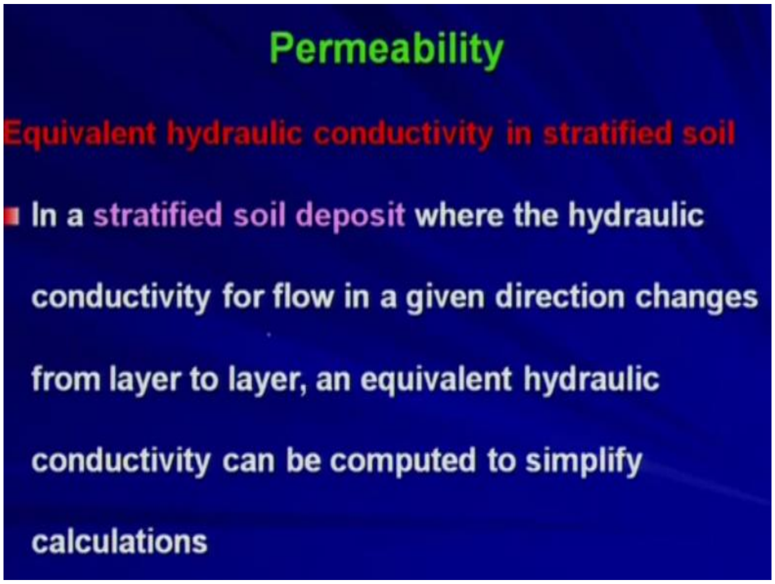
Geology and Soil Mechanics
Prof. P. Ghosh
Department of Civil Engineering
Indian Institute of Technology Kanpur
Lecture - 17
Permeability - B

Welcome. Welcome back to the course Geology and Soil Mechanics. So, in the last lecture we have seen how to find out the hydraulic conductivity from the laboratory experiments as well as there are several empirical equations were available. So, now we will see that if you have the stratified soil deposit that means it is quite common right, you will not be getting the homogeneous soil deposit rather you will be getting some layered soil deposit. Now if you have the layered soil deposit, then how to find out the equivalent hydraulic conductivity in that stratified soil.

(Refer Slide Time: 00:46)



So, let us see how to obtain that. Now in a stratified soil deposit where the hydraulic conductivity for flow in a given direction changes from layer to layer and equivalent hydraulic conductivity can be computed to simplify calculations, it is quite obvious. That means if you have layer wise deposition in the actual soil deposit so basically each layer will be having its own hydraulic conductivity or the coefficient of permeability.

But if you want to analyse the whole stratified deposit as a whole then basically you need to obtain and basically that will be your convenient way to obtain the equivalent hydraulic conductivity so that you can calculate or you can find out the total flow which is happening through the stratified deposit okay. So, let us see how we can find out that equivalent hydraulic conductivity.

(Refer Slide Time: 01:41)

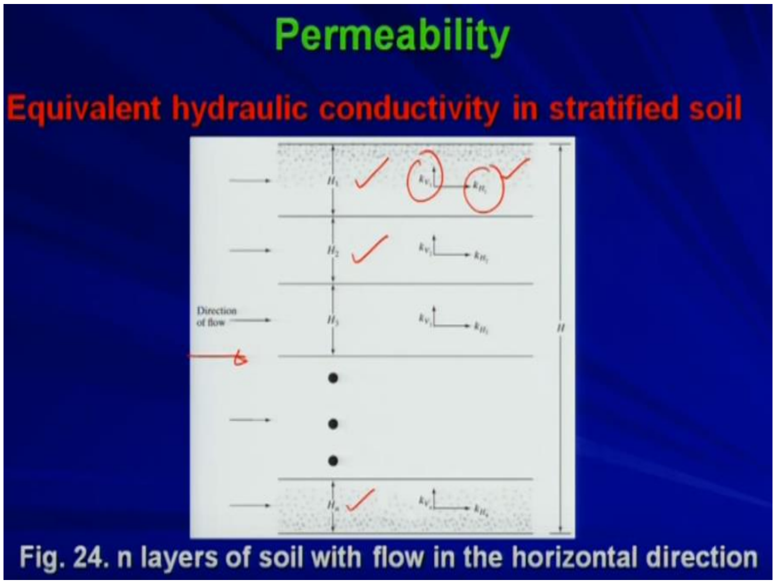
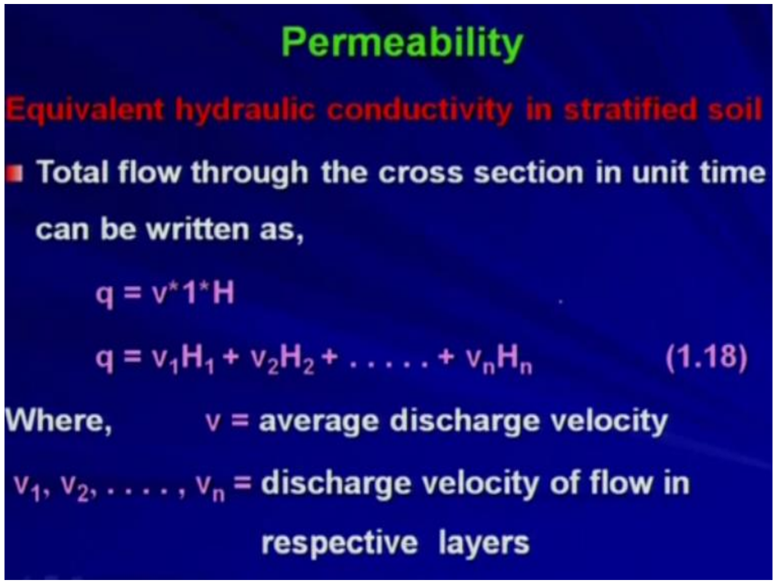


Fig. 24. n layers of soil with flow in the horizontal direction

Now in this situation basically if you look at the direction of flow in this direction that means the horizontal flow is happening and you have the different layers, so the top layer is say H 1, the depth of the top layer is H 1, depth of second layer is H 2 and so on. So, you have got n number of layers and which is having different say coefficient of permeability or the hydraulic conductivity in different direction say along so horizontal direction you have k H and along vertical direction you have k V 1.

However, we are considering the direction of flow in the horizontal direction so k H will be coming into the picture. So, for layer 1 k H 1 is the coefficient of permeability whereas for layer 2 k H 2 is the coefficient of permeability in the horizontal direction and so on and total depth of the stratified deposit is capital H. So, you have got n layers of soil with clay in the horizontal direction.

(Refer Slide Time: 02:37)

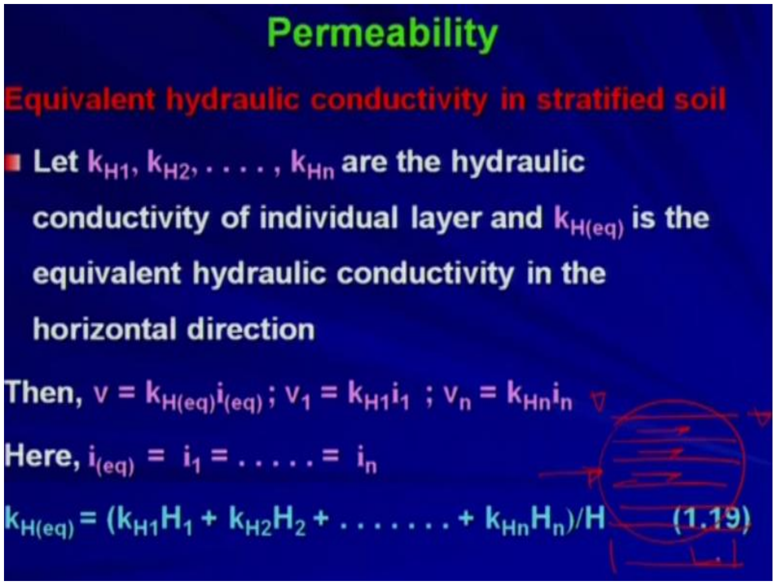


Now the total flow through the cross section in unit time can be written as v into H into 1 right. So, we are considering some unit length normal to the board or normal to the say screen okay. So, that means H is the depth of the stratified layer and 1 is the unit length normal to the screen. So, the cross-sectional area is 1 into H multiplied by v will give you the flow through the soil deposit okay.

Now q is equal to now this flow whatever flow you are getting, that is the total flow which is happening through the stratified deposit. Now if you consider the if each layer is participating that means each layer is acting as a single pipe okay. The layer 1 is a say one pipe, then layer 2 is another pipe, layer 3 is another pipe and so on. So, this total q will be contributed by different flow through the pipes okay.

So, q is nothing but equal to v 1 into H 1 that means the flow which is happening through the first layer. Then plus v 2 into H 2 which is happening through the second layer and so on up to v n into H n okay. So, that is the total flow. So, total flow is divided or subdivided into number of flow in the layers. Now where v is the average discharge velocity and v 1, v 2 up to v n is the discharge velocity of flow in respective layers.

(Refer Slide Time: 04:24)



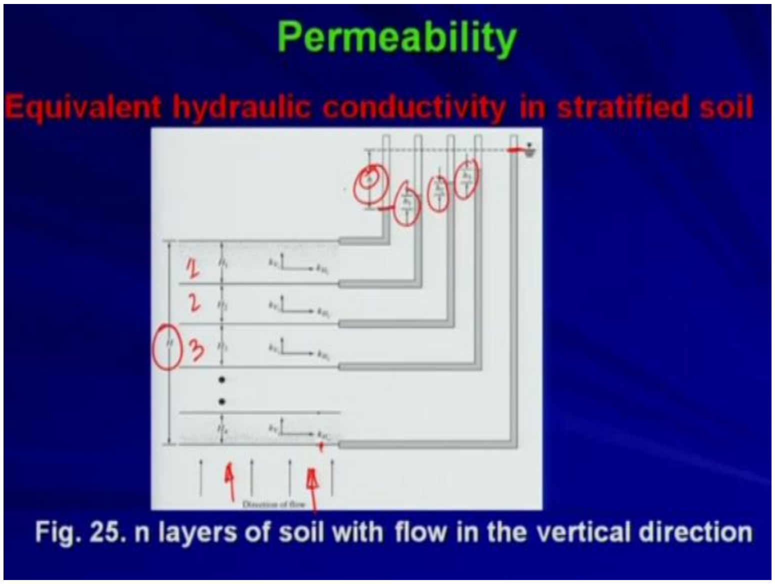
Now let k H 1 as I told you k H 1, k H 2 up to k H n are the hydraulic conductivity of individual layer and k H eq, eq is the equivalent, eq stands for equivalent. So, k H equivalent is the equivalent hydraulic conductivity in the horizontal direction. That is okay. So, now we can write v that is the velocity through the whole deposit when you are considering the whole deposit together then v that is the velocity is equal to k H eq multiplied by i eq, as simple as that ki and we can write similarly v 1 is k H1 into i 1, v n is equal to k H n into i n and so on.

Now here if you look at the problem, if you go back to because your problem was this is this was the deposit okay layer deposit, flow is happening here okay. So, whatever head was here say and whatever head you are getting here so this head difference or the head loss which will be remaining same when the flow is happening whether it is happening through the whole layer or whether it is happening through the first layer or second layer or third layer.

Whatever is the case, your head loss is same and the length along which the flow is happening, that is also remaining same whether you are considering individual layer or the stratified deposit. So, your i eq that is the i equivalent must be same to i 1, must be same to i 2 and so on up to i n right. So, hydraulic gradient is same.

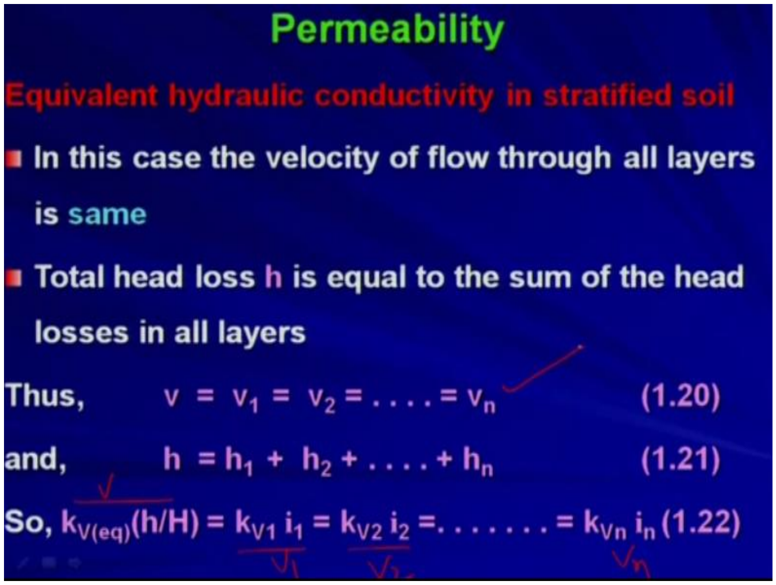
So, therefore we can write k H equivalent is equal to k H 1 into H 1 plus k H 2 into H 2 up to k H n into H n by H because from this expression from this relation we can write this. So, if you know the k H 1 that is the hydraulic conductivity in the horizontal direction for layer 1 and this is the depth of layer 1, similarly k H 2 H 2 and up to n layer if you know these parameters because these are the things you can find out and if you know the total depth of the stratified deposit then you can find out equivalent hydraulic conductivity k H eq.

(Refer Slide Time: 07:09)



Now coming to if the flow is happening in the vertical direction. Now in this situation, in this case you see the layers are I mean this H 1, this is your layer 1, layer 2, layer 3 and so on. This total depth of the stratified deposit is H and direction of flow is vertical direction. Now in this case basically you see when flow is flow is happening in this direction entering the first layer and exiting the first layer, so this is the head okay. Now similarly when it is crossing individual layer you are getting some head loss. So, this head loss you can measure through the standpipes right. So, that means your head loss is different in this case okay.

(Refer Slide Time: 08:00)



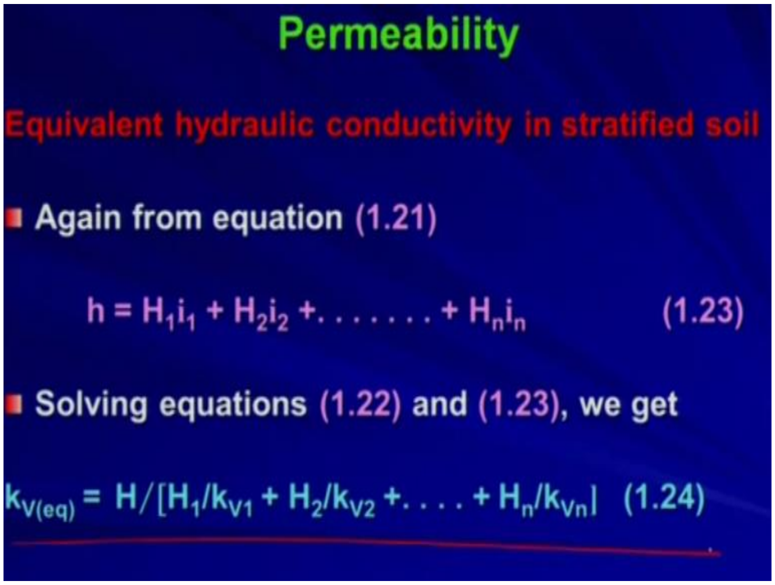
Now, so in this case the velocity of flow through all layers is same. Do you agree or not? Because the flow is happening in the vertical direction, so I mean the velocity of flow okay will be same along the along individual or along all the layers. So, the velocity of flow in layer 1 must be same, the velocity through the layer 2 and so on right. So, we can write the total head loss h is equal to the sum of the head losses in all layer's okay.

The total head loss you have seen. So, this is the total head loss. That means if the flow is happening from this side and so this is the head at the entry level and this is the head at the exit level, so total head loss is small h. So, small h must be equal to the summation of all the head losses in individual layers. Thus, v that is the velocity along the stratified deposit must be equal to v 1 that is the velocity through the layer 1 equal to v 2 that is the velocity through layer 2 and up to v n.

So, all are same, the velocities must be same and h that is the total head loss is equal to h 1 that is the head loss happening in layer 1 plus h 2 that is the head loss happening in layer 2 plus up to h n that is the head loss happening in nth layer. So, k v equivalent that is the equivalent now we are going to find out the equivalent hydraulic conductivity. So, k v eq into small h by capital H. What is small h by capital H?

That is the total head loss by the depth of the stratified deposit which will give me i equivalent right. So, k v equivalent into h by small h by capital H is equal to k v 1 into i 1. This part is nothing but your v right, that is the equivalent or the velocity through the stratified deposit. Now what is this? k v 1 into i 1, that is nothing but the vertical velocity along layer 1 which should be equal to this v, this is v 2, this is v 1 and so on up to v n. Already we have seen this thing from equation 1.20.

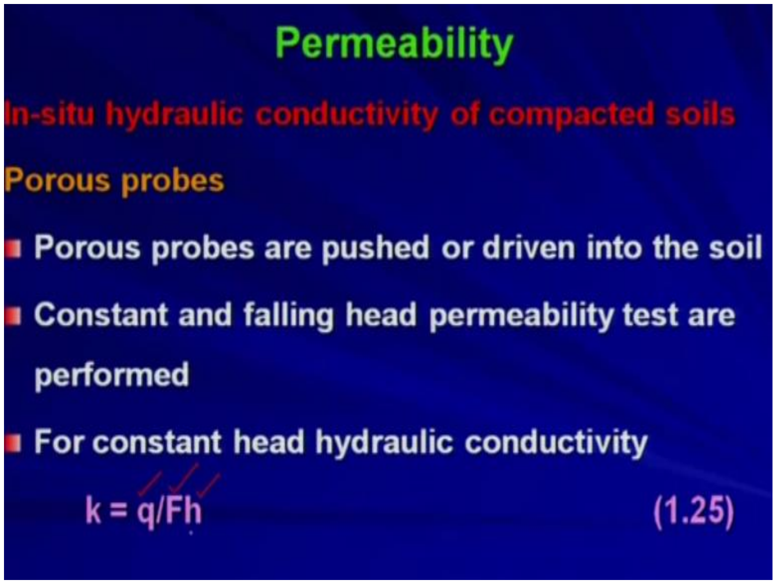
(Refer Slide Time: 10:36)



So, again from equation 1.21 we saw that small h is equal to H 1 into i 1 plus H 2 into i 2 plus up to H n into i n. So, solving equations 1.2 and 1.23, so this is the equation and 1.2 is here so this is the 1.2 and 1.23 if you solve these 2 equations you will be getting k equivalent is given by this expression where k v equivalent is equal to capital H which is nothing but the total depth of the stratified deposit divided by H 1 by k v 1 plus H 2 by k v 2 plus up to H n by k v n.

So, it is very much similar to in the electrical engineering if you think about the I mean resistance which is connected in series or which are connected to in the parallel orientation or the series orientation. So, based on that you have got some equivalent resistance right. So, you might have done that thing in your under graduate basical electrical engineering, it is very similar to that. So, we are considering the flow in vertical direction as well the horizontal direction and if you have got the stratified layer you can find out the equivalent hydraulic conductivity in this fashion.

(Refer Slide Time: 12:02)

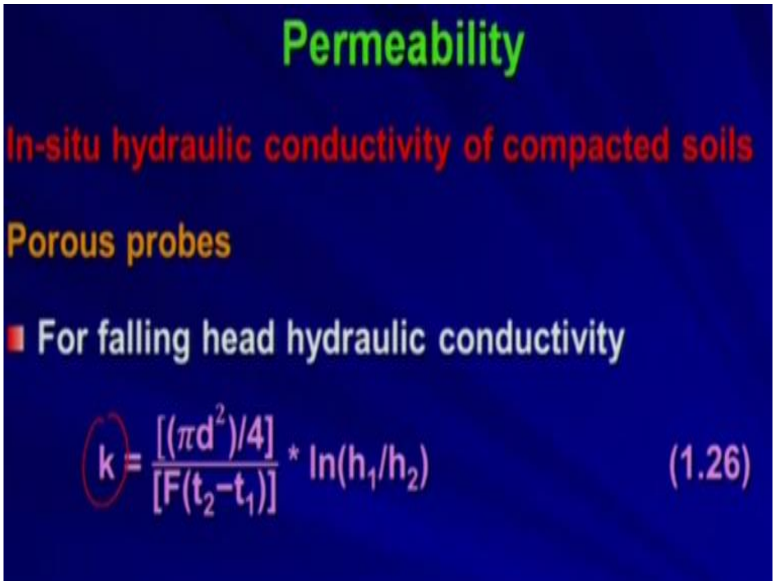


Now coming to in-situ hydraulic conductivity of compacted soil. So, now we are going to find out the in-situ that means in the field if you want to find out the hydraulic conductivity how you can find out right. So, basically in to find out the hydraulic conductivity in the field basically you have the porous probes okay. So, porous probes are pushed or driven into the soil. So, porous pores means something like which will be the material is porous and that that pore is having the surface area of the probe is very porous.

So, if you put water in the standpipe so that will allow the water to come out from the surface of the porous probe. The constant and falling head permeability test are performed so both the test whatever you have done in the laboratory the same thing can be replicated in the field through this porous probes. Now let us see how to do that.

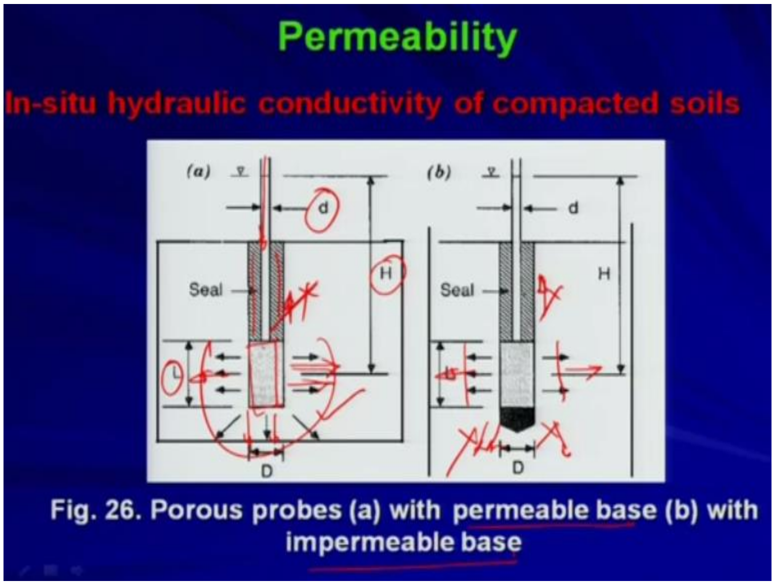
For constant head, hydraulic conductivity k is equal to q that is the flow divided by F into h, F is some parameter, some function or some constant. So, we will see that how to find out that F for different conditions okay. So, basically what I mean to say, if you know this, you can find out this. I will give you those expressions and if you know the head loss that is the for constant head because you are maintaining the head in the standpipe. So, this 3 things if you are known to you then basically you can find out the hydraulic conductivity in the field itself.

(Refer Slide Time: 13:41)



Now for falling head hydraulic conductivity so k is given by this expression pi d square by 4 log base e into h 1 by h 2 divided by F into t 2 minus t 1 okay.

(Refer Slide Time: 14:00)

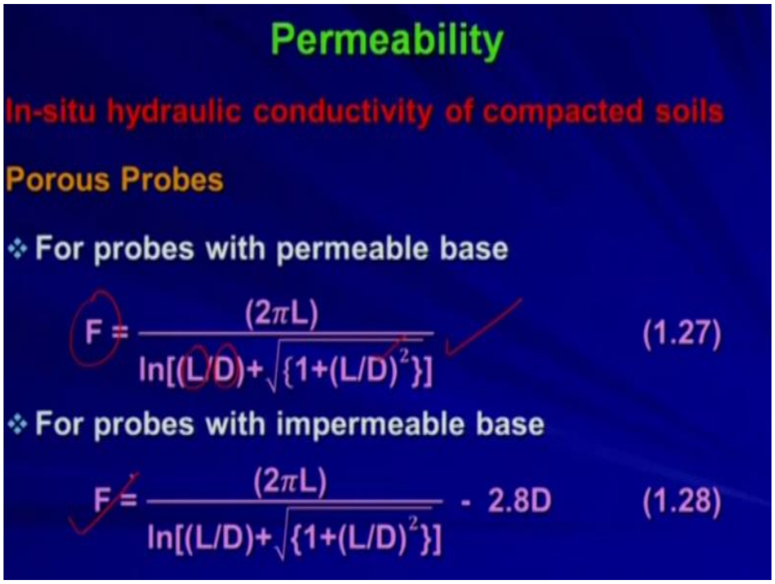


Now this is the porous probes. This porous probes will look like this. Now porous probe can have the with permeable base that means the flow is happening. So, this is the standpipe okay and at the base of the standpipe you have the porous probe, this is your porous probe. So, you are driving it or pushing it in the ground. You are sealing it so flow cannot happen in this direction okay. Flow will be happening only in the lateral direction or in the downward direction as it is shown if you have the permeable base.

So, this is for permeable base okay. So, flow is happening in this zone okay and the length of the porous probe is say capital L and the mid height depth is say capital H, small d is your diameter of the standpipe. Now if you have the impermeable base that means below the porous probe the flow is not happening. So, this so you are having the flow which is confined in the lateral direction.

So, basically you have the impermeable base so that is why the flow in this direction, this direction, this direction, these are not allowed and of course you have put the seal so in this direction also flow is not occurring. So, therefore now based on that definition so d was the diameter of the standpipe and h 1 and h 2 two different say head you are observing at the starting at the finishing and t 2 and t 1 these are 2 times you are observing at the starting point and the finishing point of the test. Now F is completely unknown to us right now at this moment. So, let us see how to find out F.

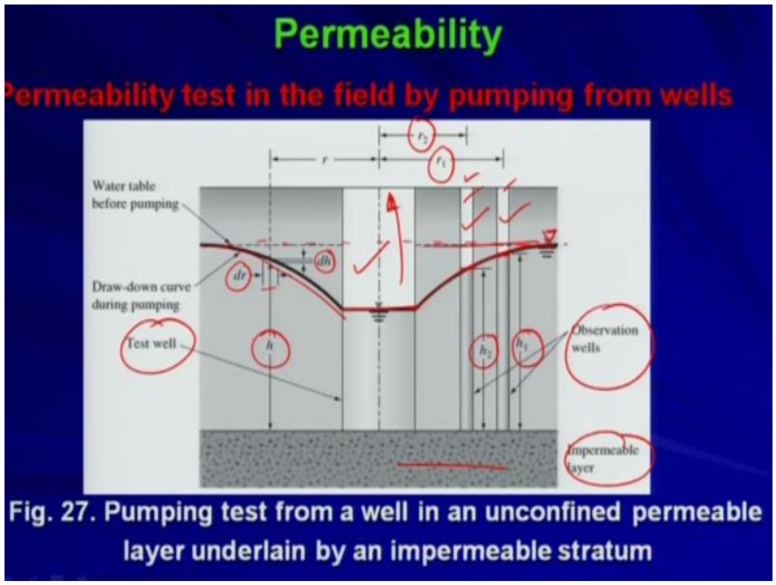
(Refer Slide Time: 15:51)



So, for probes with permeable base F is given by this 2 pi L, L is the length of your porous probe divided by log base e into L by D plus root over 1 plus L by D whole square. So, this L is known to me, D is known to me. What is D? So, if you go back to this, D is the diameter of the porous probe okay. Small d is the diameter of the standpipe and L is the length of the porous probe. So, if you know all those things about the porous probe for permeable base, you can find out F.

You go back to the earlier equations to find out the hydraulic conductivity if you are doing if you are performing the falling head test or if you are performing the constant head test, based on that you can find out hydraulic conductivity. Similarly, for probes with impermeable base you have the expression for F like this. So, similarly you can find out F from this and you can go back to the previous equations to obtain hydraulic conductivity. So, in-situ we perform the test in this fashion.

(Refer Slide Time: 17:06)



Now permeability test in the field by pumping from well. Now basically what we do here. Here actually we perform the permeability test in the field itself by excavating some wells. So, what are the wells we are excavating? This is your test well okay and these are your observations wells as it is written here. So, this is your test well as it is written here. Now basically, try to understand, and you have the impermeable layer here, so this is your impermeable layer at the base of the well.

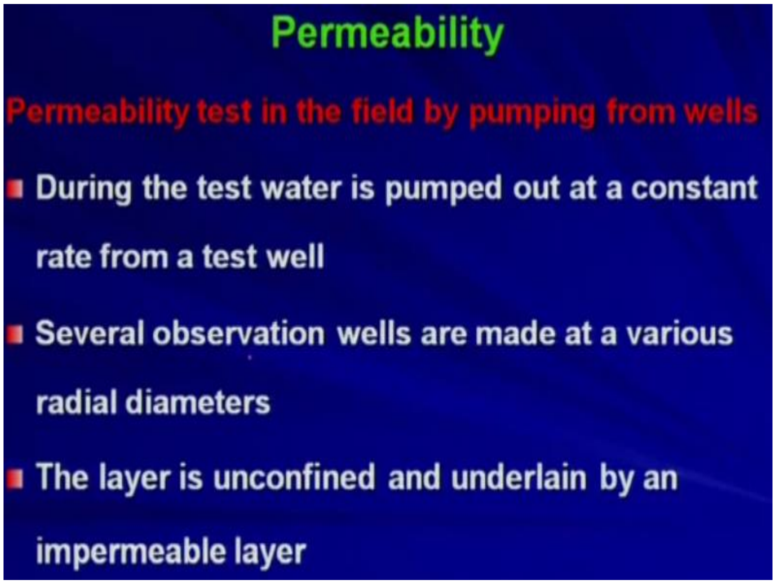
Now what you do here? Now basically you can have more number of say observation wells. So, there is no restriction for the observation wells. Now once you propose some observation wells like this so you know the location of the observation wells from the center of the test well right. So, r 1 is the radius okay or the distance from the test well to the observation well 1 and r 2 is the distance from the test well to the observation well 2 right.

Now what exactly we are doing here? So, basically this was your initial water table, it is shown here. This was your initial water table okay. Now what you do, you try to pump out the water from the test well. You try to pump out water from the test well. So, initially in all the wells before pumping, the water level was there because that is the water table say, water table available in the soil deposit. So, in all the wells you will be having the same level of water.

Now you are pumping from the test well. Now what will be happening? So, you will be getting the draw down from your water resource engineering knowledge or say fluid mechanics knowledge you will be getting the draw down curve. So, this is your draw down curve. So, this is the now this is the level okay changed level in the test well. This is the changed level in the observation well 2, this is the changed level in observation well 1 right.

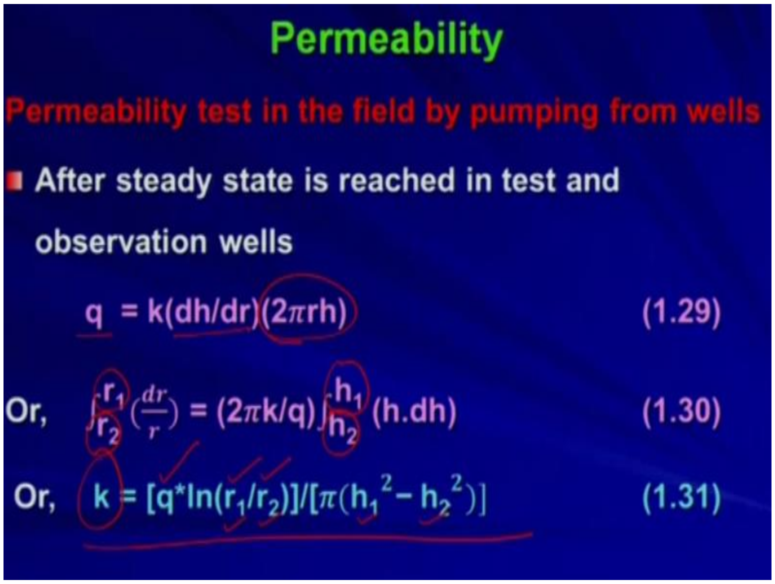
So, now your h 1 will give you the information about the level in observation well 1, h 2 will give you the information about the water level at observation well 2 and this so we are considering some say small incremental distance dr and small incremental say head difference dh and it is happening say at head h. So, these are the things are required to do the analysis or do the calculation. So, understood the phenomena? So, these are the things we are doing in the field.

(Refer Slide Time: 19:54)



Now during the test, water is pumped out at a constant rate from a test well. Several observation wells are made at a various radial disc diameters as I told you. The layer is unconfined and underlain by an impermeable layer. So, therefore no water is going below the well.

(Refer Slide Time: 20:18)

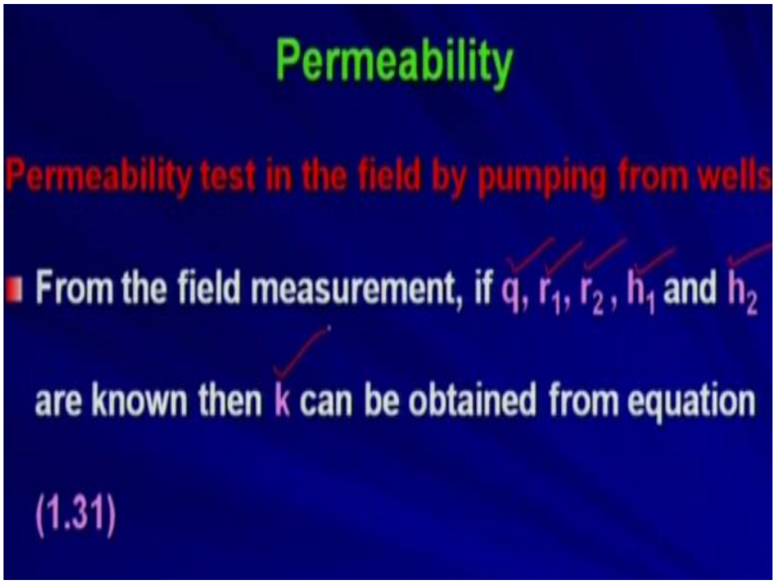


Now after steady state is reached in the test and observation well because you are pumping out, so you are allowing to reach the steady state okay. So, after steady state is reached your q that is the rate at which you are pumping out is equal to k into dh by dr. What is dh by dr? dh was the head loss which is happening with the incremental length, that means dr. So, this is giving me i right, hydraulic gradient and at what is the area 2 pi r into h. So, this is happening 2 pi r into h, that is the cylindrical surface okay.

Now we are doing the integration over r 1 to r 2 because we are having 2 different observation wells and so r 1 and r 2, these are 2 limits or h 1 and h 2 are the observations of the water levels at observation wells 1 and 2 respectively. So, from this expression I can find out k. So, that is my hydraulic conductivity. So, this is known to me because you are pumping out so you know what at what rate you are pumping out, r 1 is known to you, r 2 is known to you why because you when you are putting or placing the observation wells you know the location of the observation wells.

If you know the location of the observation wells with respect to the test well so you must know r 1 and r 2. Then h 1 and h 2 these are 2 observations in the observation well because these are the water levels available now after pumping out that means when the draw down is happening, at that time what is the water level at observation well 1 and observation well 2. So, this equation will give you the hydraulic conductivity in the field. That means I mean through the well and the pumping out water from the well.

(Refer Slide Time: 22:15)



So, from the field measurement if q as I told you r 1, r 2, h 1, and h 2 are known then k can be obtained from equation 1.31. So, I will stop here today. So, in the next class we will solve couple of problems on the permeability and we will see how well we can understood understand the phenomena of permeability. Thank you very much.