Soil Mechanics/Geotechnical Engineering I
Prof. Dilip Kumar Baidya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur

Lecture - 10
Permeability and Seepage (Contd.)

In the just previous lecture I have, I spent some time on determination of permeability value. And I have mentioned that there can be permeability can be determined from laboratory test or field test. I have shown the laboratory test in my previous lecture. Now let me discuss one or two methods in the field. And this field method, summing pumping test, I have told you that it will be consider pumping test only, I will consider in this class. So, I will discuss now pumping test. Again pumping test, various field condition, it will be condition will be different, and equation will be different, and observation will be different, we will discuss one by one.

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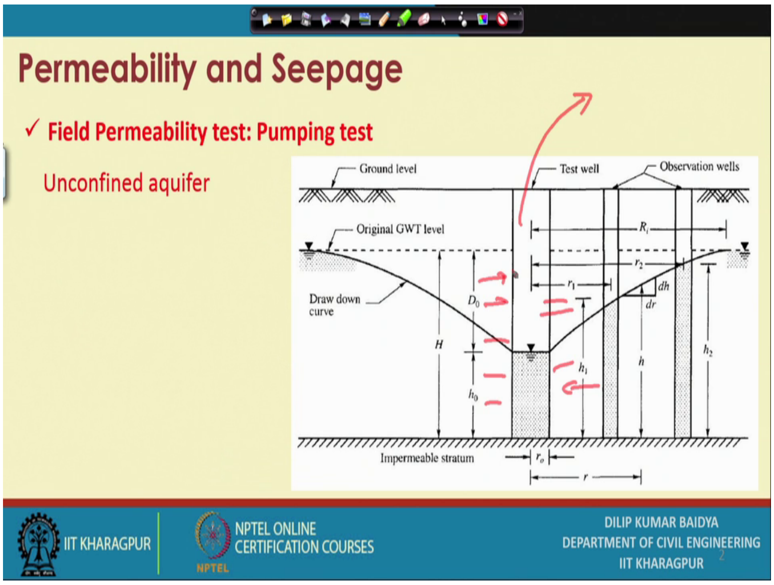

So, let me come to that. So, this is a field permeability test, and when we consider the pumping test, we have to see the water bearing layer actually. And water bearing layer can be, there in two ways one actually confined ways, and another is unconfined ways. Unconfined means there is an impervious layer, bottom and then over that there is a constant water level pop to some height, and topmost layer, topmost level of water region I have discussed that, it is a water table or ground water level we say, and where actually pressure is atmospheric. And that, from that water will be there at a particular level and then as I have mentioned before also. If you make a borehole, then that borehole actually initially will show the water, which is equal to water level same as the ground water there.

Now, if from this ground water actually we can pump out. And if we pump out from these; that means, from here if I pump out water, then water actually from the surrounding zone, from this zone from this zone, actually water will enter to the well and. So, that entering how quickly it will enter. It depends on the permeability of the soil. So, if the fine grained soil that the flow will be very less and pumping quantity will be very small. If it is a coarse grained soil then permeability will be very good, and pumping rate can be, pumping rate can be quite large.

So, we have to follow certain procedure to conduct the test. And this test actually I have shown here number of things see, as said this is the borehole, and borehole has a initial diameter R naught. And while doing this, actually we make two observation while also, that observation means, we continuously pumping, and then at a particular distance. Suppose that distance is r 1 and r 2. At a distance r 1, this is distance r 1 one observation well is kept. At a distance r 2 there is another observation, this observation well is kept. And these observation well, when this water will be pumped out, that everywhere water level will not come down uniformly, because of this, there will there will be draw down.

The maximum drawdown will be in the well itself, and when you will go away from the well the drawdown will be comparatively less. And at some distance we will not see any drawdown, and that distance is called radius of influence; that means, up to what distance, because of this pumping there is no effect.

So, that is what also, that is actually, say h is the height of water from the impervious layer, and then that is the one, and number of things; that means, at a particular time your water level in the well is h naught. So, these are the things to be observed; that means, when I will be taking pumping out, that you have to see that we are pumping at a constant rate; that means, initially pumping may not be initially constant, because you have to, this is valid for steady state condition. So, that quantity also should be constant, then only you have to take major tech measurement, otherwise it is not correct

So, when steady state discharge is at arrived, then only after a sometime we have to constantly discharge it, and then from that time you have to observe what is the water level at observation well 1, and what is the water level at the observation level 2. And those things can be correlated to key value, in terms of r 1 r 2 h 1 h 2 and all those things so that I will show in the next slide.

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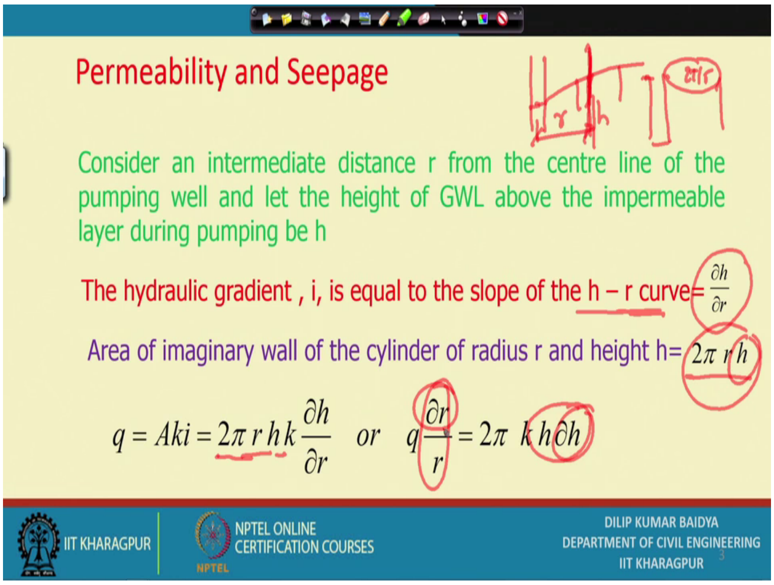

You can see. Consider an intermediate distance r from the center line of the pumping well, and let the height of ground water level above the impermeable layer during pumping ph. So; that means, what. I will just show here this is the well, and this is the water, and then this is the drawdown curve, and we have shown that two distant r 1 r 2, two h observation well h 1 and h 2 well. Instead of that I will take any arbitrary distance r one. Sorry not r 1 r, and there actually this height is h; that is the thing is explained from this statement. And then hydraulic gradient i is equal to the slope of the hr curve. So, del h by del r. So, this curve actually hr plane del h by del r

The area of imaginary wall of the cylinder of radius r and height h; that means, actually if I consider here, if I consider; that means, this is the well, and at a distance r, I can imagine a well of radius r; that is a another well I consider; that means, if I consider that well radius r; that means, through that well periphery water is entering. So; that means, what is the area through which; that means, a flow, quantity of flow is q times v into a. So; that means, I have to find out the area. So, over which area the flow is taking place at particular location. So, that area actually 2 pi r is the periphery, 2 pi r is the periphery and h, if you multiply, this is the vertical cylindrical surface, we are getting vertical cylindrical surface. So; that means, it is something like this. So, this is h, and this is the 2 pi r, this is 2 pi r.

then based on that, that is the 2 pi r you have got, then q become Aki and; that means, and again this is 2 pi r, and h is the area, and k and the i is del h by del r. And from there if I simplify q into del r by del r 2 pi k is into it. So; that means, r is a variable and h also is a variable, other things are all constant. So, h is variable. So, r and h they are variable, and r is. Sorry r also variable, r and h is a variable, so that to be integrated.

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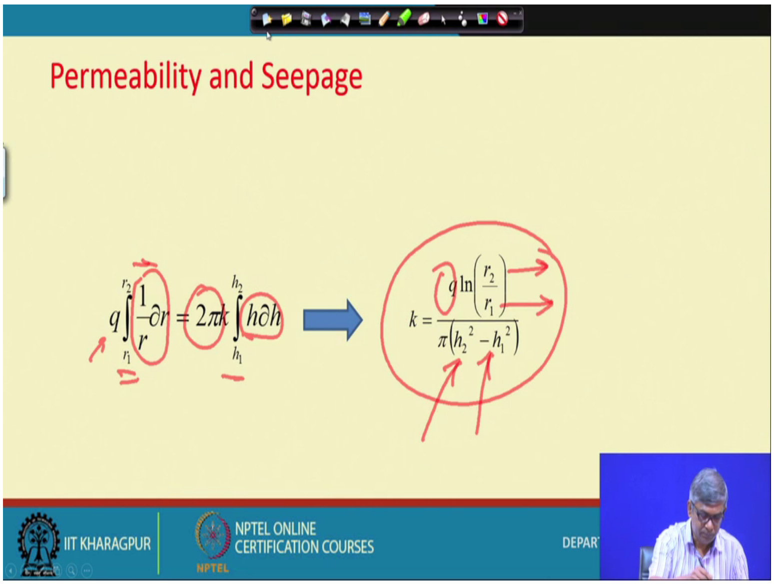

So, if I put in the integral form. So, it comes like this. You can. Since we have two observation well r 1 r 2, I can put limit r 1 to r 2, and q also I can put q already is there 1 by r del r, this is actually variable. And 2 pi k is I said I can keep constant and h del h is the variable. So, I put this and limit h 1 and h 2, and if I integrate and simplify, then I will get finally, equation for k q ln r 2 by r 1 pi h 2 square minus h 1 square. So, this is the one equation

So, what are the observation actually. Observation is, I have to fix two observation well at a distance r 1 and r 2, these two unknown. And I have to observe after steady stage discharge, what is the head observation well, what is the height. What is the observation of well 2, what is the observation of well 2 1, what is the height. These things we have to observe; this to be fixed and this to be observed, and q to be measured quantity that steady state seepage discharge.

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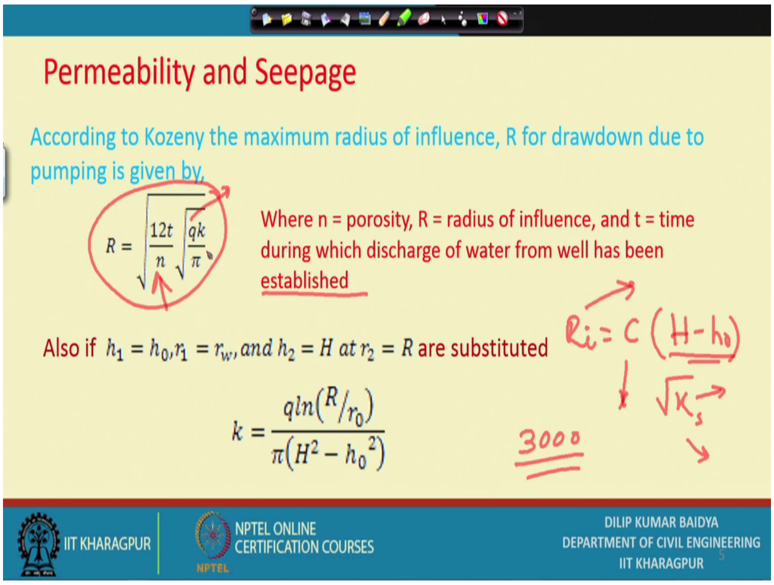

And then I can put in this equation, I can get the value of coefficient of permeability. Now the in various applications, particularly this permeability the concept is application in. One of the important application area is, that in the construction site sometime we have to dewater. That means, if suppose I have to construct at a level of suppose ten meter, but water table is at 2 meter; that means, for construction purpose. I have to lower that eight meter water level or even more to reach; otherwise with water I will not be able to excavate, and I will not be able to do the construction

So, that dewatering work, sometime some calculation will do where, actually we need to find out the radius of influence so, that radius of influence sometime given by some author; that is actually Kozeny. He has given in this form R equal to under root 12 t by n under root qk by pi.

So, q all those things are quantity to be noted, porosity of the soil to be known, when n is the porosity r is radius of influence t is the time due to the discharge of water from well has been this established, and k of course, initially we can measure by pumping observation well, and after determining the k, the next step we can find out Ri. This is one way to determine Ri. There are many other empirical equation also there; that is actually suppose Ri equal to one equation is C into H minus h naught into under root Ks

So, this C is the constant, is given for well 3000 value is a constant. And each miner is not actually original water height, and well final water height, that how much we have to lower. The difference of that actually is H minus h naught, and under root Ks that will be put in the meter per second, and then if I use this equation, finally, I will get radius equal to, a radius of influence equal to in meter. So, this is the one way. There are many other ways in the literature available. This is another way.

So, if you can find out this radius of influence, then sometime we need not have observation well. Well I can take the well itself one observation well, and since I know radius of influence, what is the water height, and what is the distance. So, that is the thing it is shown here you can see; h 1 can be considered at h naught; that means, what that is water level in the well.

And r 1 equal to rw; that means, radius of the first observation well is nothing, but rw and radius of the well. And h 2 equal to H; that means, second observation well, what is the height, is a height of water above impervious layer that itself, and at least at r 2 equal to R as substituted

So, these things if I substitute, whatever equation we have developed in the last previous slide, if I substitute those we can get this equation; this equation what it says; q is a again seepage discharge quantity, R is the radius of influence we can calculate either these or this way, r naught is the radius of the well, and h. H is the height of water table above impervious layer, h naught is the final water level after pumping what is the level came. And if I put this equation then I will get the value of k. So, this is the another way of calculating k.

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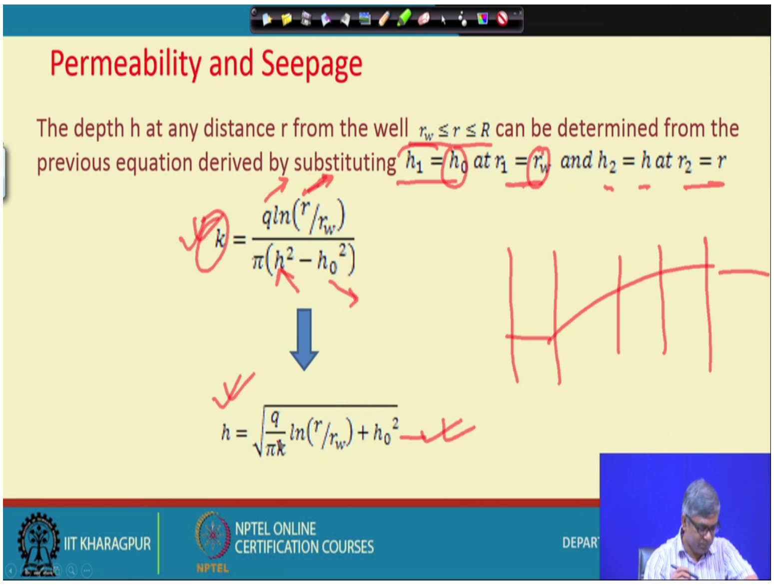

And next slide, actually sometime we need to find out what is the, at a distance, at a distance of x, what the water height, because sometime we have to find out (Refer Time: 13:30) because excavation area sometime, is a large. Suppose in a particular point we are doing this, but at a distance from this construction site, what is the water height that to be determined. For that actually we can do this way h 1 equal to r naught at r 1 equal to rw, and h 2 equal to r and r 2 equal to r

So; that means, we have taken their observation. Pumping well itself is one well observation well. Here actually what we are doing, at a distance r one. So, r 1 I can substitute by rw and h 1, h naught can be substituted by h 1, and h 2 will be h at r 2 equal to r. So, this thing if I put, then this equation will be modified to this power; that means, at a radial distance r and what is the height h.

This is the. This one if you fixed that is about ten hundred meter distance, what is the value of height as to be determined. If already k is determined, q is determined, h naught is determined, then h can be determined which. So, that is the simple, if I simplify this one h in this form q by pi k ln r by rw plus h naught square. From this equation one can find out the value of h. That means, when you are continuously taking out from well, and as I have told you that if this is the well, water triage is here, but your drawdown curve will be somewhere here like this. Now I want to find out, I know the observation well what is the value, but I want to find out maybe somewhere beyond these or somewhere in between, what is the water height. Then this is the way I can do small calculation and can find out

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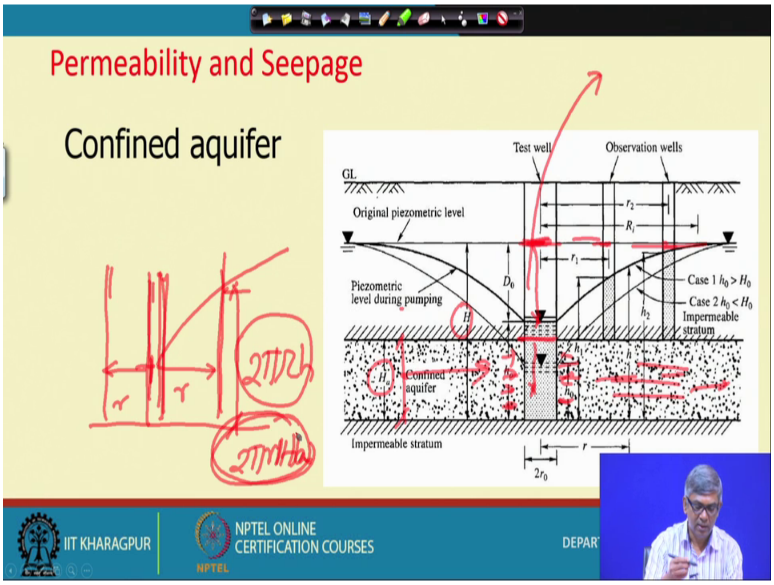

Next slide is, actually as I have told you, that water bearing layer can be unconfined or confined. This is a case of confined aquifer. This is a confined aquifer, and this confined aquifer, actually confined means what actually here. You can see it is same as previous. Only thing, this is actually maybe very thick clay layer and this is impermeable layer, this is impairment layer. This is the layer sand which holding the water.

So, and this water may be under pressure also. It is not necessarily that water in between, maybe water discharging from here. So, if I make a borehole from here. Then whatever water level it will show in this borehole that is the water equivalent water level you can imagine. So, suppose if I make a borehole, and water level is coming somewhere here; that means, that is the initial water table to be assumed. And then by pumping, suppose I have to bring down somewhere, or I want to find out that permeability value

So; that means, I can also previous, like previous case I can make different observation well. So, if I get initially pump oil is here, and observation well here, then all. Everywhere will be water level will show at this level. Now when I will taking pumping out then suppose water level is coming here, and then your drawdown will be from it like these or like this. And if water goes from this level to beyond this equation will be slightly different. I will discuss the water level when above this.

So, if I do this, then I can see, again same as previous you have taken radius of this well is 2 r r. So, that diameter is 2 r naught. At a distance radii r 1 and r 2 two observation wells are there. And earlier it was actually, your above impervious layer, what was the height of water table that was H. Here also same, I can consider, whatever water level it shows that will be noted h. The additional term here, which is constant here; that is the thickness of the water bearing layer h is ha

Now, whatever it is different from the previous one. The difference from previous one is here like this. If I imagine one well now, suppose at a distance r. If I distance r, if I imagine a well, suppose this is the well and I can this imagine at a distance r suppose here, this is at a distance r, this is distance r that is distance r. It looks unsymmetric, but it is not, because of my sketch is looking so, but this is a center, and at a distance r. So; that means, all around the well, this I can imagine a particular well. And then through which actually water will be entering.

Earlier case what we have drawn, if it the drawdown curve was like this. Then our impervious layer was this, then our area through which water was coming was 2 pi into r into h. The h was variable there, but here, since it is about this, above these there is no water is entering, from this water is not entering. Here also water is not entering. Through which water is entering. Water is entering through this only, only this much depth

So, in this case our area through which water is entering is nothing, but 2 pi r into this h a, which is constant here. So, that is the only difference from unconfined to confined. So, we will show that in the next slide that when we are considering the, your area through which water is entering to the well, that was 2 pi r into h which was, h was variable. Now we have considered. We can also considering another imaginary well at a distance r from the pump well, and in that case, and in that well through which water is entering; that is actually 2 pi r into ha, which is actually constant. So, that is what only difference. So, that we will show in the next slide

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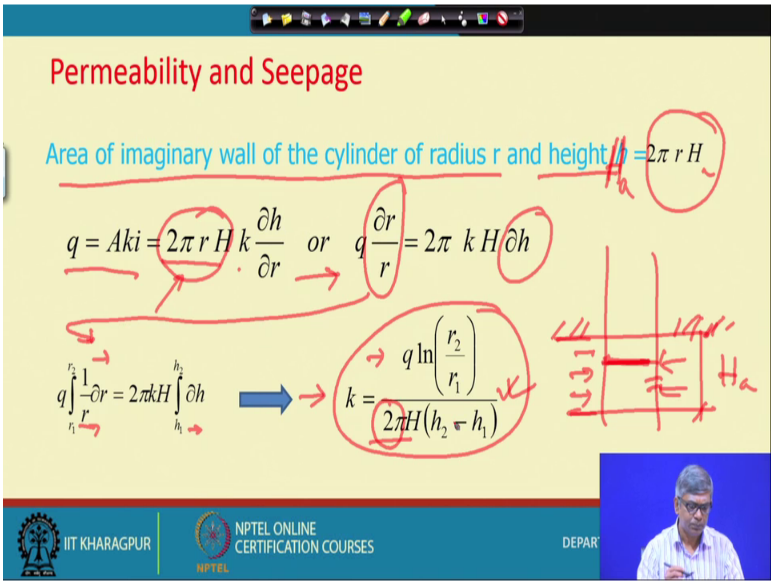

I can show. You can see here that, that is the thing I have. So, area of imaginary wall of the cylinder of radius r and height h so that we have considered; Now if I make a whatever height h I make, but actual area of flow that, through which. This is better to write ha actually, because I make a cylinder, but water is entering through this much height cylinder.

So, your cylinder is like this, but cylinder is restricted through which water is coming, is only this. So, cylinder height may be any height, but I will take only, this is the Ha that much I will be taking. So, if I take Ha or h whatever, so 2 pi r H. So, like previous case q equal to Aki, the formula was there, and that is actually 2 pi r into H. Now a is substituted by this, and in the previous case it was substituted by 2 pi and small h which was a variable. And k and i is same as previous del h by del r. And this if I simplify then q del r by del r 2 pi kH del h.

Now, this portion is variable, and here only this portion is variable, now if I put in the integral form definite integral form here and to distance. If I put to observation well at r 1 and r 2, and that part can be integrated and here actually 2 pi k into H, and del h to be integrated, and what is observation height at h 1 to h 2. So, this two which I have shown in the previous slide; the h 1 h 2 that well to observation well, that two observation well at a time, but at a particular situation after pumping, sometime steady state pumping that h 1 and h 2 reached here. So, if I do the, integrate these and simplify. Finally, I get k equal to q ln r 2 by r 1 2 pi H h 2 minus h 1. So, you can see the difference from the previous equation, it was 2 pi, and here it was a square, and here actually. So, ultimately dimensionally it has to be correct. So, that it is easy to remember. Previous external equation it is just q ln r 2 by r r 2 pi k 2 pi h 2 square minus h 1 square. And here actually square has gone, but one constant height has come

So, that is the one. Finally, this from this equation one can find out the permeability, by pumping test, and that to which is applicable for confined aquifer. Now confined aquifer, when you draw constantly for a longer time, then water may level that in the well, water level may come down somewhere here. This was the level impervious layer. And this is the impervious layer, the water level coming here.

If water level come down here, then actually there will be a different equation you have to use, because water entering through which in this, it will no longer will be 2 pi into, 2 pi r into Ha that will be different. So, because of that that is not. So, for that different formulation is there, but I am not going into that. So, like previous case also, if I want to find out what is the draw around, and at a distance that. So, what is the area of influence? All those things also similarly I can modify, and I can find out that this. Well itself can be taken under observation well, and at a distance where there is no drowned that can be taken a final observation well, and based on that I can modify this equation, and I can find out the fermented value k

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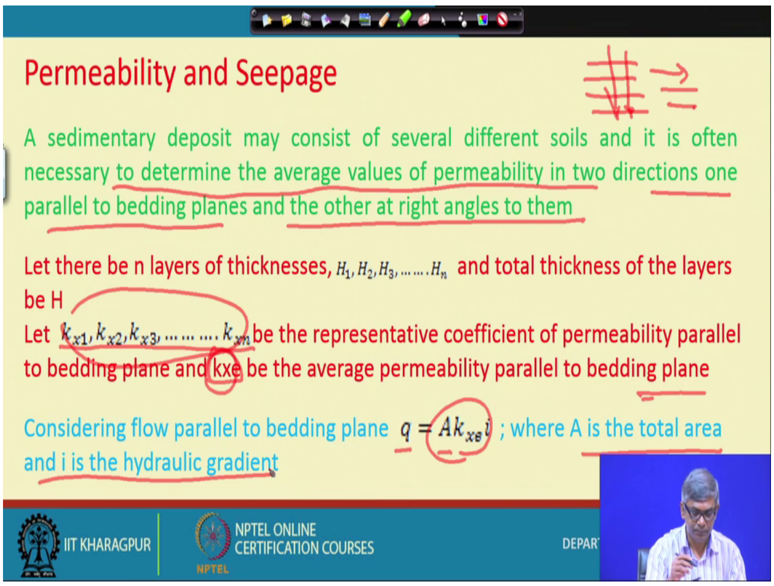

And now the permeability and seepage, now that is another thing. So, I now explain how to determine the value of permeability, but if you in the often, actually in the field the soil is stratified, and sometime also in the actual construction also we put it in layer and compact. And because of that the permeability in different layers may not be constant, in the de all direction. A sedimentary deposit may consist of several different soil, and it is often necessary to determine average values of permeability in two direction; one parallel to bedding planes, and the other one right angles to it.

That means, if you have the layer like this, and flow may be taking place in this direction, flow may be taking place in this direction. So, two direction you have to find out the average permeability, because if they are not equal in every layer. Let there be layers of thickness H 1 H 2 Hn, and the total thickness of the layers in H and kx 1 kx 2 kx 3 and kxn be the respective coefficient of permeability in the horizontal direction. And then we can consider the representative coefficient of permeability, parallel to the bedding plane, and kxe be the average permeability parallel to the bedding plane ok

So, this is the respective layer, and this is kxe, I am considering as equivalent. So, different layer having different permeability, I have to find out the equivalent. So, I am assuming this is equivalent and these are the respective value, considering flow parallel to the bedding plane, then q will be equal to a kxe into i. If I convert into equivalent layer this, where a is the total area, and i is the hydraulic gradient.

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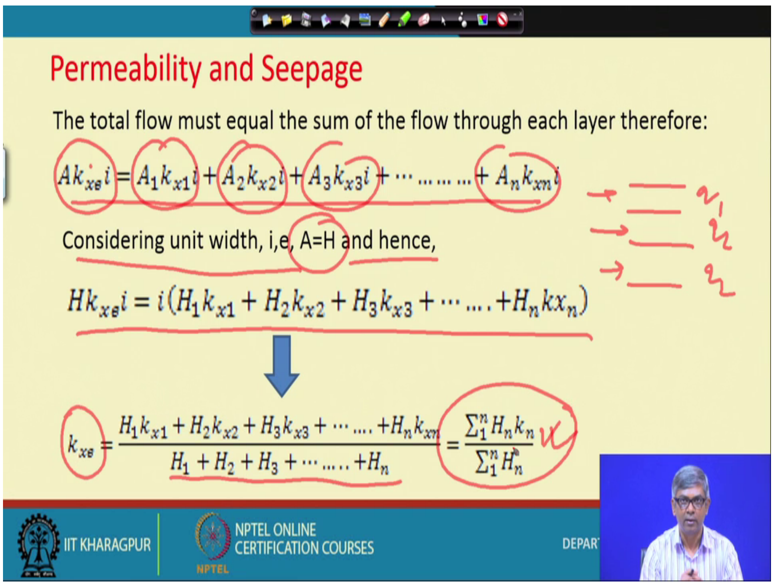

So, now the total flow must be equal to the sum of the flow through the each layer. So, suppose if there is a number of layers, flow is taking place like this. And then flow q 1 q 2 plus q 3, so when is a parallel. So, finally, whatever what water coming out from this side, will be summation of water flowing through each layer. So, that if I consider that, then it will become the respective layer these are the equation, respective layer these are the equation and if I sum it that should be equal to, because this equation is with equivalent permeability. Considering unit weight; that means, through projected width is 1, then a become thickness itself

Hence I can express this equation in this form. And if I simplify then kxe become H 1 kx 1 H 2 kx 2 H 3 ks 3 Hn ksn H 1 plus H 2 plus H 2 H 3 plus. So, that is in a very brief, or very summarized way, if I can write generalized way, I can write this form; that is equivalent permeability of a layer, of a n number of layers, when they have different layers have a different probability like k 1, k 2, k 3, k 4 like that. Then finally, equivalent permeability can be expressed this way, when the flow is taking place, parallel to the bedding plane.

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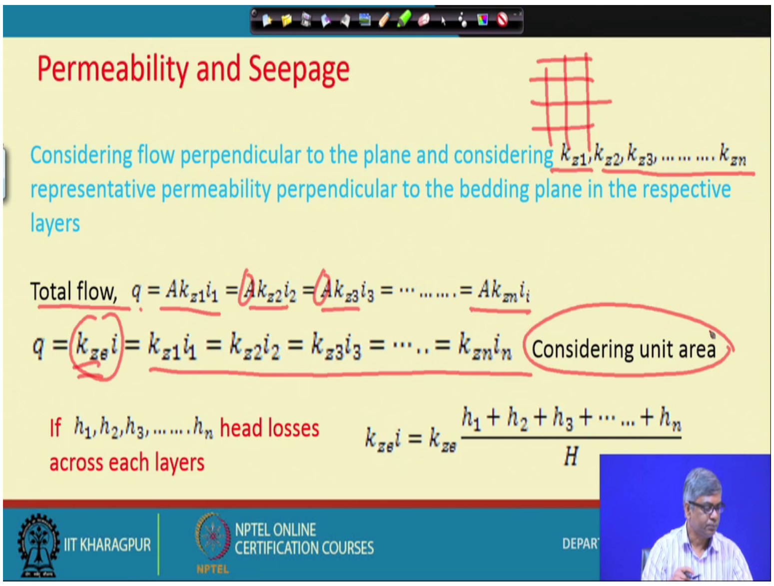

Now, the other case, when the flow is taking place, perpendicular to the bedding plane. Considering flow perpendicular to the bedding plane, and like kz the 1 kz 2 like that respective permeability value in the layers, and kze. Maybe I can take consider as a equivalent, kze is not required yeah, kze you have to find out equivalent permeability of the layer which is taken is here

Now, considering two compared to previous case what is the difference. There summation of quantity was equal to the respective flow, but here, since if the flow is taking place like this in the different layers. The flow through each layer should be constant; otherwise it will continuity of flow will not be satisfied. So, q should be the everywhere same, only head loss will be different in different layer; that is the point to be kept in mind, and total head loss will be summation of the head loss in respective layer.

So, this is the point you have to keep in mind, then all we will be able to derive quickly this one. So, total flow q will be a kz 1. So, these areas all are same, because as I have told you that continuity equation to be satisfied. And then this is equal to now if I express in this form, then again this this is the form I can write considering. So, here actually a is there. Here everywhere a is there. This is what ei to be removed, because I am considering unit area; that means, I can consider a unit area like this. This is the area through is taking place, flow is taking place. So, that unit area if I consider, everywhere it is same area. So, ei can be removed. If I remove the a then our equation becomes only kz into i kz into i like that.

So, now if h 1 h 2 h 3 h n head loss across each layer, then your kze into I will be kze into summation of head loss divided by. This is the I will be how much. This is the head loss well, what is the distance h. So, that is the i. So, this is the thing you have to keep in mind. Now next one you can see.

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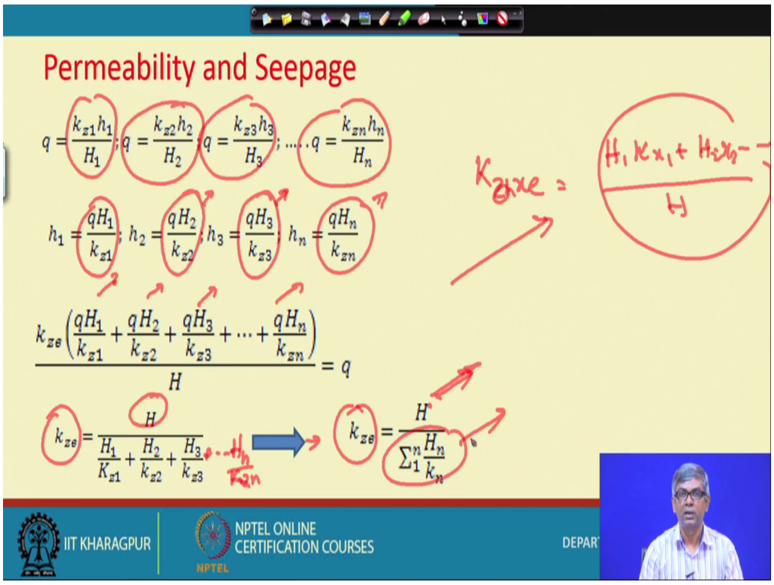

Now, q equal to I can express in this form, q I can express, I can express in this form. Again q I can express in this form, I can q also can express. Everywhere q is same for different (Refer Time: 30:35). So, H 1 I can calculate this way, H 2 I can calculate from this way, H 3 I can calculate this way. So, because q value are same, then I can find out this.

And this one I can substitute, because in the previous slide I have shown head loss H 1 plus H 2 plus H 3 plus Hn, and I can take H 1 from here, I can substitute here, H 2 from here, substitute here 3 from here, substitute here Hn from here and substitute here. And then I simplify, then our kze will become h divided by H 1 by kz 1 plus H 2 by kz 2 plus H 3 by kz 3 plus like that, H Hn by kzn can be written, and which I can be written in a very generalized form. There kze will be H divided by summation of Hn by kn; that means, respective layer, what is the thickness divided by k you find out. Find out summation of that, and H divided by that will be your kze

So, this is the two formula that means, when it will be kz h actually. Kx e; that means, H 1 kx 1, H 1 kx 1 plus H 2 kx 2 etcetera divided by H. Whereas, in z direction H will be somewhere here, and H by k, summation of H by k will be here and then from there we can find out the permeability, equivalent permeability of the layer multiple layers, with different permeability of kx 1 kx 2 kx 3 like that, or kv 1 kv 2 kv 3, or kx 1 kx 2 kx 3 like that. Then one for horizontal plane, when it is then equivalent permeability equation is this, and the flow is taking place in the perpendicular to the bedding plane, this is the value can be used. With this I will close here.

Thank you.