Rock Mechanics and Tunneling
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Lecture 38
Slopes (Continued)

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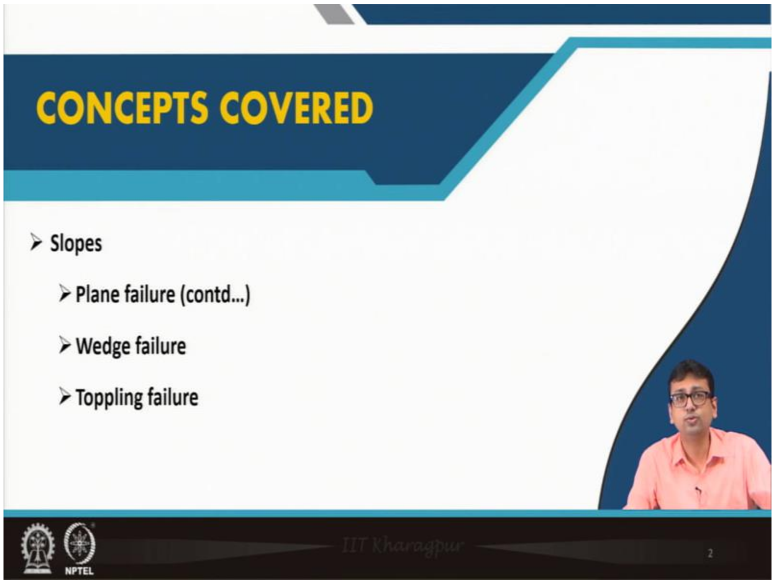

Hello everyone, I welcome all of you to the second lecture of module 8. So, in our module 8 we are discussing about slopes at present. So, in our today's lecture we will try to first try to solve a problem on plane failure, because in our previous lecture we have discussed about different types of plane failure and with the help of one problem we try to understand how to find out factor of safety.

The required expressions for three types of failure we have derived it ourselves, so I think that has given a lot of confidence, now this one problem if we see our concept will become further clear. After that we will discuss about the second type or the second mode, second type we have discussed you remember four modes of slope failure, plane failure, wedge failure, toppling and circular. So out of that the second one is wedge failure that we will discuss today and also today we will discuss about the toppling.

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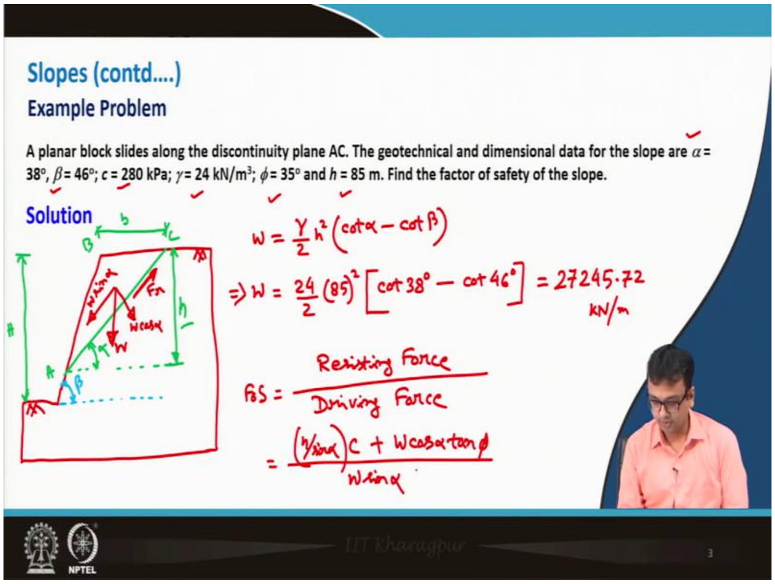

So, the example problem, we will solve wedge now, a planar block slide along the discontinuity plane AC, that we will draw maybe we will draw the diagram, the geotechnical and dimension data for the slope are like α β means these symbols are same what we have used earlier that is why you should be able to understand it very easily, where you have kept it same, α is 38 degree, β is the 46 degree, what is α and what is β? You see β is the slope angle, the face of the slope, and α is the dip angle of the dip of that discontinuity plane, c is the coefficient 280 kPa, γ is given 24 kN/m^3, ϕ = 35 degree, h is 85 m, find the factor of safety of the slope.

So, let us draw the diagram, suppose this is the ground surface here. Now, suppose this is my angle β and this is the wedge suppose ABC block is failing, this distance is suppose b and this angle is my α as per our previous in our previous class we have derived the expression for factor of safety considering this as β this as α and also we have assumed that this is our h and maybe we can draw over here this is suppose entire one is suppose H, entire height of the slope.

But this only this portion is h which is we have seen that we have used that h, now derivation. So, here so these are the things now if I show the different components like here from here weight W will act, so this will be one component, this will be another component, so this component is nothing but W$\cos\alpha$ and this is my W$\sin\alpha$. And basically the resisting force of this F_r, and the driving forces W$\sin\alpha$.

So, these are the things we need, I have drawn it over here and the thing you see α is given, β is given, c, γ, ϕ, h, all the things are given. So, now you see we know that the W for this type of failure is

$$W = \frac{\gamma}{2} hb = \frac{\gamma}{2} h^2 (\cot\alpha - \cot\beta)$$

Now, if we try to find out this one from here, so basically W is becoming γ is 24 by 2, h is 85, so 85^2 and here cotα, α is 38 degrees, so 38 degrees minus cot β, β is 46 degree. Now, if you simplify it you will get it as you can cross check, 27245.72 kN, and now out of plane direction we have considered once so you can write it over here as maybe kN/m because it is a plane strength problem we are considering, the 27245.72.

Now, so now the factor of safety, factor of safety is nothing but as we know the resisting force by driving force, now resisting forces here what? Equation is present, so we need to know the length AC and plane strength problem, so out of plane direction one we consider, so AC into 1 into c is the correlation. Now, AC is what here? It is nothing but h/sinα, so let me write down over here, so $F = \frac{(h/\sin\alpha)c + W\cos\alpha\tan\phi}{W\sin\alpha}$. So, now let us use h α c W α ϕ, all these things and let us try to obtain the final solution.

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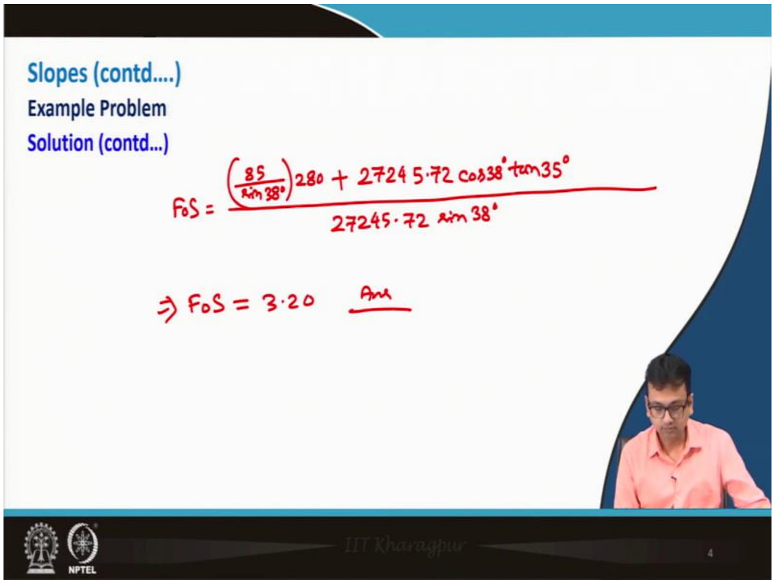

So, factor of safety is equal to it defined [(85/sin38)280 + 27245.72 cos38tan35]/27245.72 sin38, so if you simplify you will get it as 3.20. So, this is our answer. So, similarly for slopes with tension crack also we have derived the expression, so you should be able to find out factor of safety.

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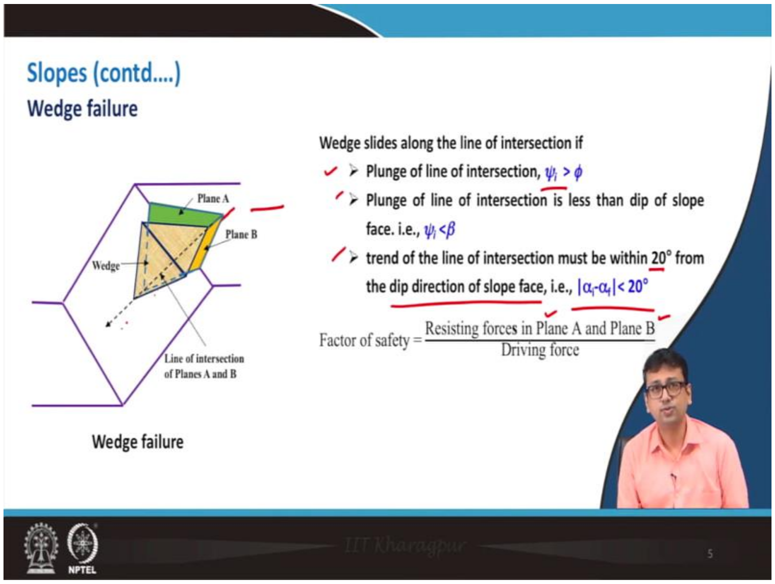

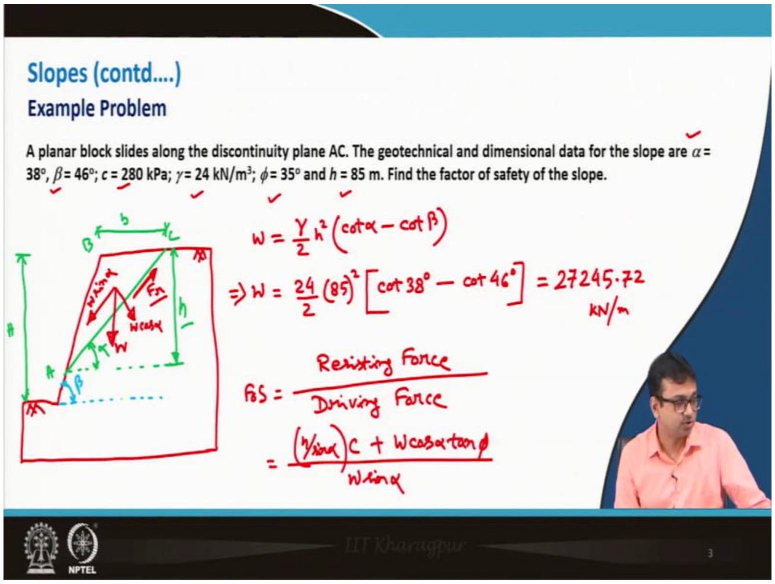

Now, so the next very important mode of slope failure in case of rock is wedge failure which is quite common, so it is something like this, you have to visualize it in three dimensions. So, 3d visualization is required for this purpose, so if you see what is happening over here is, this is the wedge is failing, this is one plane you see this is one plane which is given a name suppose plane A and this is another plane, plane B and this is this where they are intersecting with dotted also it is shown over here and it is going like this, the line of intersection of plane A and B.

And this is nothing but my wedge. So, this wedge is failing you see along this line it will slide basically along this line of intersection it will slide and this is the rough means what we observe in case of roughly what we observe in case of wedge failure is shown over here, with this nice diagram.

Now, this wedge actually slides along the line of intersection this line of intersecting its slides, if some conditions it need to satisfy, if the plunge of the line of intersection suppose that plunge of the line of intersection is this ξ_i should be greater than ϕ, ϕ is the angle of internal friction of this rock mass.

Now, another conditional also you need to satisfy that is plunge of the line of intersection is less than dip of the slope face. So, dip of the slope face is β means as we have earlier also we have considered the slope angle or the face of the slope is making an angle β with the horizontal that means that is nothing but the dip of that slope side. So, another condition is the ξ_i which is the plunge of the line of intersection, this is a line, so we are using that terminology plunge remember, so for line we use term like plunge and whereas this plane we are using this dip the dip actually.

So, plunge of the line of intersection less than dip of the slope face, so ξ_i is less then β and another condition is the trend of the line of intersection must be within 20 degree from the dip direction of the slope face. So, the dip direction of the slope face is obviously we can find out than that is really easy, I know that how to find out, so trend of the line of intersection must be within 20 degrees from the dip direction of the slope face, that is $|\alpha_i - \alpha_f|$ should be less than the 20 degrees, so within this 20 this is another very important condition to we need to satisfy.

So, wedge slides along the line of intersecting if these conditions satisfied and now whatever the factor of safety you see here the resisting force will develop from in case of you see planar failure if I go back over here, it was developing this resisting force were developing on this AC this along this line or if we consider I mean it is a plane strength problem if I consider out of plane direction unity, so this plane along this plane whatever resisting force is developing that is actually helping us to maintain the stability of the slope.

Now, in case of this wedge failure what is happening you see this wedge it is one side it has plane A another side it has plane B, so resisting forces, whatever will develop in plane A and plane B we need to consider combining both resisting effect from resisting force what we get from plane A and resting force what we will get from plane B, we have to consider both of them and that will give us the cumulative resisting force, so resisting forcing in plane A and plane B by divided by the driving force. So, in that way you have to find out the factor of safety.

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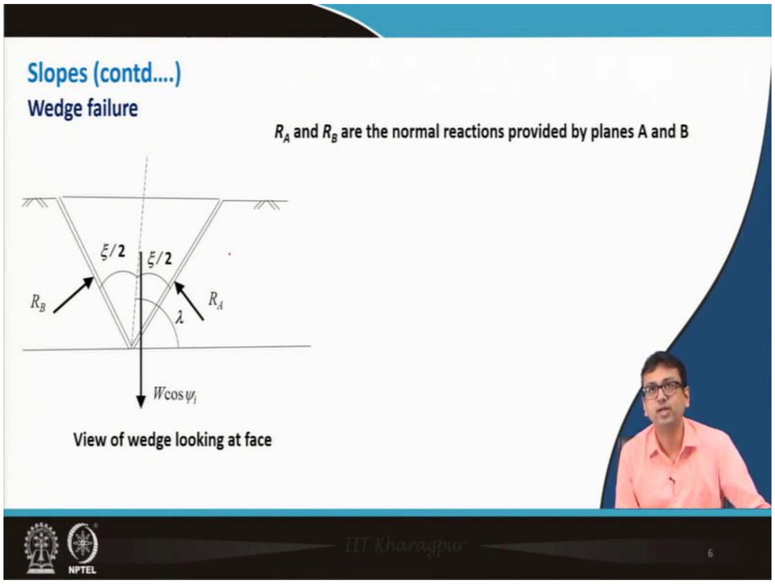

Now, this is nothing but view of the wedge looking at the face and it is very simple here RA and RB are nothing but the normal reactions provided by plane A and plane B.

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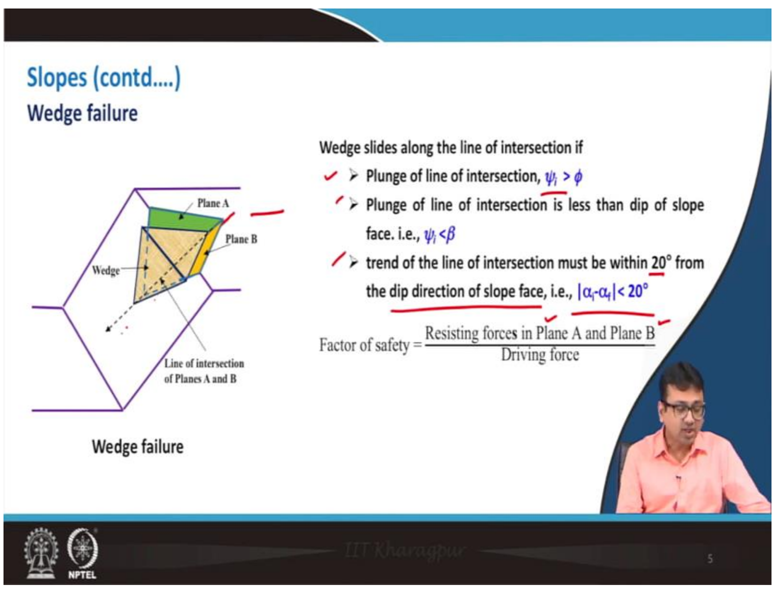

So, again let us go back here, so plane A is providing suppose normal reaction RA and plane B is providing the normal reactions suppose RB.

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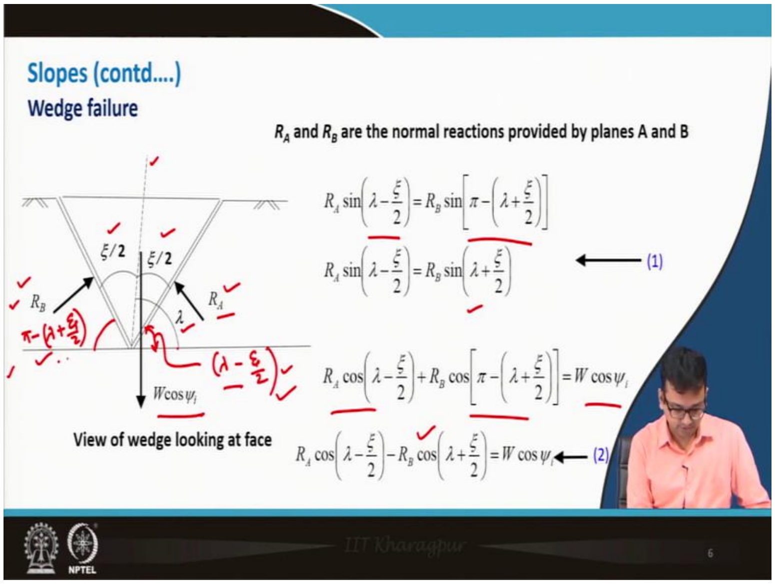

Now, resolving this RA, this forces RA and RB into components of normal and parallel to the direction along the line of intersection, along the line of intersection we get a couple of equations, so they those are nothing but the force equilibrium equation, simply we just look at this diagram and let us go for the force equilibrium.

So, one thing is what we can get from here is this equation it is what you see the RA sine, before that let us see what are the angles suppose let us consider this is your line of intersection maybe this is your total angle and this is divided into your two parts equal parts suppose $\xi_i/2$ and this is $\xi_i/2$ it is your λ, λ is the angle this angle, RA and RB are the normal reaction provided by the planes A and B.

Now, you see one equation we can get like this you see the horizontal if we resolve it these RA and RB you just simply from here this diagram if you see, so this angle is how much? Total is this is λ, so that means only this angle if I see, only this angle is how much? So, this angle is nothing but λ -ξ/2. Similarly, what about this angle? This angle is nothing but you see total is π, so π minus up to this, up to this is λ plus by 2, so this is the single, this is the angle, so RA sin this angle and RB sin this angle, they must be equal for force equilibrium.

So, we can simplify it and this can be written like this, so this is one equation, which will be used very soon. Another is another direction we can go for the force equilibrium, so basically RA cos this angle, RB cos this angle is equal to nothing but these, so these are in the upward direction, these are and this is the down word from this simple diagram we can see, so if we further simplify you see this will give us this, so minus is coming over here and this is my other equation, no confusion very simple from this diagram you can easily understand and I have for radially you should so that you can understand it just by seeing it I have written these angles also now.

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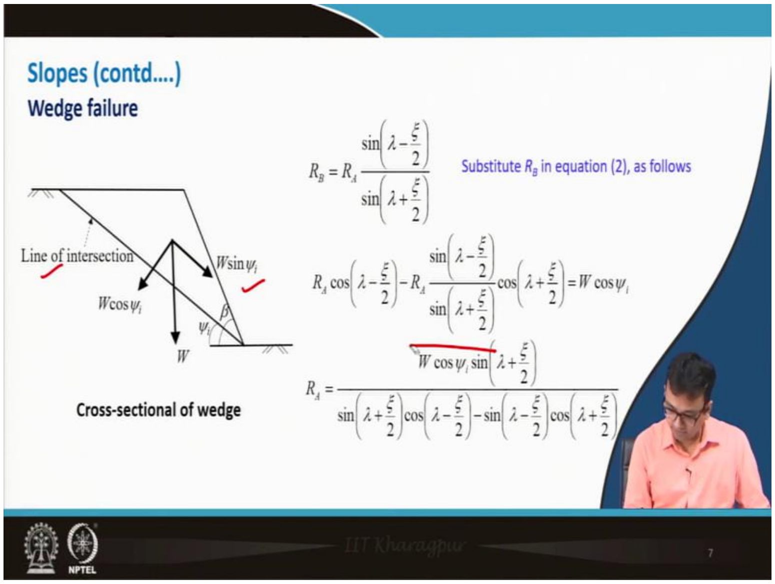

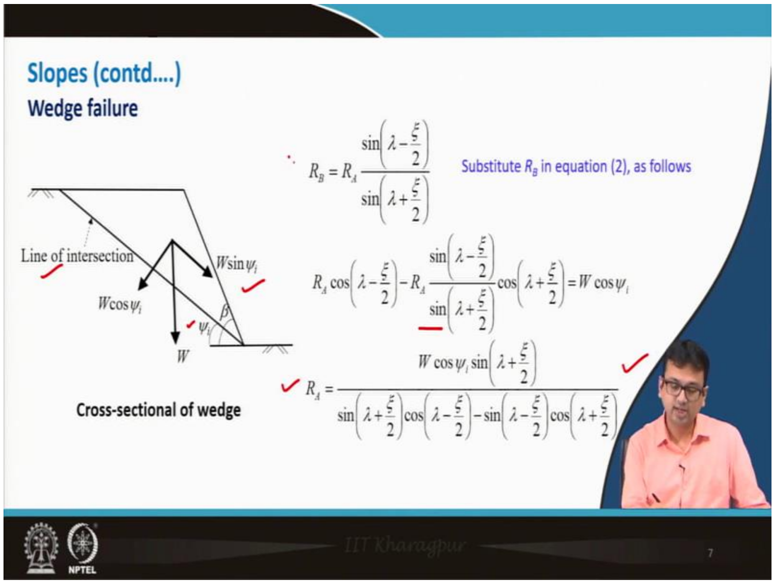

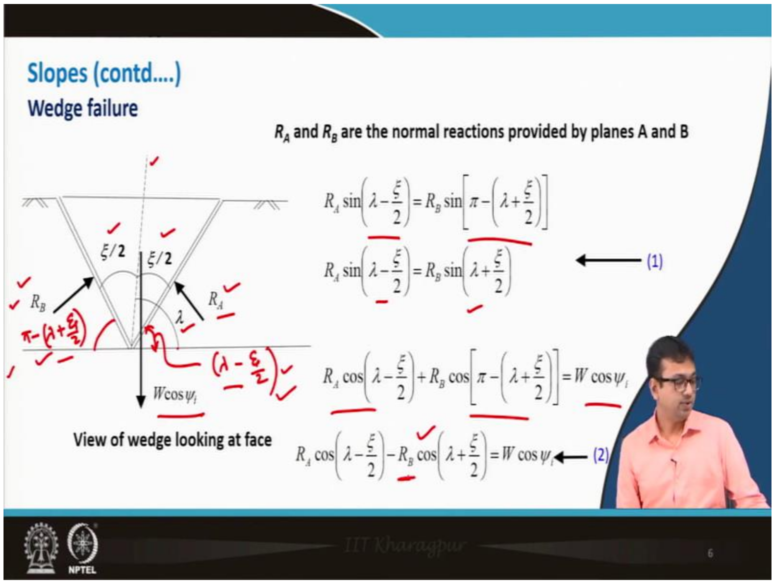

Now, so this is what the cross section of the wedge, so what is happening basically the this is my disturbing force actually driving force, and this is the line of intersection, anyway from or this substitute RB in the equation 2, what we are getting from where, how we are getting this? It where getting it from basically this equation you see, RB is nothing but RA sin this λ minus this by sin λ plus this $\xi_i/2$. So, now this one if you replace in equation 2 means equation 2 is this one, so here if you replace, so what will you get?

So, you will get this one. So, this RB is replaced with this and now if you further simplify, so further simplification will give us RA in terms of these parameters like w then this angles whatever we have considered, then this ξ_i which is the nothing but the this it is shown over here is you see ξ_i. So, these RA will get in this form, no once we can get RA I can get my RB.

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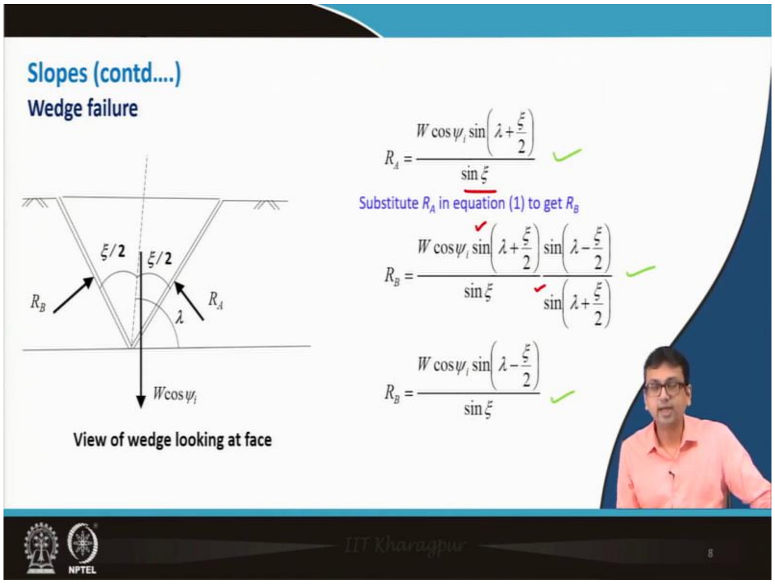

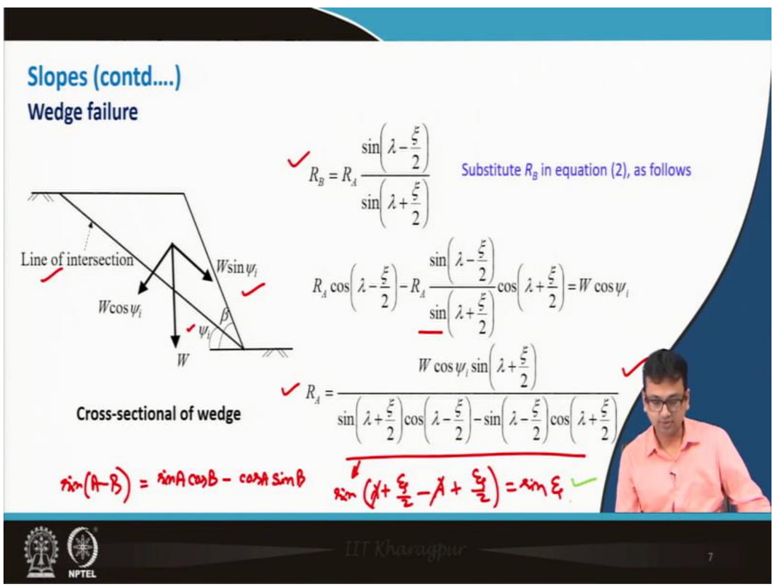

So, RA further you see further if we further simplify here it comes out to be very simple equation. So, this is this is nothing but this you see this, so how it is coming? As we know like as we know that is the sin A minus B is nothing but sin A cos B minus cos B, so if we just look at over here sin A minus B if we do, so it is nothing but sin A cos B, so sin A cos B then cos A sin B. So, this is equal to sin A minus B, so if you do that just we can cross check it, so just for our understand sin as we know sin A otherwise you may think suddenly how it is coming, sin A cos B minus cos A sin B.

So, now here accordingly it is becoming sin λ minus plus ξ_i by 2 minus λ this is minus, minus minus plus 2 λ λ canceling so sin this is 2 so, so this way it is coming out to be this. So, that is why, so do not get confused, so that is why it is coming like this and this way we can get our RA. RA now if I substitute in equation earlier equation, so we can get my RB. So, RA and RB once we have obtained again for the simplification, simplification it will give us this, because you see this term, this term and this term they are canceling and we will get it like this.

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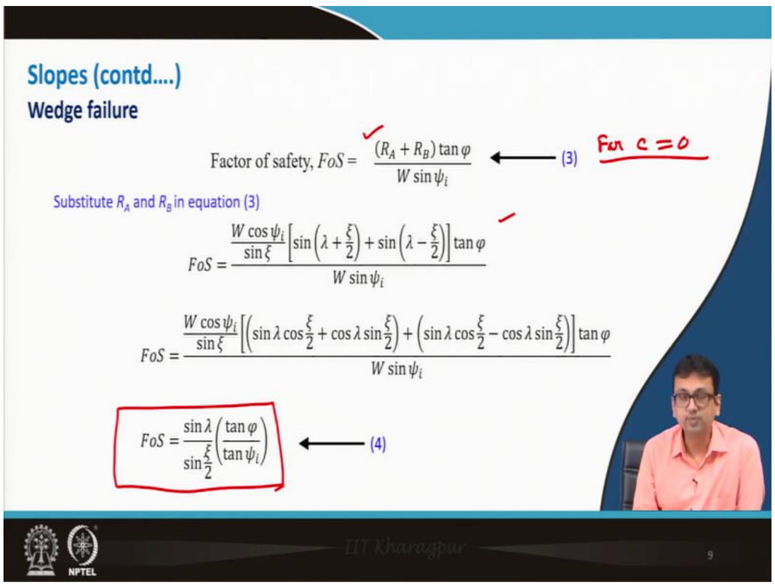

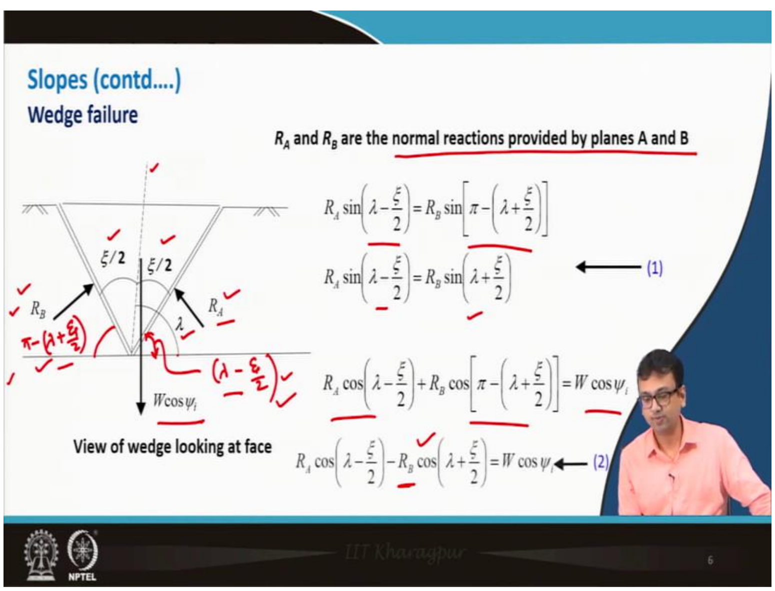

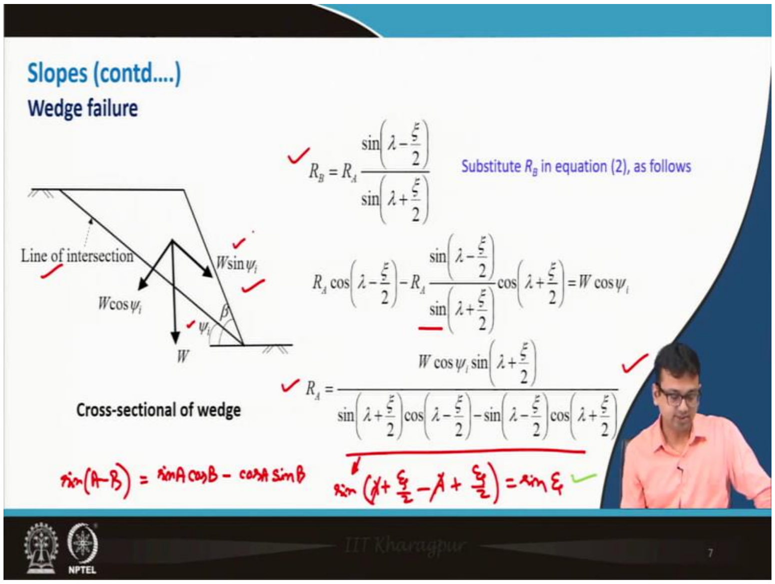

So, now RA and RB are here with us, now factor of safety suppose our cohesion for c suppose equal to 0, so if it cohesion is there then also it is no problem we have to simply obtain the area of that plane in A plane and B plane and you have to multiply that with your cohesion that will give that resisting force it will further increase, anyway if we consider simply c 0, so then our equation becomes RA plus RB they are nothing but as I have mentioned RA and RB are what?

They are nothing but the normal reactions, provided by planes A and B. Now, that means my factor of safety is (RA+Rb)tanϕ that is what is shown over here, (RA+Rb)tanϕ/Wsinξ_i. So why Wsinξ_i? Because you see this is the disturbing force or driving force. So, this is, now RA we know RB we know, we can place over here we can further simplify it and you finally will get it as a very simple equation that is this one. So, this is the equation actually though we have done so many things so many calculation, but ultimate end product is this one only, so this much you have to know to find out the factor of safety.

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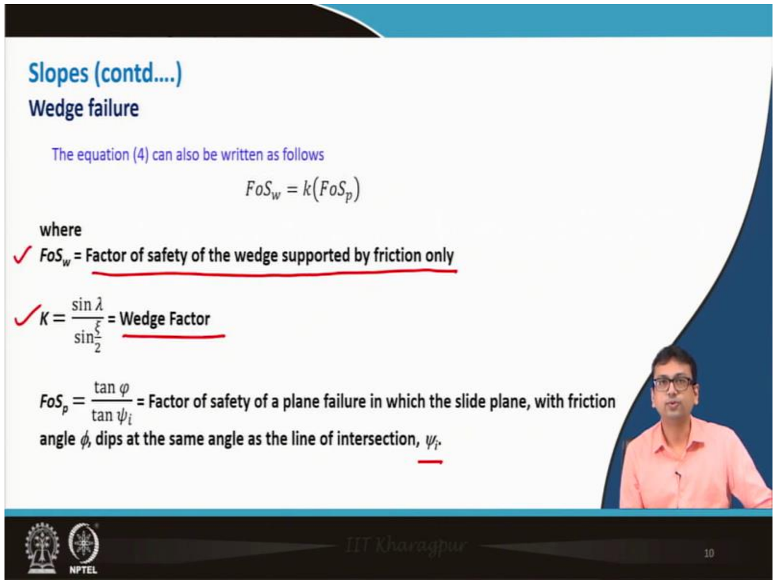

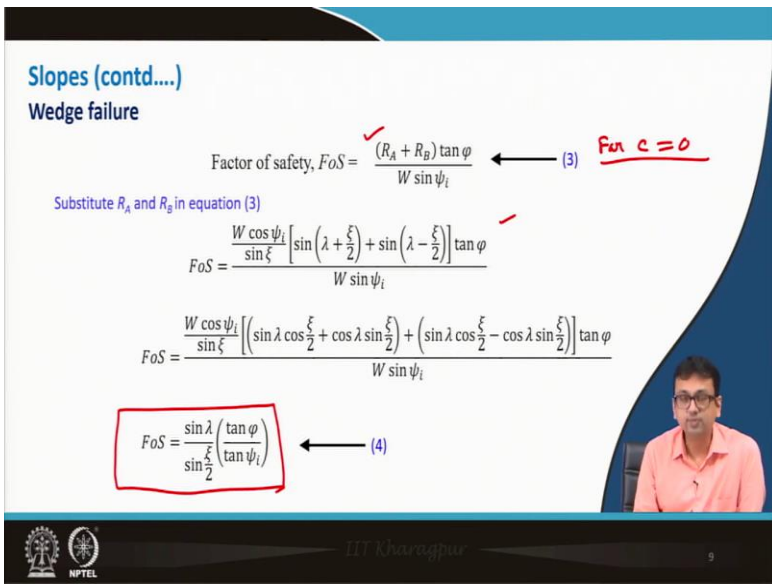

Now, this equation may have been given name like 4, this is the ultimate equation but anyway we will just introduce two more terms over here. So, this factor of safety suppose W subscript if we write and if we write a k factor of safety p, so what are they? FoS_w is ultimately the desired thing which is the factor of safety of the wedge, so factor of the safety of the wedge supported by friction only as we have considered c is 0.

Now, here k is what? k is nothing but this, because you see, k this part outside bracket part, this is called as the wedge factor and FoS_p is the tan ϕ tan ξ_i, this, this part inside bracket part, so what is this? This is the factor of safety of a plane failure in which the slide plane with friction angle ϕ dips at the same angle as the line of intersection ξ_i. So, this is what all about the wedge failure.

So, now the thing is if I give you a problem related to or if you encounter in future also suppose you have to find out the factors of p against wedge failure then you can simply use these equations or you can derive it from your, the fundamentals what I have shown you and you can obtain the factor safety against wedge failure.

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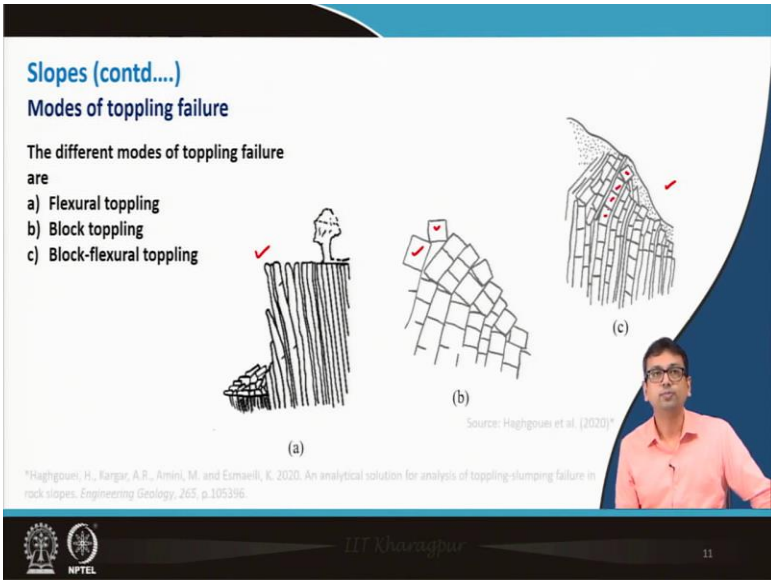

Now, so after wedge failure we will discuss about the top link failure, that is also one of the important or quite frequent failure mode in case of rock slope. So, the different modes of toppling failure are like flexural toppling you see, some flexural toppling is happening here. So, you see this is a block, this is a block they are just toppling, so block toppling is happening. So, that is block toppling, then combined block flexural toppling as you can see from here, so bending is there as well as the toppling is happening with this flexural as well as block, blocks are also willing and these type of things are happening.

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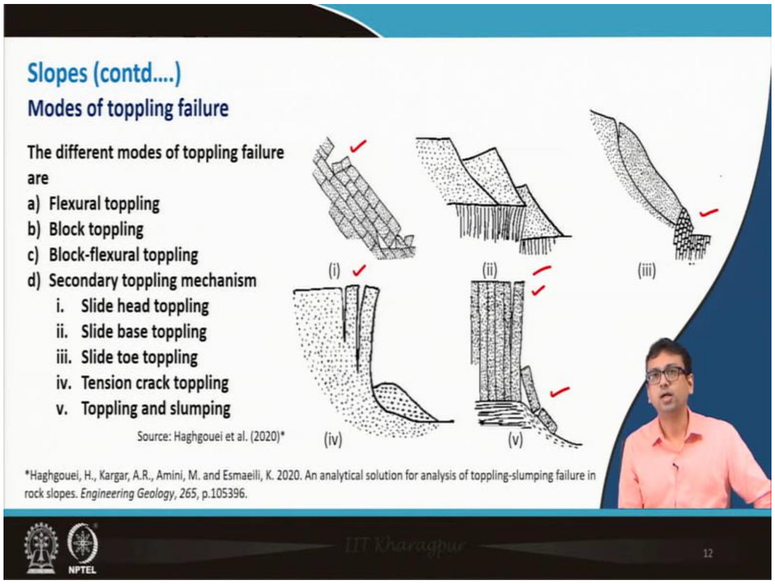

Now, another one is secondary toppling mechanism where this is called as the slide head toppling, this is slide base toppling you see, so base toppling, this is the head toppling, then the toe toppling, toe toppling and also the tension crack toppling, so you see like this, and finally another one is toppling and slumping, so toppling as well as slumping. So, these are the different types of different modes of toppling failure. But anyway the fundamental of toppling failure is we will discuss now.

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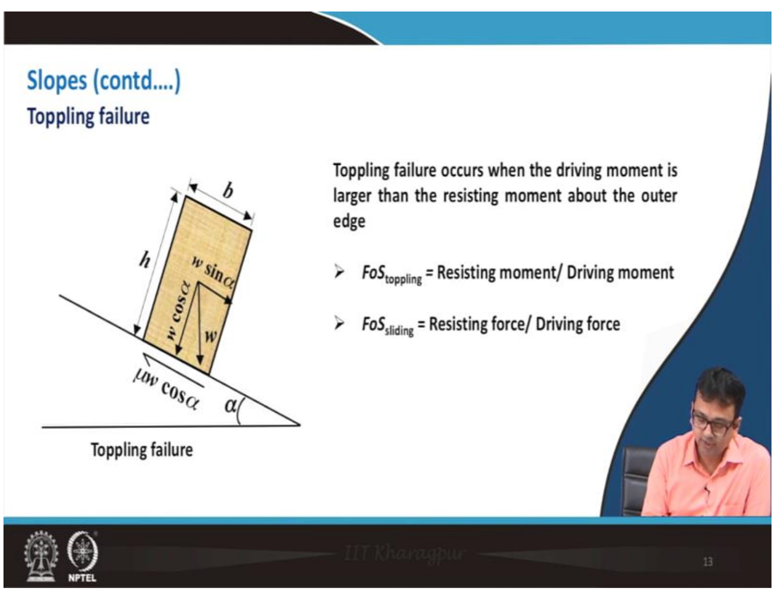

So, toppling failure means if we simply draw this diagram, this free body diagram from there we can very easily understand the mechanics behind this. So, one thing is this toppling is associated with sliding also, so that is also one thing we will notice over here. So, the toppling in some is associated with the sliding also.

So, let us see what is written over here. So, toppling failure occurs when the driving moment is larger than the resisting moment about outer edge. So, outer edge suppose it is considered this edge. So, now so factor of safety against toppling is nothing but the resisting moment about this outer edge by the driving moment. So, if driving moment is more than resisting moment so it will topple.

Now, another is as I stated toppling is associated with the sliding also, so factor of safety against sliding is nothing but resisting force the driving force as we know. Now, let us look at this diagram on very carefully to see what is there, there is a block having dimensions like b and h rectangular block, you can see plane strength like this. Now, this is the weight, so W$\sin\alpha$ is the disturbing force and this is the normal you can see W$\cos\alpha$. So, this will be this component will be definitely μW$\cos\alpha$, now for toppling we have to take moment about this point and for sliding it is very simple, so resisting force by driving force.

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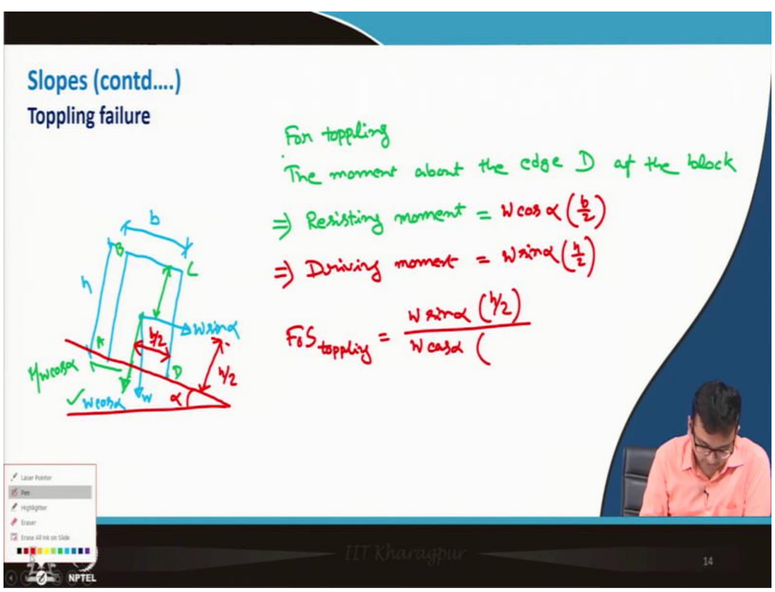

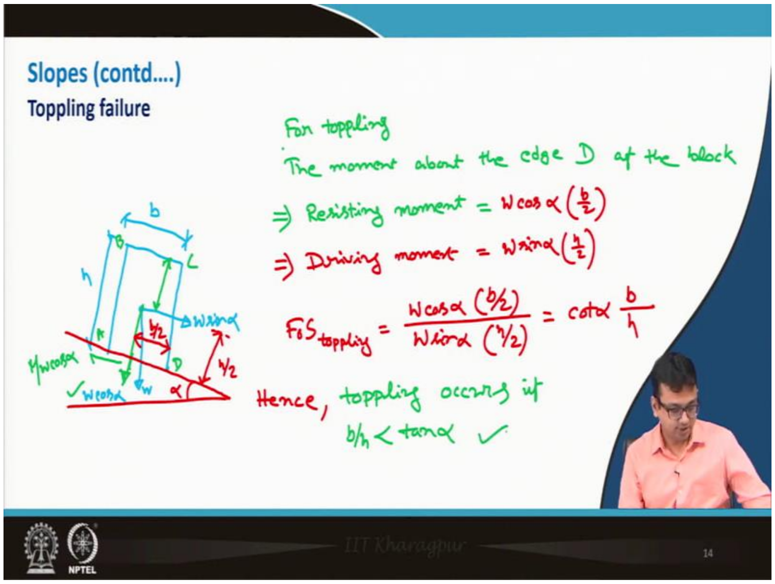

So, in case of toppling failure just quickly let me draw this diagram that is very important try to draw it now, this is my suppose α angle and suppose this is the block. And so b and h so what we can see from here that this is suppose W, now W$\sin\alpha$ and this is normal, so W$\cos\alpha$ and you can consider that here μW$\cos\alpha$ exactly.

So, now for this toppling, the moment about the edge suppose we can give the name like ABCD about the edge, suppose D of the block, first is suppose the resisting moment, resisting moment is what? Basically this is the this (W$\cos\alpha$)b/2.

So, basically what I have tried to draw is this distance b/2 and again this distance h/2, obviously here we can write the resisting moment as (W$\cos\alpha$)b/2. Similarly, we can write the driving moment is equal to (W$\sin\alpha$)h/2.

So, now factor of safety for toppling will be equal to $\dfrac{W\cos\alpha\frac{b}{2}}{W\sin\alpha\frac{h}{2}}$, so if we simplify it we get $\cot\alpha\frac{b}{h}$. So, toppling will occur if factor of safety is obviously less than one, so that means toppling will occurs if b/h < tanα.

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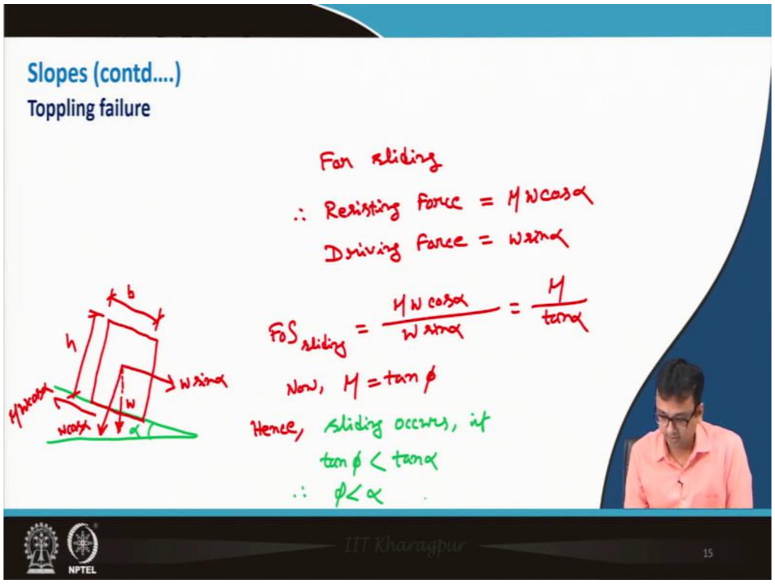

So, for sliding what will you have to consider the resisting force is what? That is nothing but μW cosα and the driving force simply Wsinα. So, factor of safety against sliding is equal to what? $\frac{\mu W \cos\alpha}{W \sin\alpha}$. So, now we can simplify it as $\frac{\mu}{\tan\alpha}$, now μ can be written as simply like tan ϕ, that we know, so we got the limiting case, so hence we can write as sliding occurs if obviously factor of safety against sliding < 1 that means tanϕ < tanα. So, when $\phi < \alpha$, sliding occurs.

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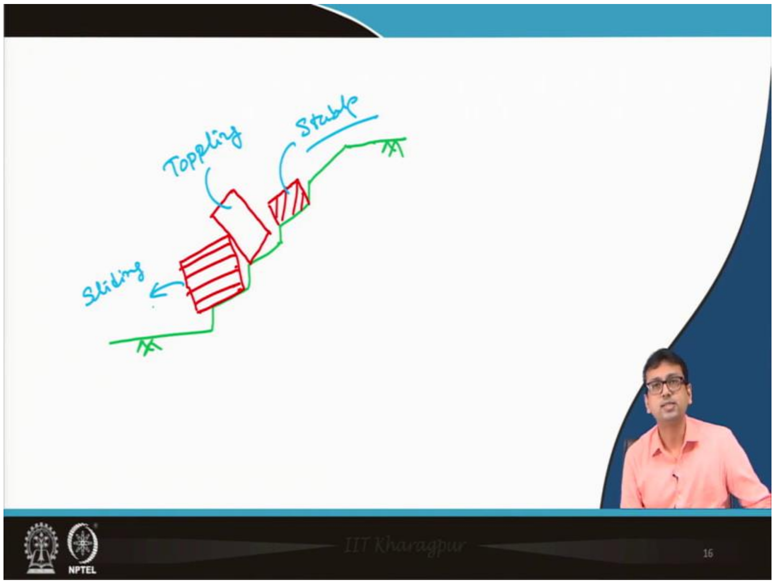

So, now small diagram where I will show you in pictorial diagram to give you some idea about this type of failure modes. This is ground surface, now what may happen, this is toppling, this block, whereas this one is sliding, so this is neither topping nor sliding.

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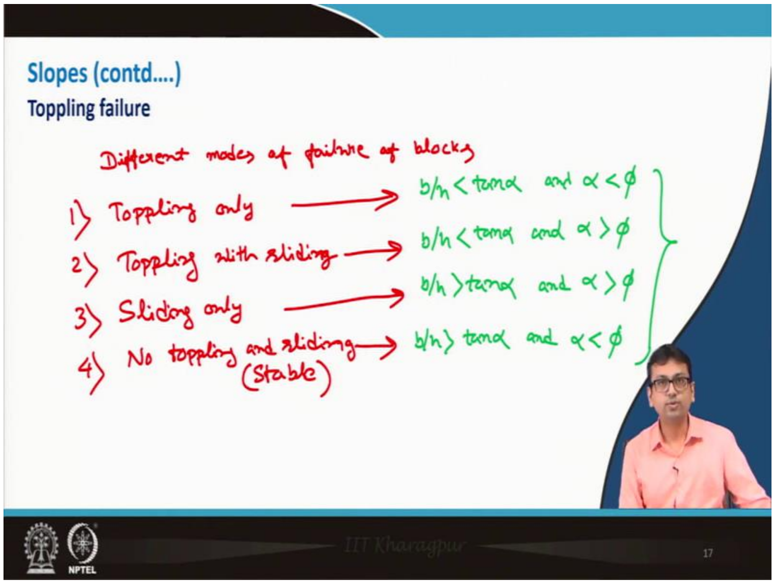

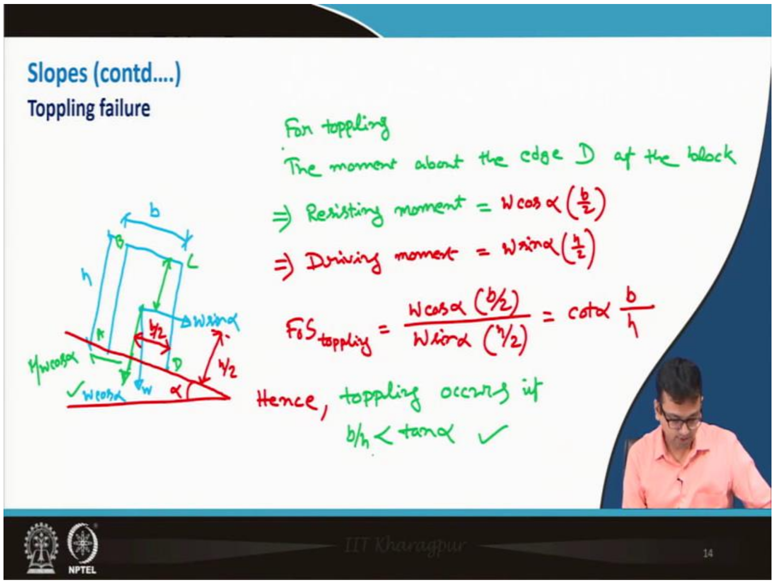

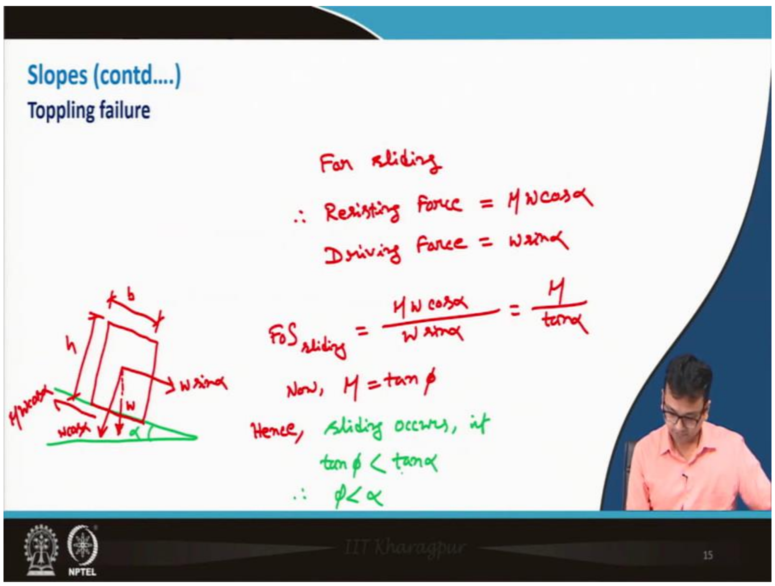

So, this type of failures we see quite often. So, now just in brief if I just finally summarize this thing what we can say the different modes of failure of blocks. So, different modes of failure of blocks. So, first one is supposed toppling only. So, toppling only that means it has to have this b/h < tan α. But sliding will occur if $\alpha > \phi$, but α is less than ϕ. Now toppling with sliding, so for toppling definitely b/h < tan α along with that what should happen and α is greater than ϕ means sliding will occur.

The third condition sliding only, so than that indicate b/h > tan α but has to satisfy α greater than ϕ, and the final one no toppling and no sliding means the stable condition that mean b/h > tan α

and α is less than ϕ. So, these are the different condition for this toppling and sliding. With this let us conclude our discussion here. In our next lecture I will discuss about the circular failure.