Advanced Hydrology

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Lecture – 37

Good morning and welcome to this post graduate video course on Advanced Hydrology. We are into the last leg of this course in fact, and we are into the ground water hydrology a module. We started with ground water hydrology in the last lecture, in which we initially define the various components of the ground water hydrology under the ground right. As we said that as a rainfall, how the water infiltrate into the ground, then there are different zones of saturation, we have unsaturated zone, we have the capillary zone we have the saturated zone.

Then we said how the important of this ground water we look that you know, how we can model what is the necessity an important of understanding the moment of ground water. Then we moved on and we looked at different types of water bearing formation, which are called aquifers, aquiclude and so on. There are different types of aquifers or ground no water bearing formations we look that, then we moved on we said that we look at what is called the aquifer properties, there are different types of properties of aquifers in terms of file property, which are important to understand. So, we look that some of those aquifer property, and then will solve an example numerical example based upon certain sample and the data, and then we calculated many of those aquifer property.

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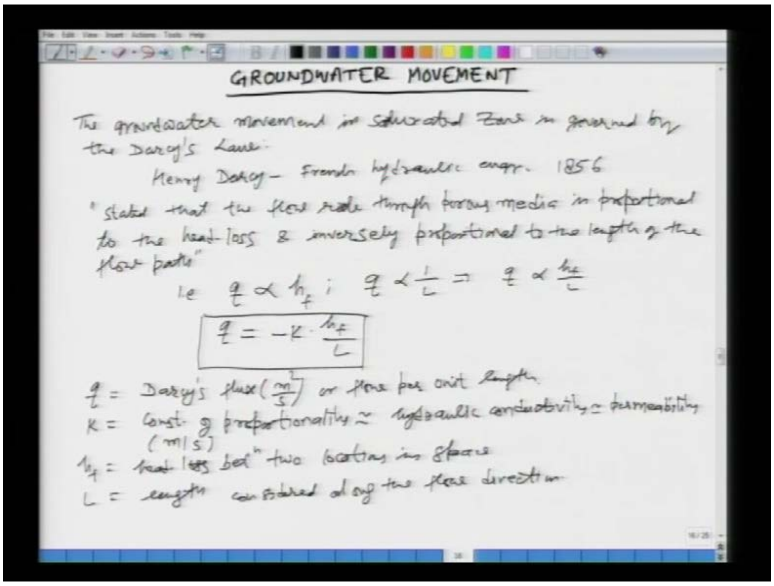

Today, we will like to start a new topic in the ground water hydrology, and we will move towards what is called the ground water movement, ground water movement. When we talk of ground water movement what comes to your mind I am sure you may have seen in your undergraduate classes some lay little basics concepts about the ground water hydrology. So, when ever we talk of a movement in the ground water saturated is known that is we talk of basic law, which governs the movement of water in the ground or in the saturated zone, which is called Darcy's law.

So, what we will do is we will start with the Darcy’s law and then we will move towards the derivation and application of the complicated equation. The ground water movement in the saturated zone and we will focus our attention in this module mainly on the saturated zone, will say is governed by the Darcy’s law. Let us look or explode the origin of this Darcy’s law, Henry Darcy was assentially or mainly a hydraulic engineer and he was from France.

So, he was we can say a French hydraulic engineer, what he did was he conducted a few experiments in different types of soils in the field and in the lab in in France way back in the 19th century. And what he observed was he made certain observation as per as the movement of water through the soil or the porous media is concern. So, what we will do is he would take different types of soil of different shapes and sizes different samples of various you know shapes and then measure the moment of water how the water is infiltrating how much water is going in what time and so on.

So, after having measured or study the movement of water in the porous media, he made certain observation and the he published a document a small paper in which he stated something very interesting and later on that became what is a what we know today is the Darcy's law. So, I am going to give you that what he publish in nineteen sorry 1856 he stated that the flow rate the flow rate through the porous media is proportional to is proportional to the head loss and inversely proportional to and inversely proportional to the length of the flow path.

So, he kept these sampler at different you know slops and of different lengths and then he made this these two observation. That is to say if q is your flow rate what he observed is or what he said is that this is directly proportional to head laws let say this is h f. And the other one he said is this q is directly proportional to the inverse or inversely proportional to the length of the flow path. So, if you combine these two you can say that q is directly proportional to your h f over L.

And then we can take a constant of proportionality and we take a negative sign in front due to the rotational you know limitation. So, this becomes q is equal to minus k h f by L this as we all know is a very famous law which is called the Darcy's law. So, in this equation you have q has what is known as the Darcy's flux and it is units are L square by t or meter square per second in the SI units it is also called the flow per unit length.

Of your aquifer or the porous medium per unit length alright perpendicular to the paper or the board whatever we want to consider. K is what is called the constant of proportionality in this particular law constant of proportionality and then later on it was define what is called the hydraulic conductivity. And is it is also known in certain books as permeability and as you all know what are the unit of this well k is L by t or let say meter per second. H f is the head laws between the two location in space between which we are trying to measure the flow. And L of course, is your length consider along length consider along the flow direction.

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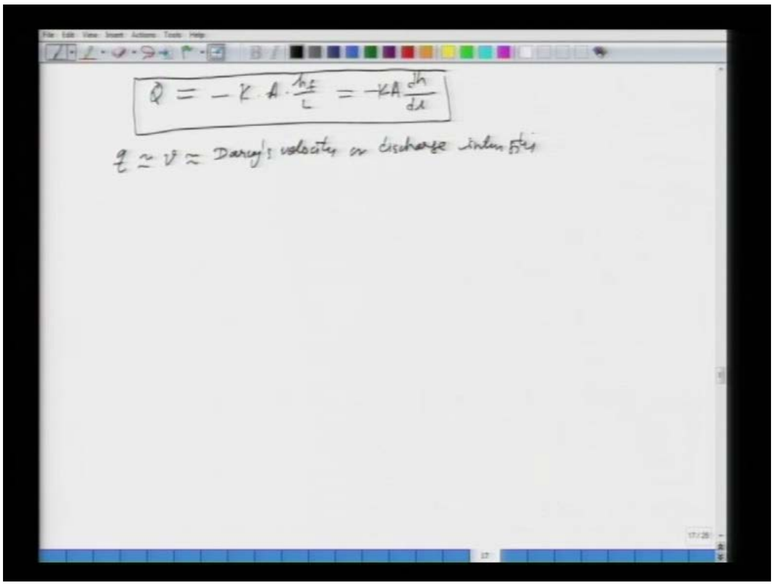

What is called the cross sectional area then we can have capital Q which will be actually minus k times A times your h f by l. See I multiply the earlier equation by the cross sectional area and that we are seeing is capital Q and h f by l is nothing but, we can represent this us d h over d l or the slop of the your hydraulic grade line. So, this is also another form of your Darcy's law, small q is sometimes refer to us v, because it has units of meter per seconds.

So, we say that this is Darcy's velocity, see if I go back you have seen that q is known as the Darcy's flux which is meter square per second. And flow per unit length it also expressed as the Darcy's velocity or the discharge intensity intensity.

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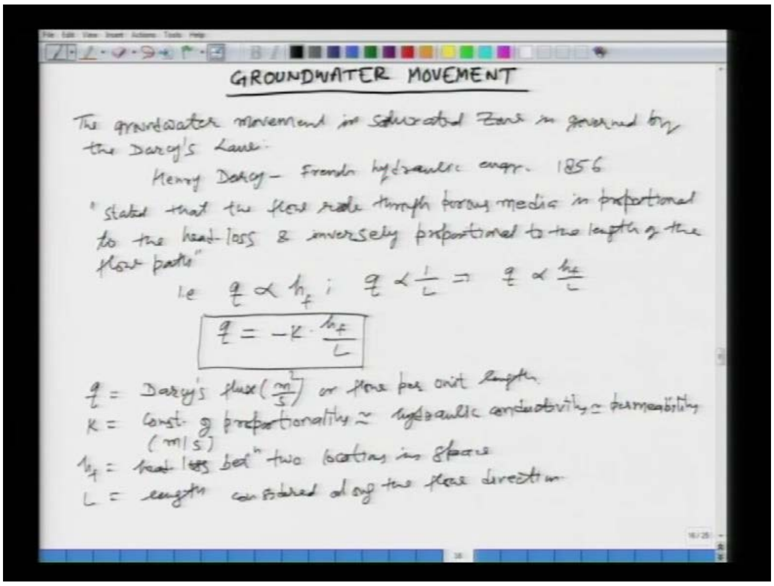

And in fact I should clarify that when I say that this units are meter square per seconds Darcy’s flux, I am taking a certain width that width actually I am taking is unity. So, we should not be confused about the units of q and v they are the same in fact, because I am taking a unit width there.

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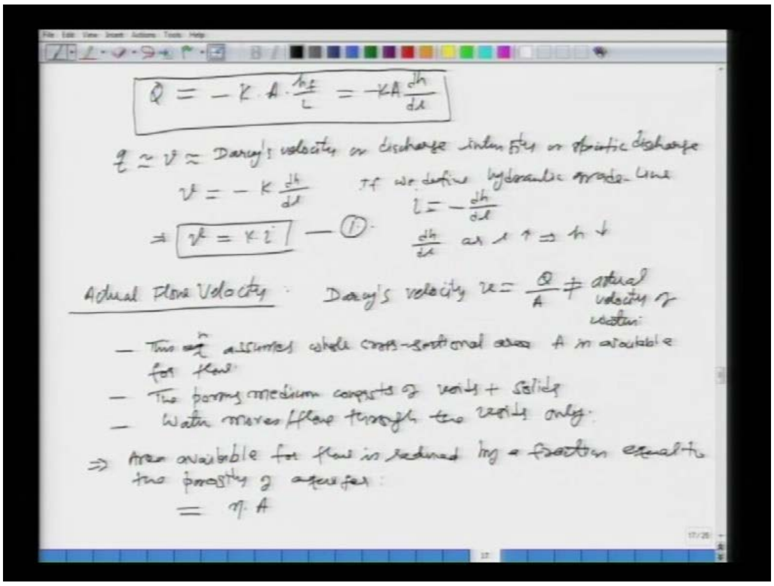

And this charge intensity or specific discharge. So, there are various terms to this q different book followed different rotation but, there are one in the same thing. So, if you represent this in that form, so this will become minus k t h over d l and if you define your hydraulic grade line as i which is negative of d h over d l that would mean that your Darcy's velocity is k times i. So, many of the book use this form of the Darcy's law I am going to number this equation as 1.

So, as you see that the Darcy's law it is basically a this couple of observation which Henry Darcy's made in 1856 or what ever. And it can be expressed in many different form all right and the most prevalent is provably are this v is equal to k i, which you may have seen in your earlier classes. Here i is as I define what is called the hydraulic grade line and there is a negative in front, why because its a positive thing. So, basically when you look at d h over d l d h over d l you put negative here in front.

Why because as you l increases or the length of your flow path increases means what your h actually goes down or the head that is available or the head lost will be decreasing. So, because of that we put a negative signs, so that your I will become positive. Now we look at a concept what is called the actual flow velocity, in the Darcy's law we have seen that q is equal to k a and d h over d l or this q is your flux per unit cross sectional area.

So, if you are looking at a porous medium in which there voids and in which there are soil solids also. So, if you look at the volumetric flow ray which is passing through that particular soil material, then in that Darcy's flux we are taking the whole of the cross sectional area.

However where is the water moving in the ground water or or in the aquifer or in the porous medium. Water is moving only through the conduits which are formed of the voids or the pore spaces and the cross sectional area for the water to move is available will be less that the total cross sectional area, which is use in the Darcy's velocity. So, the actual velocity of movement of water will be different. So, let us look at that what we mean by that.

So, we have seen that the Darcy's velocity v can be taken as q by a as per the equation we have seen above but, this is not the actual velocity this is important to understand; actual velocity of water. Why it is important to understand is because let us say you are conducting some tracer task or you want to know if there is a contamination in the ground water at a particular location. You want know how long it will take to travel let say a few kilometers or few hundred kilometer down seem.

So, if you the Darcy's velocity your results will not be correct because the actual velocity of the water which is through the pores will be different than the Darcy's velocity. What will that be well I will come to the let me first say that this equation, which we have seen assumes the whole cross sectional area a, is available for flow that is in the Darcy's flux or the Darcy's velocity. However the porous medium or the aquifer consists of what voids plus the solids as I said.

And the water moves or flows through the voids only presented. So, how can I take or how can I quantify, the cross sectional area which is available for flow I can obviously, use some parameter or some aquifer property which quantify the voids the amount of voids. And we have seen that yesterday it is nothing but, the porosity. So, what you do is, then you say that the area available for flow is reduced by a fraction equal to or equivalent to the porosity of the material or the porous medium.

So, the area available than will be equal to what it will be eta times of your A. So, if you are looking at cross section of a soil sample or an aquifer in a volume, then the whole of the are is not available but, only the voids are available the total area is A how much is available to water to move eta times A where eta is your porosity. So, then let me move to the next page.

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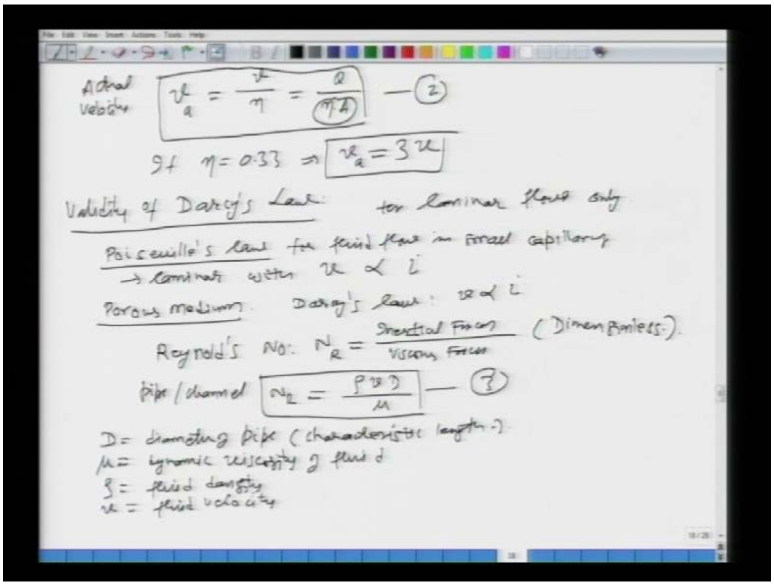

And say that the actual velocity v a let me write it here actual velocity will be equal to what will be equal to your Darcy's velocity divided by eta or we say that this will be Q over eta times A. Because eta times A is the area available for movement. So, this Q by A is v, so this is you say with your equation number 2. So, you see that the actual velocity will be much higher than the Darcy's velocity, because eta is always less than 1.

So, if for example, let say your eta is 0.33 or 33 present what will be the actual velocity actual velocity will be three times of the Darcy's velocity you see that, so you divide by 0.33. So, the actual velocity of flow in the ground water or in the aquifer will be much higher than the Darcy's flux which we calculate and we need the porosity to to make calculation as for as the what will be the time taken you know by a contaminant or a tracer or a some thing to travel through the ground water.

So, this is as for as the basics of the Darcy's law is concern now hat we will do is any law or an module which we you know study in any of the course has a certain limitation. And Darcy's law has some certain limitation or it is not applicable under all the condition what we are going to do next is we will look at the criteria under which is applicable or look at the validity of the Darcy's law validity of the Darcy's law. As we know that Darcy's law is valid for laminar flow only and things become you know or the velocity is become very high it will not be applicable.

So, it is applicable for the laminar regime or the laminar flow only when we talk of the flow of or the laminar flow through small conduits there is a from our knowledge of fluid mechanic will say there is a Poiseuille's law which is applicable. So, we can draw a simile or a similarity of the Poiseuille's law under which, that is applicable similar condition that is applicable for the Darcy's law.

So, we say that Poiseuille's law is valid or the fluid flow basically any kind of fluid in our case we are dealing with water. Where it is applicable very small, tiny capillary is laminar with velocity is directly proportional to i in the Poiseuille's law, in the porous media we have a similar thing right or in the ground water also we have the Darcy's law which is in which you can say or we are just seeing with this directly proportional to i. So, whatever are the conditions then we can use them and the conditions for applicability, is in terms or a non dimensional number, which is called the Reynolds's number.

I think all of you know whenever we talk about laminar flow and turbulent flow there is a transition or there is a limit to the non dimensional number called the Reynolds's number. Reynolds's number is less than the particular value then we say that the flow is laminar it will be moving very nicely in layers. Once the velocity is exceed the certain amount such that the Reynolds's number is excited by that particular limit then you have the turbulent flow.

So, as per at the Darcy's law or the moment of water in the ground moment or the saturation zone is concern, we will say that the Reynolds's number will be less than or equal to 1, that is the criteria people have established. So, what is the Reynolds's number first of all it is the ratio of two different types of forces, what are those two forces and how the Reynolds's number is define it is the ratio of the inertial forces to the viscous force.

So, N R is equal to inertial forces acting on your in a system divided by the viscous force system and it is a dimension less number. For pipe and channel flow we have seen from our knowledge of fluid mechanics and open channel flow the Reynolds's number is equal to what will not look at the derivation it will be row V D over mu let me say that this is equation number 3. Usually we know this where what is D? D is what is called the diameter of the pipe incase of pipe flow right or what we can say is the characteristic length, characteristic length all right in a particular phenomena. In the channel or in a conduit all right, mu is what is called the dynamic viscosity of the fluid right, row of course, is the fluid density and v is of course, your fluid velocity. So, we can adopt this equation in the ground water flow.

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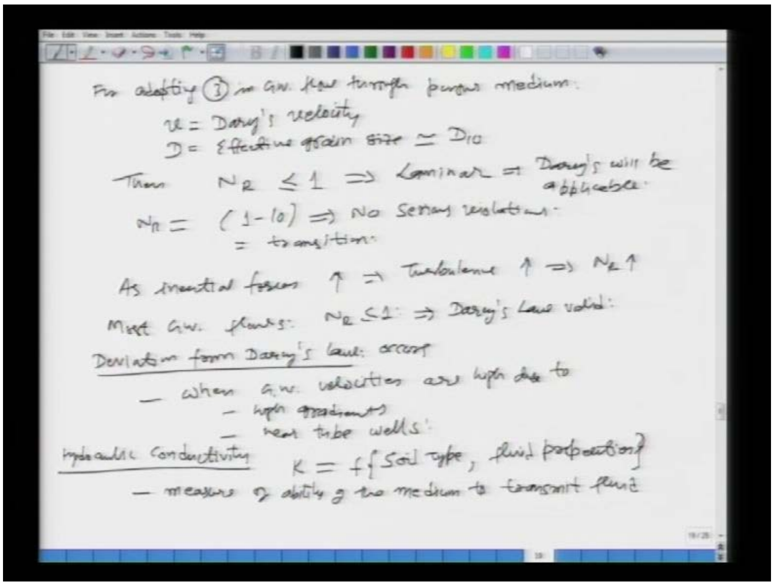

So, if we adopted we need to make slide adjustment. So, for adopting this equation 3 in the ground water flow through the porous medium we say that your we is what in the ground water flow we say that it is Darcy's velocity or the Darcy's flux. What about D, D is some kind of characteristic length and then we say that this is your effective grain size of your solid particles. So, capital D is taken as what it is some kind of characteristic length in the pipe flow it was the diameter through which the water is flowing.

So, here also we have the voids through which the the water is moving inside the you know underground. So, what we take is that the voids will be or the size of that voids will be function of the size of the grains of the soil type or the soil which is exciting. So, this D is taken as the effective grain size of the soil particles, which is normally taken as D 10 then if we use these you know parameter then if your N R is less than equal to 1 under these conditions we say the flow will be laminar. That means, the Darcy's law will be applicable when your Reynolds's number is less than 1. However when we have the Reynolds's number in the range of lets say 1 to 10 we say that there is no serious violation and in fact, this is what what is called transition. So, we can apply the Darcy's law for understanding or studying the moment of water in the aquifer as long as the Reynolds's number is in the vicinity of 1. Less than 1 is perfect even it is exceeds 1 you know may be up to 10 it is in the transition but, beyond Reynolds's number you know becomes more than 10. Then we cannot apply the Darcy's law, because the things start to move a very quickly and the turbulence you know forces or the initial forces start to dominate to much.

So, we note that as the inertial forces increase right then what happens basically the turbulence increase that is what we just said. That means, your N R increases after all what is the Reynolds's number it is the ratio of the your inertial forces and the viscous forces if it is less than one means the inertial forces are less than the viscous forces right. So, viscous forces are dominating but, when the inertial forces start to dominate that is Reynolds's number increasing, the turbulence also increases, the velocity will become high that is when we cannot apply the Darcy's law.

Now, in the most ground water flows most practical applications we have the situation which is this means Darcy's law is valid, in most cases. However, when is the Darcy's law are not valid there, there may be few you know situation in the ground water moment in the aquifer where it is not valid, can you think of some. Well whenever the hydraulic gradients are very steep, the hydraulic grade line or the water surface the ground water table is very steeply sloping.

Then the velocities will be very high in the initial forces will be dominating the velocities will be high and turbulence will be there. So, that is when you cannot use that is number 1 and when can that happen can you think of any other situation let say your pumping water out from a well. So, if your very far away from the well in the aquifer the the hydraulic grade line will not be steep they will be very mile but, as you approach towards the well you know that there is tech corn of depression.

So, as you approach the ground water well, the hydraulic gradient will become very steep and the regime will no longer be laminar and you cannot apply the Darcy's law. So, we say that, where is it not applicable or derivation from Darcy's law will occur or occurs when the ground water velocity is are high or very high due to due to what high gradients and also near the tube wells. We see that we have looked at the Darcy's law its limitation, where it can be applied, where it cannot be applied.

In this Darcy's law there is one parameter which depends upon you know the soil type and other things, which is called the hydraulic conductivity. So, what we need to know in advanced before we actually can apply the Darcy's law is this hydraulic conductivity. So, what we will do next is will look at this soil property hydraulic conductivity little bit more closely. So, we say hydraulic conductivity.

This hydraulic conductivity K is actually function of what I am sure you may have seen this in your earlier classes, the hydraulic conductivity or permeability of soil or the aquifer material or the porous medium depends upon two things. What are those two things, one is the soil type itself and other is the fluid type in our case we will be talking about water only. But, for the same material or the for same soil type if there is a different you know type of fluid moving for example, you know for the oil you know movement through the aquifer the conductivity we use will be different. So, depending upon the fluid also the, a permeability will change.

So, will say that this k will be function of two things, one is the soil itself for the soil type other is the fluid property fluid itself. And we say what is hydraulic conductively a conductivity physically it is a measure of or it measure the ability of the medium to transmit the fluid. So, what is hydraulic conductivity it is a property of a material let us say which indicates as what, which indicates or quantify or gives us some idea about how easily or how difficult it is for the fluid to move through it.

Some types of soil allow lot of movement of water or so that they will be a significant heal and some others will not allow water to move at all. Like we had seen in at the in the yesterdays class that certain types of play soil are you know in highly in permeable and they will not be significantly. So, depending upon the soil type it gives you the ability to transmit the water and then it has been shown that.

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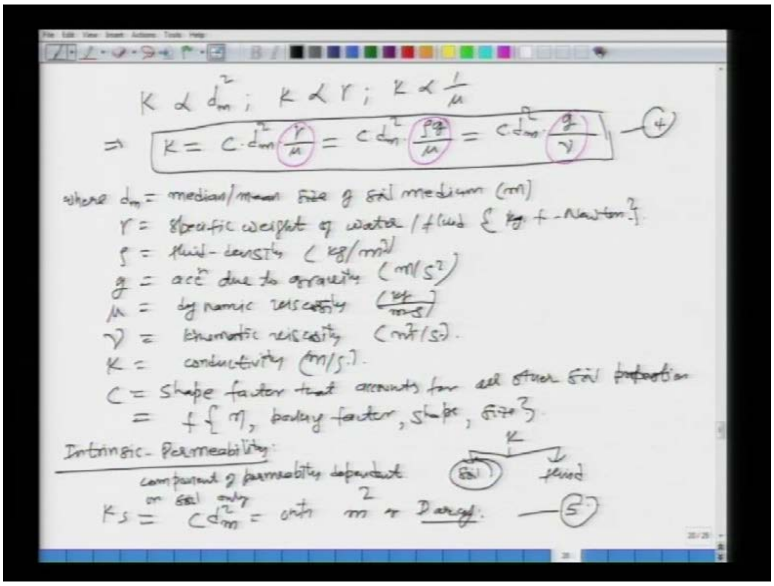

Let me go to the next page that this hydraulic conductivity K it is directly proportional to the mean diameter of the soil square and k is directly proportional to gamma, which is the pacific way and K is directly proportional to 1 by mu or inversely proportional to mu. If you combine all these things then we can say that your k is equal to some constant of proportionality C times d m square times a gamma over mu or you can say that this is your C d m squared times what is gamma specific weight as I said it is row g over mu.

This can also be expressed at C d m square of your what g over mu you take the row in the denominator that is what we will get all of these are equivalent expression. Let me define all those things where your d m is what is the median or the mean size of soil medium or the aquifer material it is units are the length units. So, we are going to say it is m, gamma is the specific weight is the specific weight of water here or you know fluid in general actually and what will be its units its basically your k g force right or Newton.

In assignments pacific weight it is the force units row is the fluid density of force and the units are s i units has k g per meter cube, g is your acceleration due to gravity. And we know and this is meter per second squared, mu is the dynamic viscosity of the fluid in k g per meter second, nu is the kinematic viscosity and it has units same as the diffusivity. Capital K of course, we are looking at the conductivity hydraulic conductivity, permeability whatever we want to call it, I am going to shot here and it is units are in meter per seconds.

And there is another coefficient we have thrown here which is called C, C takes care of all other things actually we have taken care of the fluid properties and the file properties. But some other things, which has such as the shape factor that accounts for accounts for all other soil properties. Such as compassion the shape factor of course and then how the intergranular things are arranged and so on. The soil properties and this C actually will be as is said function of what of your porosity the packing factor.

The shape of your particles they are not spherical all the time size etcetera well size is taken care of but, you know lot of other things. Related to that what we have what where going to define is what is called intrinsic permeability, you may have heard this term intrinsic permeability. What is intrinsic permeability is that, the whole permeability as we said depends upon two things, one is the soil type itself, other is the fluid. So, the soil type factors all the factors, which effects the permeability, which are which are corresponding to the soil type actually we give a name to that and it is called a intrinsic permeability.

So, if you have a K it depends upon soil and it depends upon fluid these two things right, this part is called the intrinsic permeability. So, basically we say that the component of permeability depended on soil properties only depended on soil only is called the intrinsic permeability and we say that this is K subscript as and what is this thing C times d m square.

You see everything else here in this equation, whether it is this or this or this it is all fluid property only thing that depends upon the soil is C times d m square and it is units are meter square or Darcy. So, let me number this equation actually this is 4 and let say this is 5 which is the intrinsic permeability and as I said that intrinsic permeability is the property of the soil only which has units of square meter. So, L square and it is also called a Darcy.

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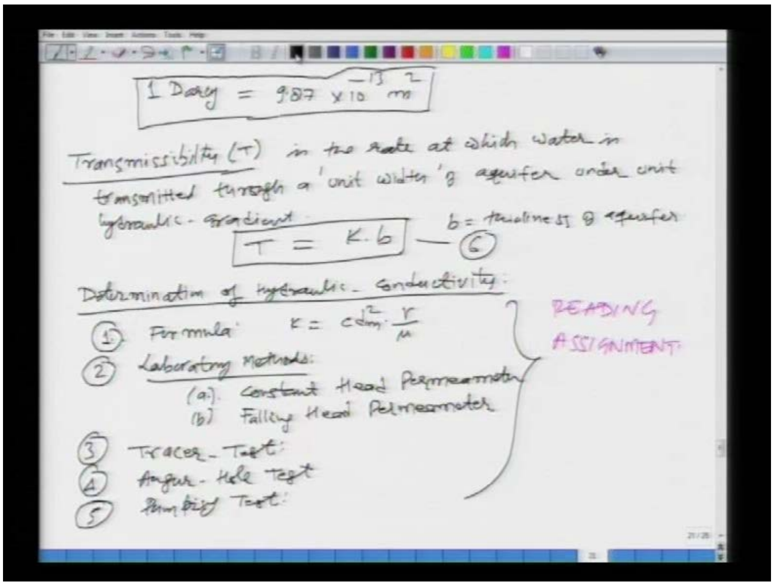

What is a Darcy, well one Darcy is equal to 9.87 times 10 to the power minus 13 square meter and this is a very small unit actually that is why its hardly used in square meter. So, we talk in terms of Darcy’s mainly. So, associated with this permeability and intrinsic permeability, we will talk about another property of the aquifer material, which is called transmissibility as I said the conductivity gives you what some idea or quantification of the ability of the medium to transmit the water. So, related to that there is another parameter called transmissibility.

In which case of course, involve this is denoted as capital T and it is defined as that it is the rate at which water is transmitted the rate at which water is transmitted through a unit width. Now, this is important the unit width of aquifer under unit hydraulic gradient under unit hydraulic gradient. So, in this is defined as T it will be equal to k times b, where b is the thickness of the aquifer thickness of the aquifer. So, you have thickness b and the width is one from that how much water can be transmitted that will depend upon mainly the k.

And this parameter we defined as transmissibility now the next thing, which we are going to just very briefly attach upon. Or mention is how do we determine this, we have seen what is this hydraulic conductivity which is a very important parameter on the Darcy’s law which we can use in most of this saturate saturated zone of the ground water. How do we determine this hydraulic conductivity there are many ways of estimation of the hydraulic conductivity we are just going to mention those there.

So, let me just do that we will not go into the details of this because it is a preliminary material and I am sure you may have covered this in your under graduate classes. Determinations of hydraulic conductivity will just list the methods, one is there various formulas and the main formula which we have just seen is equal to this C d m square times gamma over mu. So, if we can measure all these things which are actually available and the mean size of your soil material and the compacting factor or the shape factor we can find out K, number 2 is the laboratory measurement or the lab methods.

In I am just going to mention that there are two types of experiment, one can conduct in the lab. And I am sure, you may have seen this one is called the constant head permeameter, and I will not going to the details of this permeameter and b is the falling head permeameter falling head permeameter these are very simple and you can follow any book actually on ground water you can follow this. Then third one are the field test actually you know the last two a basically.

So, you have tracer test in which what we can do is you can inject the tracer at a particular location and then determine or measure the time it takes to travel a certain distant. What we do in the tracer test actually is, that you inject some kind of a tracer in in a well or injection well and there is no observation well down seen you know may be few kilometer you find out how much times it is taking.

And depending upon that you can make some calculation actual velocity Darcy’s law, which will give you the a value of the hydraulic conductivity it is one of the field task. Will not going to the details of that, the fourth one is what is called the auger hole test then finally, there lots of more pumping test.

What we do in these test basically the pumping test is we pump water out of an aquifer we measure the amount of water. How much it is we are getting out of the aquifer in what time that will give you some quantification of the transmissibility or the ability of that medium to transmit water, which is nothing but, your conductivity. So, we can convert that into hydraulic conductivity. So, these are some of the methods what I am going to say is that please go through it your style this is your reading assignment.

As I said earlier I will be taking some help from you in completing this course. So, what I will like to do next is that.

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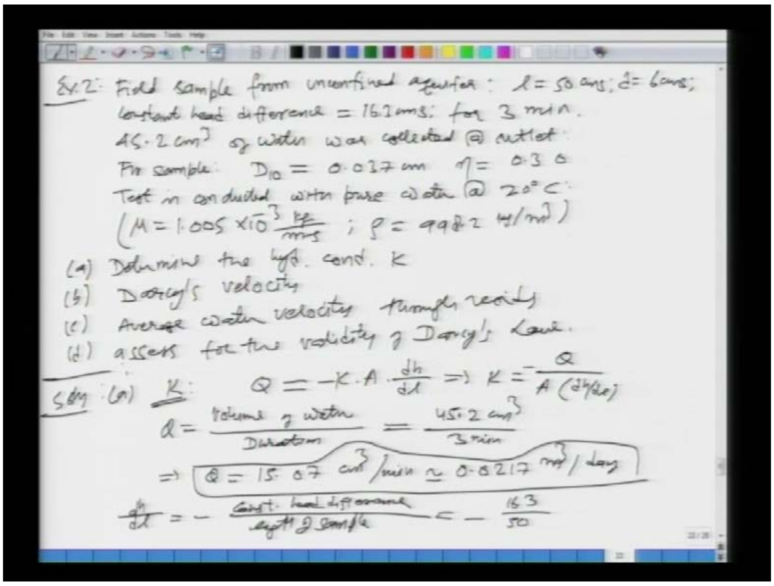

I would like to look up a take up a solid example, which will use all of these you know the Darcy’s law the hydraulic conductivity on of the permeameter and all those things. So, that we get some idea about how we can apply all these equation in solving a very simple problems of the moment of water in the ground.

So, that the next thing I will take in this chapter example two I would say let us say a field sample from un confined aquifer, will come to this later. What is a confined aquifer and un confine aquifer, we brief latest upon that earlier has these dimension. So, l is equal to 50 centimeters the diameter of the sample is 6 centimeters the constants had different. So, we where talking about constant had permeameter is 16.3 centimeter this is maintained and the water is allowed to flow. And in this case it is done for 3 minutes what happens is done 45.2 centimeter cube of water was collected at the out let.

So, you have the sampler of this dimension we may we keep a constant head difference of 16.3 and water is allowed to flow for 3 minutes and in 3 minutes this much amount of water is collected at the outlet. For sample the other data that are given to us are that the grain size d 10 which is the main is 0.037 centimeters porosity eta is 0.30 and other thing that is given is that the test is conducted, the test is conducted with pure water at 20 degree centigrade.

20 degree centigrade means what we can take the property of the water at that particular temperature the properties of water the density and viscosity will depend upon the temperature right. So, at that temperature we can just read of the value and I will give you that so; that means, your mu is 1.005, 10 minus 3 k g per meter second and density is 998 0.2 k g per meter cube that is what basically this is giving us. So, what we have to do in this problem is A determine the hydraulic conductivity k, b Darcy's velocity or the Darcy's flux right, C is the average water velocity average water velocity, what is that mean; that means, the actual velocity of water through the voids. And d assets for the validity of the Darcy's law. So, these are things we have to do a, b, c, d. So, let as quickly look at the solution the data that are given to us. So, first we will look at determining the hydraulic conductivity K.

How can we do that well we use Darcy's law what is Darcy's law it is minus k a d h over d l, we just saw that that is what the constant had permeameter does. So, that will give you K is equal to what k is equal to Q over A and d h over d l and I have a minus in front now what is Q? Q is the volumetric flow or the volume of water which is infiltrated in what ever time and we divide that but, duration or that time that will give you the flow rate.

In this case we have let see 45.2 centimeter cube of water flowing in what 3 minutes right so; that means, your Q is 15.07 centimeter cube per minute or you can converted into other units suitable units that is 0217 meter cube per day. So, this your Q, which is going through the sample, the next thing we need to find is what the hydraulic gradient d h d l what is that, as we said this is negative constants head difference divided by what, divided by the length of the sample is in it. And these two data are given to us it is negative 16.3 over 50 both of them are in centimeter.

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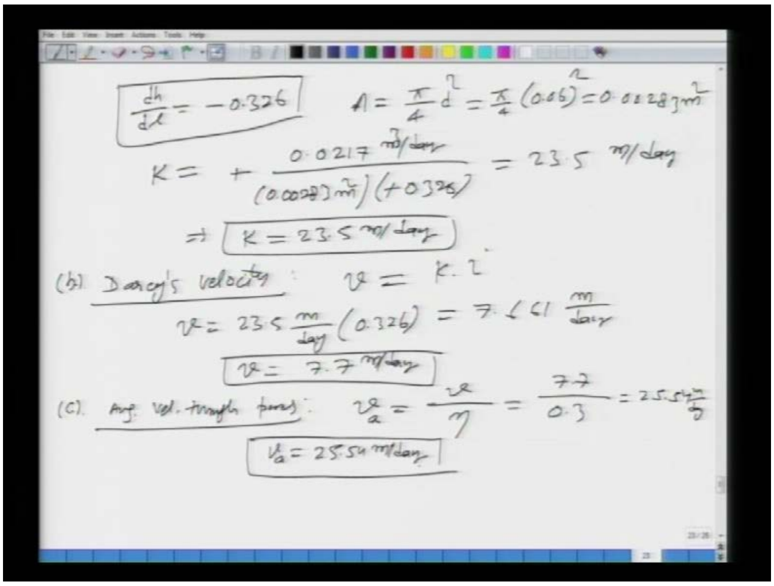

So, let me use the next page you have d h over d l is equal to what negative 0.326 area is what it is a cylindrical sampler pie by 4 d squared. So, it will be pie by four six centimeter 0.06 square right will be equal 0.00283 square meters I have converted that already. So, you put in all these things in your hydraulic conductivity. So, you will have negative 0.0217 it is meter cube per day that is the cube divided by the area which is 0.00283 this is in square meters.

And the hydraulic gradient which is negative 0.326, this negative will cancel this and what you will get is about 23.5 meters per day. So, that means your hydraulic conductivity from that constant head permeameter comes out to the 23.5 meters per day. The second thing we have this, what is called the Darcy's velocity and we know what is Darcy's velocity is nothing but, k times i is it not. So, what is we done we have just found out k which is 23.5 meters per day and what is i, i is negative of d h d l which is 0.326.

So, it is going to be equal to 7.661 meters per day, so your Darcy's velocity is 7.7 approximately meters per day that is the answer number b. Let us move on the third part is what it is the average velocity through the pores or the voids, which is nothing but, your actual velocity which is the Darcy's velocity by porosity isn't. So, which is 7.7 we have just found out and what is the porosity it is 0.3. So, it will be 25.54 and this is meters per day. So, the actual velocity or the average velocity through the pores is almost 3 times as much 25.54 meters per day.

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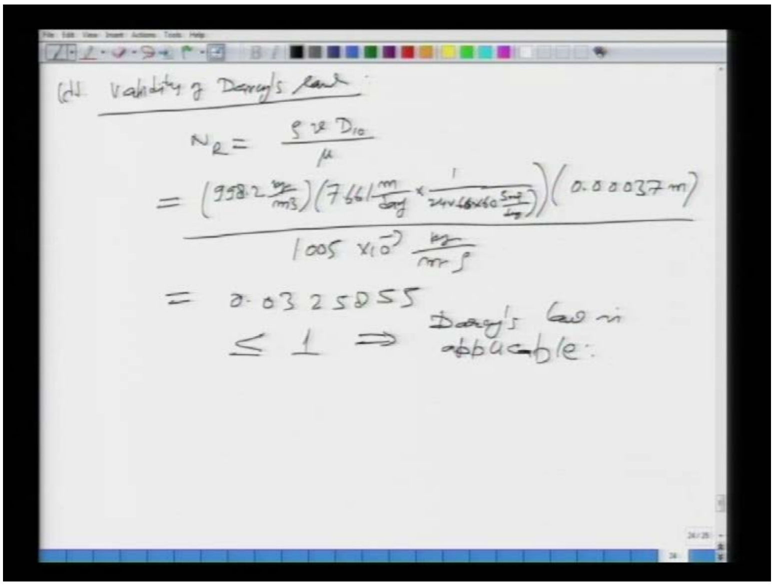

In the last one is the validity of the Darcy's law we have to check and that we can do using the or by calculating what the Reynolds's number is it not. So, what is Reynolds's number it is going to be your row v and D 10 here which is the characteristic length divided by mu. We have all these numbers here, so I am just going to put them you have 998.2 kilograms per meter cube that is your row the velocity this is the Darcy's velocity it is not the actual velocity keep that in mind here it is the Darcy's velocity 7.661 meters per day.

Times 1 over 24 times 60 times 60 seconds per day of case I am converting every thing into the S I units now what is this, this is your v and D 10 is 0.12337 this is meters divided by the dynamic viscosity which is 1.005 10 minus 3 kilograms per meter seconds. So, every thing is in S I units, we just calculate it and this will come out to 0.0325855 which is less than equal to 1 of course, that means what Darcy's law is applicable.

So, this way we see that today we have look at the Darcy's law mainly which is applicable under the laminar flow conditions. We have looked at this origin, it is definition, the properties involve the hydraulic conductivity, which we have looked at more closely, how we can calculate that. And then we have taken up a numerical example in which we can conducts some experiments in the lab to find out the hydraulic conductivity and then we can calculate the validity and other things.

So, I think I would like to stop at this point of time today and then we will take up the advanced topic in the ground water hydrology. That is how do we deal, when we have the stratified soil. Right now, we have considered that there is homogeneous type of soil. So, there is one value of k but, many times or in the most practical situation we have layer soil. So, that is what we will look at and then will move to the equation that is a continuity momentum equation.

Thank you.