Soil Mechanics/Geotechnical Engineering I
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Lecture – 56
Stability of Slopes (Contd.)

So, let me continue with the slopes stability, the other aspects. We have considered so far only for the granular soil; that means, where there is only one component shear components is that is friction and there can be only cohesion there can be both c and cohesion and friction. So, I will take a take next thing.

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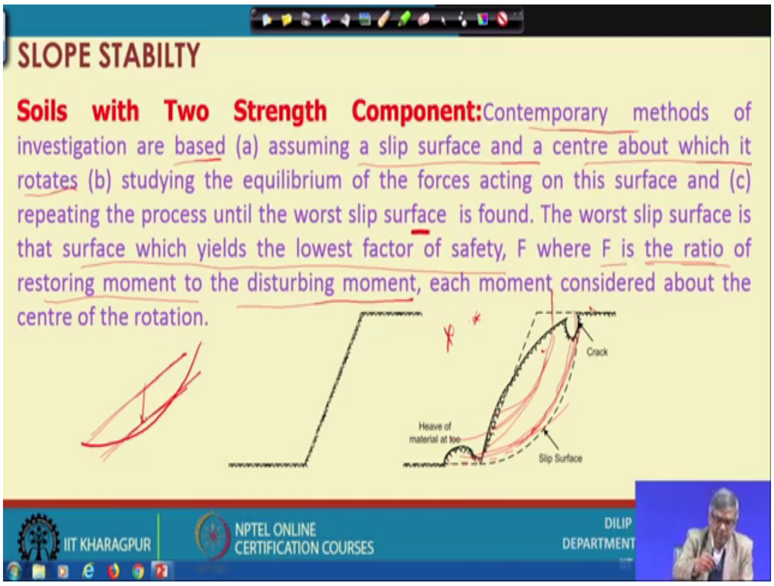

Let me see this one soils with two component. So, we can see the contemporary methods of investigation are based on assuming the slip surface and a center about which it rotates that means, slope stability when the granular soil we have considered a planar slope.

So, if it is a slope here like this the failure plane also parallel to these at some depth somewhere that the failure plane is considered there, but when there is a soil position cohesion and cohesion and friction then that will be not planar, it will be is it is something like this as shown here. So, equilibrium so, that means, to do the analysis assuming a slip surface and the center about which is rotates; that means, we are assume one slip and also we assume the point about which it is rotates the center of the slip.

And, studying the equilibrium of the forces acting on this surface and the repeating the process until the worst slip surface is found, that means, I had consider this slip surface and based on these slip surface whatever resistance is there and whatever disturbing force is that the ratio based on that I will find out factor of safety. Similarly, I will consider another center here another failure something like this and based on that again I will find out the factor if you like that we assume use to assume a different trial slip surface with different center and do investigation and find out the slip surface for which we are getting minimum factor of safety that is the conventional way of doing slope stability analysis.

And, this is the procedure will be repeated until unless we get the critical slip surface the worst slip surface is that surface which yields a lowest factor ; that means, we do analysis while doing analysis and different factor of safety you are getting; that means, the slip surface will be the critical when the factor safety become minimum F is the factor of safety and the factor of safety is the ratio of restoring moment to the disturbing moment restoring moment is what actually because of these when there is a this soil mass is trying to move this is the disturbing it will try to move this way or restoring moment is what along this failure surface there will be some shear strength will be develop that is shear strength if I take moment with respect with that is becoming restoring there it will resist the movement of this mass.

So, this two we have to equate and; obviously, resistance has to be always more than the disturbing disturbance then only it will be stable. So, with this factor several safety again a once again define.

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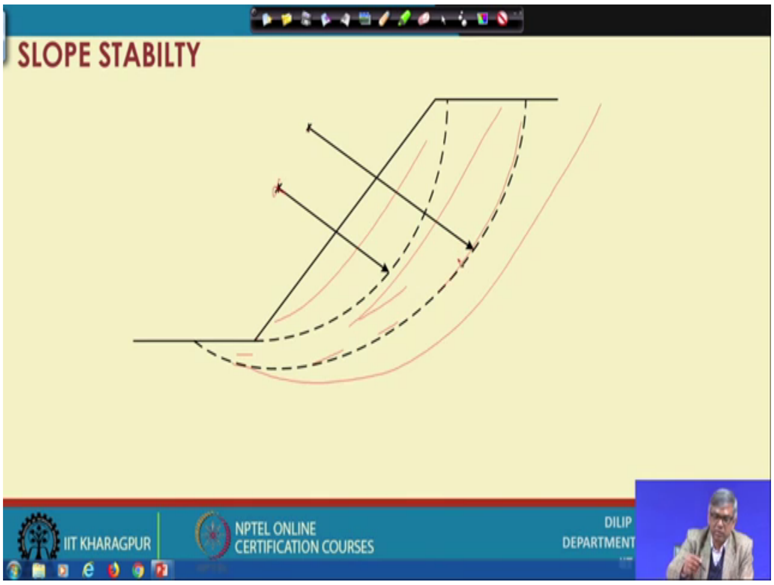

So, now, I will go this these are the procedure generally you follow you can see here initially this low failure surface is starting from the toe and passing through this one slope considered then this is the first center and you may do analysis another sloping slip surface is the with this center you do the analysis like that in finite number of failure slip surface can be assumed and analyzed and finally, we have to a find out a sufficiently large number of factor of safety with sufficiently number sufficiently large number of slip surface and finally, is examining which one is giving you the lowest factor of safety and that corresponding to that factor of safety for corresponding slip surface will be the critical slip surface and based on that finally, we do the final factor of safety analysis. So, this is the way generally follow.

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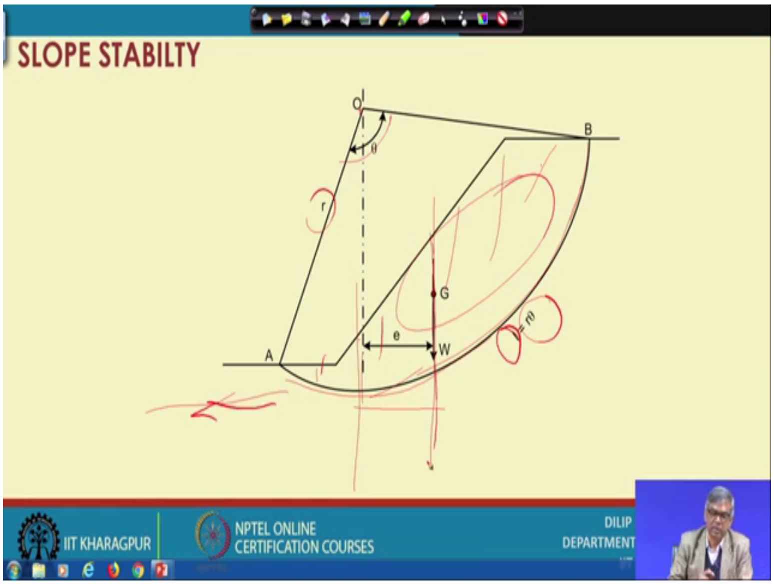

And, this is you can say typically suppose final slip surface is something like this and this is the slope and this is the slope angle and this is the slip surface and then this slip surface will have a length certain length equal to l and this length will be approximately if I considered these are the circular arc portion of a circular arc then length will be r into theta subtended here r multiplied by theta will be the length here circular arc length.

And, and the so, the along these based on the shear strength parameter then shearing resistance will develop and assuming the point of assuming this slip surface is what is the meaning actually the we assume that this must soil mass from here to here this soil mass as a block will try to move along towards this.

So, when this try to move that which will rotate since it is a it is slope and we have assumed this circular slip surface; that means, it will rotate this mass will rotate and it will rotate with respect to some point that is center. So, if this is the centre; that means, the centre of the entire mass we suppose somewhere here passing through this then; that means, how much eccentricity has.

So, this eccentricity suppose if it is if I draw a vertical line and if we draw vertical line the distance become the eccentricity of the mass. So, that means, this weight multiplied by this distance that is the moment which is causing the disturbance or causing this mass to move away from this toe whereas, along this length of the slip surface whatever resistance is developed that resistance multiplied by this radius will become the another moment which will be restoring; that means, countering this counteract this rotation, that to be estimated. So, once you estimate both then you can find out the factor of safety. So, go to the next slide.

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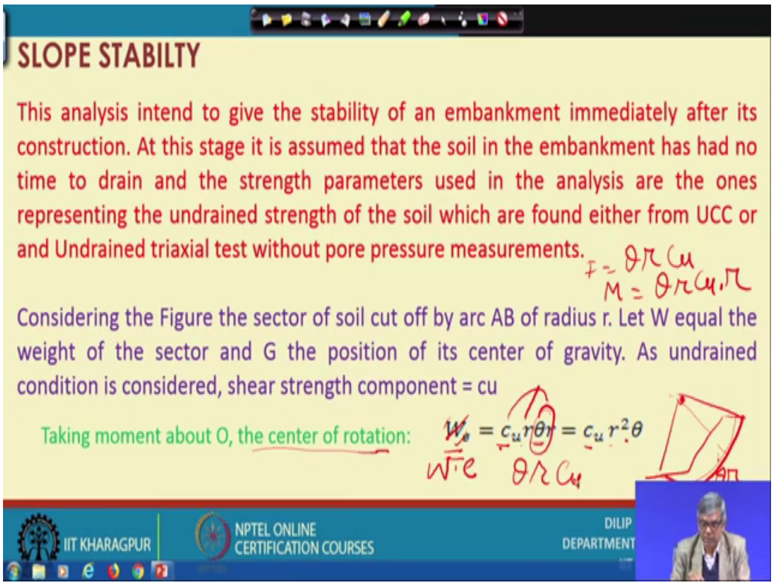

You can see here so, this analysis intend to give the stability of an embankment immediately after its construction; that means, what actually we are trying to introduce here undrained condition; that means, embankment immediately after it is construction that when there is no time to dissipate the pore water pressure. At this stage it is assumed that the soil in the embankment has no time to drain and the strength parameter used in the analysis are the ones representing the undrained strength of the soil; undrained condition we do, that means, quickest c u based on the c u.

So, that c u can be either from UCC or from undrained triaxial test based on that whatever parameter we do and based on that parameter immediately after construction there will be some condition and after sometime a after sufficiently after the construction the condition will change actually. So, the so, immediately after construction when you do the analysis you do the undrained parameter and if I considered the undrained parameter based on that whatever failure trial slip surface I have shown and mass with eccentricity I have shown then what is the disturbing moment and what is the restoring moment based on this undrained condition I can find out. Now, considering the figure the sector of soil cut off by arc AB of radius r.

So, that is the thing I have shown previous one let W equal the weight of the sector and G is the position of it is center of gravity as undrained condition is considered the shear strength component is c u; that means, if I go back to you are your previous one if I go back to your previous one.

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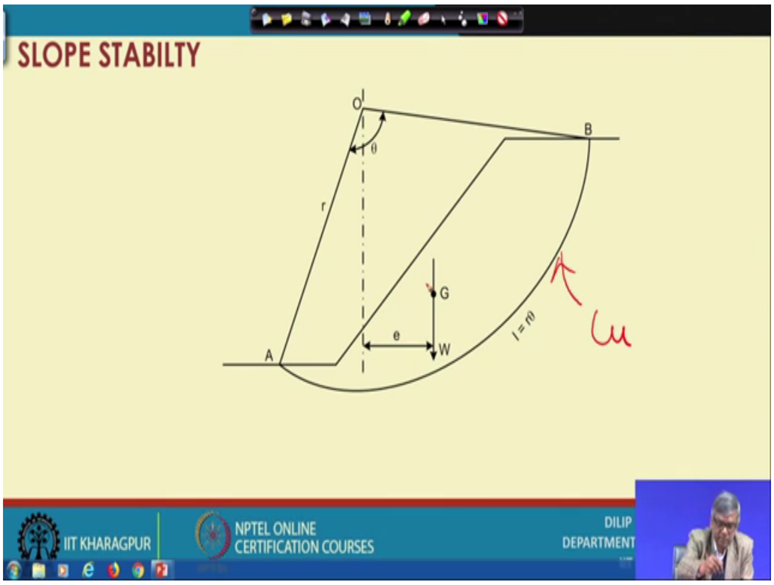

That means, along these along this c u is there and W is acting here. So, if I do that then you can see taking moment about o the center of rotation sorry center of rotation that means, the I have taken a slope something like these ok.

So, if this is a slope and then moment will be W into multiplied by e W multiplied by e. So, I think you can write better W multiplied by e then it will be you can see that must be equal to c u theta in theta multiplied by r is the arc length multiplied by c u theta r multiplied by c u is the force; that means, this is actually theta multiplied by r this length l equal to theta r and then force equal to your theta r multiplied by c u and moment will be equal to theta r c u multiplied by again this force is how are actually at a distance r. So, you once you multiply.

So, that is way c u multiplied by r multiplied by theta multiply. So, this is length this is liver arm this is the cohesion. So, ultimately this becomes c u r square theta, ok. So, this force become c u r. So, so this force if I take moment with respect to the c u r square theta.

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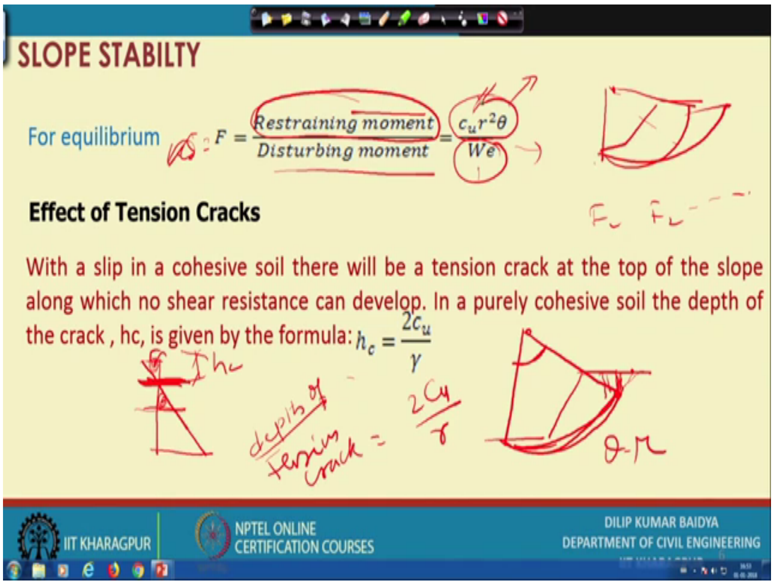

And, for equilibrium you can see restoring moment and disturbing ones this part should be bigger this part should be bigger. So, c u r squared theta that is actually restoring part which is developed from the soil itself and this is actually externally because it is soil weights it is causing. So, these divided by these is a factor of safety if I want this equal to 1.5 or 2 then we can find out what the other required things.

So, theta and other things if we required or are generally we do not do this way we do we assume different slip surface like this and now, will do the slip surface and then you find out what is the factor of safety because of based on this calculation if I take another failure slip surface something like that then again I will do W 2 e 2 and then again I calculate this then I will get F 2 like that F 1, F 2, F 3 like that n number of F I will get and from there I will find out where F minimum and F minimum gives you the critical slip surface that I will we can find out.

Now, while doing these while doing this one thing to be remember that as when there is a case or soil if the slope made of clay then sometime the cracks forms or up to what depth actually cracks can go, that I have we have discussed during the earth pressure and we have shown when there is a pure cohesive soil that depth of tension crack where depth of tension crack we will be equal to 2 c u by gamma and in fact, a depth of unsupported crack cut it will be just double because the pressure diagram was something like this ok, pressure diagram was something like this is actually 0 tension and here is the maximum tension this is a depth of zero; that means, tension crack can reach up to these and these depth is called h c.

And, since this is a negative pressure and this is a positive pressure so, that means, up to this much if I go where actually total force area of this diagram area of this diagram when become equal. So, that much after that much depth actually wall is not getting any additional pressure. So, because of that double the depth of tension crack we can ascribe it without support. So, that is the different thing we have discussed already, but now as I have mentioned that if the slope is made of clay in that case there is a chance of tension crack. So, if there is a tension crack start from here and if I assume a failure plane something like this passing through this then beyond that actually I will not though the slip surface may go here, but I cannot consider up to this I have to stop here. So, I have to consider slip surface up to this.

So, that modification you have to do while calculating the length of the length of the arc which is equal to theta into multiplied by r and because of this tension crack this I have to stop then the r will change and accordingly your length of arc will be changing and if the length of the arc change then accordingly this portion also will be change. So, if there is a tension crack your resistance is getting reduced so, that to be considered also in the analysis.

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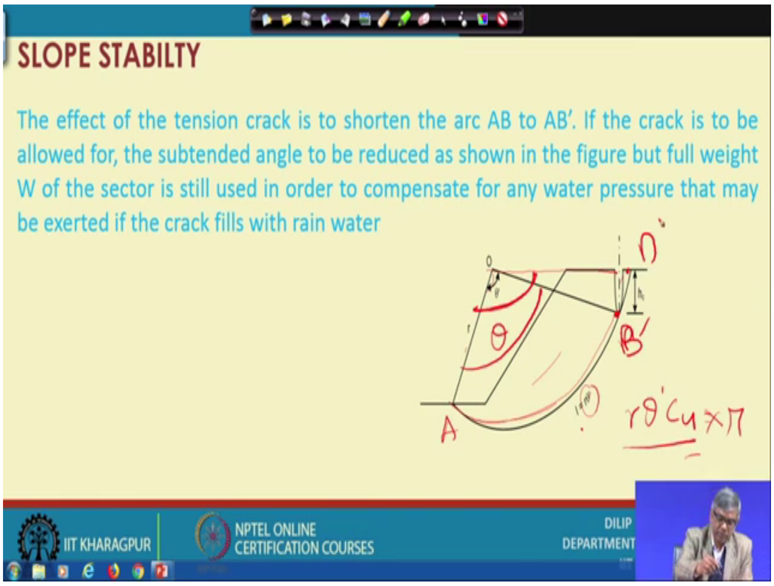

And, you can see here one again it is shown the tension crack the here and assumed we assumed a failure plane something like this and it is supposed to go up to this, but because of this tension crack I have to terminate here. So, beyond that the slip surface will not have any resistance because before that it is gets separated then because of tension crack.

So, I have to consider only this which I will be original theta was suppose based on this was theta, but I have to considered now theta dash based on that I have to find out l equal to r theta dash and r theta dash multiplied by c u become the force and multiplied by r equal to moment and this that that moment to be used to calculate the factor of safety.

So, here effect of the tension crack is to short shorten the arc AB. So, this A arc AB this is a and B B this original was this AB and now, it is AB dash if the crack is to be allowed for the subtended angle to be reduced; that means, originally angle was this now the modified angle is this that to be taken, but full weight of the sector to be, but while considering the weight you have to take entire weight, but that weight also create weight on this when. So, this is the one to be considered.

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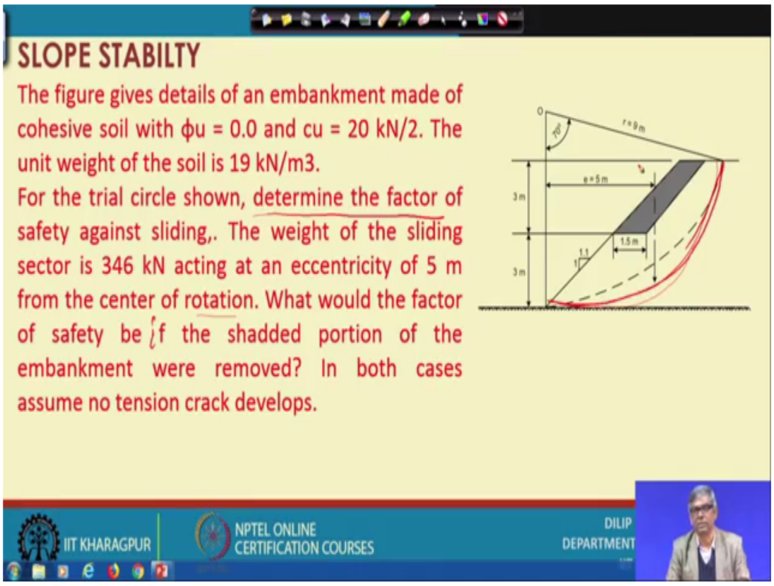

Next one so, this is the example actually one simple example we have given here this is this is not drawn properly of course, this could have been little sorry you can see here the figure gives details of an embankment made of cohesive soil with phi equal to 0 then will no friction c u equal to 20 kilo Newton per meter square the unit weight of the soil is 19 for the trial circle shown determine the factor of safety against sliding; that means, this is a in this part to be ignored initially suppose this trial surface was something circular actually it should be circular it is not does not look like circular if it is like that.

And, then the for the trial circle shown determine the factor of safety against sliding and the weight of the sliding sector is 346 suppose the suppose this under this it was 346 kilo Newton acting at an eccentricity of 5 meter from the center is here and it is acting here, so, this distance is 5 meter what would be the factor of safety know the weight of the sliding factor 346 acting at an eccentricity of 5 meter from the center of the rotation. So, so, for the trial circle shown determine the factor of safety.

So, initially because of these what of the factor of safety, and what would be the factor of safety if this I is missing the shaded portion of the embankment were removed; that means, this is the way sometimes we solve the problem in the field when in a particular slope is looks like unstable then if we remove some amount of soil from the top then it helps actually it makes stable.

So, second part so, in this first part actually you will find out what is the factor of safety and then second part is shown if this much soil is removed from the top what will be the reduction in factor of safety or improvement in this factor of safety.

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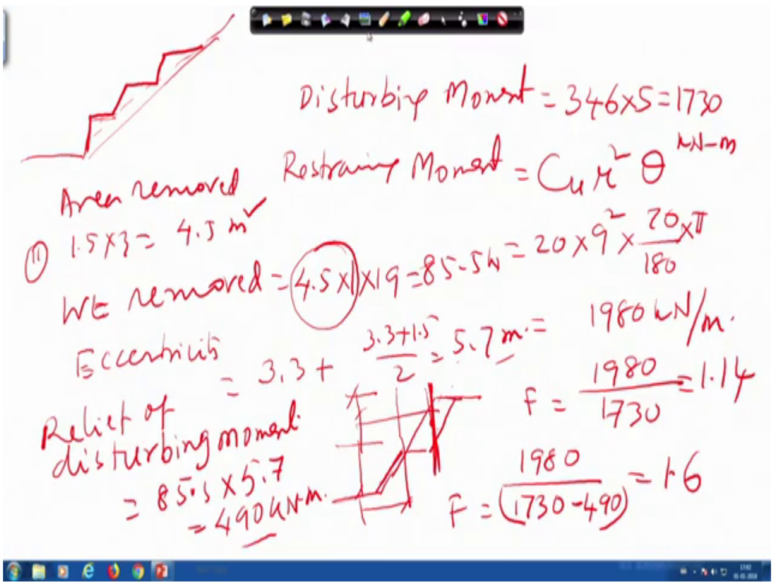

So, will go that part next and, so disturbing moment will be disturbing moment disturbing moment will be 346 the W and eccentricity is 5. So, it become 1730 kilo Newton meter. And, restraining moment will be equal to as we have there c u r square multiplied by theta. So, all those things are given. So, c u is 20, r is 9 meters and theta actually given 70, 70 degrees. So, if I convert in radian you have to multiply by pi by 80. So, this is the one so, it gets value 1980 kilo Newton meter. So, F become your F become 1980 is the restoring and disturbing is 1730. So, if the factor of safety become 1.14 quite close to one only.

So, and now you can see second part area of the force are removed you can see area approximate area is 1.5 into 3 area removed will be 4.5 meter square and then W removed weight removed weight removed will be 4.5 and you take unit weight multiplied by unit weight of the soil equal to this. So, 4.5 into 1 is the volume and multiplied by unit weight this that gives you 85.5. 85.5 kilo Newton and eccentricity that eccentricity of that mass will be equal to 3 point approximate you can find out 3.3 plus 3 point 3 plus 1.5 by 2 this is actually 5.7 meter.

So, that means, when there is a slope here and like this and we have removed this amount of soil and this is 3 meter and this is 3 meter and the slope also mentioned here what is the slope. So, you can find out where it is acting. So, that point actually shown by 3 point up to this is 3.3 meter plus this distance. So, this will be approximately this plus this divided by 2. So, 5.7 meter. So, the relief of disturbing moment relief of disturbing moment will be equal to 85.5 W and it is 5.7. So, that become your 490 kilo Newton meter.

So, now new factor of safety will become 1980 is the resisting unchanged, but disturbing moment is reduced originally was 1730. Now, 490 is minus. So, this gives you factor of safety equal to 1.6 you can see that originally your factor of safety was 1.14 when you remove some portion from the top if you remove from the bottom the effect will not be that much it will be negligible, but when you remove from the top the effect will be maximum. So, you can see that improvement of factor of safety.

So, this is the practical solution we adopt in field when there is a slope we find that it can be unstable any time. So, in that to make the slope stable we can cut from the other top actually some portion or sometime if you have a slip slope instead of making a simple slope we can make a benching; that means, this is the one. So, we can do small small benching. So, we can do small small benching. So, then, if I consider from here to here quite steep, but when you go by this looks like steep, but if I go this way this way this will be quite a mild slope.

So, that is the concept sometime adopt in the field to make to have the better factor of safety you can remove some portion from the top of the slope and. So, this is the problem which is explained already.

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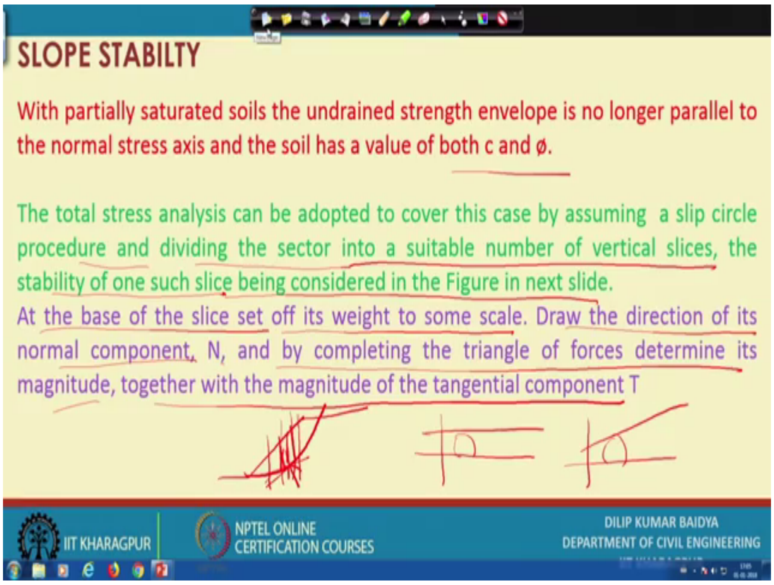

So, let me see the next one with the partially saturated soils that means, when there is soil is partially saturated it is not saturated. In fact, then I when you do triangle test you test your failure envelope will be parallel and when you have the partially saturated soil then your failure envelope will be something like this; that means, will soil will for a both c and phi and, if it happens.

So, if it happens. So, in that case you can see both c and phi will be there. So, the total stress analysis can be adopted to cover this case by assuming a slip circle procedure and dividing the sector into suitable number of vertical slices. The stability of one such slice slice is being considered in the figure in the next slide will be you show and at the base of the slice set off it is weight to some scale draw the direction of it is normal component n and component triangle of forces, determine its magnitude together with the magnitude of the tangential component that means,. So, total stress analysis will do when there is a slope something like this.

Ah, and these I can make number of slice like this and this slice will have suppose a failure plane is something like this, so, this is the slice. On this slices I will find out the weight and I will have a normal component, I will have a tangential component and I will have a gravity load. So, based on that so, graphically you can find out for each slice and finally, I can find out number of slice if I do this way and by summing all those forces in the same direction I can get total tangential force or total normal force and based on that I can finally, do the calculation whatever you have shown in the previously.

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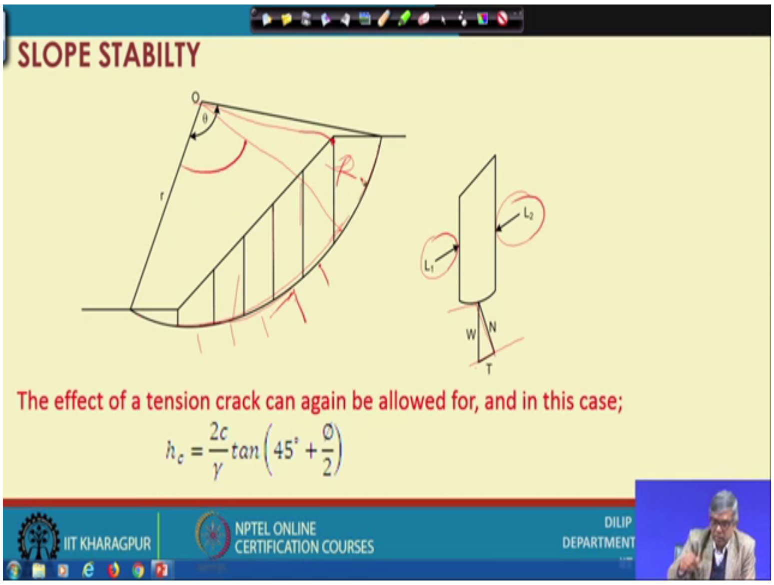

So, let us look at the next page then it will be clear you can see suppose the soil possessing c and phi and in that case the entire this this this slip surface suppose a critical or may not be critical this is one of the assume trial slip surface and to have for the analysis purpose we can divide a number of slip and for each slip I can find out normal and tangent and how to do that. So, I can isolate this one assume this equal to this actually otherwise this problem cannot be solve or it can be ignored and then the W can be calculated in scale and you can draw parallel to tangential to this another this and then draw normal to this then I will get the force polygon for this particular slice.

So, each slice so, instead of isolating at the midpoint you can do this and from there I can find out T and N I can find out. The effect of tension crack if I take then again I have to subtract h c suppose if it is tension crack is coming here then it will be terminated here sorry terminated here and I have to take these angle. So, that is similar way, but slice should be started from here ignore you have to ignore this.

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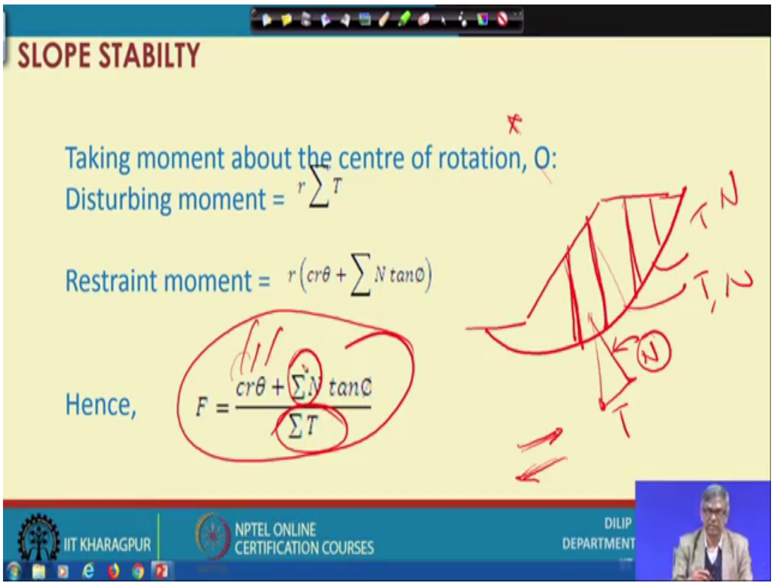

So, by this way if I do then you will have calculation will be you can see here the taking moment about the center of rotation O. So, a number of so, suppose this is the failure plane. So, you will have these. So, like that each point will have like this so, T and N, so, r r multiplied. So, it is at a distance r, so, center is here. So, this T is this one r multiplied by T r multiplied for each r multiplied by t at T I will find out for each and then if I sum it up then will get a total resistance. So, disturbing moment I will get restraint moment will be you can see r and cr theta plus in tan phi.

So, this is the one multiplied by r that will be the restraint moment and then ultimately your equation become cr theta plus sigma N tan phi by sigma t. So, that mean whatever different slice I make I have to find out in a different point in I have to find. So, I have to sum it up and I have to find out the t at different point and then finally, I sum it up and then I use this equation where the soil possessing both c and phi and then based on this calculation I can find out the factor of safety here.

So, I hope this is clear. So, when there is a slope like this and let me once again I will do if there is a slope suppose something like these and these and your failure surface is something like this and then center is somewhere here and then if I consider the slice from here. So, its gravity will work like that tangential will be like there and then normal will be acting that.

So, I will find out graphically or by reading then on T. So, for similarly for each slice for each slice I find out T and N then the another. So, here also I will find out t and n. So, all T if there in same direction simply I will sum it to get the total T and sometimes while the change of this one some T will be in this direction some T will be this directions if I consider these direction is positive if it comes other direction I will subtract it.

So, that way so, this is the cumulative T and this is cumulative N, N will be all positive. So, a normal direction so, if I know the value of c value of r and theta and n from each slice and T from each slice then I will do this calculation to get the final value of factor of safety. So, this is when soil is not saturated that mean when partially certain when soil both c and phi then this is the analyze to be to be done for finding out factor of safety ok.

So, I will again some more thing I will take in the next module.

Thank you.