Geotechnical Engineering I
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Lecture-20
Applications of Seepage Theory

In previous lecture, we have discussed about the seepage theory and we have done lot of derivations to depict the seepage which is taking place through the porous media. And this is where I introduce the concept of flow nets. And the basic premise was that flow nets are required because most of the time in real life problems, you would not be finding geometries which are very linear, which are well defined or the material properties which are homogeneous, isotropic.

And hence in the form of flow net, I can do mathematical manipulation to depict all these natural situations which are forcing geotechnical engineers to resort for mathematical modeling.. So, having said the concepts of the seepage through the porous media, it will be a good idea to talk about the problems which are contemporary and we are all this knowledge is required. So, in today's discussion mostly I will be concentrating on various studies, case studies you may say various problems which professionals are facing.

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And this is what I termed as the applications of seepage theory, now in most of the real life problems where the seepage is taking place through the porous media. We use the concept of the flow nets.

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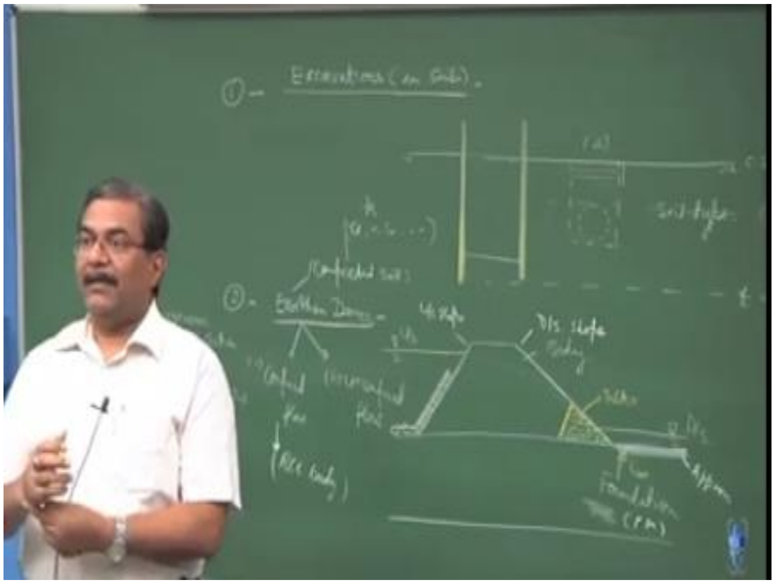

And some of these examples would be, let us say example problem number 1 or the situation number 1. I want to do deep excavations, particularly excavations in soils. Most of the metro work which is going on in the country or wherever. Most of the underground structures which are being placed different type of caverns where you are storing hydrocarbons, nuclear waste for that matter you know, oil gas, even the potable water, utilities it could be.

We go for exploration in the soil, I am sure you must have seen or you will realize the fact that suppose if this is the ground surface. And if I want to excavate to create some facility, what I will have to do is I will have to start digging alright depends upon what is the corridor. The basic intention is let us say I want to create a tunnel over here which would act like a metro tomorrow or it could be buried pipe, it could be your data communication system, fibre optic cables or electrical cables or whatever.

So, if this is my intention, what I have to do is I have to remove this soil mass and then lay the utility over here or create the space for the utility over here depending upon the soil type alright. It may so, happen that the moment you start excavating by scraping the material layer by layer after a certain depth, the entire soil mass may yield, it may collapse. Now, this part we are going to study in the second course, because that has something to do with the strength of the material.

So, I will be restricting my discussion not related to the collapse due to the strength loss. Now, because we are discussing the seepage, what I will do is suppose if I say the water table is somewhere here. You are doing a project in an area, which is what a deficit alright, no issues, seepages not going to create any problem. But imagine a situation where the water table is somewhere here.

So, most of the basements in city like Bombay, you go to different shopping malls, you go to the airports where most of the particularly modern day medical institutions like hospitals, where most of the therapy is being done underground alright. The beautiful example is a (()) (05:54) where the 3, 4 storeys are going to be underground, and it is very close to the beaches, (()) (05:58) beach particularly, so water tables are going to very high alright.

NOW the question is how I am going to solve this problem by using the concept of seepage theory. So what I will do is, I will have to, this excavation can be done without any support. But it's a good idea when you are going very deep and when you are encountering water table to insert a sheet pile into this. So, suppose this is the situation a, how this will be achieved, I will insert in the ground mass or the ground surface a sheet pile, have you ever seen a sheet pile yes or no.

So these are made up of steel, very stiff steel, there will be a cutting edge at the bottom and these are 2D elements like this made up of very high stiffness steel. So what we do normally is of certain size and shapes and the geometry depending upon your requirement. So what I will do is this element of steel I will tamp on the top, so that it goes inside excessive deep depths can also be achieved by welding the 2, 3 elements.

Normally these elements are 10 meter long, 5 meter long depending upon your requirement. So, this is what is inserted over here, this could be made up of steel, this could be made up of any composite, this could be made up of even concrete also, depending upon your requirements fine.

So, another couple of this would I will be inserting over here, so this is a sheet pile system. Now I hope you can understand once I have retain the soil mass, I can start excavating this layer by layer, and I can achieve a certain required depth is this is part clear. So, this is the excavation by employing sheet piles. If you are interested much in knowing the, how the insertion is done, you are free to watch videos.

There are many countries including India who have become pioneer in inserting the sheet piles and utilizing them. So, ultimately I have created the space, I hope you can realize this and I can do whatever I want to do. Now, this type of situation we will solve today under seepage only, we will try to see how the seepage is going to get affected here. So this is the first situation which I will be dealing with, the second situation could be when we talk about earthen dams.

Earthen dams are the dams which are made up of compacted earth or compacted soil. So, you know how to compact the soil at a given gamma D and w and saturation and so on, that knowledge is used. We have only studied the concept of hydraulic connectivity k, that means the material properties are well defined. Now, if you see a typical cross section of an earthen dam next time when you go to a dam for picnic, you should realize how the embankment where dams are constructed.

And this is somewhere I have the foundation system, so these dams have typically 2 domains. The first domain is the body of the dam and the second is the foundation of the dam alright. So, this is the body of the dam and this is the foundation system. Now, depending upon the situation, I can create from this 2 situations, one is the confined flow and another one is unconfined flow.

Remember we have already done the analysis of the wells in confined aquifer and unconfined aquifer alright. The whole idea of creating this embankment is I want to store water, one of the applications could be. When I am storing water, this side is known as upstream side and this side is known as downstream side, sometimes people also call this as a tail water. If the cross section of the embankment or the dam is homogeneous alright.

This falls under the category of homogeneous cross section, but this type of situation is going to be very detrimental. Because in the due course or time what is going to happen is any guess, if you leave it like this, this is a porous media very soon the seepage pattern will set in. So the seepage is going to take place like this, I am sure you realize the moment the seepage line comes and hits at the downstream slope, this slope is known as downstream slope.

And this is known as the downstream slope and this one is known as upstream slope. So as you see the moment this top line phreatic line comes and hits over here, there could be some erosion with might start from this point clear. So in order to stop that what is done is normally we design filters, I do not know whether you have seen this or not. Next time whenever you get a chance to visit to a dam, please go and check this out.

The moment you have inserted filters, this becomes inhomogeneous section. The whole idea of putting filter is that this seepage line is not going to hit the downstream slope. And I am making sure that the top phreatic line comes and meets the filters and not affects the stability of the downstream slope of the dam. So, I have created for situations out of it starting from earthen dam, we know the compaction state.

First thing we have done is we have defined the domain of seepage that is the body of the dam as well as the foundation system clear. The moment I replaced the body of the dam with let us say RCC concrete dam, seepage is not going to take place through concrete. And hence the seepage is going to take place only through the foundation system clear. In that case what I have done is, I have restricted the domain of seepage.

So, confined flow is one of the examples of let us say RCC dam body. So, what I have done, I have confined the flow to occur only through the foundation which happens to be a porous media. As compared to the foundation soil the RCC is much impervious, so I have created a confined flow. As far as normal earthen dam is concerned, the top phreatic line depends upon the head at the upstream side and the head at the downstream side.

So it will fluctuate and hence the system becomes unconfined fine. We will do these type of analysis in today's lecture.

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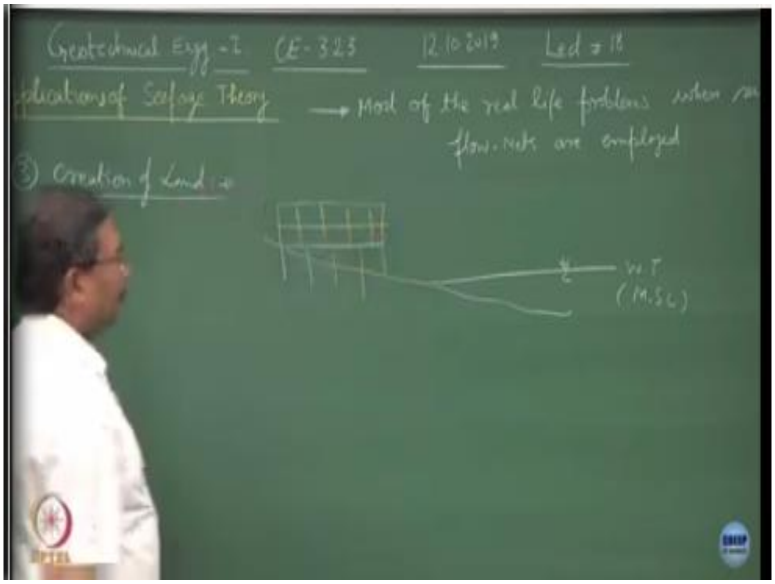

One another interesting situation could be suppose, if I want to create land because land creation is the fashion of the day. And this is what gives you money is not everybody is trying to create land, new cities are being developed. So, suppose there is a situation like this, this is the offshore environment, so water table is in the form of let us say mean sea level. And what I want to do is, I am a multimillionaire and I want to see every day morning sunrise and sunset, you know, from the Arabian sea, it is my wish, money is not an issue and I have the land.

So what I want to do is, I want to create a system of my recreation, which is going to be somewhere here like this let us say. And this whole building is going to be on the top of this, you realize what we have done, we have created land in a domain where there was no land. Now this is where we will be studying the concept of bulkheads. Just to quickly answer your hunch of what bulkhead would be.

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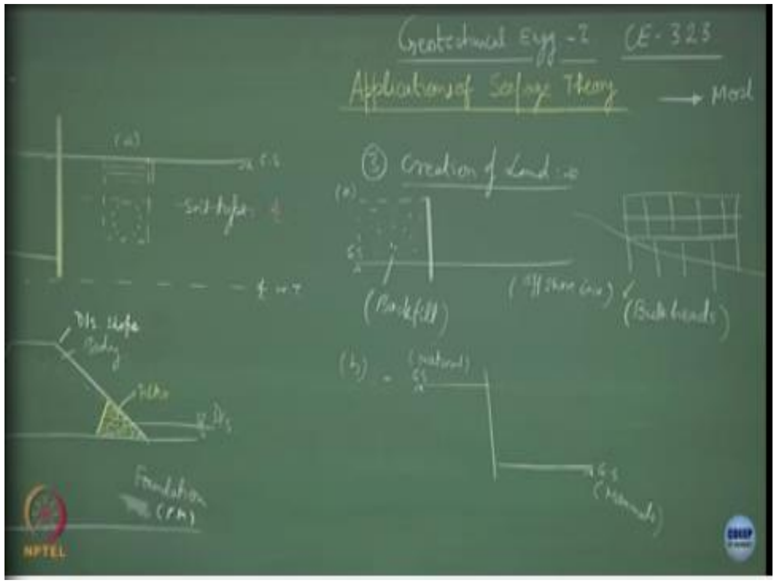

Suppose this is a ground surface alright and I want to create a system like this. So, what I have to do is, I have to create a retention system over here again I will use sheet piles and I will fill up on the side. So this becomes my backfill and this becomes my pad on which I can create something and this is the offshore environment, this is ok, this part is clear. Now, this is a manmade system where you have to compact the soil at a given density, moisture content and other stability issues you ever take into account.

This problem can be converted into another interesting problem which will be solved mathematically again in the next course. So, say this is the situation number A, situation number B, what comes to your mind opposite of the situation. Whether rather than piling up something on the ground surface, I will have to excavate or alright. So, of course, this type of situation I have discussed, but another way could be.

I would like to create a space rather than filling because this is going to be a complicated process alright. It is not going to be so easy particularly when you analyze the situation for earthquake and other things, what I will do is. I will like to excavate this whole system in such a manner that I might create a facility like this. So, this becomes manmade ground surface after excavation and this is your natural ground surface, I hope you have realized that there are several situations which can be created alright.

So, these situations are the order of the day, because depending upon your client, you would like to give them a solution where these type of things can be done. Another interesting problem which I am doing in Rajasthan deserts is very difficult to retain the dumes is it not.

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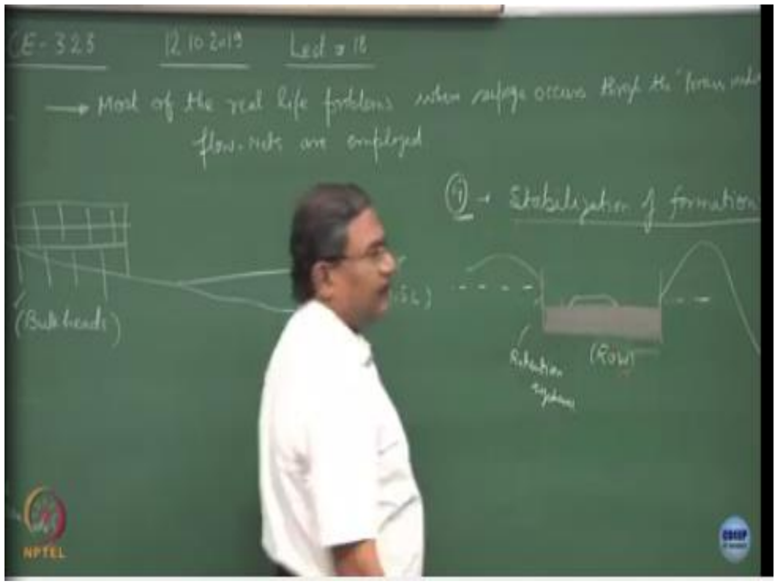

So, suppose if you want to stabilization of formations, now these formations are natural formations. So suppose if I give you a situation like this, you know, this is a series of hill rocks and when you want to do expansion either roads have to be done there or railway lines have to be done there or pipelines have to be done there or tankers have to be done there or storage tanks have to be done there.

So suppose if I want to create a right of way you understood this statement, why in your transportation engineering you must have done, creation of right of way. So, right of way is something if I would like to let us say chop-off from here, and chop-off from here, this becomes cutting. And this while I would like to fill it up in this valley to create a platform like this, you understood what I have done is okay, I have cut down the slopes.

Of course I have take permission from MOEFCC and other agencies. So after cutting this material, what I have done is I have filled it up over air to create a pad as if the ground was level. So most of the construction which is going on in the hilly regions nowadays most of the ropeways are being done for connecting different cities, strategic importance projects and so on.

Once you have done this, look at this, what you have done over here is again you are going to create a situation where the water table might interact with your sheet piles or the retention units which you have created. So, these are the retention systems and I have created the right of way and on this, I can create a railway track and that is it, is this ok. So I am sure you must be realizing that, now we started talking about the applications of the geotechnical engineering.

And this is the design, this is the analysis, this is the conceptual thinking and when you go and see some of the places where there was no civilization, no rehabilitation, say few years back, you appreciate the architects, is it not. So architects give you the philosophy of design, but who executes it, geotechnical guys. Because I am sure this is all I have discussed about is the creation of land, fine.

And most of the time in all these situations we are dealing with the soils which are in a state of compaction, is this part clear. So, what I am going to do now is I will take a few situations and I will analyze them for seepage forces, pore of pressures you know the type of hydraulic gradients, exit hydraulic gradients, and what not. Where would you like seepage to get collected upstream or downstream.

If I put a filter over here, what is going to happen, I cannot retain anything in the dam body. So, normally please come out of the wrong concepts, filters are never done on the upstream side. But if your notion of filters is re-perhaps, yeah he has added one more concept to the list, design of re-perhaps. So suppose if I have to discuss about the fifth structure would be design of aprons.

See the right place to put a apron would be upstream or downstream, what I can do is to stabilize this whole thing I can put some tetra pod here. The way you might have seen them on marine drive alright but it is very difficult to do this. Because this has to be done before the dam was constructed first of all, second thing is, it is going to be expensive, third thing is it is not going to be practical.

So, what we do normally is, we design apron over here, what this apron does, we have only talked about the i critical thing in the previous to previous lecture if remember. We have proved that because of the seepage which is going to take place through the foundation system, there would be an exit gradient i critical. And this you have defined as g – 1 over 1 + c.

So, in order to negotiate the effect of i critical, so that the downstream does not get eroded, why this Medha Patkar and other people they are protesting for creation of the dam, did you ever question this technically, this is the answer. The entire dam once you create the dam it, and once you charge it with water, what is going to happen, the downstream side of the land is going to get eroded in the due course of time that is the main issue, clear.

So, if I created apron over here, very soon you will learn what I have done is I have elongated the seepage length and hence the hydraulic gradients are going to be less, fine. So, this is also you can study under the same ahead, good, what is apron exactly good. So, see the normal practice is supposed to I want to suppress something clear, what I should be doing, I will create a thick pad of concrete, so that this mass get added up to the soil mass.

So, apron by definition is a thick mass of concrete, which is going to negotiate with the F force, F you remember the seepage force, we have analyzed that. So, F is acting in this direction seepage force. So by creating this apron, what I am doing, I am putting the w A apron which is going to be greater than F. The moment I have done this I am safe, is this part clear mathematically, now you design the system, it is not very difficult.

So, I know the density of the concrete unit weight, I know how much depth I have to design this clear and I can negotiate this. So what you have asked is a very interesting question in terms of when you design most of the rafts.

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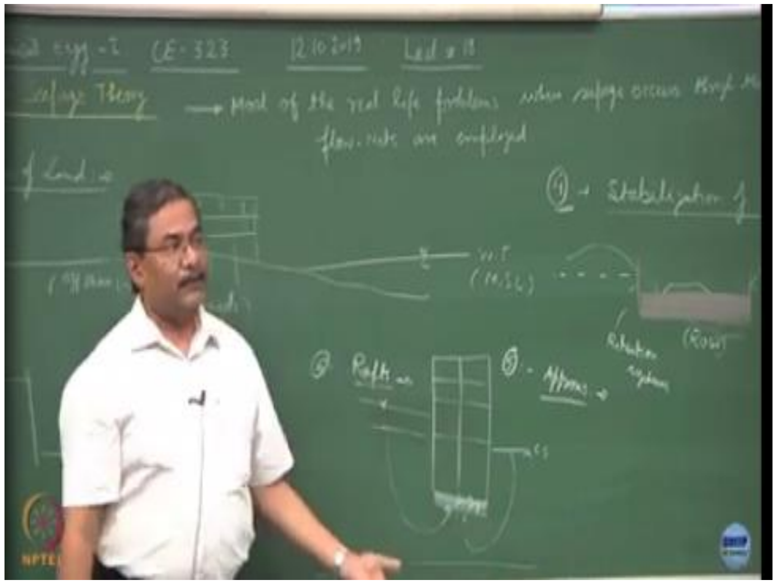

So the sixth example would be design of rafts you know at most of the industrial premises, because of the high water pressure, the rafts have cracked. And what a lost to the property, you created a basement clear and what happened. Suppose if I create a basement for a building ok, so this is a ground surface and this space I created for car parking. Now what I have done is, if I leave this raft unattended or if I do not do the raft properly, what is going to happen.

The same situation will get developed over here, this is somewhere you have impervious boundary, somewhere here you have water table and the seepage sets in. We are going to solve this case today and if this system is not strong enough to resist the seepage force what is going to happen, this whole thing will crack. And the moment it cracks, the underground storage which you created is of no use, got it.

This is happening in most of the projects in the country right now, crores of rupees are lost because of defunct properties, 3, 4 cases I am doing right now where this is the main problem. But a good answer would be anchor them, staple them you know, you can staple them, so derive anchors and grout them. Now let us start with the basic model, simple models, so that you can understand the concepts and how to use them.

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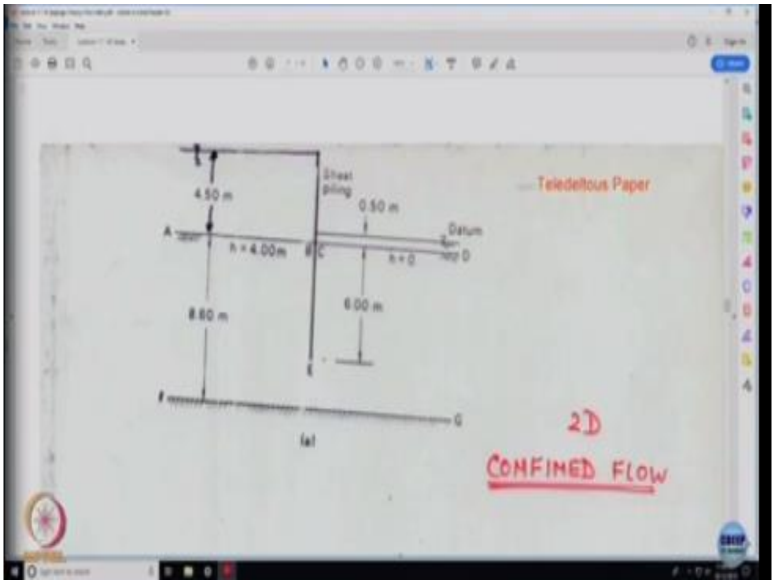

Go to the islands, Singapore and these are islands which are floating in the sea. Now suppose if I want to do excessive excavation, I hope you understand why excavation should be done. Because the entire parking system is underground, tunnels are underground, seepage disposal is underground clear, how to create the space. So, all these things are being discussed in the contemporary subject which is known as underground space creation.

Check it on net and you will find several examples of how to create underground space or they call it as underground space utilization technology. The cities are going to be buried that is the future of the cities, the entire cities will be done beneath the ground. The cost of air conditioning where is the electricity. So go to Japan, Korea, Singapore, most of the part Italy beautiful example, France, Germany rather than negotiating - 40 degree and centrally air conditioning the rooms or houses and the facilities what I should be doing, do everything underground.

I can save energy only thing is able to master the concepts of materials, rocks, soils, ground water that is it, that is easy, that is a subject, environment is heuristic. So, this is the simplest possible example of what we have been discussing that the sheet pile, I think you understand what sheet piles are I have discussed in the lecture just now. This sheet pile is serving 2 purposes, can you tell me what, have a close look at this.

Now from this point onwards as a consultant, you have it tendency to change the whole scope of the project and save the cost and negotiate the cost. Look at something specific is being done. What is your observation, look at the sheet pile only right now. So I am utilizing sheet piles in 2 ways, first of all I am utilizing sheet pile to store water or fluids or hydrocarbons or some chemicals you got this point.

Rather than creating a tank I will simply insert a sheet pile and I can store things rather than creating a dam here, you must have seen 100 meter base, 50 meter high from where you will bring soil nowadays, to create an embankment, clear. So this is how the conventional geo mechanics is getting transformed to later solutions. What I need is, I need very high strength sheet pile that is it.

So whatever my embankment was doing in terms of retention of water, I can do achieve it by simply and inserting an element up to a certain depth, fine. So, this sheet pile, the moment it is inserted, it is holding a certain water column. I use the word bulkhead sometime back, this is the bulk, clear. Any fluid, any mass which is being stored above the ground surface becomes a bulk. So, bulkhead is nothing but a sort of a pile which is helping you to retain a certain volume of the material.

So, ultimately I can store water up to this height, there is a downstream side because the moment you have inserted this you have created a hydraulic gradient. Until now we have been solving simple problems of soil mass packed in the tube and then connected to 2 reservoirs clear. Now what has happened, if you dig it today, in the due course of time, the seepage regime will develop over here and then the height of the water column on the downstream side will stabilize.

Now, this is a state when steady state seepages already stabilized through the foundation of the sheet pile system is ok. Now that would depend upon the porosity of the media, hydraulic conductivity of the media, type of the soil, type or the boundary conditions clear and the type of the inclusion which you have inserted over here. So, answering your question number 1, you asked about this drainage system and so on where should I put the filters and all.

Now, let us study this problem like this, few concepts first before we start doing the analysis.

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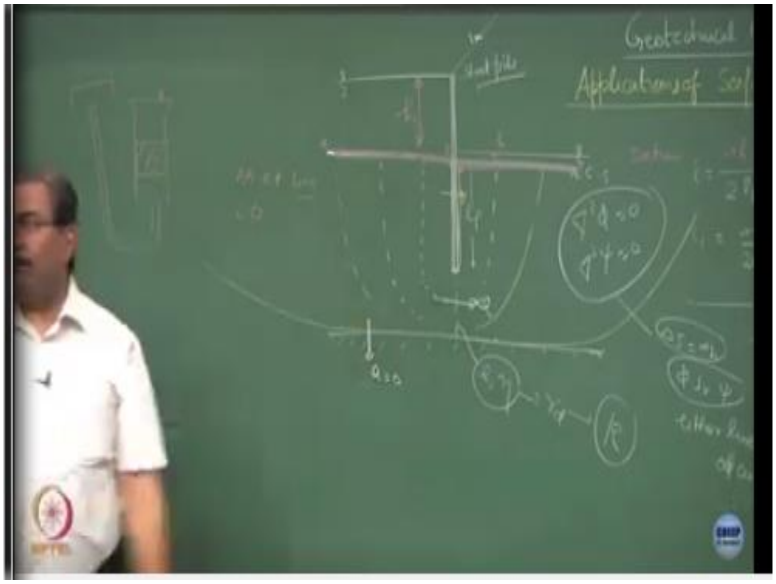

So this is the ground surface and by retaining this water you know, this is a sheet pile of certain thickness, certain modulus of what do we call it e into i, stiffness modulus. In a structure analysis you must be doing the course e into i is the stiffness modulus. So, I can select an element, this becomes sheet pile and this is how the seepage regimes develop. What I have written here is, it is a 2 dimensional flow number 1, why because we are considering everything perpendicular to the plane.

So, as if the width of the sheet pile is unity 1 meter clear and hence we have made a 3 dimensional problem into a 2 dimensional problem.

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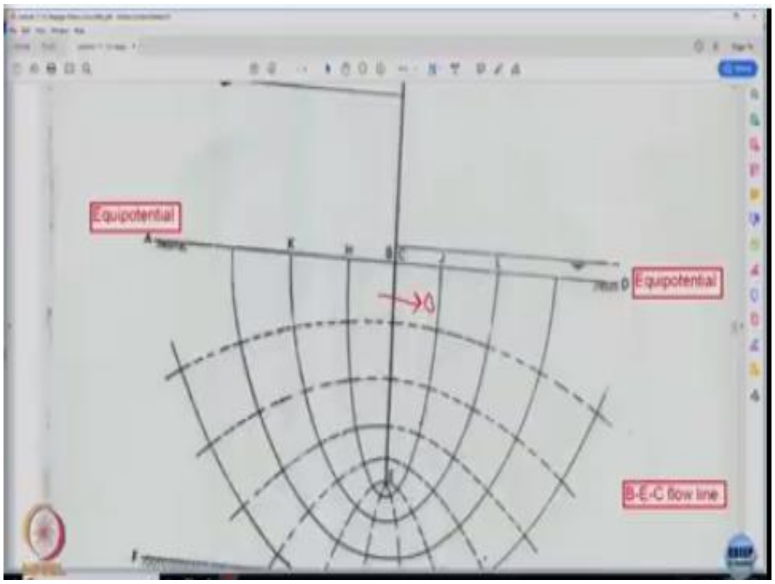

Now, this line AA is different as the Equipotential line, this is an equipotential line, why is an equipotential line, have you understood or not all of you. So, AB happens to be equipotential line, is this part clear. At each of these points, what are the total head, no height of the water column, clear, yes. So, at put simple concepts, your datum could be somewhere normally what we do is we fix datum over here alright.

At the bottom most part of the seepage system nothing but similar to this system, you remember. We have solved these problems, where this is connected to the upstream and this whole thing is connected to it reservoir, is something of this sort. This porous media is nothing but this porous media on one side it is connected to this head, another side is connected this head that is it as simple as that.

So, at each and every point here, the total head is h, I will define this as h1 height of water column. At the downstream side, this is h2, what causes flow to occur, delta h, what is delta h, h1- h2 clear.

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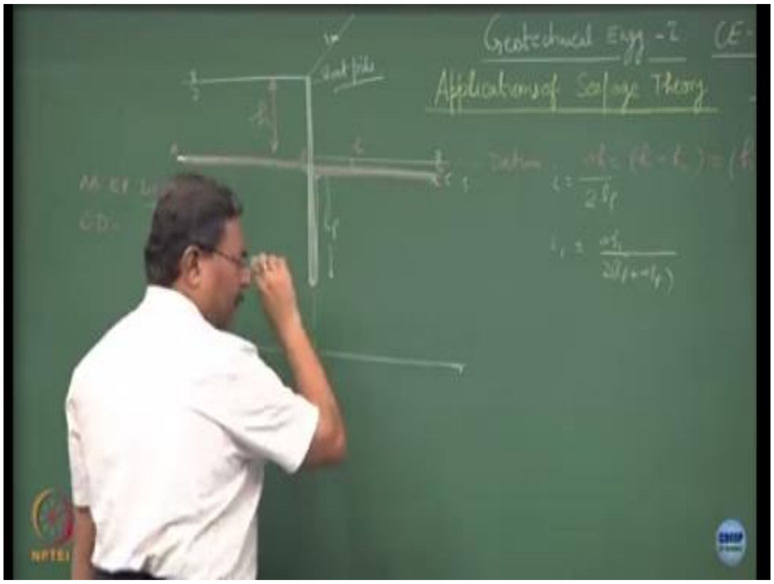

This I am defining as h, is this point clear, put a piezometer at any of these points, the height of the water column is this clear, piezometric head. So, this becomes one equipotential where is another equipotential in this figure, sorry, you are right CD. So, this is D and this is C, so CD also happens to be an equipotential line, have you understood this. So this is also an equipotential line, what abnormality you are saying.

If the sheet pile was not there would they equipotential lines would have existed, no, why. If I remove the sheet pile, this head is going to be same as this head, so the whole thing is going to be equipotential line. But why inserting a sheet pile what I have achieved, if you can answer this question, you are a genius, good, in what way. So, this becomes a point of singularity, correct because just on the left hand side and right hand side and I have been repeatedly saying the thickness of the sheet pile is extremely small, 1 inch, 2 inch maximum, alright.

So, you are correct, so what I have done, I have created a head, so you have created a head is good thing for you or it is a something which you have to be careful about, both yes, you are right, very good. So, one thing is you have create a facility, you have create a reservoir clear, second thing is you are inviting problems for yourself, why, excellent, good. So as far as your foundation system is concerned, you have created a problem.

In earthen dam this thing would not have occurred, so because you create a big cross section over here, and things will be taken care of. So what is happening is, now suppose if I asked you a question, can you draw the flow lines for the situation. So, first thing we have fixed is equipotential lines, clear. Now the flow lines are going to be perpendicular to the equipotential lines in the porous media, where is the first flow line, identify the first flow line.

The first flow line is along the inclusion, which you have created, we call this as a creep flow. That means if this is a equipotential, if this is a equipotential, the 2 heads difference is delta h is going to cause seepage to setting clear. This is how the seepage will set in and it will come out, is this correct, have you understood this, at this point seepage is 100%, at this point is 0%.

So, that means all the water will have a tendency to sweep through gaze through all along the sheet pile and come out at this point, this becomes the flow line, what conditions you have to maintain, the flow line is perpendicular to the equipotential line. So, this is 90 degrees, this is 90 degree, suppose if I play with the length of the sheet pile, what I want to achieve, one of you, yes.

Suppose if I increase the length what is going to happen of the sheet pile, you are elongating the path, elongation of the path means, radiant very good why, what is i, h by l. So, what you have done is for the same h or delta h, which was earlier acting at let us say length of lp by length 2 times lp, is this ok. Now, by increasing it what I have done, I am reducing the i value, so, i 1 becomes delta edge upon 2 times lp + delta lP, what I have achieved out of this situation.

More than that, what is more critical seepage is not critical, sorry seepage force you have reduce, excellent. So, that means all the i critical are going to be now less and hence what you are talking about the erosion and everything will be taken care of, clear, very nice, this concept is clear. So, basically length of the sheet piles are going to determine the exit radiance and based on that I can design the whole system, so that it becomes erosion proof, can I complete the flow net now.

So, conceptually what you have to do, you keep on drawing the flow lines, this is the shape of the flow line. Now, what you are seeing is this portion is going to be very tricky, but the flow is will take place alright. And this is the impervious boundary, what is the characteristic of a sheet pile is this pervious or impervious, sheet pile itself impervious correct. So, one more condition which you are going to put over here is by virtue of being impervious element.

Steel, concrete composites, no flow is going to take place across this line clear, so is this part clear. So, what we have done, we have fixed the boundary conditions equipotential line, equipotential line, flow line across this no discharge is going to take place, this is the porous media. Similarly across this there is no discharge because the impervious surface, now, if there is no discharge across this line, this is also going to be a flow line, agreed, correct.

So, that means the bottom most flow line would be something this, it is ok, correct. This is a confined flow because the domain of the flow is fixed even if h degrees at does not matter because the flow domain is fixed and confined situation we will discuss later on. See normally what we do is we have to plot these flow nets now, the flow nets are drawn when we were students we used to be given a teledeltos paper.

Check it on net what is the application of teledeltos paper, question which you are asking is related to how to establish the flow nets correct in chart.

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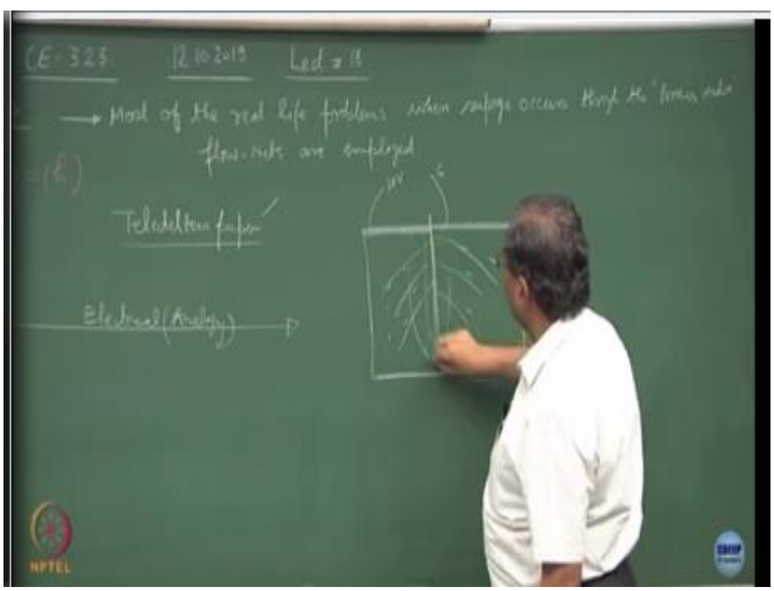

So use this teledeltos paper on this is a conducting paper, on one side there is a silver paint, on the second side it is you know resistant to electricity. The whole thing from geotechnical point of view, now I am going to transform to electrical analogy. Because I have to answer your question, this is a conducting paper, what I have to do is. A real life problem like this I have to scale down, plotted on a piece of paper which is still with the teledeltos paper, is there a way to create sheet pile on this paper.

So you cut the paper here by cutting what you have done, there is no connection the same thing as this clear. So the seepage has become equivalent to flow of current, this is the electrical analogy, the whole situation can be transformed to electrical analogy, very good. So the moment you chop it create a small slit on the paper offset and dimension. This is representing my sheet pile, how are you going to apply, voltage oh sorry I answer my question.

How are you going to create now, the equipotential, good. So what you do is on this paper, you apply some silver paint and connected to let us set 10 volt and on this side you apply silver paint and let it be ground. So, what I have done I have created a 10 volt differential between the 2. Now listen carefully answer to your question, either I should be doing you know solution of del square 5 = 0 and del square psi = 0 which we did yesterday in the classroom. And mathematically I can develop a flow net, what conditions you have to maintain.

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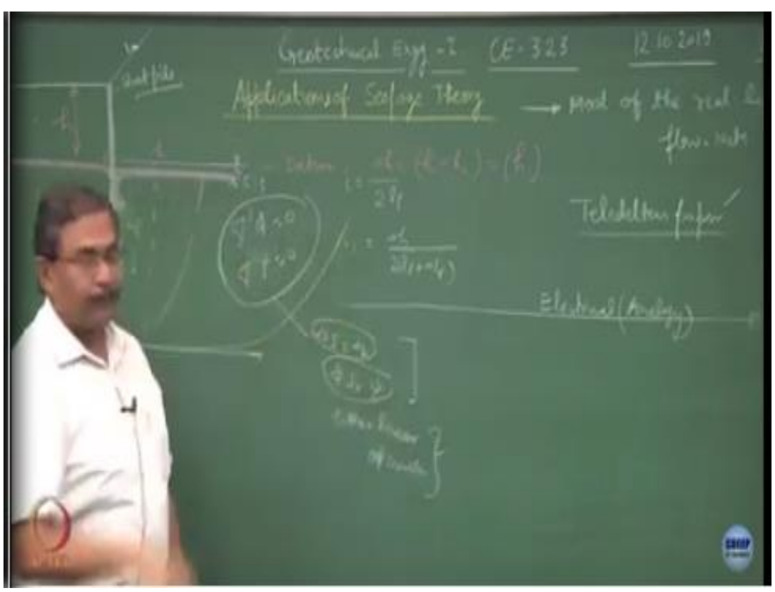

If you remember delta s equal to delta n square curvilinear square or a linear square clear and psi and 5 are going to be perpendicular to each other, got it, So, either you do mathematically you can solve this differential equations, is this ok. And you can plot the pi and psi domain you get the flow net, clear easy way would be what engineers will be doing, this is what mathematicians will do. Engineers will use this paper, scale down the whole project apply certain voltage here, 0 voltage here and then take a probe, you know this conducting probes are there, what do you call them.

In multimeters you have probes is this ok, we test bridge can also be used. And suppose if I touch at this point, if I touch at this point, if I touch at this point and so on, so what I am going to get, potential, is this ok. So, as precise as I want, I can use that probe which is connected to a digital potentiometer or whatever. And I can find out the voltages across this point, once the voltages are known, you get the equipotential lines, is this ok.

Now once the equipotential lines are obtained, what you are to do is draw the flow lines by keeping these 3 things intact either linear or curvilinear fine, is this the answer, you have understood. Then what should be again be I be doing, having done this, I can transform the whole thing on this scale also. Sometimes people use copper sulphate solution also for analyzing these things.

Ultimately everything will get affected in the form of void ratio porosity and these things will reflect on gamma d and this is going to reflect on k that is it, now does not matter, got it. So, if I do a borehole here before inserting the sheet pile, if I know the profile of the soil, I know the void ratio ratios porosity, I can compute gamma d, I can relate it hydraulic conductivity that is all.

The question is why are we do all these analysis one is ok, we have established the flow net. So, all these become the flow lines the whole idea of doing this flow net is. As somebody said correctly, I want to find out what is the discharge taking place across the sheet pile system. Because what is your whole intention, the whole intention is that this water should not be lost at all (()) (47:44) canal this is beautiful example, clear.

You have a lift irrigation system, pervious land even if you store water, everything will sweep through or the point is spending crores of rupees. So, what should I be doing, I should be computing q four different lens of the sheet piles, try to minimize it. And achieve a situation where 2 turns to 0, I have created a very pervious system engineering wise impervious through with nothing discharges, what else you wanted.

By playing with the length of the flow lines only nothing as simple solution you got it. First is apply the voltage, get the pi, once you have got the pi, from here you can get the psi, keeping the boundary in boundary conditions in place. Little go to analysis of this type of a situation I will do.

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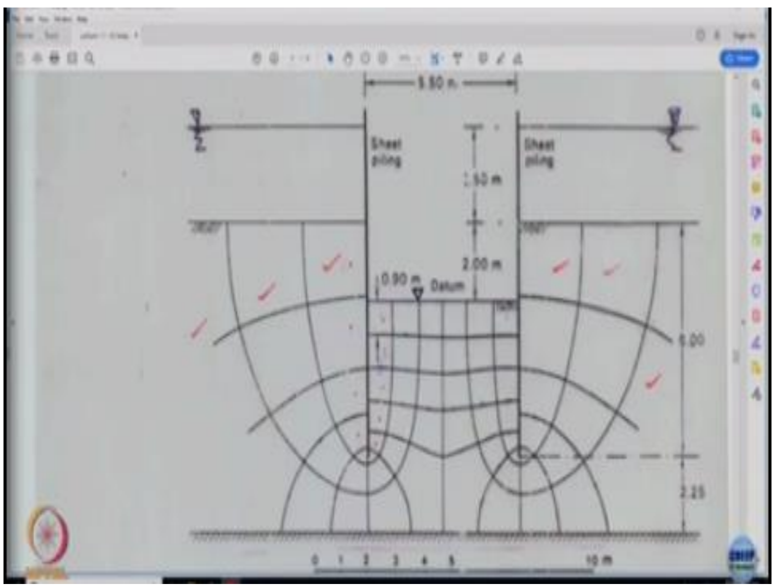

So, coming back to the deep excavations.

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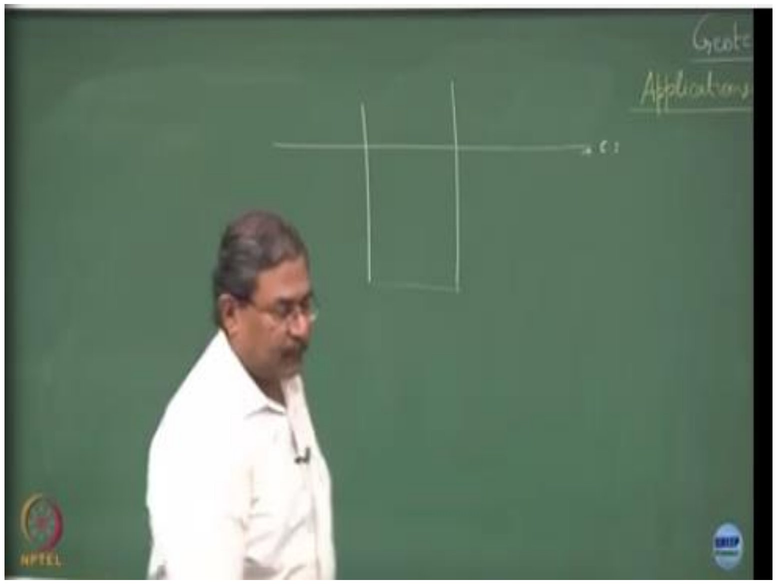

As I discussed this is the ground surface and I am creating some space and this is the end of the excavation.

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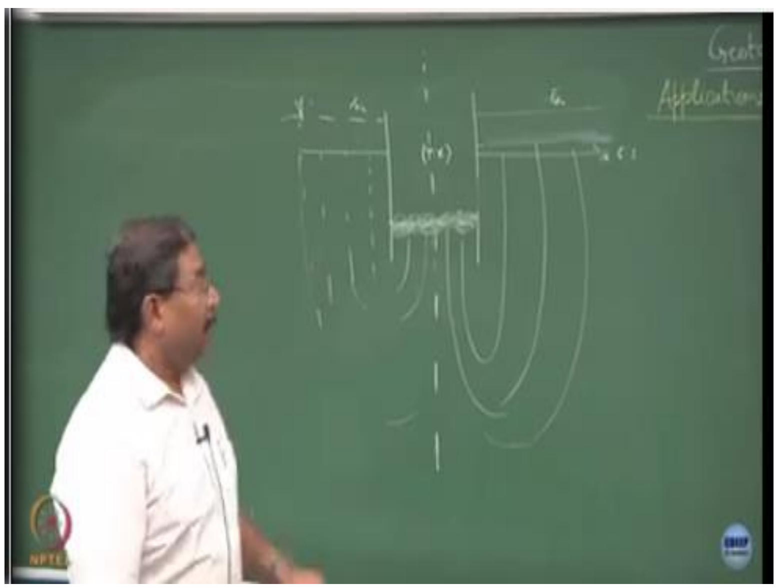

So, I have to remove the soil, tell me one thing, the moment I removed the soil what is going to happen. So, the question is, if you are putting the sheet piles and if you remove this file, what comes to your mind number 1, forget about seepage analysis and all, what is going to happen and provided yes. Now this is an interesting case, so listen the first flow line it comes and this situation, I can convert into this situation also which one is more critical.

Suppose if I say that the water is getting accumulated in the pit, so I have removed the cover overburden, how much I have remove, gamma of the soil multiplied by excavation x. This much stress has this much has been de-stressed, you understand the word de-stressed my excavation this much block has been removed. So, at this point gamma into x is the de stress which has been applied.

I have been telling repeatedly if I do not put a raft over here what is going to happen, the raft will get uplifted. That means, the moment this line comes and hits over here, what is going to happen, you are doing excavation. The whole water starts coming in from the pit, are you getting this point, this is what is going to that thing, how to stop this design a raft, overload the system, create the space.

I am getting advantage of 25 kilo Newton per meter cube of concrete RCC clear and this was how much 15, 16 kilo Newton per meter cube. So, that 9 kilo Newton per meter cube multiplied by thickness of this is going to be the added stress on the exit gradiance, mechanics done, is this ok. Now if you are not satisfied still suppose the water table is very, very close and dynamic situations and whatnot do proper anchoring, what anchors are going to do, they are going to hold the raft always.

And this much of the pressure is going to get added up to the weight of the system because 9 kilo Newton per meter cube multiplied with the x is not going to compensate for you know 25 into x value, sorry 16 times x value. So, in order to keep this holding I can put anchors also, but anchors are not going to be helpful as far as the sheet pile sorry, seepage is concerned. So if you might have noticed, what I did is I started with this situation and slightly less than this.

Now I would say if both sides are same as far as the hydraulic head is concerned, what is going to happen, this becomes the line of symmetry clear ok. So what is happening over here is the same thing is happening over here. So up to this portion this side will contribute, up to this portion this side will contribute and hence your flow nets are done, is this ok. This is what you are asking (()) (52:50) if it the difference exits there difference water level as between this and this.

So suppose if I say, this is hl and this is hr yeah so what is going to happen, unsteady state, clear. So, this system will keep on equilibrating with each other like a dashpot. So, the seepage will occur, if you are aligned seepage to take place through it does not get affected, clear. But if you are not allowing any seepage to take place through the whole problem will get changed. Because then this becomes a what, what type of boundary condition this would be now.

Flow lines coming and hitting a plane, equipotential, is this part clear, just go by the simple geometry of the thing. The flow lines comes and cuts if certain plane is going to be an equipotential, you have an equipotential here, you have an equipotential here. This exponential is connected to the atmosphere, what he was talking about. Suppose if I put a filter layer over here and I objected why I said, whatever you are holding over here it will keep on seeping out, I do not get any advantage out of it, fine.

So I am sure you are getting different dimensions of the situations, is this part clear, yeah. So just go by this fact this is equipotential number 1, this is equipotential number 2, this will be equipotential number 3, I do not know what are the equipotentials over there. So what you have done is, you have created a situation which is case specific. So maybe to answer your question, I think suppose if I give you a situation like this.

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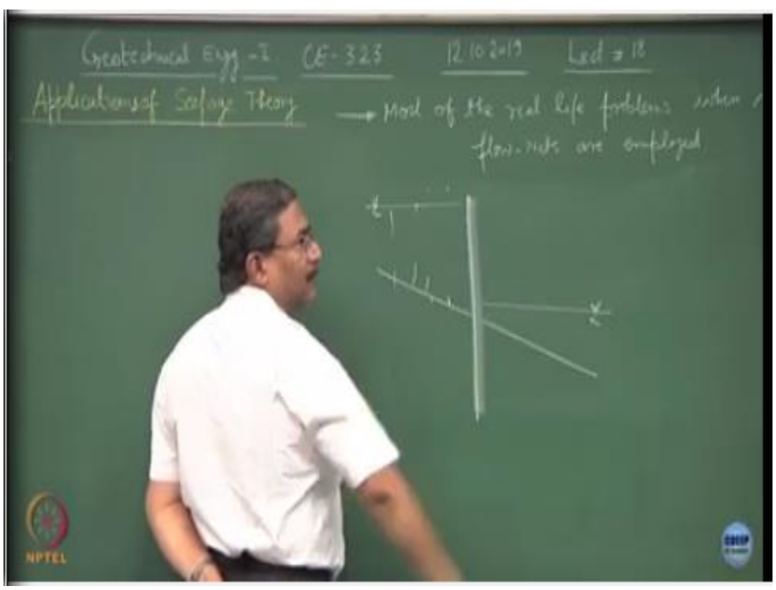

There is a sloping ground and there is a sheet piling done over here like this, now solve this problem, what about this line. This remains equipotential still or not, each and every point at this pace the location is changing, but totally head is going to be constant, that is it nothing else. The only difference between this situation the earlier situation is this was horizontal, so your elevation heads are nullified.

Now what has happened each point will contribute to a certain elevation had also and piezometric head is at this point this much, at this point this much, at this point is much, at this point this much so on.

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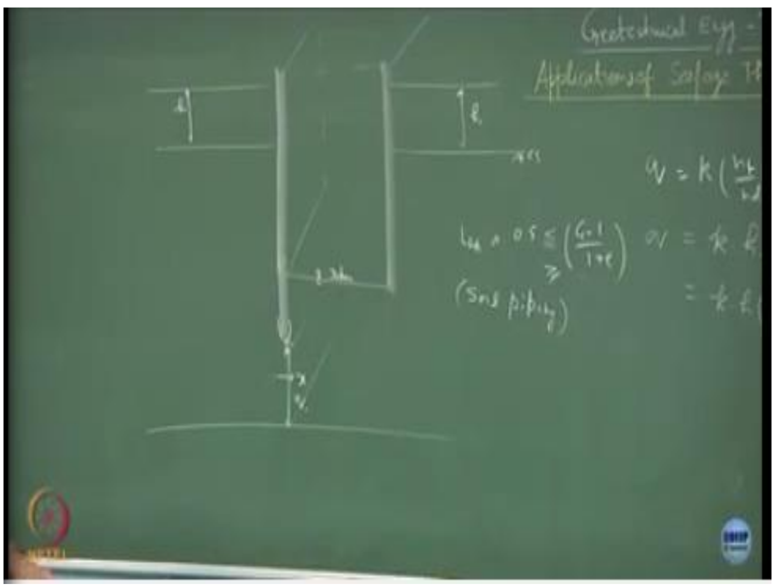

So this is a sheet pile, this is a sheet pile, this is there ground surface, here you have h1, h2 or this is h1, it could be h2 also whatever we have discussed this, this is the end of the excavation. And the water table I have shown at this point itself and I am considering this as datum. Then there is a impervious surface, having established the flow net by one of the methods either numerically or by graphically using the teledeltos paper, you can draw the flow nets and then start analyzing it.

So, when you analyze, we have to count, number of drops and number of flow lines, this is what we discussed in the last lecture.

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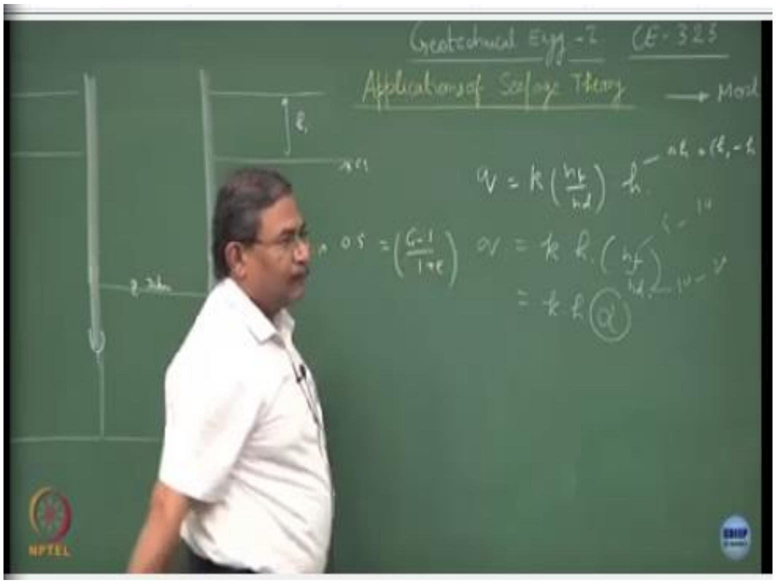

And I think I have introduced this concept that q = k into nf upon nd multiplied by h, where he is nothing but delta h. So, h could be the delta h, h1 – h2, nf is the number of flow channels, nd is the number of drops of the equipotential line. Having done the flow net, start counting, this is the equipotential, this is the bottom most flow line impervious layer. So, no discharge is going to take place through this, good, sheet pile no discharge across this.

This happens to the first flow line grazing through the sheet pile itself alright. The next flow line is this, next is this, so on symmetrical case, both sides this is the regime, flow regime which has got established. From this point to this point, which is atmospheric I hope you understand the seepage is being caused by this head – 0, clear, agreed. In other words, the head is dropping from this plane to this plane in number of drops, which I have represented as nd.

Start counting it first drop, this is the first segment, first drop, second drop, third drop, fourth, fifth, sixth, seventh, eighth, ninth, tenth, meaning there by the entire head has got dissipated in the porous media in 10 drops, is this ok, so we have counted nd's. In other words, if this is 100% potential and this is 0% potential, what will be the value of h at each of these lines equipotential lines.

If this is 100, this will be 90, this will be 80, this will be 70, this will be 60, 50, 40, 30, 20, 10 I have missed out it some other place, no. So, this is 100% let us say 100, this is 90, 80, 70 yeah

70, 60, 50, 40, 30, 20, 10, 0 ok. So, truly speaking at each of these equipotential you know the h value, is this correct or not h by 10 multiply by nd is the value of the head at that point. Now, you need not to insert piezometer and all.

Because the moment you have done flow net you know the value of h at every point, is this part clear, how many flow lines are there, ticks this is the first flow channel, this is a second flow channel, this is a third flow channel and so on. There would be a flow channel which will be grazing through the horizontal plane at infinite distance on both sides. So, that means this is the nf number 1, nf number 2, nf number 3.

But truly speaking is not this 3.something clear, so how many flow channels are there nf we have got, nd we have got h we know, if k is known, I know what is the value of q. And remember this q is the discharge which is taking place through the space between the sheet pile and the formation. So, this is the value of q over here per unit width of the cross section perpendicular to the plane. Please take 1 or 2 minutes to understand and in case you have doubts we will discuss again.

I can keep on refining the flow nets at millimeter scale also, so I can dissipate the entire delta h in 1000 steps also, how much time is required, how much computational time is required clear, whether this is really required or not. So, I can do very fine mesh to create more nd’s also there, I think this is what you are trying to ask. This is the flow line, so there is no harm in drawing a line like this of the equipotential, is this correct.

Technically, flow line is perpendicular to the equipotential line, so are you happy with the situation or not. I had written something over at del pi, del psi perpendicular to each other and then boundary condition what was that, I had written 2 more things, sorry, del s = del n and either linear grids or nonlinear is squares clear. So, what is your understanding, we should not, why, singularity point.

This concept of singularity point you will enjoy I am sure instruction analysis also. So what we are trying to discuss over here is, say this is a sheet pile, this is the flow line and then you want to join equipotential over here, I said no harm, but look at this point, this point is acting as a flow line also, it is acting as an equipotential also, you are defying the pi perpendicular to psi concept. So, these points are known as singularity points, that means we do not consider them in analysis but you cannot defy them also because they exist, fine, clear.

So **I can** I can bypass this drop and I can take some other drops in the nearby, this is how it has been done.

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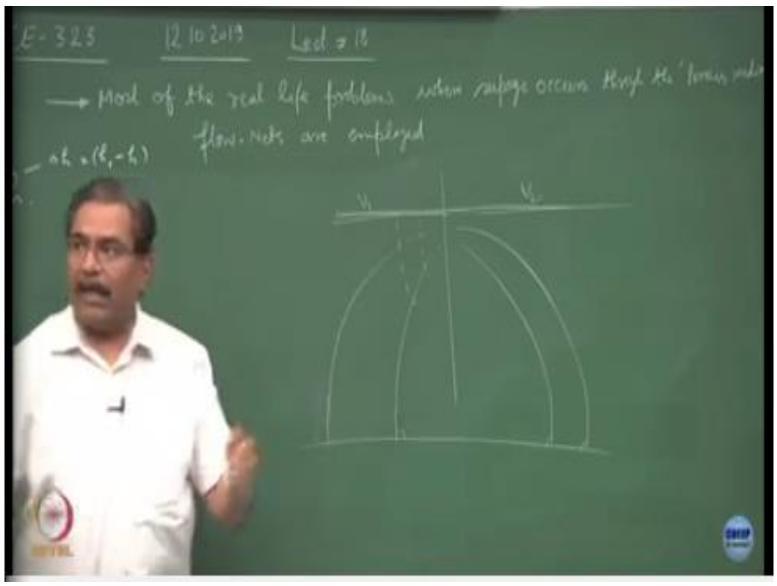

You have the voltage here V1, you have the voltage here V2 what I am doing is I am just trying to find out what is the voltage distribution in the domain that is it. So by using that probe, I am just fixing what is the voltage that is it, nothing else, there is no reading. So, you establishing the equivoltage points, so this becomes equipotential line, fine. And one of the lines is this another line, is this alright, none.

And the bottom portion if it is impervious, all these equipotential lines will come and hit the flow line because bottom is also a flow line we discussed, so they will be perpendicular 90, 90 and so on. Once the equipotential lines have been fixed, what you can do is, you start now plotting flow lines, maintaining the geometry of the squareness. So, it depends upon the step for the voltage that you have fusion because your delta s = delta n.

So, if you are going for very fine your flow lines will become very fine, more number of channels. So, ultimately what we are discussing is, it is interesting that you are asking this question. If I say fine, I will say that q = k into h into some coefficient alpha which is a geometrical coefficient. It depends upon your precision of grind the flow net. Because I am sure if you plot a very fine flow net, number of f increases nf increase and d all increases, so that gets nullified, clear, that is it.

So, I hope now this is clear to you, so if it is 5 let us say it is 10, the more precision I go for this becomes 10, this becomes 20.

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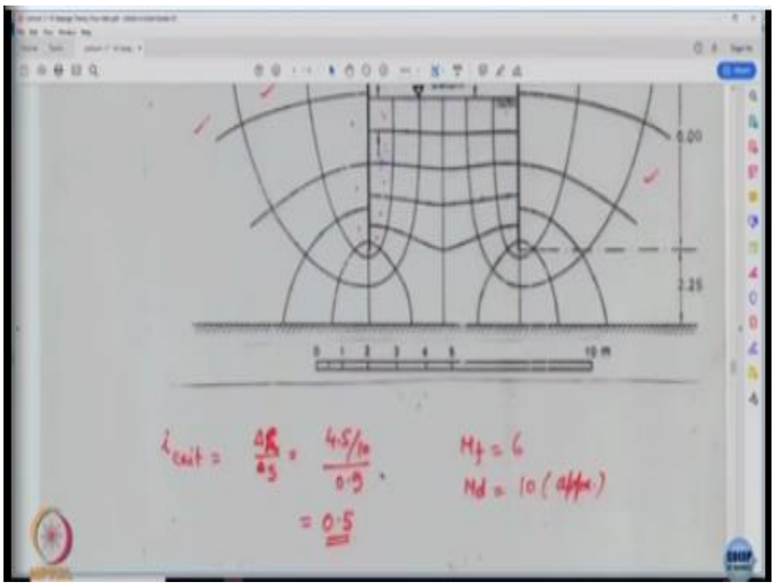

Now support if I give you an element over here alright, this is the element which is very close to exit and we want to design all those protection systems. So, you know what is the value of delta h across this element, this is 0 and this would be total delta h upon 10 because these are tenth drop, agreed. So, this is 4.5 if the 4.5 is your you know, 2 + 2.5 is 4.5, so starting from the datum the total head is going to be 4.5 upon 10 and what is the length of the element 0.9 metre. So, exit gradient is 0.5, **how to** how to check the suitability of the exit gradient.

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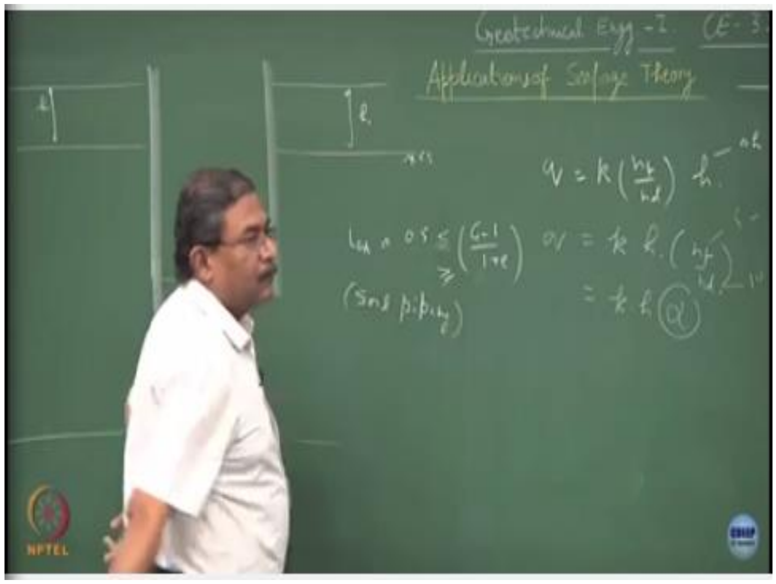

Suppose, if I compute exit gradient as i critical this will be equal to 0.5, what I should be doing with this. Now, this is equal to your G – 1 over 1 + e, we have proven this, when you are doing the seepage force analysis. Now, the material properties are coming in application in 2 ways specific gravity of the soil and the void ratios. So, suppose if I say this is inequality, and if I say the theoretical i critical is coming out to be more than i critical which you are getting from the flow net what is the implication.

And suppose if I say that this is less than equal to not equal to less than this is 1 and greater than equal to is another case, what is the implication. So, just by using these signs I have changed the implication of the entire situation. The theoretical exit gradient is going to be more than i critical which you are getting your sheet pile system is working absolutely alright. In this case exit gradients are going to be much more than the theoretical one.

It appears that the piping is going to take place, you must have done this piping, the question which you are asking about the symmetry, I hope you can realize here, what is contributing to the total discharge . We talked about only one half 1, 2, 3, 3.something and this portion is also connected with the channels 1, 2, 3 so it support 6, 7 which you might consider. And then your number of flow lines which are contributing to the system would be 7 or 6 and drops would be 10.

And then you can solve this, what is the significance of this 2.25 here, this much is the space through which the discharge is going to occur. So basically this q is going to take place through this and the way it looks like is, this is your third dimension of the entire system. So this is how the third dimension looks like.