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NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

CDEEP
IIT BOMBAY

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 17

Module-2

Permeability and Seepage-6

Welcome to lecture number 17 of advanced geotechnical engineering course module 2 lecture 6 under permeability and seepage so in the previous lecture we try to understand how to construct flow Nets if we are having isotropic conditions that means the different permeability in horizontal and vertical direction and when we have layered soils like having stratified deposits in such situations when permeability of two soils when, when it is less what will happen when the water is entering from a soil having no permeability to high permeability or high permeability to low permeability how the flow rates can be constructed we have discussed.

And we also have discussed about how to construct flow nets for unconfined seepage conditions that is nothing but embankment dams or at 10 dams and then also different construction methods for the, the phreatic surface which is the, the line of seepage or is also called as line of saturation of saturation line upper most line or topmost flow line which is called as phreatic line namely we have discussed about Dupitt method and Schaffernak's method and Casagrande's method.

We have discussed in this lecture will be discussing about some problems based on whatever we have discussed with numerical as well as some physical simulation which we have carried out at IIT Bombay in continuation of that we will try to discuss how to evaluate this performance return without filters particularly when we have to what are the general criteria which is required for a filter design we will try to cover briefly.

Thereafter we will try to calculate how to calculate the factor of safety against piping failure by both the methods Azra method and terzaghi's method for the two cases one is a when you have a sheet pile wall that is when you have a confined seepage conditions and when you have a concrete dam with a cut-off how to calculate so this particular lecture is titled permeability and see page number 6 so in the previous lecture we actually have discussed how to construct a top most reactive surface this is nothing.

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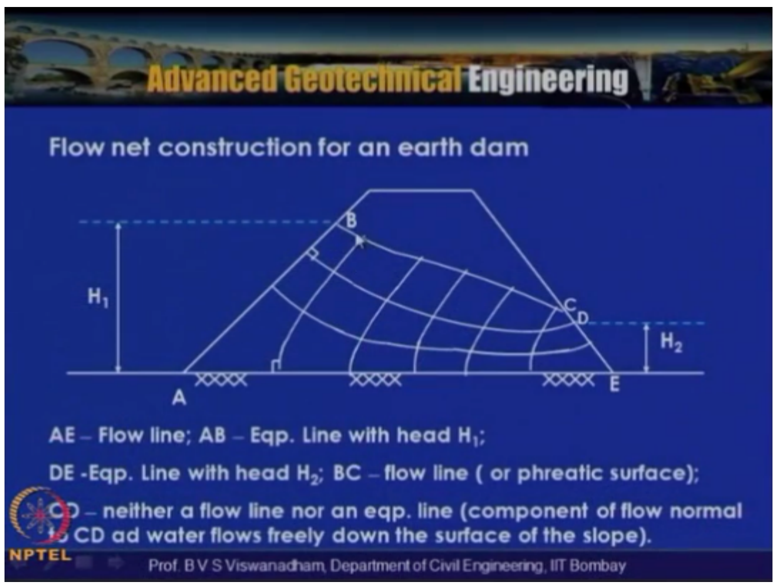

But the BC is nothing but the phreatic surface so there are number of you know methods which are actually given and some a entry and exit conditions are also given and which you are not discussing but they are required to be referred from the relevant test books but if you look into this flow net construction for a dam here AE which is the dam resting on impervious stratum AE happens to be a flow line AB is an equi-potential line and B E is equal in line with a head H2 so the head drop or potential drop is nothing but H1-H 2 and BC is the flow line what we are actually discussing is the top flow line and 1, 2, 3 or you can say the 2.5 these are the flow channels such as they should be constructed such a way that we have the aspect ratio B by L is equal to 1.

And the CD which is neither a flow line nor an accommodation line this is a component of the flow normal to the CD and water flows freely down the surface of the slope so CD are the point of conflict we can actually say that Point C point D where which is you know appear to be a point of conflict in the given example which is here so these are the potential drops because this being here the it is easy to calculate it is generally the between, between each equi-potential line.

So this is the equivalent line 2, 3, 4, 5, 6 so what actually happens is that when yes the pressure on the topmost flow line is zero so the total head is equal to pressure head plus elevation head when the pressure is zero at because of the atmospheric it is open to atmospheric condition then the total head is equivalent to elevation head so depending upon the whatever the location is there we can divide this into divide this into say number of drops that is h1- h2 by what now whatever may be the number of drops.

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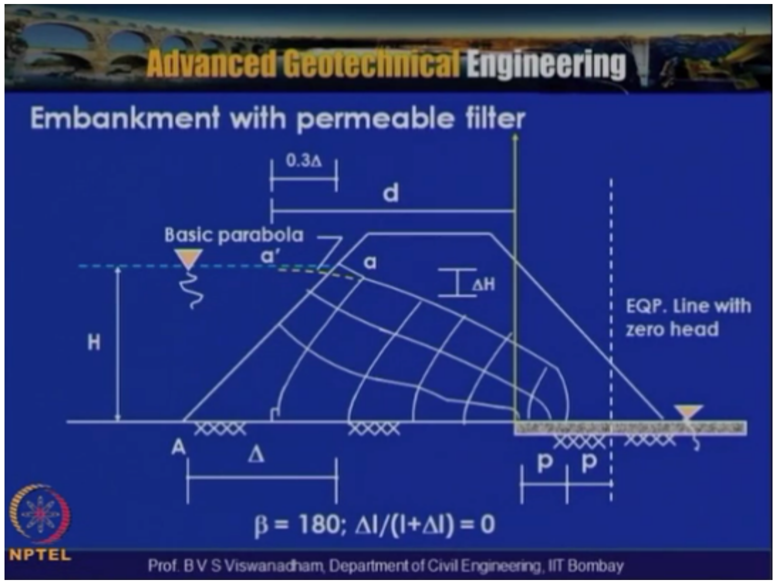

We can simply say that Δ H Δ H and Δhas equal potential drops can be divided as the water flows from this point to this point there is a you know dissipation of head which actually takes place this is an embankment dam with a parable filter these pyramid filters are actually contained they are based they are placed basically in the horizontal direction or they are placed at the toe in the form of a rock toe or they can be placed within the dam within the earthen dam as a chimney so it is also called as a Jimmy drain.

So in this example the embankment dam with a thermal filter construction is shown here wherein as suggested by Casa Grande the basic parabola is assumed to be start at .3Δ the Δ is nothing but a point from this point this, this from this distance and β is equal to180^{o} and we call with the β is equal to 180^{o} the ΔL by L+Δ L is equal to zero and here this is what actually I was telling about the Δ H Δ H and Δ these are the drops.

And so here this is the equi-potential line with zero head this is the equi-potential line with the zero head and here this is the, the topmost flow line and this is being equi-potential line you can see that this has to be orthogonal so it actually meets this at a right angle so here also this being the horizontal this being the flow line so the equi-potential line actually meets here at the right angle right angles so this is a you know how the flow net construction will happen or the flow happens in real conditions when we have where we have a verbal filter.

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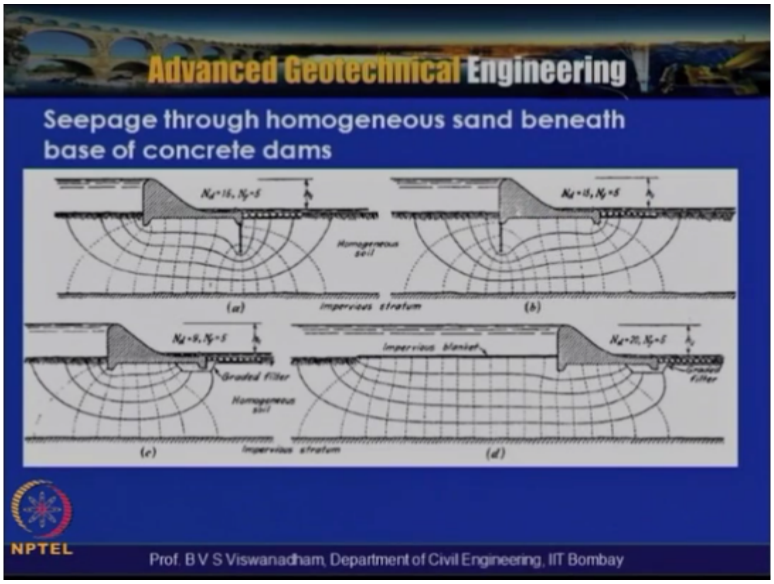

So in this particular slide the seepage through homogeneous and beneath the base of concrete dams is shown here suppose if you are having a concrete dam which is having this configuration and there is some upon layer which is placed here and this is called as the cutoff layer basically this cutoff layer is used to divert the flow away from the in the down stair in the tail water level to increase the factor of safety again striping and other conditions.

And here this cutoff can be in the downstream direction our cutoff can be in the upstream direction also so in this state in this case example where the cutoff is in the cutoff wall is provided in the at the downstream end and here in this case cut off is provided in the upstream line here this is the case where there is no cutoff is provided but you can see that how the flow happens ever happens and here for this construction the impervious blanket has been placed and then the flow which actually cannot take place through this.

So which is directed away from the, the face of the concrete dam so which actually we have the extended flow net which is like this so here we have a granular filter and there is a prawn which is actually placed here in all the cases you know where we are the upon which is actually shown so for this case also when you have a terrible sand layer and layer terrible soil layer beneath the concrete dam and how the flow, flow net actually happens so the depending upon the you know the configuration and head of the water and high flight level requirements and all only to how the parameters.

And perform the seepage analysis and based on the, the results like uplift pressure and then once we have the other issues other factors like factor of safety against piping and the next it gradient once we calculate which we are actually going to discuss in this lecture then it is possible for us to decide about an appropriate configuration for a particular sites specific problem.

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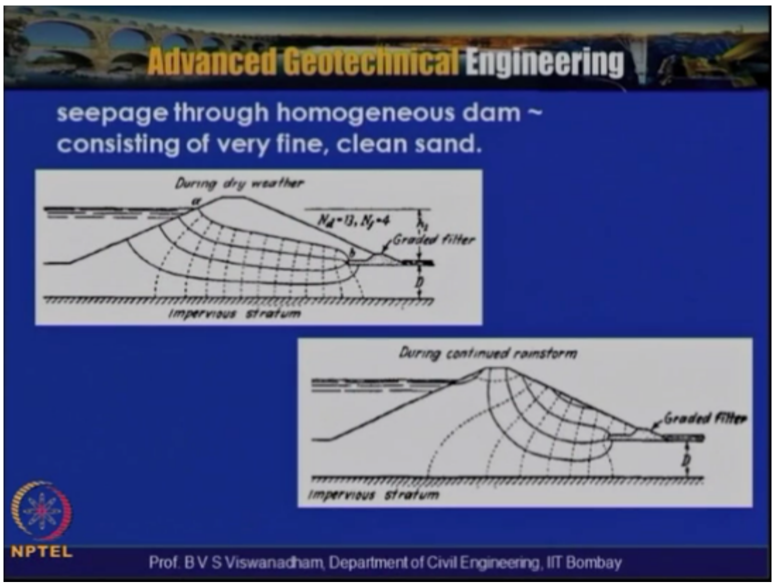

In this particular slide a seepage through homogeneous dam consisting of very fine clean sand is shown here so here there is a, a granular filter is shown so the granular filter which is actually placed here makes it you know the flow that will be like this. But this is a flow rate which is actually shown for a dry weather condition suppose when we have a condition of continued to a rainstorm then the there is a possibility that the flow rates construction will actually change and leading to instability of a dam because of the seepage failure so here because of the continued rainstorm there can be a possibility that this type of you know the complete saturation can take place and the flow rate can change the way it is actually shown schematically here and that can lead to the or endanger the stability of the tandem our homogenous demander question.

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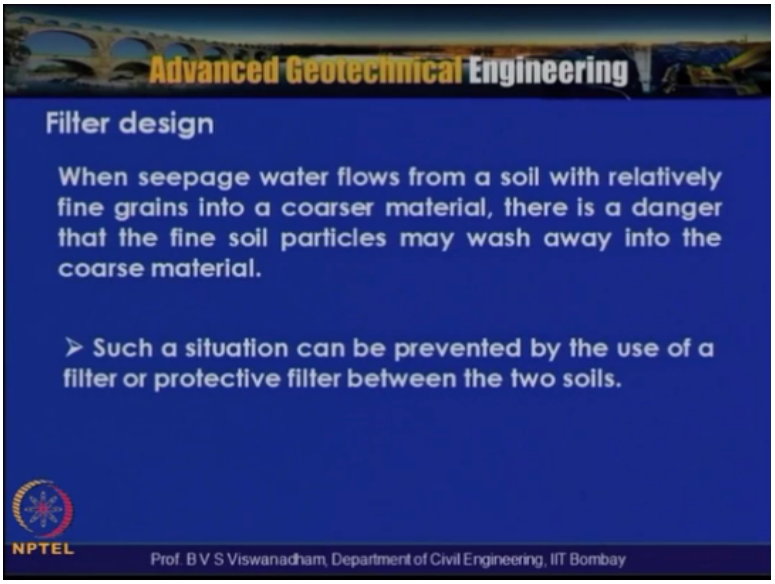

So in order to maintain or in order to contain the periodic surface within the you know the earthen dam body or conditions with the confined seepage condition one of the alternatives used to design appropriate filter materials when seepage water flows from a soil with relatively fine grace into a coarser material there is a danger that fine soil particles may wash away into the course material.

So when seepage water flows from a soil relatively soil which is actually having relatively fine grains into a coarser material there is a danger that the fine soil particles will get washed away into the coarser material and then you know that what will happen is that the coarser material which is actually having high permeability will get blocked the similar situation happens when folding off you know railway ballast will not have course.

They have they lose the you know permeability or drainage property whatever they have and also you know load sharing behavior also can get affected in case of track underlay structures so the such situation can be prevented by the use of a filter or a protective filter between the two such soils that means that when you have a soil to be protected and when you have a soil which is very hyperbola.

So in general to prevent that situation of washing of fine soil particles into coarser particles there should be a filter layer then what should be the criteria for selecting this material filter layers nowadays with the advent of materials in civil engineering some of the materials like Jo synthetics preferably a nonwoven geotechnical which are actually having adequate or appropriate opening sizes or recommended because their ease with construction and also the timelines can be very, very significantly less but moreover the performance is also superior because of the, the tailor-made product.

Whatever we install but however some of these shoes like clogging during the lifetime of its operation and so then this use of this synthetic materials also can lead to some sort of replacement of natural materials because the availability of the natural materials is scarce now and in such situations one of the viable options used to you know try out for modern materials like non woven geo textiles or geo composites for this application.

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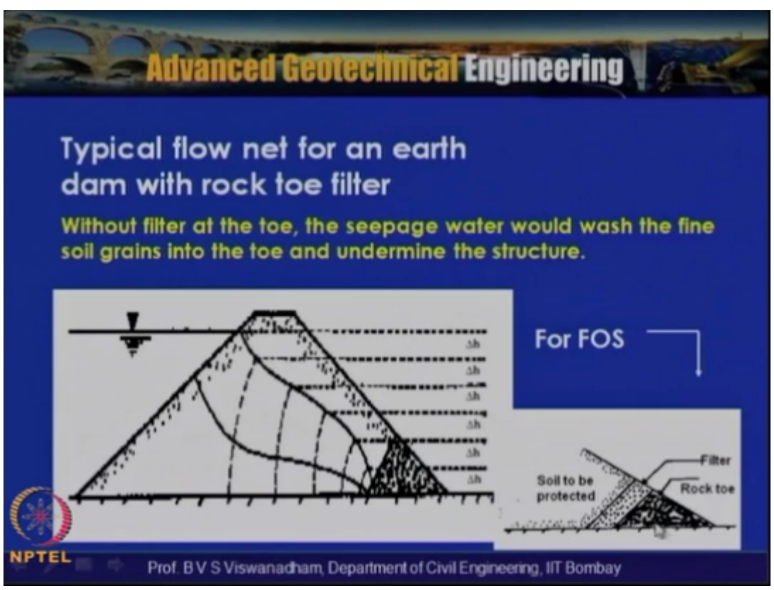

So in this particular slide a typical flow rate for an earthen dam with rock toe filter is shown so rock toe filter is nothing but this is the soil to be protected and this is the rock toe and here this is the filter material so this filter material what it does is that it prevents a fine soil particles to get washed out into the coarser portions and then if we are able to protect this then what will happen is that it ensures the stability to the structure and then the conditions of the damn ship stability can be ensured.

So without filter at the toe the seepage water would wash the fine soil grains into the toe and undermine the structure so it basically undermines the stability of a structure so this is an example what I was mentioning about a chimney drain where you have what a horizontal drain and then it is extended with a column of sand and sometimes in when we use some pervious materials here there is a layer which is called as Harting is also used so next to that Harting layer.

So harting layer is nothing but a core which is having very high very low permeability and which is having high compressibility characteristics as well as high plasticity characteristics so that remains within the center along the centerline of the one and then the you know the sand drain layer in a sand drain layer in the in place of you know the for a chimney drain can be constructed but here also like you know attempts can be made to replace these you know these layers because the constructing this layer is difficult generally this has to be constructed.

We have to construct in this layer once this layer is placed and then compacted like this and then you have a thin layer once it is compacted and then this material need to be placed and then compacted so the construction actually goes like this in the field so this is atypical flow net for an earthen dam with the chimney drain so here also what I mean to say is that one can think of replacing the conventional sand layer which can be used in the which is being used in the general construction.

Now with a Joseph the rig material like non avenger estate but however the research has to address the long term performance of such systems so before that let us look into the what are the conventional criteria's which are actually available for the proper selection of the filter material the similar criteria's also have to be are there are available for the non woven geo textile when we wanted to replace the conventional filter material that is nothing but the sand.

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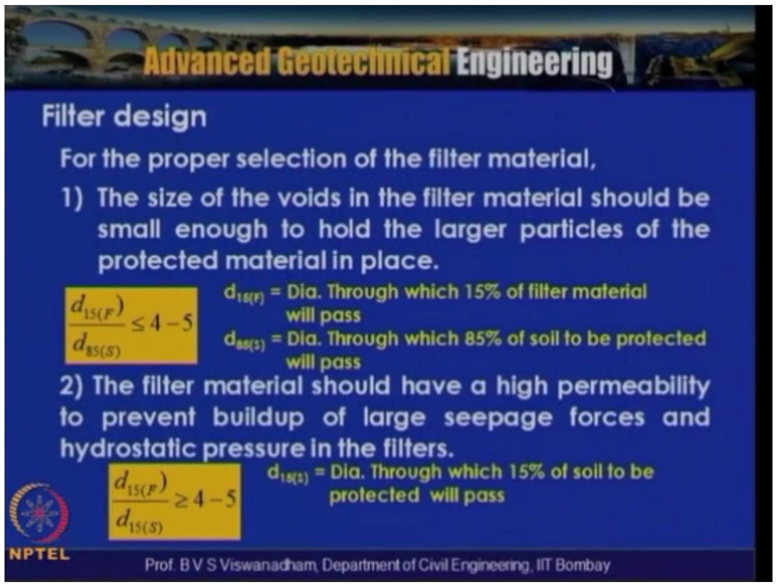

So for the proper selection of the filter material that is the sand the or a suitable soil the size of the voids in the filter material should be small enough to hold large particles of the protected materials in place so that means that the, the criteria which is actually given is that D 15 of the filter ratio of D 15of the filter to D 85 of the soil should be less than or equal to 4 to 5 so D 15filter is think diameter through which 15% of the filter material will pass d 85 soil is nothing but diameter through which 85% of soil to be protected will pass so this is criteria 1.

And the criteria 2 is that the filter material should have a high permeability to prevent buildup of large seepage pressures and hydrostatic pressure at the in the filters so here in the filter material if the material is used is fine then there is a possibility that you know the build-up of high hydrostatic pressures can happen so for that D 15 of filter 2 D 15 of soil should be greater than or equal to 4 to 5 so D 15 of the soil is nothing but diameter through bits 15 percent of soil to be protected will pass.

So once we have let us say the gradation or particle size distribution of soil to be protected particle size distribution of filter then based on of say particle size distribution of you know filter then you know we can actually see based on this criteria the ideal band for the areal band for the band of range of particle size distribution which can be used for as a filter material.

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So in this particular slide a typical attend M sections without any drainage is shown so here this is the physical simulation which is done through centrifuge based physical modeling technique at IIT Bombay so the model which is what we are seeing is the front elevation of the model when it is subjected to flooding in the upstream side.

So as can be seen as the water on the upstream side increases and with the presence of without any drainage or let us say that we have a drain which is clogged then the possibility of its failure or undermine and you know the stability of a section can be seen where it got affected the moment the periodic surface reaches to the toe of the dam which is actually shown so this step of physical simulations will allow us to understand the performance of these particular conditions in full-scale level.

And also allows us to try out a new phenomenon’s or new materials which in varying we can actually see the response of these models with the different materials and then can lead to using the field or formulation of the guidelines for the construction of dams or the hydraulic structures in the field so this is the physical simulation once again I am actually seeing here we are showing you here that this is nothing but the food by what you can see is that as the water comes these are these are the Telltale's for telling us that this is the uppermost periodic surface which actually has developed and then you know the failure has actually occurred here and then endanger the stability of a dam section which is shown here.

So let us see the numerical simulation of earthen dam the similar section without any drainage and with the clock would rain so this simulation was calculate carried out by using geo studio 2012 version and we are in the see the model 2012 was used and this is basically a final treatment based program which allows us to simulate or mimic the behavior whatever as close as possible to the field conditions are the physical simulation conditions which are actually shown.

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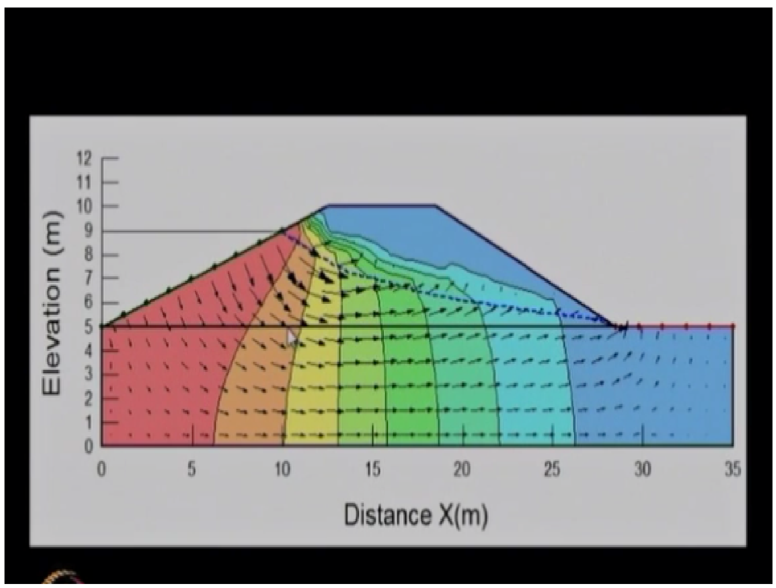

So let us see the, the video simulation of that so here what we see is that as the head of water progresses you can see that the way it happened in the physical simulation the progress of the periodic surface the flow or into the these are the flow vectors which are actually taking place can be seen and the pre Attucks surfaced developments can be seen so this shows us that you know how you know the simulations can actually help us understanding the you know the you know the flow rate behavior and the assessing the stability of these structures.

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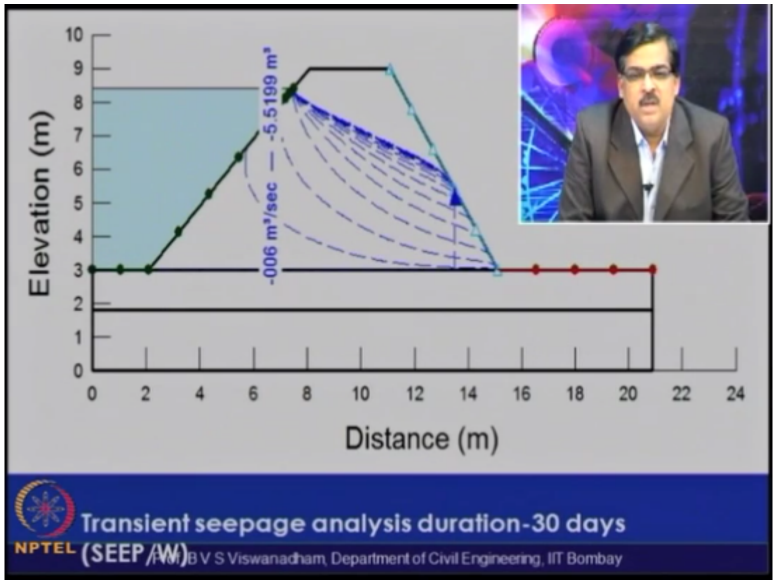

Now we will try to see you know in this particular slide this particular condition which actually has same condition by using the same program but here what we have done is that this allowed us to do the seepage analysis for about 30 days then you know this is the condition which is actually develops here and then it undergoes failure here so this is a condition where we actually have got again a physical simulation but in this case you can see here there is a parable sand layer is placed that is that horizontal drain or horizontal filter is placed and the same height but which is 6 meters.

But now you can see as the head of water increases on the upstream side on this is the employees layer this is the employees layer which is actually constructed with the clay layer and this is with a silty sand layer and this is with the very fine sand placed at 85%a--to density but as you can notice here that as the, the water progresses that this being the horizontal drain layer you can see that the water or the operatic surface which this at 90º closely you can see here this is how it is so this indicates that you know how you know appropriate physical simulations can tell us about the, the real response of a these hydraulic structures so this is a, a particular again similar case with transition seepage analysis during with a drain for 30 days.

So you can see that the as the day's progresses how the you know the periodic surface is maintained you can see that here also from the numerical analysis by using the CW we could get the similar results so we will see again the simulation of you know this by using the CW program but this is with a 0.6meter 0.6 meter drainage so you can see that now this drainage layer is indicated here and this is the drainage layer.

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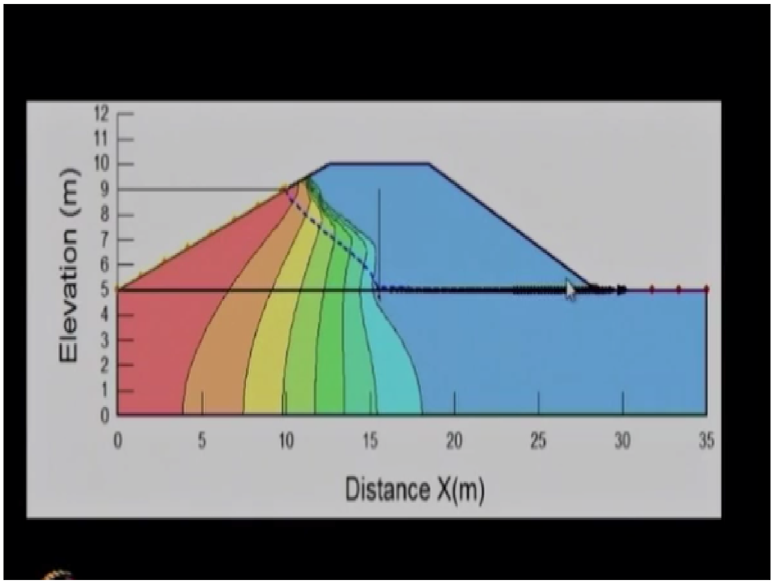

So as we observed in as we observe in the physical simulation it actually meets the you know similar way and the, the flow is contained within the dam itself the flow is contained within the dam itself you can see here so this is the periodic surface which actually develop otherwise previously we are seeing that the periodic surface is actually going with you here so this indicates that the importance of having an appropriate filters within the dam sections now let us look into some problems based on whatever we are discussed in the previous lecture so this is the problem with for a single row.

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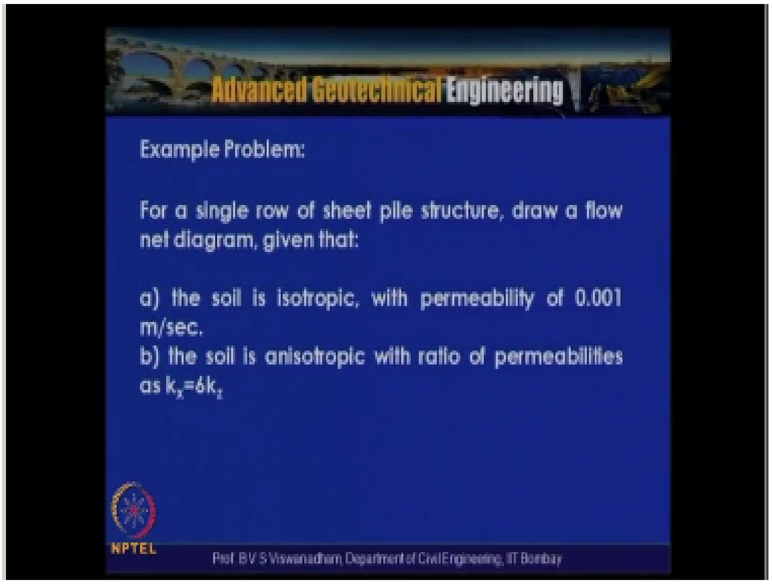

Of four sheet pile wall structure we need to draw the flow net diagram and given that the soil is isotropic in the case one or KC a is soil is isotropic which is having a permeability of 10.-3 meter per second and the second case that is case B is that soil is anisotropy where the ratio of the permeability is KX is easy 6 x KJ so first case is the hi-spec trophy so let us use the same seep/w program of Geo Studio 2012 and we would like to do it for isotropic case in the isotropic case so once we get the construction.

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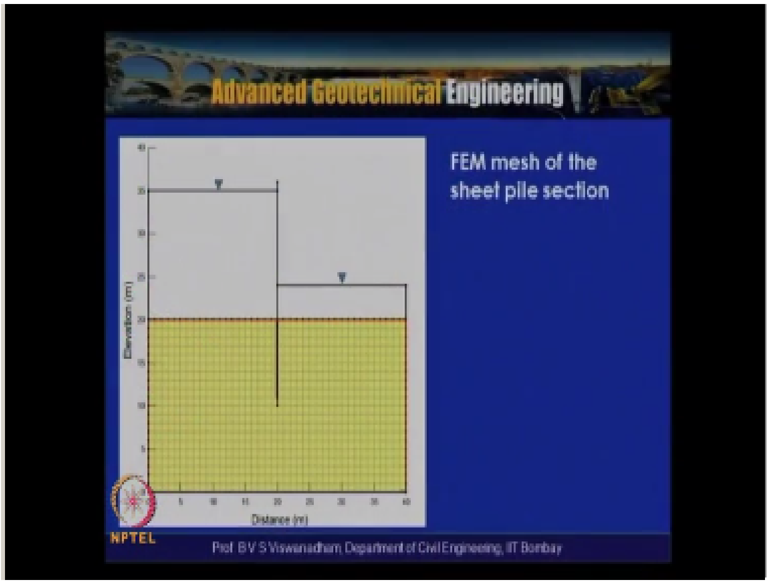

So this is the Fe M mesh for the sheet pile wall section so wherein we have here 15 meters of the upstream head and then where we have the here the 5 meters so the differential head D here is about 10 meters and this is the thimble soil layer and the extent of this horizontal distance here is 20 meters and here is 20 meters which is taken. And here also 20 meters in this problem so this is a typical hydraulic structure constructed with a sheet pile wall.

And these are actually sometimes this is can be a part of a cofferdam suppose if you wanted to construct bridge pier foundations within the river or in any case any, any situation where you need to actually ensure the stability of these coffer dams or constructed in the form with sheet pile walls again it is the you know instability problems.

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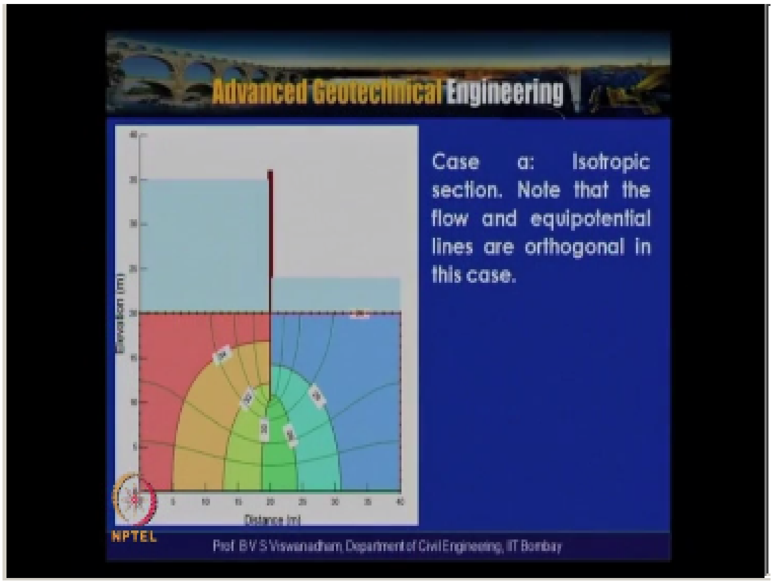

So this is a case at the isotropic section here you can say that the these are the you know the flow channels and flow net which is actually given by the CW program and this is the flow channel 1, 2,3, 4, 5 and then if you take it this as 5.5 the number of flow channels which are actually involved five point five and this is the you know the flow line so you can see that the equipotential lines are this being the flow line equip potential lines are actually commencing here and then dropping down at 90 degrees here.

So the orthogonal between the flow lines and equipotential lines can be seen and these curvilinear squares which is actually having approximately the aspect ratio one can also be seen so the program which actually gives this once you get this data then we this particular package also this particular program also has got.

The capability give the drainage or by using this we can actually calculate my number of flow channels and number of potential drops we can actually calculate by knowing the K we can calculate the, the seepage our permeability of the discharge through the a particular pimple sand layer wherein the sheet pile wall section is embedded.

Now the case B is that we are having a case which is anisotropic section and here where the program actually has a term automatically taken this condition and here you can see that because of the anesthetic in nature the even after having a transformed section the flow, flow lines and equi-potential lines are not orthogonal to each other.

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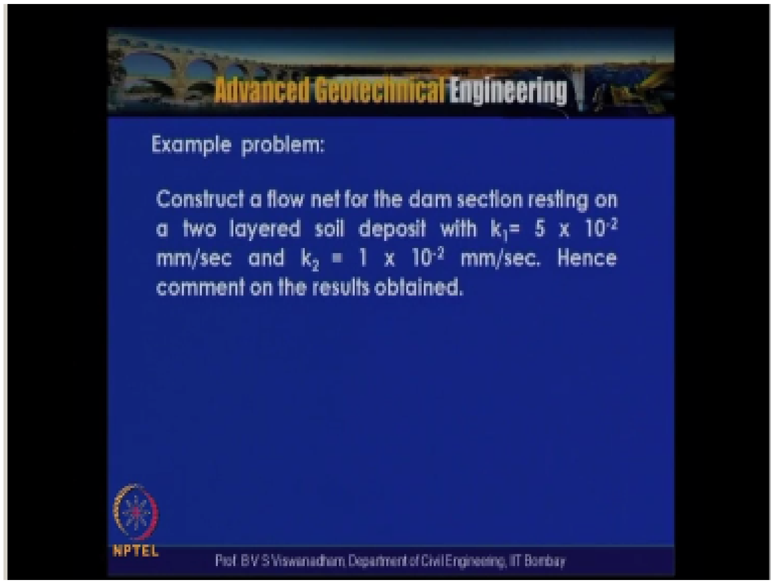

So now construct another problem so we in the previous case we have seen a sheet where wall problem now let us see a flow net for the dam section resting on two layered soil deposit with the k1= 5.10^{-2}mm per second and k2 = 1.10^{2} mm 4 second so hence you know we can see that when we have what you homogeneous soil deposit as well as when you have got say you know two layers what will happen to the flow rates and how these things can be used for constructing are calculating the discharges.

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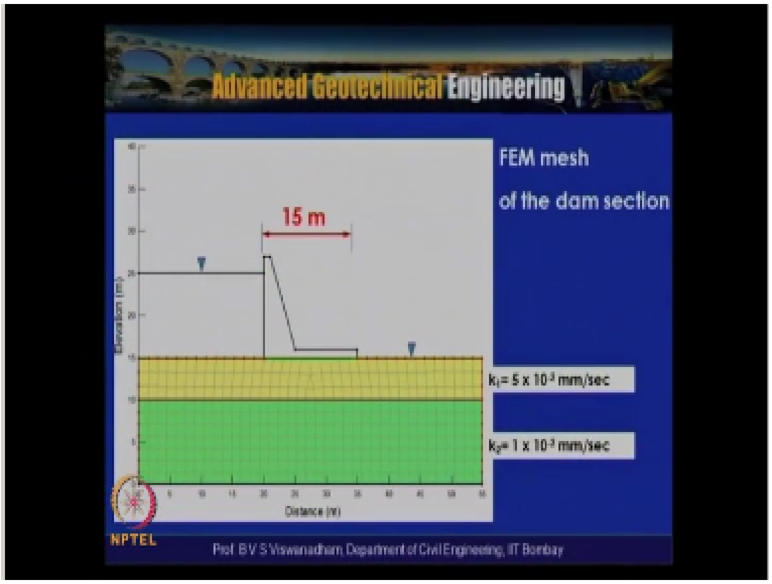

So here we have you know two plates of soils one is k1 having permeability 5.10 $^{-2}$ meter per second another one is k2 having permeability 1.10^{-2} meter per second so k1 is 5 times more people than k2 and this is a concrete dam which is actually having a head of 10 meters and the horizontal length is about 15 meters this is the upstream water level and this is the tail water level and in the field they seldom the situations are like this we have what a layered soil deposits so this is this particular layer is indicated with is a low color and the other one is indicated with a light green color.

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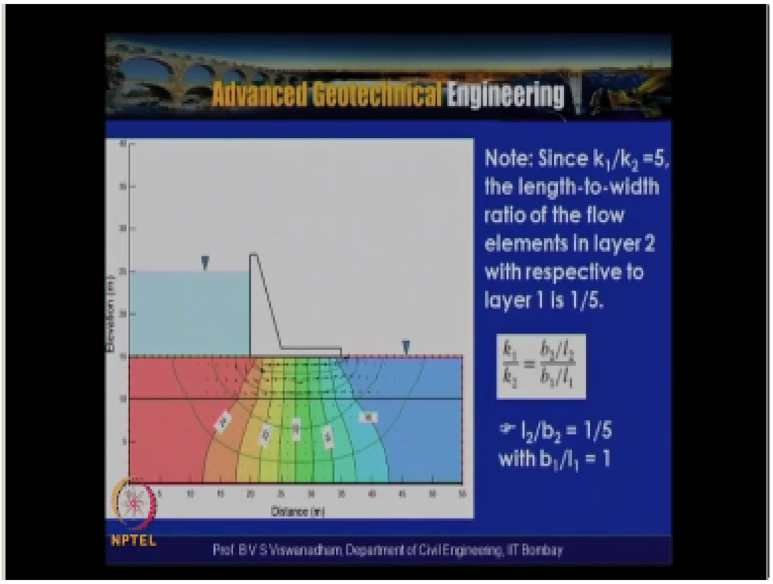

So when we construct the flow net by using seep the CW program so this is the you know equi-potential line here and what we can see is that this is the permeability and this is the permeability this is the upper layer having permeability 5 times the higher permeability than this one so based on the conditions where what we discussed for having non homogeneous soil deposits since here K 1/ K 2 is 5 the length to width ratio of flow elements in layer 2with respect to layer 1 is 1/ 5 why because we have said that when you have our 2 layers then K 1 / K 2 ratio is equal to B 2 / L 2/ B 1 / L 1 by having you know B 1 B 1 is nothing but this particular width between two flow lines that is B 1 and along the you know length of the equi-potential line that is L 1.

So here you can see that the rectangular the squares are almost we have the flow rate is actually having curvilinear squares so with indicates that with the B 1 by L 1 = 1 and K 1 / K 2 is equal to say 5 then B 2/ L 2 are Britta to the length of the, the along the flow the equi-potential lines equal to or L 2 / B 2 =1/ 5 so when you have say a compute layer on the top and impermeable layer on the bottom then we actually have the get the flow rate or the equi-potential lines with having large rectangles so that means that here the B 2/ B 2 / L2 = 5.

So the breadth will be you know let us say that if breadth is 1unit the length will be 5 units because the permeability is 5 times so if you are actually having say impermeable layer below and in thermal area above and terminal layer below then the situation is that again there is a possibility that here we get the you know the small rectangles and because of the virtue of the change in the probabilities of the layers so here what we have seen is that when you have what non homogenous soils the situation how the flow rates can actually change and this actually we have discussed here.

So this example has given us in a clear idea how we can actually you know construct the flow net for having soil which is actually K 1/ K 2 =5 that his upper layer is actually having higher permeability than the bottom layer and now you know what the same problem the drop in the pressure head along the length of the dam due to seepage losses can be seen here.

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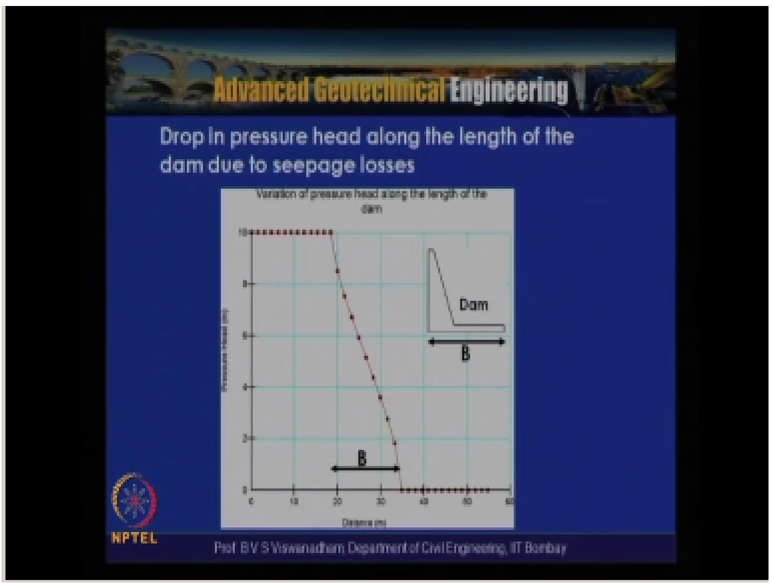

So the B is the breadth of the dam and you can see that how the as the water flows from the upstream end to the downstream end how the, you know head of water is dropping along those equi-potential lines which are actually shown.

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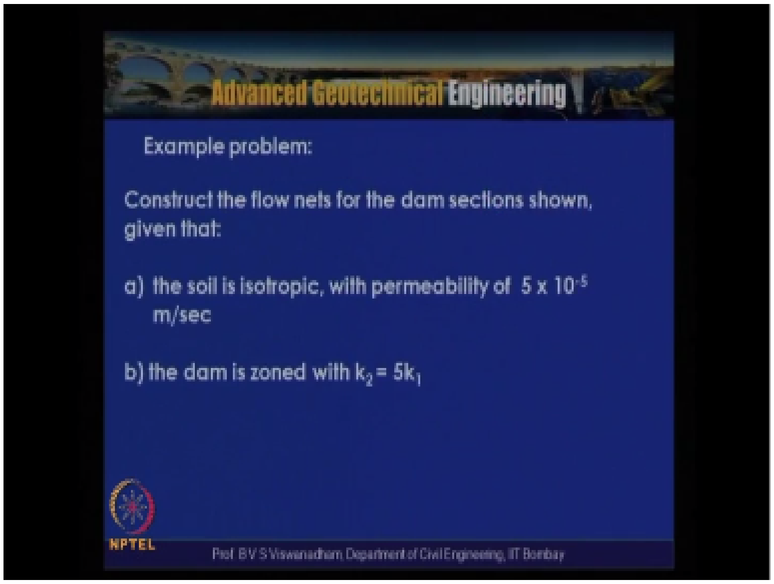

Now the, the next example problem is that the construct the flow nets for the dam sections which are actually this is the earthen dam sections well in the first case the soil is isotropic the permeability is of the order of 5.10^{-5} meter for a second for the damn section and the second case is that the dam is joined such a way that now here k2 is 5 times the k1 so k1 is the permeability of the soil 1 and K 2 is the permeability of the soil 2.

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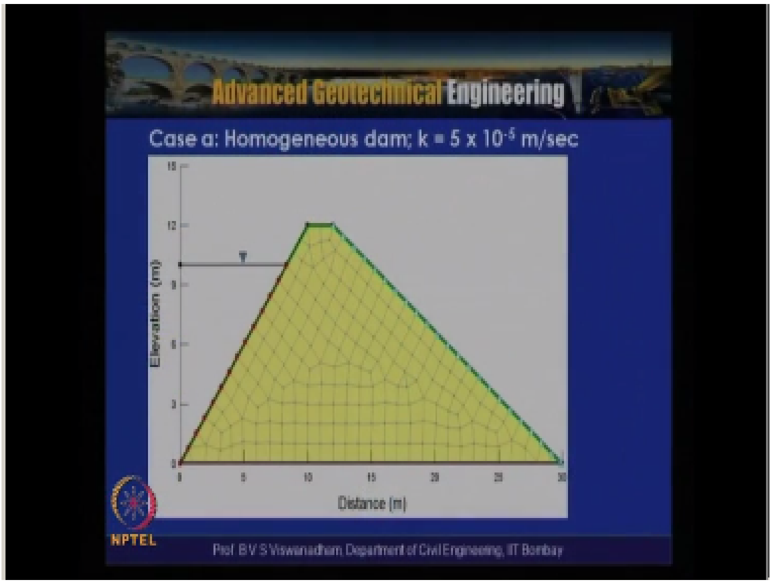

So in this particular example with case K where homogeneous dam having constructed with a soil having Phi into 10^{-5} meter per second the FIM mesh which is actually fitted to the seep/w program is given here and where the upstream head of 410 meters can be seen here and this is the you know equi-potential line and is given as the impervious phase so the flow rate which is actually constructed for solution for the problem with homogeneous section KC is shown here wherein you can see that this is the line of seepage a top most flow line.

And this is the next flow line and then this is the next flow line so here we have 1 & 2 & 2. 5 which is number of flow channels are 2.5 and number of potential drops are 10 so the program actually gives like 10 9 8 7 6 54 3 2 1 these are the 0 these are the you know potential drops so we can see that by knowing this we can actually calculate the discharge or leakage to the dam section where K. H / n D .n F now the same problem.

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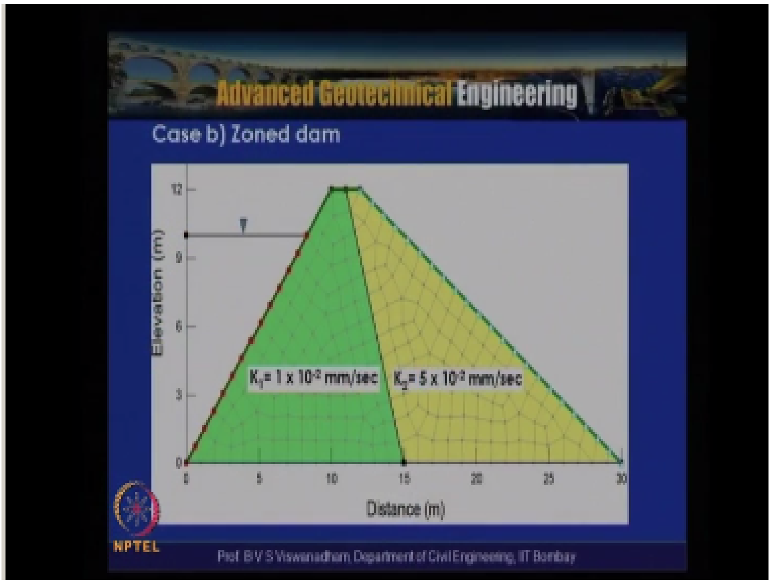

But now in this example the dam is constructed with two different materials in the layer which is on the left hand side is actually having permeability K in K is nothing but K 1 is nothing but 10. 1. 10^{-2} meter mm per second and here it is a 5.10^{-2} mm per second so the permeability of this is this layer is 5 times more than the soil 1 which is actually indicated with the green color here.

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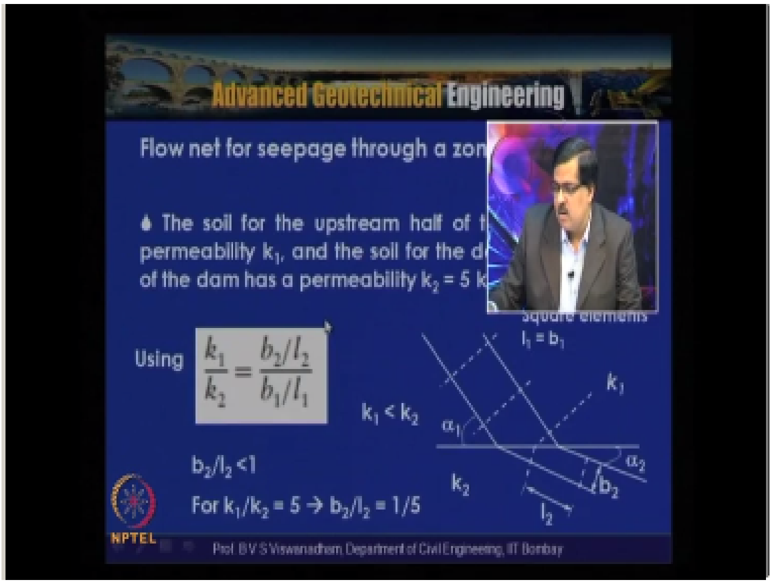

So flow rate for the seepage through a zone that dam this we have actually discussed for the you know is a general example now with reference to attend am the soil for the upstream half of the dam has a Permeability K 1 and the soil for the downstream of the dam has a permeability say K 2 so in this example we have given that you just given that K 2 = 5 times K 1 so by using K 1 /K 2 = B 2 / a 2 / B 1/ L 1we can see that now with K 1 < K2 when you have a layer soil one with less permeability than the soil 2 then we have square elements with L 1 is going to be 1 here.

And this is the α1 and this is the boundary between the two soils having K 1 and K 2 then you can see that how the flow rate changes and with the small rectangles here because the virtue of the change of the permeability so for K 1/ K 2 =K 1 / K 2 = 5 B 2 / L 2=1/ 5 so the breath to length ratios is actually now becomes 1/5 times.

So whatever we actually get B1 / L 1 let us say that if you are having 1 and 1 then here it actually reduces to that in the direction which is actually B 2 by L 2 we reduced by 1/5 times this we will see how the you know which we can interpret from the flow net which it can be obtained by from the seep/w program.

So here if you are having a case with K 1 having permeability and K 2 having while having permeability K 2 and K 1 < K 2 then you can see here the flow rate as we discussed in the previous slide it undergoes a change and it gets deflected here so the similar thing can be seen in the program also so here the number of for full flow channels in soil1 or K 1 with cave having permeability are nothing but 1 + 1 and this is approximated as 2 / 3 so 2 + 2 / 3that is 2.67 or the number of full four channels in soil one similarly here with$b_2 / l_2 = 1 / 5$ because of the virtue of $K_2 = 5 K_1$.

So what will happen is that this one will be reduced by 1 by 5 and this is also reduced by 1 by 5 and deuce 2 by 3 into1 by 5 it becomes 2 /15 so ∑1 /5 + 1/ 5+ 2 /15 the number of full flow channels in soil 2 with K 2 or 8 /8 /15 so the potential drops will remain same and though we are actually having two soil layers so we can say that the $Q = K_1 . H / n_D . n_{F1} = K_2 . H / n_D$ into n_{F2} so by knowing n_{F1} that is the number of full flow channels in soil one with the K_1.

So here in this case 2 point 6 7divided by number of potential drops which are actually here like a homogenous section here also we have got10 potential drops the only difference is that the you know because of the different soil layers you can see that the changes in the flow lines the here you can see this curvilinear squares and here the rectangles are actually small because of the virtue of the permeability which is actually different for example if you are having a different material say permeability of this layer is low and this layer is high then you can see that here you have a large rectangles.

So after having seen the examples loud now let us try to see if you are having a sheet pile wall structure or in concrete dam structure and when there is a you know water flow which actually takes place we have seen that the water flows vertically down and then you know it actually raises upwards.

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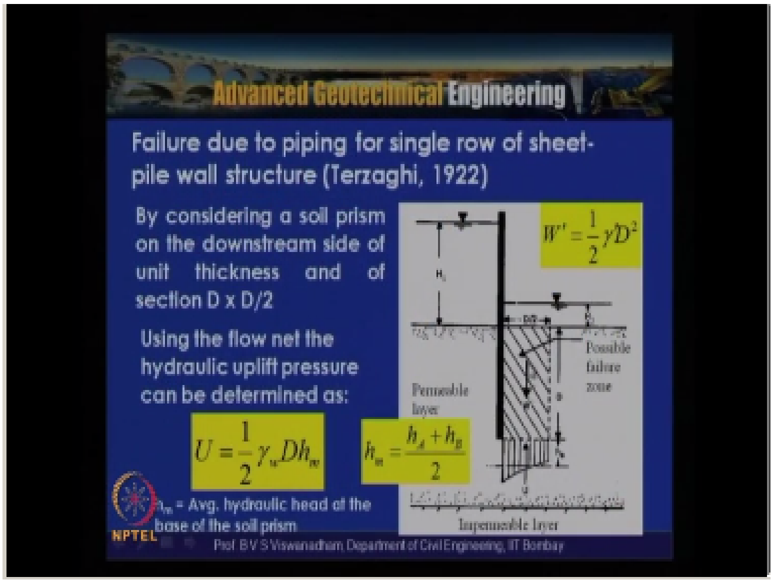

So we always have to ensure for designing these structures in the water bodies we have to see that the stability of these structures against piping or some other failures so here this particular situation which is a case for the sheet pile wall which they confined see paste problem where when you do two piping for a single row of sheet pile wall with structure which is after ski 19:22.

So here a sheet per wall structure having h1 as the upstream head and h2 as the downstream head is shown here and the based on the model tests which were carried out and then it says that it J one with ease within D /2 from the DS the depth of penetration of a sheet pile wall into the pyramid layer so the this particular zone is actually prone for failure so in order to calculate the stability which is nothing but here the w dash is nothing.

But the weight of this prism which is nothing but if you take off γ- d^2.1 meter per meter length of a sheet per wall structure when you consider this is a plane strain structure then you know you can actually take it as the weight of the prism as 1/2 γ- γ- is nothing but the submerged unit weight because of the presence of water so 1/2γ-d^2 will give me this particular you know weight of this prism.

So what it is actually has been done is that suppose if there is the uplift which is actually created so here in order to calculate this uplift pressure here we need to actually use the total head while because here in this case we because he it is the head which is actually dissipating from you know as you water flows from this direction to this direction so here we actually have downward direction.

And here there is an upward direction of the water flow so this particular this Joan is actually critical for failure and can lead to failure so here this calculation has to be done with by knowing the total head here by knowing the total head here let us say that can be obtained so if you are having one equi-potential line here and one equi-potential line here on equi-potential line here you get h1 h2 h3the average of those heads will actually give the average head for example here HA and H B is taken as H M = HF + h p / 2.

So by the uplift pressure on the area which is d by 2 which is nothing but 1/2γw .d .hm which is actually calculated as the supply pressure now we take the equilibrium of this so if the subdued pressure is high there is a possibility that this gets lifted up and this is actually has been found through model tests that it actually instigates failure by creating a you know the supreme boot to the soil increases very drastically and you know the gap between sheet pile wall and the soil in the rise.

And then lead to the pipe piping failure this particular failure is actually called as piping failure so here the average hydraulic head is considered and that is based on the total head which is actually obtained from the you know flow net diagram oh the factor of safety Against piping failure or heaving can be calculated is nothing.

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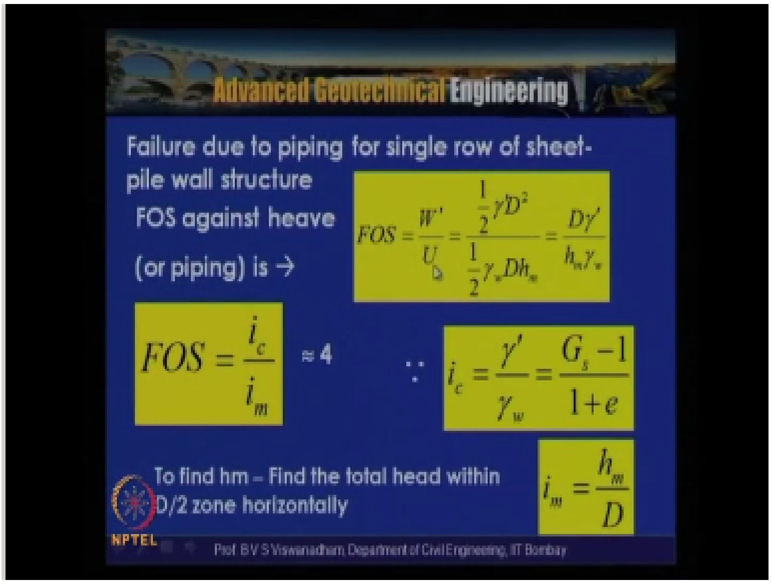

But factor safety is given by $W^{1/}U$ and for critical case for factor safety is good one we have to we get $W^{1/}U$ then we can actually calculate what should be the liquid depth of penetration of sheet pile wall in the pebble soil layer also but here $1/2\gamma^1$ d^2 /1/2γ W D. H M will give me D γ – HM γ W so this is you know you know D/ H M.$\gamma^{1/}\gamma^1$W so this is also said that has a factor of safety is equal to γ^1W is nothing but IC that is the critical gradient which we have discussed that IC is equal to critical hydraulic gradient is nothing but γ/γ W into G s- 1 /1+ E and I am I M is nothing but H M/ D H M is nothing.

But the average total head beneath that prism and D is that depth of penetration so which gives me the factor of safety again is the hobo's IC by M so by knowing the you know critical Grady critical hydraulic gradient and this particular I am which is nothing but H M/ D will give me the factor of safety this should be a should be of the order of four to five to ensure stability of the structure suppose if you are having a structure which is having no factor of safety one of the you know alternatives or options is that to provide an upon layer in the downstream side.

And that actually increases the you know resistance in the form of say W dash plus the weight due to a prompt say W then W+ W dash by u the factor of safety increases with the presence of a apparent layer in front of the a sheet pile wall structure so to find H M s given here which is nothing but H M/ D which is indicated here so as I said that we for another case with according to huzzah according to heart he has given four structures other than single row of sheet pile walls.

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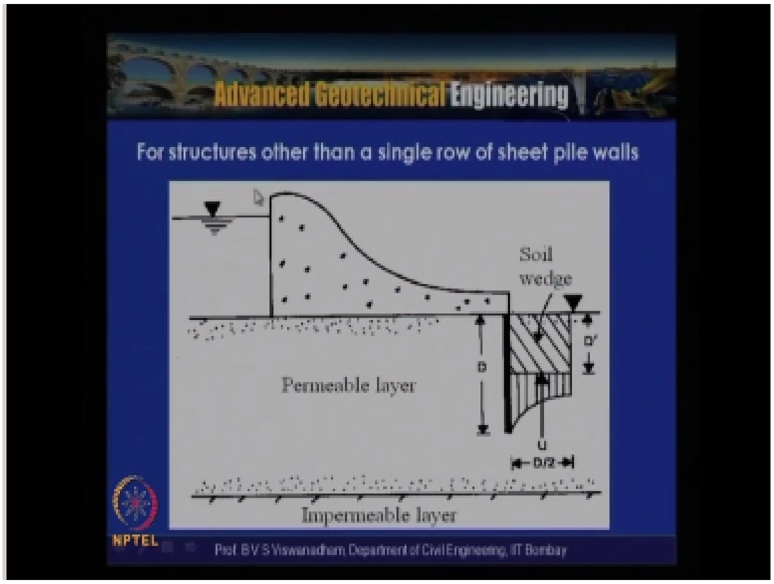

Which is having a concrete dam and with a cut off here so for this case based on the model test has been observed that the D is the depth of penetration so the D by – is you know which is indicated here and D/2 at a distance the failure wedge is actually formed here but the validation of these you know particular criteria as is still limited now here what we actually say that for safety of hydraulic structures against piping failure according to horizontal' in thirty five factor of safety.

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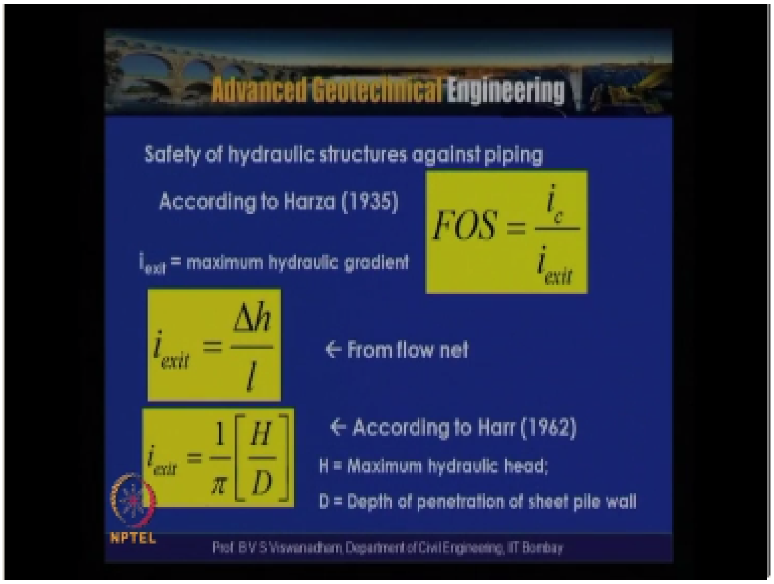

Is defined as critical hydraulic gradient by I exit gradient I exit gradient can be obtained by you know which is nothing but Δ H / L ΔH is nothing but the last you know you know equip up between the you know penultimate equi-potential line in the downstream side of the hydraulic structure or that length of that flow line in that zone can be given as I exit and we can also estimate according to year 1962 the I exit gradient has 1/ PI .H /D I did H is nothing but the maximum hydraulic head.

And D is the depth of penetration of sheet pile wall so one can determine from the flow rate or one can actually also calculate from according to Hart 1962 but I exit once we know and once we know the critical hydraulic gradient this is another way of also estimating the factor of safety against piping so here for the safety of hydraulic structures against piping.

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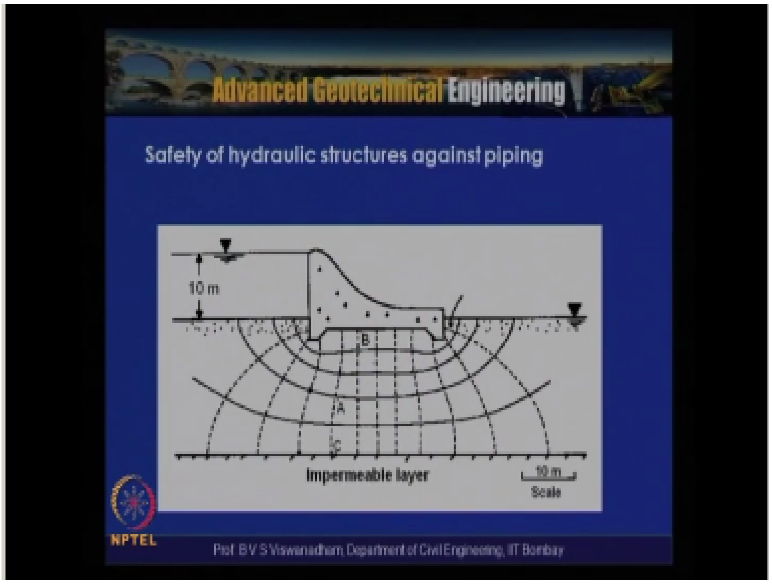

Suppose if you are having sometimes initially a configuration is such that you do not have any cut-offs suppose if it is found unstable against piping then there is a need for you know inclusion of cut-offs.

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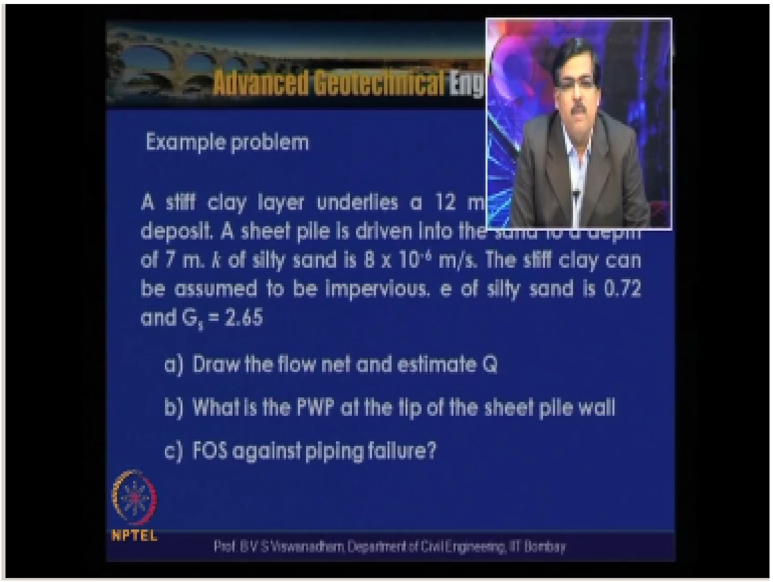

So let us look into the example problem a stiff clay layer underlies a told me to thick silts and deposit and here a sheet pile wall is driven into the sand to a depth of seven meters and K of silts sand is 8.10^{-6} meter per second the stiff clay layer can be assumed to be impervious and wide ratio of the silt sand is given as 0.72.

And the specific gravity of the solids as given as 2 .6 5 so what we need to do is that to draw the flow net and estimate the discharge and we need to calculate what is the pore water pressure at the tip of the sheet pile wall and factor of safety against piping failure and see whether the structure is stable against a piping or not so we have the configuration like this.

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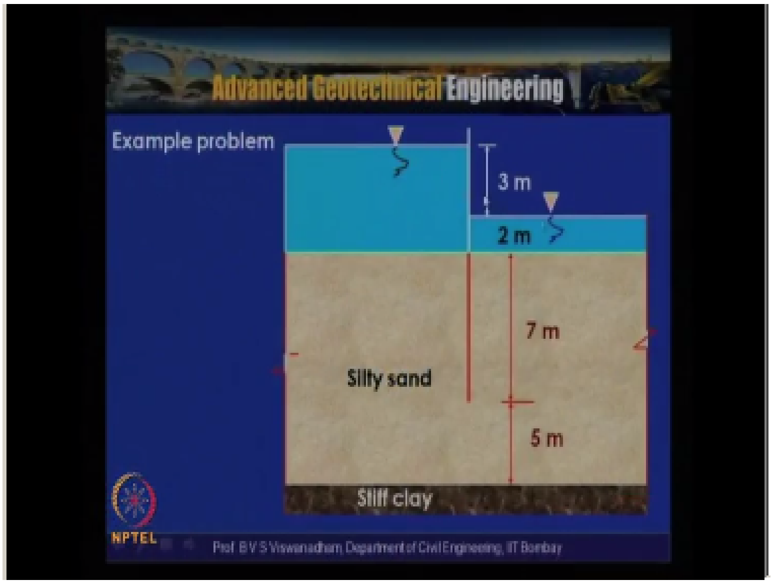

You got upstream water level and downstream water level and a silty sand which is actually shown this is the depth of penetration of a sheet pile wall and this is 7 meters and the stiff clay which is the impervious layer in this case and you have got a silty sand here and this distance from the tip of this to this one is say 5 meters and this is the downstream water level where you have got two meters and this is three meters is the so these pretended drop is the head layer at loss is three meters.

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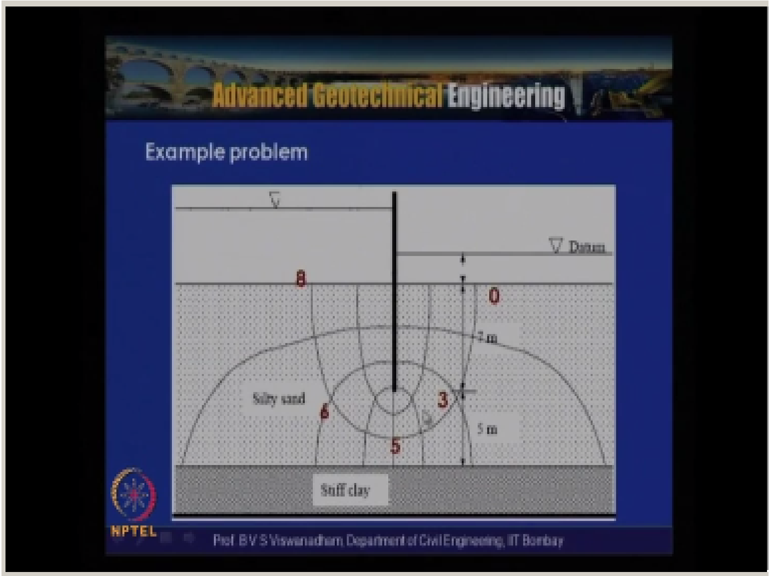

So this for construction of the flow net works out like this so eight potential drops and this is the production equi-potential line and this is the lottery last equip potential line 8,7,6,5 these equip potential lines are number are given and this is nothing but 8,7,6,5,4,3,2,1,0 the numbering is wrong in the slide and here this is the tip of the sheet pile wall and this is the flow channel one flow channel two and flow channel three or you can be explicated as 2.6 or something like that

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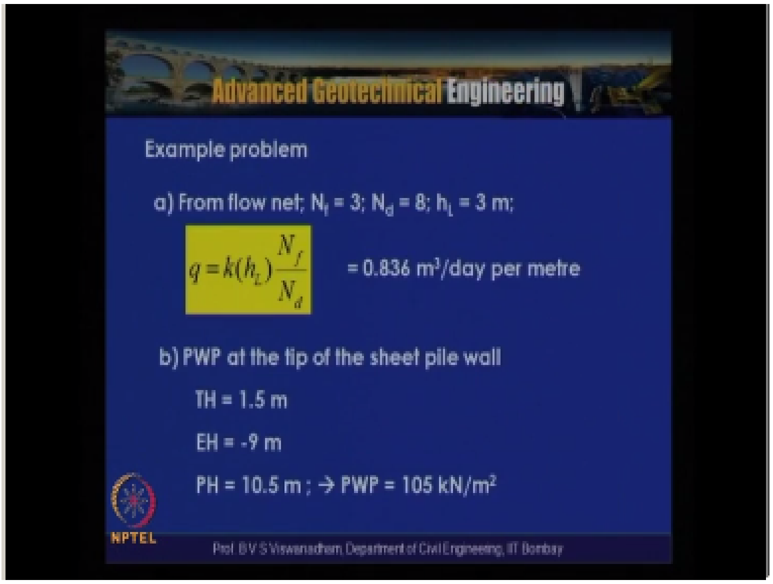

Then we can actually calculate number of flow channels and number of potential drops and head loss is three meters we can calculate the discharge we need to actually pull out the pressure at the tip of the sheet pile wall and the datum is considered here so this elevation of this one's by knowing the elevation of this we can actually calculate total head is 1.5 meters why.

Because this is 8, 7, 6, 5, 4 so 4/8 into head loss is 3meters so the total head available at the equip potential line right below the sheet pile wall is 1.5 meters so this estimated from the flow net elevation head is minus nine millimeters below the datum so pressure head distant point five meters the pore water pressure is about 1.5 kilo Pascal's at that level.

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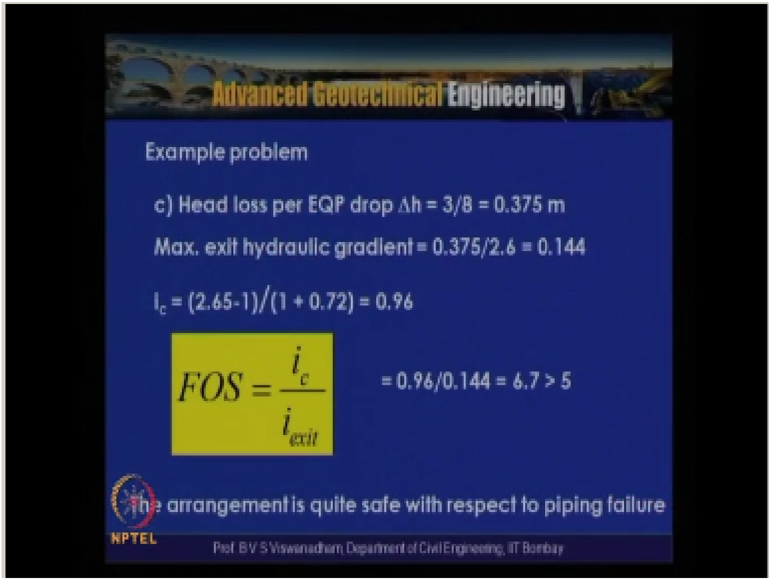

Similarly now the coming to the next example from the subset of the problem is that head loss for equi-potential drop that is Δ H = 3/ 8 so maximum exit the hydraulic gradient is nothing but 0.37 / 2.6 which is given as 0.1 for 4 and then we can actually calculate critical hydraulic gradient with GS - 1 / 1+ 0.96 so by putting point critical hydraulic gradient to the I exit we can actually calculate this actually as 6.7>5 so this arrangement is found to be quite safe against with respect to the piping failure.

So in the in this particular lecture what we actually have discussed is that you know how we can actually construct flow rates through a numerical simulation and we also have seen the self use based physical simulation of this particular cases with and without gradients within with and without filter layers and how important is the presence of horizontal drain horizontal filter is also discussed.

And then we actually have try to see in the factor of safety against failure piping failure for a sheet pile wall structure and the criteria which is actually required the similar direction the criteria which is actually the D dash which is actually given for a concrete dam is in between D / D and D and then that is given by used for concrete dams which are actually having a cutoff in the downstream level.

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