Availability and Management of Groundwater Resources
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Lecture - 22
Porosity, Permeability, Transmissivity and Storage Coefficient (Continued)

Welcome you all in the part 3 of the module 5 title porosity, permeability, transmissivity and storage coefficient. So, what we have discussed in the last two lectures related to the porosity and permeability that for the making a very good aquifer it that aquifer characteristics should have some very efficient porous spaces within it and also it should have the capacity to receive water and to send water to some other aquifer.

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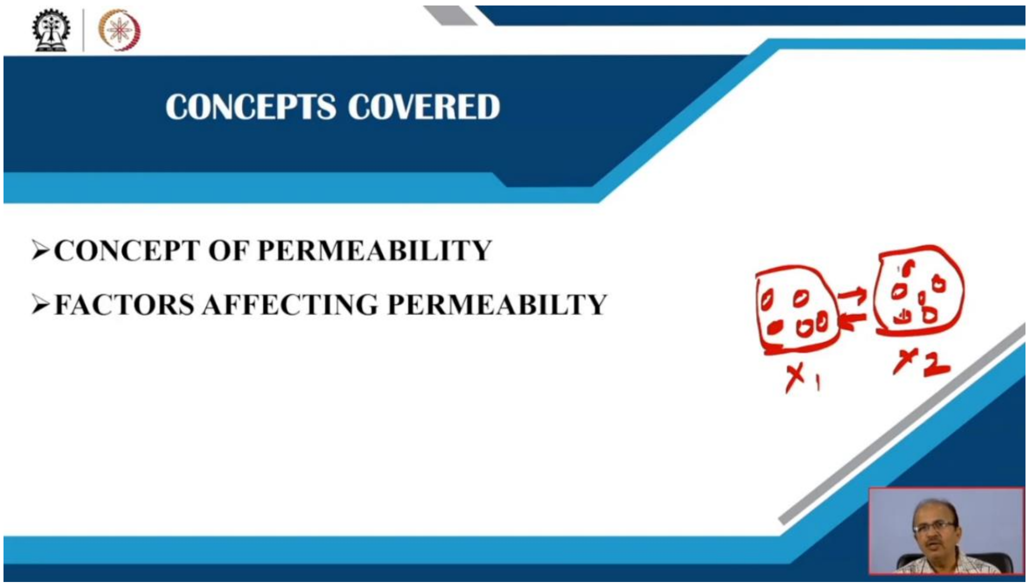

So, in this part 3 we will discuss important concepts of permeability and factors affecting permeability. So, in the last two lectures we have already discussed about the porosity we have seen how the porosity is very important for making a soil a very efficient your stage for keeping large volume of water. Now second concept for a very good aquifer is having the good permeability.

So, porosity as we know is nothing but it is the number of wide spaces within a rock. So, within a rock if the number of void resources will be more definitely it is a very good storage of the water underneath the earth surface. Now this rock; say underneath the earth's surface we are having several rock and several rocks are just occupying the place of a aquifer. So, this rock should have the ability also either to send the water to this aquifer and or to receive the water from this one.

So, suppose X1 and X2 are two different aquifers at two different places at two different alignments. So, aquifer X1 and X2 is a good aquifer only when it is having a large number of pore spaces means porosity is good and second permeability is good means having the ability to transmit the water as well as to receive the water. So, in this concept we will discuss these two important factors about the permeability.

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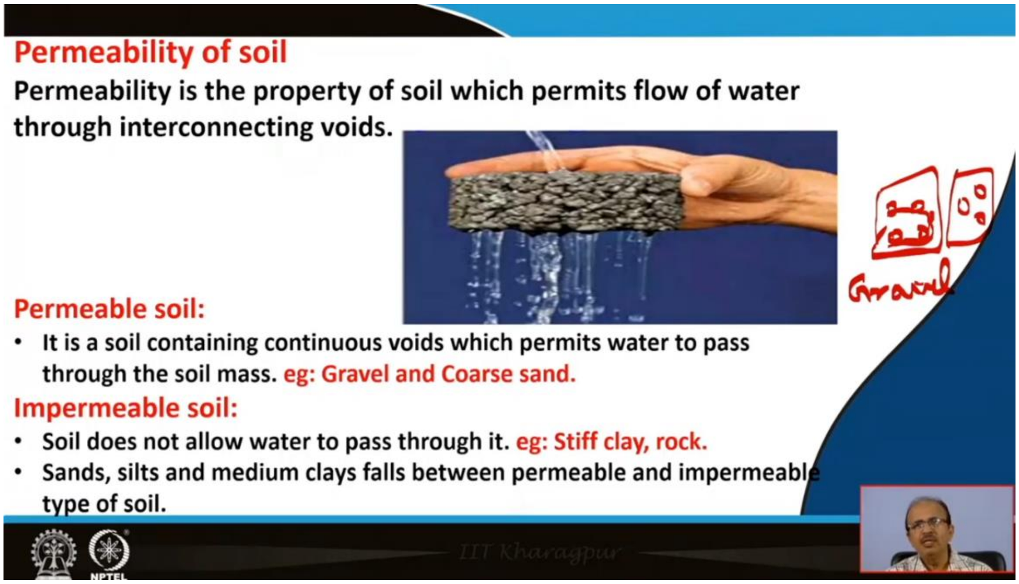

First permeability of is the property of soil which permits flow of water through interconnecting voids. So, it is just a property of soil which is allowing to flow the water through interconnecting voids available within the soil structure. Permeable soil if we are telling the permeable soil so it is a soil containing continuous voids, so only voids spaces are not essential. Suppose it is a soil structure in which the number of voids are there.

So, it is not the connection between or among the voids is also important. So, then only the water will flow from here to here or from in one aquifer to another aquifer. So, this is called as probability. So, good example is gravel is a very good example of an aquifer and coarse sand, so these are having the ability to pass the water from one place to another. Impermeable soil when we are telling when the soil does not have pore spaces sufficient pore spaces.

So, it does not allow water to pass through it example is compact rock steep clay etcetera these are the example. Now sand, silts and medium clays fall between permeable to impermeable. So, we can tell it sand, silts, medium clay as a semi-permeable in nature. So, not allowing; so much of water to pass through the soil structure. So, this is about the permeability. In salt we should know that porosity is the volume of void divided by total volume of the rock and the permeability is the ability to transmit water from one aquifer to another aquifer.

We have learnt about the example of the permeable soil as well as impermeable any compact rock which are not having the porous spaces. So, there is no question of connection of pore spaces, so if there will be no connectivity between the pore spaces or among the pore species there will be no flow of water through one rock to another rock. So, this is about the permeability of soil.

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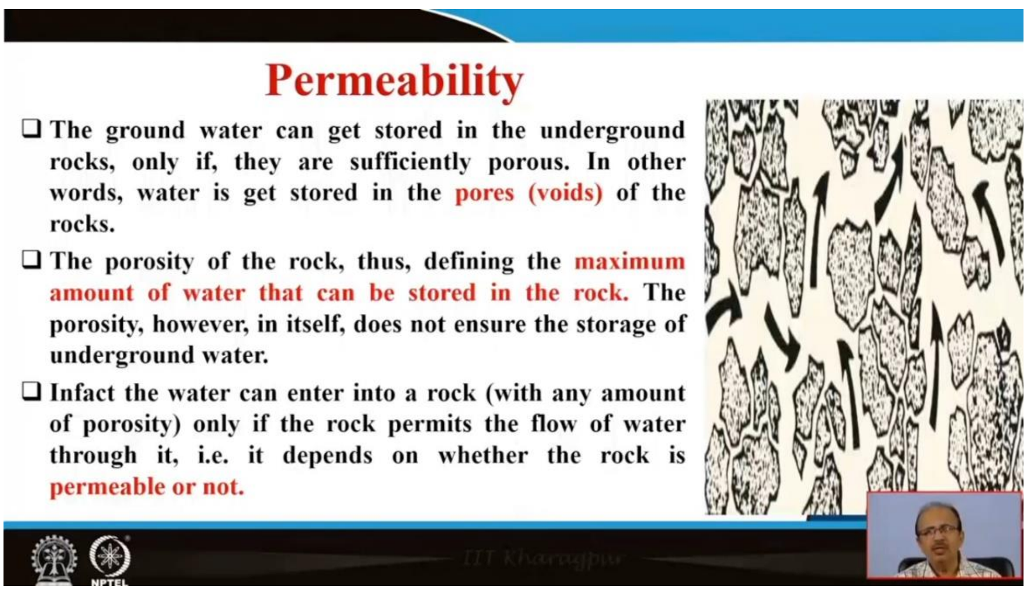

Now greater we will discuss in greater detail the groundwater can get stored in the underground rocks only, whatever groundwater we are storing. It will remain stored in the underground rocks available underneath the surface and also the rock must be very much porous. We can say in other words that water is getting stored in pores wide of the rocks. The porosity this is about the porosity of the rock is defining the maximum amount of water that can be stored in the rock.

The porosity itself does not ensure the strength of the underground water. So, only we cannot say that the rock will have a large storage of underground water if it is a very good porous no. In fact, the water can enter into a rock only if the rock permits the flow of water through it. So, then only when the flow of the water will be there then only, we can say that the water will enter into a rock and it depends on whether the rock is permeable or not in nature.

So, if the rock is permeable; then definitely the flow will take place, flow of water will take place and it will move from one rock to another rock. So, this is the importance of permeability for storage of groundwater underneath any aquifer.

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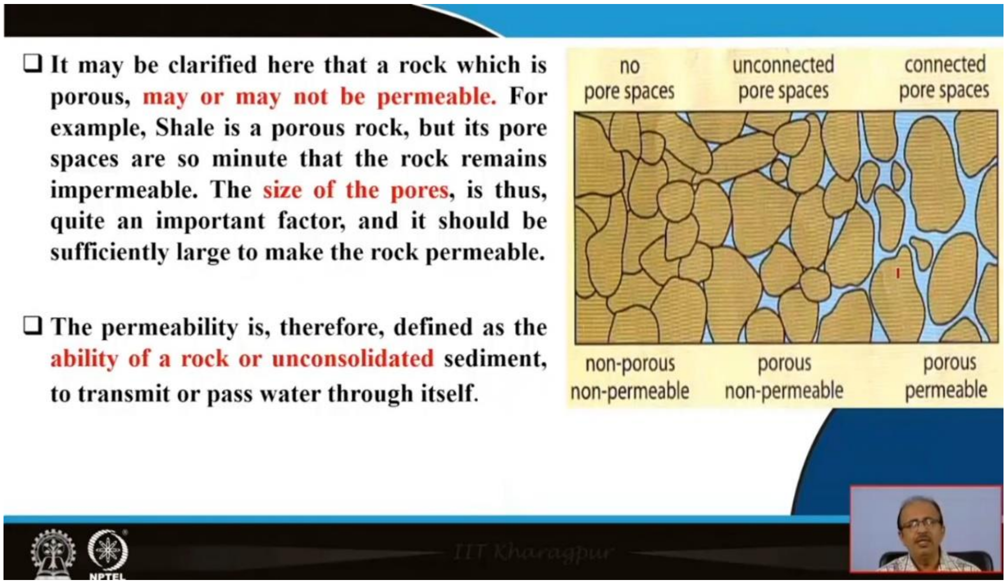

Now it may be clarified here that a rock which is porous, you can see the picture also the three different stages no porous spaces unconnected porous spaces and connected porous spaces. We can see this is the example of the no pore space here we are not seeing any pore space whereas here we are seeing the pore spaces are there but no interconnectivity are there but here we are seeing the pore spaces and interconnectivity also.

So, in the no pore spaces we are we cannot say that it is it is non-porous and non-permeable. For this is one is porous who means is allowing water to store in within the rock but non-permeable because no connection among the pores. Now this is porous as well as permeable also, so shale is a porous rock but its pores places are so minor that the rock remains impermeable. Shale is a sedimentary rock; it is a porous rock.

But its pore spaces are so fine that the rock remains impermeable in nature. So, the size of the pore is an important factor and it should be sufficiently large to make the rock permeable. So, in general if we will make the understanding first, we have made the understanding that an aquifer will be a good aquifer when it is having the pore spaces as well as it is having the property of permeability means ability to transmit water, ability to flow of water.

Now just advancing the our knowledge that this making the rock permeable it is also necessary that the pore spaces should have interconnection among each other, then only the flow of the water will take place. Therefore, permeability is the ability of a rock or unconsolidated sediment not the consolidated sediment, ability of any rock or unconsolidated sediment to transmit or pass water through itself, so this is called as permeability. Now we have understood in a very good way about the term permeability.

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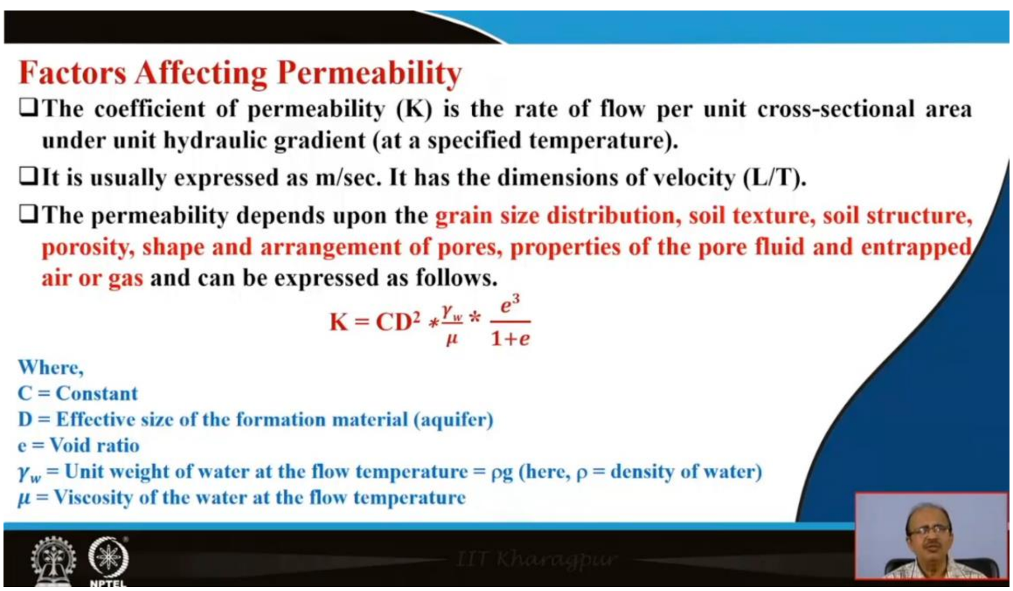

Now next is that what are the factors which are affecting the permeability. We can see that the coefficient of permeability capital K is the rate of flow of water per unit cross sectional area under unit hydraulic gradient at a specified temperature. This is the general definition of the coefficient of permeability which is usually expressed as meter per second it is expressed as meter per second and its dimension is (L /T) so, this is called as the coefficient of permeability.

The permeability depends upon the grain size distribution, soil texture, soil structure, porosity, shape and arrangement of pores, properties of pore fluid and entrapped air or gas whatever within it and this is generally these are the factors which are affecting the permeability. This can be expressed as a formula that the

$$K = CD^2 * \frac{\gamma_w}{\mu} * \frac{e^3}{1+e}$$

where we can see

C = Constant

D = Effective size of the formation material (aquifer)

e = Void ratio

γ_w = Unit weight of water at the flow temperature = ρg (here, ρ = density of water)

μ = Viscosity of the water at the flow temperature So, this is the general equations for the measurement of the coefficient of permeability.

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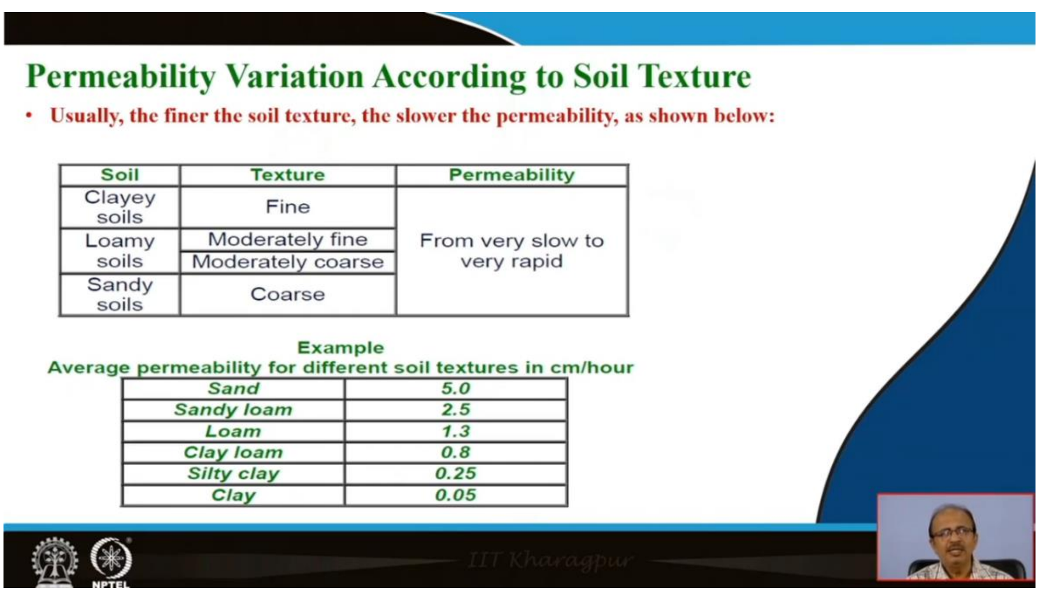

Now permeability variation according to soil texture, just we have seen this thing we have seen that the void ratio then the μ viscosity effective size of the formation material, so these are important for this. Then next we must know about the permeability variation according to soil texture because we have seen the factors affecting the permeability. So, soil texture, soil structure these are the important factors for making any rock permeable.

Means able to having the ability to not only the storage rather the movement of the water from one rock to another rock. So, on the basis of soil texture permeability we can say that the finer the soil texture the slower the permeability. So, example we can see clay soils very fine texture, loamy soil is moderately fine to moderately coarse and sandy soils the coarse. So, we can see that from very slow to very rapid it will remain permeability will remain very slow in the clay wise.

Since, the texture is very fine and comparatively rapid in the sandy soil where texture is a bit coarser. Example we can see average permeability for different soil textures in centimetre per hour, you can see sand 5.0, sandy loam 2.5 so here we have seen the permeability sandy loom is lesser than the sandy loam 1.3, clay loam 0.8, silty clay 0.25 and clay 0.05. So, clay is the finest soil but you see the permeability is only 0.05.

That is why clay is a very good porous having the number of pore spaces within it can store good amount of water but it cannot be a very good aquifer, why? Because the; permeability is very low. Whereas sand is a very good aquifer the 5.0 permeability is there, now this is according to soil texture.

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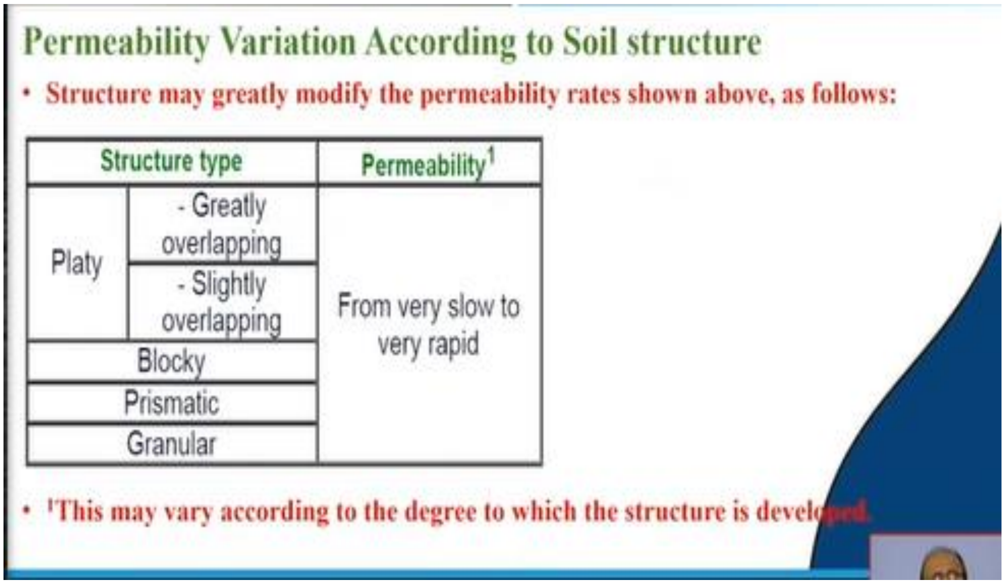

Now according to soil structure, we can see here. Generally, if the structure may greatly modify the permeability rates as shown below that that is you can see here greatly overlapping platy type of structure when the soil is having the plenty type of structure so greatly overlapping slightly overlapping through different condition may occur. Now blocky type of structure prismatic type of structure and granular type of structure.

So, we can see that from platy type it is very slow and granular type it is very rapid. So, this may vary according to the degree to which the structure is developed. So, as per the soil texture as in soil structure permeability variation is there and this plays very important role in the flow of movement of water from one aquifer to another aquifer.

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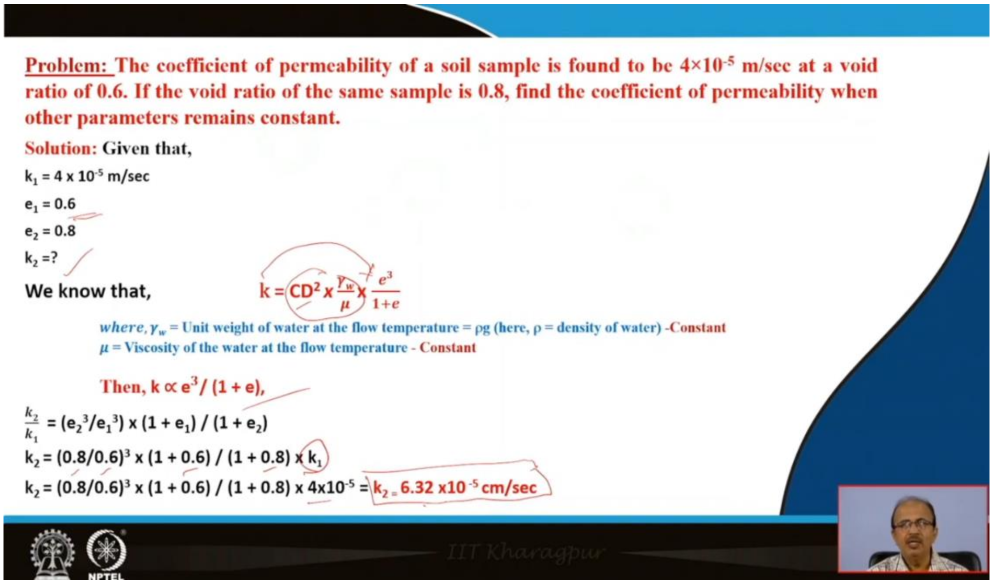

So, what we have seen that the permeability depends on the soil texture and soil structure. So, this coefficient of permeability always depending on the soil texture and soil texture. Now on that basis we can solve one simple numerical, The coefficient of permeability of a soil sample is found to be 4×10-5 m/sec at a void ratio of 0.6. If the void ratio of the same sample is 0.8, find the coefficient of permeability when other parameters remains constant.

So, just in the; prior slide we have seen that the one simple formula for the coefficient of permeability were there. So,

$k_1 = 4 * 10^{-5}$ m/sec

$e_1 = 0.6$

$e_2 = 0.8$

$k_2 =?$

We know that,

$$K = CD^2 * \frac{\gamma_w}{\mu} * \frac{e^3}{1+e}$$

where, γw = Unit weight of water at the flow temperature = ρg (here, ρ = density of water) - Constant

μ = Viscosity of the water at the flow temperature – Constant,

C = Constant

D = Effective size of the formation material (aquifer)

Then, $k \propto e^3 / (1 + e)$,

$\frac{k2}{k1} = (e_2^3/e_1^3) \times (1 + e_1) / (1 + e_2)$

$k_2 = (0.8/0.6)^3 \times (1 + 0.6) / (1 + 0.8) \times k_1$

$k_2 = (0.8/0.6)^3 \times (1 + 0.6) / (1 + 0.8) \times 4 \times 10^{-5} = k_2 = 8.42 * 10^{-5}$ m/sec

So, in this way if the void ratio is known if we can find out the coefficient of permeability also from the help of formula if other factors will remain constant.

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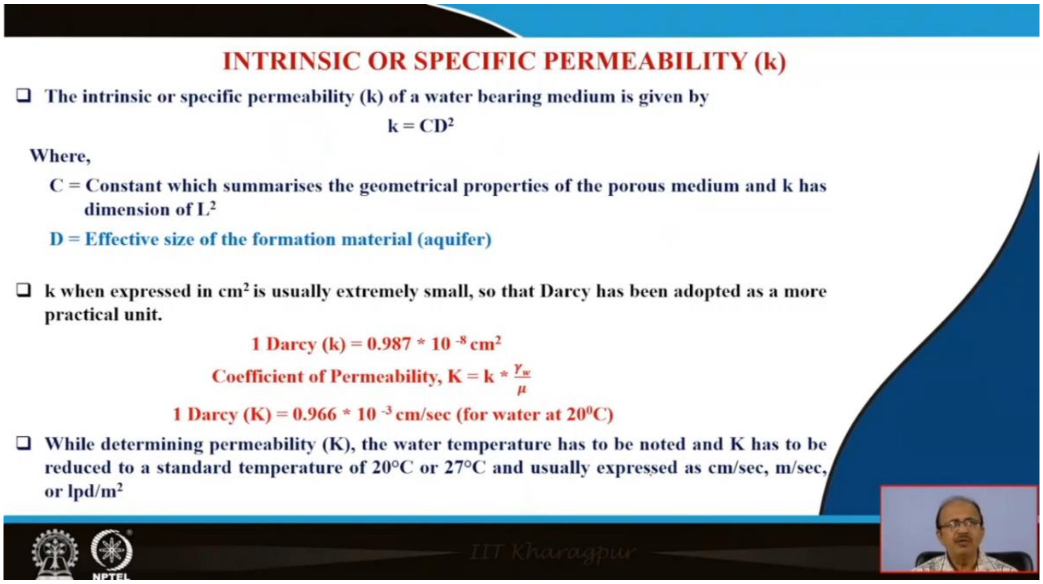

Now what is intrinsic and specific permeability? This is a bit deeper term related to the permeability. Specific permeability of a water bearing medium is given by $k = CD^2$ So, this is k where C is constant which summarizes the geometrical properties of the porous medium and k has a dimension of L^2. So, this is the constant properties of the porous medium and D is the effective size of the formation material for measurement nothing but this is the aquifer.

This CD has come in the previous numerical also where it has been asked and it was constant as per the numerical. Now k small k when expressed in centimetre square is usually extremely small very small, so that Darcy has been adopted as a more practical unit. So, we can write it 1 Darcy = $0.987*10^{-8}$ cm^2. So, this is the basis it is very small. So, we can write to $k = 0.987*10^{-8}$ cm^2.

Now coefficient of permeability K

$K = k^* \frac{\gamma_w}{\mu}$ So, 1 Darcy = 0.966 *10^{-3}cm/s, for water at 20°**C**. Now while determining permeability the water temperature has to be noted and K has to be reduced to a standard temperature of 20°**C** or 27°C and usually expresses cm/s, m/s or lpd/m^2.

So, this way we can find out the specific permeability.

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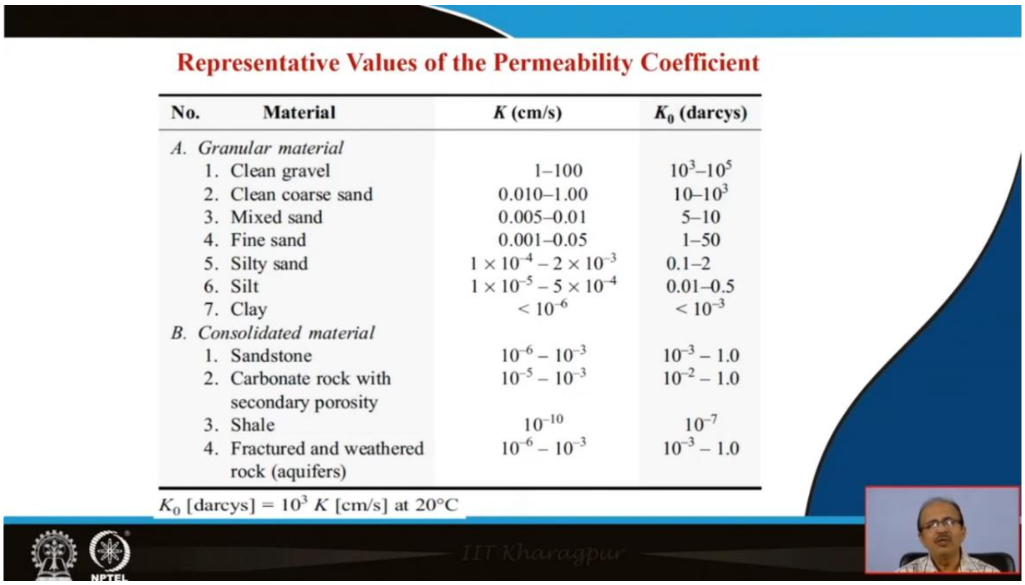

Representative Values of the Permeability Coefficient

No. Material	K (cm/s)	K_0 (darcys)
A. *Granular material*		
1. Clean gravel	1–100	10^3–10^5
2. Clean coarse sand	0.010–1.00	10–10^3
3. Mixed sand	0.005–0.01	5–10
4. Fine sand	0.001–0.05	1–50
5. Silty sand	$1 \times 10^{-4} - 2 \times 10^{-3}$	0.1–2
6. Silt	$1 \times 10^{-5} - 5 \times 10^{-4}$	0.01–0.5
7. Clay	$< 10^{-6}$	$< 10^{-3}$
B. *Consolidated material*		
1. Sandstone	$10^{-6} - 10^{-3}$	$10^{-3} - 1.0$
2. Carbonate rock with secondary porosity	$10^{-5} - 10^{-3}$	$10^{-2} - 1.0$
3. Shale	10^{-10}	10^{-7}
4. Fractured and weathered rock (aquifers)	$10^{-6} - 10^{-3}$	$10^{-3} - 1.0$

K_0 [darcys] = 10^3 K [cm/s] at 20°C

We can also see the some of the permeability coefficient K value of the different soil material for granular type of material example is clean gravel, clean coarse sand, mixed sand, fine sand, silty sand, silt clay. For this we are seeing here the different K value has been given in centimetre per second as well as in the Darcy's. In both the unit we are having the example of the general type of soil material and the consolidated type of soil material.

So, for consolidated you can see sandstone, carbonate rock with secondary porosity, shale, fractured and weathered rock aquifers. So, rocks are nothing but these are the aquifers. So, here we can see that in the granular material the permeability is more whereas in the consolidated material the permeability is less and K_0 (Darcy) = 10^3centimetre per second. So, this is about the different representative values of the permeability coefficients of different type of soil material having granular type of structure or consolidated structure.

Now what we have learnt that in the gravel coarse sand these are having very good pore spaces within it as well as very good connection of the your flow of water among the pores they are having very good connection. So, flow of water will be more from this type of sand whereas in the clay it is very less although the pore spaces are there although the storage of water is there but the movement of water in the clay structure is very low.

So, it is not a very good in the sense of permeability. So, that is why clay soil is not a very good aquifer. So, this is about the in this lecture we have learnt about the permeability what are the factors affecting permeability we have seen that the soil texture, soil structure they are playing very important role in making the rock permeable. Also, on the basis of formula we have seen how to find out when void ratio when one, permeability is given.

For different void ratio how to find out the coefficient of permeability? So, this thing we have seen in this lecture, more we will learn in the next lecture. Thank you very much to all.