Soil Mechanics/ Geotechnical Engineering I
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Lecture – 57
Stability of Slopes (Contd.)

So, in my previous lecture I will just mentioned how to find out the um factor of safety by based on assume trial slip surface ok. So, we generally assume a trial slip surface and do the analysis and there we can have two options, one undrained analysis and drained analysis total strength analysis as c phi and cs analysis.

They are actually we assume there is a trial surface and then and center and based on that we have a developed the expression for factor of safety which the ratio of resisting moment by disturbing moment from there we get the factor of safety. And we a number of trials slip surface we assume and finally, find out where the factor of safety is minimum. So, when the factor safety become minimum then we considered that is a most potential failure surface and based on that we a come and that is a factor of safety for that particular slope.

And in that major thing is you have to assume slip surface and at the same time you have to assume a center. So, that is a most important part in the analysis and finding out center is a difficult task actually and. In fact, these are the methods older method we use before. Nowadays, I will show you the method for what we use they do not use this method there are some other technique numerical technique which we will come later on.

But for the time being we are discussing this how this is developed slowly progressed for that purpose only we are saying those. So, if I want to do analysis by assume slip surface then you have to find out the center. So, how to find out the center that is there are number of methods though whether you use or not now. So, I will just explain that is how to find out the center.

So, let us see this one you can see the center of the most critical circle can only be.

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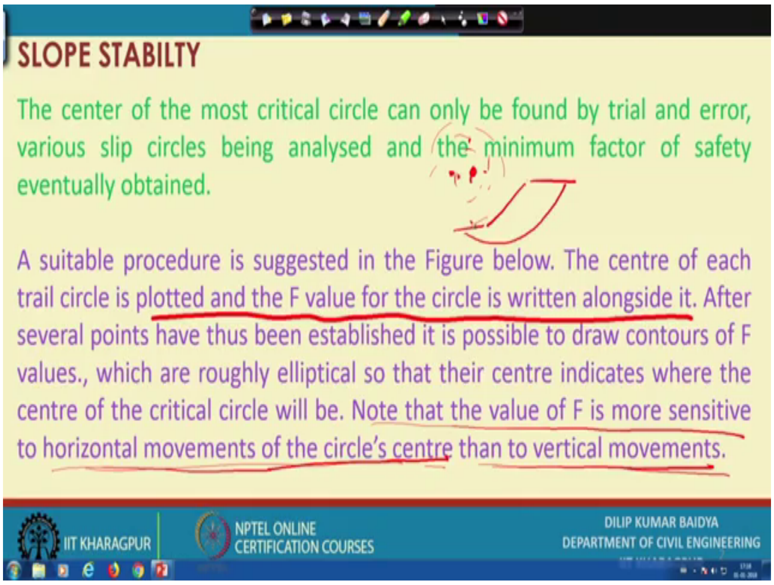

Found by trial and error, you cannot find out confidently. Various slip circles being analyzed and the minimum factor of safety eventually obtained and the suitable procedure is suggested in the figure I will show next figure. The center of the each trial circle is plotted and the value also; that means, there if there is a slope here I will show in the next if there is a slope and I will I will take a center here I will consider a slip surface. So, after doing these analyses I will find out what is the value of factor of safety there and right there.

So, like that a number of them center I will change and failure surface also I will change, I will get another factor should be like that around these I will get a large number of points with different values if factor of safety, but we do not know which one is actually the most critical.

So, when I will get a larger number of points where the points representing the factor of safety and then finally, the factor of safety may be from 1 to maybe 1.56 and there are values in between large number of values in between. Then what I can do? I can draw a contour of factor of safety of definite value suppose I will draw a contour of factor of it 1.1, contour of factor of safety of 1.2, contour of factor of safety of 1.3, contour of factor of safety of 1.4, contour of factor of safety of 1.5 like that number of them I can draw.

And then if I drew a draw these then we will typically even if it is done correctly we will find a particular pattern that that you will have a elliptical shape of those contour. And that center of this ellipse will be the center of the critical slip surface that is the thing we have to assume.

So, based on that actually we do analysis, you can see the center of each trial circle is plotted and the value of the circle is written alongside it; that means, by choose a point there whatever factor of safety we get I will right there. And after several points have does been established it is possible to draw contours of values which are roughly elliptical. So, that their center indicates whether the center of the where the center of the critical circle will be.

Note that the value of F is more sensitive to horizontal movement of the circle's center than to vertical movement; that means, if I choose here I can send change the center these direction or change the center these direction that is what it is mentioned. Note that value of F is more sensitive to horizontal movement of the circle center than to the vertical movement. So, little vertical movement whatever change will be the little horizontal movement it give more change that is why it is called sensitive.

So, while doing this change you have to change little this side, but you can change more this side. So, that is what this is the this is not this is easy to say or explained, but it is not so, easy to do so, there are some guidelines; that means, once you set this one either you can go this side or this side or you can go above or below like that you can change number of points. And for each center of center of the circle you have to find out factor of safety, write down the value the number of values we will get at different point then finally, you have to draw the contours.

So, I will show the next slide what it is done actually.

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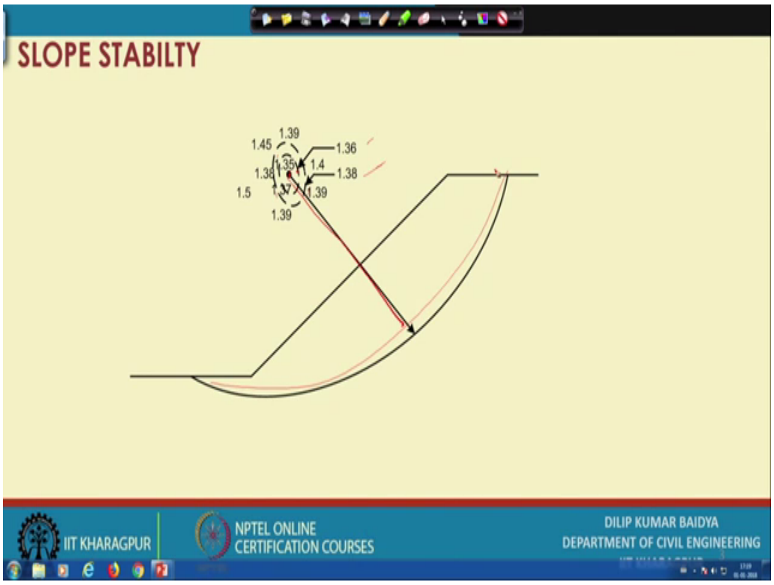

You can see here so, this is the one. So, you can see that suppose one point we have got initially suppose of the number of points and finally, we have got a contour of 1.39, contour of 1.36 sorry contour of 1.38, 1.36 and 1.35 maybe somewhere here and value maybe is there 1.39, 1.45, 1.5 there are a number of values are there.

So, finally, you could draw a contour of 1.36, 1.38, 1.35 something like that and then you can see when you draw the contour it comes elliptical and center of the ellipse become the center of the critical slip surface. So, this these become the critical slip surface so, that is actually finally, once you get this one you can analyze and find out the factor of safety.

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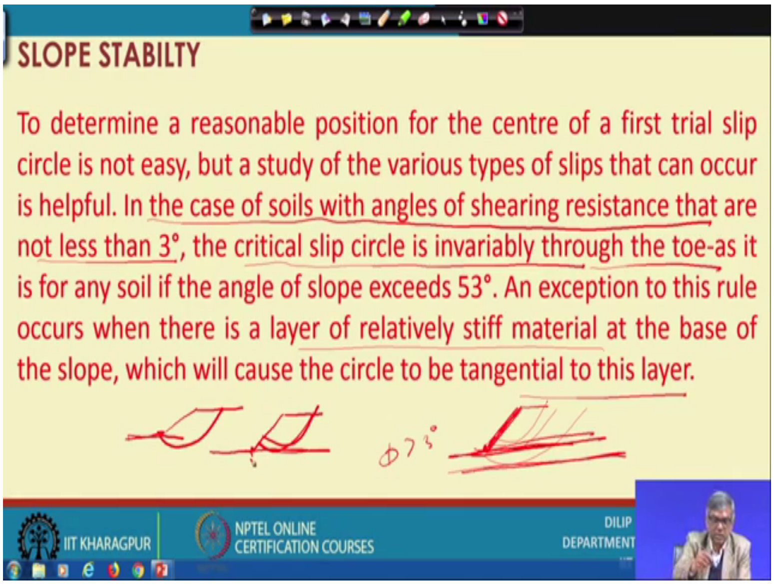

And now to determine a reasonable position for the center of a first trial slip circle is not so easy, but a study of the various types of slips that can occur is helpful though. So, what people observe in the case of soils with the angles of shearing resistance that are not less than 3 degrees that means, 5 greater than 3 degrees. The critical slip surface invariably variably through the toe; that means, if it is greater than so, your slope is there and there so, through the toe; that means, like this. And toe as it is, for any soil if the angle of slope exceeds 50 degrees. So, this angle if it is greater than 53 degrees then always it passed through this, that is one observation.

And exception to this rule occurs when there is a layer of relatively stiff material that we if there is a layer here different material is here then it can be different actually if it is if it is there it can be different. The stiff material at the base of the slope that will put is there then in that case for the same condition whatever it was going through this it may go here and tangential to this.

So, I will show in the next slide there is a layer of relatively stiff material at the base of the slope which will cause the circle to be tangential to the; that means, one is actually what I draw too slopes one is this and these; If phi greater than 3 degrees and beta greater than 53 degrees then your failure is something like that.

But if it is a slope something like this and there is a material here then your slope can be something like this, failure can be something like this ok. So, it will not reach there so, that is what is shown in the next slide let us see that.

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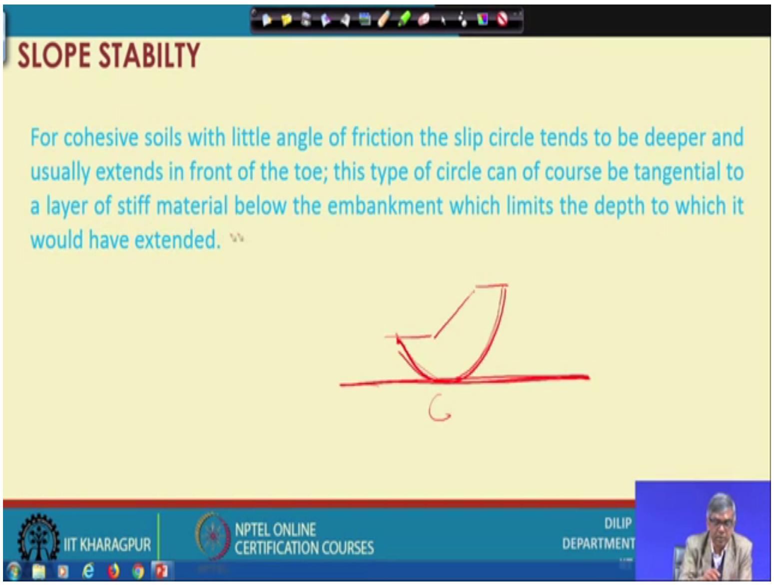

And next to next slide and for cohesive soil with little angle of friction the slip circle tends to be deeper; that means, if this is a slope here and there here. So, generally it will be something like this we go deeper usually extends in front of the toe; that means, it will go the beyond that.

So, in different finally, it will be reaching here this type of circle can be of course be tangential to the layer of stiff material; that means, if it is a material is there again there is a two layer then it goes deep, but it cannot the stiff material that it cannot go deeper this you will be tangential to that. So, that I will show there the next slide you can see here.

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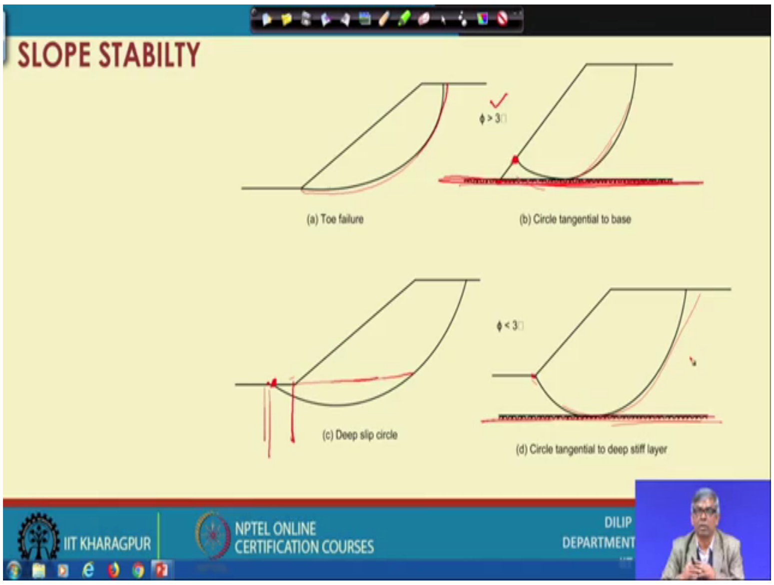

This is the normal. So, this figure actually not looks does not look like a circular, but anyway this site it is extended. So, this can be sorry.

So, normally you can see if phi greater than 3 degrees is a phi greater than 3 degrees and beta greater than 53 degrees then it will pass through these and it will go like this ok. And if there is a layer stiffer material at the base then the same condition the failures I will not come to toe instead of these it will become tangential and it will become circular and reach above toe little something like that. And when it is a cohesive soil with a very little value of phi in that case your failure surface always will be go beyond this base level and in front of failure will start in front of the toe. So, that it reaches here and it will be slightly deeper than this level.

And again if there is a another layer is present here stiffer material then the tendency will be to go here, but tangential to this ok. So, these are the.

So, these are the various observation while doing the while assuming the slip surface for the analysis. So, how to start? So, you have to see the angle slope angle, you have to see the phi, you have to see this cohesion, you have to see base the embankment material and the base material. So, it based on those observation weather you will assume these or these or these or these that to be then and then of course, we can progress further. So, this is the initial observation you have to keep in mind.

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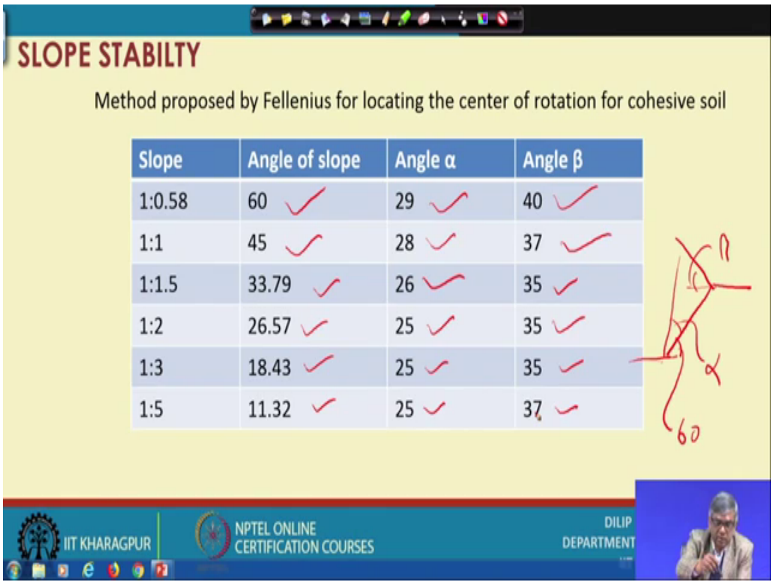

Next thing is if it is a cohesive soil actually then we can find out the center quite easily by method proposed by Fellenius. And actually if there are different types of slope suppose there is slope type different type of one is to 0.5, one is to 1, one is to 1.5, one is to 2, one is to 3, one is to 5 an angle of slope is 60 this.

Angle alpha and beta is given that when these two are actually provided by Fellenius; that means, you have to do some construction if there is a slope is given something like this, this is slope angle. And if this is the slope then angle is 60 degrees, if this is the angle is 45 degree, this is the slope, this is the angle if this is the one this is the angle, if this is the slope this is the angle. So, these are the different slope angles so, this angle is given suppose.

And then it Fellenius suggested a construction procedure based on alpha and beta to locate the value of phi sorry locate the center. So, how to do that? You can see next slide we can go this is the method you can see.

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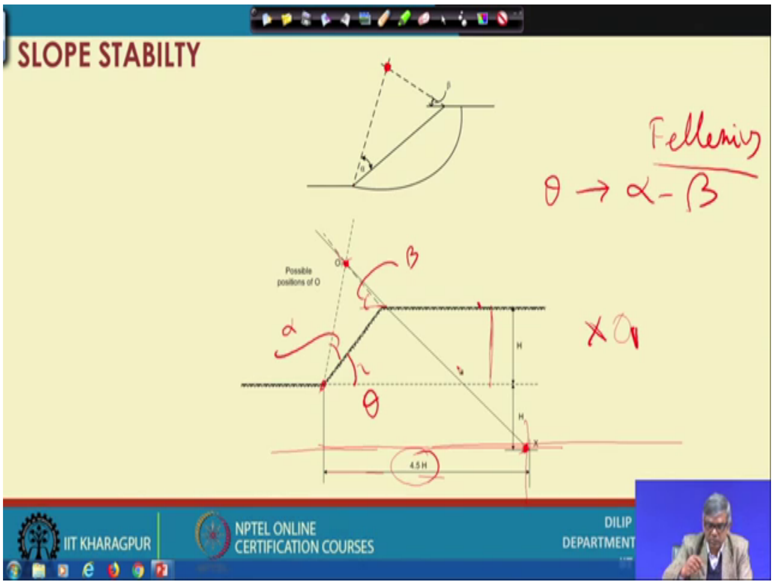

This is the failure surface sorry this is the slope and you can see you can locate 2 and locate the end of the slope, this two point. And from this point you draw a line with the sloping surface at an angle alpha this is the line with angle alpha. And again you can draw another line with angle with horizontal passing through the end of the circle with angle beta and draw another line.

So, this line should be drawn with beta from here and this line will be drawn with angle alpha from here. So, these two lines once you would draw then they will definitely intersect at a particular point and that point actually intersecting point will be the center for the most of the cohesive soil.

And so, what is the value of alpha? And what is the value of beta? So, that is actually given by the Fellenius you can see in the previous slides you can see when there is a slope when the slope is 60 degrees alpha will be 29 degrees and beta will be 40 degrees. So, ah; that means, if you have a slope like this and this is the alpha and this is beta this is beta and this is alpha. So, alpha so, if it is a this angle is this slope angle this is actually 60 degrees then this alpha become 29 degrees and beta become 40 degrees.

Similarly, if it is slope angle is 45 degrees then your alpha is 20 and 37 and if it is a slope angle is 33.8 then your alpha will be 626 and beta equal to 35. And if it is a angle is 26 degrees then alpha equal to 25 and beta equal to 35 and if the angle is 18.4 then it is 25 and 35 and the angle is 11.3 then 25 and 37. So, like that if I so, for different values of alpha beta is the intersecting point sorry you can locate and this is the point. So, this become the center of the trials circle and then taking this one and then you can draw the slip circle slip surface and then you can do the analysis.

But when it is a cheap high soil this method will not work and for that there is another as a suggested method another method proposed by Jumikis I think proposed and that actually to do that minor modification to be done. And that modification is something like this based on the tabulated value of based on this value suppose this is actually slope angle suppose theta and based on theta corresponding alpha and beta you can take from Fellenius table and you can draw this is beta and this is alpha if I do then I will get the center.

Once I get this center and for high soil oil what additionally I have to do? I have to locate a point from here at a depth 2h. So, if this is the height of the slope h so, twice distance I will draw a line like this. And then from the toe I will also draw another line vertical line at a distant 4.5h, if the h equal to suppose this then 4.5h. So, this is the vertical this is the vertical line I would draw and this is the horizontal line I would draw and they are intersecting at this point.

When they are intersecting at this point then there is a new point is located and this point finally, joining to this original center of the slip circle. So, these two point when you join X and O1 X and O1 XO1 and then after joining and they can extend it.

And after extending these then actually for c phi soil I will have I will not have on this point, but I may have center somewhere. So, where it will be? I have to along this line either this side or this side I can change the location along that line only it will be there. So, I can select any point on this and based on that again I can draw the I can draw the different slip and then I can do the analysis.

So, this is the one so, when is a cohesive soil there is a method for point locating the center and if there a c phi soil then first you have to locate based on Fellenius the center and second modification proposed by Jumikis. What you have to do? You have to locate a point 2h below the surface of the slope and at 4.5h from the toe of the slope and then locate a point. And from that point you join the originally located center by Fellenius and join these 2 point and extend and on that point you have the new center modified center. So, that is nothing is described perhaps in the next slides slide.

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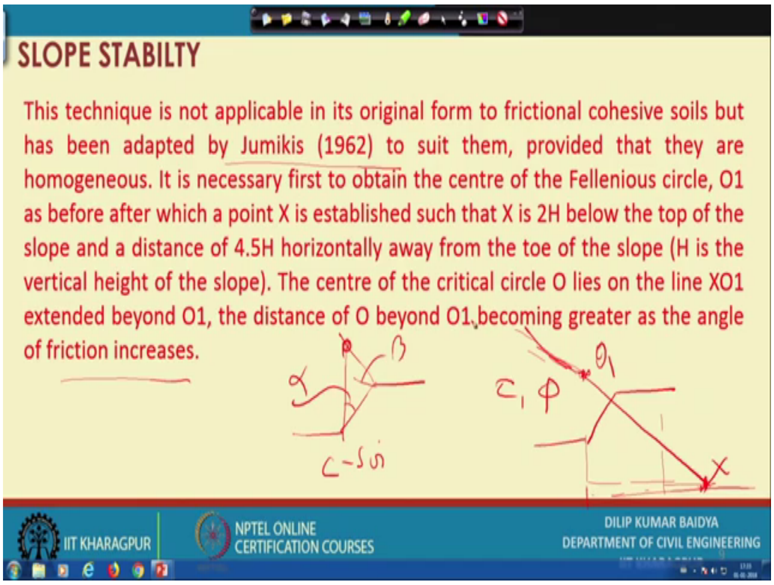

So, this technique is not applicable in it is original form to the frictional cohesive soil; that means, where soil is have processing both c and phi ah; that means, what we have we have done when they c soil you are getting by drawing a line from here and drawing a line from here this is the or c soil ok. So, this is beta and this is alpha and given by the Fellenius, but when you this is applicable for that one.

And then the same thing can be adopted by the minor modification suggested by Jumikis. How to do that? if there is a this slope is here, slope is here and we have got original center here and then I will get added 2 h distance somewhere here and 4.5h somewhere so, this is the point. So, this distance is 4.5 and this distance 2 h and then I will joined this 2 line and I will extend and along these we will have I can change the new center. So, that is what top of the slope and the distant 4.5 horizontally away from the toe of the slope; that means, these direction.

And the center of the critical circle O lies on the line X O O X X 1 this is O1 and this is X on the XO1 extended beyond O1. So, A1 to extend beyond and the distance of O beyond 1 becoming greater as the angle of friction increases. So, from 1 how far this center will be with the increase of friction it will be also increasing. So, that is the new things to be considered.

So, like this so; that means, whatever approximate initial method that when the pure cohesive cohesion less soil that you will have a planar slip surface and defined method of analysis you have mentioned. And when there is a c soil or c phi soil I can assume the number of slip surface and based on that I can do analysis and find out the factor of safety and while doing this type of analysis we need a trial slip surface with a center.

And for finding out the center there are different methods, one method is that you find out assume the center and find out factor of safety and number of them and then find out the contour of that, different values of factor of safety and the center of all those contours become the final center of the method.

And another alternative is to find out the a the cohesive soil by using Fellenius method and when it is c phi soil then modification suggested by Jumikis can be adopted along with Fellenius method to find out the center.

So, with this these are the things finally, required.

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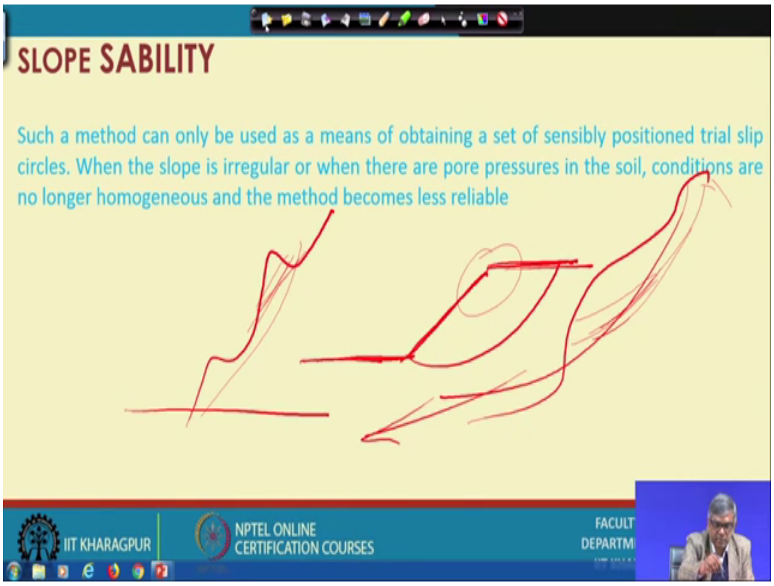

And this method such a method or can only be used as a means of obtaining a set of sensibly positioned trial slip surface. When the slope is irregular or when there are pore pressure in the soil conditions are no longer homogeneous and the method becomes less reliable.

That means, whatever method so far we have discussed; that means, there is a slope like this and first condition is homogeneous and there is no pore pressure. And then what we are doing? We are doing we are doing slip surface and consider the equilibrium and finding out the (Refer Time: 24:20) factor of safety.

But, when the slope is irregular, when slope will be irregular? we you might be or most of us we open the newspaper now and then we see that will be a landslide. Landslide is what? Is nothing, but slope failure in the hilly areas suppose the slopes are like this and during it is a significantly high slope. And during rainy season what are will enter here and because of that the pore pressure develop and many other things happens and then this entire slope sometime will be sliding to what is the toe.

So, this type of irregular slope suppose the hilly area something like this, this type of irregular slope when there will be there will be there and any time if you do analysis you may not get the enough of factor of safety. And particularly during rainy season this because of the development of pore pressure this slope becomes unstable and when this. So, far whatever slope we have shown, we have shown there is a smooth sloping surface with horizontal top surface and at the bottom also there is a horizontal level surface. So, this may be the road level, this may be another road level something like that.

Whereas, in an actual when you do the landslide analysis and all then your geometry is no longer like this and as a result this type of analysis will not be valid. And for these actually initially there was a method proposed by Jamboos and that Jamboo actually taken whatever may be the slope is the slope is something like this if there is a slope.

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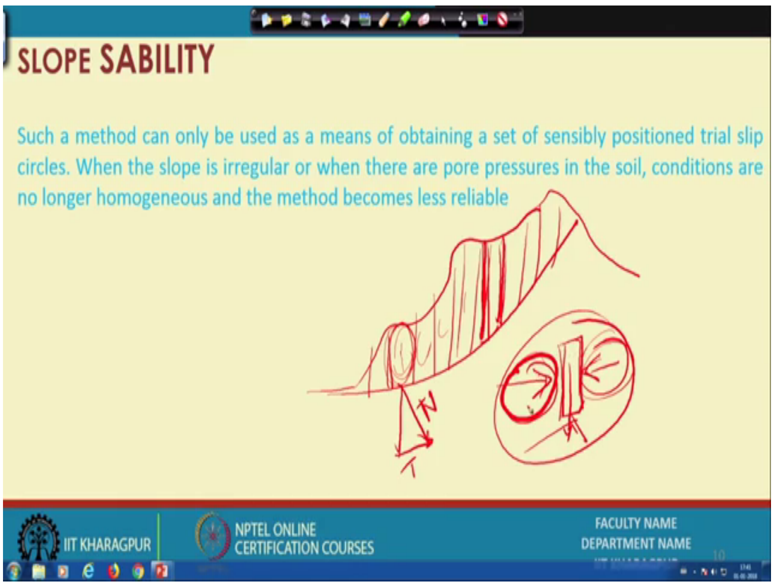

So, something like this suppose if the slope is something like this and this slope we do not know how it will fail. So, they are actually it can be taken some slip surface something like that in that case we you can do number of slice.

We have introduce the method of slice, but that is not really a method of slice, they are actually to calculate the only weight of this slice we have only divided into a number of parts. So, that was a graphical method; that means, if I divided the slice on the graph paper and then by counting the number you can find out the area, area multiplied by unit weight actually got the weight of this slice and. Then each from each slice we got normal gravity force is like that then tangential force a tangential and then normal force from there I you have got T and N sorry T here and N here. And then we have taken the summation of T and summation of N as a resistance and sliding pore and did the color.

So, that is not really the your method of slice. But what Jamboo as a state that you have to at any place and in on the slope the there is slope slices taken and equilibrium of the slice is considered; that means, slice is isolated and then on that slice what are the forces? When I will separate this pore there we have considered only these normal and tangent and you have not considered at the slice slow.

So, now Jamboo actually suggested this 2 side forces so, from this side and this side force will be different. So, considering the equilibrium when we consider the equilibrium of this then your whatever number of equation we have and whatever number of unknowns we have actually this is number of unknowns or more and because of this problem is indeterminate.

But, Jamboo initially to solve this problem what he has assumed for a small slice this portion left side portion right side portion is equal and based on that he has given a solution and it was working well. And it was a quite tedious method, but quite approxi accurate, it requires repeated calculation when it developed very early in sixties.

And later on instead of doing repeated calculation the when computer came program, the method and instead of doing repeated hand calculation the you can give the input information and then and a program it and by through that program we can instruct the program to do the calculation repeatedly to find out the final value of factor of safety. That was one method.

And there are actually so, in this method of course, the limitation was that he has considered the left side portion right side portion equal, but there are also sorry Jamboo's and bishop actually, bishops. This is originally known as Bishop's slip surface method slip method of slice.

And then later on he has introduced modified Bishop the Jamboos method there are many other (Refer Time: 30:35) many of other of them have suggested using this concept. And then finally, their concept is pogrom and number of software and now available to do the slopes stability analysis. Whatever maybe the slope it is whether it is regular or irregular, whatever maybe the height whether there is a water flowing or whether this dry, whether this partial is statutory any condition you have we can program it and then you can get the final factor of safety.

So, this is a somewhat advanced and it requires lot of calculation and it requires so, much of calculation it is not possible by doing hand and nowadays at least no one will be ready to do that since computer is there so. In fact, there are many readymade program is available what generally people are using. So, our scope giving some introduction on program is the out of our scope, but how this method works some brief description I will give in the next lecture.

Thank you with this.