Availability and Management of Groundwater Resources
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Lecture - 24
Porosity, Permeability, Transmissivity and Storage Coefficient (Continued)

Welcome to you all in the part 5 the module 5 porosity, permeability, transmissivity and storage coefficient. As we have discussed from the last four lectures that any aquifer which is a good aquifer it should have the pore spaces as well as these porous spaces should be connected with the different rock types. Then only the shale rock type is called as a good aquifer, it means that a rock which is generally termed as aquifer because it is holding the groundwater.

So, this rock should have the property of having good porosity, porosity we have discussed from the very first lecture that the number total volume of the voids divided by total volume of the rock. And the permeability means ability to transmit ability to flow having both side flow that is the rock which will have a very good permeability it will just have the connection with the other rock types then only the groundwater flow takes place inside the earth's surface.

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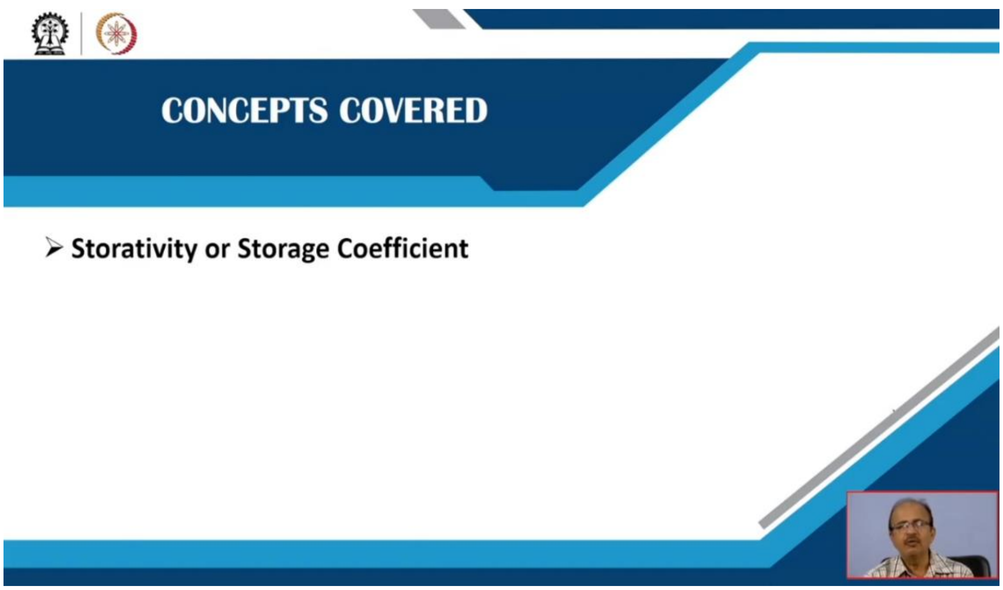

So, in this lecture I have already discussed prior to this lecture about the porosity and permeability in a greater detail. Now in this lecture we will see what is storativity or storage coefficient which is a very important parameter for any good aquifer.

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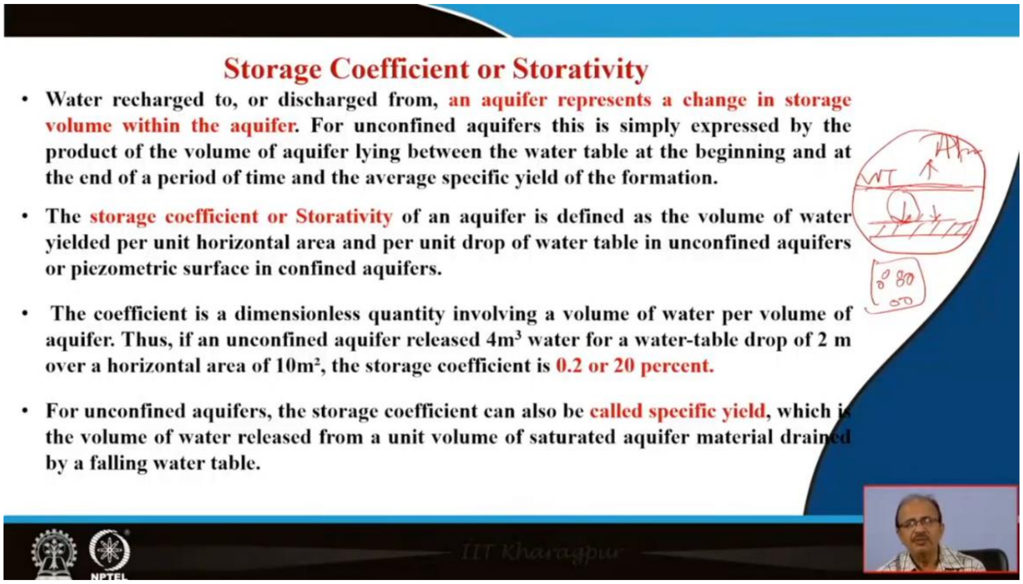

So, storativity means how much water from an aquifer is being recharged or discharged. So, water recharge or discharge from an aquifer represents just a change in storage volume within the aquifer. Because say if this is an aquifer and this aquifer is having certain capacity to store the water. So, how much water actually it remains with the aquifer with following the permeability application to the distant rocks located nearby.

So, whatever the water recharge to or discharge from an aquifer it generally shows the change in storage of volume within an aquifer. For unconfined aquifer we have discussed already in the prior lectures, unconfined aquifer is aquifer which is underlined by any unconfining beds. So, this is the confining beds this is just the confining beds means it is impermeable beds it does not allow water to move down.

So, what is happening and the upper portion remain in contact with the atmosphere this remain in contact with the atmosphere. So, this type of formation within the rock is generally termed as an aquifer, this is a aquifer but it is unconfined aquifer not a confined aquifer. So, for unconfined aquifer storativity or storage coefficient is expressed by the product of volume of aquifer lying between the water table.

So, volume of water, what is the volume of water, you see this is the water table because we know uh in unconfined aquifer generally the upper part of the water level in an aquifer is termed as water table. So, since we are discussing about the storage coefficient so the volume of water in the aquifer which is lying between the water table and at the beginning and at the end of period of time and the average specific yield of the formation.

So, it is just a product of the volume of water remains between the water table at the beginning and at the end of the period of time and the period of time what may be whatever we will consider and the average specific yield of the formation, what is the average specific field of this formation. So, these two generally termed as your storage coefficient or storativity. So, the storage coefficient or storativity of an aquifer is defined as the volume of water yielded per unit horizontal area.

So, in this way we can define this storage coefficient since storage itself means having some storage within the formation within a rock within any structure. So, just we have to find out for storage coefficient or storativity with in terms of an aquifer, so it is defined as the volume of water inlet per unit horizontal area and per unit drop of water table in unconfined aquifers or piezometric surface in confined aquifers.

So, this we have already discussed in the prior lectures that in the unconfined aquifer we are having the water table. Whereas in the confined aquifers, confined aquifers means those aquifers which are under lane as well as overlaned by confining beds, confining beds means any impermeable beds which does not allow water to move up or down, so this type of aquifer is called a confined aquifer.

So, the storativity of an aquifer in the case of unconfined aquifer is the volume of water inlet per unit horizontal area and per unit drop of water table whereas in case of in unconfined aquifers. Whereas in the case of confined aquifers the volume of water inlet per unit horizontal area and per unit drop of the piezometric surface not the water table in confined aquifer. So, the coefficient is dimensionless quantity.

This coefficient storage coefficient is a dimensionless quantity involving a volume of water per volume of aquifer. So, this is a dimensionless quantity if an unconfined aquifer released 4 cubic meter water for a water table drop of 2 meter over a horizontal area of 10 cubic square meter, then the storage coefficient is 0.2 or 20%. So, in this way we can understand it that if any unconfined aquifer condition is there which is releasing only 4 cubic meter of water.

When water table drop of 2 meter over a area is horizontal in nature's over a horizontal area of 10 square meter, then the storage coefficient is 0.2 or 20%. For unconfined aquifers the storage coefficient can also be called specific yielding, the if you will recall the meaning of the specifically which we have discussed earlier in the unconfined aquifers the storage coefficient can also be called as a specific field.

Which is the volume of water released from a unique volume of saturated aquifer is your unconfined aquifer drained by a falling water table. So, this much volume of saturated aquifer which is drained by falling a water table is generally also considered as specific yield in place of storage coefficient in the case of unconfined aquifer. So, this is very important concept that for unconfined aquifer storage coefficient can be considered as specific yield. And yield we have discussed specific yield we have discussed in the prior lecture itself.

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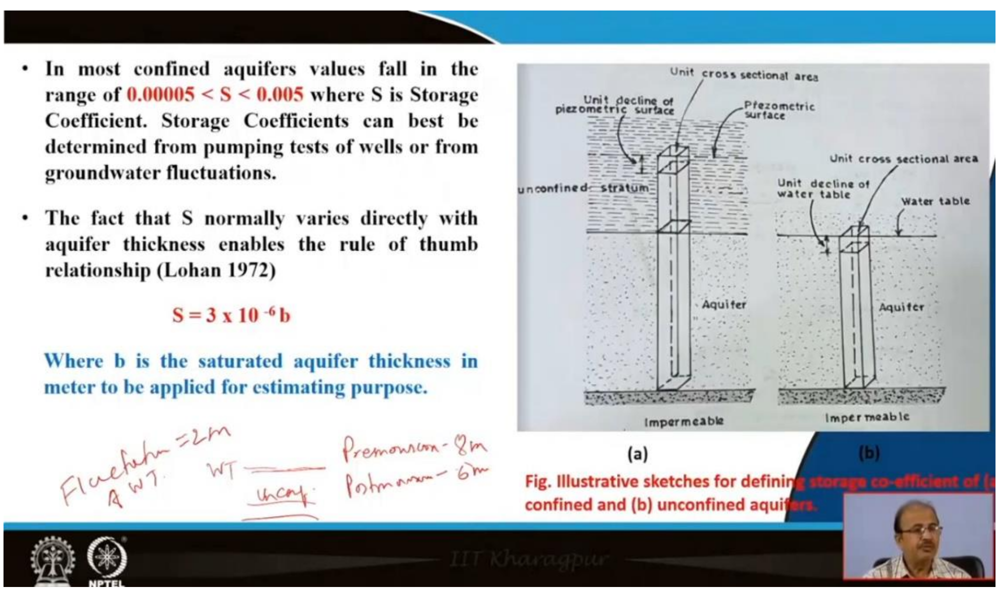

So, this storage coefficient is the very important parameters for any aquifer also because in most confined aquifer values fall in the range of 0.0005 is less than S is less than 0.0005. So, what we are seeing that S is there the storage coefficient. So, in this way generally the storage coefficient value we are getting in the case of confined aquifers, storage coefficient can best be determined from pumping test of wells or from groundwater fluctuations.

So, groundwater fluctuations can be measured say in the pre monsoon period, pre monsoon only generally before the some onset of the monsoon season. So, just we will take the reading from the wells that what is the depth of the water table. So, water table is this one, if this is water table so definitely this aquifer is an unconfined aquifer this aquifer is confined aquifer. So, now this reading say it is coming the water table depth is coming here in the case of this aquifer during pre-monsoon.

It is pre-monsoon in summer it is coming nearby your 8 meter. Whereas in after monsoon means post monsoon the water table depth this is being measured by some instrument is coming to 6 meter. So, definitely after the monsoon the well has recharged so the depth has just reduced it was earlier 8 meter and when we have measured in the post monsoon season means after monsoon season it is coming 6 meter.

So, the fluctuation of water table or water table fluctuation is your 2 meter fluctuation is 2 meter fluctuation of water table or is 2 meter in that very area, in that very area means in that very aquifer area. So, this is generally storage coefficient is generally measured by pumping test, pumping test is one of the tests through which we are finding the storativity and transmissibility and secondly by the from the groundwater fluctuation method.

So, this groundwater fluctuation is also important, groundwater fluctuation we are knowing what is the meaning of fluctuation the depth of the water table if during the pre monsoon and the depth of the water table during the post monsoon. So, whatever the difference is coming that is the fluctuation level in that very well in that very area. So, in this way generally the storativity is measured. The fact that the storage will be normally varies directly with aquifer thickness.

So, it directly varies with the aquifer thickness and which enables the rule of thumb relationship where you can see the

$$S = 3 * 10^{-6} b$$

where b is nothing but it is the saturated aquifer thickness in meter to be applied for estimating purpose. In the right side you can see one diagram through which we can also understand it that this is the case of two different aquifers here impermeable materials are lying.

So, here in this case you can see the stratum has gone down earlier it was here then the level has changed decline in the level for the piezometric surface. Earlier the piezometric surface was displaced but after that it decreased to this place. So, this is unconfined stratum, so in this case what is happening this is in the case of your impermeable stratum is lying down. But here in this you can see the water table this is the case of the piezometric surface in the case of the confined aquifer.

This is confined aquifer and this is the case of the unconfined because here we are getting the water table. Here also we are getting the decline of water table, earlier water table was at this side then it has declined at this place. So, this is defining the storage coefficient of a confined and unconfined aquifer. So, storage coefficient of confined and unconfined aquifer we are very much clear from this.

Because this is the your just the fall of the potentiometric surface which was earlier here. this piezometric surface is nothing but this is the your level of the water in the confined aquifer whereas here in the water table we are seeing here so, here decline of water table is it is the case of the unconfined aquifer where just we can see the fluctuation it was at this point earlier which has fallen down to this point.

So, unit decline of water table we are seeing in the unit cross sectional area of the volume of the aquifer. Now $S = 3 * 10^{-6} b$ this is the general equation through which we are getting the storativity.

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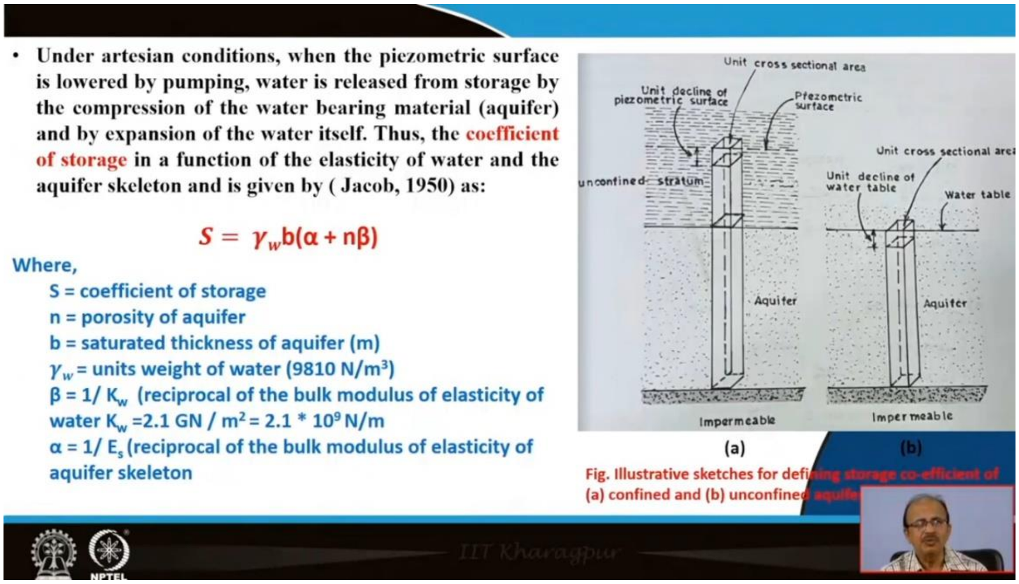

Now under artesian conditions, we have read that when you will fracture the confined aquifer all on a sudden because of the hydrostatic pressure all on the southern the water will move up to the level of the ground surface which we are generally termed as the artesian conditions. So, in this condition when the piezometric surface is lowered by pumping because pumping is containing one withdrawal of water is continuing.

So, water is released from the storage whatever storage of water over there it will release from the storage by compression of the water bearing material. And that material is nothing but that is aquifer and by expansion of the water itself, so by this compression and expansion the coefficient of storage is determined which is a function of the elasticity of water and the aquifer skeleton in general.

This equation was given by Jacob in 1950 where you can see

$$S = \gamma_w b\ (\alpha + n\beta)$$

S = coefficient of storage

n = porosity of aquifer

b = saturated thickness of aquifer (m)

γ_w = units weight of water (9810 N/m^3)

β = 1/ K_w (reciprocal of the bulk modulus of elasticity of water K_w =2.1 GN / m^2 = 2.1 * 10^9 N/m

α = 1/ E_s (reciprocal of the bulk modulus of elasticity of aquifer skeleto.

So, this we are seeing that alpha beta value is also very important because one is showing the bulk modulus elasticity of water whereas other is showing the bulk modulus of elasticity of square aquifer skeleton.

So, in this way the different storage coefficient of different types of the soil structure can also be find out what is the storage coefficient of the particular type of soil.

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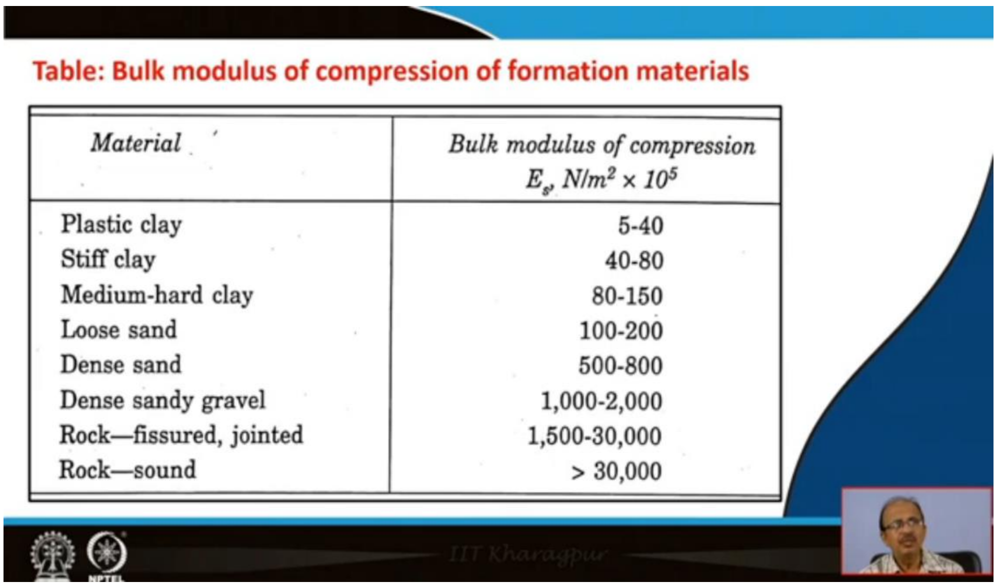
Table: Bulk modulus of compression of formation materials

Material	*Bulk modulus of compression* E_s, $N/m^2 \times 10^5$
Plastic clay	5-40
Stiff clay	40-80
Medium-hard clay	80-150
Loose sand	100-200
Dense sand	500-800
Dense sandy gravel	1,000-2,000
Rock—fissured, jointed	1,500-30,000
Rock—sound	> 30,000

So, what we have seen that in the plastic clay type of material the generally the bulk modulus is 5 to 40 it ranges from 5 to 40 whereas stiff clay it ranges from 40 to 80. Similarly, in medium hard clay, loose sand clay, dense sand, the bulk modulus of compression is generally varying from 80 to 150 100 to 200 and 500 to 800 respectively. In the case of dense sandy gravel, you can see 1000 to 2000 rock features are jointed, so this definitely these are the hard rocks.

So, you can see 1500 to 30,000 and the rock greater than 30,000 is even the perfect rock which is very compact in nature, then it is having the bulk modulus of compression is very greater than 30,000 in this. So, in this way what we are seeing that the bulk modulus of because at one place it was in the equation you have seen given bulk modulus of your water and other work modulus of your aquifer skeleton.

So, now with the earlier formula what we have discussed just the slide came just now you can see from here also

$$S = \gamma_w b\,(\alpha + n\beta)$$

. So, here we have seen that the beta is nothing but this is the bulk modulus of elasticity of water and alpha is the bulk modular reciprocal of the world modulus of the elasticity of aquifer skeleton. So, this we have discussed in greater detail.

Now based on these the different formation materials the modulus of compression is mentioned here.

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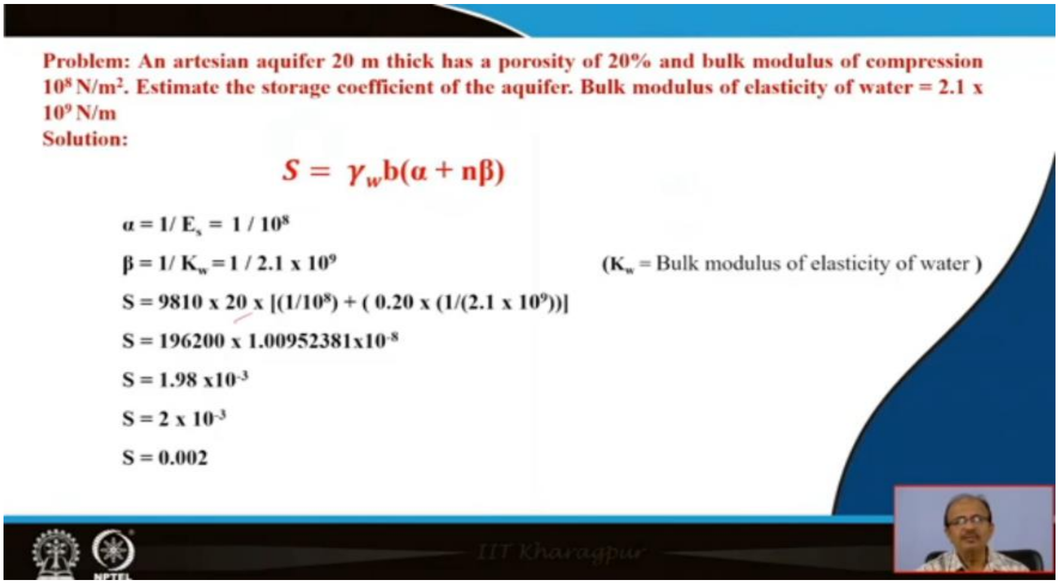

And now on this basis on this formula the simple numerical can be solved, just for example

An artesian aquifer 20 m thick has a porosity of 20% and bulk modulus of compression 10^8 N/m^2. Estimate the storage coefficient of the aquifer. Bulk modulus of elasticity of water = 2.1 x 10^9 N/m

Solution:

$$S = \gamma w \mathrm{b}(\alpha + n\beta)$$

$\alpha = 1/E_s = 1/10^8$

$\beta = 1/K_w = 1/2.1 \times 10^9$ (K_w = Bulk modulus of elasticity of water)

S = 9810 x 20 x [(1/10^8) + (0.20 x (1/(2.1 x 10^9))]

S = 196200 x 1.00952381x10^{-8}

$S = 1.98 \times 10^{-3}$

$S = 2 \times 10^{-3}$

$S = 0.002$

So, in this way the storage coefficient of artesian aquifer can be we can find it by just putting the concept as well as the value we mentioned in the problem.

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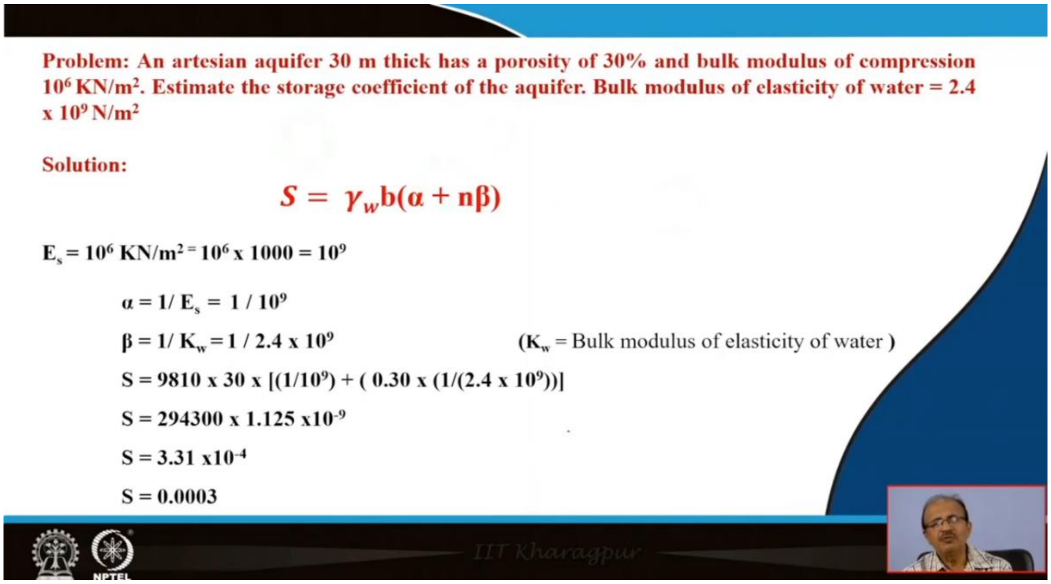

Second numerical is also based on this type of it is also An artesian aquifer 30 m thick has a porosity of 30% and bulk modulus of compression 10^6 KN/m^2. Estimate the storage coefficient of the aquifer. Bulk modulus of elasticity of water = 2.4 x 10^9 N/m^2

So, in this what we are seeing that storage we will just put the value in the formula because we have seen in the case of gamma w.

Solution:

$$S = \gamma w b(\alpha + n\beta)$$

$E_s = 10^6$ KN/m^2 = $10^6 \times 1000 = 10^9$

$\alpha = 1/E_s = 1/10^9$

$\beta = 1/K_w = 1/2.4 \times 10^9$ (K_w = Bulk modulus of elasticity of water)

$S = 9810 \times 30 \times [(1/10^9) + (0.30 \times (1/(2.4 \times 10^9))]$

$S = 294300 \times 1.125 \times 10^{-9}$

$S = 3.31 \times 10^{-4}$

$S = 0.0003$

So, this is very important how to find out when the porosity and thickness then the bulk modulus all parameters are given how to find out your storage coefficient parameter within an aquifer.

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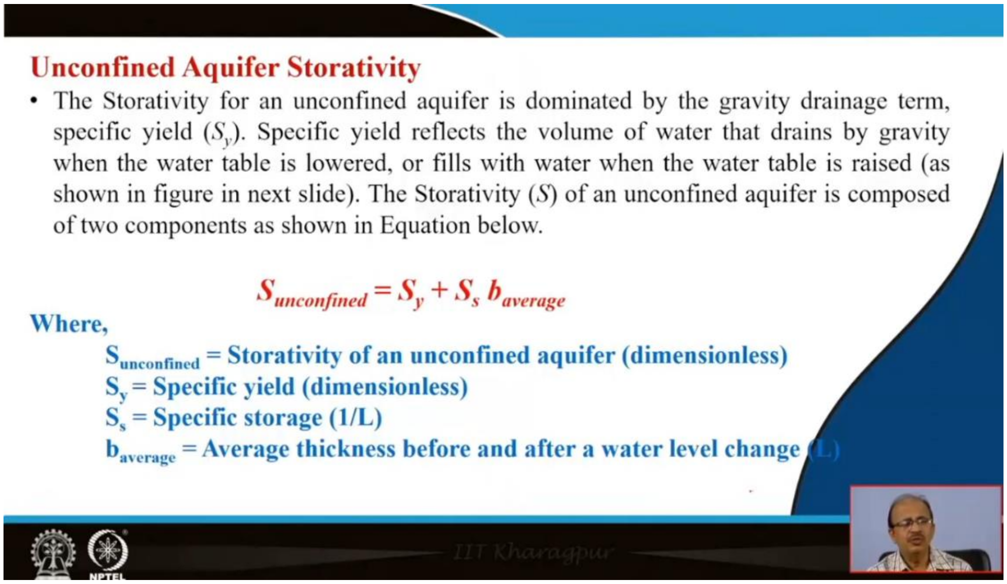

Now just a further detail we can discuss that in unconfined aquifer storativity and it is dominated by the gravity drainage term, specific yield because specific yield reflects the volume of water that drains by gravity when the water table is lowered. When the water table is lowered the volume of water that drains by gravity is reflected by specific yield or faced with water when the water table is raised.

So, this diagram this has been shown in the just the equation has been shown the storativity S of an unconfined aquifer is composed of two component as shown in equation. Below we can see

$$S_{unconfined} = S_y + S_s\, b_{average}$$

Where,

Ss is the specific storage per litre and b average is the average thickness before and after water level change take place that is the capital L. So, this is for the equation for finding the unconfined aquifer storativity.

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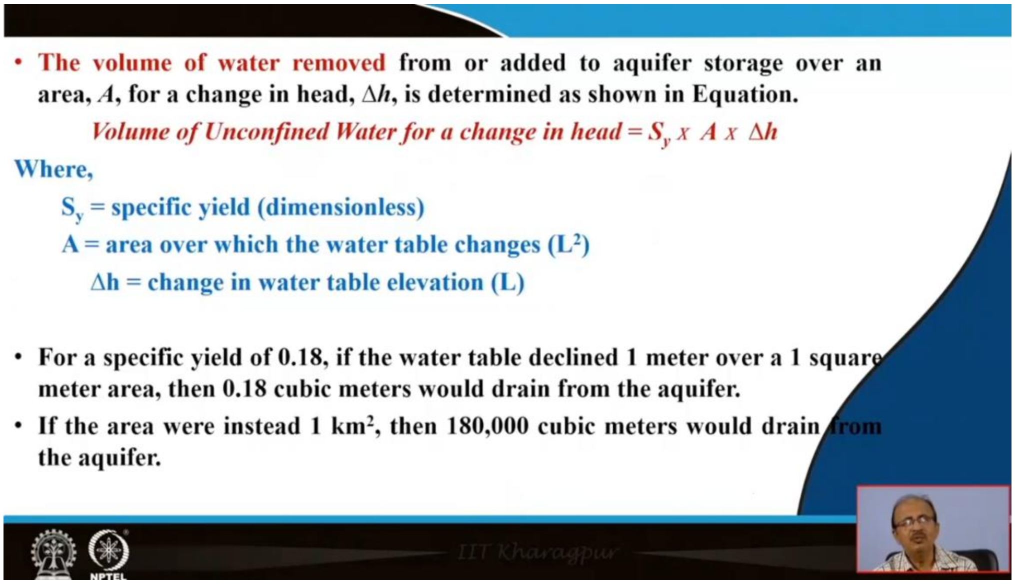

Now in this you can see that the volume of water removed from or added to the aquifer storage over an area A for a change in head delta h is determined by equation

Volume of Unconfined Water for a change in head = $S_y * A * \Delta h$

Where,

S_y = specific yield (dimensionless)

A = area over which the water table changes (L^2)

Δh = change in water table elevation (L)

Your declination of water table is also 1 meter then 0.18 m^3 would drain from the aquifer. So, this much water is being drained by aquifer if the water table is declining by 1 meter and over as 1 km^2 area. Whereas if the area where instead of 1 km^2 then 180,000 m^3 would drain from the aquifer. So, this is just the solution of the different conditions for finding out the specific yield.

Because this specific yield will be multiplied by the area and the change in the water table elevation. Then only we can know about the volume of water removed from or added to aquifer storage over an area.

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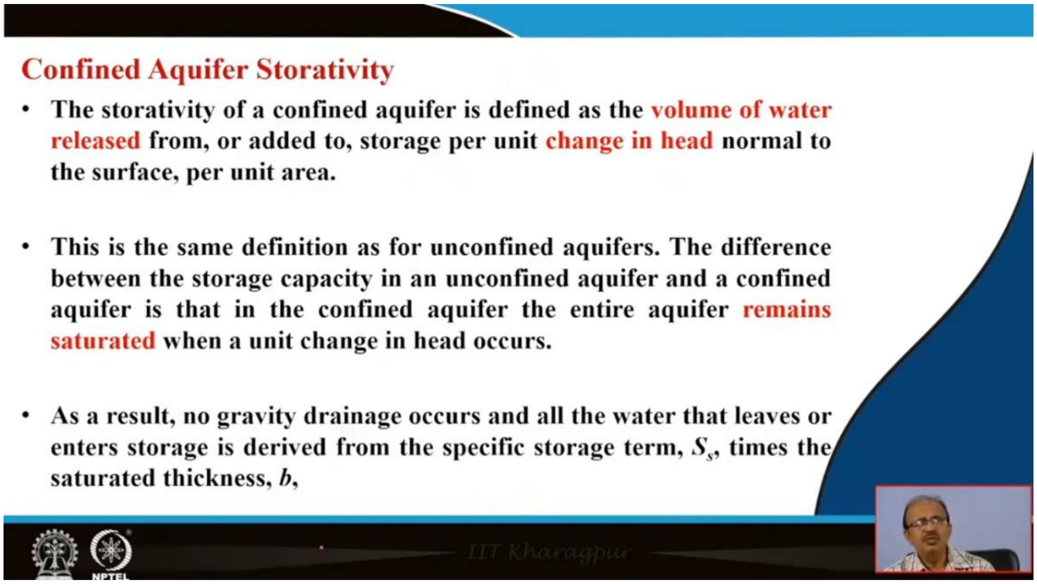

Now that earlier it was for unconfined, now for confined aquifer the storativity of the confined aquifer is defined as the volume of water released from or added to storage per unit change in head normal to the surface per unit area. So, this is important in this case the per unit change in head normal to the surface area the surface per unit area is important. This is the same definition as for unconfined aquifer that but the difference is there.

What is the difference? The difference between the storage capacity in an aquifer and we can say in an unconfined aquifer and a confined aquifer is that in the confined aquifer the entire aquifer remains saturated. In case of confined aquifer, we can see that the entire aquifer remains saturated when a change in head occurs if there will be change in head then entire aquifer will remain saturated.

As a result, what is happening no gravity drainage occurs why because the formation is saturated. So, once the formation will remain saturated then there will be no gravity drainage and all the water that leaves our winter storage is derived from thus by the multiplication of specific storage and that is S s with the saturated thickness. So, this is the case of the confined aquifer stativity whenever storativity of confined aquifer is being determined.

It is nothing but it is the volume of water released from or added to the aquifer confined aquifer, storage which is storage unit change in head normal to the surface per unit area is will be there the condition is this much. So, this is the same just like an unconfined aquifer only difference is that the storage capacity in unconfined aquifer and confined aquifer is that in the confining for the entire aquifer remains saturated. So, this is the basic difference between these two.

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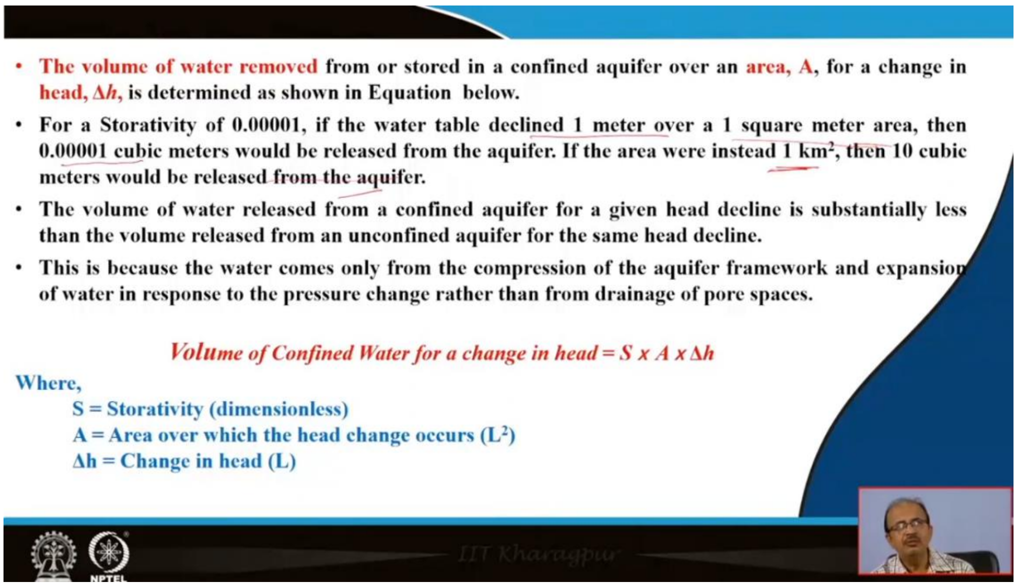

Now next we can see that the volume of water removed from or stored in confined aquifer over an area A and for a change in head delta h is determined as a so equation shown just below volume of your confined aquifer water for a change in head is shown by $S*A*\Delta h$. So, for storativity of 0.00001 if the water table is declined 1 meter over a 1 m^2 area, then 0.00001 cubic meters would be released from the aquifer.

So, this is the general condition for storativity if the water table declined by 1 meter over a 1 square meter area. Then the volume of water released from an aquifer will be 0.00001 m^3. But if the area where instead of 1 m^2 this is the area of 1 m^2 this is the area of 1 km^2, then what will happen then 10 m^3 would be released from the aquifer. So, this we can find out by the just multiplying the different units of an equation.

The volume of water released from a confined aquifer for a given head decline is substantially less than the volume released from an unconfined aquifer for the same head decline. So, this is the condition for the volume of water release from a confined aquifer. Now this is because the water comes only from the compression of the aquifer framework and expansion of water in response to the pressure change rather than the form drainage of pore spaces.

So, now the question is how it is occurring? This is occurring because the water comes only from the compression of the aquifer framework or that aquifer skeleton an expansion of water in what the water amount is there expansion of water in response to the why because in response to the pressure change rather than from drainage of pore spaces. So, we can write it the

Volume of Confined Water for a change in head = $S * A * \Delta h$

Where,

S = Storativity (dimensionless)

A = Area over which the head change occurs (L^2)

Δh = Change in head (L)

So, in this way what we have seen that porosity, permeability and storage coefficient or storativity all are having a very important rule for making a rock formation a very good aquifer. These all parameters are should be in a proper amount in the balanced amount then only any aquifer can hold proper amount of water say ground water underneath the earth surface.

So, this is about the porosity, permeability, storage coefficient, in different lectures I have tried to discuss these important parameters of an aquifer.

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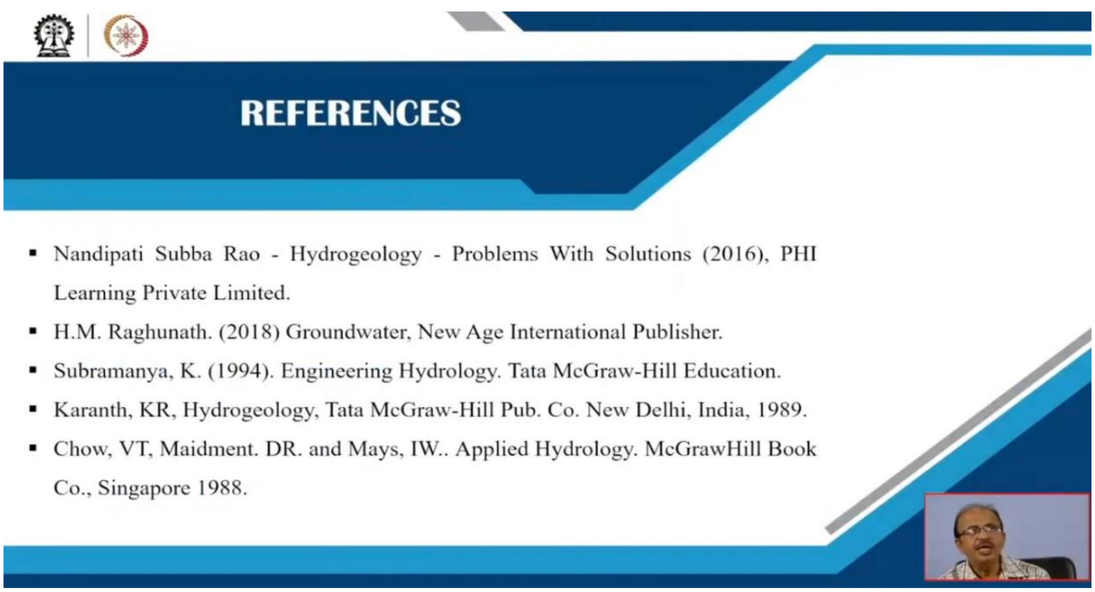

References I have taken references from this few test books which are very important you can also go through it and you can see here.

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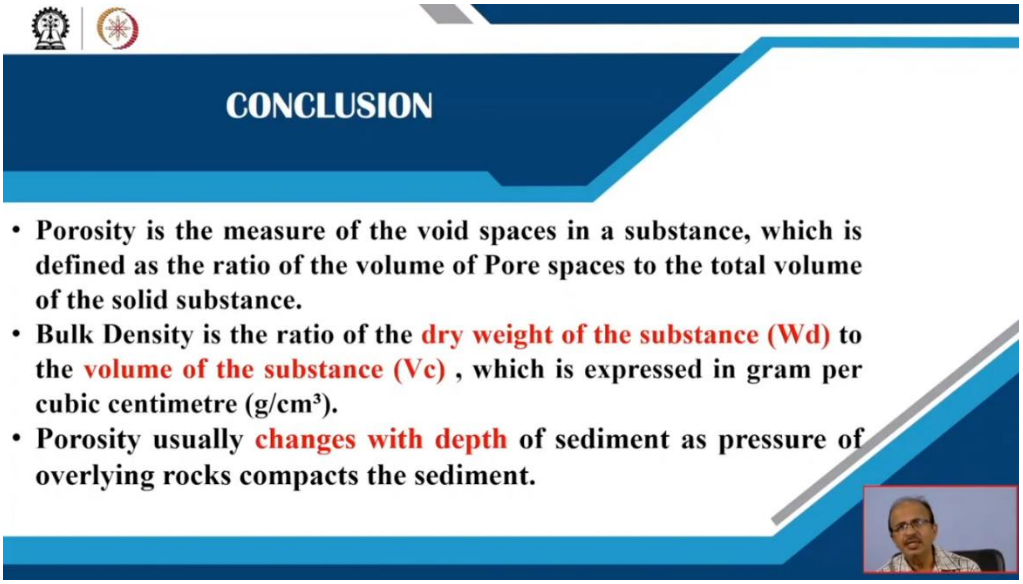

So, now the conclusion of this chapter overall chapter is that, the chapter name is the porosity, permeability, storativity or storage coefficient, transmissivity this is the few terms have come in this lecture. So, porosity is the measure of void spaces in any substance which is defined as the ratio of volume pore spaces to the total volume of solid substance. So, whatever substance is there if we wish to find out the porosity, we have to just measure the void spaces within it by different mechanism.

And because we know that it is nothing just the ratio of the volume of pore spaces to the total volume of the substance. Now bulk density is the ratio of the dry weight of the substance to the volume of substance which is expressed in general by gram per cubic centimetre cube. So, this bulk density is also very important in case of this porosity, permeability etcetera. Now porosity usually changes with depth of the sediment as pressure of the overlying rocks compress the sediment.

This is very important because you can see the porosity in the grazing land of barren land are generally remaining lesser why because of the compactness because of the movement of the animals on the land. So, the just the sediment are remaining in pressure from the overlying rocks, the overlying activities and the volume decreases. So, generally, the porosity generally changes with depth of the sediment depth.

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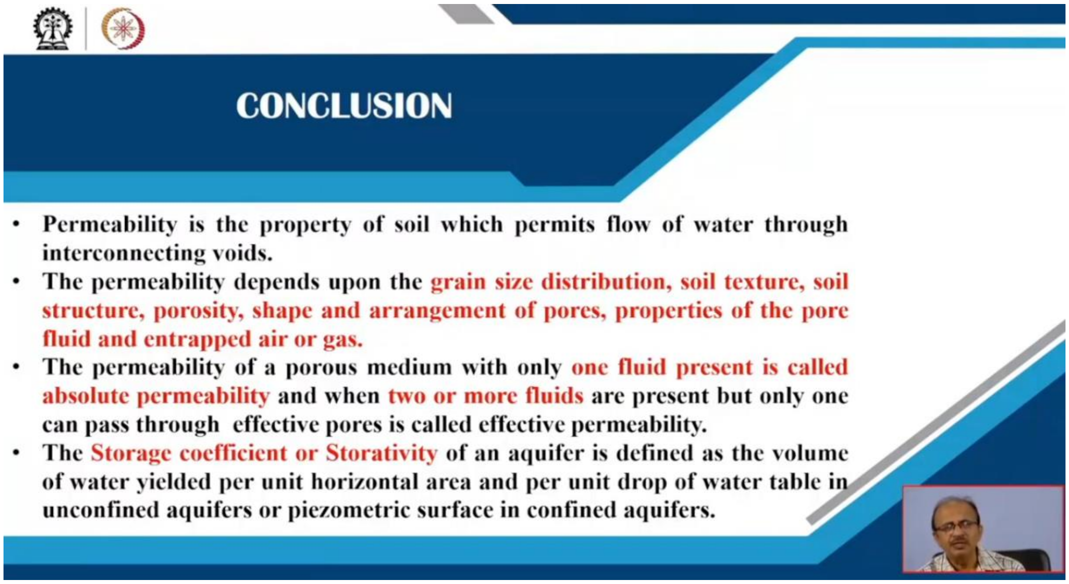

Now permeability is the ability property of the soil or ability of a formation rock formation which permits flow of water through interconnecting voids. So, if the voids will have interconnection among each other then definitely the water through the porosity characteristics the water will remain in the rock formation. And since the voids are interconnected so the movement will be also there, so this movement is called as permeability.

This permeability depends upon the grain size distribution we have seen and the different factors also the soil texture, the soil structure, the porosity, shape and arrangement of pores, properties of the pore fluid and entrapped air gas. So, these whole factors play a very important role for permeability. Now permeability of a porous medium with only one fluid present is called absolute permeability whereas the when two or more fluids will remain this is called an effective porosity.

So, the difference between absolute and effective also we have come across that only when one fluid condition will be there then absolute permeability when two or more fluid condition will be there it is your effective permeability. Now the storage coefficient or storativity of an aquifer is generally defined as the volume of water inlet per unit horizontal area and per unit drop of water table in unconfined aquifers or piezometric surface in the case of confined aquifers.

So, this is all about the porosity, permeability, transmissivity and storativity characteristics of an aquifer. We will know some further details about the aquifers because our target is to find out the availability of groundwater resources within the surface. So, with this thank you very much to all.