NPTEL

**NATIONAL PROGRAMME ON
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**CDEEP
IIT BOMBAY**

ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 18

Module-2
Permeability and Seepage -7

So welcome to lecture number 18 of the course advanced to geotechnical engineering module 2 the permeability and see page 7 so in this lecture we are going to discuss about some case study based on whatever we have discussed in the previous lectures and also I would like to present to you some assignment problems so that which can which can be used for you know addressing the topics we have discussed in this particular module.

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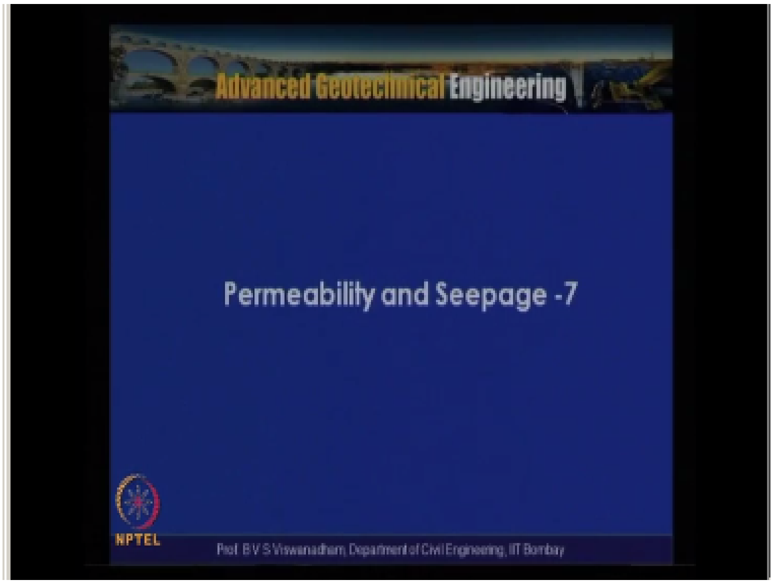

So this lecture is titled permeability and see page 7 so in order to you know address that case study which we are going to discuss let us try to recollect what we discussed in the previous lecture in order to check against the piping failure for a single row of sheet pile wall.

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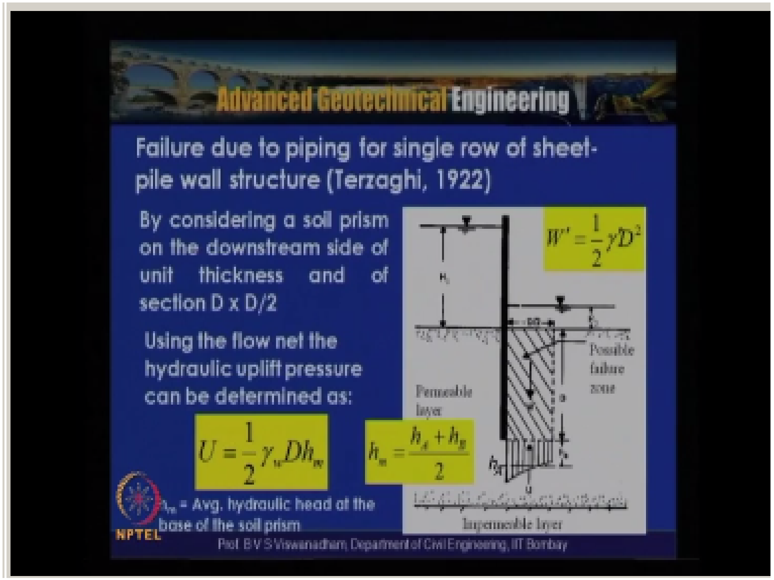

Then touch agree actually has given a method for checking the stability of a soil prism in front of the row of a sheet pile wall so if you consider in this diagram if you have got a row of sheet pile wall having you know a head of water H 1 here and H 2 is the water and the downstream level so the differential water level is H 1- H 2 so this particular portion of the prism of soil will be subjected to instability so one of the methods you know to prevent this failure is to provide in a prom or nowadays in with modern applications within in doing involving the geo synthetics can also be explored.

So by considering a soil prism on the downstream side of the you know of having unit thickness and having a section D is the depth of penetration and D / 2 so this particular you know deliberation of D / 2 was actually arrived based on the model carried out and then reported in this subject area so that is the possible failure zone and we knew that as the water flows from this side from left hand side to right hand side the water flows in the vertical direction.

So the uplift process of uplift pressure uplifts force exerted on the prism of this soil having d / 2. 1 that is the parameter length of the you know prism is being considered that is the area or which the uplift pressure is acted is d/ 2. 1 and the D is the you know the depth of penetration so this is the self-weight of the prism and this we are actually considering the self rate that is the submerged unit weight in order to do that the head which is actually you know considered is the total head not the pore water pressure at the base of the prism.

So using the flow net the hydraulic up to uplift pressure can be obtained so as you know the you know from the flow net the equipotentiallines and then within that prism area or a distance of D / 2 the average your head can be estimated so which can be given as H M =H a is the head at this point H a is the head at this point and HB is that at this point the average of this is can be obtained so this is the uplift flow so there is nothing but ½.γW into D . HM, HM is the average hydraulic redhead at the average hydraulic head at the base of the soil pressure so the self-weight the submerged unit weight of the self weight of the soil is given by $W1=1/2\gamma 1D^2$

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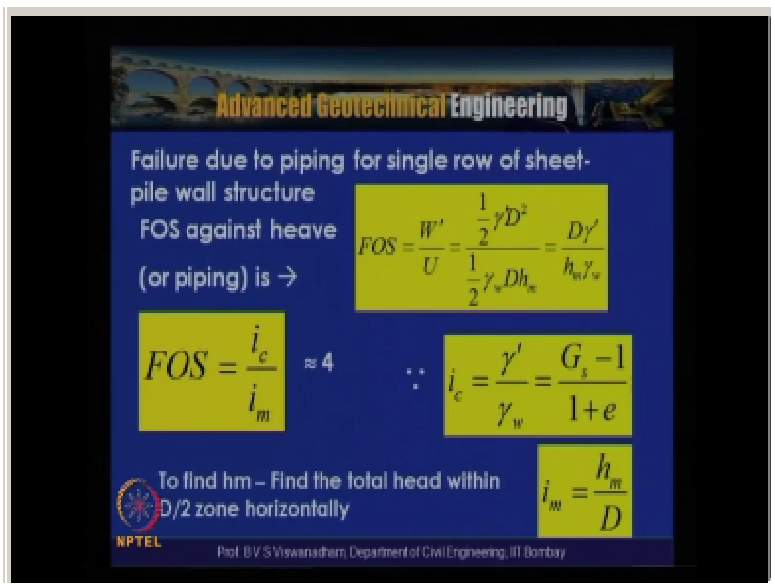

So from for the factor of safety to another to obtain the factor of safety against he or piping is nothing but the resisting force is nothing but the self weight of the prism and disturbing force is nothing but the uplift acted by the acted on at the base of the soil prism so this is obtained as factor of safety- W – B you where W - E =1/2γ - d^2/F γ W D. H M by simplification of that we get D / H M .γ dash /γ W but however we knew that the critical hydraulic gradient is defined as GS - 1by 1 + E=γ by γ W.

So by substituting for γ dash / γ W I see and writing H M /B as I M then we can write the factor of safety against the H ever piping is nothing but I sleep I am which should be generally more than four or so what is required to be noted is that from the flow net diagram to find the average mean hydraulic head find the total head within the D / 2 zone horizontally so this is required to be noted then according to huzzah method Ezra has given in 1935 the safe safety of hydraulic structures again striping.

So this you know I exit was defined here this is the maximum hydraulic gradient which is nothing but factor of safety is equal to IC by exit the I exit now it can be done with two methods one is that you know the penultimate portion of the flow net in the downstream direction that is Δ His the head drop let us say the last you know two equip potential lines that the potential drop between the two equipotential lines in the downstream direction over a length of that you know along that flow direction so that is one is that this can be obtained from flow net according to Hart1962 I exit can also be estimated by 1/ π. H / D where H is the maximum hydraulic head which is nothing.

But whatever the difference which is actually there between upstream water level and downstream water level and D is the depth of penetration of the sheet pile bar which is actually taken as d the depth of the penetration that is the penetration of this sheet pile wall so for structures other than the single row of sheet pile walls that means that.

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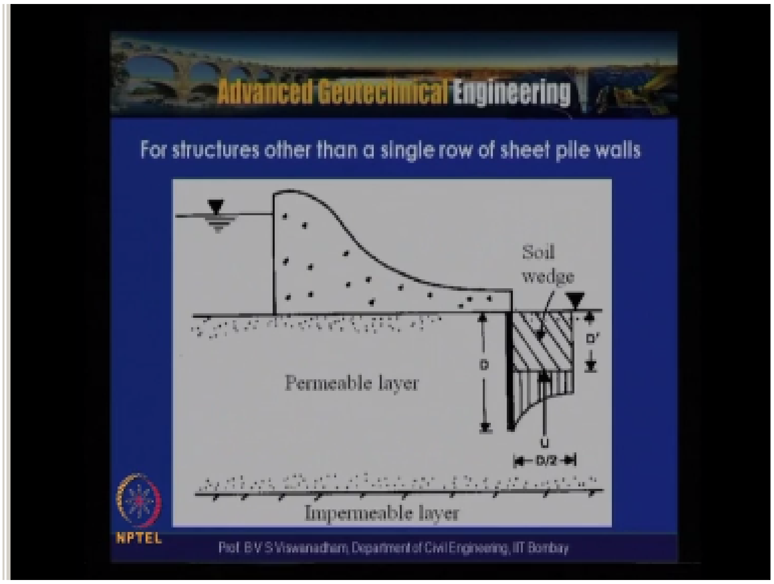

If you have got a concrete dam then in order to increase again is the safety against the uplift and all it is practice to provide it is it is a practice to provide cutoff walls in the particularly in the downstream direction as well as if required in upstream direction if required if the condition persist in the middle of the you know concrete dam also and one of the other measures also in order to divert the equipotential here to prevent the flow close to the dam here if provision of pervious blanket is also another alternative.

But if you have got a structures other than row of sheet pile walls it has been recommended that the soil which actually occurs between D dash and D where this or a length of D/ 2 that remains same but here it will not be completely d but it is actually a depth of D dash so this particular portion is actually subjected to you know instability and the rest everything will remain same that is the you know the self weight of the soil wedge and uplift force exerted in the horizontal direction by the water and this can be determined from the flow net from the total head.

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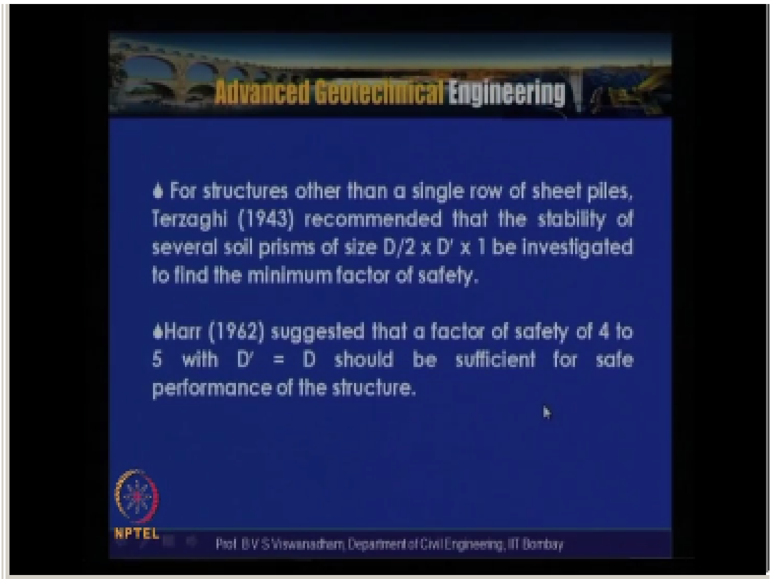

So for the structures other than single draw of sheet pile walls terzaghi 1943 recommended that the stability of several soil prisms have to be taken that means that of the sizes of D / 2 and D dash into one and can be investigated to find out the minimum factor safety so the according to terzaghi's method it is that you have to one has to take several soil prisms and then determine the one which actually gives the minimum factor of safety ha1962 suggested that a factor of safety of 4 to 5 with D dash = D should be sufficient for the safe performance of the structure.

Again going back with the D dash = D that is equivalent to the depth of penetration is sufficient for the safe performance of the structure so with that background let us look into a case study on the seepage analysis of a coffer dam so this particular coffer dam is located on the bank of a river and the real soil conditions are that it actually has got stratified soil deposits being close to the river and the coffer dam is generally constructed to facilitate the construction of the foundation for the a bridge which is being constructed.

So in this particular case the coffer dam is intended to be constructed on the riverbank where there is no flow of water but if the cofferdam is intended to be constructed within the river where the flow of river happens then the issues relevant to the velocity of the flow and then seepage analysis and the stability again is the wave forces all those things need to be considered in designing a coffer dam.

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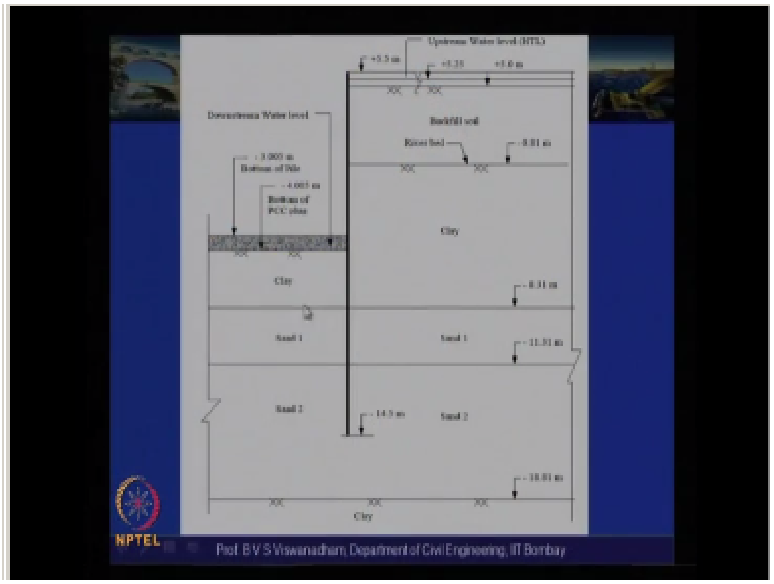

So this particular copper dam section is having a typical status like this and this is the river bank which is at minus Oh 0.81meters and the entire strata from the river bed to the -81 meters about 7.5 meters it is with a Clay's data below that there is a sand it is named as sand one so about three meters there is a sand layer and then from -11.31 to -18 meters there is a sand to layer that is two types of sand layers are there and the one of the you know row of sheet pile wall of a coffer dam is shown here wherein what is actually shown here is that this sheet pile wall penetration from is from+5.5 to -14.5 meters.

And above this there is a backfill was place and the upstream water level that is high trade level is +5.25 and the soil backfill is actually up to 5 meters so 5 meters and then +5.25 meters is the high tide level and the top of the sheet pile wall is +5.5 tip of the sheet pile wall is -14.5 meters it is penetrated into the sand layer then here there is a so you can look into this is the you know source for the water this is the river bed and then water actually tries to enter into this thing into the cofferdam.

So basically this area is being created to make to enable the installation of foundations for example for this particular bridge pier foundation is founded on piles so in order to enable to construct the piles in the middle of the river or the close of the bank of the river what it is intended is that to create a land area that is achieved through a coffer dam with ensuring all the stabilities again structural stability as well as stability from the seepage point of view.

And the question here is that in this particular type of sequences there is a need for providing a PCC plug that is called precast this is nothing but plain cement concrete plain cement concrete layer is provided the question here involved is that whether the intended the thickness of 1meter of PCC concrete plant is adequate or not this is basically done this to prevent any piping and piping failure and second thing also the resistance offered by the PCC the plague under the stability is not considered.

So here one interesting thing to be noted here is that there is a clay layer which is actually having very low permeability and then it's followed by a- sand layers so if the clay layer would not have been there is a possibility that you know the situation of their likelihood of failure for the against piping but let us look for the given strata here what would have been the what would be the you know how the you know failed a factor of safety against terzaghi's method and ASRA method we will be all right.

So here at the bottom of the you know the -4.50 meters is the downstream water level so this is the intended water level which is to be maintained and then - so one meter is the thickness of the you know concrete lake and this is the bottom of the pile so above this the pile cap will come and then the bridge GPR foundation will come so once this foundation is actually constructed and once the foundation is in place then what happens is that the cofferdam is removed and so that the foundation can be a commission.

So the below the sand layer that is below minus eighteen point one meters again the clay layer is there so this is actually assumed to be impervious stratum so water actually flows in this direction so this particular problem the seepage analysis has been carried out by using the finite element based software seep/w 2012version and the cross section adopted for the seepage analysis is shown in this slide.

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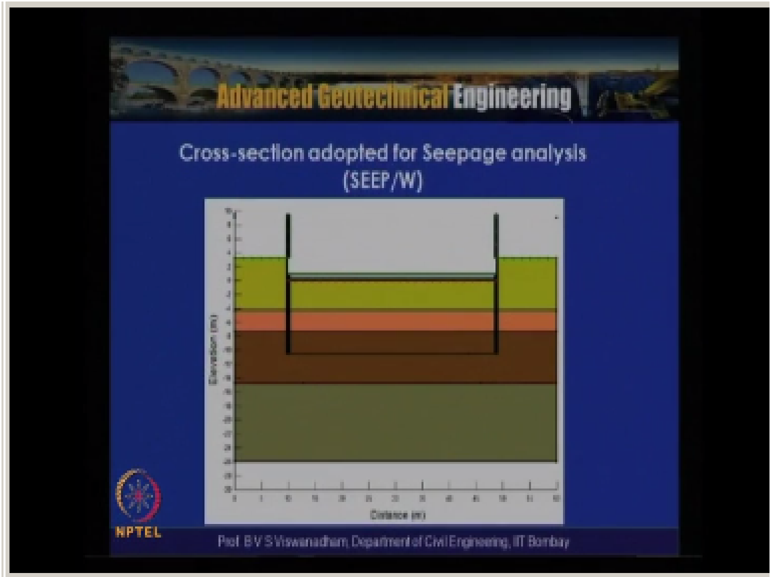

As I have told you that this is actually having a length of about 50 meters about 40 meters in his direction and the different soil layers have been represented here this is the clay layer this is the sand one and sand two and then this is a clay layer so and here this is the PCC plug which is actually considered here the plain cement concrete plague.

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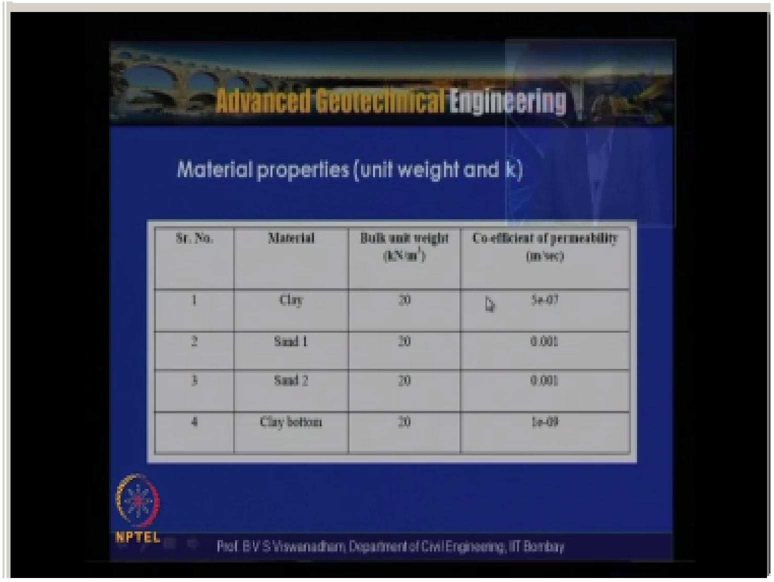

Sr. No.	Material	Bulk unit weight (kN/m^3)	Co-efficient of permeability (m/sec)
1	Clay	20	5e-07
2	Sand 1	20	0.001
3	Sand 2	20	0.001
4	Clay bottom	20	1e-09

So based on this the flow vectors can be obtained but before that let us look into material properties especially the clay though the permeability can be of the order of 10^{-9} meter per second but however here it has been considered about 10^{-75} . 10^{-7} meter per second and the sand is having high permeability that is 10 .10^{-3} meter per second and sand to is around 10^{-3}meter per second and a clay bottom which is at the bottom most clay layer that has been considered as 1 into 10^{-9} meter per second which is practically an impervious layer so these are the flow vectors which are actually obtained from seep/w

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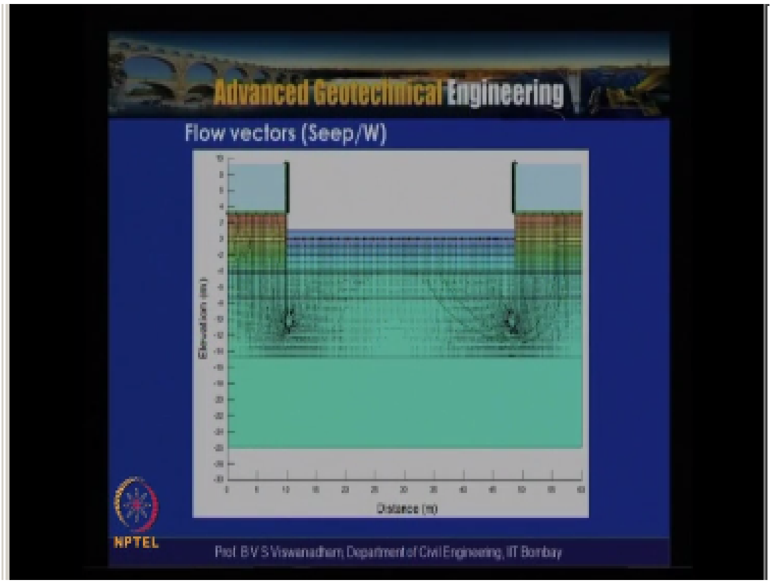

Where in you can see that the trend of flow which a flow line which is actually coming from this direction to this direction so the in order to do the factor of safety against the stability like piping then we required to know they consider a particularly a prism of soil having horizontal distance D / 2 and D depth of penetration and then we have to see the factor of safety again is the stability without and with you know the PCC like.

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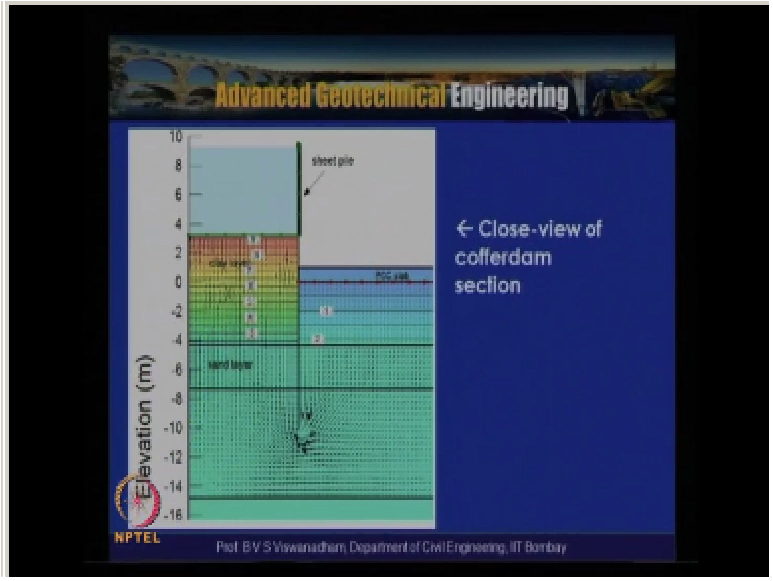

So here the close view of cofferdam section is shown here where in you can see the cluster of flow vectors and as the movement of the flow vectors towards the downstream side of the sheet pile wall structure can be seen so herein this diagram it check again is the piping failure for that to enable to that a block diagram of a prism of the depth of penetration from the PCC plate to the tip of the sheet pile wall.

And D/ 2 distance from the from the tip of this sheet pile wall horizontally was considered so this is the soil prism which is actually having you know $\gamma_1 H_1$ $\gamma_2 H_2$ $\gamma_3 H_3$ and then $\gamma_4 H_4$are these particular layers this is actually required to be considered then once we know the total head from the flow net diagram we can actually calculate what is the average head here and determine the factor of safety again is the piping.

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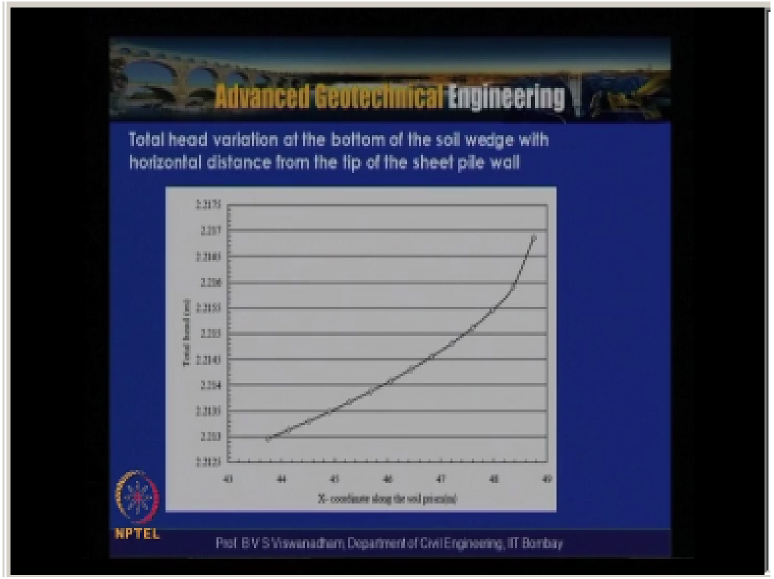

So this is the total head variation at the bottom of the soil which with horizontal distance from the tip of the Sheep l1 so total head variation at the bottom of the soil wedge here with horizontal distance from the position 12:1 as can be seen here the this is the x coordinate which starts from the tip of the sheet pile wall horizontally so it can be seen that the total head variation in the range of two point two one seven meters to two point two one three so the average will be about two point two meters.

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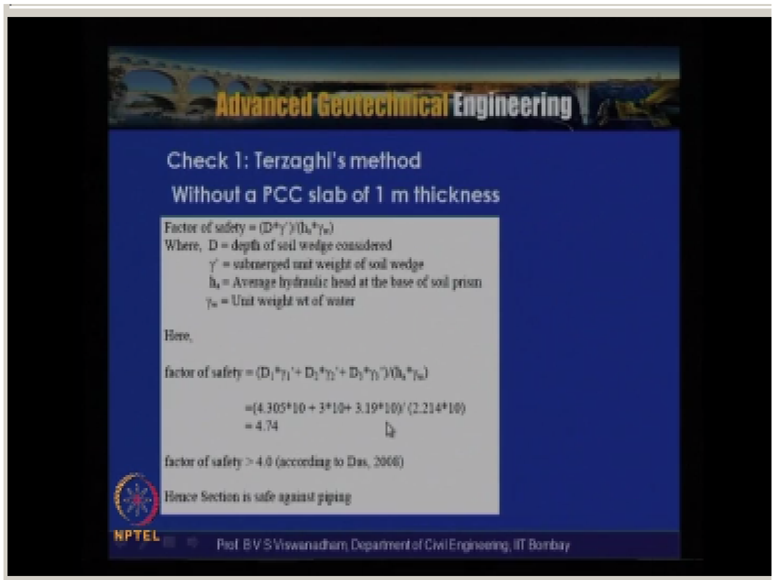

So the check against piping curve one is the check one terzaghi's method let us consider a case of without a PCC slab of1 meter thickness then factor of safety what we have defined is the D into these the depth of intuition into γ1/ HA which is the average hydraulic head at the base of the soil prism so based on that the factor of safety can be obtained with the d1. γ 1 - D 2. Γ DT-

And D 3. γ 3 so based on the unit weights respect to unit weights and by taking the submerged unit weight so we can actually get the factor of safety without a PCC slab here the PCC slab of one my one point one meter thickness is not provided so the factor of safety is found to be just more than 4 that is 4.74 and hence the section is safe again is the piping as far as the education method is concerned.

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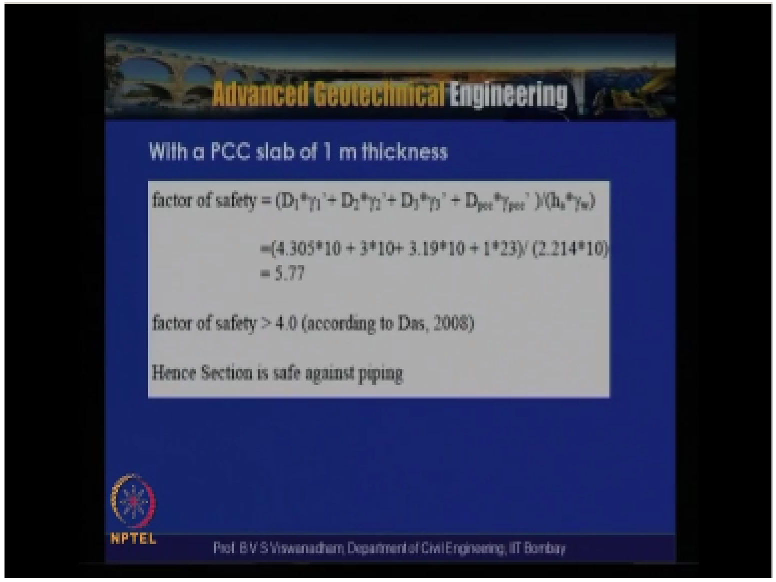

Now consider the same case with a PCC slab of 1 meter thickness once we consider the PCC slab of 1 meter thickness we can see that here the γ of PCC is taken as 23 kilo Newton per meter cube of thickness 1 meter with that the average head to point 2 1 4meters even in the previous case also the average height H a= 02 1 4 meters with that the factor of safety increased to from 4.7 4 to .77

Because of the thickness of the because of the provision of PCC but in addition to the you know you know preventing against the instability due to piping the provision of PCC also helps in preventing giving a work worked from for placement of the rigs and enabling the construction at the site so the factor of safety greater than four hence the section is found to be safe against YB.

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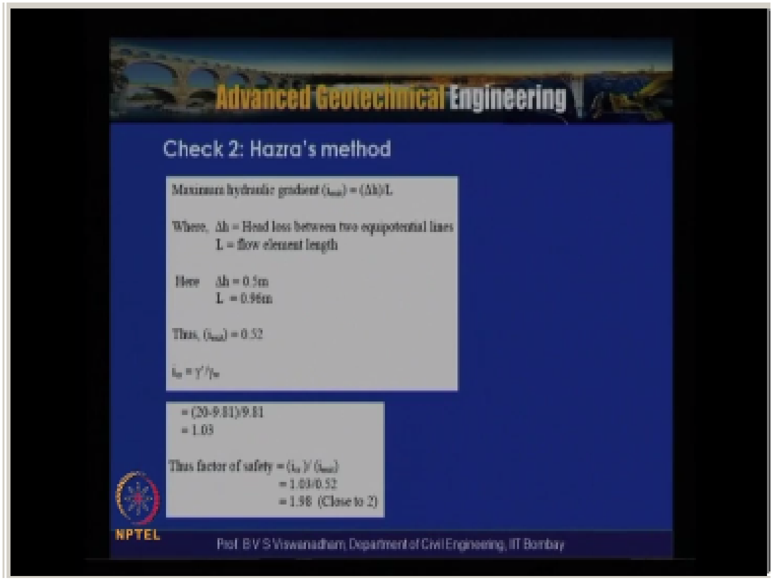

Now let us look by check by as Harass method the same problem so here we can actually obtain from the flow net IH that is the Δ H the head loss between two equip potential lines in the penultimate portion of the you know flow net in the downstream side that is can be obtained by Δ H = 0.5meters and L = 0.96 that is the flow element length with that I exit can be obtained.

As 0.5 to so then we can determine a critical I critical as nothing but γ γW where γ1is nothing but the sand unit weight which is actually taken as 20 Caliper meter cube 20 minus 9.8 1/9081 the critical hydraulic gradient is one point zero three so the factor of safety means nothing but I critical by I exit it is 0.03/ 0.5 to so the what we obtained is about 1.98 actually close to two.

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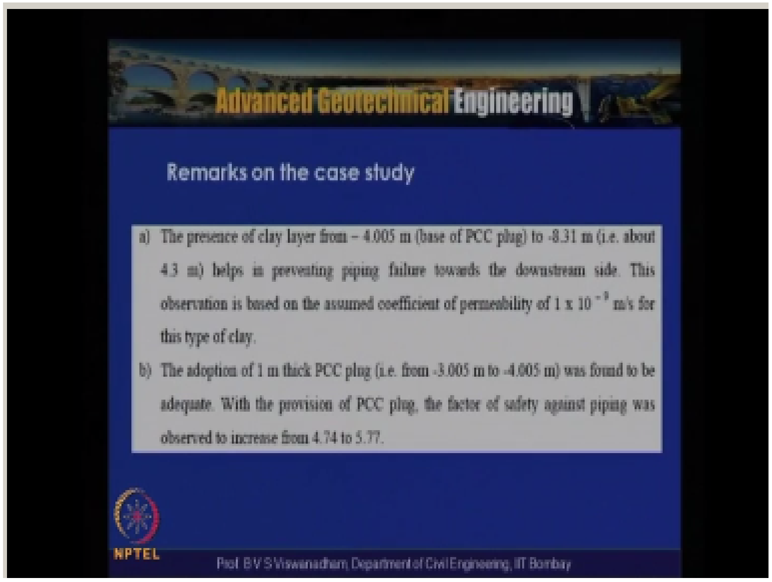

So there marks on the case study what we discussed is that the presence of clay layer from about a 4.5meters from -4 meters base of the PCC plug to -8.3 meters helps in preventing the pumping failure towards the downstream side and this observation is based on the coefficient of permeability of one into10^{-9} meter per second10^{-7} meter per second or1 into 10^{-9} meter per sec and if you look into this the adoption of one meter thick PCC plug.

And the downstream side was found to be adequate and with the provision of the PCs if you like the factor of safety again is the piping egregious and the second thing is that it also enables the construction and installation of the piles can be done with the is so having discussed with the problems you know the case study relevant to the seepage analysis of a cofferdam problem.

And having introduced two different problems and different concepts in module two pertaining to permeability and see page so in this particular, particular lecture we are assignment problems for the module two are presented and some selected problems are given so that the concepts can be revised the problem one it goes like this.

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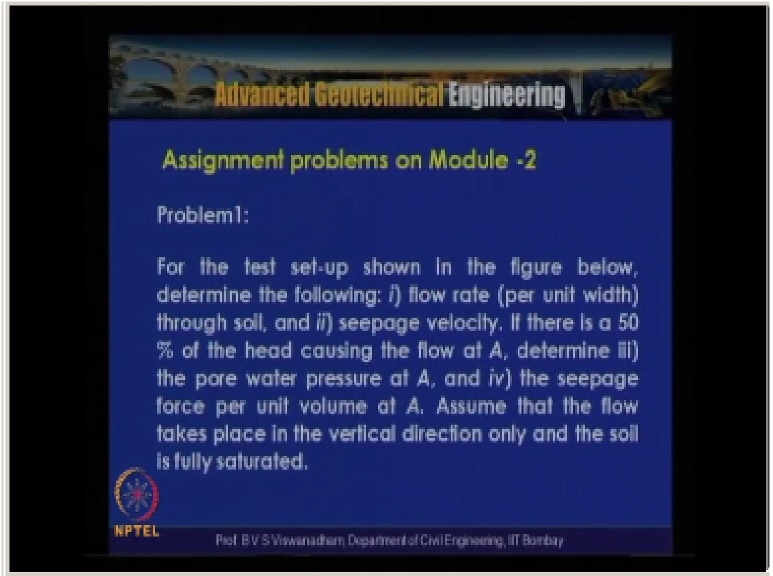

For the tests up test set up for the test set up shown in the figure below we need to determine the following one is that the flow rate that is per unit width through the soil seepage velocity if there is a 50% of the head causing the flow at a determine three is that pore water pressure at and four is the seepage force per unit volume at a assume that the flow takes place in the vertical direction only and the soil is fully saturated.

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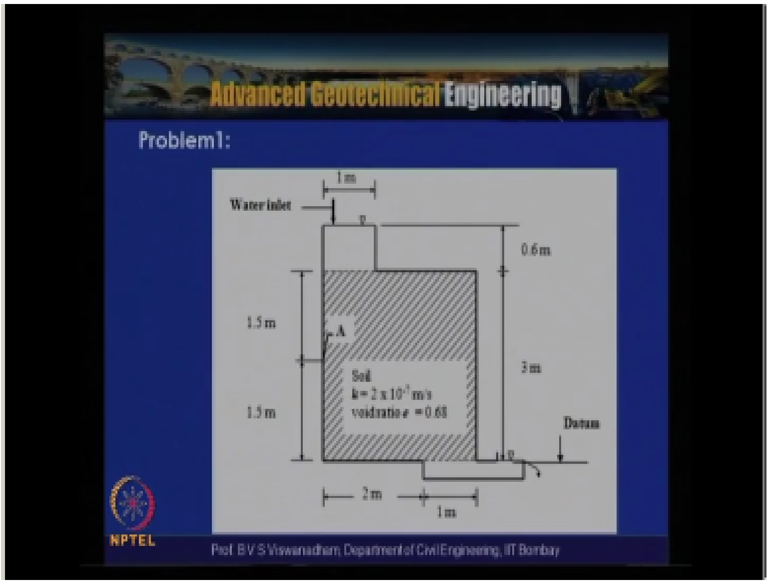

So in the problem one the for the test setup which is shown determining the flow rate determine the seepage velocity and determine the if there is a 50 percent of the head causing the flow at a determine the pore water pressure at a land for the CPS force per unit volume at a assuming that the flow takes place in the vertical direction only and the soil is fully saturated the setup is actually shown here wherein you actually have the soil which is k having 2 .10 $^{-7}$ meter per second.

The void ratio is actually given as E = 0.6 8 and here this particular horizontal distance is 3 meters and this height is about 3 meters and this width is about 1 meter and here at the point a is at that midpoint of this height of 3 meters and in the given problem the datum is actually shown here so this is the tower this water level is actually shown as the datum so this site of water above this level is about 0.6 meters so the difference in height of water is 3 33 meters + 0.6 meters at 3.6 meters.

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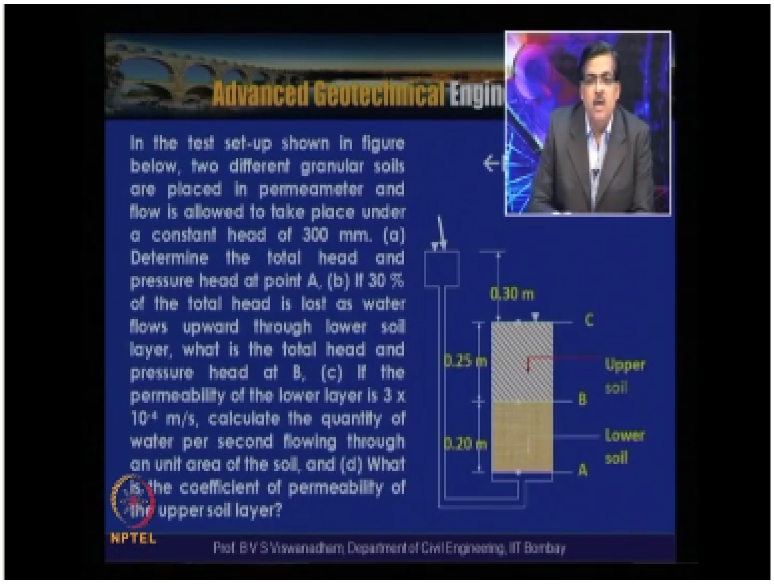

So this is the you know as far as the problem 2 is problem 1 is concerned in problem 2 the test setup is actually shown here which is actually having two layers of soils upper soil and lower soil and this limb is actually having a certain horizontal distance and it is actually height at a height of 0.3 meter you know 0.3 meter a constant water flow is actually maintained her upper soil layer is having the thickness of 0.25meter and lower soil layer having a thickness of about 0.2 meter and this is level a this is level B the Level B is interface between soil lower soil and upper soil.

And here there is that is the level C at the top surface of the upper side so the problem statement runs like this in the test setup shown in the figure below or figure which is on the right side of this slide two different granular soils are placed within the perimeter and the flow is allowed to take place under a constant head of 30 centimeters determine the total head and pressure head at Point a that is a B if 30% of the total head is lost as the water flows upward through.

The lower soil layer what is the total head and pressure headed to B so water flows vertically up in this direction because these develop this limp is actually maintained at this level so if the permeability of the lower soil layer is 3.10^{-4} meter per second calculate the quantity of water per second flowing through the unitary of the soil.
And what is the coefficient of the permeability of the upper soil layer so we need to calculate what is the coefficient of the permeability of the upper soil layer bottom lower soil layer permeability is given and so this problem is very interesting and you can attempt based on the concepts we discussed in the this module.

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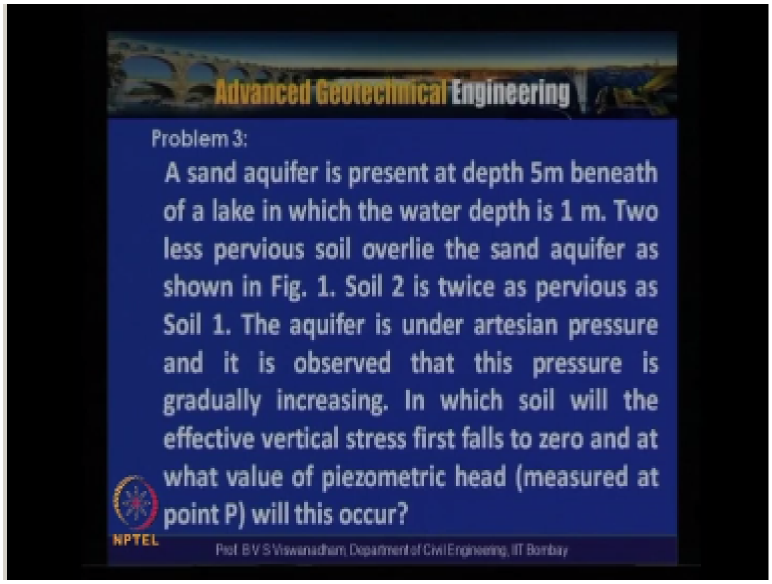

And the problem 3 statement where in a sand aquifer is present at the depth of 5meter below the lake in which water depth is 1 meter - less pervious soil or lie the sand aquifer as shown in the figure the soil - is twice as pervious as soil 1 that means that soil - is more pervious having more probability than soil 1 the aquifer is under artesian pressure and it is observed that this pressure is gradually increasing so in which soil particularly either soil 1 or soil 2 will be the effective at where stress first falls to 0 that is where the quick sand condition can come and what at what value of piezometric head measured at the point B will this occur.

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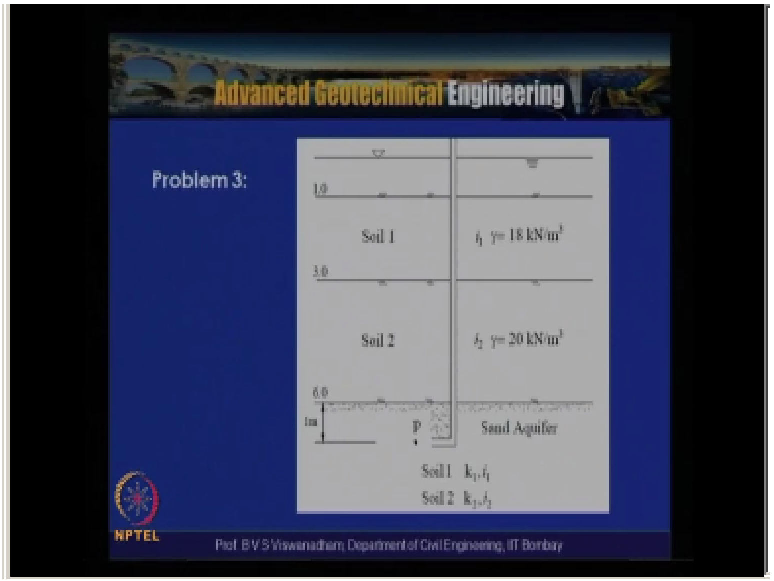

So the cross section of the figure is like this you have got a sand aquifer which is actually having a artesian pressure and here this is this level is 1 meter this is 0 so this soil 1 is having 2 meter thickness soil 2 is having a 3 meter thickness and this is the point P is 1 meter below the soil -bottom of the soil - and here is actually having a hydraulic gradient I 1I 2 γ 18 kilo Newton per meter cube γ 20 per meter cube.

So soil 1 is actually having a parent will take a 1and I 1 soil do you having a permeability K 2 and I 2 so wherein we can actually calculate what is the you know which soil will actually first undergo quicksand can be condition or the effective vertical stress first falls to 0 and what value of the piezometric head measured at Point P at EDD will this occur so this is you know based on the concepts we discussed can be attempted problem.

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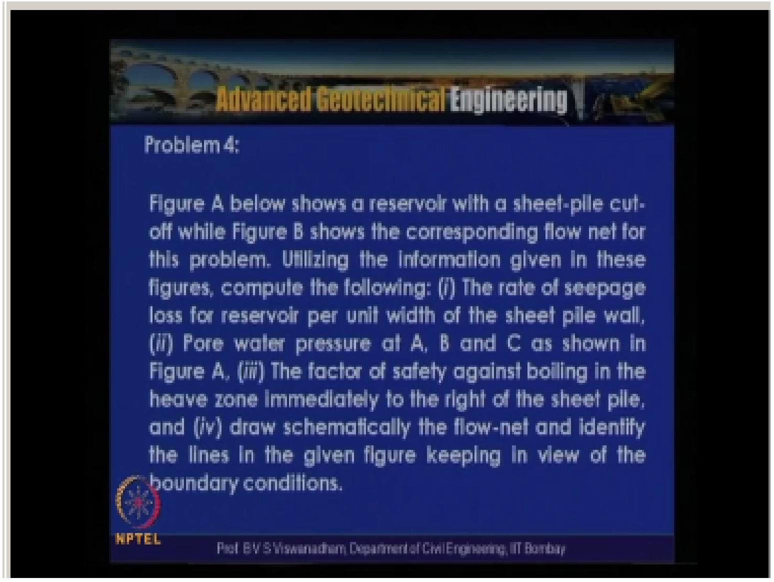

For figure a which is actually shown in the next slideshows a reservoir and a sheet pile wall cut off where Figure B shows the corresponding flow net for this problem so in Figure en figure B a cross section as well as the flow net is also given replacing the information given in these figures compute the following one is the rate of seepage loss for reservoir per unit width of the sheet pile wall to pore water pressure at a B and C as shown in the figure which we are going to see and the factor of safety against boiling in the heave zone immediately to the right of the sheet pile one this is just what we discussed in this lecture and draught him schematically the flow net and identify the lines in the given figure keeping in view of the boundary conditions.

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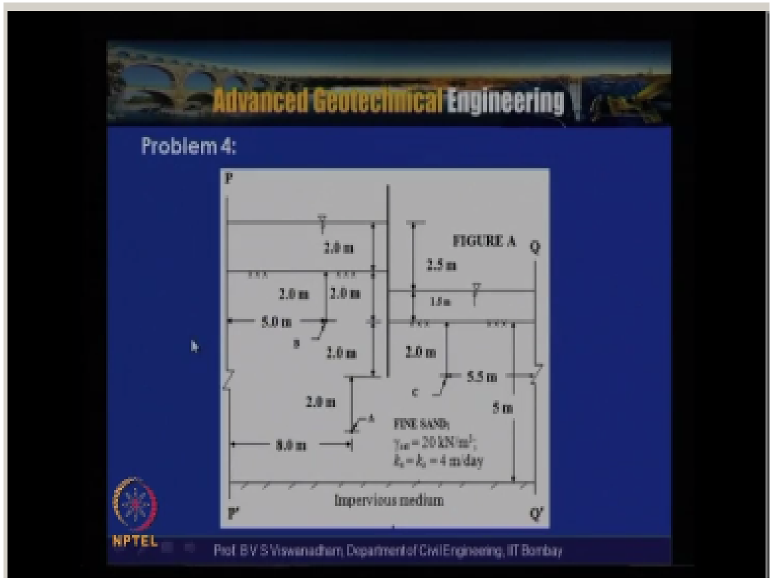

So here you are required to this is the cross section which is given impervious sign a fine sand layer having isotropic permeability KX =KJ = 4 meter per day and γ C at is equal to 20 km per meter cube the thickness of the stratums 5 meters and here the tip of the sheet pile wall is at this point at this point and this is 4 meter below this upstream soil level and this 2 meter below the downstream soil level and this is water level at the downstream side is1.5 meter upstream side is 2 meter above.

The upstream soil level so the difference is about 2.5 meters and this is the end which is a PPP - and this is the end of QQ - and we need to determine the point a is here point B is shown here and point C is here we need to determine from the flow net the flow on the pore water pressures from the flow net diagram and so based on the data me can be selected accordingly and then pressures at a B and C can be determined.

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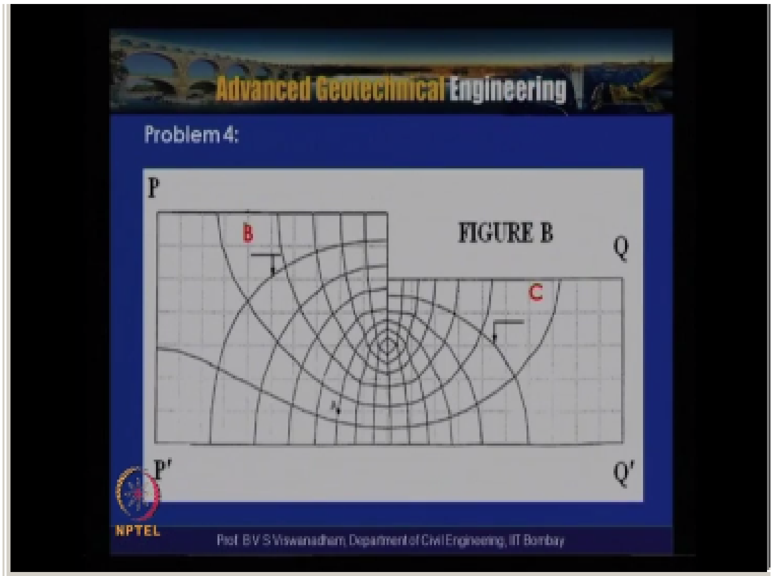

So this is the flow rate which is given so this is the point a and this is the point B which is actually market and this is the point C so the tentative flow net which actually shown here so with that based on this the problem for can be attempted and by considering the both terzaghi's method and Ezra's method one can actually calculate what is the factor of safety against piping failure and with that the safety of a stability hydraulic stability of a structure can be estimated.

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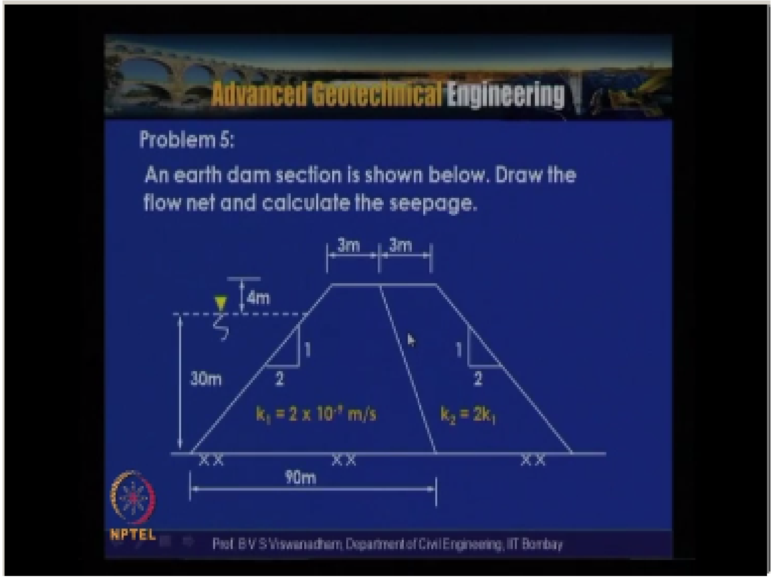

And in the problem 5 which we have discussed it in the previous lecture the similar problem and here in this section and at the dam section is shown below we need to draw the flow net and calculate the C page so here the two layers of soils are given and this earthen dam is constructed with a soil having low permeability K 1 u 2 into 10^{-9} meter per second and the soil on the right hand side is K 2=2 times K 1 that is it is two times more per impel than 2. 10^{-9} meter per second that is K 2 okay.

And these slopes are actually having one vertical to horizontal and the upstream water level is 30 meters a free board of 4 meter is actually maintained and the crust width is about 6 meters so from here to here is 3 meters from here to here is 3meters from here to here the downstream end of stream toe to the this end is 90meters horizontal distance so with this the entire configuration can be constructed and this can be solved by using the concepts we discussed like front for the seepage through zone dam.

And we said that the soil for the upstream off of the dam has a permeability K 1 and a soil for the downstream has a permeability of here it should be K 2 in this example it is shown as π K 1 but here it is 2 K 1 so with that by using K 1 /K 2 = K 1 /K 2 =1/ 2 we can actually get by putting B 1 / e 1 L 1=1 we can get K 1/ K 2 = 1 by 2 B 2=1/2

So what will happen is that the vector to the length ratios will be off ratio 1 by 2 that is on the downstream side here you will have a rectangles we are having birth to length ratios one is to two so this by using this concept the flow net for the CPS 3 a zone death by a time having two different term abilities can be constructed.

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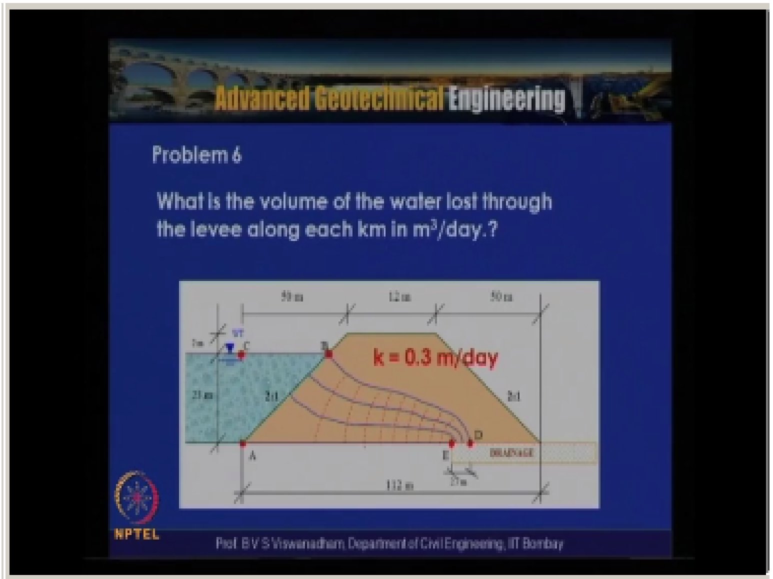

So in the problem 6 a levee section is shown so here a levee section is constructed levee is generally constructed is an embankment which is constructed along the river to prevent you know the river water entering into the downstream side of the land so for that a 12 meter about 25 meters high embankment has been constructed or levees section has been constructed for a 1 is to with the 1 is to 2 slopes both upstream side.

And downstream side a free board of 2 meter was actually maintained and 23 meters is the upstream water level here it is required to indicate what is a B whether it is a equivalent line or flow line ended whether it is a equipotential line or flow line and B D whether it is a accommodation line or flow line need to be identified and once there is identified with the permeability of K = 0.3 meter per a day because this can be achieved when we are actually having isotropic permeability can be achieved once we actually get a material from the single borrow pit area.

And here the drainage layer is actually placed and then this length is about 2.7meters and then the thickness general is preferred about 0.7 meters or some point 6 meters of the order and then this will prevent to the you know the prevent the periodic surface coming into the into the downstream side and causing the piping failure and also enhances the stability so this length is given as 112meters and this height is about 20meters and the crust width of 12 meters and the downstream height is about 50meters the downstream horizontal distance is 50 meters.

So what we need to do is that what is the volume of the water lost through the levee along each kilometer in meter cube per day that means that because as we know that we do so if water loss is actually observed more than the permissible one then the it can actually has have an impact on the stability so here a kilometer length of a these levee sections run kilometers length so particular metal length what is the permeability or what is the CPS lost or water lost can be determined.

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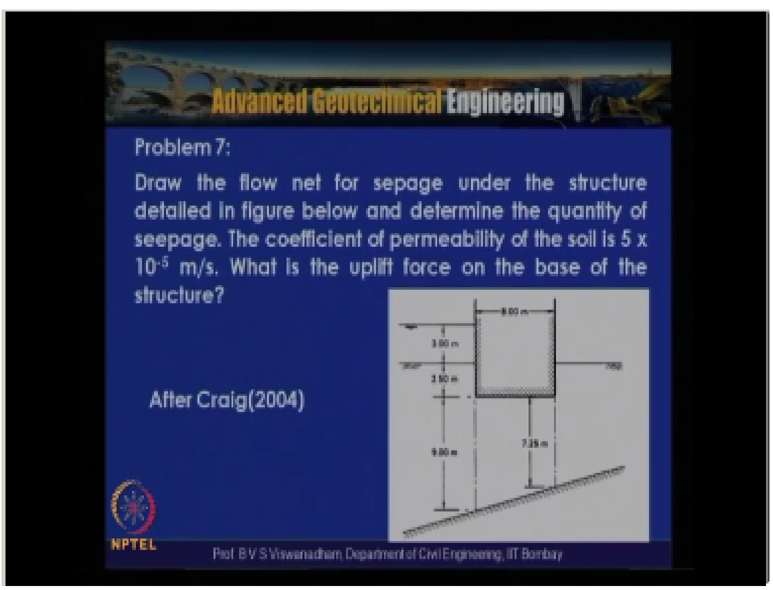

And in the problem 7 wherein we are actually having a situation that we need to draw the sea page under the structure which is the figure which is shown below so draw the flow net for these a page under the structure detailed in the figure below and determine the quantity of seepage so the question of permeability the soil is 5.10^{-5} meter second that is the soil which is actually here this is the soil portion and this is an impervious zone which is not horizontal which is actually having a certain inclination.

And with the configuration of that is given here this is the tip of this hydraulic structure is 7.2 meters 7.25 meters here and here it is 9 meters so what is the uplift force on the base of the structure so that is a you know required to be determined and this horizontal distance of the hydraulic structure is given as 8meters and this length is about 9 meters and this distance is about 2.5 meters the head of water which is nothing but which causes the flow is about 3 meters so this is according to Craig 2004.

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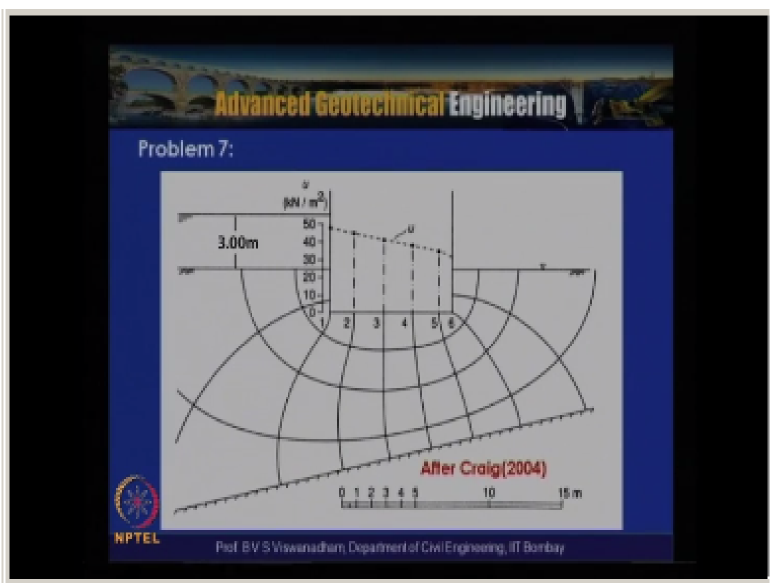

So in the in this slide where the typical flow rate diagram is actually given here for your convenience and this scale is also Shown here and this is the impervious stratum and this impervious this being impervious stratum this becomes the flow line so as you can see that a flow net is drawn with the head of water where here the head of the water which is available for this equipotential line is about three meters by the time it actually comes out it is actually zero so equipotential line this is one two three four five six seven eight nine ten equipotential lines are there.

And then you know by considering the orthogonal principle one can actually calculate draw the ears curve you know curvilinear squares which involves which gives the flow rate so this is a flow channel one and flow channel two and this can be approximated as a flow channel about a 50% of its distance so it can be total number of flow channels can be around 2.5 so we can actually calculate the C page and then by knowing by knowing the you know the pore water pressure along the horizontal distance one can actually determine what is the pore water pressure distribution.

So if the structure really say is empty or under construction there is the possibility of the uplift against the stability so in during all stages of the construction on our stages of the life of the structure the safety against the uplift is required to be ensured particularly when the hydraulic structure is empty there is a susceptibility of the uplift failure that can be observed from this particular problem so in this particular module we actually discussed about various concepts about the permeability.

And seepage issues and we have actually have discussed about the types of flows that is one dimensional flow and two dimensional flow and three dimensional flow though the three dimensional flow is not very common but the with the three dimensional flow particularly the conditions or examples are that wherein we actually have flow rates which can come particularly if you are having a drain which is actually having provided to drain the water so in a given plane it can actually come the radial flow Nets can come.

So we are in the surface of the where the water source is there the highest equipotential line will be there the close to the drain surface where it is feeding water away from the particular location where that will be having a the penultimate equipotential line and the flow lines perpendicular to that so that causes some sort of a net of radial flow Nets but the a pipeline or a drain running into the soil and then we also have considered like the theory behind these seepage.

And we actually have said that for a three dimensional flow the Laplace equation three dimensional flow having K X = K Y =K jet is =0 we said that KX $\partial^2/\partial X^2$+ K/ ∂u^2+ KJ∂2u/$\partial^2 z$=0 yes kx, ky, kz = zero in that case the three-dimensional Laplace equation is that for the flow is that $\partial u/\partial Y^2 + \partial^2/\partial z=0$ but as we have discussed with that many of our structures like we have levees at 10dams and sheet pile walls they actually can be idealized and analyzed it by using two dimensional flow conditions in that case the governing Laplace equation s $\partial^2 u/\partial + \partial=0$ that is X is the horizontal distance ordinate.

And jet is the vertical distance or date and once in order to satisfy this the you know these condition the solution for this can be worked out by using finite difference method or finite element method and then we have discussed with the finite element based method analysis by using a construction of the flow rates manually or by using a program seepage analysis based program called seep/w 2012.

And that constructs the flow nets as per the as they satisfied for different conditions suppose if you are having the I certain non isotropic that is s axis symmetric the permeability is a symmetric permeability that is having put different permeability 's and accented directions in that case we said that when KX = to K JED then need to convert that the into a transformer case this condition is called transformed condition and wherein KT the transformed permeability is given as a root over KX gadget.

And then once the section is transformed but then the analysis is done in a similar way as was done from the isotropic case and then further we discussed that if you are actually having a non homogeneous soils that means that so is having different probabilities like K 1 K 2 K 3 suppose if the flow rate is intended to be constructed by using seep/w the particular software takes automatically but otherwise for different conditions like entry conditions and exit conditions need to be understood.

So for that we have studied with the soil to homogeneous soils when you are actually having two different variability when k 1 k 1 is soil 1 and K 2 is the soil two permeability when $k1 < k2$and when what will happen when the $k1>k2$ then subsequently we actually have done some problems and thereafter we actually have introduced like how to introduce the you know base on the flow rate diagrams how to calculate the factor of safety against the hydraulic stability of the structures from the piping point of view then we have two methods one is the terzaghi's method.

And we also have discussed about the Hazards method and based on this once it is done then this stability can be against piping can been sure and in the finally we actually have discussed about a case study which is in one of the cofferdam construction for a for abridge pier foundation was discussed and basically here the idea is that where the adequacy of the intended the PCC plug which is actually planned whether that one meter thick is adequate or 1.5meters in fact which I have not presented but if we have a case situation of say one point five meter the factor of safety against stability increases that makes you know the more conservative.

But however it is found that because of the presence of the clay layer and clay layer it is adequate to actually have a thickness of about one meter for the downstream side and this actually has two purposes one is to prevent failure against the piping the other one is also to enable construction for the installing formulations for the pier and second further we actually have discussed about some assignment problems for you so based on this you know in this module we try to look into the all aspects which are actually frame.

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