ENVIRONMENTAL GEOSCIENCES

Prof. Prasoon Kumar Singh

Department of Environmental Science and Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Lecture-34

Porosity and Permeability

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module 6. In the module 6, we have discussed distribution of water on earth in lecture 1, groundwater provinces of India in lecture 2, hydrological cycle in lecture 3, aquifer and its types in lecture 4, and today we will discuss the fifth lecture that is lecture based on porosity and permeability. In this lecture, the important concepts will be covered like porous media properties, porosity, types of porosity, relationship between porosity, void ratio, saturation percentage, bulk density and effective porosity. permeability, factors affecting permeability, types of permeability, transmissivity, storage coefficient or storativity.

We have already understood in the previous lectures that groundwater and vadose zone exist everywhere under the ground, but the quantity of water present depends on the properties of the medium geological formation. The medium that is rock or soil beneath the earth's surface may be permeable or impermeable but most soils are permeable although their degree of permeability varies. Soil and rock strata that permits water flow are called porous media. Porous media is an interconnected structure of tiny conduits of various shapes and sizes. It is made up of matrix of particles and embedded voids.

Thus a portion of the soil cross section is occupied by solid particles and the remainder by voids. Infiltration, groundwater movement and storage occur in these void spaces. Those portions of a rock or soil not occupied by solid mineral matter can be occupied by groundwater. Because void spaces serve as water conduits, they are of fundamental importance to the study of groundwater. Now, porosity.

The porosity of a rock, which is a major geological criteria for occurrence of groundwater, is a quantitative measurement of interstices or voids present in the rock. Porosity, in fact, depends on the shape, the packing and the degree of sorting of the component grains in a given material. Uniform and well sorted grains give rise to higher porosity, whereas

heterogeneous grains with irregular arrangement have lower porosity. In general, a porosity greater than 20 % is considered to be large and below 5 % is small and between 5 to 20 % as medium porosity. The porosity values of some of the common type of rock formation we can see in the table.

Here in the case of quartz, granite and quartzite, porosity is near about 1.5 %. In slate and shale, 4 %. limestone 5 to 10 %, sandstone 10 to 15 %, sand and gravel 20 % to 30 %, only gravel 25 %, only sand 35 %, and clay and soil 45 %. So in this way, the, some of the concepts related to the different type of rock formation and its porosity percentage is given in the table. Now, types of porosity.

Porosity based on pore space connectivity. Actually, it is of two types, effective porosity and absolute or total porosity. Now, first we will discuss the effective porosity. It is the measure of a void space that is filled by recoverable oil or gas. In other words, the amount of pore space that is sufficiently interconnected to yield its oil or gas.

It lies commonly in range of 40 to 75 % of the total porosity, except in case of unconsolidated sediments. Absolute or total porosity, the total void space in the rock, whether it contributes or not contributes to fluid flow, is termed as absolute or total porosity. Porosity on the basis of origin. Primary porosity is the first one, it refers to gaps between particles which forms during the sedimentation. It is the void space that would be present if grains had not been altered, fractured or dissolved.

The amount of primary porosity depends on several factors like degree of informity of grain size, the shape of the grains, the method of deposition and so the manner of the packing. In the figure also you can see in between the grains we are getting having some space. some space, so this is termed as porosity. Now, secondary porosity, it is formed by later processes, for example by re-crystallization process or by dissolving of minerals. Porosity usually changes with depth of sediment as pressure of overlying rocks compacts the sediment. Clay in particular, loses porosity through this process, while sandstone often loses porosity as calcite and silica minerals grow in the pore spaces.

What's the relationship between porosity, void ratio, saturation percentage, bulk density, effective porosity? So we will just see the relationship among these different parameters. First the porosity, it is the measure of the void spaces in a substance which is defined as the ratio of the volume of pore spaces to the total volume of the soil sample. Here you can see the formula is V This is the formula.

Here you can see the formula of measurement of porosity where this one is the volume of the voids, V_s is the volume of the solid, V_c is the total volume of the soil sample and Ss is the specific gravity of the sand in gram per centimeter cube. Now void ratio, it is the count of the pore volume of the substance which is the ratio of the volume of void space to the total volume of the solid substance. Here we can see this is the formula for measurement of the void ratio in which V_V is the volume of the voids and V_S is the volume of the solids. Next is the saturation percentage. It is the percentage of the pore space that is occupied by water which is defined as the ratio of the volumetric water content V_W to the porosity of the material that is N. And the relationship for finding out the saturation percentage is this one.

Now bulk density, it is the density of the total soil or rock material, solids and voids after drying. This is the ratio of the dry weight of the substances to the volume of the substance, which is expressed in gram per cubic centimeter. And through this relation, we are finding the bulk density. Effective porosity, It is defined as a portion of the total void space of a porous material that is capable of transmitting a fluid and it is the ratio of volume of water pumped during travel time of water to the thickness of the aquifer. The formula for finding out the effective porosity is mentioned here.

In which you can see capital V is the volume of water pumped during travel time of tracer. V_D is the volume of water involved part of depression cone. T is the observation of tracer concentrations. R is the distance between injection well and pumping well. And V is the thickness of an aquifer. So by these equations we can find out the effective porosity of any formation.

Now specific yield of the aquifer. It is the volume of water released from groundwater storage per unit surface area of aquifer per unit decline in water table, which is the difference between porosity and specific retention. So by this equation, we can find out the specific yield of any formation. Change of groundwater storage, it is the product of area, water level fluctuation and specific yield. Just the equation is the groundwater, change in groundwater storage is area into drop in groundwater level and into specific yield.

Based on these parameters, there is a numerical An undisturbed core sample of the sand material has 16 centimeter height. So the height of the core of the sand material is 16 centimeter. And 4 centimeter inside diameter. The diameter of the core of the sand material is 4 centimeter.

The weight of sample is 430 gram. Weight of the sample after, before drying is 480 gram. And 380 gram after drying. After drying 380 gram. The volumetric water content is 0.25, 0.25 and the specific gravity is 2.65 gram per centimeter cube. Now, based on these, find out the porosity, void ratio, saturation percentage and bulk density. So, first we will find out the porosity. By the same formula what we have discussed, we will put the value.

Here, V_c given pi r-square into b. So, we can just calculate and we are finding this much amount for the V_c. W_d is the 380 gram given. S_s, specific gravity already given, two point six five. Now, volume of the solid we have to find out by weight by specific gravity. It is coming near about one forty-three point forty centimeter cube.

Hence, V_v is equal to V_C minus your V_S. So, N is equal to, now V_V also we have calculated. Now, just we will put the formula on this. Porosity will be, if we will divide this one and multiply it, we are getting the porosity near about 28.64, that is 0.29. Now, void ratio. By this formula, we have discussed just now.

Now, V_V is 55.56 centimeter cube. V_S is 143.40 centimeter cube. Therefore, e, is equal to, that is, void ratio is equal to 0.40. Next is the saturation percentage. Formula we have seen.

So, just volumetric water content is 0.25. And porosity we have measured near about 0.29. So here we will put the value of the different parameters. It is coming near about 86.21 % the saturation percentage. Bulk density formula already we have discussed.

Here WD is three 80 gram. V_C is 200.96 centimeter cube. So bulk density will be your 1.89 gram per centimeter cube. Now, one another problem. In an area of 100 hectares, the water table dropped by 4.5 meters.

If the porosity is 30 % and the specific retention is 10 %, determine the specific yield of the aquifer and the change in groundwater storage. So porosity we are knowing specific yield plus specific retention. So here porosity is given 30 %, specific yield we have to find out and specific retention is 10 %. Then by solving this equation, the specific yield is coming to 20 % or 0.2. Now the change in groundwater storage we have to calculate.

So we are knowing the formula area of the aquifer drop in groundwater table by specific yield. So area of the aquifer is hundred hectare. This one is drop in groundwater table is 4.5 meter, water table drop and 0.2 is the specific yield of the aquifer. So by putting the values and solving it, it is coming 90×10^4 meter cube. So, this is the total volume in the change in groundwater storage.

Next problem, in an area of 1 kilometer square, the drop in water level is 6 meter. If the porosity of aquifer is 5 % and the specific retention is 25 %, estimate the specific yield of aquifer and change of groundwater storage. So, here again by the same method, we will find out the porosity. By the formula specific yield plus specific retention specific retention we have got this one 25 % so 0.25 just we will put the value in the formula, the specific yield is coming 0.25. Change in groundwater storage with the same formula area into drop in water level into specific yield so area is 1×10^6 meter square the drop in water level is 6 meter, 6 meter and the specific yield is coming to 0.25. If we will solve it, the value is coming like this.

So in this way, we can find out the specific yield and the change in groundwater storage. Now another problem is an aquifer has an average thickness of 60 meter and aerial extent of 100 hectare. Estimate the drop in groundwater table if the aquifer is unconfined and the available groundwater storage is given as 240 hectare meter. Assume specific yield is of 16 %. So here change in groundwater storage is equal to area of aquifer into drop in groundwater table into specific yield.

Drop in groundwater table will be change in groundwater storage divided by area of aquifer into specific field. So while putting the value of the parameters we are just getting the drop in water table is 15 meter. So in this way we can calculate the different parameters. Now second is the permeability. Permeability is the property of soil which permits flow of water through interconnecting void spaces.

Permeable soil means a soil containing continuous void which permits water to pass through the soil mass. Example is gravel and coarse sand. Impermeable soil, soil does not allow water to pass through it. Example is stiff clay or rock. Sand, silts and medium clays falls between permeable and impermeable type of soil.

The Groundwater can get stored in the underground rocks only if they are sufficiently porous. In other words, water is get stored in the pores or voids of the rocks. The porosity of the rock thus defining the maximum amount of water that can be stored in the rock. The porosity however in itself does not ensure the storage of underground water. In fact, the water can enter into a rock only if the rock permits the flow of water through it.

That is, it depends on whether the rock is permeable or not. It may be clarified here that a rock which is porous may or may not be permeable. For example, shale is a porous rock, but its pore spaces are so minute that the rock remains impermeable. The size of the pores is quite an important factor and it should be sufficiently large to make the rock permeable.

The permeability is therefore defined as the ability of a rock or an unconsolidated sediment to transmit or pass water through itself.

Here you can see in these portions no pore spaces. Here unconnected pore spaces, pore spaces are available but not connected but in these cases you see everywhere the pore spaces are connected. So these are the example of non-porous non-permeable formation, then porous non-permeable formation and porous permeable formation. Factors affecting permeability. The coefficient of permeability K is the rate of flow per unit cross-sectional area under the unit hydraulic gradient at a specified temperature.

It is usually expressed as meter per second. It has a dimension of velocity L by T. The permeability depends upon the grain size distribution, soil textures, soil structures, porosity, shape and arrangement of pores, properties of pore feed and entrapped air or gases and can be expressed as the, this very equation. Where we are getting that C is the constant, D is the effective size of the formation material, that is aquifer, small e is the void ratio, gamma w is the unit weight of water at the flow temperature, which is equal to rho g, where rho is the density of water, and mu is the viscosity of water at flow temperature.

In this table, we can see the soil, its texture and permeability. So here, the finer the soil texture, the slower the permeability. Just see in the table, clay soils, they are texturally fine. Loamy soils moderately fine, moderately coarse both and sandy soils coarse, so from very slow to very rapid permeability we are seeing in such type of soils. For example we can see the average permeability for different soil textures in centimeter per hour in case of sand it is five point zero, sandy loam two point five, loam one point three, clayey loam zero point eight, silty clay zero point two five and clay zero point zero five. Now, permeability variation according to soil structure.

Structure may greatly modify the permeability rates. We can see here on the basis of structural type, the different value of the permeability. Here you can see for platy structure, which is generally greatly overlapping or slightly overlapping. Then blocky structure, prismatic structure, granular structure, the permeability remains or varies from very slow to very rapid. This may vary according to the degree to which the structure is developed.

Now, based on the permeability formula, which we have learned just now, one numerical is here. The numerical is the coefficient of permeability of a soil sample is found to be four into ten to the power minus five meter per second at a void ratio of zero point six. If

the void ratio of the same sample is zero point eight, find the coefficient of permeability. So, this formula we have read for the finding out the permeability. By this formula, we can see K is directly proportional to this value.

So, if K-one is given four into ten to the power minus five meter per second, then void ratio is also given zero point six in the first condition. In second condition, zero point eight is given wide ratio and this is we have to determine. So by this formula k is directly proportional to this much. So by putting the values in terms of k-two by k-one we can able to calculate the value of these factors and when we will calculate the value it is coming k-two value is coming to eight point four two into ten to the power minus five centimeter per second. Now intrinsic or specific permeability.

The intrinsic or specific permeability of a water bearing medium is given by K is equal to CD square where C is the constant which summarizes the geometrical properties of the porous medium and K has dimension of L square. D is the effective size of the formation material that is the aquifer. K when expressed in cm-square is usually extremely small. So that Darcy has been adopted as a more practical unit. Here we can see one Darcy is equal to this much.

Coefficient of permeability K is just by this equation. We can able to find out. And one Darcy is equal to zero point nine six six into ten to the power minus three centimeter per second for water at two hundred twenty degree centigrade. While determining permeability K, the water temperature has to be noted and K has to be reduced at a standard temperature of twenty degree C or twenty seven degree C and usually expressed as centimeter per second, meter per second or lpd per meter square. Representative values of permeability coefficient can be seen by this table.

Here we can see the granular material. the consolidated material in case of gravel, in case of clean gravel, in case of clean coarse sand, weak sand, fine sand, silty sand, silt and clay. And in terms of consolidated material, the sandstone, carbonate rock with secondary porosity, shale, fractured and weathered rock aquifers, we can able to find out the K in centimeter per second and K_0 in darcys. So these are the values. where K_0, the value in Darcy is equal to ten to the power three K [centimeter per second] at twenty degrees C. Now types of permeability.

Permeability are of different types. Absolute permeability, the permeability of porous medium with only one fluid. Absolute permeability is constant for a particular medium and independent of the fluid type. The absolute permeability only depends on the

geometry of the pore channel system. Effective permeability, when two more fluids are present but only one can pass through effective pores is called effective permeability.

More than one fluid is present in this case, each fluid will mutually reduce the pore channels open to flow for the other fluid and the effective permeability may be much lower than the absolute permeability. Relative permeability is the ratio of absolute permeability and effective permeability. Transmissivity. When describing the transmission capacity of a small representative volume of porous media, the hydraulic conductivity is used. However, the capacity of an unconfined aquifer or confined aquifer to transmit water is described in terms of transmissivity.

Transmissivity is defined as the product of hydraulic conductivity K and saturated aquifer thickness that is B. So unit of transmissivity are L square by T that is transmissivity is equal to product of hydraulic conductivity and aquifer thickness. The term transmissibility is an outdated term that is occasionally used for transmissivity. Transmissivity describes the overall transmission capacity of an aquifer system, not just the properties of small volume of the aquifer. Now compare the two different situations. In case one, the hydraulic conductivity of confined aquifer is hundred meter per day and thickness of aquifer is ten meter. In case two, if another aquifer has a hydraulic conductivity of fifty meter per day and its aquifer thickness is three hundred meter.

Now, here we can see that case one, transmissivity K into B, so hundred into ten is equal to hundred meter square per day. Case two, transmissivity is equal to K into B, again fifty into three hundred is equal to fifty thousand meters square per day. So, the situation is that higher the T value of the second aquifer, it indicates that it can transmit more water. Now transmissivity of confined aquifer. The transmissivity of confined aquifer of informed thickness is a constant value for an isotropic and homogeneous set of conditions as shown in the figure.

By definition, the head of the confined aquifer is higher than the top of the aquifer. So the complete thickness of confined aquifer is saturated. Thus B is a constant when T is determined. Here we can see this is the B value. Now, transmissivity of unconfined aquifer.

The saturated thickness of an unconfined aquifer varies with space as the water table slopes in the direction of flow. Thus, T values change with distance from a given location as shown in the figure. When water table slope is small, single value of T is commonly used to represent the aquifer. In areas with large water table gradients, average thickness

may be used to compute one representative value of T. Storage coefficient or storativity, water discharged to or discharged from an aquifer represents a change in storage volume within the aquifer.

For unconfined aquifer, this is simply expressed by the product of the volume of aquifer lying between the water table at the beginning and at the end of a period of time and the average specific yield of the formation. The storage coefficient or storativity of an aquifer is defined as the volume of water yielded per unit horizontal area and per unit drop of water table in unconfined aquifers or piezometric surfaces in confined aquifers. The coefficient is dimensionless quantity involving a volume of water per volume of aquifer. Thus, if an unconfined aquifer release four meter cube water for a water drop of two meter over a horizontal area of ten meter square, the storage coefficient is coming to zero point two or twenty %. For unconfined aquifers, the storage coefficient can also be called specific yielding.

which is the volume of water released from the unit volume of saturated aquifer material drained by falling a water table. In most confined aquifers, values fall in the range of this one, where S is the storage coefficient. Storage coefficient can best be determined from pumping test of wells or from groundwater fluctuations. The fact that S normally varies directly with aquifer thickness enables the rule of thumb relationship that is Lohan rule where S is given three into ten to the minus six into B where B is the saturated aquifer thickness in meter to be applied for estimating purposes. Another is the under artesian conditions when the piezometric surface is lowered by pumping, water is released from the storage by the compression of the water bearing material and by expansion of the water itself.

Thus, coefficient of water storage is a function of elasticity of water and the aquifer skeleton and is given by the Jacob. So this is the Jacob equation for finding out the storativity or storage coefficient with the help of porosity, saturated thickness. In this way, we can able to find storativity under artesian conditions. In this table, it is mentioned the type of the material, different types of material and the bulk modulus of the compression. Plastic clay, stiff clay, medium hard clay, loose sand, dense sand, sandy gravel, rock fissure, jointed, rock sound.

With the help of the previous equations, We can solve a numerical also. An artesian aquifer 20 meter thick has a porosity of 20 % and bulk modulus of compression 10^8

Newton per meter square. Estimate the storage coefficient of aquifer. Bulk modulus of elasticity of water is given 2.1 x 10^9 Newton meter.

So by putting the values in this equation, just for α, β, S, we can find out the S, this much, which can be further solved to have the value of S is equal to 0.002. This is the next numerical. An artesian aquifer 30 meter thick has porosity of 30 % and bulk modulus of compression is this much. Estimate the storage coefficient of aquifer. Bulk modulus of elasticity of water is 2.4 x 10^9 newton meter per square. The bulk modulus of elasticity of water is given 2.4 x 10^9 Newton per meter square.

By putting the values in this equation, we can able to find out the storativity with the help of bulk modulus. Bulk modulus we should find out the bulk modulus of elasticity of water, from the previous table also we can find out and then we will put the values in the equation. This equation it is coming to, s value is coming to 0.0003. So now I am concluding the module. The Earth's water resources are predominantly saline and stored in oceans with only 3 % constituting fresh water. Out of this, a significant portion is locked in glaciers and polar ice caps, leaving a small fraction accessible as groundwater and surface water for human and ecological needs. India has diverse groundwater provinces categorized based on geology such as Himalayan region, Indo-Gangetic Plains, hard rock regions and coastal aquifers.

Each province has unique recharge characteristics and water availability influenced by climate, geology and human activities. The continuous circulation of water through evaporation, condensation, precipitation, infiltration and runoff forms the hydrological cycle. This natural process ensure the replenishment of water resources, with groundwater recharge being a critical component for sustainable use. Aquifers classified as confined, unconfined or perched, serve as vital underground water reservoirs. Their storage and transmission capabilities depend on porosity, that is the void spaces in rocks, and permeability, that is the ability of water to flow through.

Efficient groundwater management requires understanding these characteristics. These references I have taken from the different books. Thank you very much to all.