Soil Mechanics/Geotechnical Engineering I
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Lecture – 55
Stability of Slopes

Good morning once again. I welcome you to this course online course Soil Mechanics. And we are almost towards the end of this course I have last topic which I have covered completed that is earth pressure and now the last topic which I will be covering is stability of slope.

And in the previous topic I have shown that to create different types of facility sometime you have to retain the earth by using retaining wall. And because of that to designing the retaining wall how much is the pressure etcetera. What are the different types of pressure we have discussed and their we have also mentioned that we can if we want to do some excavation then we cannot do excavation up to infinite depth.

In fact, you go beyond certain depth you need to provide a support. And then this different soil you can excavate up to different depth without support and what could be the maximum depth of excavation without support that we have discussed and that was typically given in the form of formula that is 4 C by gamma root K a and 4 C, where is C is the cohesion of the soil, gamma is the unit rate of the soil, and K a is the active earth pressure coefficient. And if it is a purely cohesive soil then K a become 1, the phi equal to zero and in that case it become 4 C by gamma so; that means, if it is a if soil has a cohesion of suppose 50, and in equate of suppose 18 or suppose 20.

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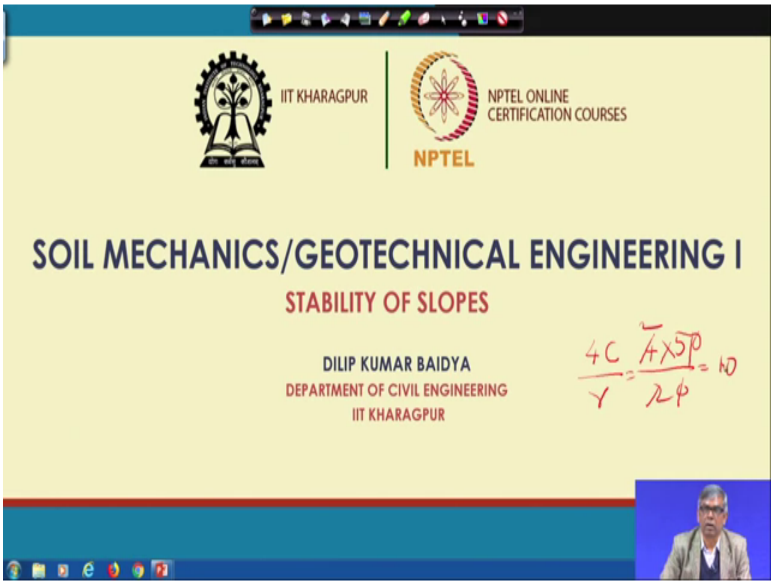

Then by a large we can suppose 4 C by gamma actually when it is a purely cohesive. So, it will be 4 multiplied by C is 50, and this is 20. So, you can see nearly 10 meter depth, you can cut vertically when it is a purely cohesive soil with cohesion value of 50. And obviously, if you want to excavate beyond that then we need to provide support or you have to make the excavation the slope manner not vertical.

So, similarly if it is a soil of granular type then this will be different obviously, in fact granular soil we will not be able to excavate without any support immediately will cut. And then it will try to collapse it will collapse soil it will collapse and it will finally, you make a slope stable slope and that slope angle generally close to the angle of internal friction or shearing resistance of the soil, so; that means, you can you can provide a certain a angle of slope to provide the stability.

So, in fact, we have different facilities where we need slope for example, if you want to make a long road some places you need to excavate, some places you need to fill and make the embankment. And similarly if you want to make a railway line then similarly somewhere you have to you may have to excavate or cut the soil or a rock or in some places you may have to feel the earth to make a embankment.

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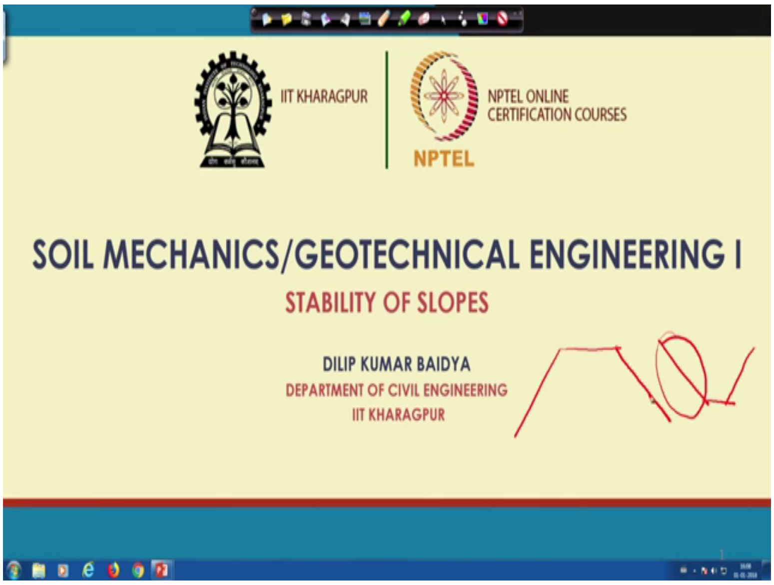

So, and when you make a cut or if you make a embankment always we make in a slope manner; that means, it will be if this is the top surface of the desired road, then your you will make either this way or if it is a excavation, then it will be like this these and this. So, that that this is the angle at slope you have to maintain for the stability purpose of this entire structure, so that means, here actually you have that slope stability analysis; that means, if you make a slope it 50 degrees angle.

And another slope you will make 15 degrees angle. So, with the both are stable which one is more stable all those things through proper analysis you have to find out. So, for this purpose let us; that means, slope stability analysis is one of the important topic in geotechnical engineering. And as an introduction I will just let you give this few lines and say you can see that already we have discussed soil and soil classification also I have mentioned.

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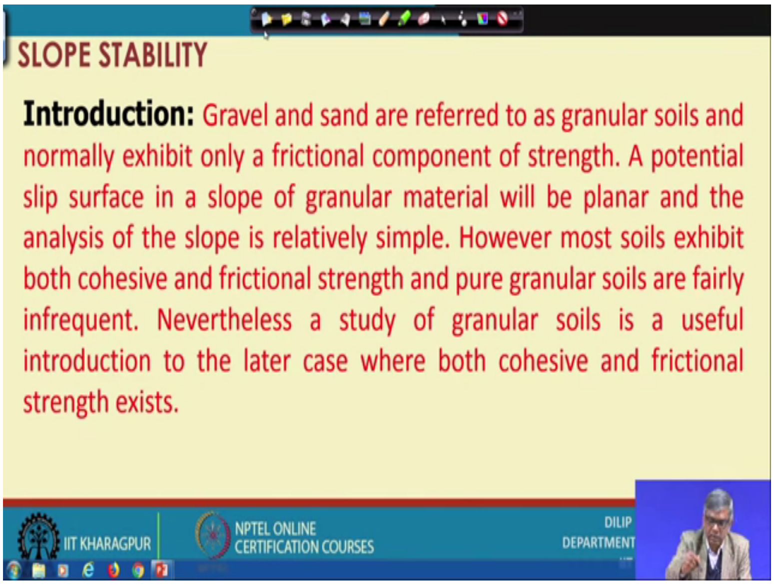

And under that is a gravel and sand one type of soil which will have will be named as granular soil and it has only a frictional component; that means, when you calculate the strength then it has only tan phi which gives you slip is constant. And potential slip surface; that means, if you make a sand a slope with sand then your slope will be granular, so material will be planar; that means, it will not be a curves.

So, if there is a slope the slope may fail like this or it may fail like this, so this is planar and this is curve, so granular soil failure plane will generally planar. And as it is relatively analysis it will be simple and; however, most soil which is not granular that is cohesive soil those type of soil will possess both cohesion component and friction component and for that actually your will not be planar.

So, a study of granular soil so, but; that means, we need to do both type of soil slope with granular soil slope with C phi soil both you need to analyze. And, but at the beginning; let us start with a granular soil as a introduction and later on will bring cohesive soil. So, which is simple that is with phi let us take first.

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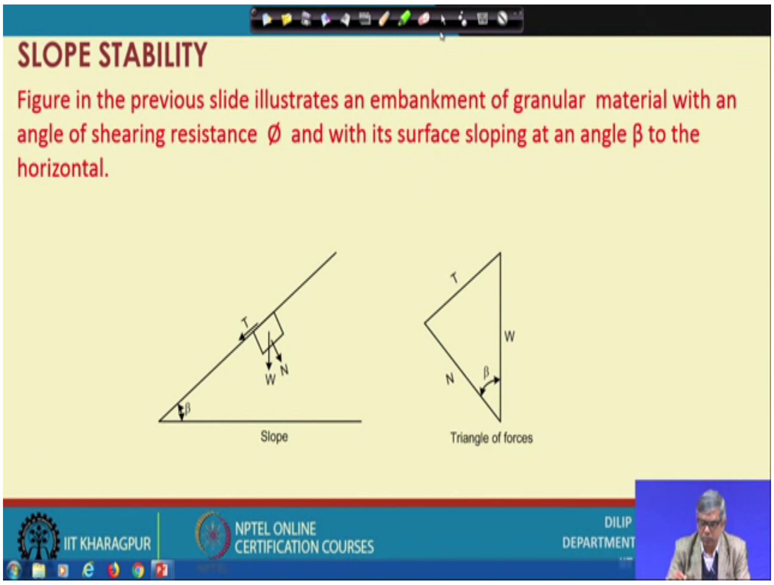

And you can see so how the philosophy in slope stability analysis we can see that this is slope suppose and that slope I can imagine a small mass of soil. So, this is should be right angle actually so it is like that. And this mass I can consider the equilibrium then what are the forces acting on it, there will be a normal force, there will be gravity force, and then it will try to since it is a slope it will try to move this way so, there will be horizontal component in this direction. And this based on the equilibrium of this if you draw a force polygon it comes like this, W is here, N is here, T is here.

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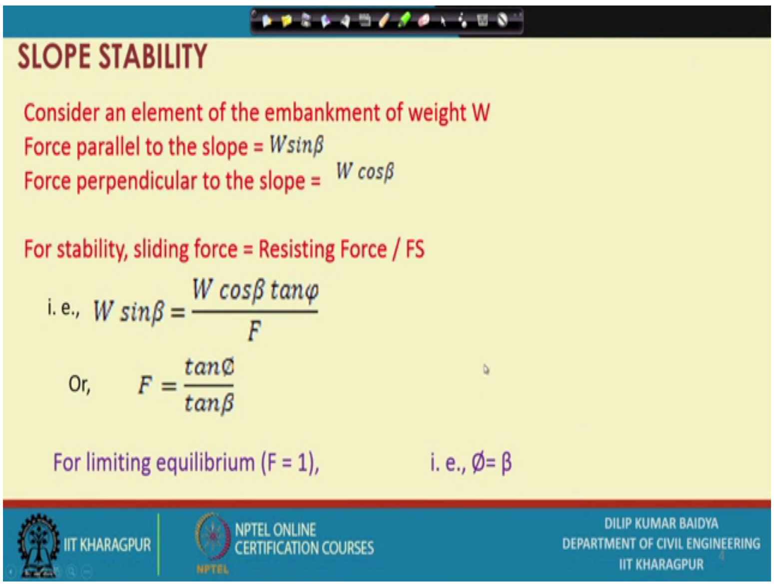

And based on these force polygon what you can do? We can we can see we can as I have mentioned we have taken the element on the embankment, and W is the force weight and the force parallel to the slope will be W sin beta which is shown as t, and force perpendicular to the slope will be W cos beta that is angular. If the slope is this angle is beta then this slope that this component and this component acknowledge W sin beta and another is W cos beta.

And for stability sliding force must be equal to resisting force divided by factor of safety ok, for stability and if it is just merge of failure; that means, F S will be equal to 1 in that case sliding force, and resisting force as long as they are equal they are just stable, but if it is little disturbance then the mass will start moving.

So, because of that for if you want always you want actually is stable slope and because of that for stability requirement the sliding force must be equal to resisting force divided by factor of safety. So, this would be little small and factor of safety l s should be greater than 1. So, this should be smaller than the resisting force so, if I if I take this definition of stability equation, then by providing this you get W sin beta equal to W cos beta tan phi.

Because this frictional force and because resisting force will be this is the W cos beta is the force frictional force n tan phi actually, n tan phi is the frictional resisting force, so that is W cos beta was the normal force. So, multiplied by tan phi that become your resisting force and divided by F and from here actually I can get factor of safety factor of safety will be tan phi by tan beta; tan phi divided by tan beta.

So, this is the actually this is the very definition is this if I keep F equal to one then limiting condition and then in that case; that means, phi equal to beta; so that means, at the beginning whatever I have mentioned that if a sand if I dump here by some means if I dump this is a ground surface I start dumping the sand here, and if I make a dump very great height then ultimately this dump cannot be vertical. So, this dump will have a slope and that slope actually natural slope which will be this beta will be equal to phi so; that means, it is if I put this small weight here again this will collapse, because this is very limiting condition.

So, factor of safety is 1 means it will phi equal to beta so this is the very simple thing we have considered we assume that slope and we have considered this small mass on the slope, and I consider the equilibrium of it. And from there actually I have tried to equate the force.

And with the requirement of factor of safety equal to greater than 1 and then ultimately I get this expression and from there if you take F equal to 1 then I get phi equal to beta; that means, if I want to if I take sand from somewhere you will see everywhere the truck loaded sand will be coming. And then it will be unloading on the road side and you will see sand will be at a particular slope it will not be vertical, it will not be totally flat. So, that actually the angle comes from here actually whatever angle of shearing resistance the soil has based on that it will make the angle. So, this is the first example or analysis of factor of safety and we will go little complicated slowly.

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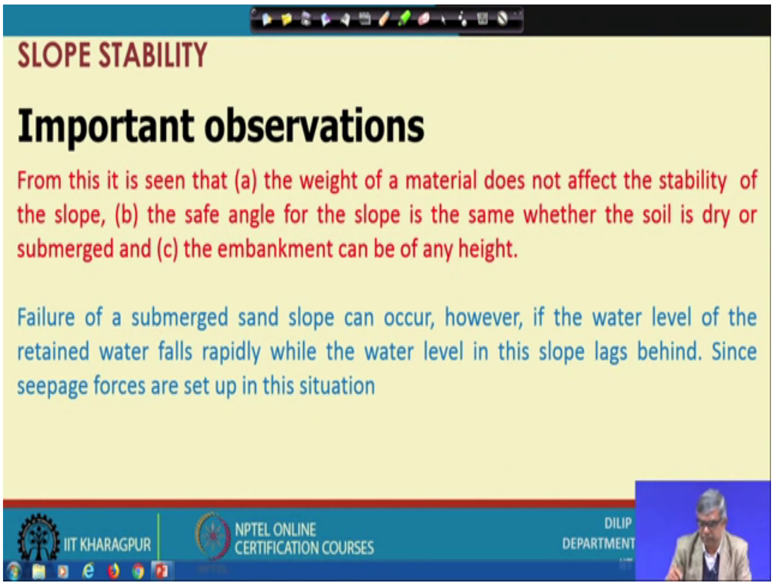

Now let us take from here actually you can make a few important observation you can see from this it is seen that the weight of a material does not affect the stability of the slope. Finally, what is the weight whether it is a if it is a friction is there whether it is a made of steel, quartz, or anything. If there is friction is the concept is same then it does not matter only it depends on the only your phi the angle of internal action angle, or angle of shearing resistance not known actually weight of the material is not there at all.

The shape angle for the slope is the same whether the soil is dry or submerged; that means, I have not considered whether it is a dry soil, or submerged soil, or partially submerged soil nothing I have considered, simply I have considered the weight. And only assumption is that it must be homogeneous because when I consider a slope and taking a small mass from here then the entire slope region should be homogeneous the same, whatever soil type here what are the all should be everywhere should be same then only that is valid.

So, we if this is homogeneous is assumed, but the whether the soil is dry, or submerged that condition actually we have not considered and; that means, it is not dependant on it. And the embankment can be of any height; that means, whether this slope is there it is called infinite slope; that means, whether the slope is 10 meter, or whether it is 10. 20 meter. If as per as this angle is constant whether it is 10 meter, or 20 meter, or 30 meter, 100 meter the analysis is same; that means, factor of safety will be tan phi by tan beta.

Similarly failure of a submerged sand slope can occur; however, if the water level of the retained waterfalls rapidly; that means, it was suppose sub merged initially and then suddenly water dropped at this level. Then of course analysis totally will change and it may fail and so the water table has gone, but some water is retained in this and to come out water from the retained soil that take some time. So, that lags because of that sometime this force failure slope will fail.

So, since the seepage forces are set up in this situation so the failure may occur so; that means, if it is a submerged the analysis is same. But submerged but suddenly dropped in that case analysis will be different. So, how different will take one by one. So, let us take next slide.

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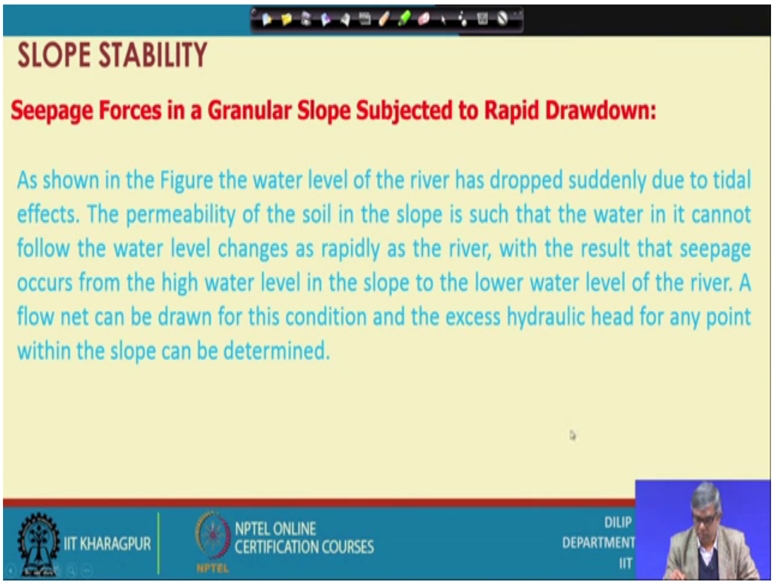

This is actually the seepage force in a granular slope subjected to rapid drawdown; that means, you are now considering introducing seepage, and you can see in the next figure I will go let me go to the next figure.

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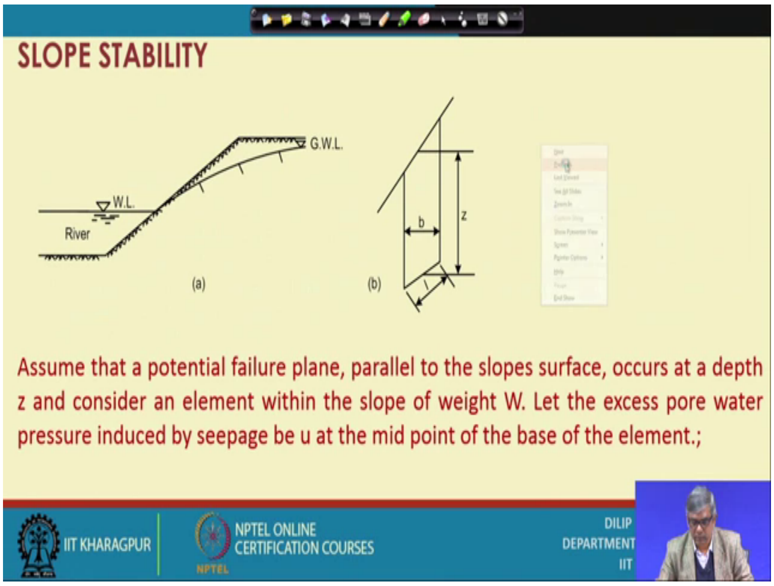

First of all I will show how doing this is the slope suppose and when water table is here the natural fleetic line or a ground vertical initially will be like this only ok. So, it will be like this and so now if I on this slope if I consider a mass like previously then it will have water pressure. So, in this there are number of things I have shown I have taken width of this slice and you have taken the height of the slice, base link everything is defined and this angle is suppose beta, this angle is beta.

So, if it is there at the midpoint of this suppose there is poor pressure equal to u, if that is the case then one by one let me go back to the previous one. And you can see as shown in the figure as which I have already shown water level of the river has dropped suddenly due to tidal effects. The permeability of the soil in the slope is such that the water in it in it cannot follow the water level changes as rapidly as the river, river water drawn the down quickly, but inside the soil it could not come out.

With the result that seepage occurs from the high water level in the slope to the water to the lower water level of the river; that means, I will come back to the next once again river. A flow net can be drawn for this condition and the excess hydraulic head for any point within the slope can be determined; that means, when water is flowing through the soil that hydraulic heat that hydraulic head actually that cause excess hydraulic head is causing that actually we have consider while seepage forces.

We have we have seepage and paralytic discussed then when flow taking place then through the soil upward direction, downward direction, then accordingly seepage force will be there. So, we have considered similar to that here also, since water table has gone down, but water still retained in the soil. So, water flow through the soil and towards the ground water table and because of that there will be seepage force will act, s, if that happens then that is the diagram.

Actually so this is the flow line and then equipotential line I can draw like this and then typically one slice I can take and this slice geometry of the slice shown here and based on these we can do some analysis like we can see the potential failure plane, this is the potential failure plane. Suppose this is the angle beta and parallel to the slope surface, that is this is the failure plane actually parallel sorry suppose this is this is not drawn properly.

So, otherwise this would have been little flatter actually parallel to this and occurs at a depth z that means, from the midpoint to the midpoint depth z and element with the slope of weight W this weight of this is W. Let the excess pore water pressure induced by seepage be u at the midpoint. So, here because of this flow everywhere seepage pressure will be different, and this is a suppose we have consider a small element and in that element what is the flow pressure.

And suppose at these this is a failure plane. So, we are considering at this point failure pressure is u, so, based on that you can do the analysis now; that means, when there is a flow taking place within the soil. So, if that flow taken place then how the analysis change let us see that.

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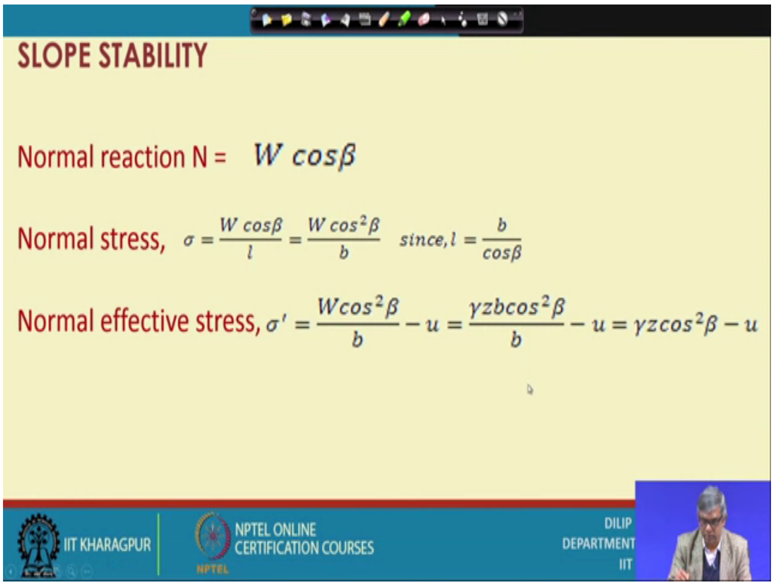

So, you can see now when normal reaction n like that it will be W cos beta and normal stress normal stress will be normal force divided by area and you can see normal force is W cos beta and length was l that you have shown before that is it was here. And it is like this and you have taken this is as this as a length l and this is b actually. So, if I consider if I put l in terms of b width of the slice, then l will be b by cos beta so if I substitute here the sigma become W cos square beta by b.

Similarly normal effective stress you can find out sigma dash will be W cos square beta by b and minus at that point suppose this is the point we have considered this is the sigma, and at this point pore pressure is u. So, effective will be total minus u so that if I substitute W equal to gamma z b cos square beta by b minus u. So, this will be the your final expression for this b b get cancel. So, gamma z cos square beta minus b minus u is the normal effective stress at this point.

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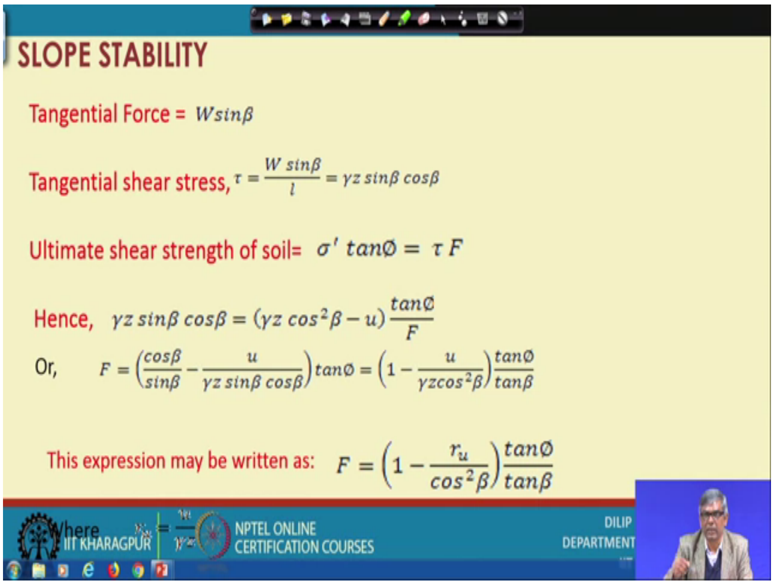

Similarly if I shear strength you have to calculate. So, you can go back to this you can see the tangential force is W sin beta and tangential shear stress again the load by area and l again to be substituted then it will be gamma z sin beta cos beta ok. And so this is the tangential shear stress.

So, ultimate shear strength will be sigma dash tan phi equal to tau into F, where F is the this is the shear strength of the soil and F is the factor of safety that should be equal to this. And so we have already calculated horizontal stress is this and you have already calculated this as a effective stress, and then multiplied by tan phi that will be effective shear stress and divided by factor of safety must be equal the horizontal stress. This is the original factor of safety or stability requirement this is the pressure you have used at the beginning.

Similar way if I use this then your factor of safety equation reduces to cos beta by sin beta minus u by gamma z sin beta cos beta into tan phi and if I simplify further one minus u by gamma z cos square beta tan phi by tan beta and equal to F multiplied by 1 minus r u by cos square beta. So, tan phi by tan beta you can see when it was a dry slope or submerged slope if the water table is here or water table is here if it is here it is dry here it is a submerged in that case you had a factor of safety of equal to this.

And now because of this at any at any point suppose poor pressure is u and when poor pressure is there then your factor of safety equation modified to 1 minus r by cos square beta. So, if I know the r u r u that is pore pressure ratio and the angle then you can calculate this multiplied by original factor of safety become the factor of safety of this equation. So, since it is a since it is always a less than 1 minus something, so these value the factor of safety is reducing.

So, it was originately the factor of safety, and this quantity is less than 1 so; that means, because of the pore pressure in the soil rise of pore pressure in the soil your factor safety will be reducing; that means, you have to that is why when you have to do the analysis of slope stability analysis you have to know the condition properly, whether it is dry, whether it is submerged, whether it is a flowing condition.

So, it is a water table is suddenly dropped here and water is flowing in this at particular rate, and if I know the pore pressure development because of that then I can find out this quantity, this quantity multiplied by regional factor of safety tan phi by tan beta is the name factor of safety ok. So, this is the one generalized we have considered.

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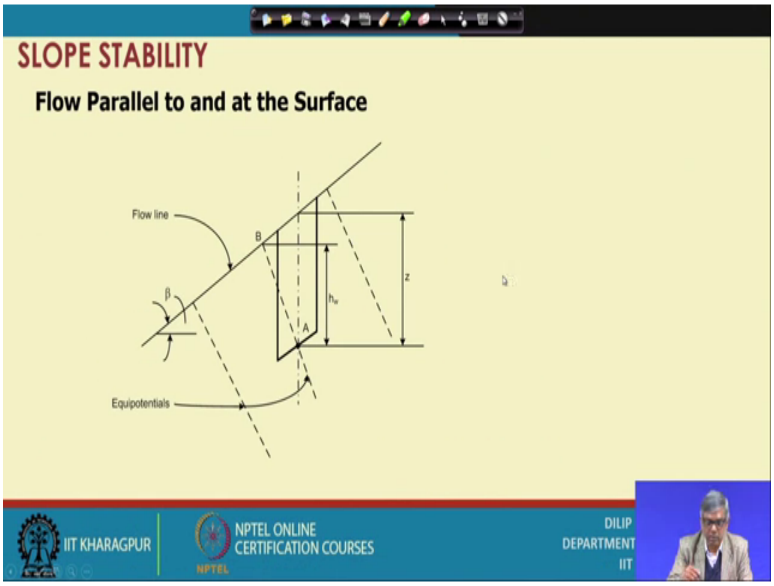

And now let us see one more a thing when the flow is taking place parallel to the slope of the so this is the one. So, earlier we have considered a theoretic surface initially you have considered a frenetic surface which was a curved one. And now that we are considering the flow is actually parallel to this along these and parallel to this, so, flow is taking place in this direction.

In that case those are flow line, so you can draw number of perpendicular lines those can be treated as your equipotential. So, this is this should be actually parallel of course you have not drawn properly this should have been parallel ok, these are all parallel these are all equipotential line, and again with respect to this equipotential line this beta and consider the equilibrium of these we can modify the analysis little and you can see in the next slide.

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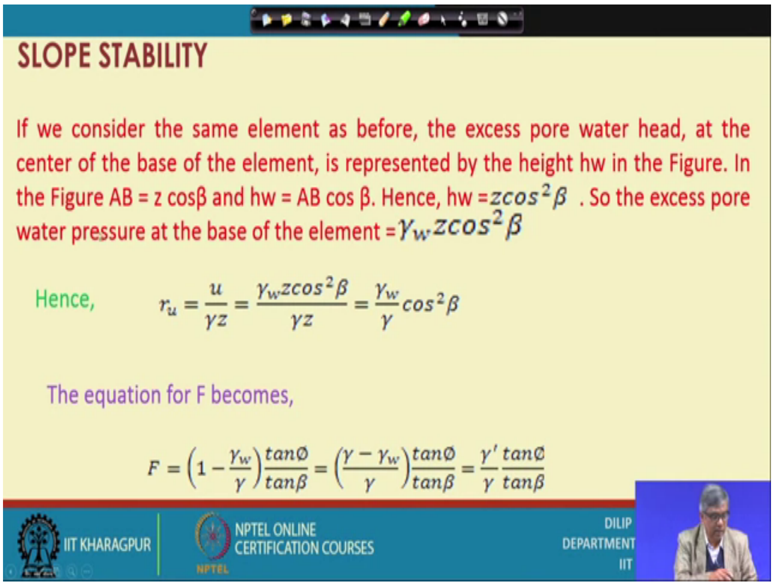

And you can see if we consider same element as before the excess pore water head at the center of the base of the element, is represented by the height h w that h w I have shown in the figure. In the figure in the figure AB equal to z cos beta sorry AB equal to and h w equal to h w equal to AB cos beta, AB cos beta, and AB equal to z cos beta so; that means, h W equal to z cos square beta. And this one if I substitute and then water pressure at the base of the element will be gamma W z cos square beta gamma W into h, so if I substitute h then gamma W z cos square beta will be pore pressure and then r u become u by u z.

So, if put this way then r u become this is the expression and if I substitute this expression to the previously just previous slide whatever you have got here, and then simplify then your this factor of safety will be reduces to this value that is phi gamma dash by gamma multiplied by tan phi by tan beta this is the special case; that means, the slope is there, flow is taking place generalized we have considered u there and last case what you have considered flow is parallel to the sloping surface so that simplifying you the problem.

And when you simplify that way then your expression become gamma submerged by gamma tan phi by tan beta gamma submerged gamma dash is what gamma submerged gamma minus gamma w and this is actually total gamma. So, if the soil is having total gamma is 18, so and then your gamma submerged will be 18 minus 9.81 that what are value for water gamma submerged will be this. So, this divided by 18 multiplied by original factor of safety will be the actual factor of safety, so that is the three different cases that is purely dry condition or submerged condition factor safety equal to tan phi by tan beta.

And if there is a flowing condition based on u there is a expression if there is a third case when there is a flowing condition, but the flow is parallel to the flow in that case your final expression will be gamma dash by gamma multiplied by tan phi by tan beta. So, this is the three cases I have shown.

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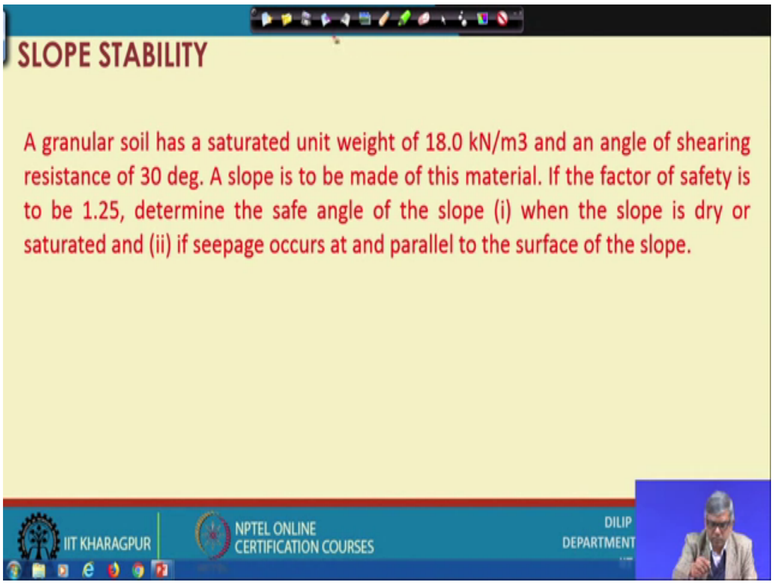

Next one there will be problem given here a granular soil has a saturated unit weight equal to 18 kilo Newton per meter cube, and angle of shearing resistance equal to 30 degree, a slope is to be made of this material. If the factor of safety is to be 1.25, determine the safe angle of the slope, when the slope is dry or submerged and the seepage occurs.

And secondly if the seepage occurs at and parallel to the surface of the slope that means in this problem we are explaining case 1, and case 3 either dry, or submerged case one and third case is flow is taking place, but it is parallel to the sloping surface.

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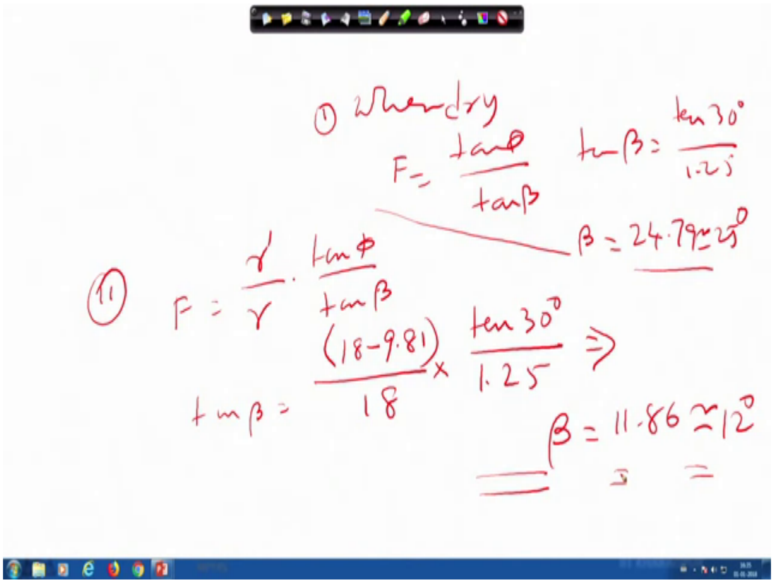

So, in that case you can see the first one you will be having when dry your F equal to tan phi by tan beta, and since the tan beta will be will be tan 30 divided by 1.25 from here I will get beta equal to 24.79 degrees equivalent to 25 degree. This is very strict forward application and where as second case when it is a flowing taking place and parallel to the sloping surface then in that case your F equal to gamma submerge by gamma multiplied by tan phi by tan beta.

So, if I do that then your tan beta will be equal to gamma submerge is the 18 is the unit weight is given and water is 9.81 divided by 18 multiplied by tan phi is 30 degrees divided by factor of safety is 1.25, this value will give you beta equal to your say beta equal to it gives you 11.86; that means, it is approximately 12 degrees.

So, you can see the requirement when it is a totally dry I can make a slope of nearly 20 5 degrees, where as if because of sudden drawdown condition with same slope it can if you keep same 25 degree it will definitely fail. Because the same factor of safety it is demanding almost half the angle, what was it was previously it was 25, now it is 12 less than half. So, if there is a tendency of frequent water level going up and down then you have to make a compatibly a flatter slope you can see the requirement almost less than half ok.

So, with this application I will stop. I will start again and may be with other cases in the next slide.

Thank you.