Geotechnical Engineering I
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Lecture-16
Permeability of soil and Ground water flow-I

Until now, we have discussed about the characteristics of soils and we have tried to characterize them. We also talked about their classification scheme, we talked about the compaction characteristics. And henceforth we will be trying to use these concepts in answering most of the real life problems which as a geotechnical engineer or as a civil engineer one has to face. I would be talking about seepage characteristics which are quantified by using a mathematical parameter permeability of soils

Sometimes people use the term hydraulic conductivity also for this. But in wider application if I replace flow water through the porous media or the soil mass this could be any example which can be set as flow of hydrocarbons, flow of chemicals and so on. So hydraulic conductivity is a misnomer we will be talking about, then flow of groundwater is a very important discussion which has to be done at undergraduate level.

To understand what are the consequences of not understanding, how the flow of water influences the stability of the soil mass and the structures which are sitting on the top of this. Now from this point onwards I will also be trying to emphasize on the concepts of soil water interaction in the form of let us say kinetic process, where the movement of the water is occurring through the porous media.

So these type of studies become very, very contemporary and useful for the profession, where we try to understand how the movement of the groundwater is influencing the overall structures and their stability. I intend to talk about 3 major topics from this point onwards this topic should be covered another 3 to 4 lectures, followed by I will be discussing quite in details the compressibility of the geo materials and the soil mass.

And to understand the compressibility characteristics of soils one has to understand how the stresses that distributed in the soils. So these are the 3 major topics I will be covering henceforth and with that I will be winding up the course. So to begin with the permeability of soils and the flow of groundwater.

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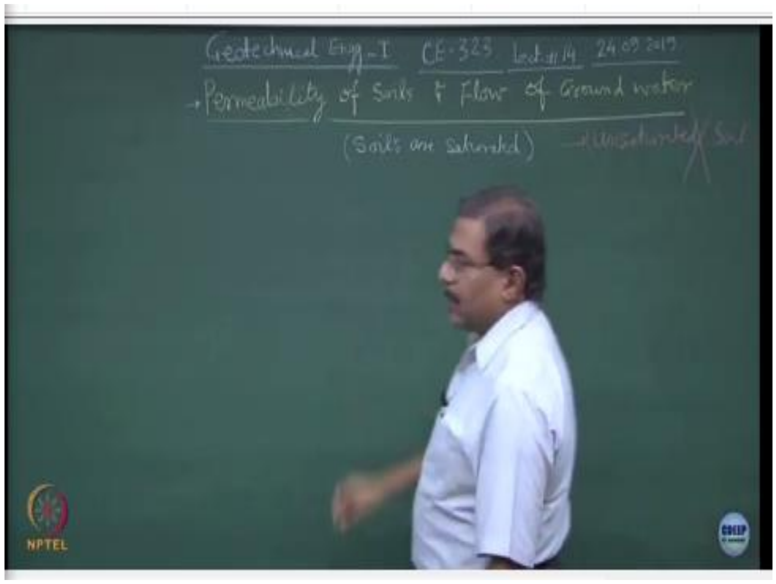

To make life simple we assume that the soils are saturated, so this is assumption number 1. If you do not assume the soils to be saturated, this becomes a completely different discussion, which falls under the realm of unsaturated soil mechanics. So at undergraduate level I will not be discussing unsaturated state of the material because the flow of water is going to be extremely complicated and combustion.

And I will restrict my discussion on the permeability of the saturated soils or the flow of water through the saturated soils. You have enough exposure of what capillary action does, what the unsaturated state of the material does, what the dry state of the soil does and so on. So the best way to understand this whole process would be.

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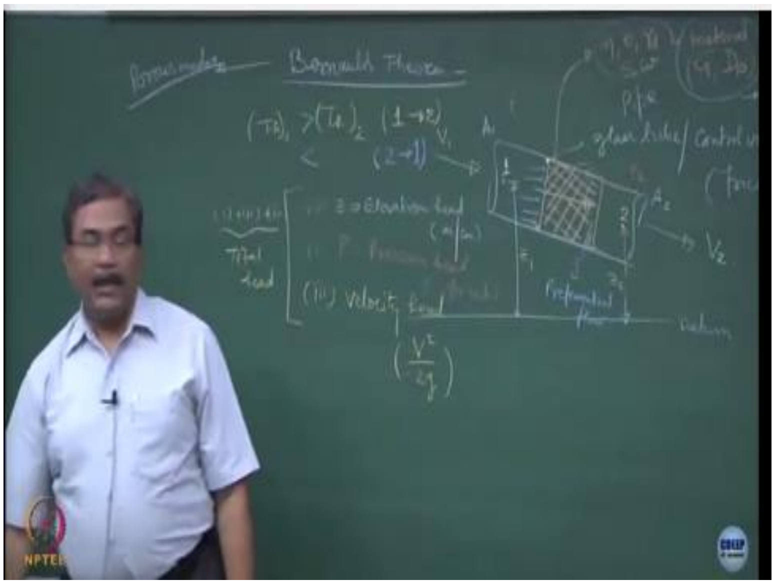

You must have studied the Bernoulli's theorem in your fluid mechanics course. Suppose if I take a glass tube and if I allow glass tube can also be considered as a control volume or this could be a pipe even through which the flow is occurring. Now suppose if I assume that these glass tube pipe or the control volume is frictionless in your hydraulics course, when you deal with the flow through conduce and the pipes, you apply the friction factor S e factor alright.

But here for the sake of simplicity we are assuming that there is no friction which is induced from the glass tube or the pipe or the control volume. And at this point, the velocity is V 1 and at this point the velocity is V 2 alright, if I know the area of cross section here as A 1 area cross section here as A 2, what we are trying to do is. We are trying to find out, what causes flow of water between point 1 and 2.

I am sure you must have done this exercise if I consider a datum somewhere here. I know what are the heads which are acting at the point 1 and 2 and the head difference is going to cause the flow to occur. So if I say at point number 1, the height of point 1 is let us say z 1. Now z 1 is defined as the location head, z is defined as the elevation head in meters or centimeters or whatever. So point 2 is located let us say here at elevation head of z 2.

Now suppose if I say that the pressure head at this point which I am defining as P 1 and pressure head at point 2 I am defining as P 2. So P corresponds to the pressure head and the units will be the pressure units, if I divide this by the density of the fluid, this becomes the height of the fluid and the pressure can be converted into the height also alright. So we have elevation head, we have pressure head and the third one I am sure you must have studied is what is known as the velocity head.

Normally this is defined as V square upon 2g alright put together that is 1 + 2 + 3 is known as the total alright. So if I say that the total head, if I say the Th the total head, at point 1 is greater than total head, at point 2 the direction of the flow is going to away from 1 to 2 is this ok. However, if I reverse the situation and if I say that Th 2 is less than Th 1 a greater than Th 1. The flow is going to get reverted, it will be from 2 to 1.

So what we are trying to analyze from here is a situation, where we can establish the direction of the flow in a glass tube is this alright. This is nothing about your Bernoulli's theorem, now most of the time when we use these concepts in cases like soils or the porous media, what is going to change. Suppose if I want to extend this to porous media alright. So porous media means yeah you have some doubts yes please total heads have said as a general situation ok

So your objection but I have given A 1 and A 2 alright, area of cross sections are different. So V 2 is different than V 1, I think this is ok yeah, so I will come to this point just keep this mind alright. So for the time being there are no fictional effects, we are ignoring it and we are trying to see whether the total energy concept can be utilized to establish the direction of the flow alright, total head always total head.

Velocity also has to be included, elevation has to be included, pressure also has to be included always remember, yeah, I will come to that. But unless you have created a context what you are saying is not correct. So now let me create the context and that is what I was trying to do here. So the moment you extend this theorem to the porous media, now what you are saying is going to be correct.

So that means what I have to do is, I have to introduce an element of a porous media somewhere in between alright. Suppose, if this is a compacted soil mass, so what I have done is I have taken some soil in the loose form and I have compacted it within this tube to create this state of the compacted soil mass. So when you say compacted soil mass, the attribute of this control volume are going to be porosity agree void ratio, gamma d.

So this is a state of compaction, saturation ok, moisture content and what else the material is this correct. So material is represented by let us say, a specific gravity particle size distribution, what is the best way to depict particle size distribution here. The entire graph cannot be fitted sorry better than that sorry very nice, good. So let us say D 10 or D x for that matter clear, normally D 10 is used to define the material.

And hence we call this D 10 as the characteristic dimension of the porous media, choice is yours. You can take here D x also, but when you say standard terminology this is D 10 normally we use to define the material. So look what we have done, we started from by Bernoulli's theorem and we are now you know extrapolating it to the porous media by including a porous media over here fine.

And henceforth now will be discussing about the flow through porous media, is this part ok, everybody has followed this any question fine. So we have defined now the porous media in the form of it is compaction state and the material. Now what is going to prevail the flow one is definitely the total energy and the second would be the Reynolds number alright.

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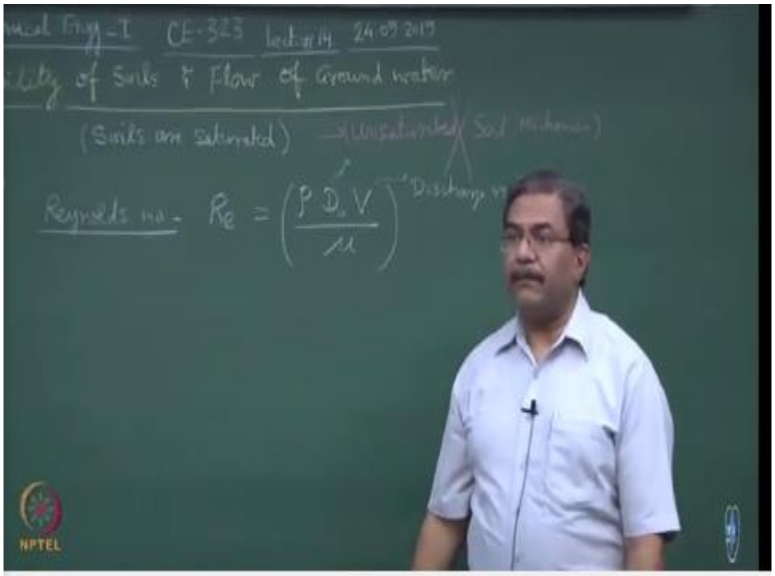

So we have to define the Reynolds number, you remember what is Reynolds number, we defined it as R e. So truly speaking is the ratio of viscous forces to the inertial forces, 2 things we should remember never get confused, what will be this D term characteristic length or the diameter, correct, you are right. So I can say this is D 10 and V happens to be the velocity, so whatever we been talking about was always discharged velocity.

Discharge velocity is the void of the porous media. I repeat discharge velocity is the void of the porous media as a porous media does not exist, what are the possibilities when porous media would not exist. The only possibility is what we call as preferential flow, that means what is going to happen. The water (()) (15:32) the porous media provides the resistance to the flow of water clear, so everybody wants easy life.

So, what seepage has done what discharge has done, it has short circuited the sample itself. Now this is what is known as a preferential flow is at the interface of 2 materials mostly, chances are when you are compacting the sample, the contact between the glass tube, the pipe or the control volume and the soil mass is not perfect. And hence, whatever discharge is taking place this might take place through the preferential flow ok, however, if I cutting this preferential flow you will ask why, how.

So, I may put a rubber gasket over here or I may put some different types of raisins or I am put different type of what you call a lubricants or sealants, so what I will be doing. I will be cutting off the preferential flow and now I am making this sure that the discharge is going to occur through the porous media only, is this story clear, is this fine, yes please, ok. So now I am forcing the discharge to occur through the porous media ok. So what I have done by doing this whole thing by manipulation.

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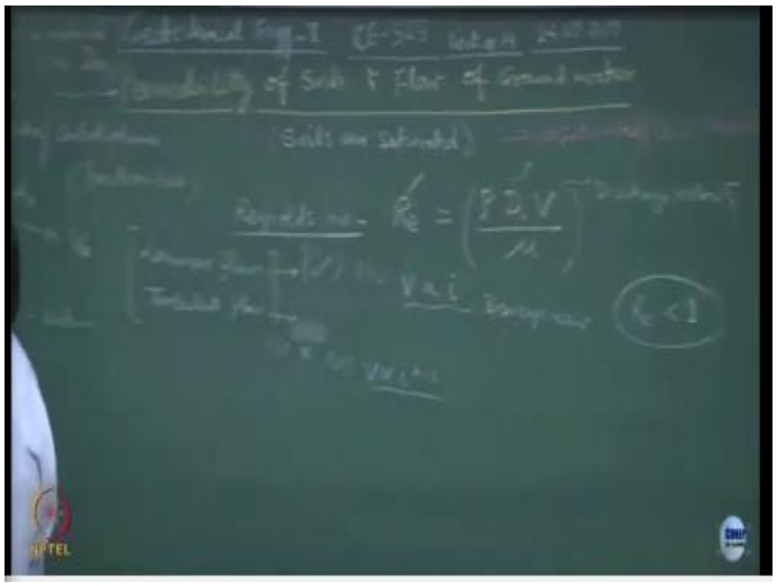

I might have created a laminar flow situation or a turbulent flow condition ok. So you are aware of what are the laminar flow condition, what are the turbulent flow conditions. If I zoom a certain portion of the sample alright and if I show it over here.

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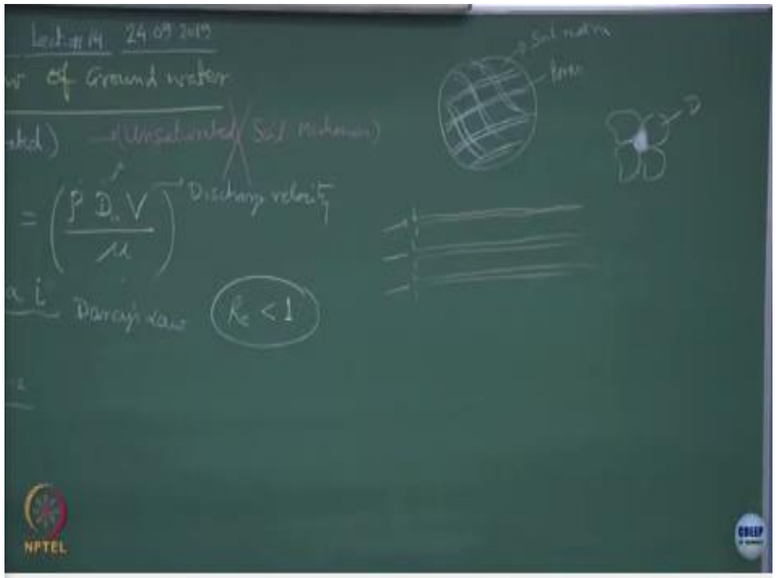

This is how the pores are distributed in compacted soils ok, so these are the pores and this is the soil matrix. As long as the flow of the fluid is parallel to all the flow paths including the bends or including the distortions, the chances are the flow might occur like this. There is a bend over here again there is a bend and if you take the next layer, you know these 2 are almost parallel to each other.

So as long as I ensure that the flow conditions are as if the flow paths are parallel to each other including the bends This is what gets followed in the laminar flow condition, the another characteristic of this type of a flow would be. So this is the first condition the second condition would be the velocity of fluid is proportional to i and this is what is known as Darcy's law.

So Darcy’s laws use normally for defining the flow through the porous media alright is a linearity. V is proportional to i and if I say in generalized from i to the power n, this becomes a turbulent or non laminar flow. So I will use this i here, this is Darcy's law V is proportional to i, if I say that turbulent flow is or non laminar flow is we have this condition gets violated.

This condition can be written as i to the power n alright where n could be equal to 2, this becomes your non laminar situation, the quantification of all this is done with the help of R e. So in case of soils, what we say is R e is less than 1 in your pipe flow or the flow through the conduits you have taken laminar flow condition up to 100 is it not R e is less than 100 is the laminar flow.

So, what I have done remember see we started from a pipe conduit and then I have stopped this the porous media. And I have created a situation, where I have forced fluid to flow through the porous media and not to get short circuited clear. Under all the circumstances, these are the assumptions or the laws which are used to define the flow through a porous system. So there are several ways of doing this, what you have to establish is you have to just say that R e is less than 1 or not.

Density of the fluid is known, rho is the density of fluid, mu is the viscosity that you know for the fluid, D 10 you know why because you know the material characteristics, a specific gravity and D 10 from the particles (()) (21:21). And at what stage you have compacted it, so stage of compaction is gamma w moisture content, if gamma w is known porosity void ratio are known and saturation is known.

So, state of compaction and the material is getting depicted over here, what fluid is passing through this is getting reflected by 1, 2 and 3, clear. So, in other words what we are studying is we are studying the interaction between the porous media and the fluid flow. Now this concept can be utilized by chemical engineers, civil engineers, hydraulics guys, petroleum geophysicist and so on, their fruits are going to be different, fluid of hydrocarbons flow of hydrocarbons through the sediments one case.

Flow of sludges through filters clear another case, for a biotechnologist, a solution having all sorts of bacterial activity microbes in it, and I am trying to filter it and I want to create a clean solution for various applications clear, the concepts remain same, yes. We call this as the characteristic length of the porous media, D 10 is known as the characteristic length, you see we never talk about the third dimension because all these tubes are going to be infinite in the length you agree.

So it depends upon how long the porous media has been created. I am not interested in that. What I am interested in is, at this point what is happening. And if I am doing a very precise modeling by using some supercomputer or something, I will try to see how the D 10 is changing all along. But imagine you have a compacted soil mass and you have to see and realize and measure how the velocity and the pressures are dropping within the sample is going to be extremely difficult, we will discuss these things today.

So for the time being, we are not interested in lens of these things. We are just interested in the characteristic diameter which is going to cause the flow of fluid to the porous system and hence D 10 is good enough for me, why. Because D 10 is going to define yeah, that is a good question. So, now suppose if I say that this is a particle arrangement alright, where is the D 10 here through which the fluid will flow, yes you are right.

So, this is a open space and this space is going to depend upon the particle diameter. So, these are the complications, I hope now you are realizing that the flow through porous media is not a very simple subject. So now you are heading towards complication, so now your next question would be, what is the relationship between D and this, clear. Another question would be what about the shape of the particles, another question would be how about the tortuous lens and so on, so this is out green topic to work on, fine it has a lot of commercial value ok. For the time being it is fine, yes please anything else ok, so let us go ahead.

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If I say the T h 1 = Z 1 + P 1 and T h 2 = Z 2 + P 2 and if I put a condition that delta T h is positive so it is inbuilt that Z 1 + P 1 is greater than Z 2 + P 2 fine even if I rotate it and if I keep it on the horizontal plane in such a manner that Z 1 becomes equal to Z 2 what I have got rid off is the elevation heads agreed. So, that means under the circumstances when Z 1 = Z 2 what I am saying is P 1 is greater than P 2.

The pressure head is causing the flow of water to occur through the porous media clear. And the easy way to understand this is by in using a term which is known as i the hydraulic gradient. So, what is i, i = delta p alright divided by length of the sample and length of the sample is let us say L. Now how would I read this one of the way of reading this would be even is acting at this point or total head is acting this point, total head is acting at this point.

We have done some mathematical manipulation to get rid of Z 2 does not matter even if I include Z 2. As long as the flow is taking place from this to this point, clear, energy at this point is higher than energy at this point the dissipation of the energy is taking place per unit length of the sample, clear. So, hydraulic gradient is the term which is defined to show how pressure is getting dissipated over a certain length of the sample.

Now your question and why it is not negative ok, so what we have understood until now is the discharge is going to be equal to no not that is a not discharge. Let us say V = k into i, Sometimes k is also known as Darcy velocity or Darcy's permeability Darcy's coefficient also we call it as, we also call this as hydraulic. So, I normally do not use this word coefficient of hydraulic conductivity sometimes people also call this as a coefficient of permeability, it has different names.

This is the proportionality constant, what we have done is V proportional to i we have change to V into k into i. Now suppose if I say is i to the power n, i cannot be negative because what is the flux which is acting across the 2 points A 1 into V 1 correct. So, it is the flux which is getting dissipated at in length L, this is another interpretation. So flux has to be positive gradient agreed, as long as the saturate soil is concerned, remember.

The moment is becomes unsaturated it is a different case altogether, we are not talking about that situation. So, as long as delta p is positive, getting dissipated along L, your velocity of the flow is going to be proportional to the hydraulic gradient, agreed, it cannot be reverse of that. What it says is, if I increase the hydraulic gradient, the velocities are going to be more and vice versa and that is true.

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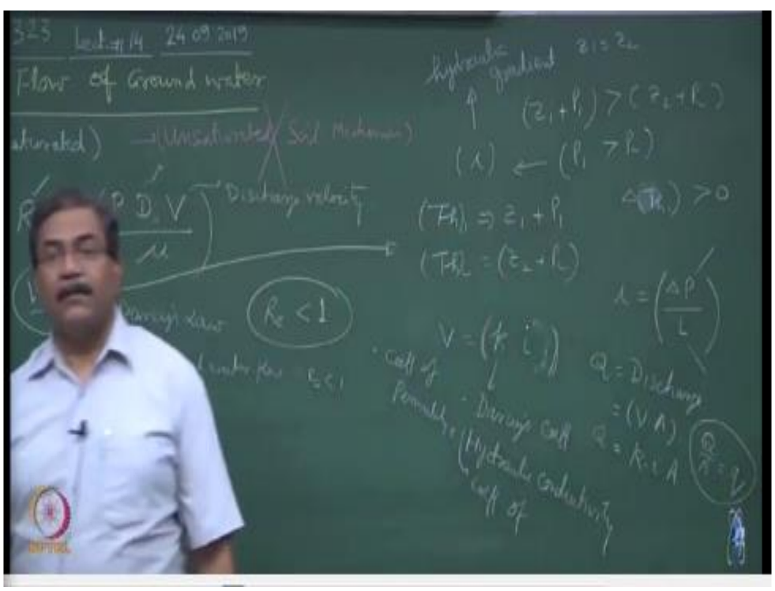

So, this term we now we have agreed that i will be 1 positive I can write another expression, that Q is the discharge and this is equal to velocity into area of cross section. So, Q will be equal to k into i into A alright and for your quick reference, if I say Q upon A what is Q upon A this small q, so small q is nothing but the flux fine. Now, in today's world how these equations are being manipulated please understand in 2 minutes.

We are talking about here all fluid flow, clear, what I had to do is I have to apply a flux gradient to cause the flow of something, is this correct. So the guys who are working in the field of electromagnetism, what they will be doing, they will be applying electric field gradient across the sample to pass current. Chemical Engineers what they will be doing, they will be applying concentration difference across the 2 points to create a diffusive current agreed.

C 1 concentration of chemical, C 2 concentration of chemicals delta c upon L is nothing but the driving force, which is equal and to the concentration gradient. And I can compute everything like this only thing which is going to change is k. So, here k was Darcy’s coefficient, hydraulic coefficient, permeability coefficient there k will become diffusion coefficient, is this part ok. This is in market right now, everybody is trying to do extrapolation of these things in different energy field concepts.

To cause the change in the total head, yes how can I manipulate the total head tell me one of the ways would be I can lift this up, but it is not going to help, why. As long as datum remain same, I am not going to achieve anything, when pressurize the points pressurize apply the same problem number 4. So there is atmospheric pressure or some gas pressure, which is acting over here.

Now what is going to happen, this pressure gets added to this, unfortunately, this pressure will not get delegated up to this point, why because there is a shock absorber, pressure absorber, clear. So now you have to do an experiment to find out how much pressure is getting delegated this point, which is definitely going to be less than this. So what I have done, I have done 1 manipulation to create a different type of total head at this point as compared to this point.

And that is my requirement, is this funda clear, what could be another way. Suppose if I rotate the whole system now what is going to happen, that is a trick, are you getting this point. So suppose if I rotate the whole thing, so this point always sits above this point, agreed. Head at this point elevation itself is going to be higher than elevation at this point so the discharge is going to take place from this place to this place another n manipulation, clear.

Imagine now hundreds of situations like this and go ahead with the engineering. There is another good application of D 10 which you might come across in some books, you know there are people who tend to find out k. Now the question is how would I get the k value, so let us discuss this a bit.

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So determination of k, please make sure that you write a small k because later on I will be using capital K intentionally for something else. So, right now, I am dealing with all small k's alright, do not mix up small k with the capital K. There are different test which you can do, some are the laboratory test which you will be conducting in the laboratory. And they are known you know constant head test and falling head test.

These are the 2 most prevalent test, anybody is doing centrifugal modeling here. Either BTP or whatever, no centrifuges also utilize to get the hydraulic conductivity. We have done a lot of work in this field, so you can check the theses and the papers written by A. K Gupta myself and some of your seniors who are doing BTP with me, Anub Ramchadar Rao, he is the guy who has done a lot of work, he was my B.Tech student, I will show you what he has done.

And so, you may use the centrifuge, centrifuge modeling also what essentially these tests are. The first test is a constant head test, number 2 is falling head test, number 3 is centrifuge test. In a centrifuge, I can do both the test 1 and 2.

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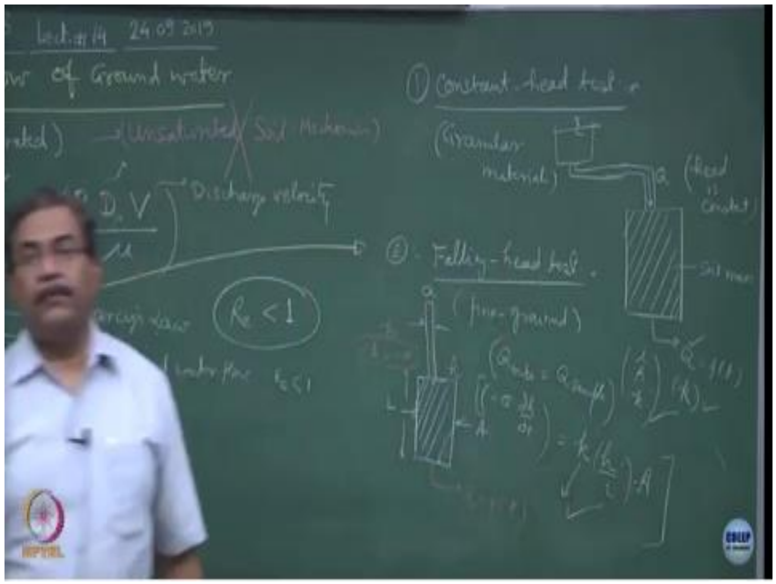

So, in the first one what we do is that is known as constant head test. Normally this is performed over granular materials, granular why because the permeability so much. That if I make a control volume I alright, just now I was talking about rotating the whole setup by certain angle, so that it becomes like this. So, suppose this is my porous media or the sample which I have prepared this is the soil mass compacted soil mass.

So, I must now what we do is the principle is like this that we allow flow of water to occur by maintaining the head constant here, so, head remains constant. And then I was explaining to you why porous media has to be granular when you conduct constant head test because the permeability so high that unless you maintain the constant head, the hydraulic conductivity values are going to be incorrect, fine.

So, what we do normally is we connected to a reservoir you know, there will be something like this, which is connected to a reservoir and this reservoir will supply the constant pressure head at this point. And the discharge takes place here and we measure this over a period of time and then from here we can compute k value, is this okay. If you measure q hydraulic gradient can be obtained, area of cross section is known alright, velocity can be obtained or k can be obtained directly, simple test, used normally for granular materials.

Because of very high their high permeability, the more challenging is the one the second one which is falling head test. This is normally done on the materials of the soils which are fine grained, why. Because the permeability of the fine grain compacted materials are going to be extremely low, so you need not to maintain the pressure always alright, constant head. So, here what we do is, we will expose this system this is the control volume of the soil which I have taken which I have made and this will be connected to a tube glass tube which is graduated

So, here you have graduations we fill it up with the full water after compacting the sample to a certain moisture content gamma d. And we wait for this water to drop over a period of time and we measure Q value. So, this Q is also the function of time one thing you can appreciate here is that the total head which is causing the fluid flow is decreasing, is it not you agree. So, delta h is negative, so this is a experiment which will be doing in the lab.

So, if the area of cross section of this tube is known, let us say small a, if the area of cross section of the sample is known as capital A, you can do the continuity equation. This is nothing but the continued, is it not, so continuity equation will be this q which is dropping down or the discharge is taking place is entering into the soil sample and hence Q in the tube will be equal to the Q in the sample, is this ok, q in the tube is not a porous media.

So, this is only the area of cross section multiplied by the velocity, what is the velocity in the tube or the falling water level del h by del t is this ok, negative sign, why negative sign because h is decreasing clear. So, this has to be equal Q of sample permeability of the soil mass multiplied by i what is causing i h the hydraulic gradient at a given time. So, what I am assuming is that the head difference at this point is h though h is decreasing and that is what I am getting reflected it over here multiplied by k into h upon L, L is the length of the sample, physical dimension of the sample alright.

So, k into i into A solve this expression and get the value of k you understood. In this expression because I am doing experiment I can find out as a function of time, how h is changing I can record the values and I can measure the discharge. So, h is known for a given instance L is known, area of cross sections are known, you solve this thing this comes out to be a log function, do you remember the function 2 point say something I mean you can solve this.

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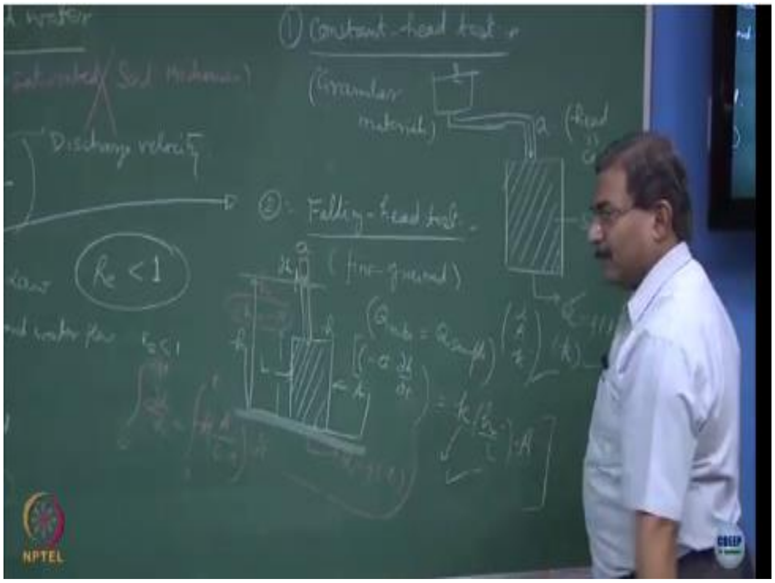

This will be d h upon this will be del h upon h = k A upon L into A into the Dt and then integrated from 0 to H capital H or whatever fine. So, this becomes a log function log of h = k into L into t, time you are measuring at a given time what is the value of the head substitute it and solve this, this is ok. Remember, the dimensions of the k are going to be velocity dimension, I hope you can realize this.

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Because in this expression V = k into I, so i is a non dimensional term, pressure can be equivalent to the height, elevation is height clear. So, this is the height term normally we deal with heights only. Similarly at this point divided by L of the sample which is a height, so i is a non dimensional term hence k is mostly in meter per second unless a specified, is this okay. So, what we have done is, we have obtained the k value in laboratory setup.

You are assuming that whatever head is dropping over here delta h alright, that is this value. So, velocity is delta h upon delta t multiply by area of cross section this is the discharge and this discharge goes into the sample, continuity that is it, h is the head. So, I will introduce these concepts slightly later alright. So, if the head is causing the flow to take place, this is the equation.

Now, what I can do is I can make miniature models of these setups install them in the centrifuge and do the test. That is what most of the Japanese, Koreans and Americans are doing, yes this is your k into i what is causing the hydraulic gradient, the head across the sample, I can do a manipulation I can keep the datum over here everything becomes 0 at this point total head total head this point is h, this becomes h upon L.

So, another way of finding a k is what some people are using, particularly consulting people they use equation 100 times D 10 square, this is in centimeter per second, you will find this type of equation. Unfortunately, these equations are valid only for the granular materials, though they are extending it to the fine grain materials also, because D 10 is being used. So let us remove D 10 from here, make it as D square. So, let us take a simple case so, that you can follow and get rid of all your doubts.

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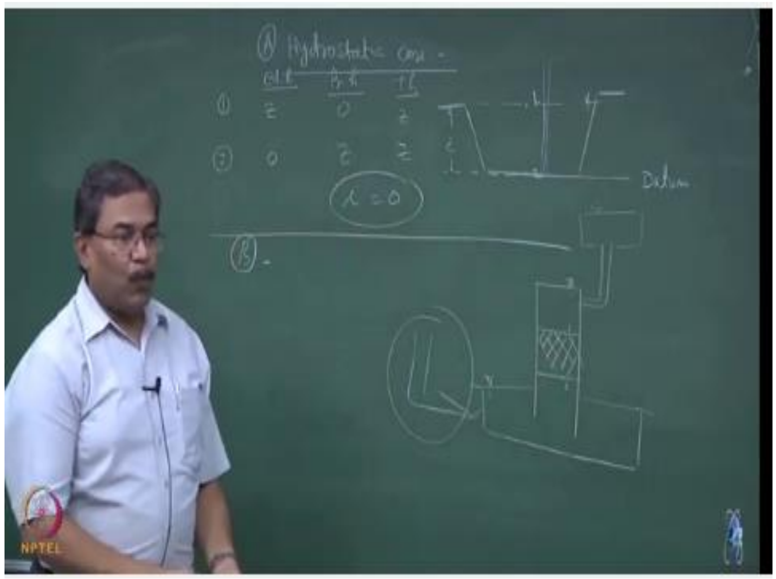

Suppose, if I take a case like this, suppose there is a vessel and in this vessel water is filled up, up to this point, I give you 2 points. Let us say one is here, another one is here, show me what is the direction of the flow. So, the best formula to understand these type of things is fix a datum here, compute the point number 1, point number 2, let us say elevation head, what is elevation head at point 2, what is elevation head at point number 1.

Make life simple let us make it at atmospheric surface itself piezometric surface, you remember piezometric surface. So, where the atmospheric pressure, temperature conditions are acting, what about point 1, elevation is that. At this point elevation is 0, what about the pressure head at point 1, atmospheric is acting here also by the way, 0, you are right, what about the pressure head at point 2 are you sure, why.

Take a Piezometer here install it up to where the water level will go h z simple rule always put the piezometer or tensiometer clear, up to what height it goes clear, what is the total head, what is the hydraulic gradient, followed. So, i is 0 what is the meaning of this, this is a case of hydro static problem, agreed. I can do different types of manipulations over here clear.

The real fun is the moment for porous media comes in the picture as long porous media does not come in to picture there is no fun, it is a hydro static case. I will induce flow through the porous media by you remember that tube which I had plotted and just tilt it a bit. So this is the case A and now let us talk about the case B. This is the porous media, this is the water level and this is kept in the water bath. So here I am showing this as the free water surface, this is a free water surface.

Now how do I maintain is my headache, I can connect these to a reservoir upstream and the downstream I can connect it to another reservoir does not matter. This is all redundant as long as I have the pressure conditions over here. Now let us say point number 1 and point number 2 do the same analysis.

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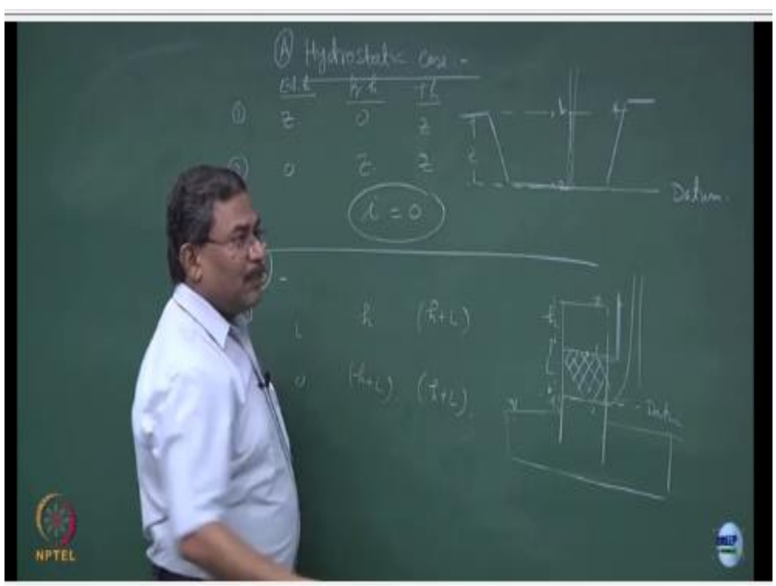

Suppose if I say L is the length of the sample, area of cross section is known, material properties are known. This is the height h ok and at this point, suppose this is h 1 let us do one by one, what is the elevation head of point 1, so select 1 datum, correct. Datum is normally we to eliminate all this, what I can do is I can put the datum here itself, this elevation and all agreed. It is your choice you can put the datum here also, but then becomes more complicated.

At point 2, what is happening, what is the elevation head 0, point 1 this is L, what is the pressure head at point 1, how do you compute pressure head please understand this do it your notebooks. So use the piezometer, the small tube fix it over here up to where this will go, fine h height, what about this point h + why, you are right. But why have you understood this or to the guess, why, that is a interesting thing.

So until now whatever you studied saturation, partial saturation, variably saturation case remember tutorial number 3 where I have created s as a function of depth. And I have specified saturation limits as long as this happens over here, your answer is wrong, is this correct. However the moment you assume the whole thing is saturated after steady state has been achieved, clear.

Now if you put a piezometer over here, you have 2 options, what are the 2 options, this atmospheric, this is also atmospheric are you getting the point. This point is connected to atmosphere, is it not, so let us do in simple way. If I shift my datum over here, what is the position head at this point, this much. If I put a piezometer here, where it will go, this is what you have to understand, it can never drop.

Even if I put a piezometer here, what is going to happen, it is going to go up to this level it will never drop down. So please do not get confused with this, that could be the capillary action, when you have negative tension zone getting developed in the system. Then only the pressure at this point will try to get nullified with the atmospheric pressure as long as this pressure and this pressure are atmospheric.

The only possibility is that if you put a piezometer over here, it will go up to this plus this, is this funda clear. So your answer was correct but have you understood the thing chalo this ok, got. Everything is under positive pressures, so there is no reason that the pressure will drop from here because the entire thing is exposed to the atmosphere. This surface is same as this surface as far as the pressure conditions are concerned.

These are basically iso pressure points, there is no capillary remember this is the glass tube, this is the soil I am just talking about this is the water body in which the glass tube is dipped. Complication I have done is I have raised this level a bit, so that here also you have water, but truly speaking the pressure at this point and this point is all atmospheric. So, what I have to do either I have to reduce the size so much make it a capillary tube number 1, these are finite dimensions these are not infinitesimally small in dimension, clear.

So, capillary it does not come into the picture, second thing is we have assume that the system gets saturated over a period of time, so this soil is completely saturated clear. Now you are connecting the whole system like this. So what I am trying to expose you to the concept is try to understand what are the pressures which are acting across the samples. So, this is C easy somebody said atmospheric one of you atmospheric is acting here also atmospheric acting here also, that gets nullified.

Now what is over here is the elevation head plus pressure right because of this water column, it is okay. This fellow said elevation is whatever depends upon the datum, so elevation is 0 here and what is the total head this plus this because of the pore water pressures. So let us write here the pressure would be h + L, so what happens with the total pressures. See again I have created a situation where the flow is not going to take place through the system, why. Because he said that at this point, what is the total head, he said h + L.

So, one of the ways to come out of the whole situation would be if this whole thing is placed in a water bath like this, what is the total pressure at this point. So, this is the L yes, so what I can do is I can assume this water column of delta h, very infinite small volume and I can assume that this is the head over acting at this point which is variable, so now it is alright. So as your h changes, this is a velocity which through which the water is getting discharged in this tube area into velocity of water.

This h remains universal, this h is also acting on the sample, this remains h, what is causing flow to take place h. So, h upon L is hydraulic gradient, area is the cross section, I have generalized the whole thing I do not care what is the pressure acting at what point. I am simply saying as far as this is a datum, I am assuming everything from this point to h which I can measure alright and at this the moment h is measured h is generalized.

So, rate of change of h in the glass tube is nothing but the velocity of water discharge multiply by area cross section, clear and this h is also causing discharge to take place through the sample. So, this becomes your h by L i into k into area of cross section, h by l h is the hydraulic gradient which is causing the flow to occur. Because delta h of h is causing the flow to take place, a small change in the height of the water column is your velocity component.

That it the small change in the h is also causing the hydraulic gradient which is acting on the sample all the time. So now your question is what repeated, integration choice is mine, I might be doing this experiment to measure h 1 and h 2. And fall in h 1 to h 2 is in a given time t, that is it, got it. So basically, this is going to be from h 1 to h 2 in a time 0 to t, ok. Now the rule of the game is normally we do not allow significant changes in the head to take place, why.

Because we are talking in terms of the infinite decimal changes delta h. So truly speaking delta should not become a meter because by the time the entire water passes through what is going to happen h is getting drastically changed. So if you look at this expression, discharge in the tube though it remains same as the discharge in the sample. But truly speaking h is decreasing and when h is decreasing what happens to k is decreasing.

So you are doing a test, where the hydraulic conductivity or the parameter which you wanted to obtain is a function of time or a function of head not a very good thing. Truly speaking, this should have been a constant parameter. So normally we do not allow delta h to become more than few centimeters 5 centimeter clear. So the moment 1 test is over, again you fill it up to the top, again go for 7 centimeter drop, 3 centimeter drop.

Because it is going to take time, it is a fine grained material, is this ok. Now let us restart this business, now using all these concepts, you know where these concepts are being used number 1 and what type of questions are being answered. I am just trying to show you, concentrate a bit, will answer that sand boiling phenomena also. If you remember first lecture you had Santa movie, correct. So now you are going to get the answers to all those questions, what is seepage does to the soils.

(Video Starts: 59:39)

So if you type on net sand boiling alright, this is what happens when earthquake strikes and if you really want to do the analysis of these type of situations what we are studying here is a static case. Though this is a hydrostatic case and I am trying to convert this problem into a flow through the porous media case. A real dynamic case will come when earthquake strikes the deposits are the soils and tries to liquefies.

I hope you can see that this is what is going to happen these are beautiful sand boils which you can see on the beaches and that is why the warnings are given do not go to the beaches when it rains the whole thing are liquefied you know. This is a beautiful example of what seepage does to the sandy soils. You are seeing a boil and the entire soil has got lifted up and it is flowing like a flood, this is what is known as liquefaction.

Another beautiful example you can see over here there is a huge crater getting form because of the liquefaction of the soil and this video very nicely describes. As if this is a volcano, volcanic eruption which is taking place the sand comes along with the water and these types of systems are very difficult to deal with in real life. There are several examples you can think of look at the sizes of the craters and so on.

This is the sand boiling phenomena, I will prove how sand boiling occurs, if you see this video it is a interesting video where the influence of seepage and the concept of effective stresses is demonstrated. This is something which you can go through whenever you get time, how the effective stresses come in the picture and how the boiling of sands might occur. It is the beautiful example of how the pore water pressure rises and how it gets changed when the water table changes.

Another interesting ppt on levees which are founded on the peaks and organic soils, this is a big headache for geotechnical engineers. It is a interesting slide if you read through, what you will observe is that most of the levees which have been designed embankments have failed, they have liquefied. So, this is what the land subsidence is, we have been talking about land subsidence in the very first lecture. So the more and more water you draw for irrigation purposes or for commercial purpose the whole thing might subside and ultimately the failures might occur.

So, the embankments have failed because of the subsidence of the ground. You remember, we were talking about the Delta formation sedimentary deposits and whether they liquefy or not because of the earthquake. Though PT soils are cohesive soils, they are also bound to liquefaction. A lot of research is being conducted in this context. And here the question has been that does delta have Seismic hazard and the answer is yes, because they have done the seismic hazard mapping and they have shown that it fails.

So, this is the influence of the earthquake, which they are studying on the soil mass and this is how the modeling has been done. So, before the earthquake you know the whole condition is like this of the embankment and after the soil liquefies, what happens there is a sort of a subsidence and there is a failure. So, all these problems can be modelled easily by using the concepts which we have going to discuss, we have to define a few terms like what are the hydraulic gradients. And what is the seepage force which is acting on the system.

There is a interesting paper you should go through those of few who are interested in 2011 when the earthquake occurred in Japan, house and boiling characteristics are modeled. Everything comes from the basic principles like liquefaction, sand boiling, grain size distribution and permeability. So, intentionally I am showing you this paper because many people think that R and D something, you know, very extraordinary.

But truly speaking R and D is also simple concepts, which you pick up from third year onwards, and then you just build on them to answer the questions which society is asking. So this is how (()) (1:04:56). We will be talking about the piping which is the northern embankment which is holding water. And then we want to see how the embankment will become unstable because of the excessive seepage force.

This is the piping which is getting generated, I will just show you 1 minute. This is the pipe which gets generated in the sand bed because of the gradients and then the whole thing liquefies, watch this video. So this is a dam which is being modeled and this is retaining water, now, if you increase the height of the dam tension, look at how the whole system is about to fail, concentrate at this point.

So, when you are increasing the height of the water column, the entire sample might yield and that is happening at the critical hydraulic gradient. So, look at the soil this has caved in look at this because of the boiling process, loss of strength. So, imagine the building in which you are living and because of geomorphological alterations but it is a big world in today's context alright, geomorphological alteration could be how many underground structures are being constructed in Bombay city any idea right now.

Let us find it out and what could be the impact of that, we have discuss this lowering a water table alright, mathematically we have obtain a solution, we have shown the sigma prime increases and ultimately what happens. So, these are the models which you can go through, fine. So, a hydrostatic case has got converted into a seepage case and seepage is causing all this to happen.

(Video Ends: 1:10:42)