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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 43

Module-5
Lecture – 4 on Stability of Slopes

Welcome to module five on stability of slopes lecture number four in the course on advanced geotechnical engineering. So in the previous lecture we actually have discussed about the number of methods of stability analysis of slopes and along with some solid examples. In this lecture we will try to introduce ourselves how to introduce a critical failure surface through some conventional methods as well as some numerical methods as well as by using some renown software's.

In addition to that we will try to look into a special condition called rapid drawdown condition this will occur after a dam or reservoir when it is established with the steady state seepage conditions when there is a change in the water levels outside the slope then these conditions can be trivial as far as the reservoir or dam slope stability is concerned.

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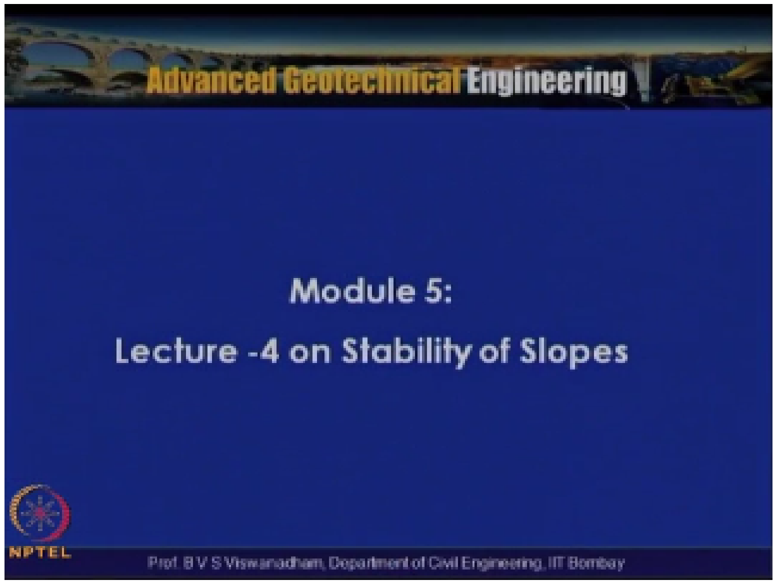

So this is the lecture number 4 in module 5 you on stability of slopes.

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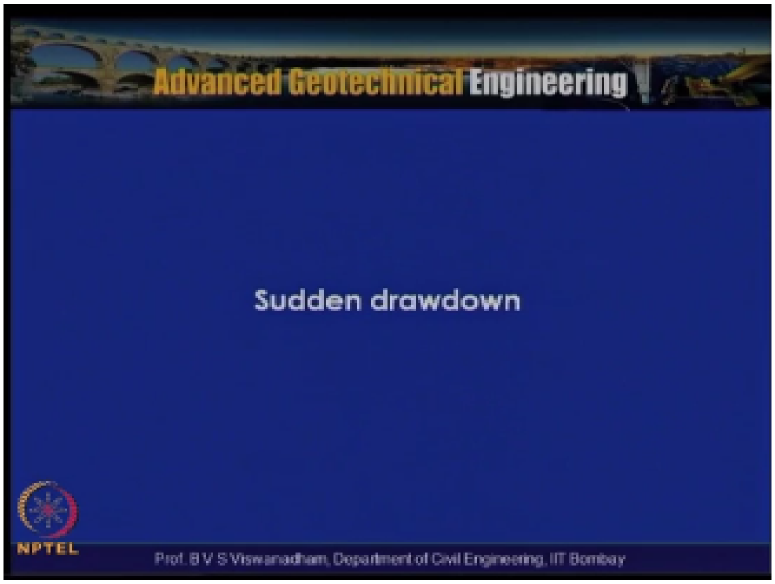

And this particular topic for this lecture we will be discussing in length about the rapid drawdown condition or sudden drawdown condition. In addition we will try to see what is the effect of rainfall on a stability of a slope if there is a you know a consistent intensity of rainfall with long duration or with increasing intensity of rainfall for a given duration and how this can vary our can affect the stability of slope if the slope inclination changes. Before discussing this rapid drawdown condition.

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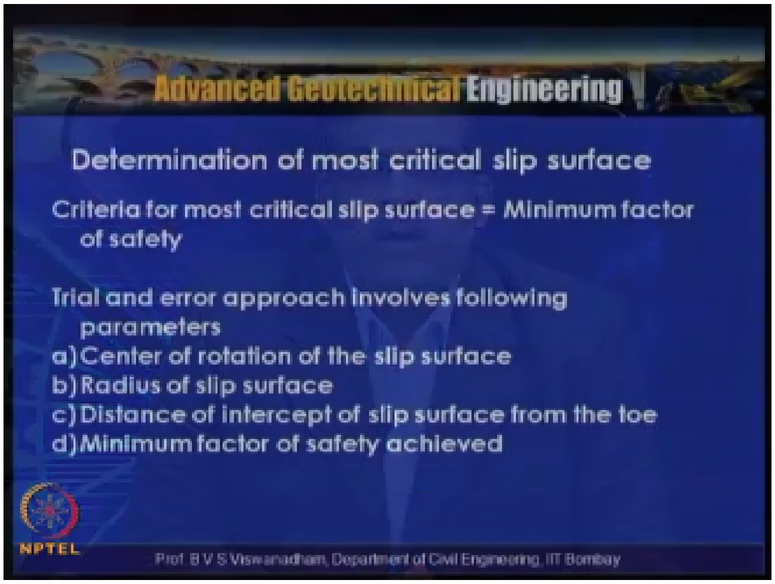

Let us look into the determination of the most critical slip surface, most critical slip surface implies that with the slip surface whichever the surface which actually gives the minimum factor safety. Now criteria for selecting the most critical surface is that the surface which actually gives the minimum factor of safety and which can be the potential failure surface. So there are trail and error approaches are involving basically it involves the location of the center of the rotation and radius of the slip surface and distance of interceptor surface from that toe and minimum factor safety issue.

Generally it is done by if a slope is there with a perpendicular bisector from that within that a grid of centers are selected and among the grid of centers then we have when we select innumerable number of circles with radius R minimum and R maximum like this when we have this grid of centers which are selected are located at the almost at the perpendicular bisector of the slope surface and each the grid of center.

When you analyze for number of slip surfaces the one whichever is the center or a grid of center which gives the least factor of safety that is actually treated as the minimum factor of safety. So if that grid the selected grid is inadequate or inappropriate then one needs to reselect the grid such a way that the minimum factor of safety is achieved.

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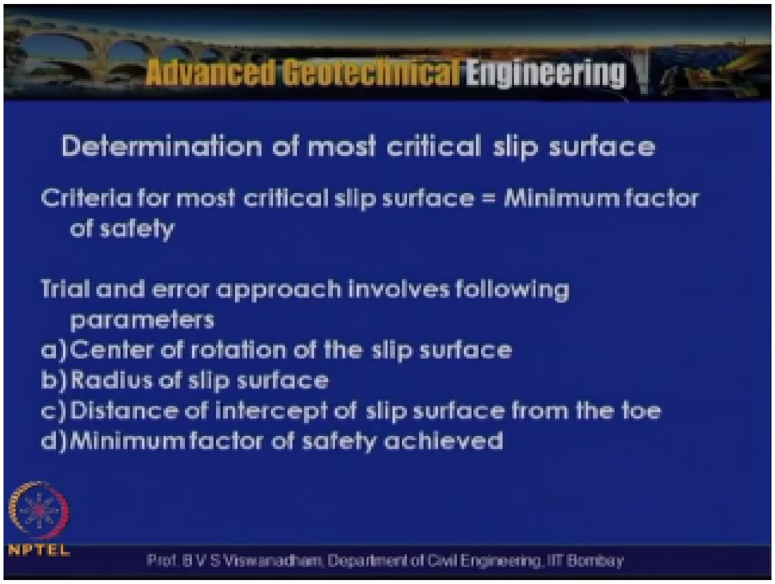

The way back Fellenius 1935 proposed empirical approach for the cohesive soils particularly for undrained condition for $\phi = 0$ that is with the soil with Cu and that is with undrained equation and different slopes like one way 1:1one one vertical one point horizontal or one vertical 0.58,1:2, 1:3 and 1:5 with α that is this angle and ϕ this angle these are the cosines direction cosines with that for this β is the slope inclination.

So draw a line through the converse of the slope at angle α and ϕ as far in the table and O1 will be the center of the rotation, so this is one of the conventional method. The another conventional method which was actually given by Jumikis case that is the possible location of Centers for C' and ϕ' soil.

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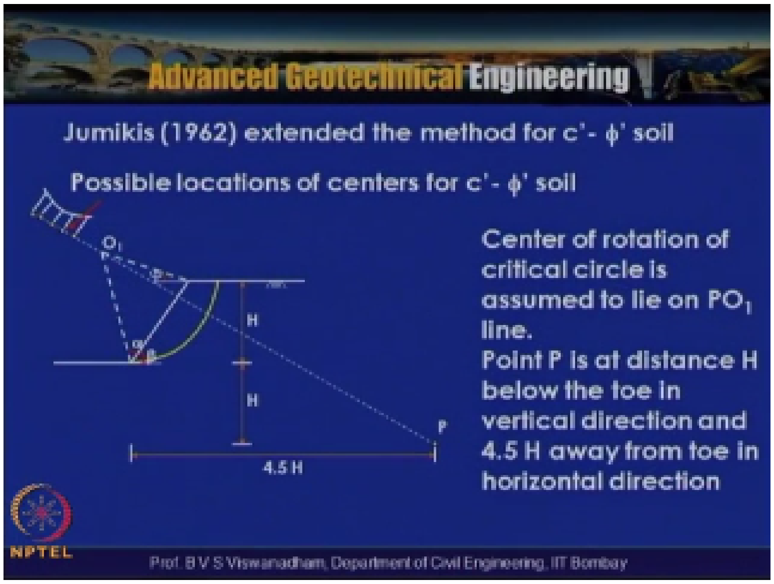

Where in here when the center of the rotation of the critical circle is assumed to be lie at point PO1, PO1 and point P is at a distance H above the H below the toe that is this H below the toe and 4.5 times the height towards from the toe of the slope. So when you draw the line wherever it actually meets along this line the one we check this analog is nothing but the different factor of safeties and this is the one which actually gives the least factor safety and that is actually selected as the possible you know potential failure surface.

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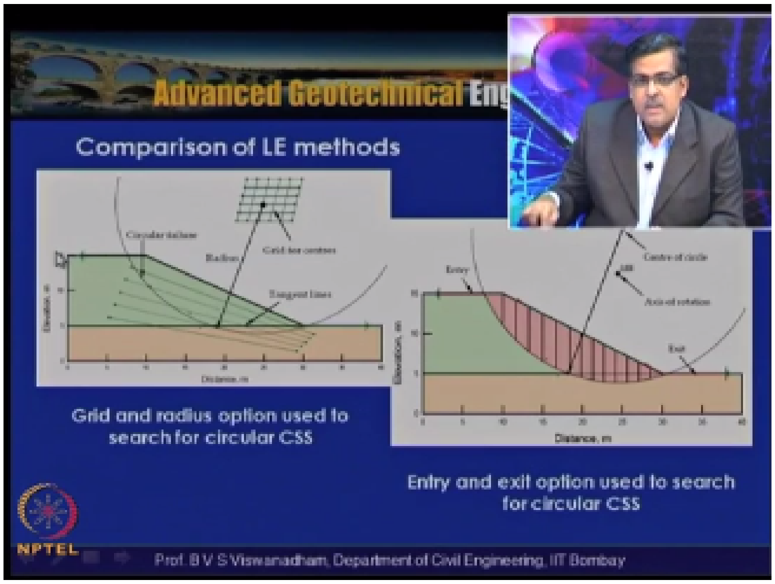

But however some LE methods which are actually done through you know software's like GeoStudio, varying slope W which actually takes like grid of centers and it also gives the possible tangent lines so it sets the circles within this grid of the tangent lines and with the prescribed intercepts with the at all at the top and then it the near the toe and with the grid of the centers it tries number of circles and the one which actually gives the least factor safety is evolved as a you know the critical failure surface.

And this is actually called as the entry point and this is actually called as the exit point, so we know that whenever there is a soft soil and then there is a tendency that the circle actually draws down towards the base of the slope. But if there is you know the hard stratum then with the if the slope is actually constructed above the ground surface are above the hard stratum then the slope fails within the toe or the slope surface.

So this entry and exit option is actually used for circular critical surface slip surfaces and this is actually you know used widely for selecting the potential value surface or potential slip surfaces or some circles in the early methods by using a slope stability software's. So comparison to when we have let us discuss about if you are having an embankment.

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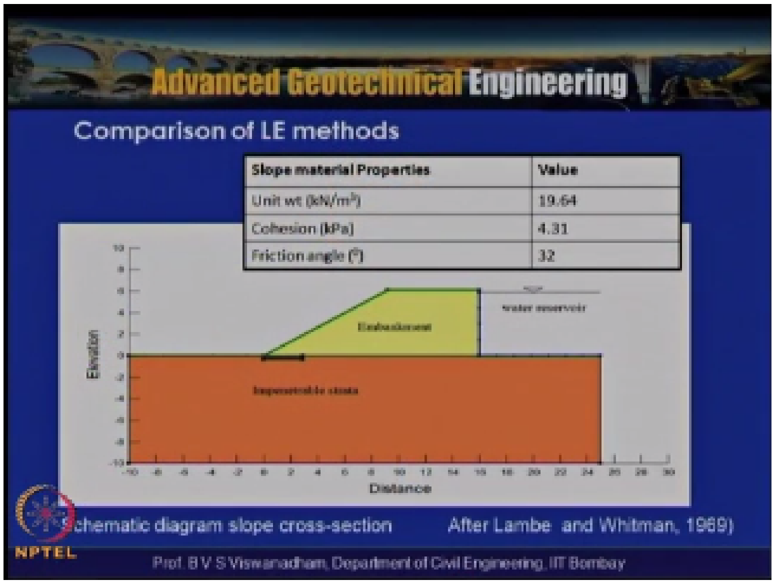

Which is a know a dam reservoir and water reservoir with impermeable strata at the base and this is the embankment which is constructed with a material having unit weight of 19.64kN/m^3 cohesion is about 4kPa and friction angle is about 32˚ so this is actually subjected to you can say water head is there and the slope height is about 6meters and the slope is one vertical is having one vertical 1.5 horizontal you can see that this horizontal distance is 8 meters vertical height is 6 meters.

So the slope inclination is about one vertical 1.5 horizontal and this is an example after Lampion Whitman and assume that there is a drainage layer at the base there is a drainage layer at the base. So this is the filter layer having very high permeability compared to the embankment soil.

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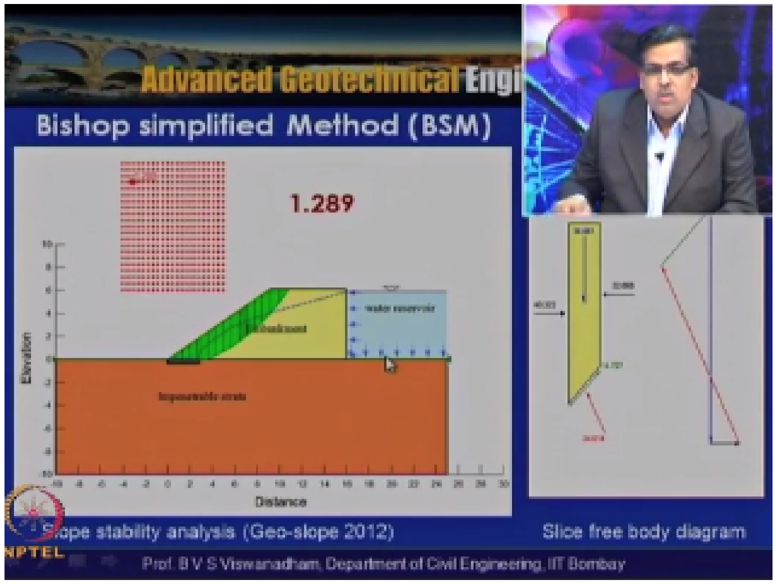

So let us see that when we do the seepage analysis and when we perform the seepage analysis what we get is this is called the phreatic surface and this is the phreatic surface as this being the flow line and you can these this being the equipotential line as this being the equipotential line with the head is equal to 0 here what you see is the upper most flow line and the soil below this is actually saturated and this condition is actually once this conditions are prevailing then this is actually said to be subjected to a steady state seepage conditions.

So afterwards this selected the grid of centers are selected as we discussed in the previous slides and from each center the number of circles are actually have been tried and out of this the one which actually gives the least factor safety is actually reported here that is nothing but here which is actually having a factor of safety of 1.289. So when you look into the you know this is actually my analysis is done by bishops simplified method and we know that where tangential forces along the slices were assumed to be 0.

And the forces on the normal to the slice vertical slice surface that is actually considered so if you see the free body diagram of the slice 11 that is actually countered from here this is actually shown here and this is when it is projected here what you can see is that these are the normal forces which are actually acting on the vertical surface of this slice and this is the base of the slice and this is the self weight of the slice depending upon the so this is, this portion is partially saturated and this portion is saturated.

So this portion this weight of this slice is given and that is indicated here as a force polygon here and this is the normal force this normal force is indicated here and this tangential force which is nothing but the shear stress that is indicated here the difference of this forces acting this side that is this one. So for example, if you do this analysis by using they say seepage method of slices as these forces are assumed to be 0 you will see that the there will be a force that triangle there will be a polygon will be in the form of a triangle.

But here because of this condition you will see that there is a net horizontal forces because this is are represented here.

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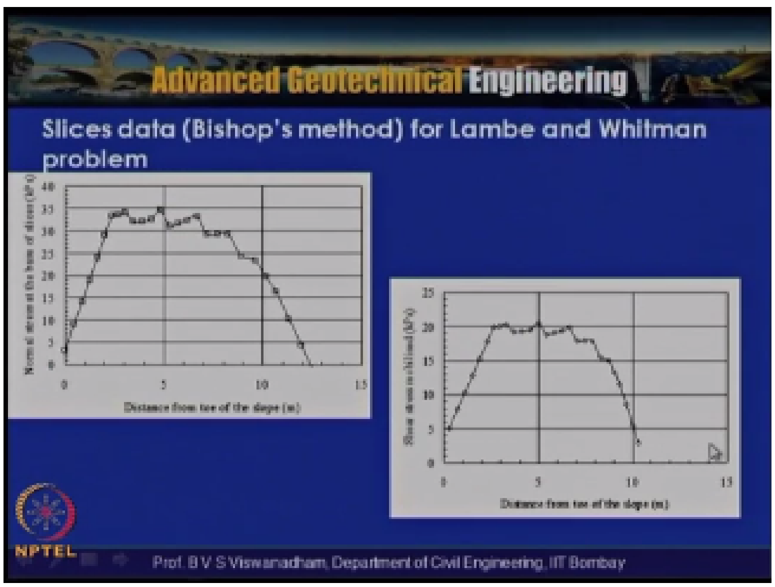

Now when you plot this distance from the toe of the slope with the normal stress at the base of this slice then you can see that the Mobley's due to normal stress at the base of the slice is about 35kPa and then which actually drops down when you go away from the toe of the slope. Similarly here the shear stress mobilized is also plotted in whatever it has been recorded in from the program. So this is the plot showing the distance from the toe of the slope to the shear stress in the most shear stress mobilized along the base of the slice.

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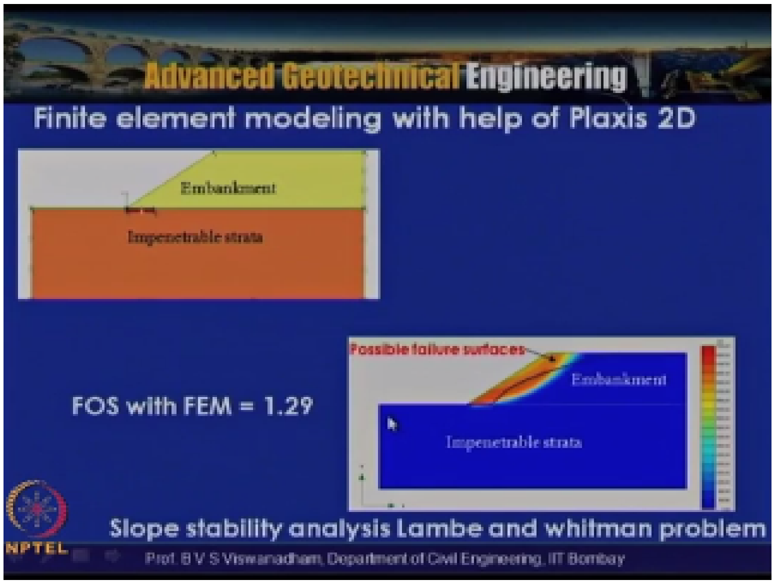

So the same problem has been analyzed by using Plaxis by strength reduction method and with that the factor of safety is actually obtained as 1.29 so what you can see is that the possible failure surface is actually obtain the same phreatic surface what actually has been obtained from the seepage analysis has been fielded here in Plaxis two dimension analysis and the potential failure surface which is actually obtained is recorded in here.

So what actually has been obtained from the early analysis and then from the you know for the example of Lambein Whitman problem is found to be in agreement the factor of safety which is actually obtained by using early analysis is found to be 1.289 and with this method it is found to be about 1.29.

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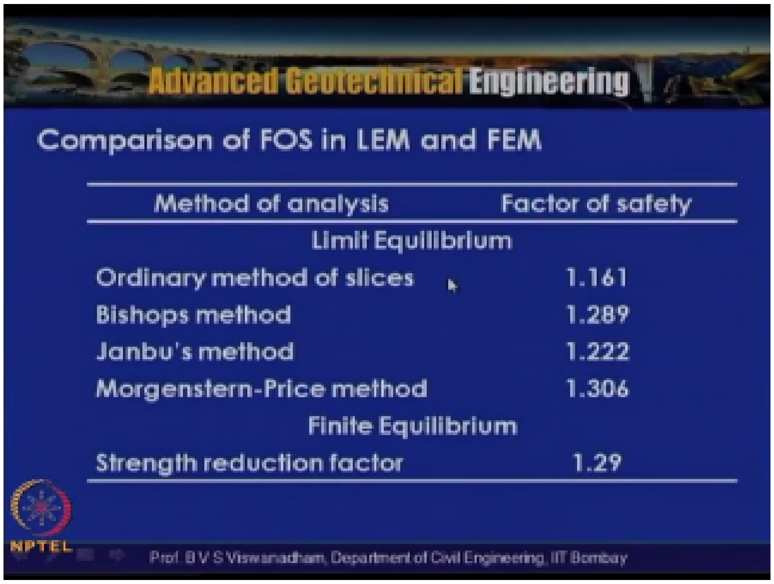

So the comparisons of factor of safety with the LEM and FEM is given here, if you perform the ordinary method of slices it is actually given as 1.161 and if you do the Bishops method it is 1.289 and Janbu's method which is 1.22 and Morgenstern Price method with finite equilibrium when 1.306 so what does it imply is that if you look you know the slope with a factor of safety 1.2 if you go with the ordinary method of slices we actually tend to over conservative.

But if you are not say Bishops method, Morgenstern price method it indicates that the slope will be stable up to a factor of safety of 1.3, so you know this is the advantages of you know the different methods the comparison is actually shown here in this particular slide.

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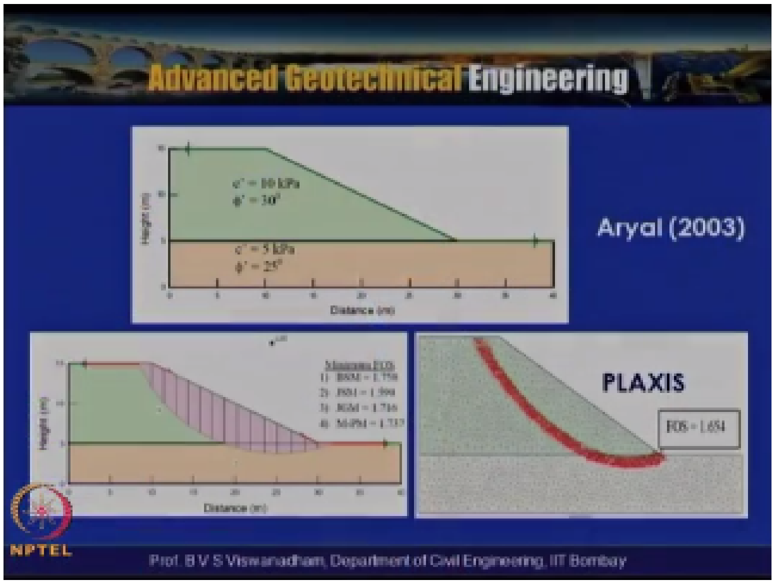

So here again the slide which was actually shown earlier was actually shown again and this was the Aryal 2003 work where in the limiting analysis was actually done by using Bishops method and Janbu's method and Morgenstern price method and the results were actually found whatever the results which are actually obtained for the real ambient problem performed to be consistent with the results were actually presented by Aryal 2003 as you can see that you know 1.758 and then the Morgenstern Price method is actually coming around 1.737 and the Plaxis is actually giving about 1.654.

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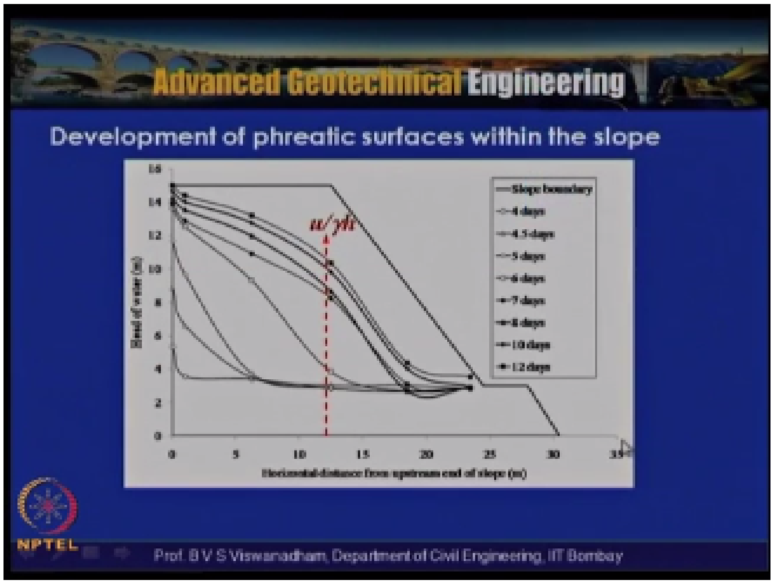

Now this is a particular slope which is having an inclination of about one vertical one horizontal these lines which are actually shown here it shows that if you are inducing a seepage from the side of a slope then how the phreatic surface will raise to the slope, so you can see here in the fourth today so this is the slope boundary and in the fourth day the fair phreatic surface is only this and as the flow takes place and as the head is actually raised you can see that the phreatic surface you know reaches the climbs up and the pore water pressure for example at this particular point continues to increase.

Now what will happen is that if the given slope is actually stable and with these phreatic surface conditions are the flow line top flow line condition the slope will be actually subjected to steady state seepage condition and remain safe but if, but in the long term what will happen is that the internal erosion is the one which actually can occur rapidly. So for in order to avoid this internal erosion and piping problems at the downstream of this slope there is a need for the you know to take care adequate measures about preventing the internal erosion piping at the downstream of the slopes.

So the reason why this has been actually shown is that the phreatic surface which are actually obtained experimentally or actually campaigned were compared with the one which are actually obtained from the seepage analysis.

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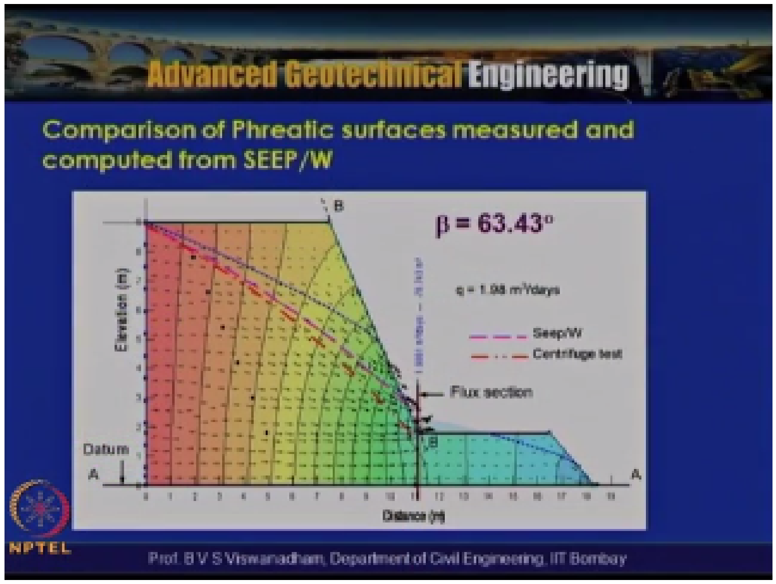

As well as from some experimental works which is carried out at IIT Bombay, so this is for the slope of this comparison is actually for a slope of 63.4˚ what you can see is that this is the result of the seepage analysis with the water actually at this level and this is the phreatic surface which is actually measured from this height to this height and with the seep/W what actually is obtained is this and from the experimental investigation the obtained is this much.

So this is actually found to be consistent and very in vertical you can see is that both seep/w and this actually found to be in order.

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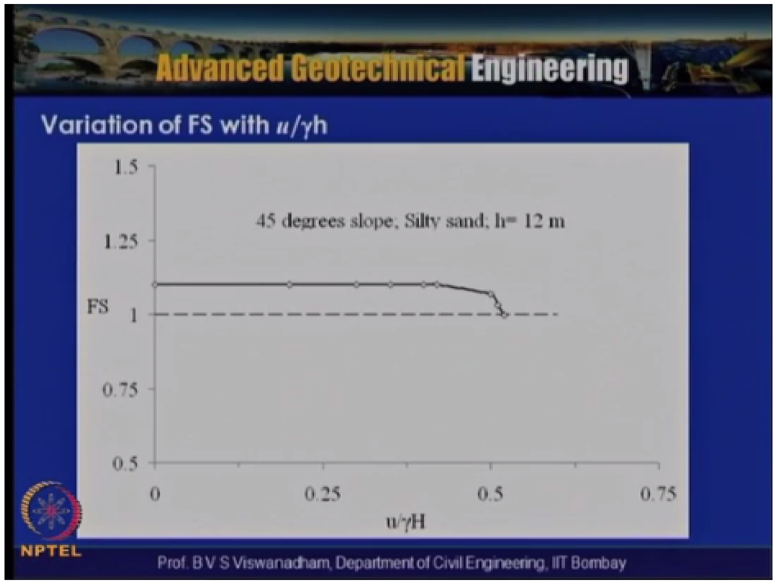

So when you when you with increase in you know $u/\gamma H$ the $u/\gamma H$ which is nothing but a pore water pressure measured at a certain horizontal distance from the crust of the slope and if you normalize that with a bulky weight of the soil into height of the slope and if you do then you can see that off once this $u/\gamma H$ value reaches to attains a value of you know 0.5 for a 45˚slope the slope is actually attending value of 1.

That means that the slope as the $u/\gamma H$ is actually increasing as the phreatic surface is traversing and then in contact with the toe of the slope then there is a possibility that the slope instability can be instigated.

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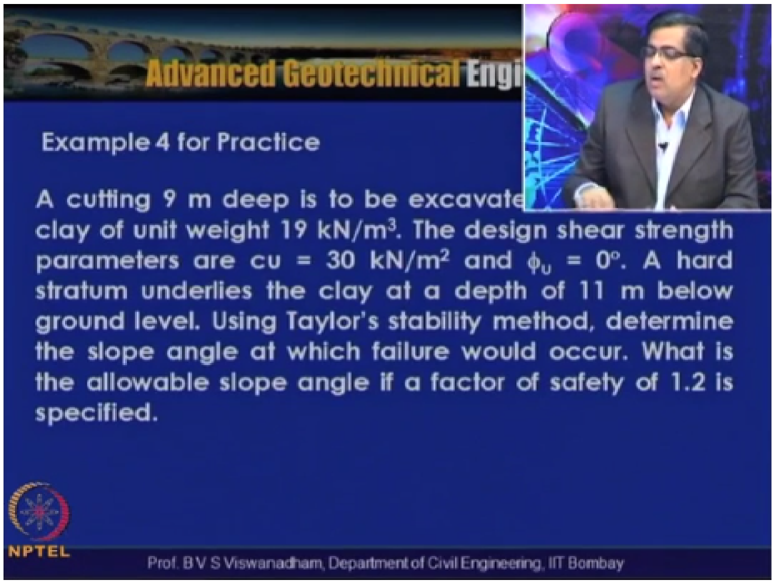

So before discussing the rapid drawdown conditions let us look into the example 4 for the practice and this in this particular problem a cutting of 9m deep is to be excavated in a saturated clay having a unit weight of19kN/m^3 the design shear in parameter surveys are Cu 30kN/m^2 and if ϕu=0 a hard stratum underlines the clay at a depth of 11m below the ground level so using the Taylor stability method which we have discussed earlier.

Determine the slope angle at which is the failure occur and what is the allowable slope angle if a factor of safety 1.2 is specified, that means that you need to determine what is the determine the slope angle at which the failure will occur and what is the local slope angle if a factor safety of 1.2 is specified. So this is an example for the Taylor's stability method which we have discussed and here a cutting of 9m high a deep is to be excavated in a saturated clay of unit weight 19kN/m^3 and shear strength parameters are undrained that is Cu= 30kPa is given.

And hard stratum underlies the clay at a depth of level meter below the ground level. The another example for the practice example 5 is for the given failure surface which will be shown in the next slide.

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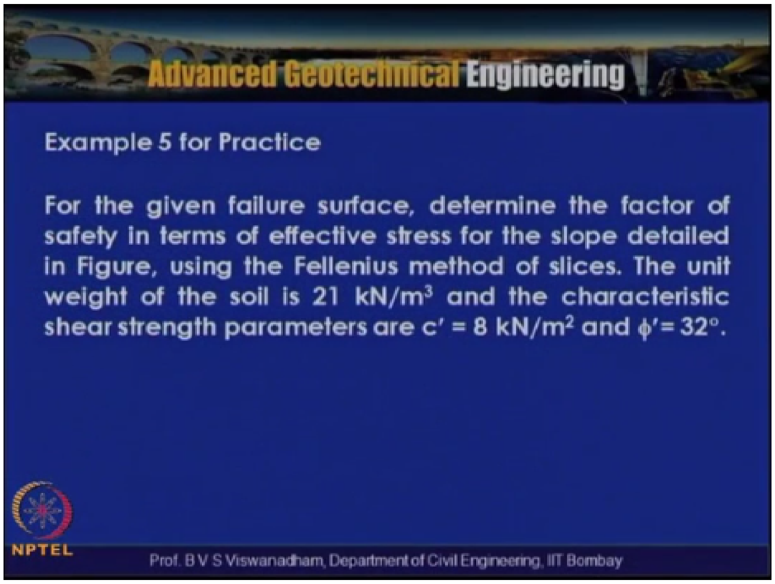

We need to determine the factor of safety in terms of effective stresses for the slope detailed in figure using the Fellenius method of slices the unit weight of the soil is $21 kN/m^3$ and the characteristics just parameters are c′ that is the drain parameters effect to cohesion is $8 kN/m^2$ and effect to friction angle is $\phi' = 32^\circ$.

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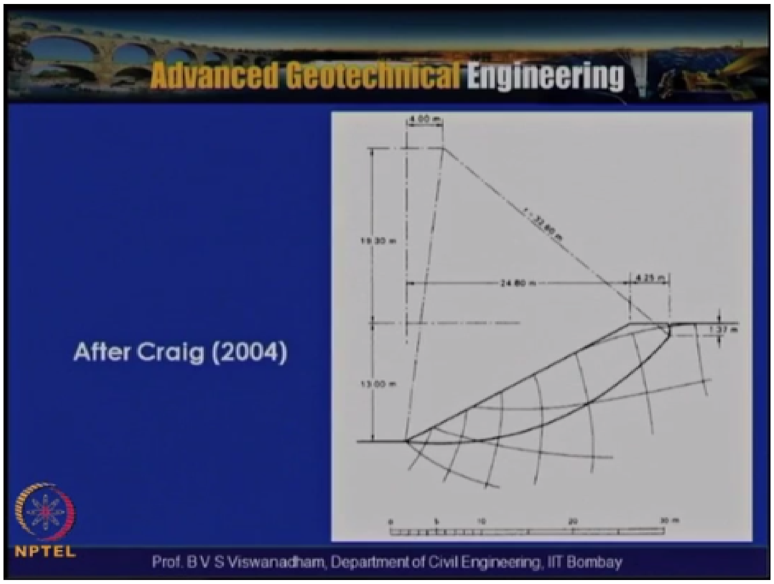

So the slope is actually shown here and wherein the this distance.

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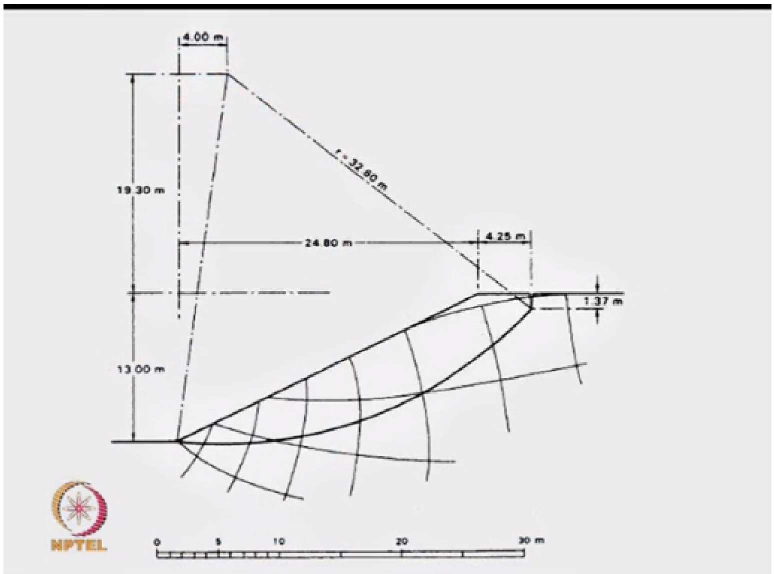

So here this particular portion is the tension crack and the depth of the tension crack actually is given as 1.37 and the horizontal distance from the crest of the slope is about 4.26meters so the failure surface is assumed it to be fitted up to from this point to this point, so this is the entry point because this portion is already cracked so there cannot be any generation of the you know mobilizing shear resistance.

So what we do is that we select from the tip of the crack to the say toe of the slope in this case and this is the center of the rotation and this is the horizontal distance from this point to this point and this is this height is 19.2 meters and this is 12meters height and this horizontaldistance is given as 24.8 and these are the equipotential lines and these are the flow line which is actually given here like this.

So for this condition the scale is actually given here and this is after crate 2004 and this by using this very new surface failure condition which is actually shown the this particulare xample five need to be solve.

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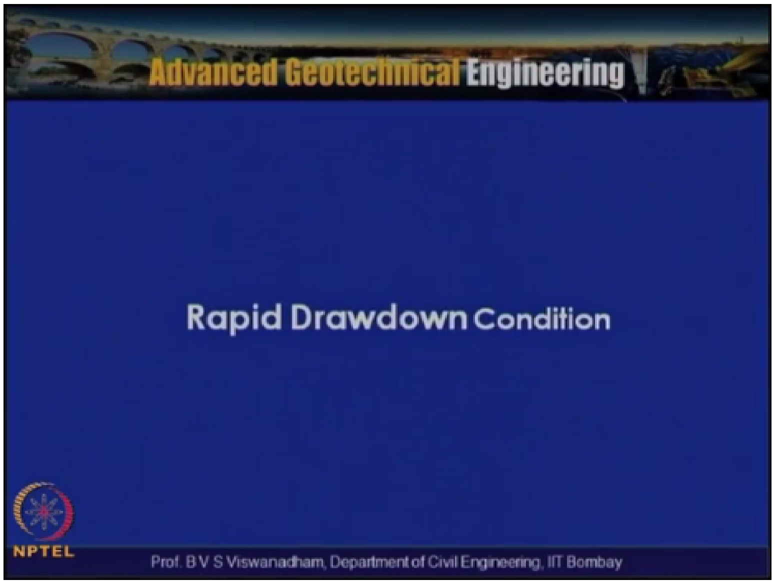

So now the coming to the rapid drawdown condition the topic for this particular lecture wherein we before addressing that one let us look into the steady state seepage condition. Once the reservoir or a dam which is actually has been full for some time.

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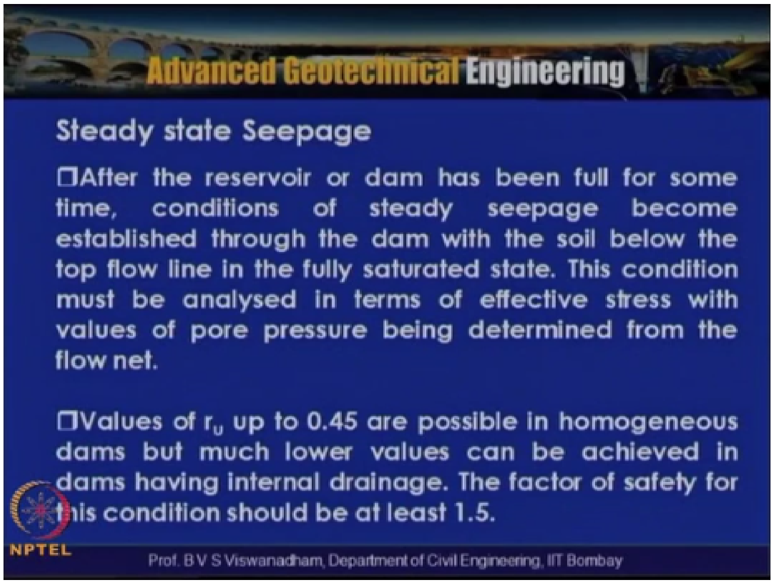

The condition of the steady state seepage becomes established through the dam with the soil below the top flow line in the fully saturated state, so the soil below the top flow line are nothing but the phreatic surface is completely saturated. The condition must be analyzed in terms of effective stresses with the value of pore water pressure being determined from the flow net and the values of RU that is the pore water pressure coefficient which is nothing but the ratio of u/γH γsatH is nothing but it upto 0.45 possible.

In case of homogeneous dams but much lower values can be achieved in if in dams having internal drainage that means that if you are having dams with internal drainage that is like filters or chimney drains as the phreatic surface will be subjected to a dip and because of that the Ru value can be much lower. The factor safety for this condition should be at least 1.5 but one thing one has to be established is that there can be eventualities of the occurrence of the internal erosion problem.

So this need to be addressed, so after the reservoir dam which has been full for some time the condition of study seepage becomes established through the dam with the soil below the top flow line is actually completely saturated and effective stresses conditions need to be considered. So this so in the rapid drawdown condition suppose any change.

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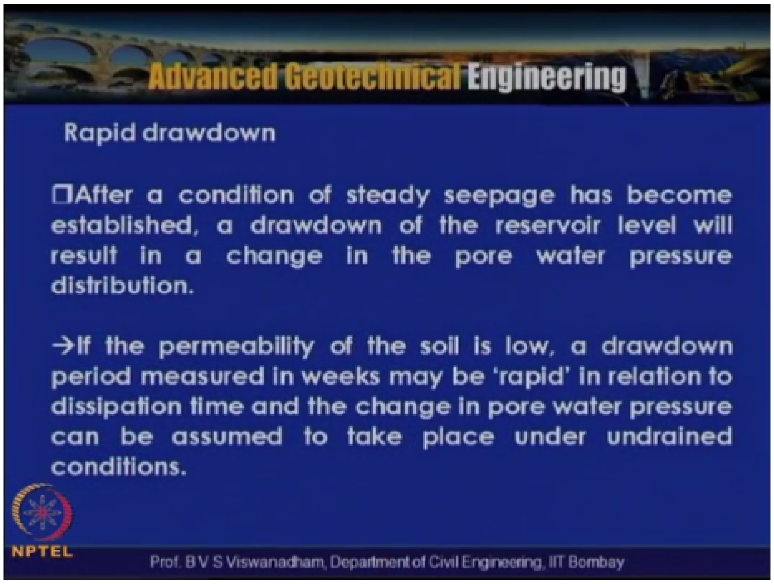

Once you know steady state seepage conditions are established because of certain constant water level it rot out of the reservoir level will result in a change in the pore water pressure distribution within the slope, and this actually depends upon the rate at which this drawdown is actually taking place and also the permeability or coefficient of permeability of the soil. So after condition of study seepage condition has become established a drawdown of the reservoir level or the water level in the dam will result in a change in the pore water pressure distribution.

So if the pore of a permeability of the soil is low a drawdown period measured in weeks may be rapid in relation to this even if you are having permeability of soil is low drawdown period which is actually measured in weeks may be rapid can be treated as a rapid in relation to dissipation time and change in pore water pressure can be assumed to take place under undrained conditions the pore water pressure changes can actually take place in undrained conditions.

So in this particular slide a slope stability analysis in drawdown condition or a response of a slope to the drawdown condition is shown.

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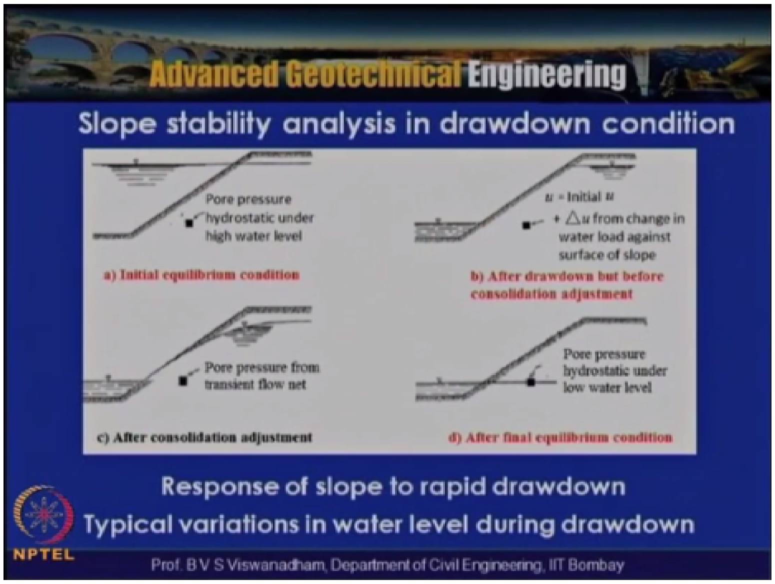

So here the this particular first figure actually shows the pore water pressure under hydrostatic under high water level that means that this is the initial equilibrium condition wherein the pore water pressure is under hydrostatic conditions. Here with a drawdown which actually has taken place the water level which actually from here to here it has dropped at a certain rate but before the any consolidation settlements or consolidation adjustments that U the pore water pressure at this point is initial you what is the whatever is the hydrostatic water condition plus ΔU from the change in the water load against the surface of the slope.

So this is actually nothing but there is an increase that is nothing but initial U+ΔU so in at this particular stage with an increase in the pore water pressure within this flow there can be a danger for the slope stability that means that the factor of safety of aslope can you know will be will reduced to a certain value. So after once it is subjected to consolidation adjustments and at a pore water pressure obtained from the transient flow rate is actually shown here.

And once the equilibrium is existent and with the low water levels the pore water pressure is actually established to these things. So when these things happen under cyclic manner with increasing water level and then decreasing water level so there can be possibility of it can get get hampered with the factor of safety. So in this particular slide let us consider the analysis which is actually pertaining to rapid drawdown condition.

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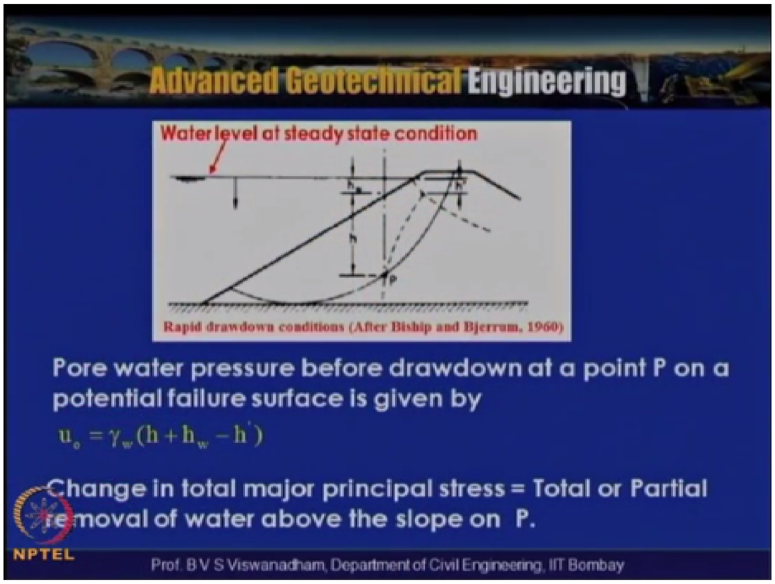

So here consider a slope which is after the Bishop and Bjerram 1960 which is a particular dam or a reservoir and this is the water level in steady state condition and this particular this is the potential failure surface and this was the initial hydrostatic this is the water level and this can be a phreatic surface after a certain drawdown. So at Point P the pore water pressure before drawdown at point P on a potential surface is given as so which is nothing but U0 which is nothing but the pore water pressure at this point γWH there is this water level +hw so we are actually at this point.

But this h ′ which is actually loss which actually has taken place because of the drawdown which actually has taken place from this level to, so the H dash is nothing but the loss of the head because of the C pH so u0=γw.h +hw - h dash now it is actually easier to assume that change in total major principle stress that is due to the resulting due to the soil slope is equal to total or partial amount of water above this slope that means that the any change the net to change in the total stress that is nothing but this σ the principal stress nothing.

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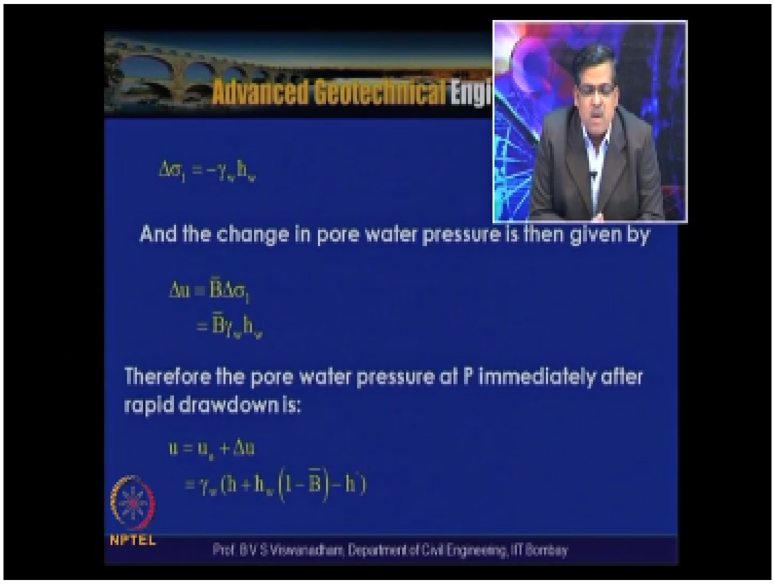

But the σ one the Δσ-1 = γw HW that the γ w HW which is nothing but -γW HD at the end of the change in water pressure what will happen is that this Δ U which is actually - b dash Δσ dash so which is written as -b dash γ WH W so this further Δσ-1=Δ U so for this fields once you when you substitute here and when you write u = u0+ Δ u then Δ U when we substitute for B dash γ WH W - u0 is substituted which is nothing but γ WH into + HW -H dash when you write here then we get U is equal to pore water pressure at Point P immediately after the rapid drawdown once it is actually then γ W .H + HW . 1- B dash - H –

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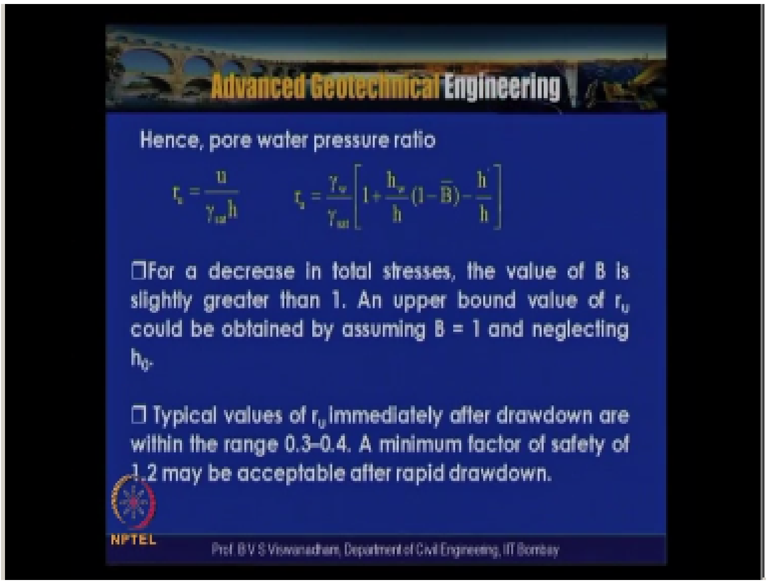

So you by using the pore water pressure ratio that is a γ W = u / γ CH now substituting for you here this particular expression which is γ W. h + h TW .1 -b- - h - so this you it is that γ you now are you will be γ double comma w by γ side into 1 +h 2 by H . 1 - B - H -by H so for a decrease in total stress the value of B which is nothing but B bar is slightly greater than 1 and upper bound value of the area you can be obtained by assuming B = B dash = 1 and neglecting, neglecting H –

So neglecting H - it is not H not it is H - so with the neglecting H - this will be 0 and with this be 1 so the upper value is nothing but γu / γ W / γ set the ratio of γ W /γ said is approximately equal to 0.5 so the problem you will be upper bound will be basically about close to 0.5 so typical values of R you immediately after that round within the range of 0.3 to 0.4 a minimum factor of safety of 1.2 may be acceptable after the rapid draw down continue so when we are actually investigating we have to ensure that a minimum factor of safety of 1.2 is ensured.

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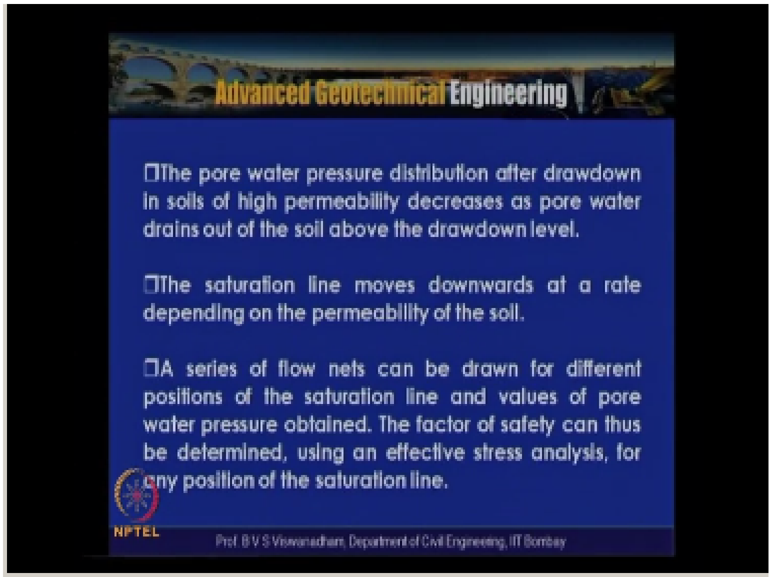

So the pore water pressure distribution after drawdown in soils of high permeability decreases as the pore water drains out of the soil above the rainwater drawdown limit so one inference is that the pore water pressure distribution after drawdown in soils having high permeability decreases as the pore water drains out of the soil the saturation line moves downward at a rate depending upon the parameter soil yessirree.

The rate at which the saturation line are the periodic surface our top flow line moves that depends upon the type of the soil our soil actually having a particular permeability that means that it depends upon the type parameter of the soil so abased on this a series of flow needs can be drawn for different issues of saturation line and very and values of pore water pressure can be obtained the factor safety can thus be determined using an effective stress method for any position of saturation line.

So as the slope the condition is actually coming close to the before coming close to the equilibrium condition or just after the rapid drawdown we can determine and once the slope actually reaches to some equilibrium condition we can determine so the vulnerability is that you know once actually immediately after route down transition the factor of safety reduces so for that condition we need to ensure that it is actually having any adequate factor of safety.

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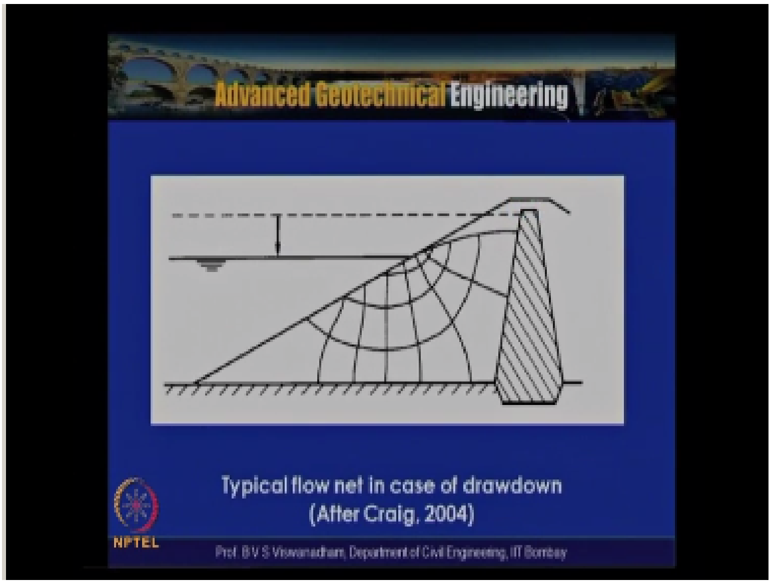

So the in this particular slide a typical flow rate with a particular saturation line for a particular drawdown so here the draw down actually happened from here to here and this is the core which is actually with the low permeable soil and this is a relatively pure imbed soil and this is the flow rate in the case of a draw down so this is the top flow line for a particular state this is the tough flow line.

So you can see that for this is the top flow line this is the top floor line so you can see that these are the these are the flow lines which are actually these are the flow channels flow channels and these are the operations this is the impervious surface so it is assumed that the water actually will not penetrate through this and this is the impervious stratum so the typical flow rate in the case of a drawdown condition is given.

So for this particular flow line and flow rate condition you were able to do the affirm stability analysis and then we have to see that for this drawdown with particular this thing what will be the factor of safety by using the effective stress analysis parameters with C Dash and ϕ dash can be determined.

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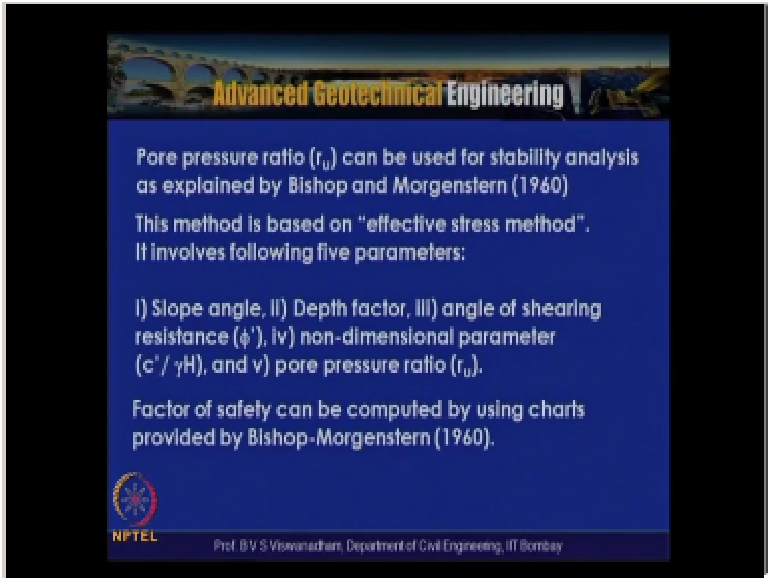

And the pore water pressure ratio can be used for stability analysis as explained by Bishop and Morgenstern in 1960 this bestirred is based on the effective stress analysis it involves the following parameters slope inclination depth factor that is nothing but the soil below the start that is D slope height and the ratio death tract is nothing.

But soil below the toe that is the height is if it is if the tide is say D and the slow fight is H that is the ratio of this D by Hand angle of shearing resistance that selection angle ϕ dash and non-dimensional parameter which is nothing but C dash where gamma H and His either slope and pour water pressure ratio so factor of safety can be computed using the charts provided by this thing but these are not covered in this particular lecture.

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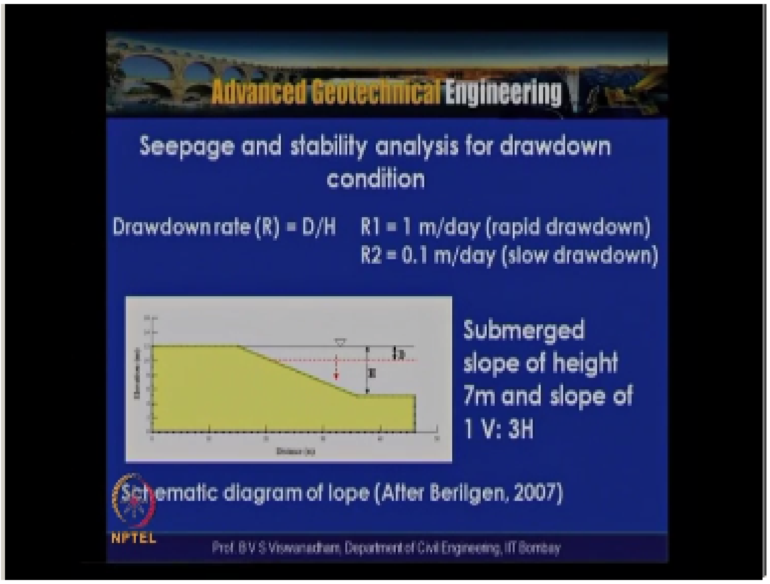

So but however what has been done is that a typical slope which is actually after building in 2007 was actually considered and here the seepage and stability analysis for drawdown conditions were carried calculated and by using geo Studio 2012so the schematic diagram of the slope which is actually shown here and the drawdown rate is which is to draw down rates are considered one is actually rapid Rodham another one is slow Rodham.

The rapid drawdown which is actually one meter per day so the one meter the slow drawdown these submerged slope of height seven meters so initially the water level is up till here and the slope is actually having soil parameters which will be disclosed and one vertical three horizontal is the slope inclination and seven meter is the height of the slope.

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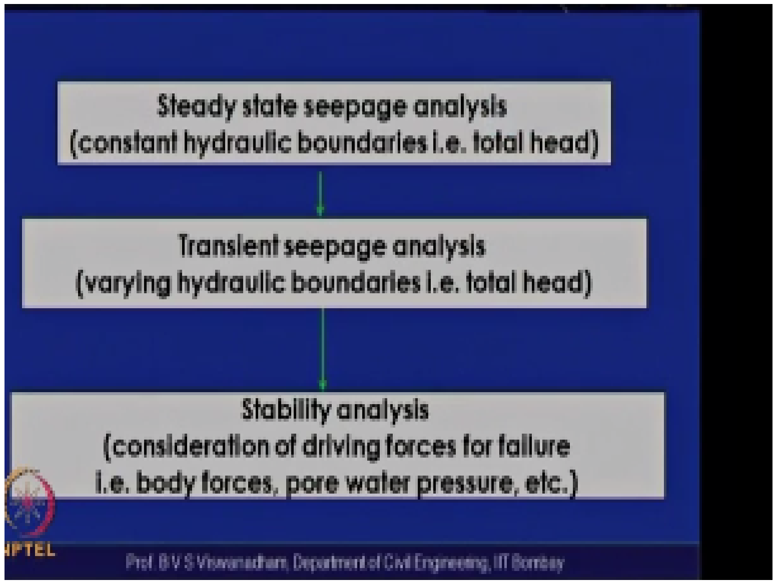

So the flow chart which actually involves this thing is that first to steady state seepage analysis and constant hydraulic planner boundaries total height and transitional phase analysis and stability analysis consideration of driving forces for failure body forces and pours water pressure

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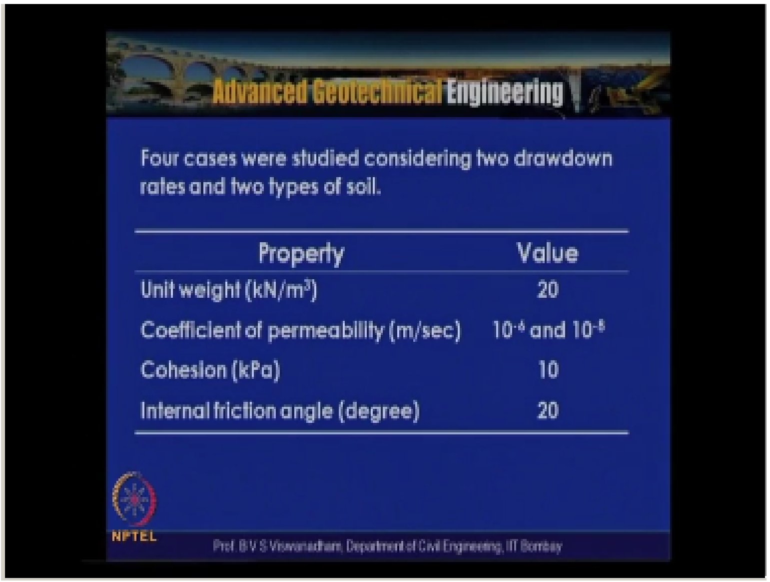

So the properties which are actually considered are unit weight for the slope is 20 Cal per meter cube and coefficient of permeability is 10^{-6} and 10 - 8 meter per second and the cohesion is about 10kilo Pascal's an interval attraction angle is 10 20 degrees so this is drained barometers cohesion10 kilo Pascal's and internal friction angle 30 degrees.

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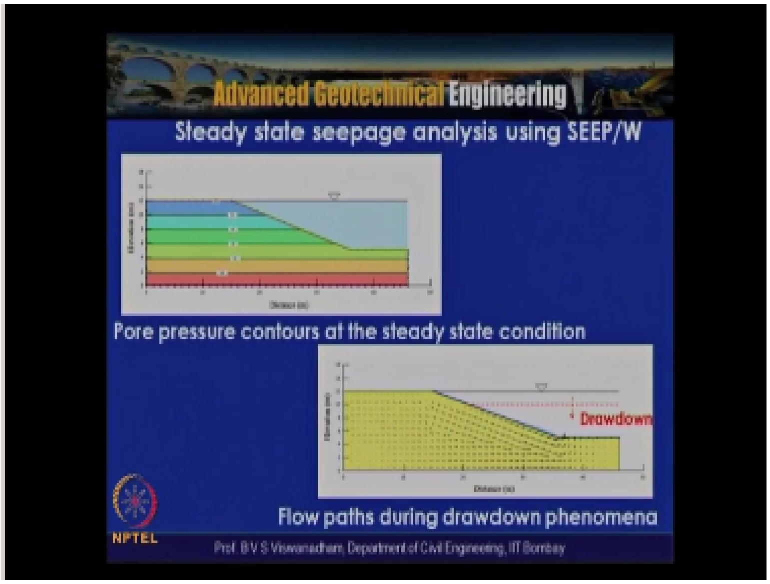

So this is the steady state seepage condition analysis using seep/w so at the steady state seepage condition this is the you know the pore pressure conduits and the flow path during the drawdown phenomenon you can see that when the drawdown is actually occurring how the flow vectors actually you know collaborating here that can be seen here.

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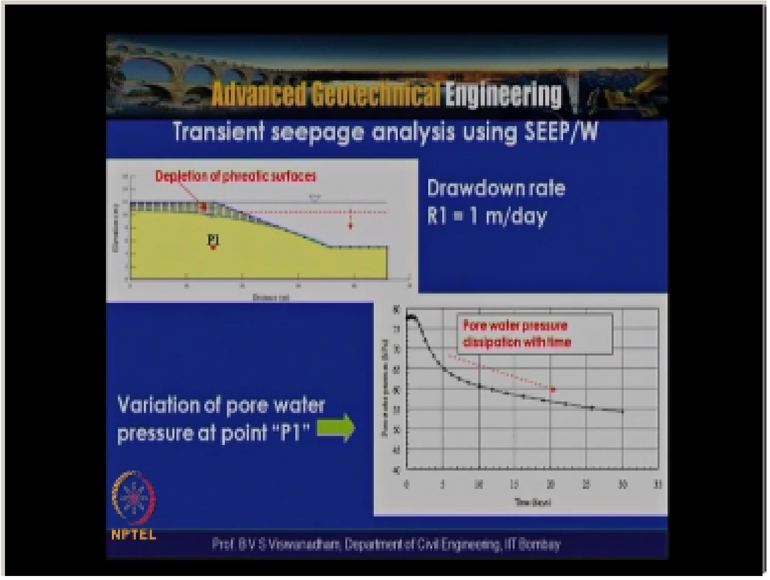

Now here with a drawdown rate of 1 meter per day and with a permeability of 10 $^{-6}$ meter per second what can be seen here the pore water pressure from here the periodic surface from here depleted to this particular level and the variation of the pore water pressure at Point P 1if it is plotted you can see that the pore water pressure dissipation with the time can be seen here so the pore water pressure actually splits with the time.

So that it can be seen from this particular slide so the stability analysis by using the slope W for that problem for that case where critical factor of safety is equal to one point four nine seven so you can see that as with10 ok with 10 $^{-6}$ meter per second with one meter per day is the drawdown rate that is the water depletion it is nothing but a draw down rate is nothing but the height to the height of water per unit time.

So the critical factor of safety obtained is about one point four nine seven so you can see that the initially the factor of safety is high but as the draw down actually taking place you can see that the effect of safety depletes and then remains constant and increases slowly so this particular condition you know herein this case for this condition we actually have got a factor of safety of one point four nine seven.

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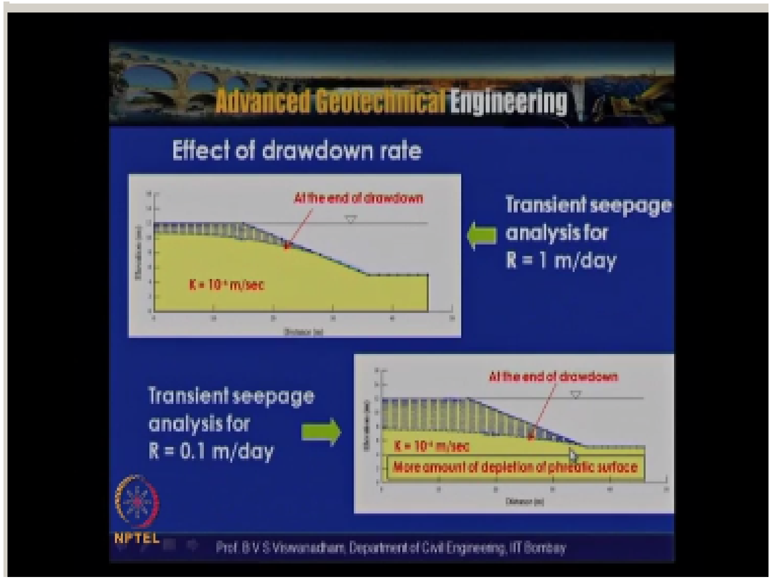

Now when we have actually got slowed drawdown so both what will actually happen is that here this R 1 is 1 meter per day and R 2which is 0.1 meter per day so you can see that at the end of the draw down there is a depletion of the planet a surface takes place so this is because you know the dissipation of the pore water pressure takes place simultaneously when the drawdown is actually happening.

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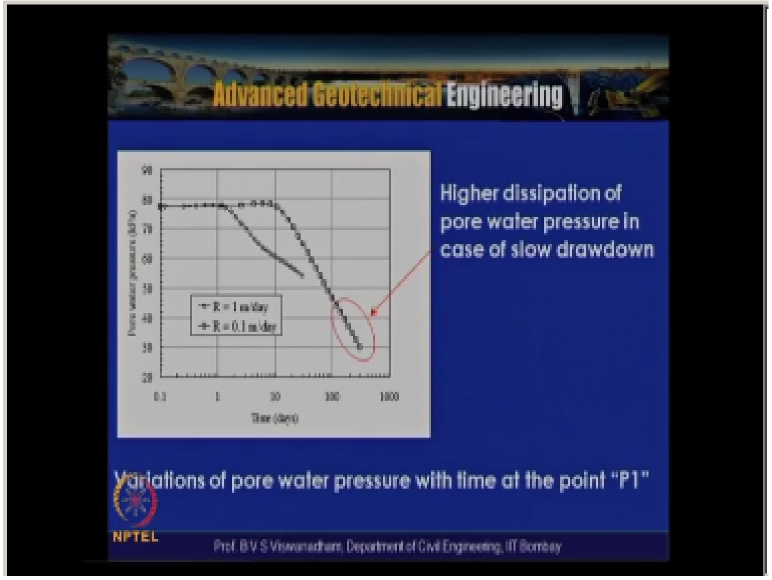

So if you plot the variation of the pore water pressures with time at this particular point what we selected here and these points when you compare so you can see that with the slow drawdown there will be high dissipation of pore water pressure takes place with the rapid drawdown with a very less dissipation of pore water pressure takes place this implies that with the high pour water pressures in the soil there can be you know factor of safety can be affected and low factor of safety s can be obtained.

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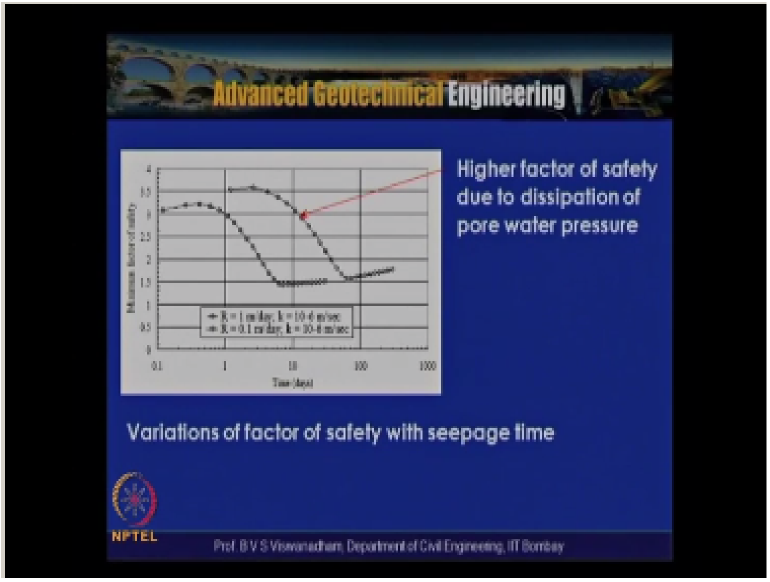

So the same thing is actually presented here when we have the variation of factor of safety with the seepage time and we here with a draw down rate of 1 meter per day and point 1meter per day the one which actually with a rapid drawdown of 1 meter per day you know gives very low factor of safety or compared to the one with actually higher with relatively slow drowned off so what it implies that you know the when the drawdown rate is high.

And because of the high pour water pressure development the factor of safety of aslope can be endangered so here I our factor of safety due to dissipation of pore water pressure can be seen with the distribution with minimum factor of safety with the time in days which is actually plotted here so this is for a for a for a for a for a for example let us say second a third day the factor of safety is two here but the same slope with the slaughter on the factor of safety ensured is about 3.5 or so that is what actually is actually explained herein this slide.

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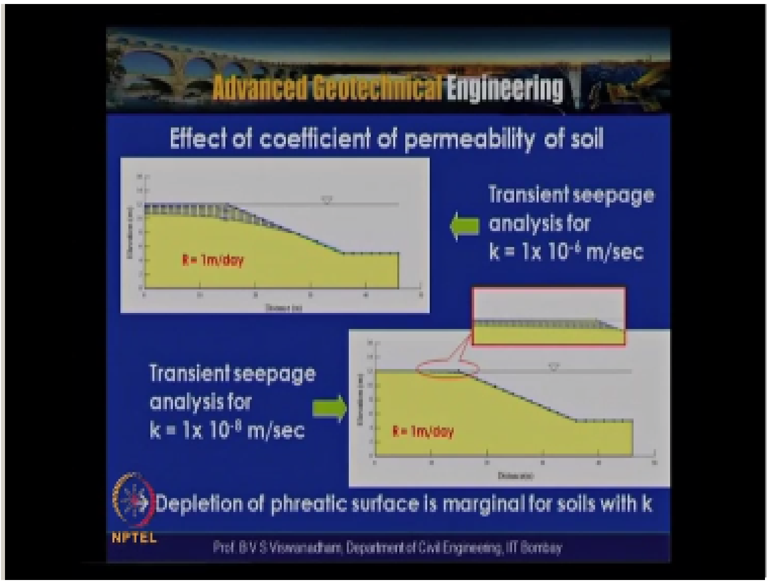

Now what will happen when the drawdown rate is same but the permeability is actually of soil is low so if you see that if the permeability of the soil is low then there is a possibility that the pore water pressure dissipation and depletion of the periodic surface is marginal for soils with no K values so depletion of periodic surface is marginal for soils with low K values so here you can see that this is a soil with 10^{-6} meter per second.

And this is this analysis actually carried out with soil with 10^{-8} meter per second so what you can see is that this and this the drawdown rate is same but permeability is actually here 1 by 100times which is actually less so you can see the magnified version of the insect which is actually shown here so this is the depleted periodic surface so the depletion of periodic surfaces is marginal for soils with low permeability.

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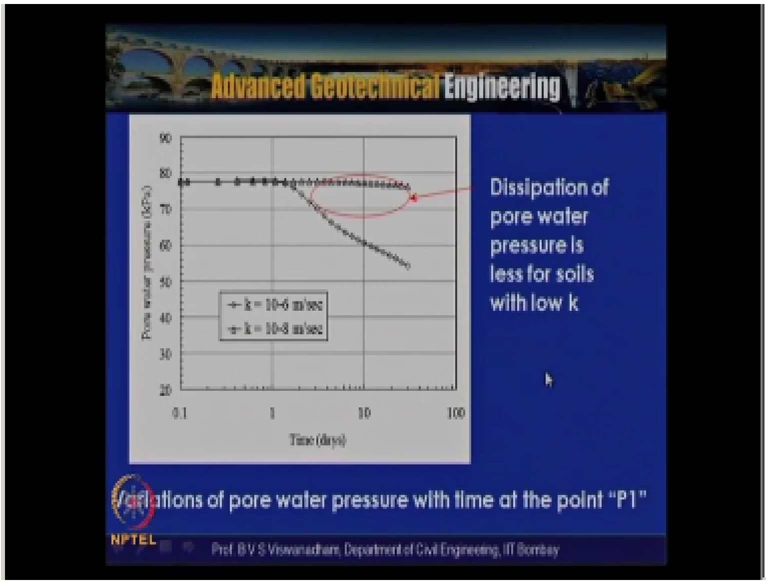

The same issue is actually shown here the pore water pressure distribution at particular point p1 and with two soils having two different permeability's 10^{-6} and 10^{-8} meter once again the dissipation of pore water pressure is less for soils with low permeability and similarly the factor of safety s if you look into this higher factors of having the higher factor safety for the soils having high coefficient of permeability.

So that means the soil with relatively because of the because of the because of the you can see that because of the dissipation of the pore water pressure with this thing there is a possibility that high factor safety is obtained but soils with no permeability the factor of safety is low that is actually which is shown here and you can see that this particular case reaches to the critical factor of safety which is equal to 1 here.

So here this particular value where it can actually if this situation prevails at the site there is a possibility that this slope can undergo failure due to draw down condition with a 1 meter per the condition so that that was actually the discussion about the rapid draw down condition and so we in this particular the forthcoming two slides we discuss about the torture stress analysis and effective stress analysis requirements and some general comments we actually have discussed the, the common requirement is that our total stress in the soil mass .

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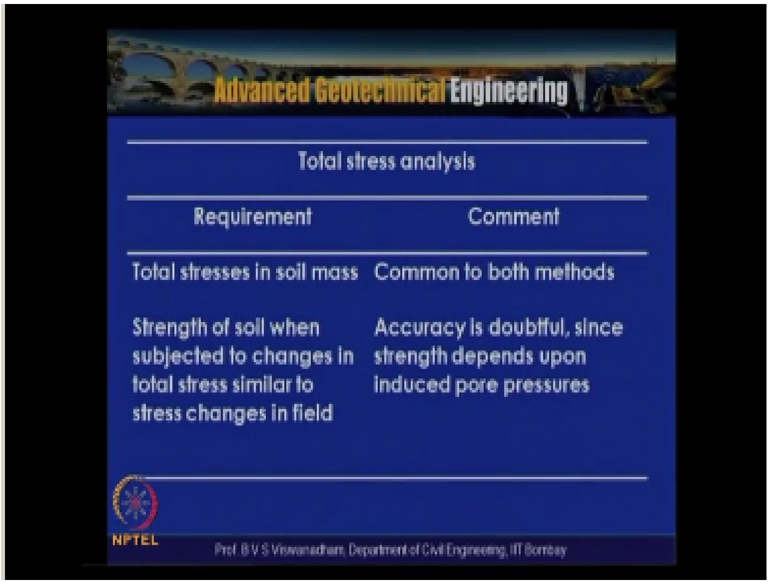

And which is actually common in both the methods but the strength of the soil when subjected to changes in total stress similar to similar to these stress changes in the field the accuracy is doubtful in the standard depends upon the new sort of pore pressures and in the effective stress analysis here also we require total stresses in soil mass.

And common in both the methods that is both the methods in the sense that effective stress and total stress analysis the strength parameters are in relation with the effective stress and the considerable accuracy since there is a insensitive of the test condition and determination of changes in external loads accuracy depends upon the measurement of the pore water pressure in this case

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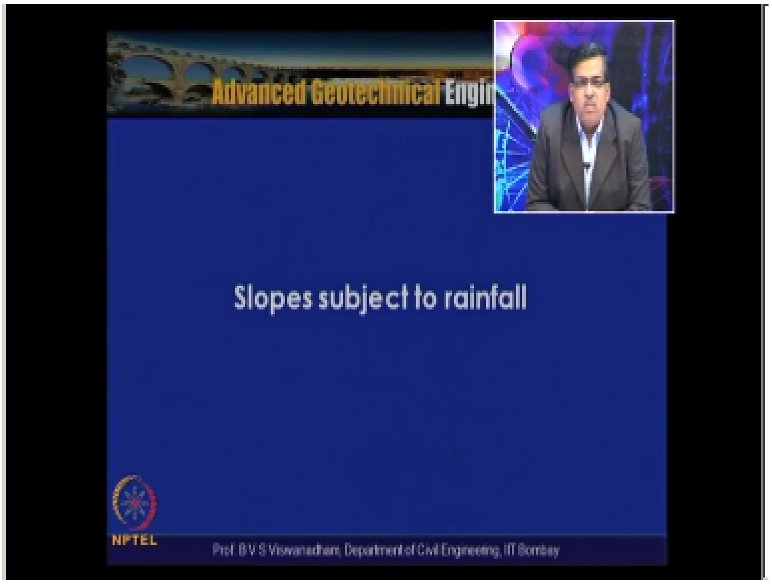

So after having discussed about this particular issue of rapid round in condition and method so what will happen when the slopes particularly the slopes can be as we discussed if they can be natural slopes or can be man-made slopes or if they can be you know some conventional retaining walls or when they are subjected to say rainfall storms what will happen so the rainfall intensity is actually vary from the measured in a.

So many millimeters per day or per hour and if the rainfall intensity with, with certain intensity and is actually subjected to certain duration what will happen to the stability of a slope so this particular discussion is actually we try to present to you with the analysis by a performer through seep/w so the seep/w is a program we which actually a finite element based program in the Geo Studio2012 which allows the simulation of a rainfall of different densities intense as intensities we are with different durations numerically.

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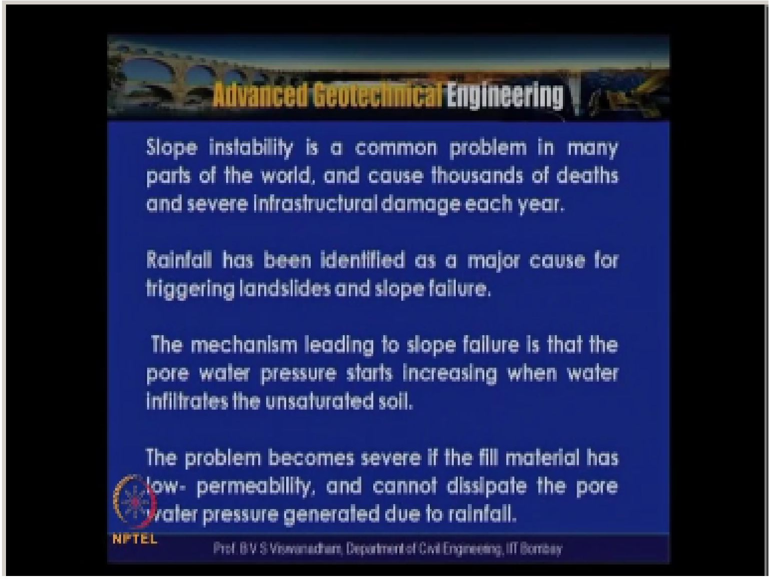

So the slope instability is basically a common problem in many parts of the world causes you know number of casualties and several infrastructural damages each year and the rainfall basically what will happen is that at the onset of the rainfall the suction which is the need to pore water pressure increases and changes into pore water pressure and that results in you know lead to the loss of cohesion and that makes the slopes to fail.

So rainfall has been identified as a major cause for the triggering landslides and slow failure the mechanism leading to the slow ferry is that pore water pressure starts increasing when water infiltrates into the unset aerosol in unsaturated soil with the predominantly the suction we prevail and that gets nullified the problem becomes severe if the fill material has low permeability and cannot dissipate the pore water pressure generated due to rainfall so if the forward if the pore water pressure generated cannot be dissipated and that can lead to as we have seen in previous analysis can lead to the low factor safeties.

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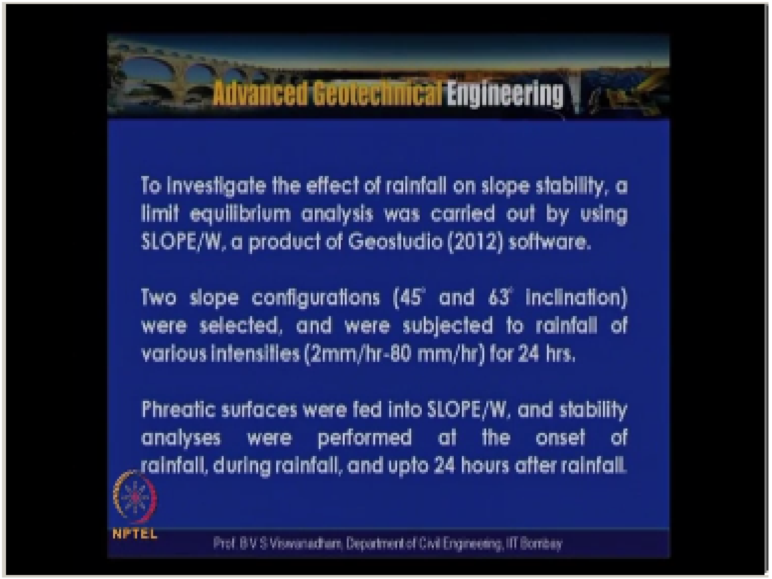

To investigate this effect of rainfall and slope stability a limit of low limit equilibrium analysis was carried out by using slope w a product of geostudio 2012 software the two slope configurations were considered here one is one vertical or horizontal other one purposefully a steep slope inclination of two vertical one horizontal that is 63 degrees slope inclination with horizontal was selected.

And was subjected to rain fall of various intensities like industry ranging from 2 mm per hour to80 mm power over 80 mm per hour is very high intensity and the duration of the rainfall for each intensity of24 hours a day one day the periodic surface were fed into the slope/w and the stability analyses were performed at the onset of rainfall during the rainfall and up to 24 hours of the rainfall so basically this intention is to bring out the effect of rainfall we intend with rainfall intensity and its duration and the stability of a stop.

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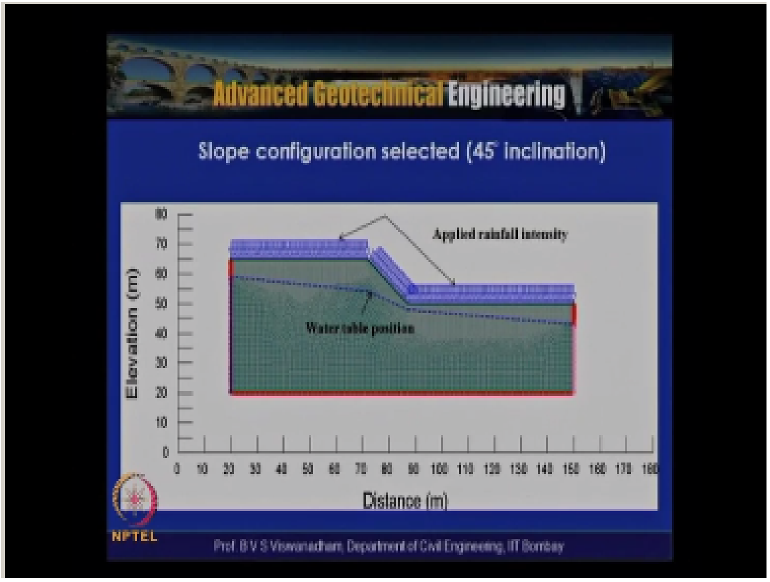

So here in this particular slide a slope configuration is actually shown here wherein we have the horizontal the this particular lines which are actually shown here this is this is nothing but applied the rainfall intensity and this is the initial water table position which is actually observed that means that initially the static water table is actually zoom there and then above that it is assumed that.

That means that the portion here is rumored to be saturated and then here this particular portion is unsaturated and we're in after giving the adequate appropriate soil parameters to this and this analysis is carried out and the parameters which are actually considered in this low W are like this cab computed by bishops modified method of slices and the cohesion is about three point four kilo Pascal's and π is about that one point five degrees.

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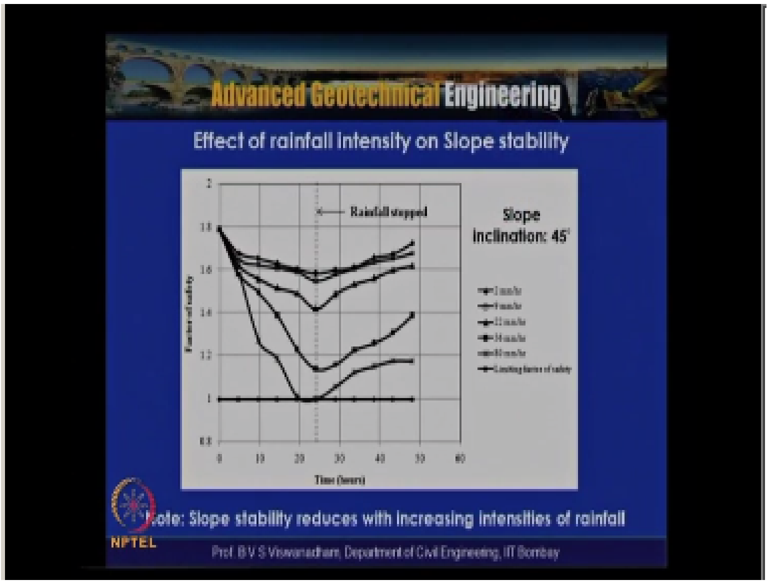

So here in this particular slide it can be seen here the effect of rainfall intensity and slope stability so herewith factor safety is plotted on they-axis and time in hours on x-axis and can be seen here this is the threshold the factor of safety are one is actually Markley here but with for aslope in turn slope the duration of this is actually up till here you know the rainfall is actually you know rainfall which is actually allowed the pitch that he duration of the rainfall is from here to here.

So you can see that for a rainfall intensity of 2 mm per hour on that particular slope having certain configuration you can see that the factors you have to decrease for 1.211.8 to 1.6 but the same slope with the ink the rainfall intensity you can say that let us say that at 36 per mm per hour you can say that the factor of safety at the beginning of the rainfall is say 1.8and at the end of the rainfall it is actually reduced to about 1.1 π also that indicates that.

The criticality of the slope and for a slope with a subjected to a rainfall intensity for 80mm per hour for 24 hours duration as can be seen here and the factor safety touches to 1 that means that the slope actually can be subjected to failure on the wedge job once it is subjected to a particular rainfall intensity for the particular duration so this shows the slope stability reduces with increasing intensity of rainfall.

So these are actually very much important particularly if you are having and but once we after the rainfall let us assume that here what you can say that there once a rainfall is actually is elapsed hen you know you can see that there is an increase in factor of safety that because there is a dissipation of pore water pressure is taking place but what will happen with the slopes which are actually constructed with low permeable soils.

And the dissipation minute is actually not happening so the decrease also will not take place rapidly but even if the decrease actually take place but the increase in factor safety will not result rapidly so that actually determines the vulnerability of a slope to faith so this particular analysis which is actually demonstrated for a particular slope inclination of 45 degrees with the increasing rainfall intensity the factor of safety decreases till the period of rain fall duration so in this case say 24hours rainfall is actually shown.

So with rainfall intensity as high as 80 mm per hour we can see that the factor safety reaches to limiting factor of safety and subsequently if the slope survives the factor safety can increase but that actually proves to be vital for the slope stability and for ensuring slope stability similarly in this next slide what we are seeing is that the slope inclination of 63 degrees suppose if you are having a rainfall intensity on the slope stability for these.

Let us say that in this case we are having say a factor of safety which actually decreases below the limiting value so if you are having a slope which is too vertical one horizontal which is a steeper slope so even with the you know a rainfall intensity of about 22 mm per hour within the rainfall duration itself you can see that the slope is actually subjected to failure that means that you can see herewith the low rainfall intensity there is not much variation.

But we can what we can see is that once the slope actually you know the sloping relation with the city nearly 22 mm per hour you can see there within 10 hours the slope is actually coming to the limiting factor of safety and further with 36 and 80 mm per hour the slope actually reaches with a very you know short durations of rainfall so this in this actually shows that the steeper slopes having have no initial factor of safety and.

And the effect of rainfall on such slope is more devastating as compared to flatter slope that is actually a usual natural conclusion but basically this exercise is actually done to show that how the rainfall intensity is you know severely can affect the stability of a slope particularly when you are actually having you know increase the rainfall intensity even with a slope which is as flat as one vertical one horizontal can be subjected to a failure.

But the slope is actually steeper say nowadays the steeper slopes are common in the urban areas because of you know land availability and you know the land scarcity so in such situations one need to actually adopt appropriate strengthening measures for the slopes and under these are all these conditions one has to ensure that the slope stability is actually ensure so this leads to our topic very you know the measures for the enhancing.

The stability of a slope and in the forthcoming lectures what we do is that we will try to understand about the seismic stability of the slopes and some interaction or a concept discussion on the relevant reliability analysis of the slopes so in this particular lecture we have actually discussed about the especially about the rapid drawdown condition.

And the second thing is that we also have try to understand the effect of rainfall intensity on the slope stability particularly with stone with the range with increasing rainfall intensity we have seen that the slope factor safety decreases and with increase in sloping relation respond to be much more devastating.

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