Ground Improvement
Professor Dilip Kumar Baidya
Department of Civil Engineering
Indian Institute of Technology, Kharagpur
Lecture 29
Dewatering Design Principle

Hi everyone, once again I welcome you to this lecture Ground Improvement, and we are towards the end of the module six. We have taken 2-3 lectures on Drainage and Dewatering and now we are, will be facing in within one or two lecture and drainage and dewatering some of the aspects I have already discussed and then towards the end of last lecture, I was trying to identify the design parameter and there we have seen that coefficient of permeability, then depth of lowering and all those things are actually the main design parameter.

And then the permeability is the most important parameter actually and because of that the we need to know how to determine the permeability, but in this course, I will not be able to discuss in detail there are many methods for determining the coefficient of permeability particularly in the graduate class and in soil mechanics there are permeability, falling head method, constant head method there are different field methods. Those all those things and what is the basic principles in that permeability test actually, when we carry out a test.

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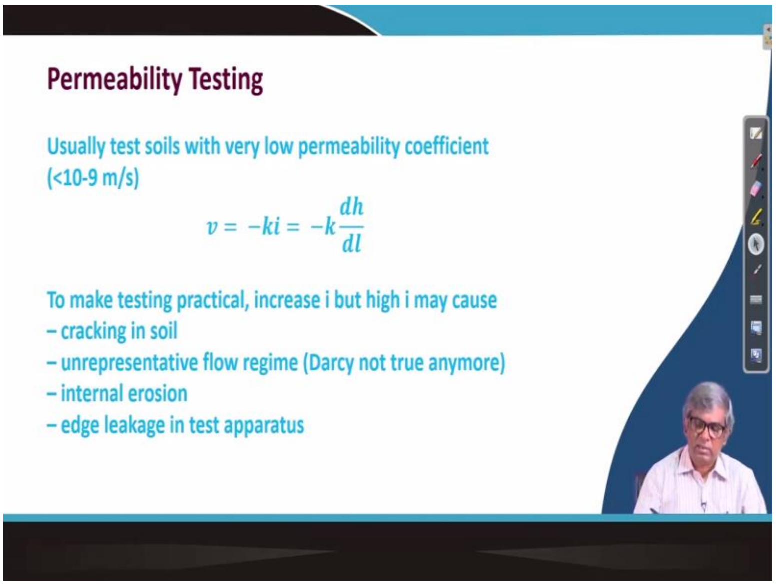

Just one slide I will show that we usually test with a very low permeability coefficient generally 10 to the minus 9 meter per second and our governing equation actually v equal to minus ki equal to minus k dh dl. So, from there actually using these ultimately will try to find out and here actually we need to know certain amount of flow and to make the testing practical that means, to make some flow, we can increase i if the i actually will cause the velocity actually to the flow and if there is no i actually 0 then the flow will not be there.

$$\textit{Usually test soils with very low permeability coefficient}(10-9m/s)$$

$$v=-ki=-k\frac{dh}{dl}$$

To increase i actually you can make the testing practical however, if you make i value too high, then there are number of problems will be there cracking in soil, then on representative flow that means, floor is that when is the Darcy’s law the whatever we try to do here, all based on Darcy's law, because we consider flow is laminar and all and if you make too much of a head, then there will be the dabbler flow condition will not be satisfied and then nothing will be applicable.

Those problems will be there, then internal erosion will be there then when there will be flow velocity is very high, then sometime fine particles will be carried by the, the water and that also problems, that will not give you a correct result and then edge leakage in test apparatus sometime if you do in some apparatus then some leakage will be there.

These are all some condition I am telling about the permeability test because that is one of the most important design parameters. And then, but when you carry out certain load dewatering wall or something, then best thing is to do by field test. And there are many field tests, perhaps, you know, because in undergraduate, at least more than one place, actually we learned that pumping method so, I will discuss that.

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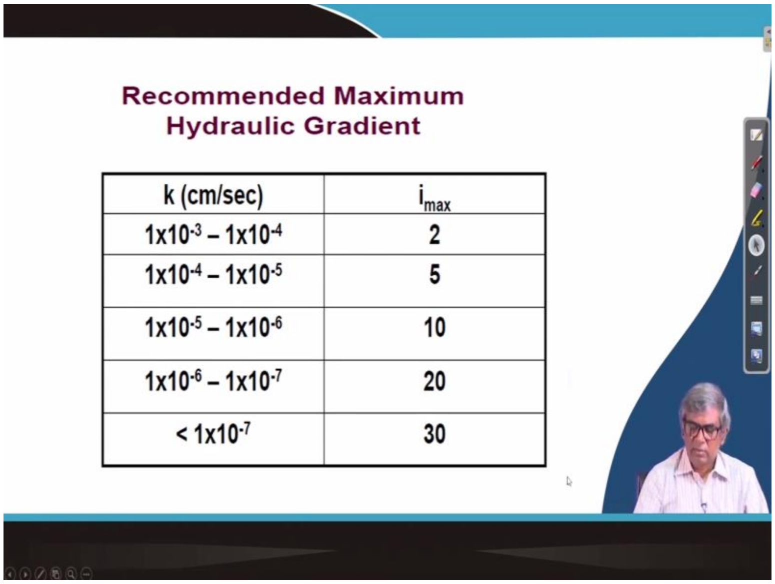

Before going to that, let me recommended maximum hydraulic grade as I have told you that to make a reasonable hydraulic gradient one can make the flow satisfactory or desired flow can be maintained or may make the test practical, but if I make it too high you need to get in there are some problems mentioned.

Here actually it is given that the different permeability value if the soil is having different permeability range 10 to the minus 3 to 10 to the minus 4, then i max can be maximum of 2, and if it is a 10 to the minus 4 to 10 to the minus 5 range, then you can apply 5. And 10 to the minus 5 to 10 to the minus 6 then again, the make hydraulic gradient at 10 to minus 6 to 10 to the minus 7, then you can make hydraulic gradient 20 and less than or greater than what is less than 10 to the minus 7, then we can make a hydraulic gradient 30. This is the range actually sometime to determine the hydraulic gradient one has to apply. If you have more than that, if you are less than that also, if you do of course, the test will be little impact your value more than that, this is a maximum limit. To less than that if you do also problem or too high you also will do there will be number of problems that we have mentioned the previous lecture slide.

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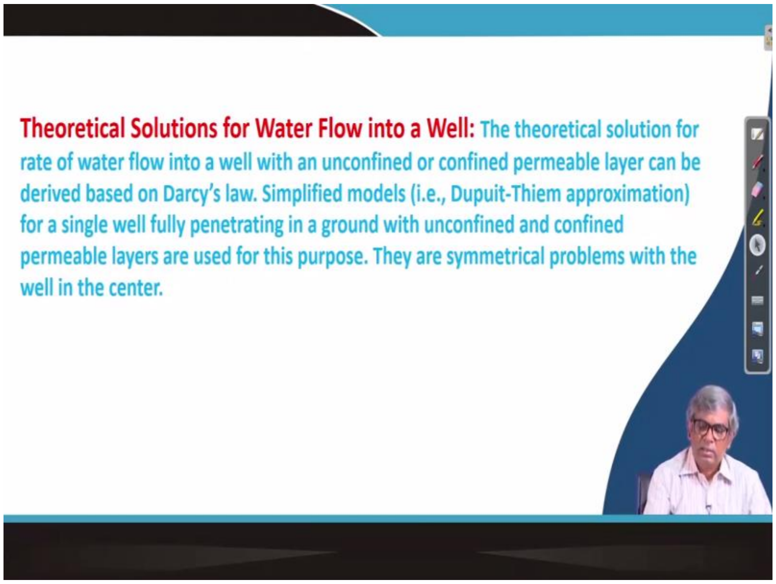

Let us go to the next slide. The theoretical solution for water flow into well, that I have not mentioned that that pumping from well that test is very popular to find out sometime to the know the yield of the well suppose from the well sometime we collect water and sometime to determine the, the power coefficient of permeability.

They are interrelated sometime by knowing the permeability we try to find out quantity of flow or sometime you we know the permeability, we want to know permeability quantity of flow is not important, but how much quantity you are able to draw out a particular time and based on that you can find out the what is the value of permeability coefficient of permeability.

In these actually to find out pumping method there are Dupuit-Thiem model is that two models are there that two models basically speak about that pumping from a confined aquifer and unconfined, unconfined aquifer and confined aquifer. And if this is if it is unconfined aquifer then we will make a borehole and then you pump water from that then how will we the drawdown curb and other features that is actually is a particular model.

And again, through a confined aquifer again if you make a borehole and pump water and then how will be the drawdown curve and other features that is also shown via another model. And using those these two models one can find out the relationship between permeability flow and other parameters like diameter, length and many other things.

Which will be will try to discuss here and when you talk about well pumping well, then the problem will be symmetrical that means, water will be coming from all direction and the wall is in the center point. That is what this is a symmetrical problem with the well in the center that is the point actually you have to consider and let me come to the next slide.

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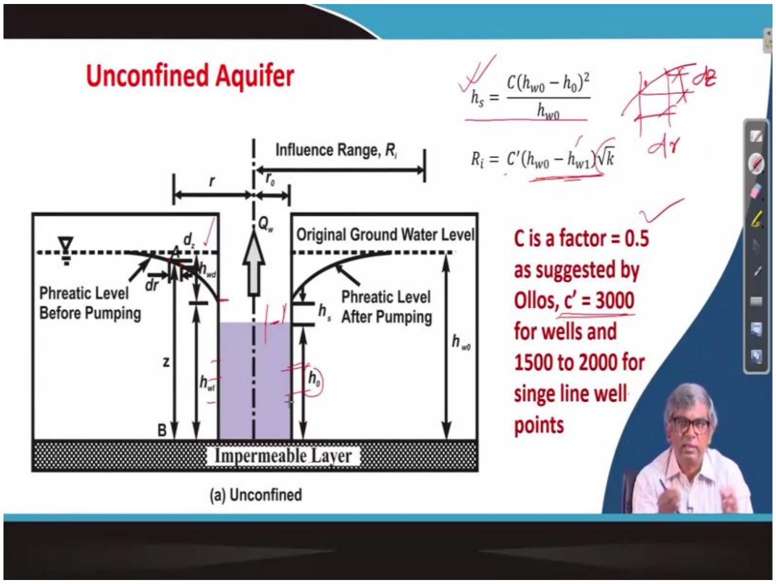

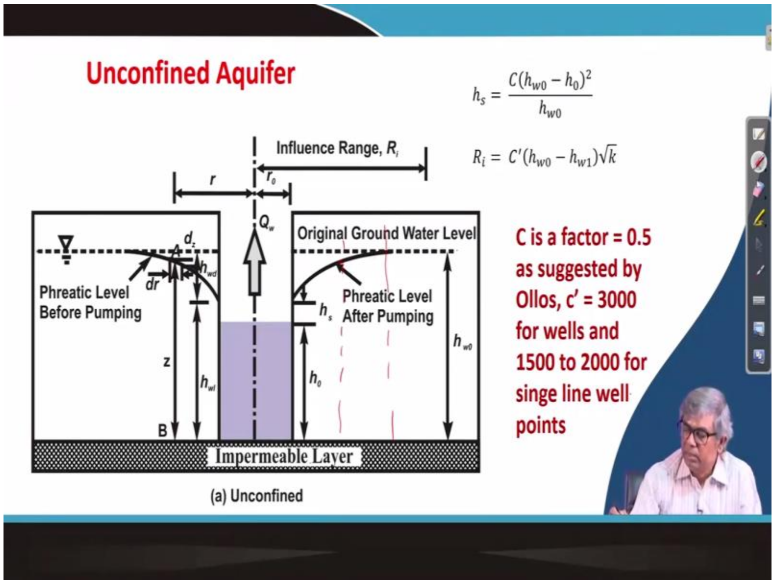

You can again this is a model actually for confined aquifer. And you can see here a number of things are shown here, this is actually well and it is a pump out from here. And if you take water from the originally groundwater level was here and you continuously then water sometimes lower in here and the water is entering through this cylindrical surface area all around and each time this area is decreasing, of course and but here you can see the water level here, there is some height up to which water is entering the but it is not showing the same level.

It will be entering from here then it will be coming water from here. This portion is given name is given h_s and then this is mentioned as h naught this is h_w naught what that means water table original water table then after pumping original table that means only h naught and then hw1 is actually up to which that actually the phreatic surface is there, phreatic surface you can say that this is the phreatic surface and then coming down and joining here it is a discontinuous this portion you can assume, assume.

$$h_s = \frac{c\left(h_{wo} - h_0\right)^2}{h_{wo}}$$

$$R_i = c^{'}\left(h_{wo} - h_{w1}\right)\sqrt{k}$$

c is a factor=0.5 as suggested by Ollos, $c^{'} = 3000$ for wells and1500 to 2000 for single line well points

And this is the way actually we have to do and then that then actually h_{wd}. This is actually what the drawdown depth, the drawdown depth is h_{wd} because this is the original water table. And water table is lowered here we can assume that this is h_{wd} and here actually there is a portion is shown, which is not very clear which I can show you like this, if this is a drawdown curve and then I can collect I fixed two point to these two point distances is d_r and this height difference is suppose dz that is a thing is shown here this small distance it will get on the curb they taken two points one point is somewhere here another point is somewhere here.

These two points are, from these two points, these two points actually what is the distance horizontal distance what is the vertical distance? this vertical distance the horizontal distance is nothing but the gradient there actually that point actually if I want to show this is the one will be required in the next slide which I will show you that other things actually what is shown in this diagram you can see that small r naught is the diameter of the well it is considered and then this these r this these r actually is a radius where actually consider the point at radial distance r you have consider points suppose.

And as you can see that, when we will be pumping, this water getting lower and then and slowly this water table will be lowered, but it will not be suddenly lowered everywhere close to the well, it will be lowered maximum and if you go away from the well that is lowering will be reducing and at some distance you will find that it will not be having any effect therefore water table will be unchanged.

The distance up to which there is a no effect will be the distance beyond the h that pumping will not make any effect that is called influence radius. That in a number of things are there and whatever other things I have shown here h_s this is actually politically difficult to estimate. So, people have observed with different tests and through which that tried to give an empirical equation.

So, h_s is given by this equation, you can see h_s is equal to c that is a constant h_w naught which is original water table height minus h naught actually final water table after pumping that whole square divided by h_w naught that means original water table. So, this is the equation by which one can find out the estimate that means, we can measure the h_{wl}, h_{wl} we can level actually water level in the well you can find out but again the lowering is done how much actually it is not this much it is slightly less.

So, because of that you have to add h_s so that is why you have to find out h_s, this is the equation and what is the value of C? C is a factor and it is 0.5, it is different soil it can be different, but some percent ollos is given as a recorded 0.5 and Ri is an influence radius which are influenced range all around that is actually given by another equation C dash h_w naught minus hw1 multiplied by root k where k is the permeability of the soil h_w naught is the original water table and h_{wl} is the water table in the well and C dash is another constant.

Here actually everything is can be measure during test and then you can find out after pumping for some time we can see these this one and then based on that you can find out k also and then knowing these you can find out Ri. Here you can see C dash actually recommended values 300 for wells and 1500 to 2000 for single line single line well points. There are two different values recommended can we use for different application.

With this, this is the model for confined of unconfined aquifer. Actually, this is, this is the water we are layer this one the well is connected, it has gone up to the impermeable layer, impermeable layer that is why it is called entire thing is unconfined. This is called unconfined aquifer. Using these on can derive the relationship between flow of quantity or amount of water and then permeability and other parameters.

And when you do this pumping test, there are another two things actually I forgot to mention here, there will be some observation well at some distance at a distance r_1 and r_2 if the observation is h_1 and h_2, then that can be applied. That I will show you in that next slide. Here actually you can see that.

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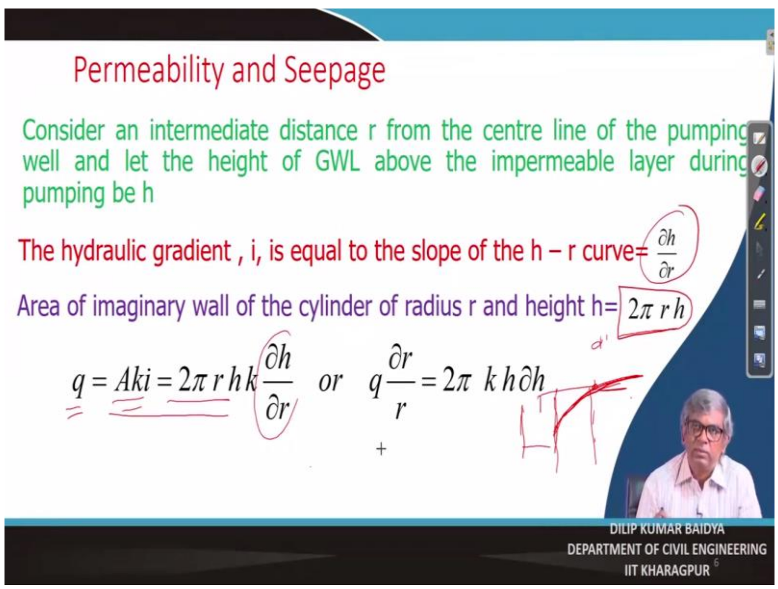

I can see here now that consider an intermediate distance r from the centerline of the pumping well and let the height of groundwater level above the impermeable layer during the pumping be h. So you can imagine that the well is somewhere here, and water is here, and that is the water that is line. So at a distance r I will be considering a point somewhere here and there actually suppose h is the h is the groundwater table.

And so, and hydraulic gradient, how you can find out? You can find out dh by dl or dr, d already I have told, so, the hydraulic gradient i is equal to the slope of hr curve. So, the h is height and r is the distance if I consider a slope of h, this is slope of h and slope of hr curve will be i and so, this will be del h by del r.

So, that means at any time so, this is the well and if I consider our distance r so I can imagine all around the well at a distance r there is a cylindrical surface where water is there up to h and through which that water is entering so because of that, I can imagine that area through which water is entering through at that level is 2 pi r into h this is the cylindrical surface.

What are up to which water is there up to h. 2 pi r into h is a cylindrical surface through which water is entering so that when quantity of flow q will actually v equal to ki so if you want to multiple you want to find to quantity of water then I have to multiply by area, q become A into k into i. So, that means, if I substitute area 2 pi rh and k is there and i is del h by del r.

This equation can be written and this equation can be further modified q del r by r equal to 2 pi k del h. This one actually can see can be integrated and you can see as you have mentioned that we can keep two observation well at a distance r_1 r_2 that r can vary from r_1 to r_2 and h actually I have told you that two observation will reading suppose h_1 and h_2. The here actually h can vary to h1 to h_2.

The hydraulic gradient i, is equal to the slope of the h-r curve= $\frac{\partial h}{\partial r}$

Area of imaginary wall of the cylinder of radius r and height h=2πrh

$$q = Aki = 2\pi rhk\frac{\partial h}{\partial r} \;\; or \;\; q\frac{\partial r}{r} = 2\pi kh\partial h$$

That way if I do then there is a finite integral can be done and that suppose I will show you the next slide. If you do that, then you will have the relationship finally.

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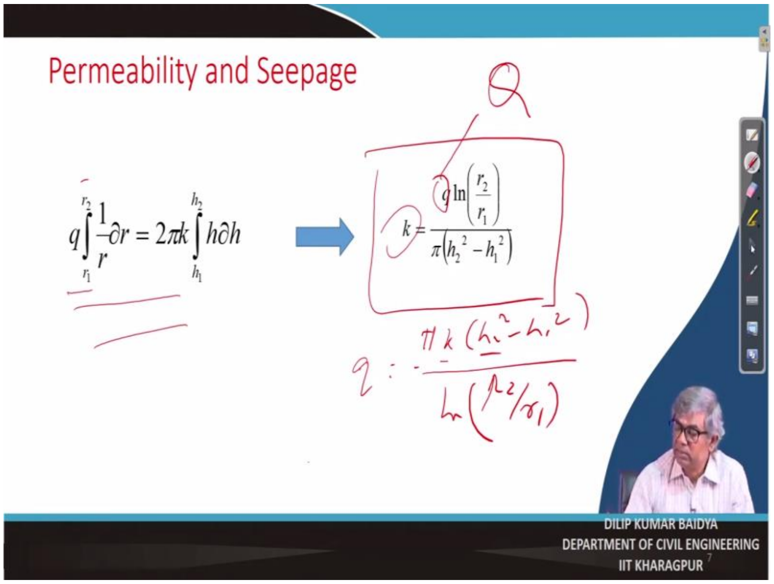

And you can see that as I have told you that I can put r1 to r2 that this is r is the variable so, that has to be integrated and h del h is the variable and so, this is a function h is the function and this is a h is variable. So, this is h_1 to h_2. So, this integration if I do and simplify this will raise this, equation that k equal to q ln r_2 by r_1 pi is 2square minus h1 square. So, this is the thing show in the diagram whatever I have shown, I have shown actually capital Q.

That do not get confused the same quantity of flow there and all with time multiplied by that also some time you can write, q is here whatever diagram which is shown that is capital Q and rest of the things are same. This is the final formula. That means, if I know q then I can find out k or if I know the if I know the k sometimes, we need to k, this is public health engineering people they are interested in the quantity of flow and we shall know that is people are interested to interested on permeability. We are to find out this we express equation this way, otherwise, sometimes equation is expressed other way also. Instead of these sometimes we can express q equal to something q equal to pi k pi k h_2 square minus h_1 square divided by ln r_2 by r_1. This is the way also equation can be expressed. Either way it can be done. Anyway, next let me go to the next slide.

$$q\int_{r_1}^{r_2}\frac{1}{r}\partial r = 2\pi kH\int_{h_1}^{h_2}\partial h$$

$$k = \frac{q\ln\left(\frac{r_2}{r_1}\right)}{2\pi H\left(h_2 - h_1\right)}$$

$$q = \frac{\pi k\left(h_2^{\,2} - h_1^{\,2}\right)}{\ln\left(\frac{r_2}{r_1}\right)}$$

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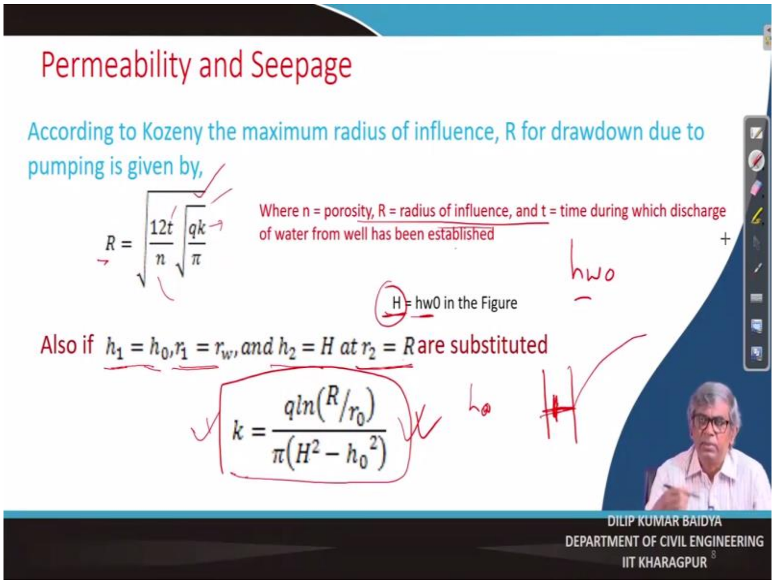

That equation can be modified actually to find out a certain parameter you can see according to Kozeny the maximum radiation of influence we have empirical something we have mentioned, but here are also similar to that they have given another equation where actually you can see r equal to 12t n under root, root under root, these root under this root, so qk by pi, so here actually k is the permeability, q is the flow, t is the time, n is the porosity all those things are mentioned here and r is the radius of influence, so which is r_i, it is shown in the diagram.

$R=\sqrt{\frac{12t}{n}\sqrt{\frac{qk}{\pi}}}$ where n=porosity, R=radius of influence, and t=time during with discharge

H=h_{w0} in the figure

Also if $h_1=h_0, r_1=r_{w,} and\ h_2=H$ at $r_2=R$ are substituted

$$k=\frac{q\ln\left(\frac{R}{r_0}\right)}{\pi\left(H^2-h_0^{\ 2}\right)}$$

And in these an h wherever we have used h actually that h actually nothing but h_w naught whatever diagram is shown as a h_w naught that is actually in whatever expression I am getting h there actually h_w naught. This small difference please maybe noted and you can see if h1 equal to h naught h1 equal to is naught means what? Actually, h naught actually also uses nothing but h_w naught, yes h naught equal to h naught, that is correct.

That means, if there is a well and you have this is this type of things. I am considering the pumping well itself is one of the observations well, in that case your h_1 equal to h naught and r1 equal to r_w , r from sub center of these to these the r_w so r_1 equal to r_w h_1 equal to h naught that means, one of the observation, will get, will itself can be considered as one of the observation well, and another thing is I already know the R.

An h_2 equal to H, that means, h_2 equal to H means, where there is no change in water table. So, that is h so, that means that is the distance h_2 suppose if I consider and add r_2 equal to R at r_2 to equal to R, h_2 equal to H, r_2 equal to R. That means, that this influence distance can be obtained that distance h_2 actually H, if I know these, then this can be substituted k can be this equation can be used instead of the earlier equation where we have shown q ln your r_1 by r_2 pi h_2 h_1 square minus h_2 square.

This is the way also using the well as without there is no observation well is required first of all we estimate that the radius of influence and then consider well, well as one of the observations well and at a distance where there is no influence that is another observation point these two observation point both everything is known. That is why that can be applied and this equation can be used alternatively, when there is no observation well. This is actually some modification to actual earlier equation, otherwise, it is same thing.

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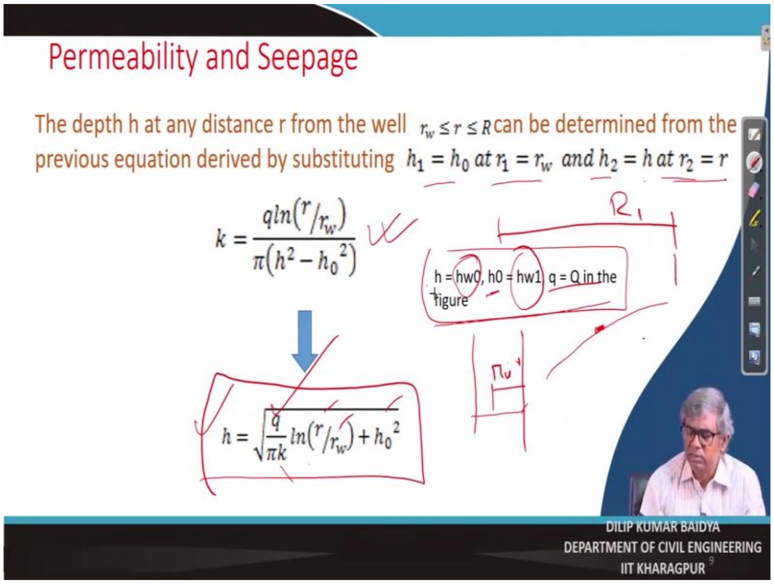

Now, if I the depth h at any distance r from the well if because sometime you want to find out that this is the well and this is a drawdown curve and at a distance somewhere at a distance actually this is r this is R_i and this is r_w so, in between this is r_w, r_w to R_i between any point if I consider at that point, what is the h if I want to sometimes we need to find out if you want to find out that also can be done by using an h1 equal to h naught at r1 equal to r_w.

And h_2 equal to h at r_2 equal to r, then this equation can be and from this equation one can simplify to find out h one can express by this observing quantity q, k then r, r_w, h naught by knowing all those things, one can find out what is the drawdown at a distance h. So, 2-3 things can be done. I One is actually by pumping water what is the radius of influence can be obtained, then by some empirical equation, if there is no observation.

The depth h at any distance r from the well $r_w \le r \le R$ can be determined from the previous equation derived by substituting $h_1 = h_0 at\ r_1 = r_w and\ h_2 = h$ at $r_2 = r$

$$k = \frac{q \ln\left(\frac{r}{r_w}\right)}{\pi\left(h^2 - h_0^2\right)} \quad h = h_{wo}, h_0 = h_{w1} \ q = Q \text{ in the figure}$$

$$h = \sqrt{\frac{q}{\pi k} \ln\left(\frac{r}{r_w}\right) + h_0^2}$$

Well, then how to find out the quantity of lower permeability coefficient by modifying the equation that is there and then in between at any other location between the well point to the point where there is no influence some point what is the location of water table if I want to find out or what is the head there, then this can be this equation can be used with modifying this.

And from this equation we can express h in terms of all those parameters and here actually to be noted in the model itself whatever I have not shown notation on whatever h I am showing here that h is nothing but h_w naught whatever h naught I am showing that is nothing but hw1, q equal to Q, all those things to be accordingly to be read. This is particularly for solving problem will be essential. So, this may be noted. So, let me go to the next slide.

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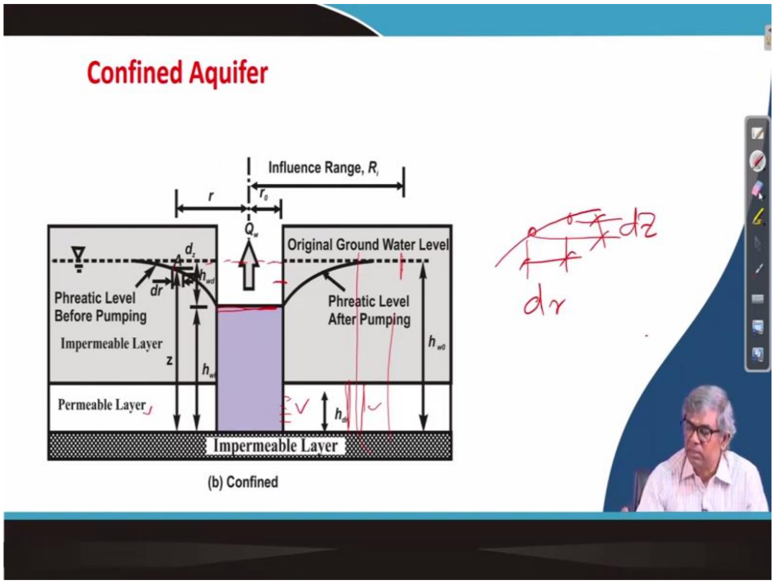

This is actually confined aquifer model and you can see confined means actually water bearing layer is this one and this is something other layer impervious and this is also but if you now penetrate this well now we will be seeing water because this is under some pressure and if I make an observation well you will show water level somewhere here. In under these actually, the well when will punch then we will go water is only is here, but I see the water here only.

And correspondingly if I pump continuously the originally, if I punch originally, you may see the water is coming is here, then if I go a pump for some time, then water table will be drawn there will be drawdown curve as usually observed that can be obtained like this and here actually since water is entering from here only there is no free surface like previous case.

There is directly there is directly this water surface in this is itself head here are a water level. So, there is no free surface under this condition. And similar to these here also on this curve one that is a clumsy portion is somewhere here and here, then this distance is d_r and this distance is d_j to show d_z by d_r actually I have this coming at a particular point that is the point is shown.

This is again the model for confined aquifer, again it has r naught distance r we are considering a radius of influence everything is similar, except here actually, when water is entering through the, the aquifer, then actually can see the surface area is constant. There actually if I consider here, then the 2 pi r into this height, because that is a cylindrical surface water is entering.

But when it is a confined aquifer, the cylindrical surface is constant, 2 pi r into this thickness. Because of that is the only difference in the derivation which I will show you in the next slide. You can see here.

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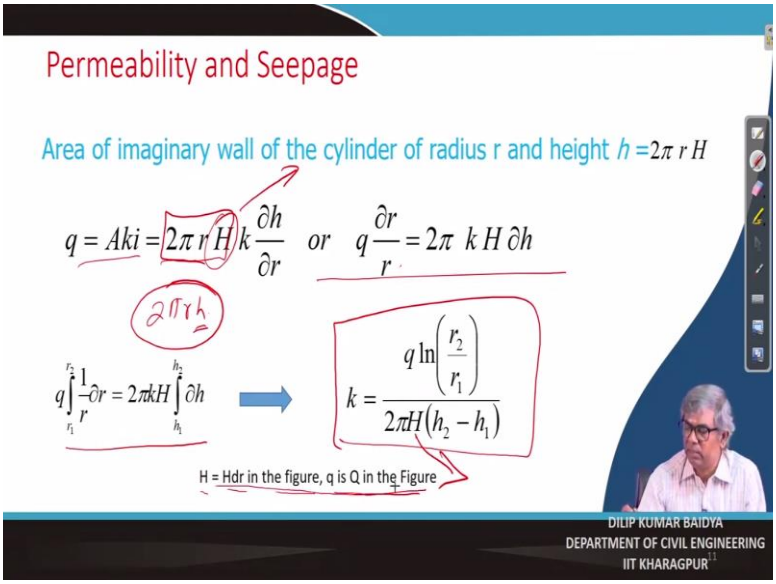

You can see here a similar to q equal to Aki 2 pi here actually what they are actually 2 pi r into 2 pi r into h, h is variable, but here this h is constant it is a thickness of the confined layer, which is shown differently H dr in the figure so H equal to H dr that I will show you a and everything is same you can see a previous expression it was there these expressions this is the H, H equals small h is expressed by capital H, small h is a variable whereas capital is constant which is the thickness of the confined layer.

Area of imaginary wall of the cylinder of radius r and height h=2πrh

$$q = Aki = 2\pi rhk\frac{\partial h}{\partial r}\ \ or\ \ q\frac{\partial r}{r} = 2\pi kh\partial h$$

$$Q_w = \frac{\pi k\left(h_{wo}{}^2 - z^2\right)}{\ln R_i - \ln a_w}$$

$$Q_w = \frac{\pi k\left(h_{wo}{}^2 - z^2\right)}{\ln R_i - \left(1/N_w\right)\ln\left(x_1.x_2..........x_{Nw}\right)}$$

N_w is the number well

$$q = Aki = 2\pi rHk\frac{\partial h}{\partial r}\ \ or\ \ q\frac{\partial r}{r} = 2\pi kh\partial h$$

$$q\int_{r_1}^{r_2}\frac{1}{r}\partial r = 2\pi kH\int_{h_1}^{h_2}\partial h$$

$$k = \frac{q\ln\left(\frac{r_2}{r_1}\right)}{2\pi H\left(h_2 - h_1\right)}$$

$H = Hdr$ in the figure, q is Q in the figure

If you simplify it will come like this, then it will be integrated, the if you put then ultimately you will get an expression like this. Here actually this h is actually thickness of the layer. H equal to Hdr in the figure gives the Q in the field that is what this is the only difference you have to note because hurriedly I have drawn the type this equation but I have a forgot to maintain consistency with whatever is the figure. Wherever there is a change I have mentioned here. This can be noted while studying this. So, next slide.

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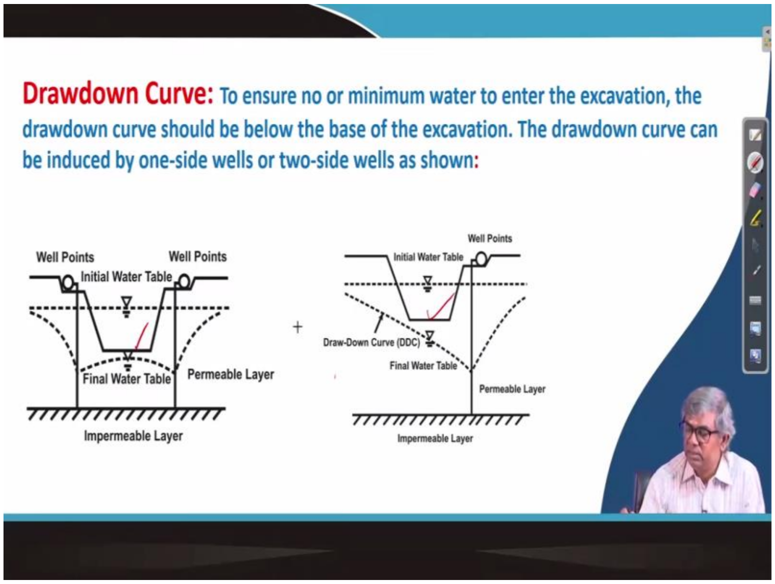

you can see the drawdown curve already I have told you the drawdown the how much is the drawdown curve how much it how it will be how much to be so drawdown curve should be exceeding the to ensure no or minimum water to enter the excavation. The drawdown curve should be below the base of the excavation. If this is the base of the excavation and you can see this is the base of the excavation, this is the base of the excavation.

Then what drawdown curve should be just below this. By applying pumping from here pumping from here, we can lower like these and if you want to pump from one side, then you can pump like you can have the drawdown like this. This is some schematically what is drawdown and the drawdown curve can be induced by one side wells or two sidewalls as shown that is what we have mentioned already.

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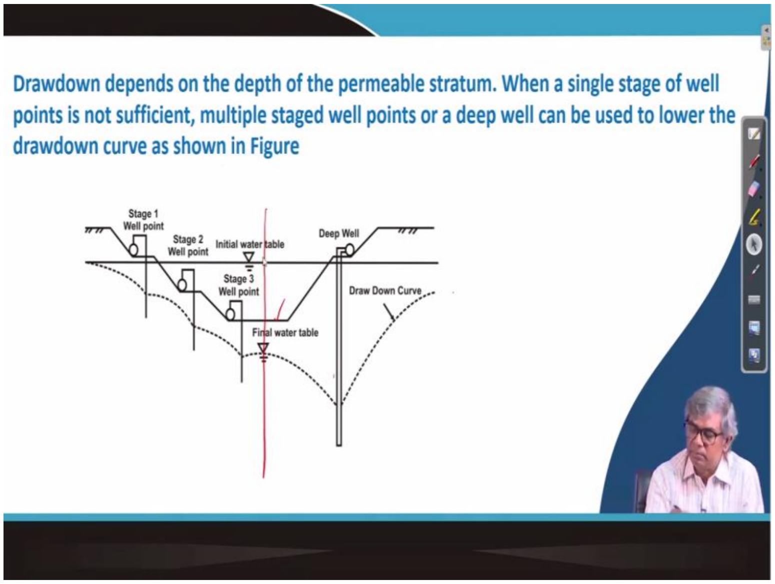

And then drawdown depends on the depth of permeable stratum another against when the single stage well, point is not sufficient like suppose, I consider this is a symmetric this side suppose, one tried like this, but this is this much is our lowering this point is enough, but if I want to lower further sometime, we may do we may have to do multi stage, that is what we have already discussed what is multi stage what is single point or multi stage well point. Either like this or like this, both ways can be done

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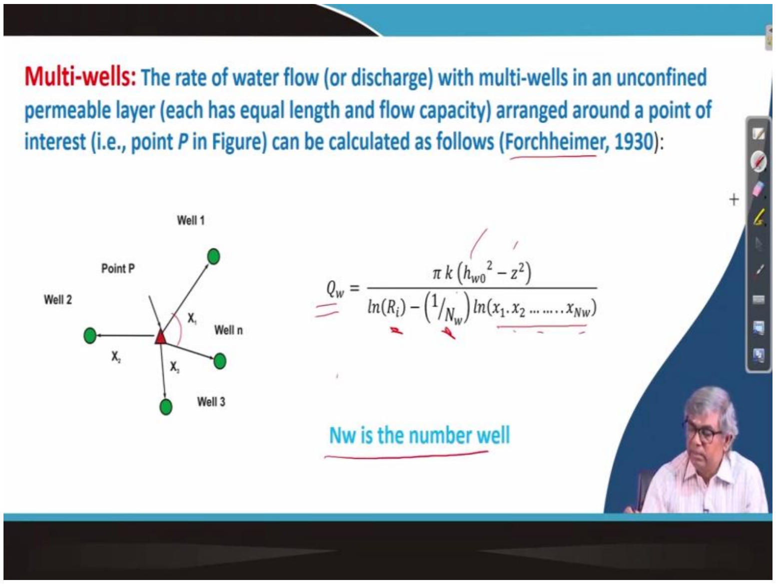

Then you can see multiple here actually can see, I can imagine the number of wells actually 1, 2, 3, 4 and I can consider a point P somewhere here and they are distance X_1, X_2, X_3, and then if I do that, then I can find out quantity of flow Q_w in terms of those parameters you can see here is w naught square z square and a distance.

This is the point actually, what is the value we have to find out. To find out that these are the expressions used Ri area of influence, then number of wells and then x_1, x_2, xN_w these are actually distance from this point. Point P when there is a distance x_1, x_2, x_3, x_{10}. And then h naught, h_w naught square minus z square.

This is observed actually in all well perhaps, and then what is the z square actually at this point by this equation one can find out. So, that means, with multi wells in an unconfined permeable layer equal each has equal length and flow capacity arranged around a point of interest suppose point P can be calculate as follows that is the person who has given this equation by using this equation one can find out. N_w is the number of well.

$$Q_w = \frac{\pi k \left(h_{wo}^{\ 2} - z^2 \right)}{\ln R_i - \left(\frac{1}{N_w} \right) \ln \left(x_1 . x_2 .... x_{Nw} \right)}$$

N_w is the number well

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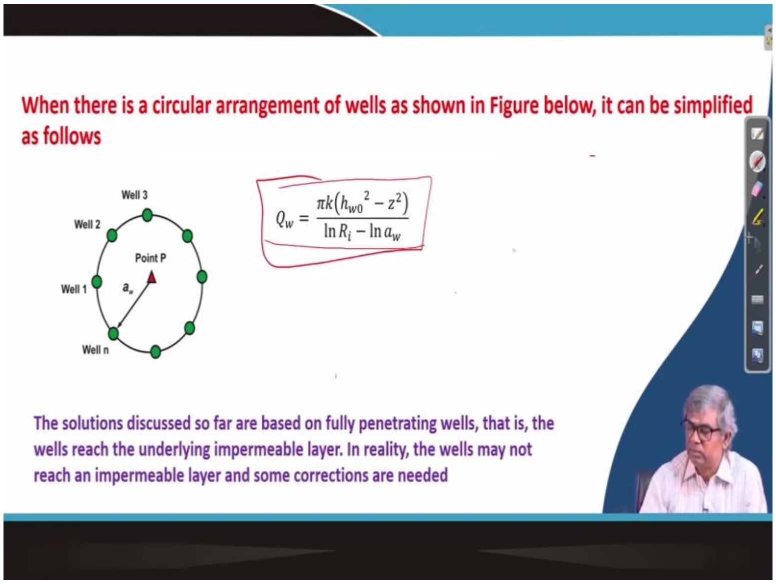

And then and if it is same problem supposes this is N is little differently, you stop putting the well in randomly, if I put, if I arrange in such a way it is forming a circle, then at the point inside at the center, then that flow can be how it will be. This can be this is the expression when there is a circular arrangement of well as shown in the figure below. It can be simplified as for the same previous equation it will be simplified in this form.

$$Q_w = \frac{\pi k\left(h_{wo}{}^2 - z^2\right)}{\ln R_i - \ln a_w}$$

The solution discussed so far are based on fully penetrating wells that means, when I will be confined or unconfined that it has to penetrate and it has to go to up to the impermeable layer that is the assumption. But many times, this does not happen it does not happen then always actually there will be error. So, because of that one has to correct otherwise there will be error so that is what.

With this of different types of well with this, perhaps I will close this lecture. And I have so far taken almost all aspects of Drainage and Dewatering methods and some calculation method. And now I will try to take the next lecture one problem and there are minor issues when we will do dewatering how to overcome that issue that also I will discuss. With this I will close here. Thank you.