application of fertilizer and manures, amendments like liming and gypsum, and irrigation bring about changes in the soil structure that influences other soil properties, thereby affecting root growth, water and nutrient uptake, crop growth, and yielding. Classification of soil structure. Classification of soil structure for field descriptions is based on type as determined by the shape and arrangement of the peds, class as differentiated by the size of the peds, and grade as determined by the distinctness and durability of the peds. Dynamic properties of soil.

The behavior of soil to an applied stress is expressed in terms of dynamic properties of soil which are mostly governed by two physical properties that is adhesion and cohesion. Adhesion, it refers to the attraction of two dissimilar phases. For example, attraction of a liquid phase such as water on the surface of a solid phase such as solid soil particles. Cohesion, it is the attraction between two similar phases. In soils, cohesion is bonding of the particles due to attractive forces between them due to Van der Waal's forces, electrostatic attraction of negatively charged clay surfaces and positively charged clay edges, cationic bridges, cementation effects of organic matter, and surface tension forces.

Cohesion also takes place between the water molecules which remain as films between the adjacent soil particles. Soil consistency, the manifestations of the physical forces of cohesion and adhesion acting within the soil at various moisture contents are designated by the term soil consistency. It includes such properties of the soil as resistance to compression, friability, plasticity, stickiness, etc. Thus, most soil exhibit four forms of consistency from progressively wet to dry soil moisture conditions. The first is the hard or harsh consistency.

Second is friable consistency. Third is plastic consistency. And fourth is the sticky consistency. Hard or harsh consistency, it has the pronounced characteristics of hardness. At low moisture contents, the soil remains very hard and coherent due to the cementation effect between the dried particles.

Friable consistency as the moisture content of the soil increases. Water molecules are adsorbed on the surface of the soil particles and decrease the coherence. The soil mass becomes friable. Friability characterizes the ease of crumbling of soils. The range of soil moisture contents in friable condition is optimum for tillage operation.

Plastic consistency, it is manifested by the properties of toughness and the capacity of the soil to be moulded into any desired shape. Sticky consistency, it is evident by the property of stickiness to various objects. The sticky point is defined as the moisture content of the soil when it ceases to stick to any foreign object. Soil plasticity. Soil containing more than fifteen percent clay exhibit plasticity.

Plasticity is defined as the property which enables a soil to take up water to form a mass that can be deformed into any desirable shape and to maintain the shape after the deformation pressure is removed. Plasticity results from the plate-like nature of the clay particles and the combined binding, lubricating effect of the adsorbed water. With the adsorption of water, thin films are formed around the soil particles. With applied pressure or force, the particles slide over each other and are held in that condition by the tension of the moisture films even after the pressure is removed. Indices of plasticity and their significance.

Plasticity is exhibited over a range of moisture contents referred to as plasticity limits. There are three indices called the lower plastic limit or simply the plastic limit, the upper plastic limit or liquid limit and the plasticity index. The plastic limit is the lowest moisture content at which a soil can be deformed without cracking. It is the upper limit of moisture content for tillage operation for most crops except rice. Tilling at moisture content above plastic limit results in smearing and puddling of the soil.

The upper plastic limit or liquid limit is the moisture content at which a soil ceases to be plastic. It becomes semi-fluid and tends to flow like a liquid under an applied force. This limit is used for classification of soils for engineering purpose. The difference in the moisture content between the upper and lower plastic limit is the range over which a soil remains plastic and is called plasticity index. Soils with high plasticity index are difficult to plough.

Soils with expanding lattice clays such as smectites having high liquid limits and plasticity indices. Clay minerals like kaolinite have low liquid limit values. Soil plasticity is determined by an apparatus called liquid limit device. Soil compression and compaction. First the soil compression. It is defined as the change in the volume of a soil under an applied stress, whereas soil compaction refers to the increase in density of a soil as a result of applied pressure or load.

Volume of soil is consisted of solid phase and the voids between it which are occupied by water and air. So compression denotes the decrease in the void ratio per increment of applied pressure or load. Whereas soil compaction encompasses compression plus increase in density of a soil, it is the dynamic behavior of the soil. The degree of compaction depends upon the nature of the soil, amount of energy applied, water content and extent of manipulation of the soil. Compaction is also associated with the rearrangement of the soil's solid particles so that the soil water and soil air are compressed within the pore space.

Because of the incompressible nature of soil particles and high internal friction, dry soils cannot be compacted to high densities. An increase in water content decreases cohesion between the particles and internal friction, thereby facilitating compaction. During compaction, the density of soil under a load increases with the increase in soil water content up to a certain limit, beyond which further addition of water does not increase compaction because of incompressible nature of soil solids and water. This critical limit is called proctor moisture content. Now soil crusting.

Soil crust is the thin compact layer of high bulk density formed at the soil surface following dispersion of natural soil aggregates as a result of wetting and impact of raindrops and its subsequent rapid drying due to radiant energy of the sun. Crust formation. When the raindrops strike the exposed dry soil surface, there is disintegration and dispersion of the aggregates. The finer clay particles move down along with infiltrating water and clog the pores immediately beneath the surface, thereby sealing the soil surface. Also, the dispersed soil may remain in suspension, coarse particles start to settle out, but fine clay particles remain in suspension.

As the water evaporates, clay settles on the top of the coarse particles forming a crust on drying. The soil particles tend to pull together due to surface tension forces and form a dense, strong soil layer with decreased porosity. Soil crusting is a major structural feature of soils of arid and semi-arid regions. The problem of soil crusting is severe in silty clay loams of older alluvial terraces and levees due to their unstable soil structure. Now soil infiltration.

Soil infiltration is the process by which water enters the soil surface and moves downwards through the pore spaces. It is a crucial factor in determining water availability for plants, drainage and groundwater recharge. Factors which affect the soil infiltration are soil texture that is sandy soils, having high infiltration due to large pores. Clay soils, low infiltration because of small compacted pores. Loamy soils, moderate infiltration, providing a balance of water retention and drainage.

Next factor is the soil structure. Well aggregated soils allow better water movement. Compact soils slow down the infiltration process. Soil moisture content, that is dry soil, absorbs water faster, whereas saturated soil has low infiltration because the pores are already filled with water. Next is the vegetation cover.

Plants and organic matter improve infiltration by reducing runoff and increasing soil porosity. Bare soil experience crusting, reducing infiltration. Land slope, steep slopes cause faster runoff and reduce infiltration whereas flat land allows water to soak in more effectively. Soil compaction, heavy machinery, food traffic and livestock can compact the soil and hence reducing the infiltration.

Importance of soil infiltration, soil infiltration process prevents surface runoff and erosion. It reduces soil loss and water wastage. It enhances groundwater recharge, that is, it helps in refilling underground water sources, improves plant growth, ensures water reaches plant roots efficiently, and reduces water logging. It prevents excess water accumulation in fields. How to improve the soil infiltration?

By adding organic matter, it increases porosity and water retention. Avoiding soil compaction, limit heavy machinery use, and livestock trampling. Using cover crops protects soil moisture, protects soil structure and enhances infiltration. Mulching reduces surface crusting and slows evaporation. Practicing conservation tillage prevents hardpan formation and maintains soil porosity.

Soil permeability. Soil permeability refers to the ability of water and air to move through soil pores. It determines drainage, aeration and water availability for plants. Factors affecting permeability are soil texture, soil structure, pore size, organic matter and compaction. Soil texture.

Sandy soils have high permeability while clay soils have low permeability. Soil structure. Well aggregated soils allow better water flow. Pore size. Larger pores increases permeability while compacted soils reduce it.

Organic matter improves permeability by enhancing soil property. Compaction, it reduces permeability by squeezing out pore spaces. Importance of soil permeability. First, it prevents water logging, ensures proper drainage. Enhances root growth that it provides oxygen to roots.

It supports microbial activity that it helps beneficial microbes to thrive. Improves irrigation efficiency that it ensures water reaches plant roots effectively. Then soil temperature. Soil temperature is the heat energy present in the soil affecting seed germination, root growth, microbial activity and nutrient availability. Factors affecting soil temperature are sunlight and season, that is warmer in summer, cooler in winter.

Soil moisture, wet soils heat up and cool down slower than dry soils. Soil color, dark soils absorb more heat while light soils reflect heat. Soil texture, sandy soils heat up quickly, while clayey soils retain heat longer. Vegetation and mulch reduce temperature fluctuations by providing insulation. Importance of soil temperature.

It affects seed germination. Optimal temperature is needed for sprouting. Influences microbial activity. Warmer soils promote decomposition and nutrient release. Regulates root growth.

That is, its extreme temperature can slow or damage the plant roots. And controls water evaporation that is high temperatures increase evaporation affecting the soil moisture. Now let us conclude the lecture. Firstly, we have discussed about the physical properties of soil. Soil's physical properties affect water retention, aeration and plant growth influencing agriculture and engineering.

Key parameters include texture, structure, density, porosity and permeability which determines soil behavior. Physical properties influence root penetration, nutrient availability, and water holding capacity. Then we have discussed about the soil texture and structure. Soil texture depends on the proportion of sand, silt, and clay, affecting drainage and fertility. Soil structure influences aeration, root growth, and water movement with types like granular, blocky, and platy.

Fine-textured soils are prone to compaction and erosion, while sandy soils are more prone to leaching. Thirdly, we have discussed about the soil moisture and porosity. We have discussed porosity determines the space available for air and water affecting plant growth. Soils retain water based on texture and organic matter influencing infiltration and plant availability. Moisture levels impact microbial decomposition and nutrient cycling in the soil.

And lastly, we have discussed the soil compaction and permeability. We have seen that it increases soil density, reduces pore space and restricts root and water movement. Determines how easily water moves through soil, influencing drainage and erosion control. And heavy machinery, overgrazing and repeated tillage can lead to compacted soil layers. Thank you very much to all.