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ADVANCED GEOTECHNICAL ENGINEERING

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Lecture No. 41

Module – 5

Lecture – 5 on Stability of Slopes

Welcome to lecture no 2 of module 5 stability analysis or slopes in the course advanced geo technical engineering. So the title of this lecture is lecture 2 which is the part of module 5, stability of slopes.

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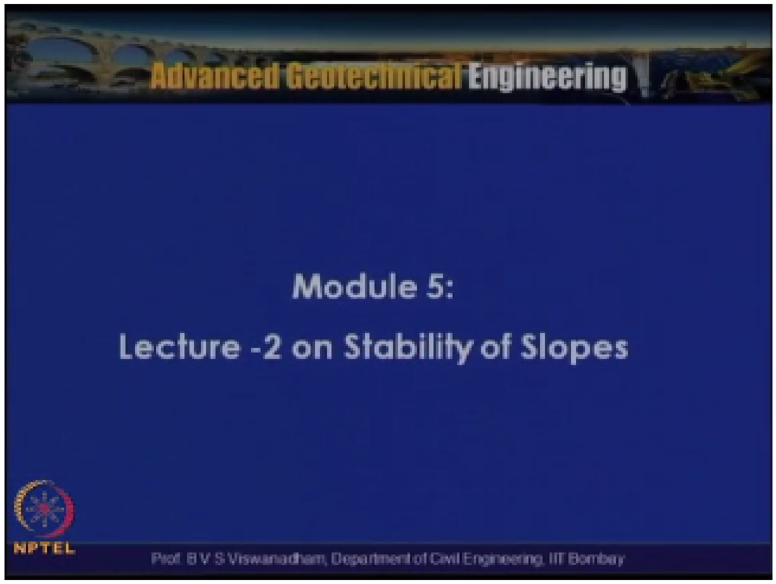

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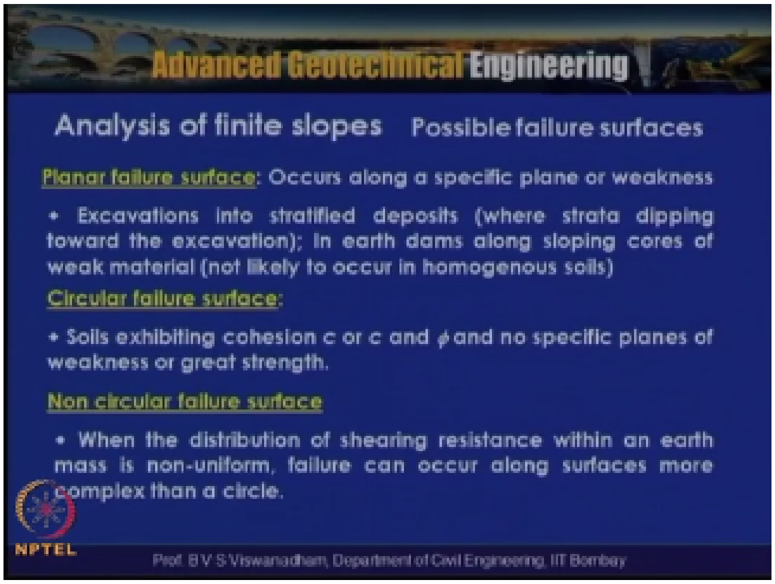

So in the previous lecture we understood about different types of slope failures, and cause it to factors for slope failures and we also discuss about infinite slope stability analysis methods and we have also discuss that two types of slopes predominantly they are infinite slopes and finite slopes then the finite slopes are the one which are manmade slopes to the maximum extent and some hill slopes also can be called as finite slope.

Now when we look in to the analysis of in finite slopes there are different possible failure surfaces the failure surfaces can be planner in nature or if it is a homogeneous soil then there can be possibility that you can get a circular failure surface and if you are having a different stratification of soils there can be possibility that we can get non circular failure surfaces. So in this slide three different failure surfaces are shown one is defined as planar failure surface this occurs along a specific plane or weakness.

So where the potential weak plane will exist and this failure surface occurs along a specific plane or a weak plane of weakness, this basically excavation in to stratify deposits where strata dipping towards the excavation that is the layers of soil dipping towards the excavation and in earth and dams along the sloping cores of weak materials not likely to occur in homogenous soil. So this planar failure surfaces they occur a long specific plane of weakness, and the circular failure surface this is the for soils exhibiting cohesion c or cohesion and friction angle and no specific plane of weakness or great strength.

So this actually takes in the form of a circular failure surface and non circular failure surface when the distribution of shearing resistance within an earth and damp is non uniform and failure can occur along surfaces more complex than a circle. So this is said that non circular failure surface mostly occurs in layer soils.

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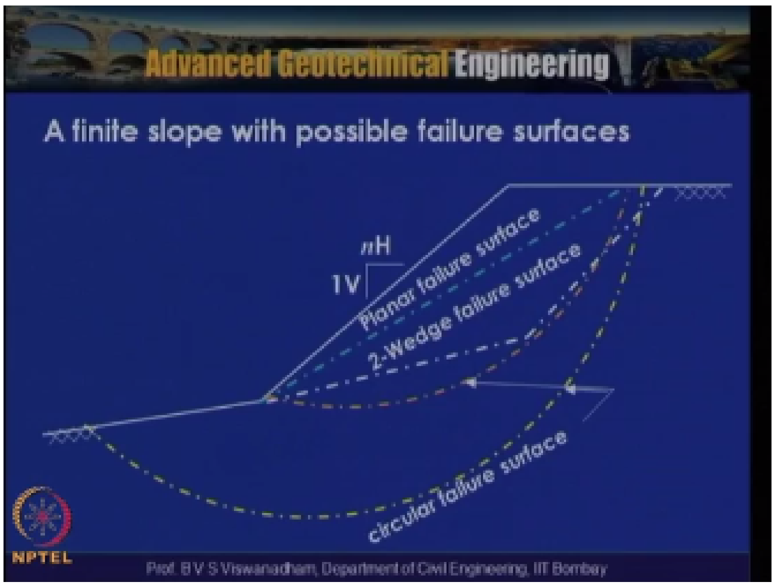

So in the typical cross section of finite slope with one vertical and horizontal where the small n is the number if n = 2 it indicates that the slope is having one vertical to horizontal sloping gill nation, that is about 26 ^{0} with horizontal and if n = 1 that indicates that the slope is actually having a 45^0 sloping inclination with the horizontal. And the horizontal surface indicates that the back slope which is 0^0 but in practice there can be a possibility that the slope can also have a particularly especially for natural slopes nature slopes in nature there can be with natural sloping ill nations of back sloping gill nations ranging from 10 to 20^0 also.

So in this for a cross section of a finite slope a typical planar failure surface is depicted here and then a two wedge type of failures surface like as it is been told in earth and damp suppose a sloping core under the if this happens to the weakness potential weakness plane then the two wedge failure mechanism can come and this is the typical circular failure surface and this is also a circular failure surface where the majority of the failure surface extending in to the a soft soil which is under the say for example beneath this level .

And this is a toe slope failure where it can be seen that the entry and the exits point is from the toe of the slope. So this is called the entry point commitment of the entry point of the failure surface and this is the exits failure surface. So in a given slope there can be number of failure surfaces but one is to determine the failure surface which actually gives the critical factor safety or the least factor safety and that particular failure surface is called as the potential failure surface.

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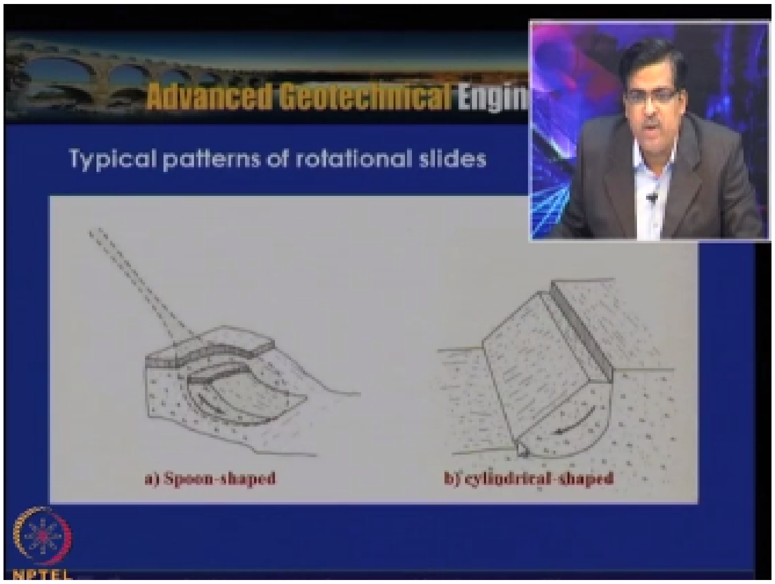

Now in this particular slide there can be typical rotational slides which are shown one is a cylindrical shaped failure surface you can see that his is the circular arch but the failure surface which actually shown is mostly this is common for plane strain structures there can be a settlement at the certain point away from the crust of this slope and a failure surface which actually occurs because of the soil moment which is actually shown here.

And this is a typical rotational slide and which is called as a spoon shaped failure surface, so you can see that the failure mode or a slide which is actually called as a spoon shaped slide.

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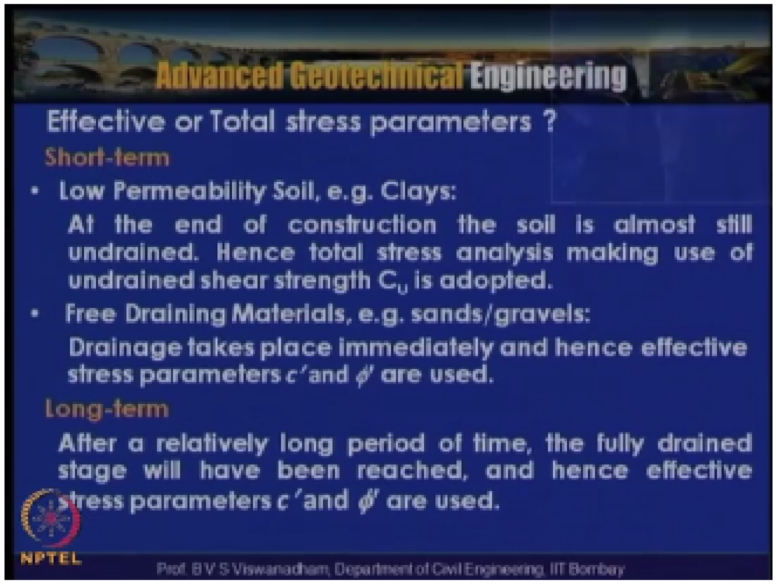

Now we actually yesterday introduced ourselves to that there is a effective or total stress parameters, we knew we know that the total stress parameters maybe can be adopted for the short term conditions and effective stress parameters can be adopted for the long term conditions or getting the long term stability of a slope. Total stress parameters can be obtain for the short term stability assessing the short term stability of a slope.

So the short term basically low permeable soil basically in clays at the end of the construction the soil is almost still undrained. So here the adoption of total stress analysis making use of undrained shear strength Cu is adopted. So at the end of the construction of the soil which is clay is almost still undrained, hence the total stress analysis making use of undrained shear strength is used adopted.

Some free draining materials sand and gravels if you look in to it the drainage takes place immediately hence effective stress parameters c' and φ' are used. Suppose if you have got a free draining materials sands and gravels when the drainage takes place immediately, so there is a need for adopting effective stress parameters that is c' and φ'. Long term relatively after a long period of time let us say that an embankment is constructed in soft soil after having waited for certain duration the fully drained condition might have been a time.

So the fully drain stage we have been reach hence the effective stress parameters c' and φ' can be used. So what we broadly say is that the effective stress parameters are used for long term conditions are also used for you know the assessing the stability of a slope with feed draining materials like sands and gravels, in case if there is a short term condition with low permeability then the adoption of total stress parameters is more relevant.

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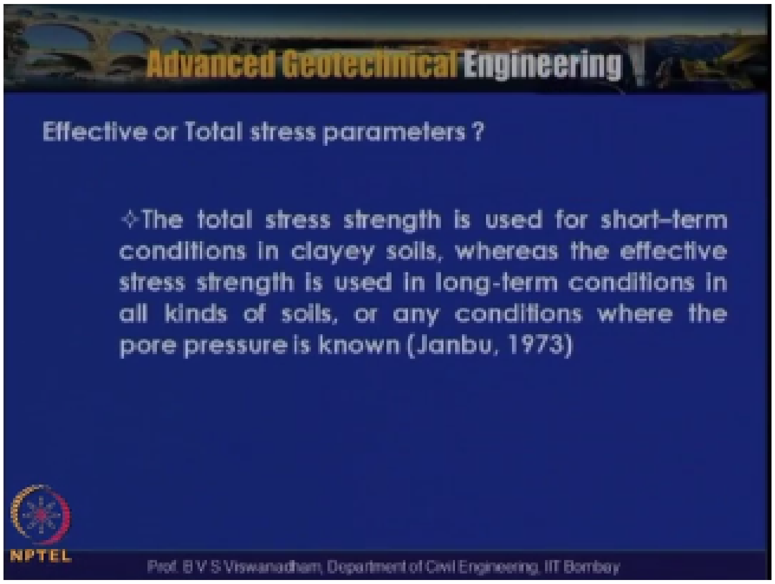

So the total stress strength is used for short term in clayey soils whereas the effective stress strength is used for long terms conditions in all kinds of soils or any condition where the pore pressure is known. So this is after Janbu 1973, Janbu 1973 stated that the total strength is used for short term conditions in clay soils, whereas the effective stress strength is used in long term conditions in all kinds of soils or any conditions where the pore water pressure is known.

So this pore water pressure may result due to ingress of rain water in to the slope that we have discussed one of the causative factors of the slope in stability is rain fall. So because of this once the ingress of grain water is captured in the form of periodic surfaces, we can actually get the pore water pressure having known then we can actually estimate the total stress parameters and then the long term conditions can be used.

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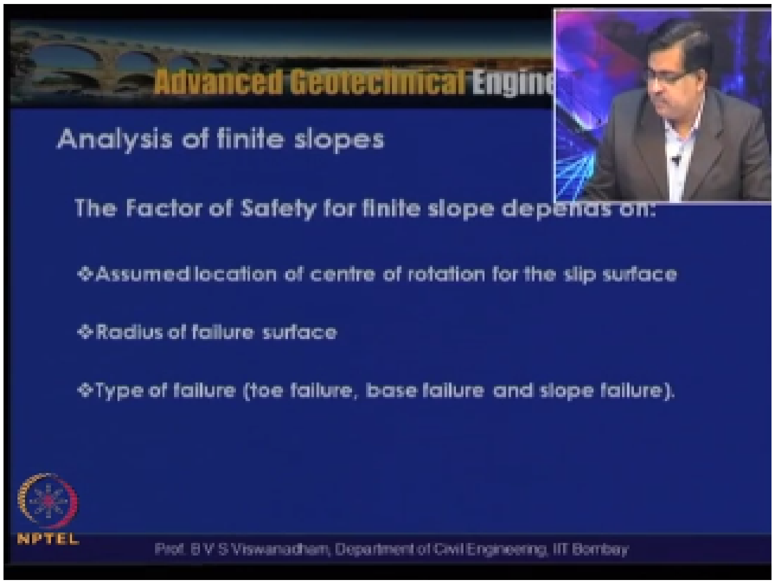

The analysis of the finite slope particularly with factor or safety the factor of safety for finite slopes depends basically on the assumed location of the center of rotation of the slope surface. So as it was shown in the typical failure surface as particularly for a circular arch failure surface wherein it all depends upon the location of center of rotation in suppose if a slope analysis which is done in two dimensions that is basically for a plane strength structure in x and y direction.

The assumed location of the center of rotation for this slip surface and the radius of the failure surface basically what radius it actually exists and type of failure that is toe failure, base failure or slope failure.

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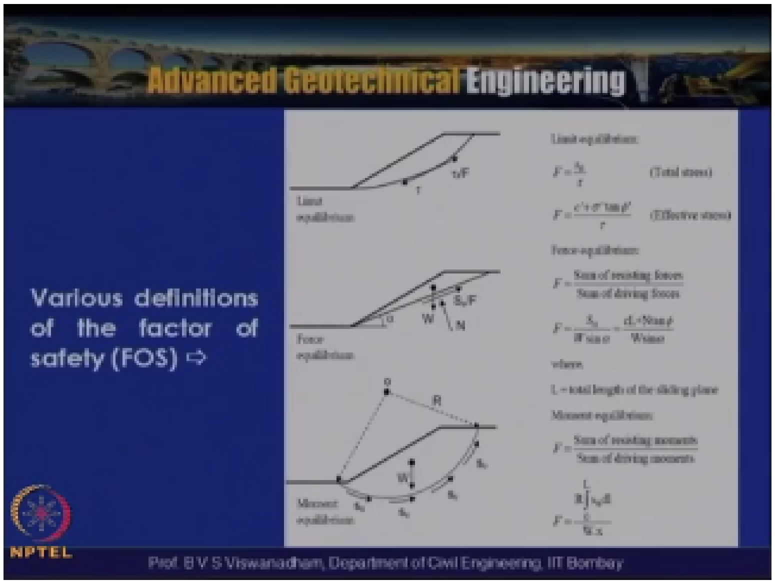

So before attempting the analysis methods let us look in to the various definitions of factor safety here the definitions are given with respect to limit equilibrium point of view force equilibrium point of view and moment equilibrium point of view the top moist figure if you see there is a failure surface which is indicated and there is shear strength which is actually shown and there is a shear stress which is actually shown.

The shear stress is mobilized due to the disturbing forces and shear strength is mobilized to as a resisting force. So as a limit equilibrium condition for total stress we can write factor safety as shear strength available divided by the shear stress. In case of effective stress which can be written as factor of safety is equal to C + σ' tan φ' / the shear stress which is mobilized. As for as the force equilibrium is concerned for a typical wedge failure which is having a planar failure surface extending a unit length perpendicular to the plane of this figure wherein we can actually write the force equilibrium as a factor of safety is equal to sum of resisting forces divided by sum of deriving forces or disturbing forces.

So here if you look in to it the resisting forces are nothing but the resistance offered by the soil that is nothing but the shear strength and driving forces is nothing but the because of the weight of the slices which is actually acting vertically downwards and by resolving this along the potential plane of failure that is the planar failure where which is actually taking place and that component will work out to be w sin of α.

So by writing factor of safety is equal to su / w sin α, so we can write this as cl is nothing but cohesion which is mobilized along the it is assumed that the cohesion is mobilized uniformly and over a length l, l is nothing but the length of the failure surface that is measured from this point to this point in to +n that is n is nothing but the normal force tan φ / w sin α. Where total length of the sliding plane which is actually shown here which is nothing but this is the length of the sliding plane.

Then similarly for a moment equilibrium the factor of safety is defined as resisting moment by driving moment, so here the summation of resisting moments divided by summation of driving moments so when we try to do the, to get the resisting moment by taking the shear strength along this particular arch let us assume that we are having SU1, SE 2, SE 3, SE4, then we say that SU1 x DL 1, SU 2 x DL 2, SE 3 x DL 3 + SE 4 x DL 4 x r that is the this is the force which is acting over this particular length.

We have taken each arch length as DL 1 c 1 unit that is the unit perpendicular to plane of this figure x r will get the force in to moment that is the resisting moment divided by w which is nothing but the entire mass is actually assumed as the CG of this area is assumed to act here and the at the center of gravity here this w x this horizontal distance from the center of rotation that is x.

So that is actually called as wx, so factor of safety is equal to Interviewer: he integration form if you show at r = 0 to l su x dl so this indicates that you know the factor of safety can be define from the force equilibrium point view or limit equilibrium point of view or moment equilibrium point of view.

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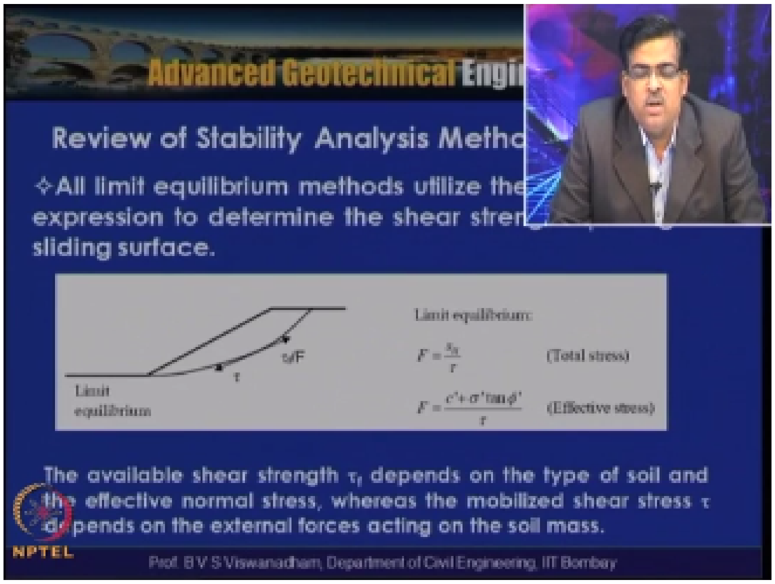

Now let us try to review the different stability analysis method basically all limit equilibrium methods utilize the Mohr- Coulomb expression to determine the shear strength τ f along the sliding surface. So prime of ac the Mohr- Coulomb expression is used to determine the shear strength τ f along the sliding surface and then has we defined in the previous slide the factor of safety is given by su / τ which is for total stress conditions and for effective stress conditions f or Fs= c' + σ' tan φ' / τ.

See basically the available shear strength τ f depends on the type of soil, so if it is say a particular type of soil and the effective and the effective normal stress whereas the mobilized shear stress τ depends upon the external forces acting on the soil mass that is the self weight of the soil which are called geo static conditions and as well as any external loading if it is there on the crust of the slope that also act to the d stabling or disturbing force.

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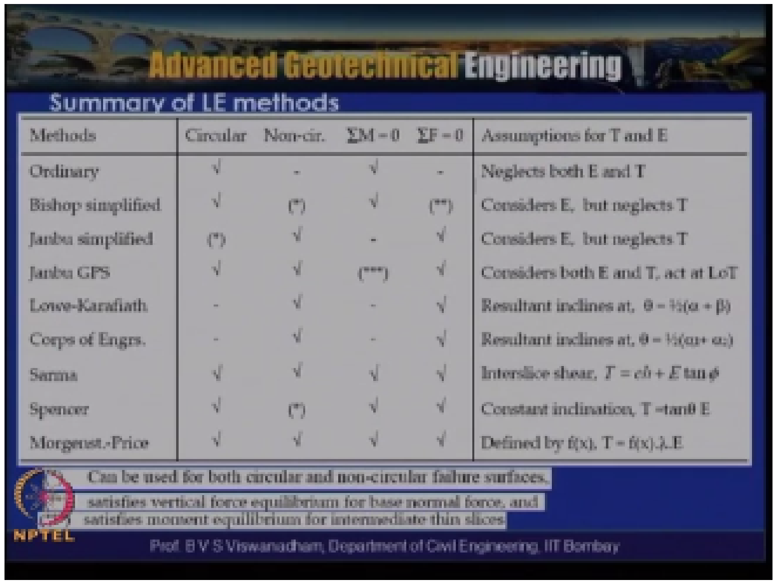

So here different methods are summarized here but we are going to discuss about some selected methods, we have many methods as you can see from this slide the first method is ordinary method of slices and then it is followed by bishop simplified method is there, so in all this methods the zone or area within the failure surface is assumed to be divide in to the number of slices basically vertical slices.

And then the slice equilibrium is considered either from the for the force equilibrium point of view or moment equilibrium point of view and based on that the reductions for the factor of safety is have been obtained, say for example in the case of ordinary method of slices the circular failure surface is assume d and moment equilibrium is consider and in this method the both normal forces acting inter slice forces that means that normal forces acting on the perpendicular to the vertical face of the slide as well as the tangential forces are neglected.

In the case of bishop simplified method it is for circular failure surfaces and whereas moment equilibrium is satisfied but it considers e that is the normal force perpendicular to the vertical surface of the slide but on both sides of the a slice but neglect the tangential forces the tangential forces are assumed to be 0, in the case of Janbu' s method it is mainly predominantly for non circular failure surfaces and this also can be used for circular and non circular failure surfaces, but here this method is basically predominantly on the force equilibrium, so the moment equilibrium is not satisfied the force equilibrium is satisfied.

So it considers the normal forces perpendicular to the slice forces but it again like bishops method neglects the tangential forces that is one of the components of the inter slice forces. Then we have method by Spencer method wherein it considers the t and e with some constant equation where t = a relationship between tangential force and the normal force e which is give as with the constant negation t = tan θ x e and then Morgenst- price method wherein it can be used for both circular and non circular failure surface and it satisfied both moment and force equilibriums and the assumptions for t and e which is defined by a function x.

Where t = function x x a constant δ x e, so if you look in to this the Sarma's method and Morgenst's price method it satisfied both moment equilibrium and force equilibrium methods but the majority of the applications the bishop simplified method is used or to some extent the Janbu's method is also used. So this is the typical section of the unit width is assumed for the analysis as the slope is assumed to be like a plane strain structure.

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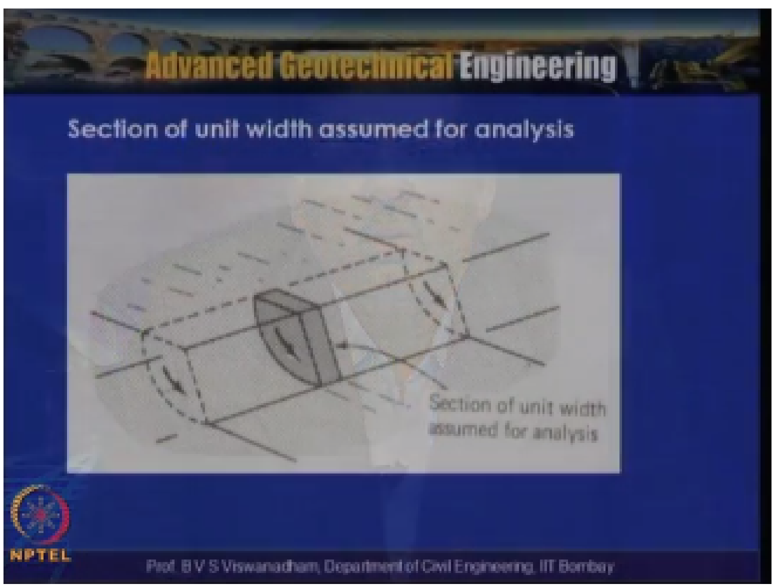

So a unit width is consider for the analysis like a per meter width of the analysis is considered for doing a two dimensional stability analysis. Of course now there are the methods which are actually available or performing the three dimensional slope stability analysis.

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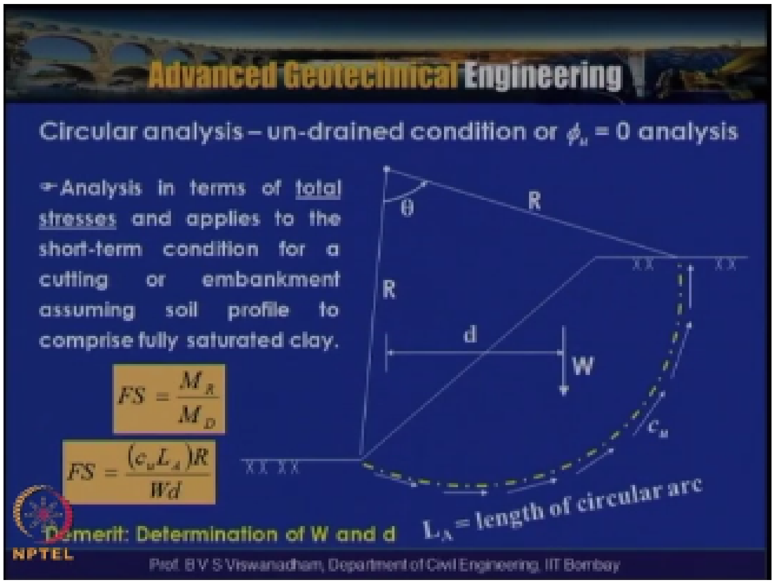

Now before discussing about the ordinary method of slices let us look in to the evolution of different types of method of undrained conditions and drained conditions and then we will introduce for the ordinary method of slices and bishop simplified method and the other method like Morgenst price method. In the case of circular arch analysis for undrained condition or it is also called as π suffix u that is angle of internal friction undrained condition is equal to 0 analysis basically this is for analysis basically performed in terms of total stress analysis and applies to short term condition only for a cutting and embankment assuming the soil profile to come price of fully saturated clay.

And the on the right hand side a cross section of slope or an embankment which is shown here and this is the slope inclination which is you know require to be determine, here what sloping inclination is need to be provided so that the adequate factor of safety need to be ensured that is the point of you know the importance. Now here it is assumed that the potential failure surface which is indicated with thi9s yellow broken line can be seen here and this is the cohesion undrained cohesion is assumed to be mobilized along the failure arch, and w is the cg of this you know the weight of the entire area which is subscribed in this zone a, b, c, d, in this zone.

So this requires determination of the, you know area of this portion and then by knowing the area in to the one meter length perpendicular to plane of this figure we can calculate by knowing also the unit weight of the soil for used for embankment or unit weight of soil in the cutting, we can determine what is the weight and with respect to the moment of rotation which is considered we can also determine what is the you know the horizontal distance from the center of the rotation horizontal distance that is d is nothing but the distance from the cg of the area where the weight w is acting to the center of rotation.

So for this by taking mount equilibrium where by taking moment about all the moment of all resisting forces about the center of rotation to moment of the driving forces about the center of rotation, so here there is no this w is because of the self weight of the soil so factor of safety is equal to mr / md where mr is nothing but cu x la, la is nothing but the length of the entire arch in to that r cu la x r si nothing but the resisting moment divided by w d, wd is nothing but the driving moment or disturbing moment.

So here one of the disadvantages of this method of is that abrasive in which with which actually you determine the weight w, or area and the determination of d which is actually involve.

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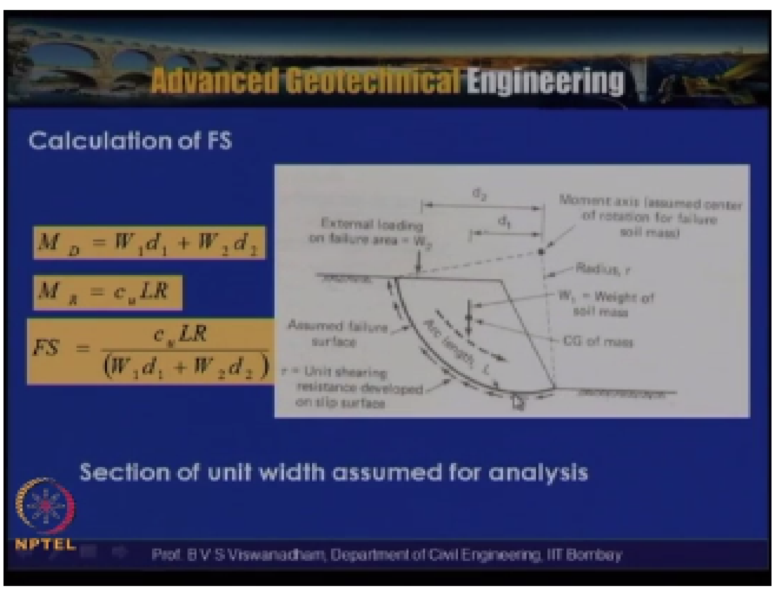

So by calculation of factor safety if you are having let us say an external load on the within the failure job if the external load which is either due to distributed load or due to if it there is a distributed load then one need to consider the you know the if this is identified as the potential failure surface then in this zone the load is distributed over this length in to the length which is perpendicular and that the cg of that load is actually located, but in this case let us assume that there is a boundary wall which is located at a certain distance where when we consider about this intensity of the load we can actually now take the disturbing moment is nothing but w2 x d 2 w1 that is due to the self factor soil x d1 okay.

So resisting moment is nothing but still the cu x l x r so the factor safety in this case is nothing but cu lr / within brackets w1 d1 + w2d2, now from the undrained analysis Taylor 1948 as developed a method wherein the potential failure surface is given so that the least factor safety can be determine. So this development is sourced from the undrained analysis which we are discussed just now.

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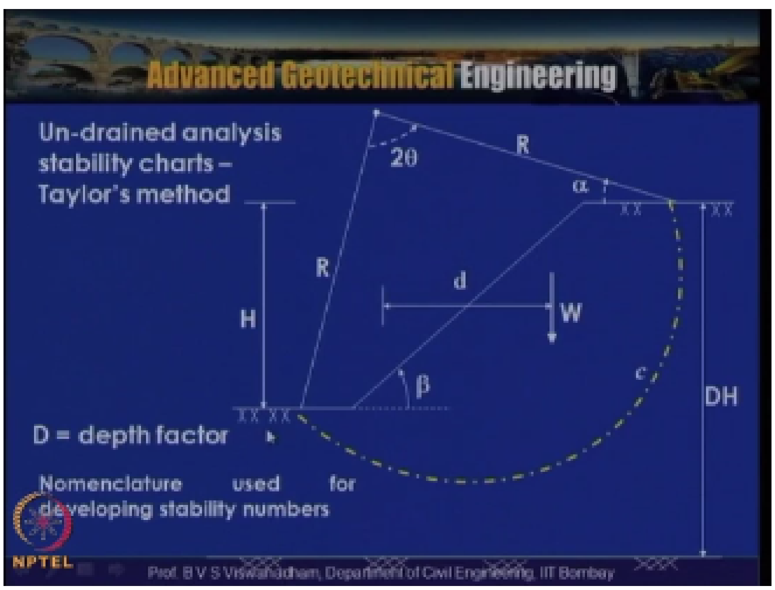

Wherein here it is actually consider that this entire the soil portion below this depth is consider as d and then this height is say h and here this is the sloping inclination which is β and β = 90^0 means it is a vertical cut and this inclination is 2 θ and this inclination with horizontally is α. And this is the cohesion which is actually mobilized and this is the weight and then this is the d from which is horizontal distance measured from this eg of the weight from the weight of this entire portion from the center of rotation.

So d is nothing but the depth factor what we call which is the normal clays are used for developing the stability charts.

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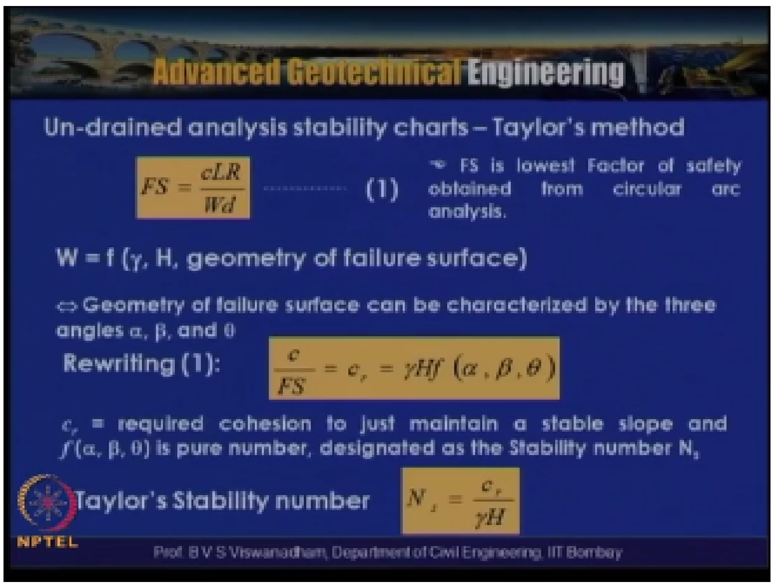

Wherein here the factor of safety we know that we have just discuss in the previous slide where factor of safety is equal to clr / wd where factor of safety is the lowest factor of safety obtain from the circular arch analysis and the factor of safety are the self weight of the area or portion involved in the failure which is the active zone what it is called is function of γ and h and geometry of the failure surface is geometry of failure surface can be characterize by three angles α, β, θ.

So what it has been taken is that the by rearranging the terms here c / factor of safety is return and which is return as cr= γ h x function of α, β, θ, cr is nothing but the required cohesion of a soil just to maintain a stable slope and function of α, β, θ is a pure number and basically that is actually designated as a stability number, so the Taylor stability number is actually given by stability number is equal to cr/ γ h so c r is nothing but required cohesion to just maintain a stable slope otherwise it can also be written as c / γ h / fs x c r even you substitute for c / f s we can write by c / f s x γ h.

So for factor safety is equal to one it actually induces that ns = c / γ h, so the required cohesion c r is nothing but the required cohesion to just maintain a stable slope, so here the particularly the with reference to the angles α, β, θ, what has been done is that the weight portion which is actually consider there that is weight which is subscribe as the function of γ h and geometry of failure surface or consider in the form here as I to represent the geometry of the failure surface.

So based on that deliberation the Taylor actually has given stability charts which are known as popularly known as Taylors curves wherein on the x axis we have sloping gill nation.

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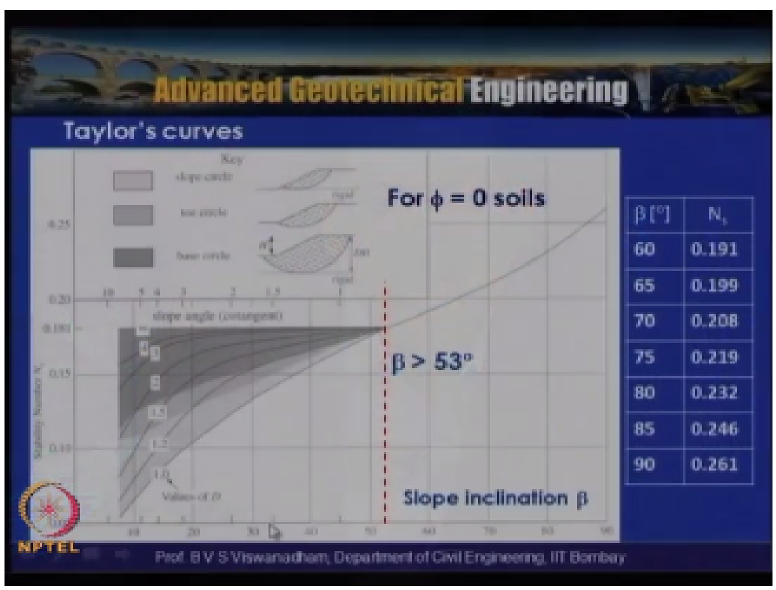

It ranges from 0^0 to $90^0$and on the y axis it is the stability number that is ns = c / γ h so here it can be seen that one up to β = < 53^0 it is actually depending upon the d which is nothing but this failure surface is assume to pass through below the base but when the β > 53 it is found to independent of d so it is only depend upon the sloping inclination which is when it is more than 53^0.

So it can be seen there for more than this it is the constant the stability number will be constant, so here this is used for φ u = 0 and mostly for undrained conditions this is use.

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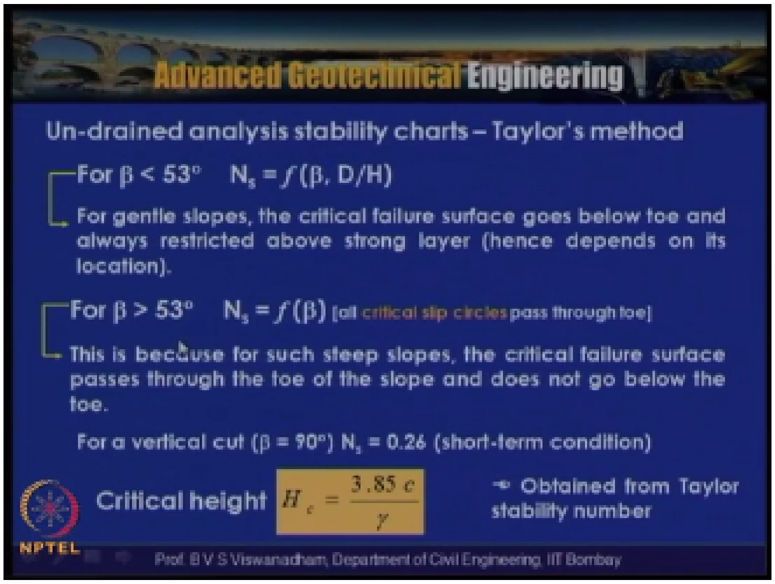

Now the undrained analysis of the by using this Taylor method basically for $\beta < 53^0$ as we discussed in the previous slide the stability number is a function of β and d / h so that means that there can be a possibility of the base failure for gentle slopes the critical failures surface goes below the toe and always restricted above the strong layer hence this depends upon the its location.

For $\beta > 53^0$ when the sloping inclination is greater than 53^0 the stability number is only function of sloping inclination that is β all critical surface is pass through the toe. So this is basically because the for such deep slopes the critical failures surface pass the toe the slope and does not go below the toe. Let use assume the say for vertical cut β = 900 ns = 0.26 from the short term condition so it can be seen here for $\beta = 90^0$ the ns value is about 0.26.

So when we calculate back when by substituting this particular expression wherein the critical height which nothing but where the factor safety is equal to one the critical height is defined as a height at which the factor safety attending to one by doing this we can actually get hc as 3.85c / γ, and this is actually obtained from the Taylors stability number. Whereas one performs to the conventional analysis by using at pressure theory it is can be obtained as hc = 4c / γ.

Which is nothing but by considering the earth pressure equation like σ a = k a γ h – 2c √ ka and wherein if you consider both negative pressures that is the depth of the tension crack that is where the negative pressure is adjusting and equal and portion below the this particular zone and when you take the equilibrium that we can actually get the 4c / γ that is nothing but the critical height or the critical height of a vertical cut which is called. And this is the height at which by attaining this height the soils suppose to fail.

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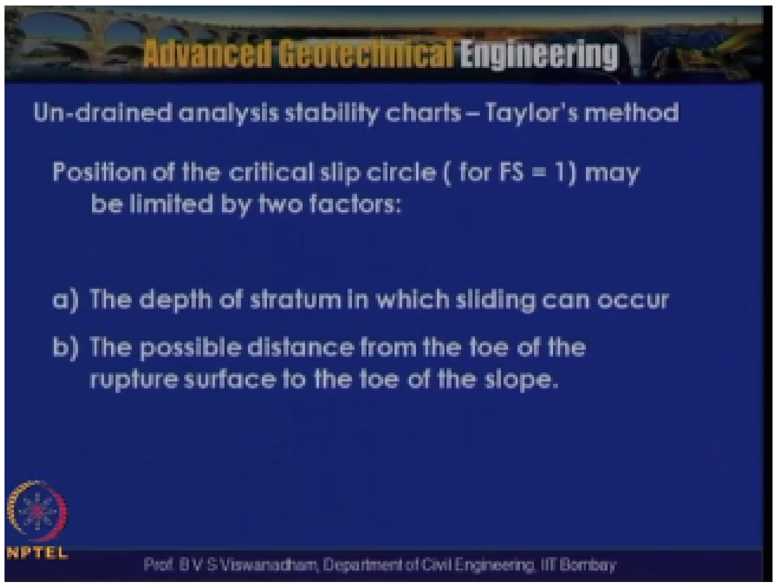

So undrained analysis stability charts given by Taylor method the position of the critical surface maybe limited by 2 factors one is the depth of the stratum in which the sliding can occur and the possible distance from the toe of the rapture surface of the toe of the slope. So the possible distance from the toe of the failure surface from the toe of the slope that is nothing but from the Taylor actually has given chart.

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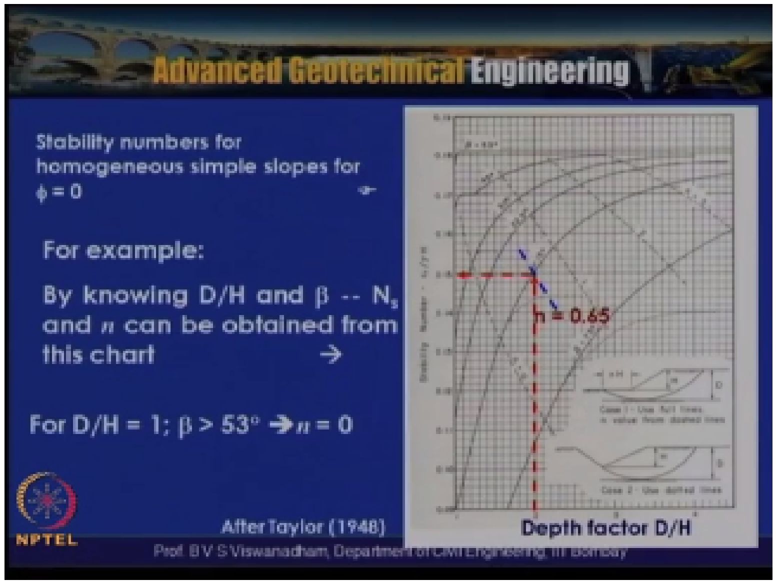

For determining this particular value n nh in terms of nh it has been given like this is you know the distance in terms of n multiplied by h h is nothing but he slope height and this is the failure surface which is obtain for slope which are actually less than 53^0 also. So the stability number s for homogenous slopes for φ = 0 say for example by knowing d/ h that is the depth factor and β the ns and n can be obtain from this chart.

So here n is nothing but by knowing this we can see that where it actually cuts and that is the n and then by taking this horizontal projection how to on to the stability number we can get the stability number ns. So for d/ h = 1 that is d / h = one β>530 the n = 0 that means that the slope actually the failure surface passes through the toe of the slope.

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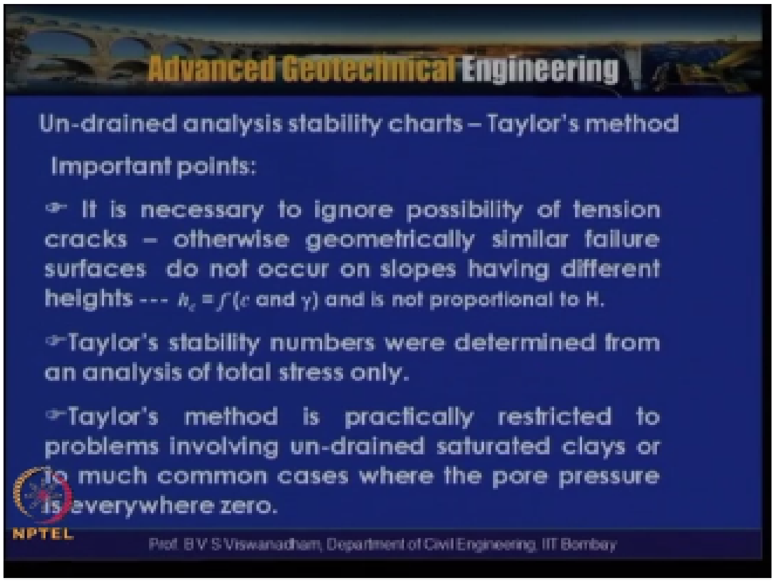

So and some more important points as for the Taylors method is concerned they are actually summarized in this slide it is necessary to know the possibility of the tension cracks otherwise geometrically similar failure surface do not occur on slopes having different heights, so the possibility of the tension cracks is ignored here and Taylor stability number for determine from the analysis of total stress condition only that is basically for undrained or short term conditions only.

And total Taylors method is practically redistricted to problem solving undrained saturated clays or too much common cases where the pore pressures is everywhere 0. That means that the pore water pressures are everywhere 0.

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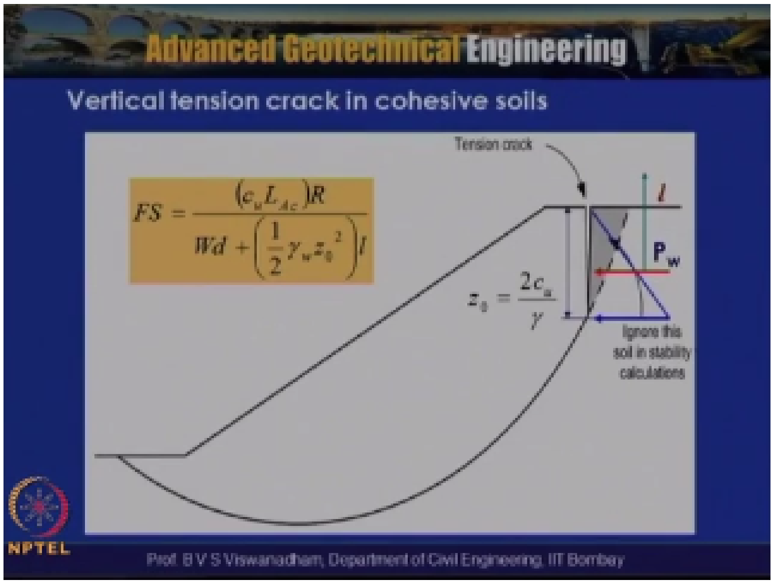

In case if you are actually getting a tension crack let us assume that the tension crack which is can be determine let us say from the by suing the earth pressure fundamentals where σ a is = k γ h – k γ z – 2c √ ka when for a clay soil when φ = 0 we can say that c = cu and k = 1 and at point where the pressure tends to become 0 you can say that z0 = 2c u / γ that is nothing but the depth of the tension crack.

Now when we consider the tension crack and let us assume that if the tension crack is filled with water and it can actually cause a d stabilizing force and the portion within this tension crack zone that is the circular arch which is actually passing beyond this point is not considered in the analysis that means that in the factor safety determine by this particular method is nothing but cu x l ac from her to here that is the length of this arch x to the radius divide by w x d + ½ γ w z0 ^{2} that is this force in to the laver on that is say l.

The l is nothing but from this distance to the vertical distance from this horizontal vertical distance l is nothing but the vertical distance measured from the center of rotation to the location of the horizontal force pw. So like this when we have the tension crack this as need to accounted, now let us look in to the ordinary method of slices in this method the potential failure surface is assumed to be circular arch.

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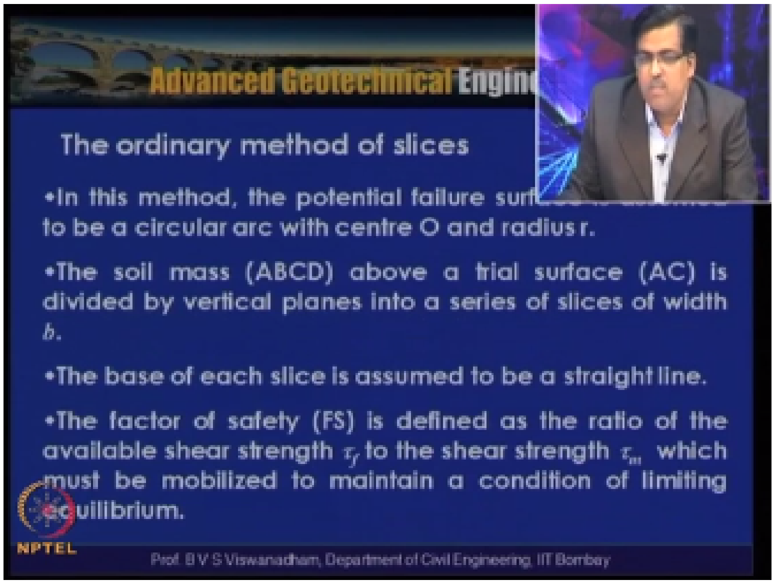

With center o and radius r the soil mass basically, the soil mass a b c d above a trail surface ac is divided by vertical plane in to a series of slices as we have discuss with that one of the limitations of the undrained slope stability analysis with φ = 0 analysis is that determination of area and then you know determination of the weight and then d. so here what has been done is that the portion within the you know soil mass a b cd which is undergoing failure surface it divided in two number of slices.

The number of slices it depends upon the by convenience it is actually divided and the slices are divided such a way that they have some uniform horizontal distance not necessarily uniform but mostly the uniform horizontal distance and the base of each slice is assumed to be straight line and so the circular arch is assumed to be as a straight line and factor safety is defined as the ratio of the available shear strength to the shear strength τm which must be mobilized to maintain the condition of limiting equilibrium.

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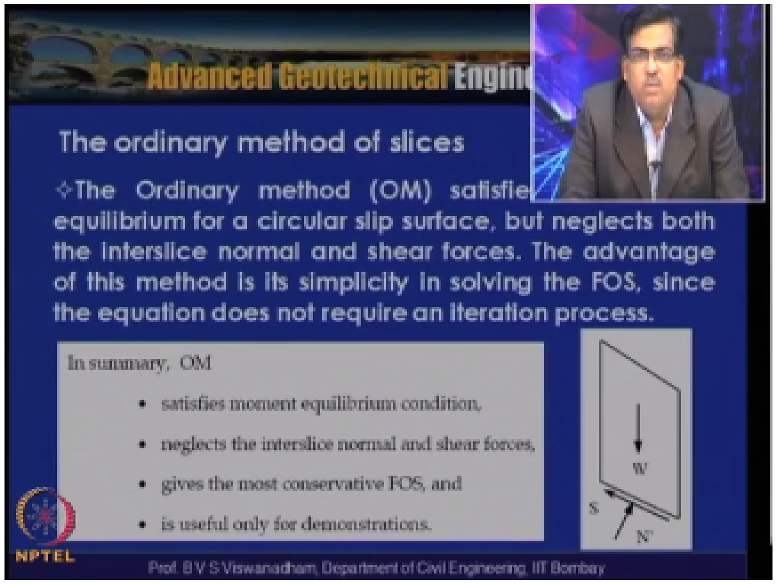

So here what actually we can say is that the ordinary method of slices satisfies the moment equilibrium for circular surface but neglects the inter slice normal that is here the normal forces on this slices and tangential forces, so this is a typical slice so the free body diagram of a slice in case of a ordinary method of slices where there is a vertical force which is shown that is this is w is the weight of the particular slice, if there are n number of slices and if this is the I^{th} number of slice then the weight of I^{th} slice is w.

I and this is the resisting force that is s and this is the normal force that is n', so it is satisfies moment equilibrium condition and neglects inter slice normal and shear forces normal and shear forces, shear forces in this direction one acting downward one acting upwards and gives the most conservative factor safety. So this gives the most conservative factor safety basically useful for demonstration.

So ordinary method of slices the moment equilibrium for slip surface but neglects both inter slice and normal shear forces the advantage of this method if you look in to it is simple in solving the factor of safety. Since the equation does not require any iteration process.

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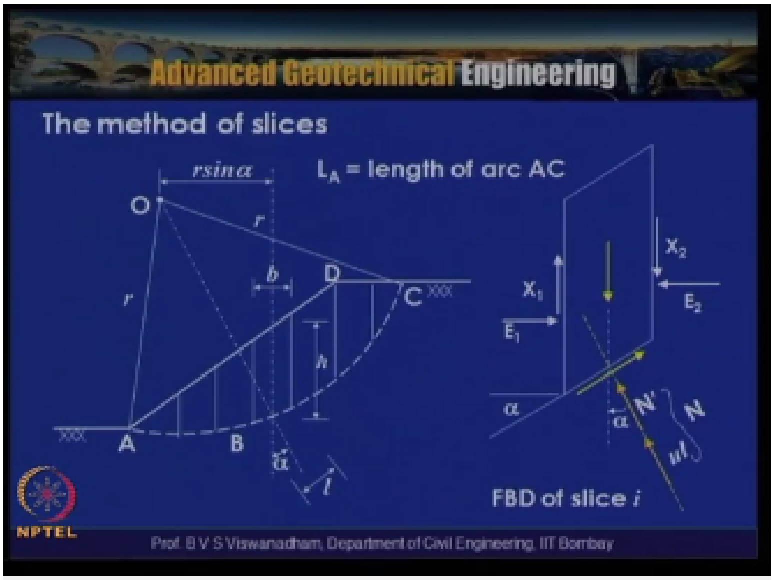

So this is described in the form of a figure which is actually shown here, where this is a typical slope and this is a b c this is the failure surface which is assumed to be a one of the potential failure surfaces there can be in numerable number of failure surfaces and but a b c d in this particular case is assumed as a a b c is assumed as a failure surface and d is the point of the crust and o is the center of rotation and r is the radius of rotation and if you divide this slices of certain horizontal length let us say is b and if you consider the free body diagram of this particular this thing and it actually has the normal forces E1 and E2 both are different and x1 and x2 the shear forces when we consider when you do not consider this forces then ee – e2 = 0 x1 – x2 = 0.

And then here e1 = 0 and e2 = 0 x1 = 0 and x2= 0 and this is the you know from the vertical this is the weight is actually assumed to be weight of each slices is assumed to be act at the center of this slice of width b horizontal distance and the arch is assumed to be as a straight line here and this is the tangential force and n' is acting on the base of the slice and ul is actually acting a pore water pressure acting on the base of the slice.

So this is n' ul which actually gives this normal force and this angle which is subtended from the this n' directly extends to the center of the rotation that means you can see here and this angle is called as the α. So as we travels from this side to this side the angel α changes that can be noted from here.

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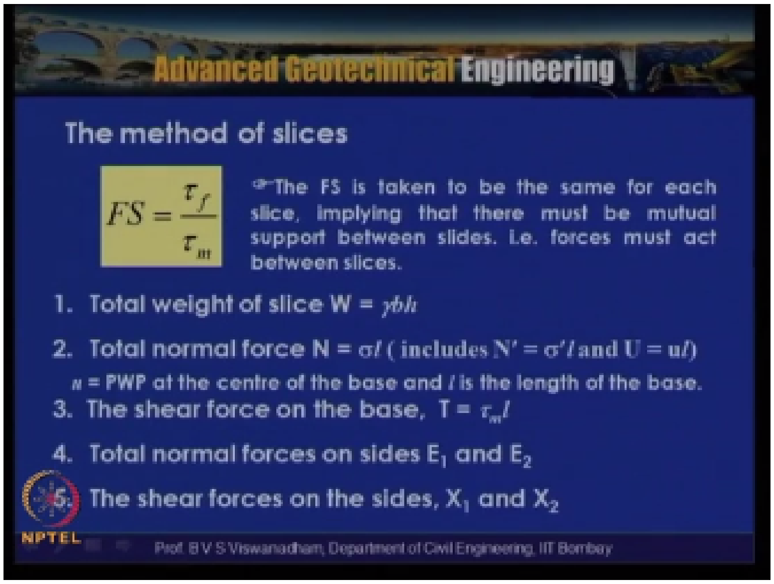

So the method of slice from the limit equilibrium conditions point of view it can be given as factor of safety as τ f / τ m the factor of safety is taken to be the same for each slice implying that there must be mutual support between the slides and force must act between the slices and the total weight of the slice w = γ bh, so if you consider this slice of width b and the height is actually measured at the center that is this height which is actually regarded as the height of the slice, this is the height of the slices at the center where weight is actually acting.

And then the weight is equal to γ x b x h and if so let us assume that in determination of this we are having in a given slice there are three layers of soils then we have to take γ 1 h1 γ2 h2 γ3 h3 x b the b is nothing but the width of the slice. The total normal force n = σ x l σ is the normal stress acting over the length l in to perpetrated to plane of that figure what we consider is one meter so it is the force is nothing but σ x l x 1.

So this includes n' = σ' l and u = ul and u is the pore water pressure at the center of the base and l is the length of the base, and the sheer force on the base is nothing but t = τ m x l the l is the length along the failure surface in a given slice of having width b the total normal force on slice e1 and e2 and the shear forces on the slides x1 and x2.

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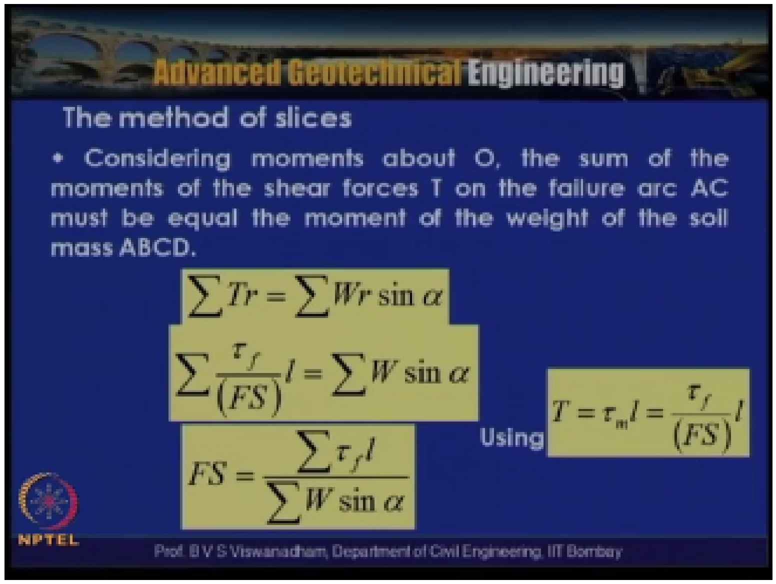

So the method of slices considering the moment about o the sum of the moment of the shear force t on the failure arc ac must be equal to the moment of the weight of the soil mass a b c d. so this we can write as σ t x r = σ wr sin α, so by writing by using t = τ m x l = τ m = τ f / factor safety x l and we can write σ tr as σ τ f / factor safety dl = σ w sin α, so factor safety is given by rearranging this turns we can write factor safety is equal to τ f x l / σ that is nothing but the resisting portion divided by the driving that is disturbing one w sin α. So factor safety is nothing but σ τ f x l / σ w w sin α this is from the limit equilibrium conditions.

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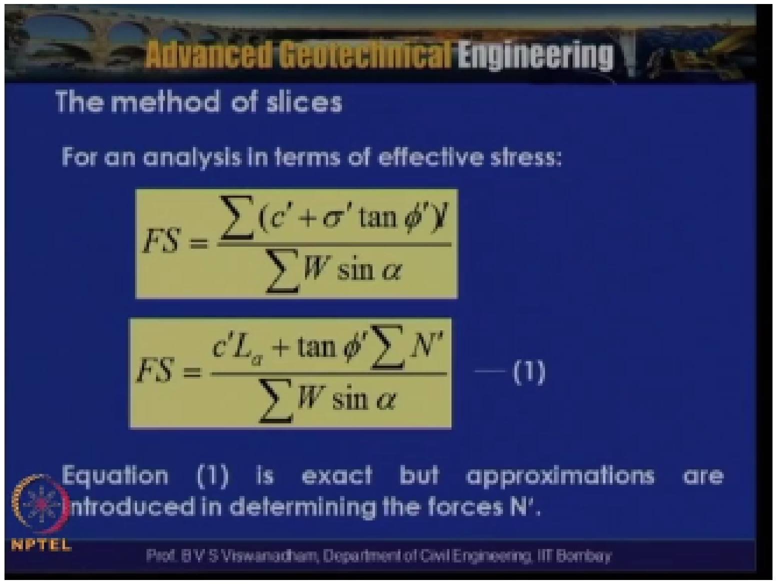

For an analysis in terms of effective stress we can write factor safety is equal to σ c + σ’ tan φ x l so by writing σ’ x l as n’ we can write c’ x la + tan φ’ x σ n’ / w sin α, so equation one is exact but approximations are introduce in determining the forces n’. so in factor safety is equal to c’ x la + tan φ’ in case if you are having a cohesion less soil slope then we get factor safety is nothing but when c’ is going to 0 the first terms will get cancelled and where we have tan φ’ x σ’ n’ / w sin α.

So this can be used for both undrained this short term stability as well as for the long term stability by substituting the relevant characteristics and parameters.

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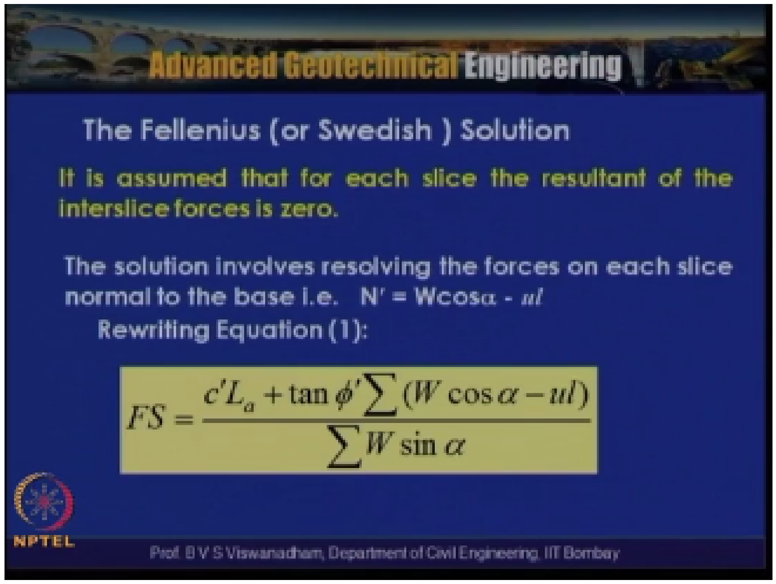

The Fellenius or Swedish solution is actually given it is assumed that for each slice the resultant of the inter slice forces is 0 and the solution are involves resolving the forces on each slice normal to the base where we give $n' = w \cos \alpha - u \alpha$ and this is actually given by rewriting the equation one which is shown in the previous slide as this particular one c’ l a + tan φ' x σ' n’ where n which is actually re written this equation in terms of so this is nothing but c’ la + tan φ' x σ w cos α – ul / w sin α.

So this expression is actually or this with this modification this is called as the fellenius or Swedish method of slices, both are ordinary method of slices and fellenius method of slice one on the same but this is the minor difference which is actually there c’ x la + tan φ' x σ of w cos α – un w / w sin α which is summation.

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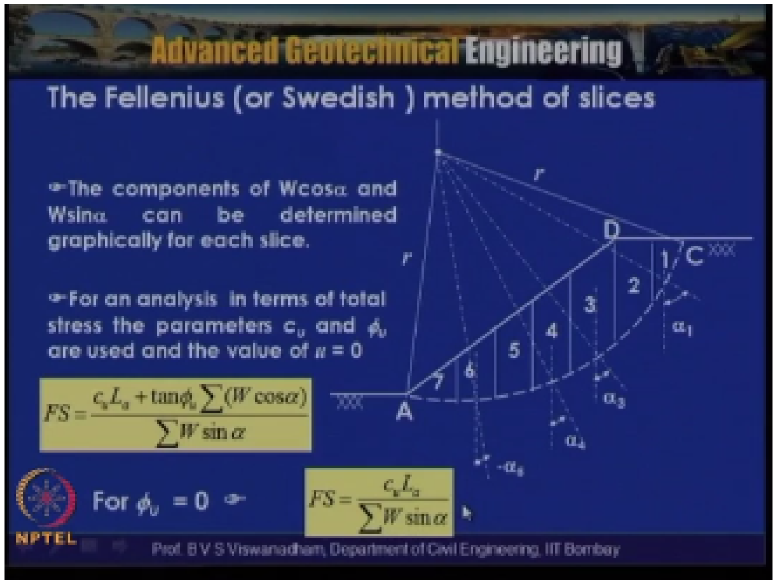

So the how we can actually do the analysis by using the fellenius method of slices means in a given portion we need to assume the potential failure surface and then divide this slices of the horizontal width and then number the slices like the numbering is done from one order 1 2 3 4 5 6 and with a given center of rotation and for a given potential surface this is the entry point and this is the exit point and wherein from the each center of the slice is actually identified and the angles α1, α2, α3, α4, α5, α6, α7 are determine, so for an analysis in terms of total stress the parameters cu and φ u can be used and the expression will be like this and for a φ u = 0 analysis which is nothing but factor safety nothing but cu la / w sin α.

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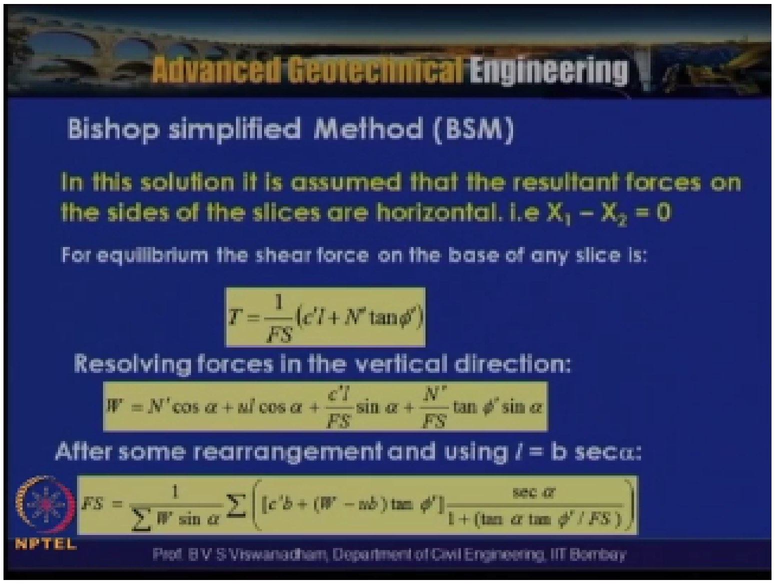

So this particular Swedish method of slices was extended by bishop in this solution basically assumed that the result in forces on the slides of slices are horizontal where x1 – x2 = 0 is considered. So the result in forces on the sides of the slices are horizontal and assumed that this x1 – x2 = 0, by with this assumption the equilibrium of the shear force on the base of any slice is given as t = 1 / factor safety x c’ x l + n’ tan φ’.

So resolving the forces in vertical direction we can get w = n’ cos α + ul cos α + c’ x l sin α / factor safety + n’ tan φ’ sin α / factor safety after some rearrangement and using l = b seek and α because that inclination is α, and horizontal distance is b, l is the length along the straight line length along the slice. So by simplifying we get the factor of safety expression as 1 / σ od w sin α in a summation c’ b + w n- ub within brackets tan φ’ x sec α / 1 + tan α tan φ’ / factor of safety.

So this expression wherein you can notice that the factor of safety is exist in the both the methods, so the generally how it is done is that this is done by iteration methods and the factor of safety which is obtained by performing and couple of iterations will eel to a factor safety. So for this here what it is done is that the factor safety is determine first primarily by Swedish method of slices and that is used as a initial value and then the number of iterations are specified or performed based on the logic which is actually set in the software which is actually used for determining this or manually with a couple of iterations it can be determine by using this expression. In Bishop 1955 it is simplified method of slices.

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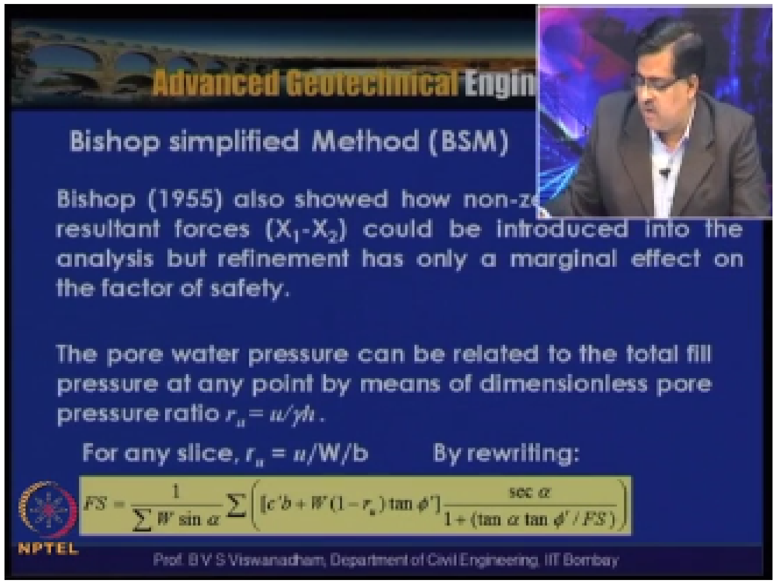

He showed that how non 0 values of the resultant X1 – X2 could be introduced in to the analysis but refinement has only a marginal effect on the factor safety. So the pore water pressure also can be related to total fill pressure where it is given as the pore water pressure cohesion which is nothing but u / γ h u is nothing but the pore water pressure at any point divided by γ h the h is the let us say the height of the slice.

So it is pore water pressure is define in terms of a total fill pressure at any point by means of dimensional as pore water pressure ratio which is called as ru when ru = 0.5 it is set that the slope is completely saturated and for any slice ru = u / w / b by rewriting this one in the previous equation what we have given we can write or express factor safety as 1/ σ w sin α x σ c' b + w x 1 – ru tan φ' x sec α 1 + tan α x tan φ / factor safety.

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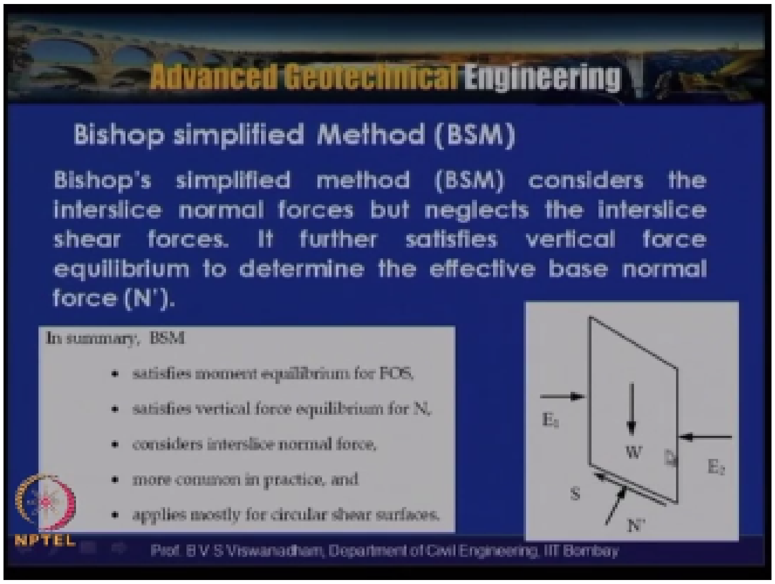

So in the Bishop simplified method as is actually shown here is satisfies the equilibrium of the factor of safety and satisfaction the vertical force equilibrium for vertical force equilibrium for n and moment equilibrium for factor of safety by determining factor safety the moment equilibrium is satisfied and vertical force equilibrium is satisfied with respect to n and considers the inter slice forces e1 and e2 and more common in practice applied mostly for circular failure surface.

The salient features are actually given here and this is the typical free body diagram of a slice in case of Bishop simplified method where the weight of the slice and the shear strength which is actually mobilized along the failure surface n' is the normal force acting on the failure surface normal to the failure surface and e1 and e2 are the inter lice forces on a particular slice force. So the Bishop simplified method consider the inter slice normal forces but neglects the inter slice shear forces it further satisfied the vertical force equilibrium to determine the effect to base normal force n', and further we also said that the Janbu simplified method.

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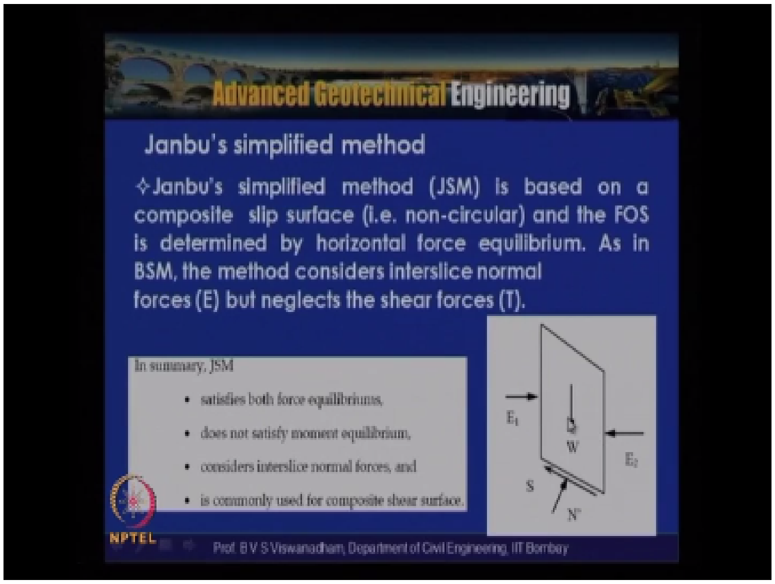

Is basically based on a composite slip surface and the factors are determined by the horizontal force equilibrium basically here both horizontal and vertical force equilibriums are satisfied and it does not satisfy the moment equilibrium, Janbu simplified method does not satisfy the moment equilibrium, and considers the interstice forces E1 E2 like bishop only and it is commonly used for composite shear surfaces.

So basically for laid soils or state fade soils are when you are having the non homogeneous soils is the Janbu method further it is used and basically it is used for composite slip surface or non circular slip for surfaces and the factor safety is determined by horizontal and moment equilibrium is not satisfied and in this slide the free body diagram of a slice.

Which is actually consider in the Janbu simplified method is shown where in which is actually very similar to simplified method, where in the difference is that it does not satisfy mould equilibrium only the force equilibrium that is vertical and horizontal are satisfied. So in this lecture we try to introduce ourselves to different failure surfaces and we will also look into different types of method.

We have seen the $\pi = 0$ method and tailors stability chart method which is the deduction of from the extension of undrained slope analysis method and from there we also discussed about the ordinary method of slices and failure method of slices and then bishop method which is mostly used for commonly used for circular failure surfaces and for composite slip surfaces or non circular slip surfaces in soil.

The Janbu simplified method is also introduced so in the next lecture what we do is that we will try to look into some examples where in we can actually see how the problems can be solved by using typical calculations with the manual calculations as well as the in this particular we will actual try to see some demonstrate some problems by using some relevant packages for academic purposes.

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